Robert J. Bartz

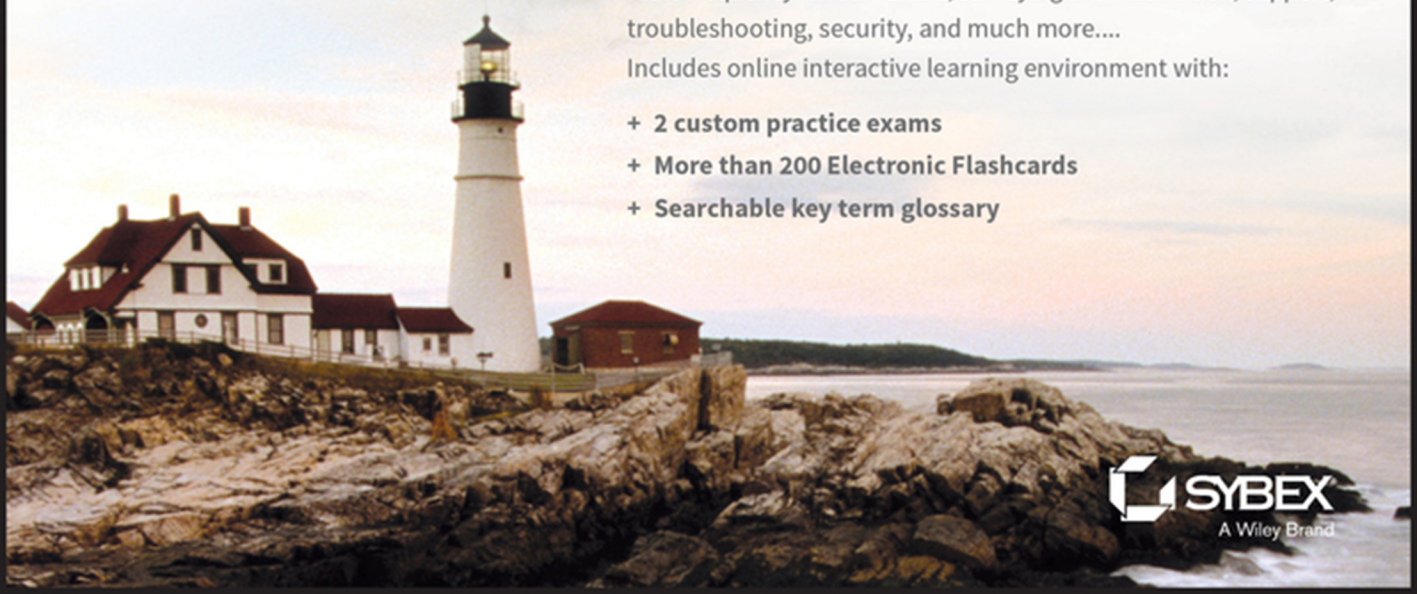
CWTS®, CWS, and CWT

COMPLETE STUDY GUIDE

EXAM PW0-071
EXAM CWS-2017
EXAM CWT-2017

Covers 100% of exam objectives, including hardware and software, radio frequency fundamentals, surveying and installation, support, troubleshooting, security, and much more....
Includes online interactive learning environment with:

+ **2 custom practice exams**
+ **More than 200 Electronic Flashcards**
+ **Searchable key term glossary**



SYBEX
A Wiley Brand

CWTS®, CWS, and CWT

Complete Study Guide

Exams PW0-071, CWS-2017, CWT-2017

Robert J. Bartz

SYBEX®
A Wiley Brand

Development Editor: Kelly Talbot
Technical Editors: Bryan Harkins and Ben Wilson
Production Editor: Dassi Zeidel
Copy Editor: John Sleeva
Editorial Manager: Mary Beth Wakefield
Production Manager: Kathleen Wisor
Executive Editor: Jim Minatel
Book Designers: Judy Fung and Bill Gibson
Proofreader: Kim Wimpsett
Indexer: Ted Laux
Project Coordinator, Cover: Brent Savage
Cover Designer: Wiley
Cover Image: © Jeremy Woodhouse/Getty Images, Inc.

Copyright © 2018 by John Wiley & Sons, Inc., Indianapolis, Indiana

Published simultaneously in Canada

ISBN: 978-1-119-38503-5
ISBN: 978-1-119-41940-2 (ebk.)
ISBN: 978-1-119-41939-6 (ebk.)

Manufactured in the United States of America

No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 646-8600. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at http://www.wiley.com/go/permissions.

Limit of Liability/Disclaimer of Warranty: The publisher and the author make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation warranties of fitness for a particular purpose. No warranty may be created or extended by sales or promotional materials. The advice and strategies contained herein may not be suitable for every situation. This work is sold with the understanding that the publisher is not engaged in rendering legal, accounting, or other professional services. If professional assistance is required, the services of a competent professional person should be sought. Neither the publisher nor the author shall be liable for damages arising herefrom. The fact that an organization or Web site is referred to in this work as a citation and/or a potential source of further information does not mean that the author or the publisher endorses the information the organization or Web site may provide or recommendations it may make. Further, readers should be aware that Internet Web sites listed in this work may have changed or disappeared between when this work was written and when it is read.

For general information on our other products and services or to obtain technical support, please contact our Customer Care Department within the U.S. at (877) 762-2974, outside the U.S. at (317) 572-3993 or fax (317) 572-4002.

Wiley publishes in a variety of print and electronic formats and by print-on-demand. Some material included with standard print versions of this book may not be included in e-books or in print-on-demand. If this book refers to media such as a CD or DVD that is not included in the version you purchased, you may download this material at http://booksupport.wiley.com. For more information about Wiley products, visit www.wiley.com.

Library of Congress Control Number: 2017951652

TRADEMARKS: Wiley, the Wiley logo, and the Sybex logo are trademarks or registered trademarks of John Wiley & Sons, Inc. and/or its affiliates, in the United States and other countries, and may not be used without written permission. CWTS is a registered trademark of CWNP, LLC All other trademarks are the property of their respective owners. John Wiley & Sons, Inc. is not associated with any product or vendor mentioned in this book.

10 9 8 7 6 5 4 3 2 1

About the Author

Robert Bartz is a technical trainer, computer networking consultant, technical author, and speaker. He is a graduate of California State University Long Beach, College of Engineering, with a Bachelor of Science degree in Industrial Technology. Prior to entering the field of computer networking, Robert was employed as an aerospace test engineer working with military fighter aircraft radar systems and communication satellite spacecraft. After leaving the aerospace industry, he attained numerous technical certifications over the years, starting with Novell NetWare and moving on to Microsoft networking, CompTIA, Cisco Systems, and the CWNP program. Robert currently holds the Certified Wireless Network Expert (CWNE) and Certified Wireless Network Trainer (CWNT) credentials. He has more than 27 years of experience with computer networking technology and has been involved with the CWNP program since its inception.

Robert attended the first-ever CWNA class in 2001 and has taught vendor-neutral IEEE 802.11 wireless LAN technology to thousands of people from various industries and markets across the United States and around the world. Robert is the founder of Eight-O-Two Technology Solutions, LLC, a computer networking technical training and consulting services company that provides technical education and consulting services to various businesses and organizations. He spends his spare time learning and working with new technology, having fun outside, and enjoying the beauty of his surroundings at his home in Colorado. He can be contacted by email at `robert@eightotwo.com`.

Acknowledgments

I would like to thank my wife and two adult children for their support and patience during the writing of this book.

I would also like to thank everyone at Sybex who helped with the creation of this book, including executive editor Jim Minatel, production editor Dassi Zeidel, and copy editor John Sleeva. I owe all these individuals a lot of thanks for their patience while working with me on this book and keeping things on track. Kelly Talbot is the development editor for this book. It was great to work with Kelly once again. Many thanks go to Kelly for his time and work to help make this book an educational and enjoyable read. His editorial skills and attention to detail, in addition to assisting with the flow, organization, and suggestions, were a huge help to me. Also, thanks to Ben Wilson, the proofread technical editor.

The technical editor for this book is Bryan Harkins. It is always a pleasure to work with Bryan. I want to thank Bryan once again for his timely reviews, comments, and great suggestions that helped make this book a valuable reference source. His many years of experience as a technical trainer, engineer, security specialist, and author were a great contribution in creating a book I am sure you will enjoy reading.

I would like to thank the thousands of students who have taken the time to attend the computer networking classes I was given the opportunity to teach over the last couple of decades. Educating, mentoring, and entertaining so many of these individuals gave me the inspiration and motivation to author this book and share my knowledge with people who want to learn more about this wonderful technology.

CWNP has realized the need for vendor-neutral wireless LAN training and certification and has done a great job of building a brand over the years that is known worldwide. The CWNP program continues to grow at a strong pace, adding many new certified individuals every day. I offer a special thank-you to the CWNP team for providing a much-needed product in the industry.

Finally, a thank-you to all the manufacturers, vendors, organizations, and individuals that I have worked with in the industry, providing me the technology and tools needed to help write this book.

Contents

Introduction *xvii*

Assessment Test *xl*

Chapter 1 Computer Networking Fundamentals 1

Network Types 2
The Local Area Network 3
The Wide Area Network 3
The Metropolitan Area Network 4
The Campus Area Network 5
The Personal Area Network 6
Network Topologies 7
The Bus Topology 8
The Ring Topology 9
The Star Topology 10
The Mesh Topology 10
Ad Hoc Connections 12
Point-to-Point Connections 13
Point-to-Multipoint Connections 13
The OSI Model 14
Layer 1 – The Physical Layer 15
Layer 2 – The Data Link Layer 16
Layer 3 – The Network Layer 17
Layer 4 – The Transport Layer 17
Layer 5 – The Session Layer 18
Layer 6 – The Presentation Layer 18
Layer 7 – The Application Layer 18
How the Layers Work Together 18
Peer-Layer Communication 19
Data Encapsulation 20
Device Addressing 21
Physical Addressing 22
Logical Addressing 23
Network Address Translation 25
Summary 27
Exam Essentials 28
Review Questions 30

Chapter 2 Wireless Local Area Networking, Standards, and Certifications 35

The Wireless Computer Network 36
The Wireless Personal Area Network 36
The Wireless Local Area Network 37
The Wireless Metropolitan Area Network 37
The Wireless Wide Area Network 38
Building-to-Building Connectivity Using Wireless LAN Technology 38
Wireless Point-to-Point Connections 38
Wireless Point-to-Multipoint Connections 39
Radio Frequency Regulatory Domain Governing Bodies and Local Regulatory Authorities 40
United States: Federal Communications Commission 41
Europe: European Telecommunications Standards Institute 42
The IEEE 42
The IEEE 802.11 Standard 43
The IEEE 802.11a Amendment 44
The IEEE 802.11b Amendment 45
The IEEE 802.11g Amendment 46
The IEEE 802.11n Amendment 49
The IEEE 802.11ac Amendment 50
Summary of IEEE 802.11 Communications Standards and Amendments 52
Additional IEEE 802.11 Amendments 53
Interoperability Certifications 55
The Wi-Fi Alliance 56
The Wi-Fi Protected Access Certification 56
The Wi-Fi Protected Access 2 Certification 57
The Wi-Fi Multimedia Certification 58
Wi-Fi Multimedia Power Save Certification 58
Wi-Fi Protected Setup Certification Overview 58
Common Wireless Local Area Network Deployment Scenarios 59
Small Office/Home Office 60
Enterprise Deployments: Corporate Data Access and End-User Mobility 61
Extension of Existing Networks into Remote Locations 62
Public Wireless Hotspots (Public Wi-Fi) and Hospitality 62
Office (Carpeted) Deployments 64
Educational Institution Deployments 64
Industrial Deployments 67
Healthcare Deployments 67

Last-Mile Data Delivery: Wireless ISP 69
High-Density Deployments Including Conference Centers 70
Municipal, Law Enforcement, and Transportation Networks 71
Summary 71
Exam Essentials 72
Review Questions 73

Chapter 3 Infrastructure and Client Devices Used with Wireless Networking 77

The Wireless Access Point 80
Autonomous Access Points 82
Controller-Managed Access Points 91
Cloud-Managed Access Points 93
Wireless Branch Router/Remote Access Point 94
Wireless Mesh 95
Wireless Bridges 96
Wireless Repeaters/Range Extenders 97
Wireless LAN Controllers and Cloud-Managed Architectures 98
Centralized Administration 99
Virtual Local Area Networks 99
Power over Ethernet Capability 99
Improved Mobile Device Transition 100
Wireless LAN Profiles and Virtual Wireless LANs 100
Advanced Security Features 100
Captive Web Portals 100
Built-in RADIUS Services 101
Predictive Modeling Site Survey Tools 101
Radio Frequency Spectrum Management 101
Firewalls 101
Quality of Service 102
Infrastructure Device Redundancy 102
Wireless Intrusion Prevention System 102
Direct and Distributed Access Point Connectivity 102
Layer 2 and Layer 3 Access Point Connectivity 102
Distributed and Centralized Data Forwarding 103
Power over Ethernet 104
Power Sourcing Equipment 105
Powered Devices and Classification Signatures 106
Benefits of PoE 107
Radio Hardware Used with Wireless LAN Technology 108
USB 1.0, USB 1.1, USB 2.0, and USB 3.0 108
Features of USB 109
Installation and Configuration of USB Devices 110

Peripheral Component Interconnect 112
Features of PCI 112
Installation and Configuration of PCI Cards 113
Mini-PCI, Mini-PCIe, and Half Mini-PCIe 115
Features of Mini-PCI, Mini-PCIe, and Half Mini-PCIe Cards 116
Installation and Configuration of Mini-PCI, Full Mini-PCIe, and Half Mini-PCIe Cards 117
Wireless Workgroup Bridges 118
Features of Wireless Workgroup Bridges 119
Installation and Configuration of Wireless Workgroup Bridges 120
Client Device Drivers 121
Client Utility Software 121
Manufacturer-Specific Client Utilities 122
Third-Party Client Utilities 123
Summary 124
Exam Essentials 125
Review Questions 126

Chapter 4 Radio Frequency Fundamentals for Wireless Networking 131

Understanding Radio Frequency 133
Wavelength in Wireless LANs 136
Frequency in Wireless LANs 137
Amplitude in Wireless LANs 138
Phase in Wireless LANs 138
Radio Frequency Used in Wireless LANs 139
Wireless LAN Coverage and Capacity 143
Wireless LAN Coverage 144
Wireless LAN Capacity 146
Radio Frequency Channel Reuse and Device Co-location 149
Radio Frequency Range and Speed 150
Line of Sight in Wireless Networking 150
Wi-Fi and Non–Wi-Fi Interference 152
Adjacent Channel and Co-channel Interference 152
WLAN/WPAN Interference 154
Environment: Radio Frequency Behavior 155
Basic Units of Radio Frequency Measurement 158
Absolute Measurements of Radio Frequency Power 158
Relative Measurements of Radio Frequency Power 160
Radio Frequency Signal Measurements 162
Summary 166
Exam Essentials 167
Review Questions 168

Chapter 5 Antenna Technology for Wireless Networking 171

Basic Radio Frequency Antenna Concepts 172
Radio Frequency Lobes 173
Antenna Beamwidth 173
Antenna Gain 176
Passive Gain 176
Active Gain 178
Antenna Polarization 178
Wireless LAN Antenna Types 180
Omnidirectional Antennas 180
Omnidirectional Antenna Specifications 182
Semidirectional Antennas 184
Highly Directional Antennas 193
Highly Directional Antenna Specifications 194
Radio Frequency Cables and Connectors 195
Radio Frequency Cable Types 196
Radio Frequency Cable Length 196
Radio Frequency Cable Cost 197
Impedance and VSWR 197
Radio Frequency Connectors 198
Factors in Antenna Installation 199
Addressing the Effects of Earth Curvature 199
Antenna Placement 199
Minimizing the Effects of Multipath Using Antenna Diversity 200
Combating Effects of Wind and Lightning in Wireless LAN Installations 201
Lightning Arrestors 202
Grounding Rods 203
Installation Safety 203
Antenna Mounting 203
Internal and External (to the Access Point) Antennas 204
Pole/Mast Mount 205
Ceiling Mount 206
Wall Mount 206
Maintaining Clear Communications 206
Visual Line of Sight 207
Radio Frequency LoS 207
Fresnel Zone 207
Summary 208
Exam Essentials 209
Review Questions 211

Chapter 6 Communication for Wireless Networking 215

Wireless LAN Operation Methods 216
The Independent Basic Service Set 217
The Basic Service Set 222
The Extended Service Set 224
The Basic Service Area 225
Connecting to an IEEE 802.11 Wireless Network 227
IEEE 802.11 Frame Types 227
Wireless Network Discovery 228
Passive Scanning 228
Active Scanning 230
IEEE 802.11 Authentication 231
IEEE 802.11 Association 235
IEEE 802.11 Deauthentication and Disassociation 236
The Distribution System 237
Data Rates 238
Throughput 240
Dynamic Rate Switching 246
Wireless LAN Transitioning/Roaming 247
IEEE 802.11 Power Save Operations 249
Active Mode 249
Power Save Mode 250
Automatic Power Save Delivery 251
IEEE 802.11 Protection Mechanisms 251
IEEE 802.11g Extended Rate Physical Protection Mechanisms 252
IEEE 802.11n High-Throughput Protection Mechanisms 253
Summary 254
Exam Essentials 256
Review Questions 257

Chapter 7 Modulation Technology for Wireless Networking 261

Network Access Methods 262
Detecting Network Traffic Collisions with CSMA/CD 263
Avoiding Network Traffic Collisions with CSMA/CA 264
Reserving Time for Data Transmission Using Distributed Coordination Function 265
Effects of Half-Duplex on Wireless Throughput 266
Narrowband vs. Spread-Spectrum Communication 267
Spread-Spectrum Technology 269
Frequency-Hopping Spread Spectrum 269
802.11 Direct-Sequence Spread Spectrum 270
802.11b High Rate/Direct-Sequence Spread Spectrum 271
IEEE 802.11 DSSS and HR/DSSS Channels 271

IEEE 802.11g Extended Rate Physical 273
IEEE 802.11n High Throughput 275
IEEE 802.11a, 802.11g, 802.11n, and 802.11ac OFDM 275
IEEE 802.11a, 802.11g, 802.11n, and 802.11ac OFDM Channels 276
IEEE 802.11n/ac Multiple Input/Multiple Output Technology 278
IEEE 802.11n/ac MIMO Channels 280
Co-location of IEEE 802.11b HR/DSSS and IEEE 802.11a/g/n OFDM Systems 282
Adjacent-Channel and Co-channel Interference 284
WLAN/WPAN Coexistence 285
Summary 287
Exam Essentials 287
Review Questions 289

Chapter 8 Security Fundamentals for Wireless Networking 293

Introducing IEEE 802.11 Wireless LAN Security 295
Wireless LAN Threats and Intrusion 295
IEEE 802.11 Standard Security 297
IEEE 802.11 Open System Authentication 298
IEEE 802.11 Shared-Key Authentication 298
Early Wireless LAN Security Methods 298
The Service Set Identifier 299
SSID Hiding 299
The Media Access Control Address 300
MAC Address Filtering 301
MAC Address Spoofing 302
IEEE 802.11 Authentication and Data Encryption 302
About Wired Equivalent Privacy 303
How Wired Equivalent Privacy Was Used 303
IEEE 802.11 SOHO and Enterprise Security Technologies 304
Wi-Fi Protected Setup PIN-Based or Push-Button Configuration Wireless Security 304
PIN-Based Security 305
Push-Button Configuration Security 306
Wi-Fi Protected Access and WPA2 Personal Security 307
Passphrase Characteristics 307
WPA and WPA2 Enterprise Security 308
IEEE 802.1X/EAP 308
IEEE 802.1X 309
Extensible Authentication Protocol 310
IEEE 802.1X and EAP Together: IEEE 802.1X/EAP 310
Remote Authentication Dial-In User Service 310
Authentication, Authorization, and Accounting 312

IEEE 802.11 Encryption Methods 313
Wired Equivalent Privacy 314
Temporal Key Integrity Protocol 315
Counter Mode with Cipher Block Chaining Message Authentication Code Protocol 316
Role-Based Access Control 317
Virtual Private Networking 318
Point-to-Point Tunneling Protocol 320
Layer 2 Tunneling Protocol 320
Components of a VPN Solution 320
The Wireless Intrusion Prevention System 328
WIPS Configuration and Maintenance 330
Overlay and Integrated WIPS Technology 331
The Captive Portal 334
Wireless Network Management and Monitoring Systems 334
WNMS: Software, Hardware, or Cloud? 335
Wireless Network Monitoring 337
Industry Regulatory Compliance 339
PCI Compliance 339
HIPAA Compliance 340
Summary 340
Exam Essentials 341
Review Questions 343

Chapter 9 Design for Wireless Networking 347

Wireless Site Surveys 349
Size of the Physical Location 351
Intended Use of the Wireless Network 351
Number of Wireless Devices 352
Wireless Client Device Capabilities 352
The Environment 353
Performance Expectations 353
Bring Your Own Device Acceptance 354
Building Age and Construction Materials 355
Network Infrastructure Devices 355
Gathering Business Requirements 356
General Office/Enterprise 357
Interviewing Stakeholders 358
Manufacturer Guidelines and Deployment Guides 362
Gathering Site-Specific Documentation 362
Floor Plans and Blueprints 362
Furnishings 363
Electrical Specifications 364
Existing Network Characteristics 364

Identifying Infrastructure Connectivity and Power Requirements 366
Understanding Application Requirements 368
Understanding Radio Frequency Coverage and Capacity Requirements 369
Client Connectivity Requirements 369
Antenna Use Considerations 370
The Physical Radio Frequency Site Survey Process 374
Radio Frequency Spectrum Analysis 375
Spectrum Analysis for IEEE 802.11 Wireless Networks 375
Wi-Fi and Non–Wi-Fi Interference Sources 378
Wi-Fi Interference 384
Received Signal Strength 385
Performing a Manual Radio Frequency Wireless Site Survey 387
Obtaining a Floor Plan or Blueprint 388
Identifying Existing Wireless Networks 388
Testing Access Point Placement 390
Analyzing the Results 391
Considering the Advantages and Disadvantages of Manual Site Surveys 391
Performing a Software-Assisted Manual Site Survey 392
Using a Manual Site Survey Toolkit 398
Performing a Predictive Modeling Site Survey 400
Internet-Based Predictive Modeling Site Survey 402
Performing a Post-Deployment Site Survey 403
Protocol Analysis 403
RF Coverage Planning 410
Infrastructure Hardware Selection and Placement 410
Testing Different Antennas 411
Testing Multiple Antenna Types 411
Choosing the Correct Antennas 412
Wireless Channel Architectures 413
Multiple-Channel Architecture 413
Single-Channel Architecture 414
Wireless Device Installation Limitations 414
Site Survey Report 415
Summary 417
Exam Essentials 418
Review Questions 420

Chapter 10 Mobile Device Management and BYOD Fundamentals 425

Mobile Device Management Solutions 427
The Software as a Service Solution 428
The On-Premises Solution 428

Common Mobile Device Operating System Platforms 430
The Mobile Application Store 431
Pushing Content to Mobile Devices 435
Mobile Device Management Administrative Permissions 436
Understanding Mobile Device Management High Availability and Redundancy 436
Mobile Device Management Device Groups 437
Location-Based Services 438
Geo-fencing 438
Geo-location 439
Mobile Device Telecommunications Expense Management 440
Captive and Self-Service Portals 440
Captive Portals 440
Self-Service Portals 441
General Technology Network and Security Policy 442
Security Policy Framework 443
Information Technology and Security Policy Implementation and Adherence 443
Acceptable Use Policy 445
Balancing Security and Usability 445
Backup, Restore, and Recovery Policies 445
Operating System Modifications and Customization 446
Operating System Vendors 446
Original Equipment Manufacturer 447
Vendor-Default Device Applications 447
Technology Profiles 448
Mobile Device Profiles 448
Directory Services Integration 449
Issuing Digital Certificates 450
End-User License Agreement 450
Understanding Group Profiles 451
Corporate-Owned Mobile Device Profiles 452
Employee-Owned Mobile Device Profiles 452
Outside Consultants' and Visitors' Mobile Device Profiles 453
Policy and Profile Pilot Testing 453
Summary 454
Exam Essentials 455
Review Questions 456

Chapter 11 Troubleshooting for Wireless Networking 461

Identifying Wireless LAN Problems 462
Radio Frequency Transmitters and Receivers 464
Wireless LAN Connectivity—Coverage and Capacity Problems 465
No Wireless Connectivity 465
Intermittent Wireless Connectivity Problems 473
Wireless LAN Throughput 477

Application Performance Problems 480
Wireless Device Software and Hardware Upgrades 481
Optimizing Wireless Networks 488
Wireless Infrastructure Hardware Selection and Placement 488
Identifying, Locating, and Removing Sources of Wi-Fi and Non-Wi-Fi Interference 489
Wireless Client Device Load Balancing and Infrastructure Device Redundancy 490
Wireless Infrastructure Device Redundancy 491
Analyzing Wireless Infrastructure Capacity and Utilization 492
Radio Frequency Performance Problems: Multipath 492
Radio Frequency Performance Problems: Hidden Node 493
Quality of Service Considerations 497
Summary 498
Exam Essentials 499
Review Questions 500

Appendix Answers to Review Questions 505

Chapter 1: Computer Networking Fundamentals 506
Chapter 2: Wireless Local Area Networking, Standards, and Certifications 508
Chapter 3: Infrastructure and Client Devices Used with Wireless Networking 509
Chapter 4: Radio Frequency Fundamentals for Wireless Networking 511
Chapter 5: Antenna Technology for Wireless Networking 512
Chapter 6: Communication for Wireless Networking 514
Chapter 7: Modulation Technology for Wireless Networking 516
Chapter 8: Security Fundamentals for Wireless Networking 517
Chapter 9: Design for Wireless Networking 519
Chapter 10: Mobile Device Management and BYOD Fundamentals 521
Chapter 11: Troubleshooting for Wireless Networking 525

Index 529

Table of Exercises

Exercise 1.1 Viewing Device Address Information on a Computer 25
Exercise 3.1 Installing a USB 2.0 Wireless LAN Adapter 110
Exercise 3.2 Installing a PCI Card 113
Exercise 3.3 Installing Mini-PCI and Mini-PCIe Cards 117
Exercise 4.1 Demonstrating Fresnel Zone and Blockage 151
Exercise 5.1 Demonstrating Passive Gain 178
Exercise 5.2 Installing a Pole/Mast Mount 205
Exercise 6.1 Measuring Throughput of a Wireless Network 241
Exercise 8.1 Setting Up a VPN 322
Exercise 8.2 Setting Up a VPN 325
Exercise 9.1 Using Spectrum Analysis Tools for Wi-Fi Networks 379
Exercise 9.2 Installing Ekahau HeatMapper 394
Exercise 9.3 Installing a Protocol Analyzer 405
Exercise 10.1 Installing Android Emulator Software in Microsoft Windows 433
Exercise 10.2 Resetting the Default Application—Android 448
Exercise 11.1 Upgrading a Device Driver 483

Introduction

This book is intended to provide an introduction to the exciting and emerging world of IEEE 802.11 wireless LAN (WLAN) technology. This technology continues to expand at a phenomenal pace, with constant improvements in speed, performance, reliability, and security. This book will teach you the fundamentals of IEEE 802.11 standards-based wireless technology, giving you an overview of the terminology, hardware and software components, radio frequency (RF) communication principles, and support and maintenance associated with WLAN technology, commonly referred to as Wi-Fi™.

In addition to providing an overview of the technology, this book will help you prepare for the Certified Wireless Technology Specialist (CWTS) certification exam, the Certified Wireless Specialist (CWS) certification exam, and the Certified Wireless Technician (CWT) certification exam, which are all available from the Certified Wireless Network Professional (CWNP) program.

CWTS is an entry-level enterprise WLAN certification and is recommended as preparation for the Certified Wireless Network Administrator (CWNA) certification. This certification is geared specifically toward WLAN support staff, sales and marketing personnel, or anyone who wants to become more familiar with the enterprise WLAN industry.

CWS is targeted for those who need to be able to explain basic features and capabilities of WLAN solutions, including access points, controllers, WLAN management solutions, and 802.11 networks. It also helps you assist in selecting the best equipment for a deployment or communicate well with those who are responsible for such decisions. The CWS is not responsible for the configuration and management of the WLAN but must have the ability to gather information to determine requirements and match technologies to those requirements for a deployment.

CWT is geared toward the individual who can install access points based on a design document, configure access points for initial operations, and ensure connectivity. The CWT can troubleshoot basic problems and assist users in-person or through remote communications in problem resolution. The ability to configure a WLAN client for connectivity is paramount and includes an understanding of the configuration process for service set identifiers (SSIDs), security settings, and other client adapter settings. The CWT is not responsible for WLAN design, analysis, or security design; however, the CWT should be able to gather information from a design specification document to properly configure an access point and troubleshoot individual connection issues. The CWT may not be aware of the actual WLAN architectural design, the RF design, or the full feature set in use to implement the WLAN.

In addition to helping you prepare for all three certification exams, this book will give you the fundamental knowledge, tools, and terminology to more effectively sell and support enterprise IEEE 802.11 WLAN technologies. The main goal of this book is for you to learn "what it is," not "how it works." The "how" part comes later, in other Study Guides and instructor-led courses. After reading this book and completing all the available practice exam tools included, you will have the knowledge needed to take the CWTS, CWS, or CWT certification exams.

For more information about these and other vendor-neutral WLAN certifications from the CWNP program, visit `www.cwnp.com`.

About CWNP®

CWNP, the abbreviation for Certified Wireless Network Professional, is the industry standard for vendor-neutral, enterprise WLAN certifications. The CWNP program develops courseware and certification exams for IEEE 802.11 WLAN technologies in the computer networking industry.

CWNP offers several levels of enterprise WLAN certifications, from novice to expert. The goal of CWNP is to provide educational resources and certifications that are recognized worldwide to information technology (IT) and sales professionals in the field of IEEE 802.11 wireless networking technology. By acquiring this knowledge, these professionals will be able to enter any business and sell, design, install, manage, and support a WLAN infrastructure, regardless of which manufacturer's solution is used.

In addition to CWTS, CWT, and CWS, five other wireless certifications are currently offered from CWNP:

CWNA: Certified Wireless Network Administrator The CWNA (Certified Wireless Network Administrator) certification is the foundation-level enterprise WLAN certification for the CWNP program. The CWNA certification will validate one's skills to successfully administer enterprise-class WLANs. Passing the CWNA exam will also earn the base certification toward the more advanced CWNP certifications. The CWNA exam measures one's ability to understand all of the features and functions of IEEE 802.11 WLAN technology. Passing the CWNA-107 certification exam will satisfy the requirement to become CWNA certified.

CWSP: Certified Wireless Security Professional The CWSP (Certified Wireless Security Professional) certification is one of the advanced-level WLAN certifications offered by the CWNP program. Acquiring this certification will prove one's ability to successfully apply the most up-to-date IEEE 802.11 WLAN security solutions to an organization's IEEE 802.11 wireless network. This certification will ensure that the successful candidate understands the security weaknesses inherent in IEEE 802.11 WLANs, the solutions available to address those weaknesses, and the steps necessary to implement a secure and manageable WLAN in an enterprise environment. Successfully passing two exams is required to become CWSP certified:

- Exam CWNA-107 – Certified Wireless Network Administrator
- Exam CWSP-205 – Certified Wireless Security Professional

CWDP: Certified Wireless Design Professional The CWDP (Certified Wireless Design Professional) certification is a professional-level career certification for those in wireless computer networking who have already obtained the CWNA certification and have a thorough understanding of RF technologies and applications of 802.11 networks. This certification prepares WLAN professionals to properly design an IEEE 802.11 WLAN for various environments and for optimal performance. Successfully passing two exams is required to become CWDP certified:

- Exam CWNA-107 – Certified Wireless Network Administrator
- Exam CWDP-302 – Certified Wireless Design Professional

CWAP: Certified Wireless Analysis Professional The CWAP (Certified Wireless Analysis Professional) certification is a professional-level career certification for those in wireless computer networking who have already obtained the CWNA certification and have a thorough understanding of RF technologies and applications of 802.11 wireless networks. This certification provides an in-depth look at 802.11 operations and prepares WLAN professionals to be able to perform, interpret, and understand wireless packet and spectrum analysis. You must successfully pass two exams to become CWAP certified:

- Exam CWNA-107 – Certified Wireless Network Administrator
- Exam CWAP-402 – Certified Wireless Analysis Professional

CWNE: Certified Wireless Network Expert The CWNE (Certified Wireless Network Expert) credential is the highest certification offered by the CWNP program. By successfully completing the CWNE requirements, you will have demonstrated that you have the most advanced skills available in today's IEEE 802.11 WLAN market. The CWNE certification ensures that you have mastered all relevant skills to administer, install, configure, troubleshoot, and design wireless network systems. Protocol analysis, intrusion detection and prevention, performance and QoS analysis, spectrum analysis and management, and advanced design are some of the areas of expertise you will need to know. Successfully passing four exams is required to become CWNE certified:

- Exam CWNA-107 – Certified Wireless Network Administrator
- Exam CWSP-205 – Certified Wireless Security Professional
- Exam CWDP-302 – Certified Wireless Design Professional
- Exam CWAP-402 – Certified Wireless Analysis Professional

The following criteria must also be met:

- Three years of documented enterprise Wi-Fi implementation experience
- Three professional endorsements
- Two other current, valid professional networking certifications
- Documentation of three enterprise Wi-Fi projects in which you participated or led in the form of 500-word essays
- Re-certification every three years by completing continuing education (CE) credits. During the three-year CWNE cycle, a CWNE professional must report a minimum of 60 CE hours.

For additional information on the details required for CWNE certification, including information regarding what is valid for continuing education credit hours, visit `www.cwnp.com`.

CWNT: Certified Wireless Network Trainer Certified Wireless Network Trainers (CWNT) are qualified instructors certified by the CWNP program to deliver CWNP

training courses to IT professionals. CWNTs are technical and instructional experts in wireless technologies, products, and solutions. CWNP Authorized Learning Centers (ALC) are required to use CWNTs when delivering training using official CWNP courseware.

Keep in mind that the certification exam numbers listed in this book are as of this writing. When CWNP updates an exam, the exam reference number will change. For the most current information regarding all certifications and exams, visit `www.cwnp.com`.

CWNP Learning Resources

A variety of resources are available to help you learn vendor-neutral WLAN technology. Listed are some of these resources:

- Self-study materials
- Study guides from Sybex
- Online practice exams from `www.cwnp.com`
- Instructor-led classroom training
- Online live training
- Computer-based training (CBT)
- CWNP website
- CWNP forums
- CWNP blog
- CWNP learning center, offering 1,000+ white papers

How to Become a CWTS

To become a CWTS, you must complete the following two steps:

- Agree that you have read and will abide by the terms and conditions of the CWNP confidentiality agreement.
- Pass the CWTS PW0-071 certification exam.

A copy of the CWNP confidentiality agreement can be found online at the CWNP website.

When you take the CWTS certification exam, you will be required to accept the confidentiality agreement before you can continue to complete the exam. After you have agreed, you will be able to continue with the exam. When you pass the exam with a score of 70 percent or higher, you will have met the requirements to become CWTS certified.

The information for the CWTS exam is as follows:

- Exam name: Certified Wireless Technology Specialist
- Exam number: PW0-071
- Cost: $150.00 (USD)
- Duration: 90 minutes
- Questions: 60
- Question types: Multiple choice/multiple answer
- Passing score: 70 percent
- Available languages: English
- Renewal: None—lifetime certification. Recommended prior to CWNA.
- Availability: Register at Pearson VUE (`www.vue.com/cwnp`)

When you schedule the exam, you will receive instructions regarding appointment and cancellation procedures, ID requirements, and information about the testing center location. In addition, you will receive a registration and payment confirmation email. Exams can be scheduled weeks in advance or, in some cases, even as late as the same day.

After you have successfully passed the CWTS exam, the CWNP program will award you the lifetime certification. If the email contact information you provided the testing center is correct, you will receive an email from CWNP recognizing your accomplishment and providing you with a CWNP certification number. After you earn any CWNP certification, you can request a certification kit from CWNP. You will need to log in to the CWNP tracking system, verify your contact information, and request your certification kit.

How to Become a CWS

To become a CWS, you must complete the following:

- Pass the CWS-2017 certification exam.

The information for the CWS exam is as follows:

- Exam name: Certified Wireless Specialist
- Exam number: CWS-2017
- Cost: $75.00 (USD)
- Duration: 90 minutes
- Number of questions: 60
- Type of questions: Multiple choice/single correct
- Passing score: 70 percent
- Available languages: English
- Renewal: 3 years
- Availability: Online

To register for the CWS certification exam, visit the CWNP website at `www.cwnp.com`.

How to Become a CWT

To become a CWT, you must complete the following:

- Pass the CWT-2017 certification exam.

The information for the CWT exam is as follows:

- Exam name: Certified Wireless Technician
- Exam number: CWT-2017
- Cost: $75.00 (USD)
- Duration: 90 minutes
- Number of questions: 60
- Type of questions: Multiple choice/single correct
- Passing score: 70 percent
- Available languages: English
- Renewal: 3 years
- Availability: Online

To register for the CWT certification exam, visit the CWNP website at `www.cwnp.com`.

Who Should Get This Book?

Reading this book will provide you with an overview of IEEE 802.11 WLAN technology. This book is written with the CWTS, CWS, and CWT exam objectives in mind and "what it is," not "how it works." The exam objectives were designed based on the skill set the intended audience should need in order to perform their job functions or roles in an organization. One thing to keep in mind is that this book will introduce and teach you a technology, a combination of computer LAN and RF technology.

If you follow the exam objectives, perform the hands-on exercises, and utilize all the available exam questions and practice exams at the book's companion website (`www.wiley.com/go/sybextestprep`) and at `www.cwnp.com`, you should be prepared to pass the certification exams. This book will also serve as a stepping-stone to more advanced books that teach the technology in more depth, as well as a reference guide for the technology.

How to Use This Book and the Companion Website

Several testing features are in this book, and an exam engine that contains flashcards and additional practice exams is available on the book's companion website (`www.wiley.com/go/sybextestprep`). These are designed to test your knowledge of the information you have learned from reading the book and performing the exercises. Although there is no guarantee you will pass the certification exam if you use this book and the additional online material, you will have all the tools necessary that effectively prepare you to do so.

Before You Begin At the beginning of the book (right after this introduction) is an assessment test you can use to check your readiness for the certification exams. Take this test before you start reading the book; it will help you determine the areas you may need to brush up on. The answers to the assessment test appear on a separate page after the last question of the test. Each answer includes an explanation, shows a chapter reference, and describes why the other options are incorrect.

Chapter Review Questions To test your knowledge as you progress through this book, there are review questions at the end of each chapter. As you finish each chapter, answer the review questions and then check your answers. The correct answers appear in an appendix at the back of the book. You can go back and revisit the section that deals with each question you answered wrong to ensure that you understand the material and answer correctly the next time you are tested on that topic.

Electronic Flashcards You will find flashcard questions on the book's companion website (`www.wiley.com/go/sybextestprep`). These are short questions and answers, just like other flashcards you may be familiar with and have used in the past. You can answer them on your PC or download them onto a tablet, smartphone, or other client device for quick and convenient reviewing.

Test Engine The book's companion website (`www.wiley.com/go/sybextestprep`) also contains the Sybex Test Engine. With this custom test engine, you can identify weak areas up front and then develop a solid studying strategy that includes each of the robust testing features described previously. The readme file will walk you through the quick, easy installation process.

In addition to the assessment test and the chapter review questions, you will find two bonus exams. Use the test engine to take these practice exams just as if you were taking an actual exam (without any reference material). When you have finished the first exam, move on to the next one to solidify your test-taking skills. Getting a high percentage of the answers correct is an indication you are ready to take the actual certification exams.

Labs and Exercises Several chapters in this book have lab exercises that use evaluation software that is downloadable from the manufacturer's website. These exercises will provide you with a broader learning experience by providing hands-on experience and step-by-step problem solving.

The Certification Exams Are Based on the Exam Objectives

It is important to note that in order to pass the certification exam, you should study from the currently posted exam objectives. Use this book as a learning aid to understand the exam objectives. For the most up-to-date certification exam objectives, visit the CWNP website at `www.cwnp.com`.

CWNP Exam Terminology

The CWNP program uses specific terminology when phrasing the questions on any of the CWNP exams. The terminology used most often mirrors the language that is used in the IEEE 802.11 standard. While technically correct, the terminology used in the exam questions often is not the same as the marketing terminology that is used by the Wi-Fi Alliance or the manufacturers of WLAN equipment.

As of this writing, the most current IEEE version of the 802.11 standard is the IEEE 802.11-2016 document, which includes all the amendments that have been ratified since the IEEE 802.11-2012 standard. Standards bodies such as the IEEE often create several amendments to a standard before "rolling up" the ratified amendments (finalized or approved versions) into a new standard.

For example, you might already be familiar with the term *802.11g*, which is a ratified amendment that has now been integrated into the IEEE 802.11-2016 standard. The technology that was originally defined by the 802.11g amendment is called *Extended Rate Physical* (ERP). Although the name 802.11g effectively remains the more commonly used marketing terminology, exam questions may use the technical term ERP instead of 802.11g. A document with exam terms is available from the CWNP website. At the time of this writing, the URL to access this document is `www.cwnp.com/uploads/misc/cwnp_exam_terms.pdf`.

CWTS, CWS, and CWT Exam Objectives

The CWTS, CWS, and CWT certifications, covering the current objectives, will certify that successful candidates know the fundamentals of RF behavior, can describe the features and functions of wireless components, and have the skills needed to understand and/or install and configure wireless network hardware components. A typical CWTS candidate should have a basic understanding of data networking concepts.

The skills and knowledge measured by this examination are derived from a survey of wireless networking experts and professionals. The results of this survey were used in weighing the subject areas and ensuring that the weighting is representative of the relative importance of the content.

CWTS, CWS, and CWT Complete Study Guide has been written to cover every exam objective at a level appropriate to its exam weighting. The following sections provide a breakdown of this book's exam coverage, showing you the weight of each section.

CWTS Exam Objectives

Subject Area	Percent of Exam
Wi-Fi Technology, Standards, and Certifications	25%
Hardware and Software	20%
Radio Frequency (RF) Fundamentals	20%

Subject Area	Percent of Exam
Site Surveying and Installation	10%
Applications, Support, and Troubleshooting	15%
Security and Monitoring	10%
Total	100%

Wireless Technologies, Standards, and Certifications - 25%

1.1 Define the roles of the following organizations in providing direction and accountability within the wireless networking industry

- IEEE
- Wi-Fi Alliance
- Local regulatory authorities

1.2 Define basic characteristics of and concepts relating to Wi-Fi technology

- Range, coverage, and capacity
- Frequencies/channels used
- Channel reuse and co-location
- Infrastructure and ad hoc modes
- BSSID, SSID, BSS, ESS, BSA, IBSS
- Network discovery via active and passive scanning
- 802.11 authentication and association
- Data rates and throughput
- The distribution system and roaming
- Protection Mechanisms
- Power saving operation
- Dynamic rate switching

1.3 Summarize the basic attributes of the following WLAN standards, amendments, and product certifications

- 802.11a
- 802.11b
- 802.11g
- 802.11n
- Wi-Fi Multimedia (WMM) certification
- WMM Power Save (WMM-PS) certification

- Wi-Fi Protected Access (WPA/WPA2) certification
  - Enterprise
  - Personal

1.4 Explain the role of Wi-Fi as a network access technology

- WPAN, WLAN, WMAN, WWAN
- The OSI reference model

Hardware and Software - 20%

2.1 Identify the purpose, features, and functions of the following wireless network components. Choose the appropriate implementation or configuration steps in a given scenario.

- Access Points
  - Controller-based
  - Autonomous
  - Cooperative
- Mesh
- Wireless LAN Routers
- Wireless Bridges
- Wireless Repeaters
- WLAN Controller
  - Distributed and centralized data forwarding
- Power over Ethernet (PoE) Devices
  - 802.3af and 802.3at
  - Midspan
  - Endpoint

2.2 Identify the purpose, features, and functions of the following client device types. Choose the appropriate installation or configuration steps in a given scenario.

- PC Cards (ExpressCard, CardBus, and PCMCIA)
- USB2
- PCI, Mini-PCI, and Mini-PCIe, and Half Mini PCIe cards
- Workgroup Bridges
- Client utility software and drivers

2.3 Identify the purpose, features, and proper implementation of the following types of antennas

- Omni-directional/dipole
- Semi-directional
- Highly-directional

2.4 Describe the proper locations and methods for installing RF antennas

- Internal and external (to the AP) antennas
- Pole/mast mount
- Ceiling mount
- Wall mount

Radio Frequency (RF) Fundamentals - 20%

3.1 Define the basic concepts and units of RF measurements, identify when they are used, and perform basic unit conversion.

- Watt (W) and milliwatt (mW)
- Decibel (dB)
- dBm
- dBi
- RSSI
- SNR

3.2 Identify and explain RF signal characteristics

- Frequency
- Wavelength
- Amplitude
- Phase

3.3 Identify factors which affect the range and rate of RF transmissions

- Line-of-sight requirements
- Interference (Wi-Fi and non-Wi-Fi)
- Environmental factors, including building materials
- Free Space Path Loss

3.4 Define and differentiate between the following physical layer wireless technologies

- 802.11b HR/DSSS
- 802.11g ERP
- 802.11a OFDM
- 802.11n HT

3.5 Define concepts which make up the functionality of RF spread spectrum communication

- 802.11 channels
- Co-location of 802.11a/b/g/n systems
- Adjacent-channel and co-channel interference

- WLAN/WPAN co-existence
- CSMA/CA operation
- Half duplex communications

3.6 Understand and apply basic RF antenna concepts

- Passive Gain
- Beamwidth
- Simple diversity
- Polarization

3.7 Identify the use of the following WLAN accessories and explain how to select and install them for optimal performance and regulatory domain compliance

- RF cables
- RF connectors
- Lightning Arrestors and grounding rods

Site Surveying and Installation - 10%

4.1 Understand and describe the requirements to gather information prior to the site survey and do reporting after the site survey

- Gathering business requirements
- Interviewing stakeholders
- Gathering site-specific documentation including existing network characteristics
- Identifying infrastructure connectivity and power requirements
- Understanding RF coverage requirements
- Understanding application requirements

4.2 Define and differentiate between the following WLAN system architectures and understand site survey concepts related to each architecture. Identify and explain best practices for access point placement and density.

- Multiple Channel Architecture (MCA)
- Single Channel Architecture (SCA)

4.3 Describe the primary purpose and methodology of manual and predictive site surveys

4.4 Define the need for and the use of a manual site survey tool and differentiate between the following manual site survey types

- Active surveys
- Passive surveys

4.5 Differentiate between manual and predictive site surveys

- Advantages and disadvantages of each site survey methodology

4.6 Define the need for and use of site survey software or a protocol analyzer in a manual site survey as it relates to identifying, locating, and assessing nearby WLANs

4.7 Differentiate between site survey methods for indoor and outdoor wireless service

4.8 Define the need for and use of a spectrum analyzer in a site survey

- Identification and location of interference sources
- Differentiation of Wi-Fi and non-Wi-Fi interference sources

4.9 Understand industry best practices for optimal use of directional and omni-directional antennas in site surveys

Applications, Support, and Troubleshooting - 15%

5.1 Identify deployment scenarios for common WLAN network types and suggest best practices for these scenarios.

- Small Office/Home Office (SOHO)
- Extension of existing networks into remote locations
- Building-to-building connectivity
- Public wireless hotspots
- Carpeted office, education, industrial, and healthcare
- Last-mile data delivery – Wireless ISP
- High density environments

5.2 Recognize common problems associated with wireless networks and their symptoms, and identify steps to isolate and troubleshoot the problem. Given a problem situation, interpret the symptoms and the most likely cause.

- Throughput problems
- Connectivity problems
- RF coverage or capacity problems
- Interference from Wi-Fi or non-Wi-Fi sources
- Application performance problems
- RF performance problems, such as multipath and hidden nodes

5.3 Identify procedures to optimize wireless networks.

- Infrastructure hardware selection and placement
- Identifying, locating, and removing sources of interference
- Client load-balancing and infrastructure redundancy
- Analyzing infrastructure capacity and utilization

Security & Monitoring - 10%

6.1 Identify and describe the following legacy WLAN security technologies.

- SSID Hiding
- WEP
- MAC Filtering

6.2 Understand the basic operation of and implementation best practices for the following WLAN security technologies.

- WPA- and WPA2-Personal
- WPA- and WPA-2 Enterprise
- 802.1X/EAP
- AAA and RADIUS
- Encryption – TKIP/CCMP

6.3 Understand the basic functions and implementation best practices for the following WLAN security technologies.

- Role Based Access Control (RBAC)
- Virtual Private Networking (VPN)
- Wireless Intrusion Prevention Systems (WIPS)
- Captive Portals
- Network management and monitoring systems

Exam domains and objectives are subject to change at any time without prior notice and at CWNP's sole discretion. Please visit their website (`www.cwnp.com`) for the most current information.

CWS Exam Objectives

Knowledge Domain	Percentage
Understand Basic RF Hardware and Functions	15%
Identify 802.11 Features and Functions	30%
Identify Wireless LAN Hardware and Software	30%
Understand Organizational Goals	25%

Understand Basic RF Hardware and Functions -15%

1.1 Identify RF characteristics

- 1.1.1 RF waves
- 1.1.2 Amplitude
- 1.1.3 Frequency
- 1.1.4 Wavelength

1.2 Explain basic RF behaviors

- 1.2.1 Reflection
- 1.2.2 Absorption
- 1.2.3 Signal strength

1.3 Understand antenna types

- 1.3.1 Omnidirectional
- 1.3.2 Semi-directional
- 1.3.3 Highly directional
- 1.3.4 Internal vs. external

Identify 802.11 Features and Functions - 30%

2.1 Know the frequency bands used

- 2.1.1 2.4 GHz – 802.11b/g/n
- 2.1.2 5 GHz – 802.11a/n/ac
- 2.1.3 Sub-1 GHz – 802.11ah
- 2.1.4 60 GHz – 802.11ad

2.2 Identify Physical Layer (PHY) characteristics

- 2.2.1 Data rates
- 2.2.2 Bands used
- 2.2.3 Supported technologies (laptops, tablets, video devices, Internet of Things (IoT))

2.3 Select appropriate channels

- 2.3.1 Channel selection best practices
- 2.3.2 Common channel selection mistakes

2.4 Identify factors impacting wireless LAN (WLAN) performance

- 2.4.1 Coverage requirements
- 2.4.2 Capacity requirements
- 2.4.3 Required features
- 2.4.4 Poor configuration and implementation

2.5 Explain the basic differences between WPA and WPA2 security

- 2.5.1 Authentication and key management
- 2.5.2 Encryption
- 2.5.3 Personal vs. Enterprise

2.6 Describe features of enhanced 802.11 functions

- 2.6.1 Mesh
- 2.6.2 Quality of Services (QoS)
- 2.6.3 SISO vs. MIMO
- 2.6.4 Dynamic Rate Switching (DRS)
- 2.6.5 Backwards compatibility

Identify Wireless LAN Hardware and Software - 30%

3.1 Identify AP features and capabilities

- 3.1.1 PHY support
- 3.1.2 Single-band vs. dual-band
- 3.1.3 Output power control
- 3.1.4 Operational modes
- 3.1.5 Multiple-SSID support
- 3.1.6 Guest access
- 3.1.7 Security features
- 3.1.8 Management interfaces
- 3.1.9 Internal and external antennas
- 3.1.10 PoE support

3.2 Describe AP management systems

- 3.2.1 Autonomous
- 3.2.2 Controller
- 3.2.3 Cloud
- 3.2.4 Management systems

3.3 Determine capabilities of client devices

- 3.3.1 PHY support
- 3.3.2 Single-band vs. multi-band
- 3.3.3 Support for MIMO
- 3.3.4 Supported channels in 5 GHz
- 3.3.5 Supported security options

3.4 Identify when Power over Ethernet (PoE) should be used

3.5 Explain the requirements of fast and secure roaming for non-technical professionals

- 3.5.1 Latency requirements for streaming communications
- 3.5.2 Pre-authentication
- 3.5.3 Key caching methods

3.6 Understand the basic requirements for voice over WLAN (VoWLAN)

- 3.6.1 Latency
- 3.6.2 Jitter
- 3.6.3 Signal strength

3.7 Determine the best solution for BYOD and guest access

- 3.7.1 User provisioning
- 3.7.2 Captive portals
- 3.7.3 Device and software control solutions

Understand Organizational Goals - 25%

4.1 Understand issues in common vertical markets

- 4.1.1 Standard Enterprise Offices
- 4.1.2 Healthcare
- 4.1.3 Hospitality
- 4.1.4 Conference Centers
- 4.1.5 Education
- 4.1.6 Government
- 4.1.7 Retail
- 4.1.8 Industrial
- 4.1.9 Emergency Response
- 4.1.10 Temporary Deployments
- 4.1.11 Small Office/Home Office (SOHO)
- 4.1.12 Public Wi-Fi

4.2 Gather information about existing networks

- 4.2.1 Network diagrams
- 4.2.2 Wi-Fi implementations
- 4.2.3 Neighbor networks
- 4.2.4 Available network services
- 4.2.5 PoE availability

4.3 Discover coverage and capacity needs

- 4.3.1 Define coverage areas
- 4.3.2 Define capacity zones

4.4 Discover client devices and applications in use
- 4.4.1 Laptops, tablets, mobile phones, desktops, and specialty devices
- 4.4.2 Real-time applications
- 4.4.3 Standard applications (e-mail, web browsing, database access, etc.)
- 4.4.4 Data-intensive applications (file downloads/uploads, cloud storage, cloud backup, etc.)

4.5 Determine the need for outdoor coverage networks and bridge links
- 4.5.1 Bridge link distance and required throughput
- 4.5.2 Outdoor areas requiring coverage
- 4.5.3 Use cases for outdoor access

4.6 Define security constraints
- 4.6.1 Regulatory
- 4.6.2 Industry standards and guidelines
- 4.6.3 Organizational policies

4.7 Discover use cases and access types
- 4.7.1 Authorized users
- 4.7.2 Onboarded guest access
- 4.7.3 Public Wi-Fi

4.8 Match organizational goals to WLAN features and functions

Exam domains and objectives are subject to change at any time without prior notice and at CWNP's sole discretion. Please visit their website (`www.cwnp.com`) for the most current information.

CWT Exam Objectives

Knowledge Domain	Percentage
Basic RF Characteristics	15%
WLAN Client Features and Capabilities	25%
WLAN AP Features and Capabilities	25%
Configuration of 802.11 Security Parameters	20%
Troubleshooting Common WLAN Connection Issues	15%

Basic RF Characteristics - 15%

1.1 Describe RF signal characteristics
- 1.1.1 Frequency
- 1.1.2 Amplitude
- 1.1.3 Phase
- 1.1.4 Wavelength

1.2 Explain RF behaviors and signal propagation
- 1.2.1 Gain and loss
- 1.2.2 Reflection
- 1.2.3 Refraction
- 1.2.4 Scattering
- 1.2.5 Diffraction
- 1.2.6 Absorption
- 1.2.7 Free space path loss

1.3 Understand how to detect RF signal factors
- 1.3.1 Wi-FI scanner tools
- 1.3.2 Client signal strength reports
- 1.3.3 RSSI vs. dBm
- 1.3.4 Output power vs. received signal strength

1.4 Create basic RF channel plans
- 1.4.1 Available 2.4 GHz channels
- 1.4.2 Available 5 GHz channels
- 1.4.3 Regulatory constraints on channel selection
- 1.4.4 Best practices for channel selection
- 1.4.5 Co-Channel Interference (CCI)

1.5 Describe the basic differences among antenna types
- 1.5.1 Omnidirectional
- 1.5.2 Semi-directional
- 1.5.3 Highly directional
- 1.5.4 Antenna mounting kits

1.6 Select the appropriate external antenna when required
- 1.6.1 Antenna pattern charts
- 1.6.2 Antenna cables and connectors
- 1.6.3 Passive antenna gain

WLAN Client Features and Capabilities - 25%

2.1 Describe client types and varying capabilities

- 2.1.1 Laptops
- 2.1.2 Tablets
- 2.1.3 Mobile phones
- 2.1.4 Desktops
- 2.1.5 Specialty devices (video cameras, Wi-Fi peripheral connections, printers, IoT, etc.)

2.2 Explain the basic WLAN location processes

- 2.2.1 Passive scanning
- 2.2.2 Active scanning

2.3 Describe the basic steps required in the WLAN connection process

- 2.3.1 Authentication
- 2.3.2 Association
- 2.3.3 802.1X/EAP authentication
- 2.3.4 4-way handshake

2.4 Determine the channels and streams supported by client devices

- 2.4.1 2.4 GHz channels
- 2.4.2 5 GHz channels
- 2.4.3 Channel widths
- 2.4.4 Number of spatial streams (1x1, 2x2, 3x3, etc.)

2.5 Configure client devices

- 2.5.1 Configure client drivers for optimum performance (band preference, roaming threshold, regulatory domain, etc.)
- 2.5.2 Configure various client operating systems for wireless connectivity, including security parameters
- 2.5.2.1 Windows
- 2.5.2.2 Mac OS
- 2.5.2.3 Chrome OS
- 2.5.2.4 Linux
- 2.5.2.5 Tablets and mobile phones (iOS and Android)

WLAN AP Features and Capabilities - 25%

3.1 Identify AP features and capabilities and understand configuration options related to them

- 3.1.1 PHY support
- 3.1.2 Single-band vs. dual-band
- 3.1.3 Output power control
- 3.1.4 Operational modes
- 3.1.5 Multiple-SSID support
- 3.1.6 Guest access
- 3.1.7 Security features
- 3.1.8 Management interfaces (web-based, CLI, remote CLI)
- 3.1.9 Internal and external antennas
- 3.1.10 PoE support

3.2 Select appropriate mounting kits for a specified installation location

- 3.2.1 Wall mount
- 3.2.2 Pole/mast mount
- 3.2.3 Ceiling mount

3.3 Ensure proper PoE provisioning when required

- 3.3.1 Power levels required
- 3.3.2 PoE switches
- 3.3.3 PoE injectors
- 3.3.4 Testing power availability

3.4 Configure APs as standalone devices

- 3.4.1 Admin account credentials
- 3.4.2 Administration interfaces
- 3.4.3 Wireless network profiles
- 3.4.4 Security parameters, including authentication, authorization and encryption

3.5 Validate AP wired interface connectivity

- 3.5.1 IP configuration
- 3.5.2 Internet access
- 3.5.3 Infrastructure service access
- 3.5.4 Appropriate Ethernet switch port settings

3.6 Validate proper AP WLAN configuration

- 3.6.1 Client connectivity
- 3.6.2 Accurate security settings
- 3.6.3 Client throughput performance

Configuration of 802.11 Security Parameters - 20%

4.1 Understand the basics of 802.11 standard security solutions

- 4.1.1 WPA vs. WPA2
- 4.1.2 Personal vs. Enterprise
- 4.1.3 Pre-Shared Key
- 4.1.4 802.1X/EAP
- 4.1.5 Common EAP methods

4.2 Identify legacy security technologies that should not be used

- 4.2.1 WEP
- 4.2.2 Shared Key Authentication
- 4.2.3 Hidden SSIDs
- 4.2.4 MAC filtering

4.3 Configure security parameters in an AP

- 4.3.1 Pre-Shared Key
- 4.3.2 RADIUS server
- 4.3.3 802.1X/EAP
- 4.3.4 WPA-WPA2

4.4 Configure security parameters in a client device

- 4.4.1 Pre-Shared Key
- 4.4.2 802.1X/EAP
- 4.4.3 WPA/WPA2

Troubleshooting Common WLAN Connection Issues - 15%

5.1 Troubleshoot connectivity problems

- 5.1.1 Configuration errors
- 5.1.2 Interference
- 5.1.3 Poor signal strength
- 5.1.4 Driver issues
- 5.1.5 Supplicant issues
- 5.1.6 Feature incompatibility

5.2 Troubleshoot performance problems
- 5.2.1 Configuration errors
- 5.2.2 Interference
- 5.2.3 Low data rates
- 5.2.4 Co-channel interference (CCI)

5.3 Troubleshoot security problems
- 5.3.1 Configuration errors
- 5.3.2 Incorrect passphrases
- 5.3.3 Incompatible EAP methods

5.4 Troubleshoot mobility problems
- 5.4.1 Configuration errors
- 5.4.2 Improper network settings
- 5.4.3 Unsupported fast roaming methods
- 5.4.4 Non-implemented roaming feature

Exam domains and objectives are subject to change at any time without prior notice and at CWNP's sole discretion. Please visit their website (`www.cwnp.com`) for the most current information.

Assessment Test

1. What two software items must be installed on a notebook computer prior to connecting to a wireless network? (Choose two.)
   - **A.** Site survey software
   - **B.** Device driver software
   - **C.** Signal strength software
   - **D.** Client utility software
   - **E.** AutoConfig software

2. IEEE 802.11 WLAN technology operates at which two layers of the OSI model? (Choose two.)
   - **A.** Physical
   - **B.** Data Link
   - **C.** Network
   - **D.** Transport
   - **E.** Application

3. The amount of output power and usable frequency ranges for WLAN devices is determined by which organization?
   - **A.** Wireless Ethernet Compatibility Alliance
   - **B.** Wi-Fi Alliance
   - **C.** Institute of Electrical and Electronics Engineers
   - **D.** Local regulatory authorities

4. Which statement is accurate regarding controller-managed access points compared to autonomous access points?
   - **A.** Controller-managed access points are considered legacy technology, and the priority should be to select an appropriate upgrade path.
   - **B.** Controller-managed access points connect together with at least two paths for every access point, whereas autonomous access points do not.
   - **C.** Controller-managed access points can be centrally configured, whereas autonomous access points must be individually managed.
   - **D.** Controller-managed access points require a separate radio for management functions and therefore can be more expensive to implement than autonomous access points.

5. Wireless repeaters are devices in wireless networking that are _____.
   - **A.** Used to extend the radio frequency cell of an access point
   - **B.** Used to repeat and strengthen the RF signal for better performance
   - **C.** Used as a backup solution in the event of an access point failure
   - **D.** Used to increase the bandwidth of the WLAN

6. Some common wireless personal area network (WPAN) devices, such as Bluetooth, use a communication technology that has the potential to interfere with IEEE 802.11g/n WLANs. What is the name for this technology?
   - **A.** FHSS
   - **B.** DSSS
   - **C.** HR/DSSS
   - **D.** HR/FHSS
   - **E.** ERP-OFDM

7. The manual site survey process allows the site surveyor to perform the survey in one of two modes. What are these two modes? (Choose two.)
   - **A.** Passive
   - **B.** Visual
   - **C.** Predictive
   - **D.** Active
   - **E.** Placement

8. A third-party client utility such as Microsoft Windows AutoConfig can be used with _____.
   - **A.** SOHO implementations
   - **B.** Enterprise implementations
   - **C.** Both A and B
   - **D.** Neither A nor B

9. Which of the following options are required components of the gathering of technical information for an IEEE 802.11n/ac WLAN site survey in a new installation? (Choose three.)
   - **A.** Number of devices
   - **B.** Applications in use
   - **C.** Other IEEE 802.11 wireless networks
   - **D.** Cost of equipment

10. Manufacturers' client software utilities for WLAN adapters _____.
    - **A.** Allow for ease of additional configurations
    - **B.** Are required in order for the adapter to operate
    - **C.** Are usually available at an additional fee
    - **D.** Are generic regardless of the manufacturer

11. An independent basic service set (IBSS) requires a minimum of how many access points?
    - **A.** 0
    - **B.** 1
    - **C.** 2
    - **D.** 3

12. What is the horizontal angle of measurement in degrees of an omnidirectional antenna with a gain of 2.2 dBi?

A. 0

B. 90

C. 180

D. 270

E. 360

13. Which IEEE 802.11 amendment specified the use of four radio chains per band and multiple input/multiple output (MIMO) technology to transmit data?

A. 802.11

B. 802.11a

C. 802.11g

D. 802.11h

E. 802.11n/ac

14. Which amendment to the standard operates in the 2.4 GHz ISM band and supports maximum data rates of up to 54 Mbps?

A. 802.11a

B. 802.11b

C. 802.11g

D. 802.11n/ac

15. An HR/DSSS channel used to transmit data in an IEEE 802.11b/g/n WLAN is _____ wide.

A. 2.412 GHz

B. 5.160 GHz

C. 11 MHz

D. 22 MHz

E. 40 MHz

16. IEEE 802.11g/n wireless networks can operate in which unlicensed RF band?

A. 902 – 928 MHz ISM

B. 2.400 – 2.500 GHz ISM

C. 5.725 – 5.825 GHZ UNII

D. 5.250 – 5.350 GHz UNII

E. 5.725 – 5.875 GHz ISM

17. What network type is usually contained in the same physical area and typically bounded by the perimeter of a building?

A. Local area network (LAN)

B. Campus area network (CAN)

C. Wide area network (WAN)

D. Metropolitan area network (MAN)

18. Which Data Link layer (Layer 2) security methods are weak and should not be used to secure an IEEE 802.11 WLAN? (Choose three.)

A. SSID hiding

B. WPA

C. VPN

D. WEP

E. WPA 2.0

F. RBAC

G. MAC filtering

19. Which RF channels are considered nonoverlapping for an IEEE 802.11g/n network that is using HR/DSSS modulation technology? (Choose two.)

A. 1 and 4

B. 6 and 9

C. 1 and 6

D. 3 and 7

E. 11 and 13

F. 2 and 7

20. What can have a negative effect on the capacity of an IEEE 802.11a/b/g/n/ac WLAN access point?

A. Reflections caused by furnishings

B. Frequency range in use

C. Number of associated users

D. Output power of access point

21. What could cause low throughput in an 802.11a/b/g/n/ac wireless network?

A. Access point output power is too high.

B. Too many client devices are associated.

C. Load-balancing features are moving clients.

D. The clients are too close to the access points and are overpowered.

22. What can contribute to voltage standing wave ratio (VSWR) in an IEEE 802.11a/b/g/n/ac WLAN circuit?

A. Output power of the access point

B. Impedance mismatch

C. Gain of an antenna

D. Attenuation value of cable

23. IEEE 802.11 open system authentication is _____ in an IEEE 802.11-2016 wireless network.

A. Flawed

B. Optional

C. Secure

D. Required

24. The service set identifier (SSID) in an IEEE 802.11 WLAN is also known as what?

A. The name of the wireless network

B. The Media Access Control address of the radio

C. The name of the access point

D. The wireless medium identifier

25. What does the term *authenticator* identify in an IEEE 802.1x secure WLAN?

A. The RADIUS server

B. The access point

C. The client device

D. The RAS server

26. A virtual private network (VPN) most commonly operates at which layer of the OSI model?

A. Physical, Layer 1

B. Data Link, Layer 2

C. Network, Layer 3

D. Transport, Layer 4

E. Application, Layer 7

27. You are a WLAN engineer hired to perform a predictive modeling site survey for a 150,000-square-foot office building. This space includes walled offices as well as cubicles. What is an advantage of a predictive modeling site survey over a manual survey in this specific application?

A. Predictive modeling site surveys are the most accurate survey type available, including determining RF coverage and interference.

B. Predictive modeling site surveys require much less time than a complete manual site survey, which requires a walkthrough of the entire facility.

C. Predictive modeling site survey software has an extensive attenuation database and will be able to determine the interference values of any obstructions.

D. Predictive modeling site surveys allow you to experiment with different access point criteria and therefore never require a site visit.

28. What are some of the main factors in determining the number of access points that will be required for an IEEE 802.11n/ac WLAN deployment? (Choose two.)

A. Type of client devices in use

B. Number of associated client devices

C. Manufacturer of client devices

D. Applications to be used on the WLAN

29. What purpose will an 802.11 protocol analyzer provide during the manual site survey process?

A. Perform an RF analysis of the proposed area

B. Help locate sources of RF interference

C. Identify existing IEEE 802.11 wireless networks

D. Describe security requirements of the WLAN

30. What could be the cause of intermittent connectivity for a wireless client device in an IEEE 802.11a/b/g/n/ac wireless network?

A. A weak received signal strength on the wireless client.

B. A signal-to-noise ratio of 35 dB and RSSI of –60 dBm.

C. The access point power is set too high and overpowering the client device.

D. The WLAN radio in the client device is disabled.

31. Which layers of the OSI model do *not* specifically address WLAN technology? (Choose three.)

A. Session

B. Network

C. Physical

D. Application

E. Data Link

32. The signal-to-noise ratio (SNR) is the difference between the _____ and the _____.

A. Noise floor

B. RF channel

C. Fresnel zone

D. RF line of sight

E. Received signal

33. If an autonomous access point is set to what is commonly referred to as root mode, it will be able to perform which function?

A. Connect to a distribution system and allow client devices to send information to other devices

B. Connect to a distribution system as a root bridge and allow two or more LANs to connect wirelessly

C. Connect to a distribution system but be seldom used, as this mode requires extensive configuration

D. Connect to a distribution system as a repeater, which allows the RF cell to be extended

34. Wi-Fi Protected Access 2 (WPA 2.0) requires _____ for the encryption mechanism and _____ for the cipher.

A. TKIP, RC4

B. TKIP, RC5

C. WEP, RC4

D. CCMP, RC4

E. CCMP, AES

35. The access method that an IEEE 802.11n/ac wireless network would use to get control of the wireless medium in order to transmit data is called what?

A. CSMA/CD

B. FHSS/CCK

C. HR/DSSS

D. CSMA/CA

E. CSMA/DSSS

36. An antenna will propagate RF energy in specific radiation patterns, both horizontally and vertically. How do antenna manufacturers identify the horizontal radiation patterns?

A. Elevation

B. Azimuth

C. Dipole

D. Longitude

37. A beacon is an example of what type of frame used in an IEEE 802.11 WLAN?

A. Control

B. Management

C. Data

D. Null function

38. What is the difference between a consumer-grade Wi-Fi router and a Wi-Fi access point?

A. Consumer-grade Wi-Fi routers offer peer-to-peer communications, but Wi-Fi access points do not.

B. Consumer-grade Wi-Fi routers are a combination of a router and a Wi-Fi access point.

C. Consumer-grade Wi-Fi routers offer better security options than Wi-Fi access points.

D. Consumer-grade Wi-Fi routers can be used with wireless controllers, but Wi-Fi access points cannot.

39. Where would be the best location to install an omnidirectional antenna that is connected to a wireless access point?

A. At the perimeter of the RF coverage cell

B. At one end of the RF coverage cell

C. At the center of the RF coverage cell

D. At all hallway locations

40. Which tool can be used to locate areas of RF coverage and interference from non–Wi-Fi devices?

A. Protocol analyzer

B. Predictive modeling software

C. VSWR meter

D. Spectrum analyzer

E. Network discovery software

Answers to Assessment Test

1. B, D. A device driver allows the computer operating system to control the wireless network adapter and must be installed in order for the adapter to function. Client utility software allows a user to configure the adapter with network specific settings, such as the SSID and security settings. Client utility software may be part of the computer operating system or third-party software provided by the manufacturer of the adapter. Site survey software and signal strength software may be part of the client utility software. AutoConfig is a service that runs on a Microsoft Windows computer. For more information, see Chapter 3.

2. A, B. IEEE 802.11 WLAN technology operates at the Layer 1 (Physical) and Layer 2 (Data Link) layers of the OSI model. The Network layer is responsible for addressing and routing of frames and is where IP addresses are used. The Transport layer is responsible for connection-oriented or connectionless protocols, and the Application layer is the "interface to the user." For more information, see Chapter 1.

3. D. Local regulatory authorities manage the RF spectrum used in both unlicensed and licensed applications. The IEEE creates standards, and the Wi-Fi Alliance certifies devices for interoperability. Wireless Ethernet Compatibility Alliance is the former name of the Wi-Fi Alliance. For more information, see Chapter 2.

4. C. Controller-managed access points can be centrally managed by a hardware controller. Autonomous access points are considered stand-alone devices and require individual management. Mesh access points require at least two paths for every access point. Controller-managed access points are not legacy technology, are implemented in very large networks, and do not require a separate radio for management functions. For more information, see Chapter 3.

5. A. A wireless repeater—which in most cases is a function of an access point—will extend the RF cell to allow users at a greater distance to connect. This will have an impact on throughput for users connected to the repeater, and this solution is recommended only when necessary. For more information, see Chapter 3.

6. A. Some wireless personal networks (WPANs), such as Bluetooth, use FHSS for communications. This will potentially interfere with IEEE 802.11 wireless networks. DSSS, HR/DSSS, and ERP-OFDM are all used in WLANs. HR/FHSS does not exist. For more information, see Chapter 7.

7. A, D. Passive and active are the two modes in which a manual site survey can be performed. Passive mode monitors all RF, and active mode requires a client association. For more information, see Chapter 9.

8. C. Third-party client utilities such as Microsoft's AutoConfig can be used in either SOHO or enterprise implementations. Because this utility is built into the Microsoft Windows operating system, it is very common in both types of installations. See Chapter 3 for more information.

9. A, B, C. The number of devices, applications both hardware and software, and other IEEE 802.11 wireless networks are technical areas that must be known for a new IEEE 802.11 WLAN installation. The cost of the equipment does not fall under the technical category. For more information, see Chapter 9.

10. A. Most manufacturers that offer utilities for WLAN adapters allow for additional configuration above and beyond the settings that are included with an operating system. Manufacturer utilities are not required for the adapter to operate, because some settings can be made in the device driver or a third-party client utility. Unless it is specialty client software, the utility is usually included with the adapter and is not subject to additional fee. Manufacturers' client software utilities are unique to only those adapters and will not work across manufacturers. See Chapter 3 for more information.

11. A. An independent basic service set (IBSS) is an ad hoc network that is used for peer-to-peer communications. No access points are used in an IBSS implementation. For more information, see Chapter 6.

12. E. An omnidirectional antenna has a horizontal radiation pattern of 360 degrees. The vertical radiation pattern will vary based on the gain of the antenna. This measurement is known as the *beamwidth* and is used for both horizontal and vertical radiation patterns. Beamwidth is measured at the –3dB or half-power point. For more information, see Chapter 5.

13. E. 802.11n/ac with MIMO can use up to four radios in the 2.4 GHz ISM band (802.11n) and up to eight radios the 5 GHz UNII band (802.11ac). 802.11a/g uses one radio per band but can use two antennas for diversity. 802.11h is for spectrum management. For more information, see Chapter 7.

14. C. The IEEE 802.11g amendment and the 802.11a amendment both support up to 54 Mbps maximum data rates. Of the two amendments, however, only 802.11g operates in the 2.4 GHz ISM band. 802.11b also operates in the 2.4 GHz ISM band but only supports a maximum data rate of 11 Mbps. The IEEE 802.11n/ac amendment allows support of up to 600 Mbps for devices operating in the 2.4 GHz ISM band. IEEE 802.11ac is 5 GHz only. For more information, see Chapter 2.

15. D. Both DSSS and HR/DSSS channels are 22 MHz wide. 2.412 GHz and 5.160 GHz is the center frequency of some channels used. For more information, see Chapter 7.

16. B. IEEE 802.11g/n networks operate in the 2.4 GHz ISM band. 802.11a networks operate in the 5 GHz UNII band. IEEE 802.11ah networks, also known as sub-1G wireless networks, will allow for use in the 900 MHz ISM band. For more information, see Chapter 4.

17. A. A local area network (LAN) is usually contained in the same physical area and typically bounded by the perimeter of a building. A campus area network (CAN) includes a set of interconnected LANs within an office or school campus and is usually within a limited geographical area. A wide area network (WAN) mostly consists of point-to-point or point-to-multipoint connections between two or more LANs. A metropolitan area network (MAN) consists of networks that may span from several blocks of buildings to entire cities. For more information, see Chapter 1.

18. A, D, G. SSID hiding, WEP, and MAC filtering are legacy security mechanisms for IEEE 802.11 wireless networks and should not be used. WPA and WPA 2.0 are Wi-Fi certifications and are more advanced. Virtual private network (VPN) is a Layer 3 security solution typically used for remote access. RBAC is role-based access control. For more information, see Chapter 8.

19. C, F. In the 2.4 GHz ISM band, 25 MHz or 5 channels of separation is considered nonoverlapping. Based on the IEEE 802.11-2016 Standard Clause 17, HR/DSSS channels must be separated by 25 MHz or greater in order to be considered nonoverlapping. For more information, see Chapter 4.

20. C. The number of associated users will affect the capacity of an access point. The frequency range will affect the propagation as well as the output power. Reflections will cause multipath in IEEE 802.11a/g networks, but 802.11n/ac networks can benefit from multipath. For more information, see Chapter 4.

21. B. Low throughput may occur when too many client devices are associated to an access point and cause overloading. Load balancing would help to solve this problem. Because of DRS, the closer the client device is to an access point, the better the throughput. For more information, see Chapter 11.

22. B. An impedance mismatch between connections in a WLAN system will cause VSWR. The gain of an antenna is a relative value that has to do with the size or shape of the RF pattern emitted. Attenuation of cable adds to the overall loss of the system. For more information, see Chapter 5.

23. D. Open system authentication is addressed in the original IEEE 802.11 standard and allows a wireless client device to perform an IEEE 802.11 authentication to an access point in order to allow an IEEE 802.11 association. Shared-key authentication is legacy and flawed, and either cannot or should not be used. Open system authentication is a "null" authentication, is automatic and not secure but is required for a client device to connect to an access point. For more information, see Chapter 6.

24. A. The SSID is the name that identifies a wireless network. The MAC address of the access point radio is the BSSID. For more information, see Chapter 6.

25. B. 802.1X is for port-based access control, and the terminology for the access point is *authenticator*. The RADIUS server is the authentication server, and the client device is a supplicant. The RAS server is the predecessor to RADIUS. For more information, see Chapter 8.

26. C. A virtual private network (VPN) solution is a Layer 3 (Network) security solution and is commonly used for remote access connectivity from unsecured networks, such as hotspots. For more information, see Chapter 8.

27. B. A predictive modeling site survey will minimize the time required on-site for testing and analysis. This site survey will be accurate if the information about the location input is accurate. A manual site survey requires a walkthrough of the area and can be time consuming. For more information, see Chapter 9.

28. B, D. The number of associated devices is an important determining factor in the number of access points required for a WLAN deployment as well as the software and hardware applications that may be used. The type and manufacturer of devices are not concerns. For more information, see Chapter 9.

29. C. A protocol analyzer will help identify existing IEEE 802.11 WLANs in an area and provide other information about these networks that can be used in the RF site survey/design process. An RF analysis is performed by a spectrum analyzer, which will also help locate sources of RF interference. A protocol analyzer can help identify security-related issues from existing wireless networks but will not describe security requirements of a new WLAN. For more information, see Chapter 9.

30. A. The received signal strength represents how much of a transmitted signal is being received. If this signal is weak, the difference between the signal and noise may not be high enough to recover the data. If the power on an access point is high, it would provide more received signal. A signal-to-noise ratio of 35 dB and RSSI of –60 dBm is more than adequate. If the radio on the client were disabled, it would not be able to connect at all. For more information, see Chapter 11.

31. A, B, D. WLAN technology operates and is specified at Layer 1 (Physical) and Layer 2 (Data Link) of the OSI model. The Session layer opens, closes, and manages sessions between end-user application processes. The Network layer is responsible for addressing and routing functions of data. The Application layer is the interface to the user. For more information, see Chapter 1.

32. A, E. The SNR is the difference between the received signal and the noise floor. The common noise floor value is –95 dBm, and an acceptable receive signal is –65 dBm. Therefore, the SNR is 30 dB. The RF channel is a specified frequency a WLAN operates in. The Fresnel zone consists of a number of concentric ellipsoidal volumes that surround the direct, RF line of sight between two points, such as an RF transmitter and receiver. For more information, see Chapter 4.

33. A. Most enterprise-level autonomous access points have the capability to operate in root, repeater, or bridge modes. Root mode is the most common. Root mode allows devices to authenticate, associate, and access network resources and services. For more information, see Chapter 3.

34. E. Wi-Fi Protected Access 2 (WPA 2.0) requires CCMP/AES. TKIP/RC4 is optional. WEP/RC4 is legacy and should not be used; it cannot be used with a robust secure network. RC5 is a stream cipher and not used with IEEE 802.11 WLANs. CCMP uses AES, not RC4. For more information, see Chapter 2.

35. D. CSMA/CA stands for Carrier Sense Multiple Access/Collision Avoidance and is used as an access method for WLANs to share the communication medium, which is the air. CSMA/CD is Carrier Sense Multiple Access/Collision Detection and is used with Ethernet networks. FHSS/CCK and HR/DSSS are spread-spectrum technologies used with some standards or amendments. CSMA/DSSS does not exist. For more information, see Chapter 7.

36. B. The technical term for the horizontal radiation pattern is azimuth. The elevation is the vertical radiation pattern. For more information, see Chapter 5.

37. B. A beacon frame is a management frame and is used to advertise information about the WLAN. For more information, see Chapter 6.

38. B. A consumer-grade Wi-Fi router is a combination of a router and a Wi-Fi access point, two different functions contained in the same physical device. Both consumer-grade Wi-Fi routers and access points will allow for peer-to-peer communications between the devices that are connected to the same access point. Consumer-grade Wi-Fi routers do not offer better security options than access points; however, enterprise-grade access points will offer more extensive security options, and consumer-grade Wi-Fi routers are usually not able to operate with WLAN controllers. For more information, see Chapter 3.

39. C. The best location to install an omnidirectional antenna is in the center of the RF coverage area. Access points installed at the perimeter of an RF coverage area would be used for location services. A patch/panel antenna would be best installed at one end of the RF coverage area. It is best to avoid hallway installations unless they are justified by the WLAN design. For more information, see Chapter 5.

40. D. A spectrum analyzer is used to view RF coverage and interference from non–Wi-Fi devices. A protocol analyzer is a tool that can be used to troubleshoot 802.11 WLAN problems. Predictive modeling software is used to aid in the design of a WLAN. A voltage standing wave ratio (VSWR) meter is used to measure the impedance mismatch of a system. Network discovery software is used to find information about 802.11 devices in an area. For more information, see Chapter 9.

Chapter 1

Computer Networking Fundamentals

THE FOLLOWING CWTS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

✓ **1.4 Explain the role of Wi-Fi as a network access technology**

It is important to have an understanding of basic computer networking concepts before you begin exploring the world of over-the-air (wireless) networking technology, wireless terminology, and mobility. This chapter looks at various topics surrounding foundational computer networking, including computer network types, computer topologies, the OSI model, and network device addressing. It is intended to provide an overview of basic computer networking concepts as an introduction for those who need to gain a basic understanding or for those already familiar with this technology and want a review of these concepts.

You will learn about the various types of wireless networks—including wireless personal area networks (WPANs), wireless local area networks (WLANs), wireless metropolitan area networks (WMANs), and wireless wide area networks (WWANs)—in Chapter 2, "Wireless Local Area Networking, Standards, and Certifications."

Network Types

Computer networking technology has evolved at a tremendous pace over the past couple of decades, and many people across the world now have some type of exposure to the technology. Initially, personal computers were connected, or networked, to share files and printers and to provide central access to the users' data. This type of network was usually confined to a few rooms or within a single building and required some type of cabled physical infrastructure. As the need for this technology continued to grow, so did the types of networks. Computer networking started with the local area network (LAN) and grew on to bigger and better types, including wide area networks (WANs), metropolitan area networks (MANs), and others. The following are some of the common networking types in use today:

- Local area networks (LANs)
- Wide area networks (WANs)
- Metropolitan area networks (MANs)
- Campus area networks (CANs)
- Personal area networks (PANs)

You may also come across the term *storage area network (SAN)*. The SAN is basically a separate subnet for offloading large amounts of data used within an enterprise network. High-speed connections are used, so the data is easily accessible because it appears to be part of the network. The connections are commonly Fibre Channel or iSCSI utilizing the TCP/IP protocol.

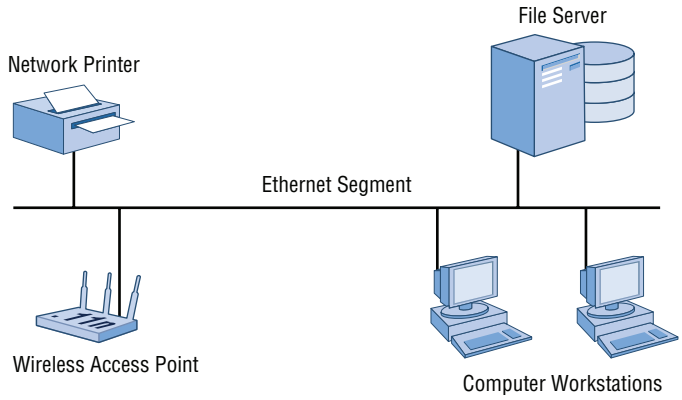
Most computer networks today contain some type of wireless connectivity or may consist of mostly wireless connectivity. The need for wireless networking and mobility continues to be in great demand and is growing at a rapid pace.

The Local Area Network

A *local area network (LAN)* can be defined as a group of devices connected in a specific arrangement called a *topology*. The topology used depends on where the network is installed. Some common legacy topologies (such as the bus and ring) and more modern topologies (such as the star and mesh) are discussed later in this chapter. LANs are contained in the same physical area and usually are bounded by the perimeter of a room or building. In some cases, however, a LAN may span a group of buildings in close proximity that share a common physical connection.

Early LANs were used primarily for file and print services. File services enabled users to store data securely and provided a centralized location of data for accessibility even when the user was physically away from the LAN. This central storage of data also gave a network administrator the ability to back up and archive all the saved data for disaster recovery purposes. As for print services, it was not cost effective to have a physical printer at every desk or for every user, so LANs allowed the use of shared printers for any user connected to the LAN. Figure 1.1 illustrates a LAN that includes both wired and wireless networking devices.

FIGURE 1.1 Example of a local area network (LAN)

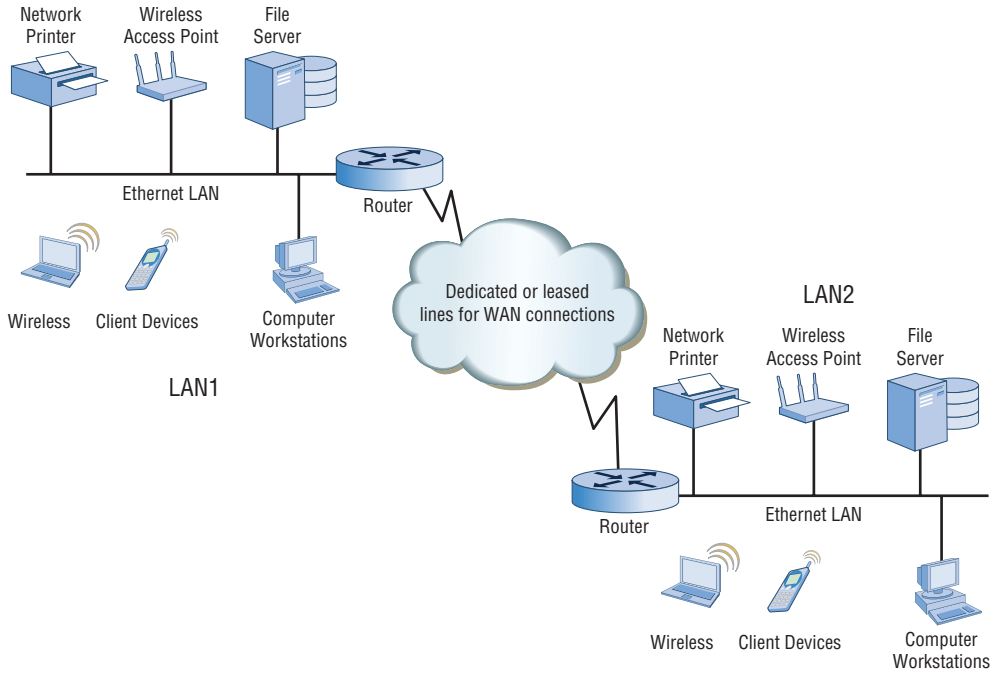


The Wide Area Network

As computer networking continued to evolve, many businesses and organizations that used this type of technology needed to expand the LAN beyond the physical limits of a single room or building. These networks covered a larger geographical area and became known as *wide area networks (WANs)*. As illustrated in Figure 1.2, WAN connectivity

mostly consists of point-to-point or point-to-multipoint connections between two or more LANs. The LANs may span a relatively large geographical area. (Point-to-point and point-to-multipoint connections are discussed later in this chapter.) The WAN has allowed users and organizations to share data files and other resources with a much larger audience than a single LAN would.

FIGURE 1.2 Example of a wide area network (WAN) connecting two LANs



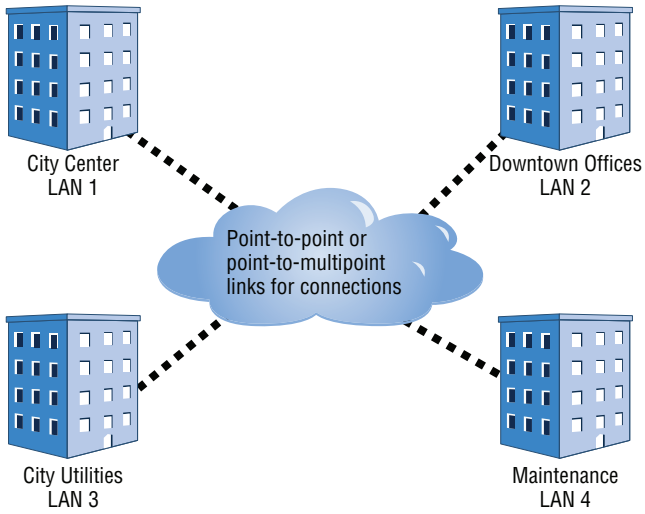
WANs can use leased lines from telecommunication providers (commonly known as *telcos*), fiber connections, and even wireless connections. The use of wireless for bridging LANs is growing at a fast pace because it can often be a cost-effective solution for connecting LANs.

The Metropolitan Area Network

The *metropolitan area network (MAN)* interconnects devices for access to computer resources in a region or area larger than that covered by LANs but yet smaller than the areas covered by WANs. A MAN consists of networks that are geographically separated and can span from several blocks of buildings to entire cities (see Figure 1.3). MANs include fast

connectivity between local networks and may include fiber optics or other wired connectivity that is capable of longer distances and higher capacity than those in a LAN.

FIGURE 1.3 Example of a metropolitan area network (MAN) connecting a small town

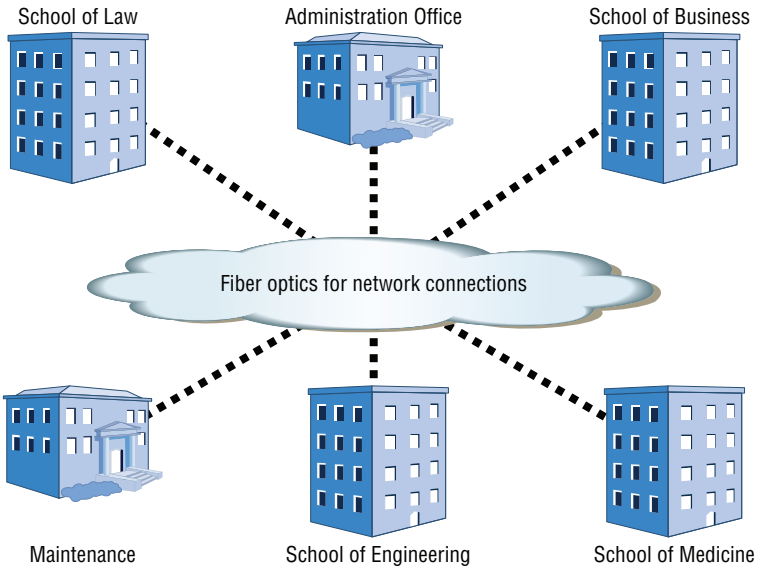


MANs allow for connections to outside larger networks such as the Internet. They may include cable television, streaming video, and telephone services. Devices and connectivity used with MANs may be owned by a town, county, or other locality, and may also include the property of individual companies. Wireless MANs are also becoming a common way to connect the same type of areas but without the physical cabling limitations.

The Campus Area Network

A *campus area network (CAN)* includes a set of interconnected LANs that basically form a smaller version of a WAN within a limited geographical area, usually an office or school campus. Each building within the campus generally has a separate LAN. The LANs are often connected using fiber-optic cable, which provides a greater distance than copper wiring using IEEE 802.3 Ethernet technology. However, using wireless connections between the buildings in a CAN is an increasingly common way to connect the individual LANs. These wireless connections or wireless bridges provide a quick, cost-effective way to connect buildings in a university campus, as shown in Figure 1.4.

FIGURE 1.4 Example of a campus area network (CAN) connecting a school campus



In a university campus environment, a CAN may link many buildings, including all the various colleges—such as the College of Business, College of Law, College of Engineering, and so on—as well as the university library, administration buildings, and even residence halls. Wireless LAN deployments are now commonplace in university residence halls. With the rapidly increasing number of wireless mobile devices on university campuses, the number of wireless access points and the capacity of each need to be considered.

As in the university campus environment, a corporate office CAN may connect all the various building LANs that are part of the organization. This type of network will have the characteristics of a WAN but be confined to the internal resources of the corporation or organization. Many organizations are deploying wireless networks within the corporate CAN as a way to connect various parts of the business. As with the university CAN, in the corporate world a wireless CAN is a quick, cost-effective way to provide connectivity between buildings and departments.

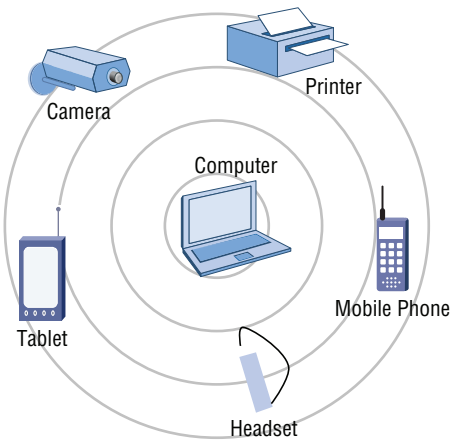
All the physical connection mediums and devices are the property of the office or school campus, and responsibility for the maintenance of the equipment lies with the office or campus as well.

The Personal Area Network

Personal area networks (PANs) are networks that connect devices within the immediate area of individual people. PANs may consist of wired connections, wireless connections, or both. On the wired side, this includes universal serial bus (USB) devices such as printers, keyboards, and computer mice that may be connected with a USB hub. With wireless

technology, PANs are short-range computer networks and in many cases use Bluetooth wireless technology. Wireless Bluetooth technology is specified by the IEEE 802.15 standard and is not IEEE 802.11 wireless LAN technology. Bluetooth will be discussed in more detail in Chapter 2. Like wired PANs, wireless PANs are commonly used in connecting an individual's wireless personal communication accessories, such as phones, headsets, computer mice, keyboards, tablets, and printers, and are centered on the individual personal workspace without the need for physical cabling. Figure 1.5 illustrates a typical wireless PAN configuration.

FIGURE 1.5 Example of a wireless Bluetooth network connecting several personal wireless devices



Network Topologies

A computer's physical network topology is the actual layout or physical design and interconnection of a computer network. A topology includes the cabling and devices that are part of the network. In the following sections you will learn about several different types of network topologies:

- Bus
- Ring
- Star
- Mesh
- Ad hoc
- Point-to-point
- Point-to-multipoint

The bus, ring, star, mesh, and ad hoc topologies are typically what make up the LAN you learned about previously. Point-to-point and point-to-multipoint topologies can be commonly used for connecting LANs but are mostly used for WAN connections. The size of your network will determine which topologies will apply. If your network is a single building and not part of a larger corporate network, the LAN topologies may be the extent of the technologies used. Once that LAN connects to a different LAN, however, you are moving up and scaling to a WAN.

The Bus Topology

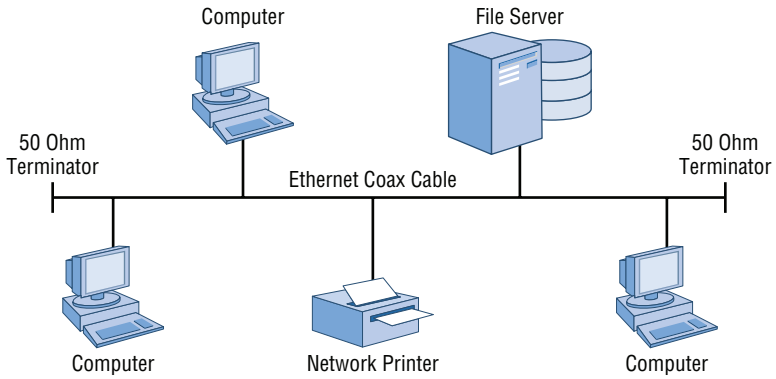
A *bus* topology consists of multiple devices connected along a single shared medium with two defined endpoints. It is sometimes referred to as a *high-speed linear bus* and is a single collision domain in which all devices on the bus network receive all messages. Both endpoints of a bus topology have a 50-ohm termination device, usually a Bayonet Neill-Concelman (BNC) connector with a 50-ohm termination resistor. The bus topology was commonly used with early LANs but is now considered a legacy design.

One disadvantage to the bus topology is that if any point along the cable is disconnected, damaged, or broken, the entire LAN will cease to function. This is because the two endpoints communicate only across the single shared medium; there is no alternative route for them to use in the event of a problem.

Troubleshooting a bus network is performed by a technique known as the *half-split method*. A network engineer "breaks" or separates the link at about the halfway point and measures the resistance of the link on both ends. If the segment measures 50 ohms of resistance, there is a good chance that side of the LAN segment is functioning correctly. If the resistance measurement is not 50 ohms, it signals a problem with that part of the LAN segment. The engineer continues with this method until the exact location of the problem is identified. Depending on the length of the segment and the type of installation, this can be a time-consuming and tedious process.

Figure 1.6 illustrates an example of the bus topology.

FIGURE 1.6 Example of the bus topology



Real World Scenario

Troubleshooting the Bus Topology

Many years ago I was called to troubleshoot a problem on a small LAN using a bus topology. The network consisted of a network file server, about 20 client stations, and a few network printers. The users complained of intermittent connection problems with the network. After spending some time looking over the network, I decided to test the bus using the half-split method and checked to verify that the cable was reporting the correct resistance using a volt-ohm-milliammeter (VOM) meter. Sure enough, one side of the network cable reported the correct resistance reading, but the other side was giving intermittent results.

After spending some time repeating the troubleshooting method, I was able to determine the problem. Someone had run the coax (bus) cable underneath a heavy plastic office chair mat, and one of the little pegs used to protect the flooring was causing the intermittent connection as it struck the cable when the user moved their chair around the mat. I quickly replaced and rerouted the section of cable in question. It is a good thing I was there during the normal business operating hours when the person was moving around in the chair, or I might have never found the problem. Ah, the joys of troubleshooting a bus topology.

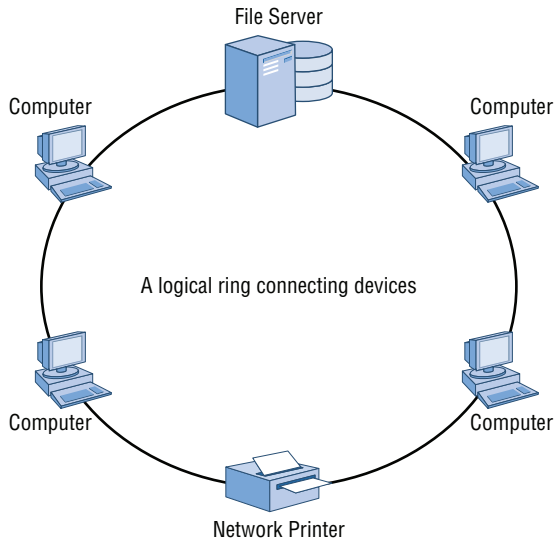
The Ring Topology

In the *ring* topology, each device connects to two other devices, forming a logical ring pattern. The ring topology is rarely used with LANs today, but it is still widely used by Internet service providers (ISPs) for high-speed, resilient backhaul connections over fiber-optic links.

Ring topologies in LANs may use a token-passing access method in which data travels around the ring in one direction. Only one device at a time will have the opportunity to transmit data. Because this access method travels in one direction, it does not need to use collision detection and often outperforms the bus topology, achieving higher data transfer rates than are possible using a collision detection access method. Each computer on the ring topology can act as a repeater, a capacity that allows for a much stronger signal.

The IEEE standard for LANs is IEEE 802.5, specifying Token Ring technology. IEEE 802.5 Token Ring technology used in LANs was a very efficient method used to connect devices, but it was usually more expensive than the bus or star topologies. Because of the token-passing method used, early 4 Mbps Token Ring networks could sometimes outperform a 10 Mbps IEEE 802.3 collision-based Ethernet network. Token Ring technology speeds increased to 16 Mbps but decreased in popularity as Ethernet speeds increased. Even though this is a ring topology, devices are connected through a central device and appear to be similar to devices on an Ethernet hub or switch. Figure 1.7 shows an example of the ring topology.

FIGURE 1.7 Example of the ring topology



The Star Topology

The *star* topology, as shown in Figure 1.8, is the most commonly used method of connecting devices on a LAN today. It consists of multiple devices connected by a central connection device. Hubs, switches, and wireless access points are all common central connection devices, although hubs are rarely used today. The hub provides a single collision domain similar to a bus topology. However, the Ethernet switch and wireless access point both have more intelligence—the capability to decide which port specific network traffic can be sent to. Note that in Figure 1.8, the wireless star topology includes an Ethernet switch, which could also have extended devices connected to it with wires. In that sense, it is possible to have a wired/wireless hybrid topology.

A big advantage to the star over the bus and some ring topologies is that if a connection is broken or damaged, the entire network does not cease to function; only a single device in the star topology is affected. The central connection device, such as a switch or wireless access point, can be considered a potential central point of failure.

The Mesh Topology

A device in a mesh network will process its own data as well as serving as a communication point for other mesh devices. Each device in a *mesh* topology (see Figure 1.9) has one or more connections to other devices that are part of the mesh network. This approach provides both network resilience in case of link or device failure and a cost savings compared to full redundancy. Mesh technology can operate with both wired and wireless infrastructure network devices. Wireless mesh networks continue to grow in popularity because of the potential uses in various deployment models and the cost savings they provide.

FIGURE 1.8 Example of a common star topology using either wired or wireless devices

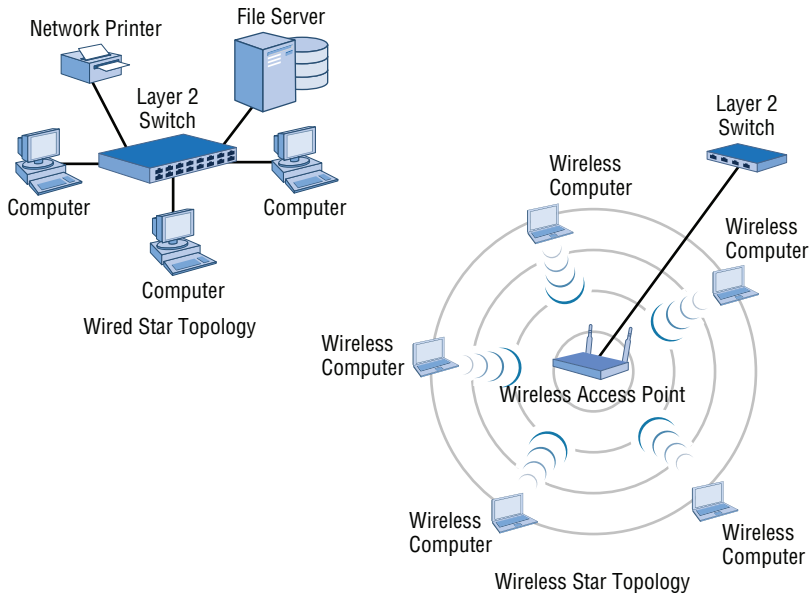
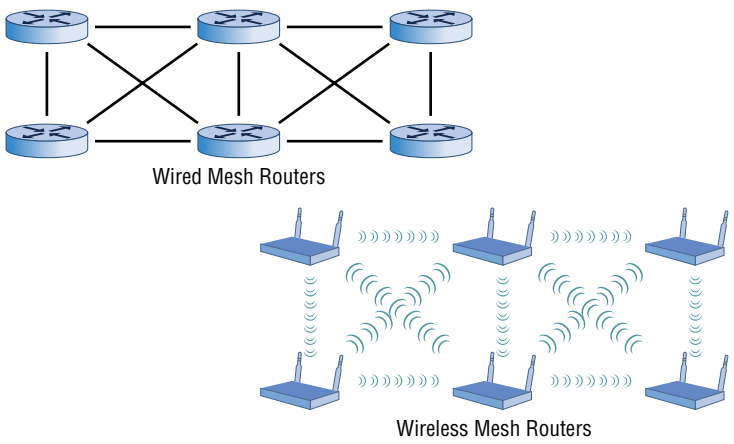


FIGURE 1.9 Mesh networks can include either wired or wireless devices.



From an IEEE 802.11 wireless perspective, wireless mesh technology has now been standardized, although most manufacturers continue to use their proprietary methods. The amendment to the IEEE 802.11 standard for mesh networking is 802.11s. This amendment was ratified in 2011 and is now part of the latest wireless LAN standard, IEEE 802.11-2016. In addition to IEEE 802.11 networks, mesh is also standardized in IEEE 802.15 personal

area networks for use with Zigbee and IEEE 802.16 wireless MAN networks. Wireless standards will be discussed in more detail in Chapter 2.

As mentioned earlier, IEEE 802.11 wireless device manufacturers commonly use proprietary Layer 2 routing protocols, forming a self-healing wireless infrastructure (mesh) in which edge devices can communicate. Manufacturers of enterprise wireless networking infrastructure devices provide support for mesh access points (APs) such that the mesh APs connect back to APs that are directly wired into the network backbone infrastructure. The APs, wireless LAN controllers or software-based cloud solutions in this case, are used to configure both the wired and mesh APs.

Ad Hoc Connections

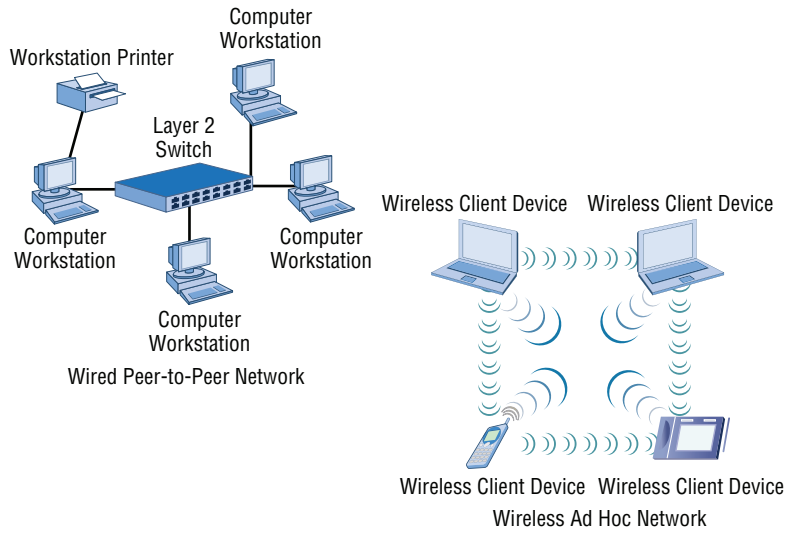
In the terms of computer networking, the *ad hoc* network is a collection of devices connected without a design or a plan for the purpose of sharing information or resources. Another term for an ad hoc network is *peer-to-peer network*.

In a wired peer-to-peer network, all computing devices are of equal status. In other words, no server manages the access to network resources. All peers can either share their own resources or access the resources of their devices on the network.

An ad hoc wireless network is one that does not contain a distribution system, which means no wireless access point is contained in the system to provide centralized communications.

Figure 1.10 shows an example of a wired peer-to-peer network and a wireless ad hoc network.

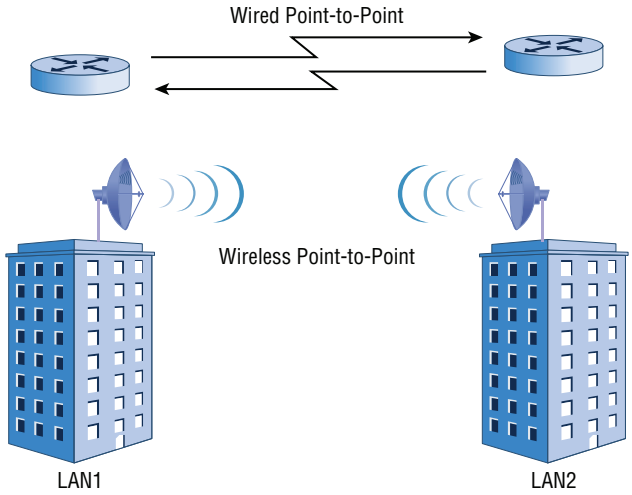
FIGURE 1.10 Wired peer-to-peer and wireless ad hoc networks



Point-to-Point Connections

When at least two LANs are connected, it is known as a *point-to-point connection* or link (see Figure 1.11). The connection can be made using either wired or wireless network infrastructure devices and can include bridges, wireless access points, and routers. Wireless point-to-point links can sometimes extend very long distances depending on terrain and other local conditions. Point-to-point links provide a connection between LANs, allowing users from one LAN to access resources on the other connected LAN.

FIGURE 1.11 Point-to-point connections using either wired or wireless connections



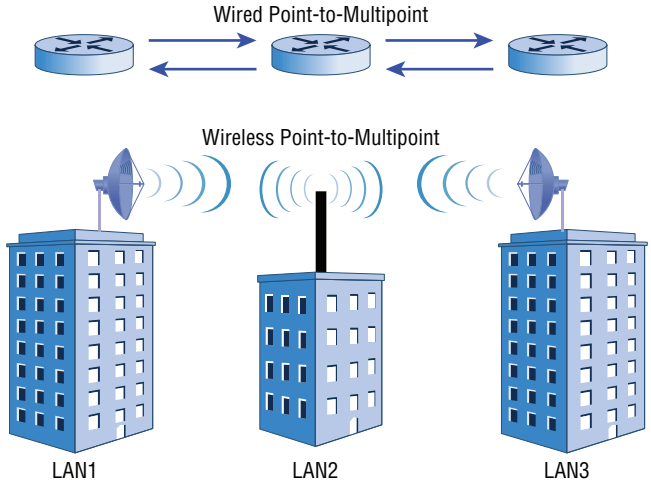
Wired point-to-point links consist of fiber-optic connections or leased lines from local telecommunication providers. Wireless point-to-point links usually call for semi-directional or highly directional antennas. Wireless point-to-point links include directional antennas and encryption to protect the wireless data as it propagates through the air from one network to the other. With some regulatory domains such as the Federal Communications Commission (FCC), when an omnidirectional antenna is used in this configuration it is considered a special case, called a point-to-multipoint link.

Point-to-Multipoint Connections

A network infrastructure connecting more than two LANs is known as a *point-to-multipoint connection* or link (see Figure 1.12). When used with wireless, this configuration usually consists of one omnidirectional antenna and multiple semi-directional or highly

directional antennas. Point-to-multipoint links are often used in campus-style deployments, where connections to multiple buildings or locations may be required. Like point-to-point connections, wired point-to-multipoint connections can use either direct wired connections such as fiber-optic cables or leased line connectivity available from telecommunication providers.

FIGURE 1.12 Point-to-multipoint connections using either wired or wireless connections

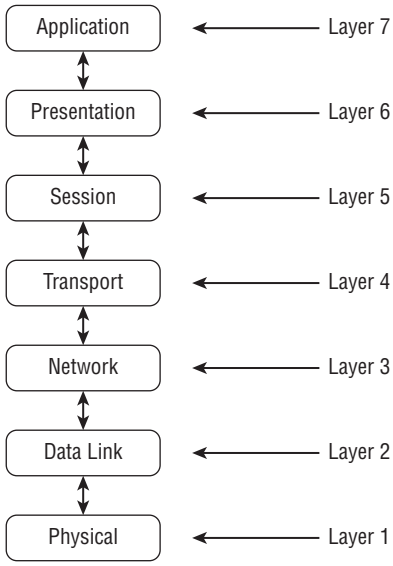


The OSI Model

Before we continue with other mobility topics, you should have some background on computer networking theory. The basics of a computer networking discussion start with the *Open Systems Interconnection (OSI)* model, a conceptual seven-layer model. The OSI model has been around for decades. It came about in the late 1970s and early 1980s, being published in 1984, and was developed by the International Organization for Standardization (ISO). The ISO is a worldwide organization that creates standards on an international scale. The OSI model describes the basic concept of communications in the computer network environment. Be careful not to confuse the two.

There are seven layers to the OSI model. Each layer is made up of many protocols and serves a specific function. You will take a quick look at all seven layers of the OSI model. Figure 1.13 illustrates the seven layers of the conceptual OSI model.

FIGURE 1.13 Representation of the OSI Model



The following sections describe how each layer is used.

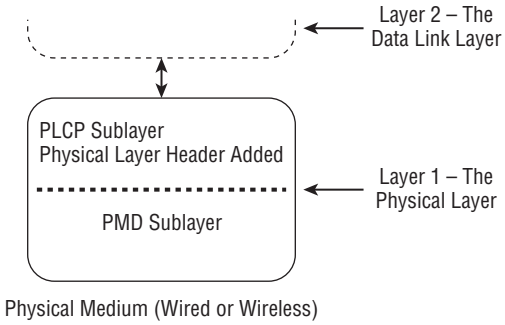
Layer 1 – The Physical Layer

The *Physical layer* (sometimes referred as the *PHY*) is the lowest layer in the OSI model. The PHY consists of bit-level data streams and computer network hardware connecting the devices together. The hardware that connects devices includes network interface cards, cables, Ethernet switches, wireless access points, and bridges. Keep in mind that some of these hardware devices, such as Ethernet switches and bridges, actually have Data Link layer (Layer 2) functionally and operate at that layer but also make up the actual physical connections. In the case of wireless networking, radio frequency (RF) uses air as the medium for wireless communications. With respect to wireless networking, the Physical layer consists of two sublayers:

- Physical Layer Convergence Protocol (PLCP)
- Physical Medium Dependent (PMD)

The PLCP, the higher of the two layers, is the interface between the PMD and Media Access Control (MAC) sublayer of the Data Link layer. This is where the Physical layer header is added to the data. The PMD is the lower sublayer at the bottom of the protocol stack and is responsible for transmitting the data onto the wireless medium. Figure 1.14 shows the two sublayers that make up the Physical layer.

FIGURE 1.14 Physical layer sublayers, PLCP and PMD



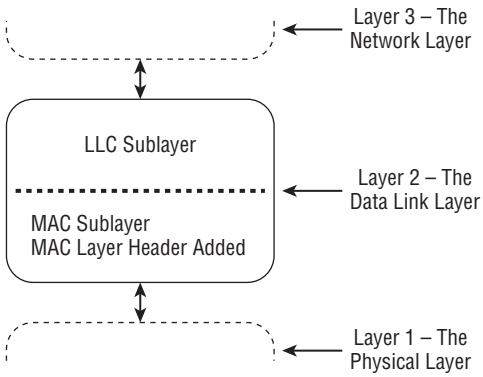
Layer 2 – The Data Link Layer

The *Data Link layer* is responsible for organizing the bit-level data for communication between devices on a network and detecting and correcting Physical layer errors. This layer consists of two sublayers:

- Logical Link Control (LLC)
- Media Access Control (MAC)

The bit-level communication is accomplished through Media Access Control (MAC) addressing. A *MAC address* is a unique identifier of each device on the computer network and is known as the *physical address* or sometimes referred to as the *hardware address*. (MAC addresses are discussed later in this chapter.) Figure 1.15 illustrates the two sublayers of the Data Link layer, Layer 2.

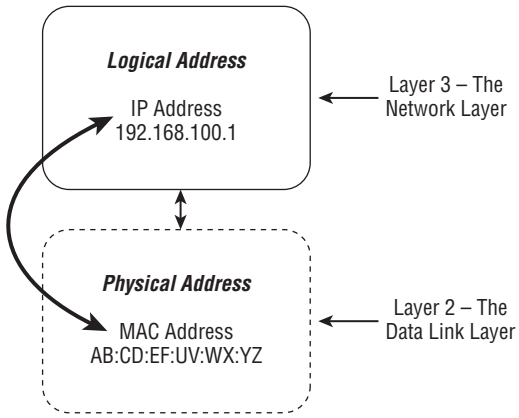
FIGURE 1.15 Data Link layer sublayers, LLC and MAC



Layer 3 – The Network Layer

The *Network layer* is responsible for addressing and routing data by determining the best route to take based on what it has learned or been assigned. The Internet Protocol (IP) resides at the Network layer. An IP address is defined as a numerical identifier or logical address assigned to a network device. The IP address can be static, manually assigned by a user, or dynamically assigned from a server using Dynamic Host Configuration Protocol (DHCP). (IP addresses are discussed later in this chapter.) Figure 1.16 illustrates the Layer 2 MAC address translation to a Layer 3 IP address.

FIGURE 1.16 Data Link layer (Layer 2) to Network layer (Layer 3) address translation



Layer 4 – The Transport Layer

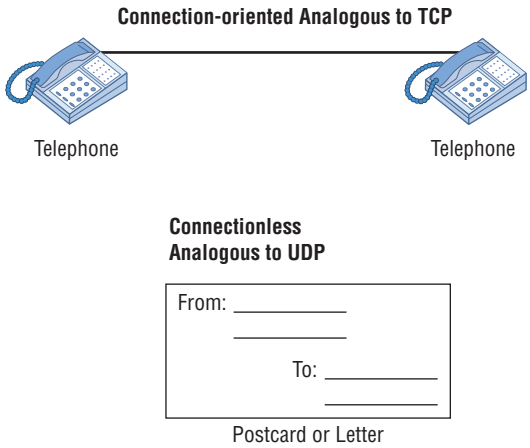
The *Transport layer* consists of both connection-oriented and connectionless protocols providing communications between devices on a computer network. Although several protocols operate at this layer, you should be familiar with two commonly used Layer 4 protocols:

- Transmission Control Protocol (TCP)
- User Datagram Protocol (UDP)

TCP is a connection-oriented protocol and is used for communications that require reliability, analogous to a circuit-switched telephone call.

UDP is a connectionless protocol and is used for simple communications requiring efficiency, analogous to sending a postcard through a mail service. You would not know if the postcard was received or not. UDP and TCP port numbers are assigned to applications for flow control and error recovery. Figure 1.17 represents the relationship between the Transport layer protocols TCP and UDP.

FIGURE 1.17 Comparison between TCP and UDP protocols



Layer 5 – The Session Layer

The *Session layer* opens, closes, and manages communications sessions between end-user application processes located on different network devices. The following protocols are examples of Session layer protocols:

- Network File System (NFS)
- Apple Filing Protocol (AFP)
- Remote Procedure Call Protocol (RPC)

Layer 6 – The Presentation Layer

The *Presentation layer* provides delivery and formatting of information for processing and display. This allows for information that is sent from one device on a network (the source) to be understood by another device (the destination) on the network.

Layer 7 – The Application Layer

The *Application layer* can be considered the interface to the user. Application is another term for a program that runs on a computer or other networking device, and that is not what we are looking at here. Protocols at this layer are for network operations such as transferring files, browsing web pages, and sending email. The following list includes some of the more common examples of Application layer protocols we use daily:

- File Transfer Protocol (FTP) for transferring data
- Hypertext Transfer Protocol (HTTP) for web browsing
- Post Office Protocol v3 (POP3) for email

How the Layers Work Together

In order for computers and other network devices to communicate with one another using the OSI model, a communication infrastructure of some type is necessary. In a wired

network, such an infrastructure consists of cables, repeaters, bridges, and Layer 2 switches. In a wireless network, the infrastructure consists of access points, bridges, repeaters, radio frequency, and the open air. Some of these devices will be discussed in more detail in Chapter 3, "Infrastructure and Client Devices Used with Wireless Networking."

Wireless network technology operates at the two lowest layers of the OSI model, Layer 1 (Physical) and Layer 2 (Data Link). However, to some degree Layer 3 (Network) plays a role as well, generally for the TCP/IP protocol capabilities. It is also important to note that wireless networking technology does use all seven layers for certain functionality.

OSI Model Memorization Tip

One common method you can use to remember the seven layers of the OSI model from top to bottom is to memorize the following sentence: All people seem to need data processing. Take the first letter from each word and that will give you an easy way to remember the first letter that pertains to each layer of the OSI model.

- **A**ll (**A**pplication)
- **P**eople (**P**resentation)
- **S**eem (**S**ession)
- **T**o (**T**ransport)
- **N**eed (**N**etwork)
- **D**ata (**D**ata Link)
- **P**rocessing (**P**hysical)

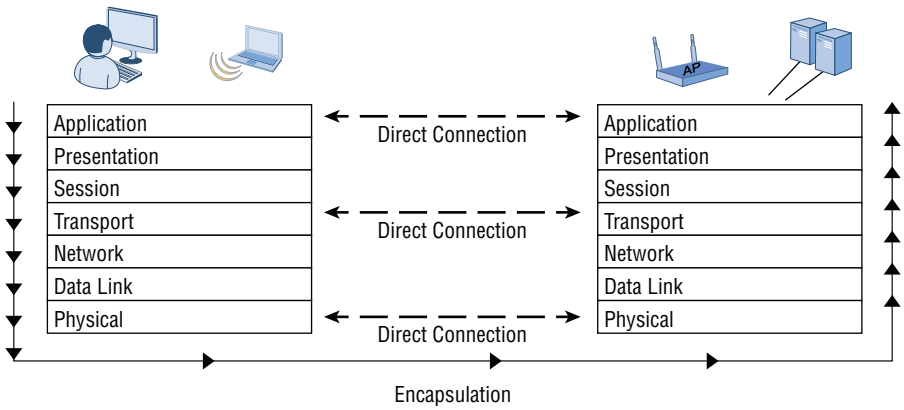
Here's another one, this time from the bottom layer to the top layer:

- **P**lease (**P**hysical)
- **D**o (**D**ata Link)
- **N**ot (**N**etwork)
- **T**hrow (**T**ransport)
- **S**ausage (**S**ession)
- **P**izza (**P**resentation)
- **A**way (**A**pplication)

Peer-Layer Communication

Peer layers communicate with other layers in the OSI model, and the layers underneath are their support systems. Peer-layer communication is the "horizontal" link between devices on the network. Figure 1.18 shows three examples of *peer-layer communication*. Keep in mind, however, that this principle applies to all seven layers of the OSI model. This allows for the layers to communicate with the layer to which a device is sending or receiving information.

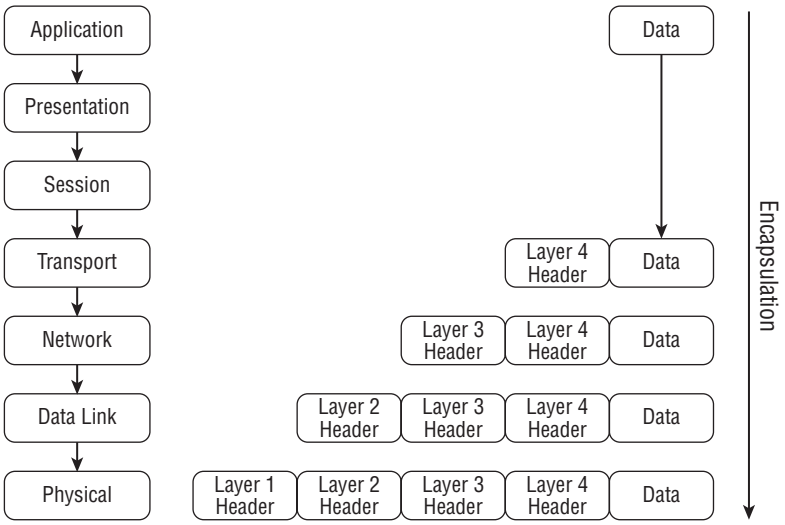
FIGURE 1.18 Peer communication between three of the seven layers



Data Encapsulation

The purpose of *encapsulation* is to allow Application layer data communication between two stations on a network using the lower layers as a support system. As data moves down the OSI model from the source to the destination, it is encapsulated. As data moves back up the OSI model from the source to the destination, it is de-encapsulated. Some layers will add a header and/or trailer when information is being transmitted and remove it when information is being received. Encapsulation is the method in which lower layers support upper layers. Figure 1.19 illustrates this process.

FIGURE 1.19 Information is added at each layer of the OSI model as data moves between devices.



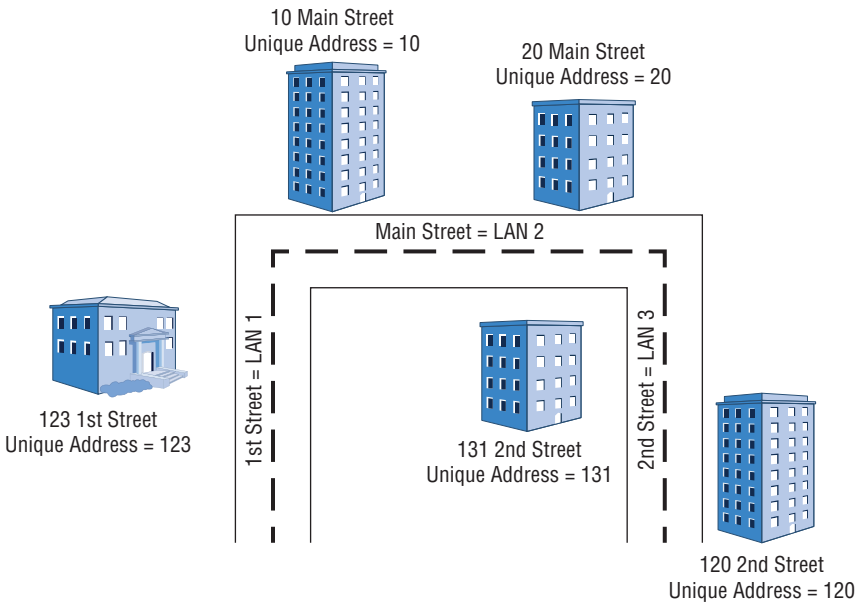
Device Addressing

Every device on a network requires unique identification. This can be accomplished in a couple of ways:

- Physical addresses
- Logical addresses

The *physical address* of a network adapter is also known as the Media Access Control (MAC) address. As shown in Figure 1.20, every device on a network (like every street address in a city) must have a unique address. The physical address is required in order for a device to send or receive information (data). An analogy to this is sending a package to be delivered via a courier service. Before handing over the package to the courier, you would write the name and physical street address of the recipient on the package. This ensures that the package is delivered correctly to the recipient.

FIGURE 1.20 The MAC address is analogous to the address of buildings on a street.



The streets shown—1st, Main, and 2nd—represent local area networks. The numbers 10, 20, 123, 131, and 120 represent the unique address of each structure on the streets just as MAC addresses would represent devices on a LAN.

The *logical address* is also known as the Internet Protocol (IP) address. Each device on a Layer 3 network or subnet must have a unique IP address (like every city's zip code). The IP address can be mapped to the physical address by using the Address Resolution Protocol (ARP).

The streets shown in Figure 1.20—1st, Main, and 2nd—represent LAN subnets. The street addresses—10, 20, and so on—represent the unique address of each structure on a street as a MAC address would a device on a LAN.

Physical Addressing

The physical address of a network device is called a MAC address because the *MAC sublayer* of the Data Link layer handles media access control. The MAC address is a 6-byte (12-character) hexadecimal address in the format AB:CD:EF:12:34:56. The first 3 bytes (or octets) of a MAC address are called the *organizationally unique identifier* (OUI). Some manufacturers produce many network devices and therefore require several OUIs. A table of all OUIs is freely available from the IEEE Standards Association website at

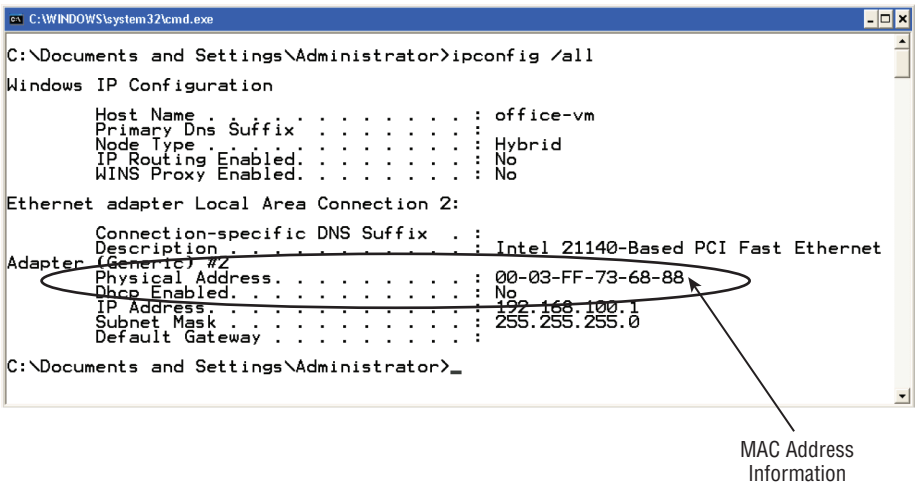
`http://standards.ieee.org/develop/regauth/oui/oui.txt`

MAC addresses are globally unique; an example is shown in Figure 1.21. The first 3 bytes or octets (6 characters) are issued to manufacturers by the IEEE. The last 3 bytes or octets (6 characters) are incrementally assigned to devices by the manufacturer.

FIGURE 1.21 Example of a Layer 2 MAC address showing the OUI and unique physical address

The MAC address of a device is usually stamped or printed somewhere on the device. This allows the device to be physically identified by the MAC address. By typing the simple command **`ipconfig /all`** in the command-line interface of some operating systems, you can view the physical address of the network adapter. Figure 1.22 shows an example of the information displayed by using this command-line utility in the Microsoft Windows operating system.

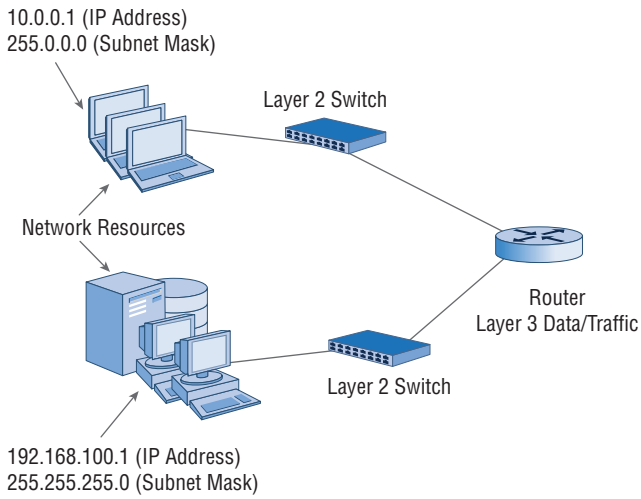
FIGURE 1.22 The `ipconfig` command-line utility displaying a physical/MAC address in Microsoft Windows



Logical Addressing

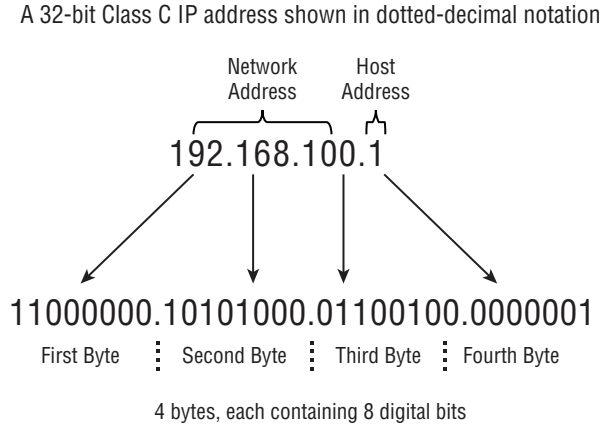
Network devices can also be identified by a logical address, known as the Internet Protocol (IP) address. The Layer 3 IP protocol works with a Layer 4 transport protocol, either User Datagram Protocol (UDP) or Transport layer Protocol (TCP). You learned earlier in this chapter that UDP is a connectionless protocol and using it is analogous to sending a postcard through the mail. The sender has no way of knowing if the card was received by the intended recipient. TCP is a connection-oriented protocol, used for communications analogous to a telephone call, and provides guaranteed delivery of data through acknowledgements. During a telephone conversation, communication between two people will be confirmed to be intact, with the users acknowledging the conversation. Routable logical addresses such as TCP/IP addresses became more popular with the evolution of the Internet and the Hypertext Transfer Protocol (HTTP) that is used with the World Wide Web (WWW) service. IP moves data through an internetwork such as the Internet one router (or hop) at a time. Each router decides where to send the data based on the logical IP address. Figure 1.23 shows a basic network utilizing Layer 3 data traffic.

FIGURE 1.23 A network with Layer 3 network device logical addressing



Logical addresses (IP addresses) are 32-bit dotted-decimal addresses usually written in the form `www.xxx.yyy.zzz`. Figure 1.24 illustrates an example of a logical Class C, 32-bit IP address. Each of the four parts is a byte, or 8 digital bits. There are two main IP address types: private addresses and public addresses. Private addresses are unique to an internal network, and public addresses are unique to the Internet. These addresses consist of two main parts: the network (subnet) and the host (device). Logical addresses also require a subnet mask and may have a gateway address depending on whether the network is routed. IPv4 addresses fall under three classes: Class A addresses, Class B addresses, and Class C addresses.

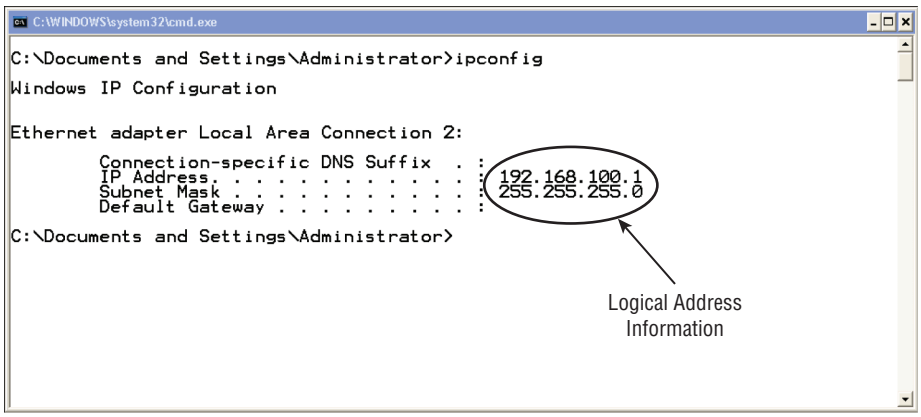
FIGURE 1.24 Example of a Class C logical IP address



The logical IP addresses you just learned about are known as *IPv4 addresses*. Newer addresses, called *IPv6 addresses*, also exist and are discussed in the following section, "Network Address Translation."

Unlike a MAC address, an *IP address* is logical and can be either specified as a static address assigned to the device manually by the user or dynamically assigned by a server. However, the same command-line utility used to identify the physical address of a device can be used to identify the logical address of a device. Typing **`ipconfig`** at a command prompt displays the logical address, including the IP address, subnet mask, and default gateway (router) of the device. The `ipconfig /all` command, illustrated earlier in the chapter, yields additional information, including the physical or MAC address of the device's network adapter. This command is for a computer using the Microsoft Windows operating system. For some Apple and Linux devices, the `ifconfig` command will yield similar information. Figure 1.25 shows the `ipconfig` utility displaying the logical address information, including the IP address and subnet mask.

FIGURE 1.25 The Microsoft Windows `ipconfig` command-line utility showing logical address information



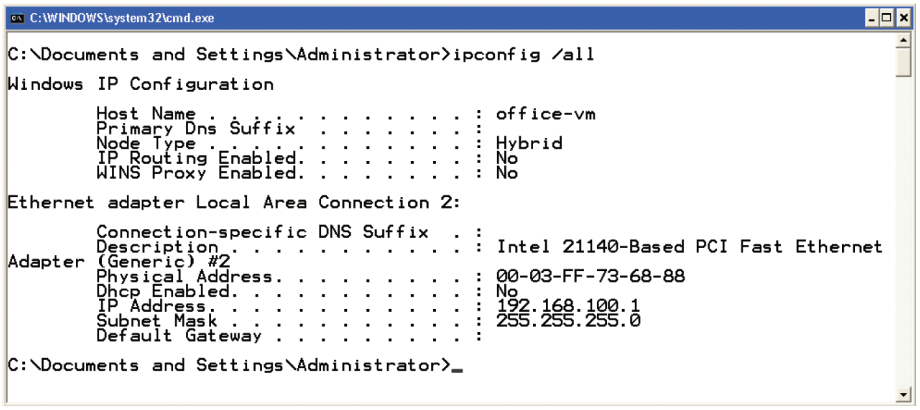
In Exercise 1.1, you will use the `ipconfig` utility from a command prompt on a computer using the Microsoft Windows operating system. This will allow you to see the address information for any available network adapters within the device.

Exercise 1.1 was written using a computer with the Microsoft Windows 10 operating system. If you're using a different version of the operating system, the steps may vary slightly. Keep in mind that there are many different shortcuts and ways to get to a command prompt in the Microsoft operating systems. The steps in this exercise use one common method.

EXERCISE 1.1

Viewing Device Address Information on a Computer

1. Click the Start menu.
2. Click the All Apps icon near the bottom of the menu.
3. Navigate to and click the `Windows System` folder.
4. Click the Command Prompt. The command window will appear.
5. In the command window, type **ipconfig /all**.
6. View the results in the command window. Notice the physical address of the network adapter as well as other information. The results should look similar to that shown here for Microsoft Windows 10 but may vary slightly based on the OS version in use.



Network Address Translation

In the mid-1990s, the use of the Internet along with the TCP/IP protocols was fueled by the release of the Hypertext Transfer Protocol (HTTP) and the World Wide Web. The heavily used Internet Protocol version 4 (IPv4) of assigning IP addresses was in jeopardy because

of the increased use of TCP/IP networks. Because the IPv4 mechanism has a finite number of addresses, there was a possibility of running out of IP addresses. Table 1.1 shows the number of IPV4 addresses available based on the IP address class.

TABLE 1.1 IPv4 IP addresses

Class Type	1st Octet – Decimal	Max Number of Hosts
A	1–126	16,777,214
B	128–191	65,534
C	192–223	254

Newer technology, Internet Protocol version 6 (IPv6), was the answer to the IPv4 address limitation issue. As you learned earlier in this chapter, IPv4 uses 32-bit binary addresses; there is a limit to the number of possible public addresses, as shown in Table 1.1. Keep in mind that all the Class A addresses were reserved by organizations and companies early on and therefore not available to the general public. The IPv6 method of addressing new IP technology is what was going to solve the problem of IP address exhaustion. IPv6 uses 128 bits (2^{128}), which equates to a potential 3.4×10^{38} IP addresses. That's a lot of IP addresses. The switch to IPv6 would not be an easy task. Computer operating systems, servers, and network infrastructure hardware lacked support for IPv6, causing delays in the implementation.

So why all this discussion about IP addresses or potential lack thereof? Well, this is where *Network Address Translation* (NAT) technology comes into action. NAT allows the use of a *private* IP address network for internal use and mapping it to a single *public* IP address connected to the Internet. This is accomplished by modifying the header in the IPv4 packet, which is where the term *address translation* comes in. NAT allows for a home network, a very small organization, or even a very large organization to be represented by a single public IP address on the Internet. It is addressed in RFC 2663 and allowed for the continued use of IPv4 addresses. NAT consists of different implementations. The following are two common implementations:

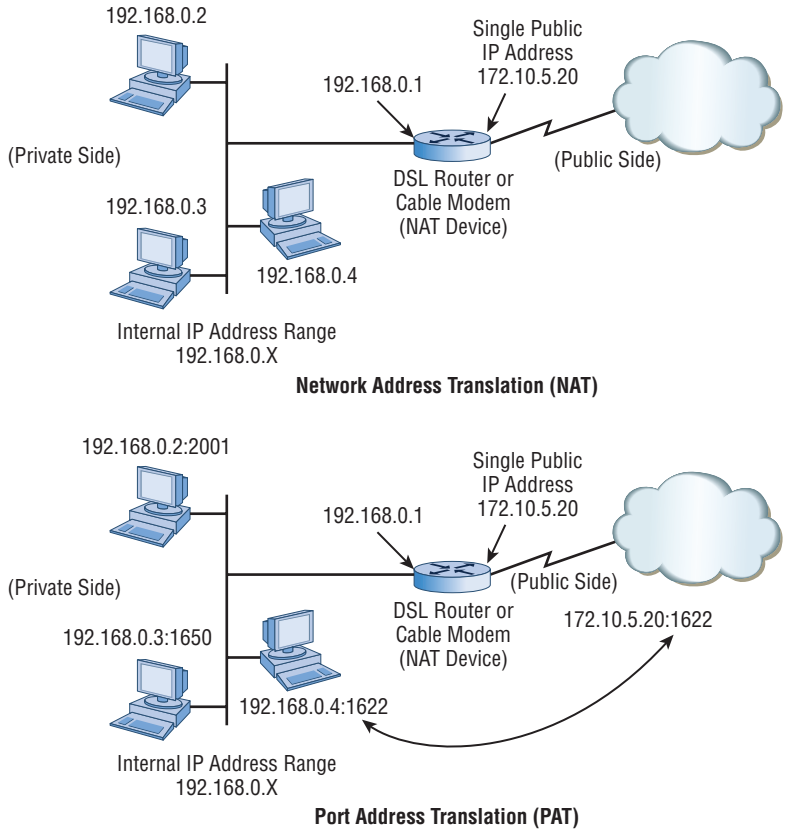
- One-to-one NAT
- One-to-many NAT

One-to-one NAT will map an IP address on the outside to an IP address on the inside. This can be accomplished through either a static assignment or a dynamic assignment. The static NAT entry is a permanent entry and needs to change manually. The dynamic process is useful when there are a limited number of addresses and the one-to-one assignment occurs when needed.

One-to-many NAT allows for the translation of one single public IP address on the outside of a network to service many devices with private IP addresses on the inside network.

This is accomplished by modifying the information in the IP packet. Figure 1.26 shows how NAT on a DSL router or cable modem will provide IP address translation. Notice that the private IP addresses on the private side of the router in this example are in the 192.168.0.X range. These private IP addresses will be translated to the single public IP address 172.10.5.20 on the public-facing side.

FIGURE 1.26 Network Address Translation (NAT) and Port Address Translation (PAT). The IP addresses shown are examples.



Summary

This chapter provided a simple review of computer networking topics. It began with an outline of the common network technology types:

- Local area networks (LANs)
- Wide area networks (WANs)

- Metropolitan area networks (MANs)
- Campus area networks (CANs)
- Personal area networks (PANs)

The next fundamental networking concept discussed was computer network topologies. You learned about network topologies ranging from the legacy high-speed linear bus and ring to the current star topology, the most common topology used today with both wired and wireless networks. You looked at the following various topologies:

- Bus
- Ring
- Star
- Mesh
- Ad hoc
- Point-to-point
- Point-to-multipoint

You then reviewed the basics and different layers of the OSI model, including a brief overview of each layer illustrating the different protocols and sublayers where applicable. Then the chapter discussed the basics of peer communications and data encapsulation.

The chapter's final topic was device addressing. You explored the concepts of physical (MAC sublayer) and logical (Network layer) addressing, including the IP address and subnet mask. A simple exercise using a computer with the Microsoft Windows operating system showed how to view device addressing information.

Exam Essentials

Understand the components of a local area network (LAN). A LAN is a group of computers connected by a physical medium in a specific arrangement called a topology.

Know the different types of networks. The basic networks types are LAN, WAN, CAN, MAN, and PAN.

Become familiar with various networking topologies. Bus, star, ring, mesh, and ad hoc are some of the topologies used in computer networking. Bus is considered a legacy topology, whereas star is one of the most common topologies in use today.

Understand point-to-point and point-to-multipoint connections. These connect two or more LANs and can consist of both wired and wireless connections.

Understand the basics of the OSI model. Know that each of the seven layers of the OSI model serves a specific function.

Remember the details of the lower two layers of the OSI model. The Physical layer and Data Link layer are the two lowest layers of the OSI model. Wireless networking technology operates at these layers. The Data Link layer consists of two sublayers: the Logical Link Control (LLC) sublayer and the Media Access Control (MAC) sublayer. The Physical Layer consists of two sublayers: the Physical Layer Convergence Protocol (PLCP) sublayer and the Physical Medium Dependent (PMD) sublayer.

Understand device addressing. Devices are assigned a unique physical address by the manufacturer. This address is known as the MAC address. MAC addresses consist of two parts, the organizationally unique identifier (OUI) and the unique physical address. A logical address may also be assigned at the Network layer to identify devices on different internetworks using the Internet Protocol (IP).

Review Questions

1. At which two layers of the OSI model does wireless LAN technology operate? (Choose two.)
   - **A.** Session
   - **B.** Network
   - **C.** Physical
   - **D.** Application
   - **E.** Data Link

2. A high-speed linear topology is defined as a _____.
   - **A.** Ring
   - **B.** Mesh
   - **C.** Bus
   - **D.** Star

3. The lower three layers of the OSI model are the _____, _____ and the _____.
   - **A.** Data Link, Physical, Transport
   - **B.** Physical, Data Link, Network
   - **C.** Session, Physical, Application
   - **D.** Application, Presentation, Session

4. The IP address of a network adapter is also known as which address?
   - **A.** MAC address
   - **B.** Logical address
   - **C.** Layer 4 address
   - **D.** Mesh address

5. Which layer of the OSI model is responsible for organizing bit-level data for communication between devices on a network and detecting and correcting Physical layer errors?
   - **A.** Application
   - **B.** Transport
   - **C.** Network
   - **D.** Data Link
   - **E.** Physical

6. Which layer of the OSI model is responsible for addressing and routing?
   - **A.** Physical
   - **B.** Network
   - **C.** Transport
   - **D.** Application

7. _____ allows for Application layer data communication between two stations using lower layers as a support system.
   - **A.** Logical addressing
   - **B.** Physical addressing
   - **C.** Data encapsulation
   - **D.** Peer communication
   - **E.** Point-to-point

8. Which topology may use a token-passing access method?
   - **A.** Ring
   - **B.** Mesh
   - **C.** Bus
   - **D.** Star

9. Which layer of the OSI model provides an interface to the user?
   - **A.** Physical
   - **B.** Network
   - **C.** Transport
   - **D.** Application
   - **E.** Data Link
   - **F.** Presentation

10. The physical address of a network adapter is the _____.
    - **A.** MAC address
    - **B.** Logical address
    - **C.** Layer 3 address
    - **D.** Mesh address

11. The term encapsulation means to _____.
    - **A.** Add an IP address to a network adapter
    - **B.** Add a MAC address to a network adapter
    - **C.** Add topology information to a frame
    - **D.** Add layer header and trailer information to a frame

12. Which of the following is an accurate description of peer communication?
    - **A.** The horizontal link between devices on the network
    - **B.** The vertical link between devices on the network
    - **C.** The logical link between devices on the network
    - **D.** The physical link between devices on the network

13. Physical addresses on a network device are responsible for which of the following?

- **A.** To identify the logical location on the network
- **B.** To identify which device should receive the information
- **C.** To identify the routing information on the network
- **D.** To identify the protocol in use on the network

14. At which layer of the OSI model are bits compiled into frames?

- **A.** Physical
- **B.** Data Link
- **C.** Network
- **D.** Transport
- **E.** Application

15. Which protocol is used to guarantee delivery of data?

- **A.** UDP
- **B.** IP
- **C.** ARP
- **D.** TCP
- **E.** HTTP

16. Which protocol is responsible for addressing and routing?

- **A.** IP
- **B.** TCP
- **C.** UDP
- **D.** ARP

17. Which layer of the OSI model allows physical addresses to be converted to logical addresses?

- **A.** Application
- **B.** Session
- **C.** Transport
- **D.** Network
- **E.** Data Link

18. The Data Link layer of the OSI model is divided into which two sublayers?

- **A.** PLCP, PMD
- **B.** LLC, MAC
- **C.** TCP, UDP
- **D.** HTTP, FTP

19. Which layer of the OSI model uses physical addresses to deliver data to the destination?

A. Physical

B. Data Link

C. Network

D. Transport

20. Which is a valid logical IPv4 address?

A. 255.255.0.0

B. 192.168.200.1

C. AB.CD.EF12.34.56

D. 12.34.56.AB.CD.EF

Chapter

2

Wireless Local Area Networking, Standards, and Certifications

THE FOLLOWING CWTS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ 1.1 Define the roles of the following organizations in providing direction and accountability within the wireless networking industry:
- ✓ 1.3 Summarize the basic attributes of the following WLAN standards, amendments, and product certifications:
- ✓ 1.4 Explain the role of Wi-Fi as a wireless network access technology
- ✓ 5.1 Identify deployment scenarios for the following common WLAN network types and suggest best practices for these scenarios:

THE FOLLOWING CWS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ 2.1 Know the frequency bands used
- ✓ 2.2 Identify Physical Layer (PHY) characteristics
- ✓ 4.1 Understand issues in common vertical markets
- ✓ 4.8 Match organizational goals to WLAN features and functions

THE FOLLOWING CWT EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ 2.4 Determine the channels and streams supported by client devices
- ✓ 4.1 Understand the basics of 802.11 standard security solutions

IEEE 802.11 wireless computer networking continues to take computer communication to a new level. This communication technology is the combination of computer local area networking (LAN) and radio frequency (RF) technology. By combining these two technologies, computer users have the opportunity to access and share information in ways that would seem unattainable not too many years ago.

This chapter will examine various ways in which wireless local networks are used and deployed. We will also cover organizations that determine the use of RF and those responsible for creating and managing WLAN standards. We'll look in detail at the IEEE 802.11 standard and its amendments, illustrating the communications and functional aspects. Finally, we will discuss interoperability certifications for IEEE 802.11 wireless networks for communications, quality of service (QoS), and security that are available from the Wi-Fi Alliance.

The Wireless Computer Network

The main objective of this book is to provide an introduction to IEEE 802.11-based wireless computer networking, following the "what it is not how it works" philosophy. However, it is important to understand the various ways in which wireless fits with computer networking in general and the various physical applications. In this section, we will take a look at how wireless technology allows users to connect to and use resources in a wireless networking environment. Wireless networks come in a variety of types and sizes and include the following wireless topologies:

- Wireless personal area network (WPAN)
- Wireless local area network (WLAN)
- Wireless metropolitan area network (WMAN)
- Wireless wide area network (WWAN)

In Chapter 1, "Computer Networking Fundamentals," you learned about the different types of computer networks. You will now look at some of these network types from a wireless perspective.

The Wireless Personal Area Network

The personal area network (PAN) is a network that connects devices within the immediate area of individual people, as you saw in Chapter 1. With the use of wireless technology, PANs have evolved into the wireless personal area network (WPAN). This type of network

allows users to connect various devices wirelessly to their own personal area network, including but not limited to computer keyboards, mice, and headsets.

Bluetooth technology is the most popular type of WPAN and uses frequency-hopping spread spectrum (FHSS) for communications. Bluetooth falls under the IEEE 802.15 standard, which specifies the WPAN standards. Bluetooth devices operate in the unlicensed 2.4 GHz Industrial, Scientific and Medical (ISM) band, as do WLANs. The effects of FHSS and Bluetooth on a WLAN will be discussed further in Chapter 7, "Modulation Technology for Wireless Networking."

WPANs may also use infrared technology, which uses near-visible light in the 850 nanometers to 950 nanometers range for communications. Infrared technology was specified in the original 802.11 standard, was considered obsolete in the 2012 version of the standard, and has since been removed from the latest version of the standard, IEEE 802.11-2016.

The Wireless Local Area Network

As you learned in Chapter 1, local area networks (LANs) can be defined as a group of computers connected by a physical medium in a specific arrangement called a topology. LANs are contained in the same physical area and usually are bounded by the perimeter of a building or a group of buildings. Wireless local area networks (WLANs) fall under the same description as a LAN but do not require a physical wire to connect devices together. WLANs have been in existence for many years, even prior to IEEE 802.11 standards-based technology, and mostly included proprietary technology or government deployments.

Since the IEEE released the original 802.11 standard in 1997, WLAN technology has continued to excel and is becoming a major component of every computer network. WLANs can operate in either the licensed or unlicensed RF spectrum. The most commonly used frequency spectra for WLANs are the unlicensed 2.4 GHz ISM band and the unlicensed 5 GHz Unlicensed National Information Infrastructure (UNII) band. The frequency bands used with IEEE 802.11 wireless networking are discussed in this chapter in the "RF Regulatory Domain Governing Bodies and Local Regulatory Authorities" section.

The Wireless Metropolitan Area Network

Metropolitan area networks (MANs) consist of networks that may span from several blocks of buildings to entire cities, and interconnect devices for access to computer resources in a region or area larger than that covered by LANs but smaller than the areas covered by WANs. You learned about this network type in Chapter 1. You can expand on this technology and add much flexibility to MANs by incorporating wireless technology and creating a wireless metropolitan area network (WMAN). The IEEE 802.16 standard was developed to address this type of wireless network. This technology may fall under the Worldwide Interoperability for Microwave Access (WiMAX) category and addresses different technologies. The WMAN may include a combination of public and private entities that encompass town services such as police, fire, and public utility access.

WiMAX has had its share of ups and downs. One major provider, Clearwire Inc., was a major player in the US market and was working on large-scale deployments throughout the United States. Although they previously had part ownership, Sprint acquired 100 percent of Clearwire in June 2013. Since that time, Sprint has been shifting from the WiMAX side in favor of building its own LTE network or fail-back to 3G. In November 2015 Sprint ceased operations of the Sprint 4G (WiMAX) network. The use of WiMAX networks worldwide have been decreasing since that time.

The Wireless Wide Area Network

You know from Chapter 1 that a WAN consists of point-to-point or point-to-multipoint connections between two or more LANs. WANs can extend very long distances through the use of fiber-optic connections or leased lines from telecommunications providers. When it comes to the wireless wide area network (WWAN), this extends beyond the point of connecting LANs together. The WWAN will encompass very large geographical areas and may include different wireless technologies, including cellular.

The WWAN also provides wireless broadband communications for Internet access through the use of special external adapters or even adapters built into notebook computers or other mobile devices, including smart phone technology. Because of the technology used, performance such as data rates will be lower than that expected and realized with IEEE 802.11 wireless networking.

Building-to-Building Connectivity Using Wireless LAN Technology

Connecting two or more wired LANs together over some distance is often necessary in computer networking. Depending on the topology, this can be an expensive and time-consuming task. WLAN technology is often used as an alternative to copper cable, fiber optics, or leased line connectivity between buildings. Whether connecting two or multiple locations together, point-to-point or point-to-multipoint links can be a quick and cost-effective solution for building-to-building connectivity.

Antenna selection plays an important role in this type of connectivity and will be discussed further in Chapter 5, "Antenna Technology for Wireless Networking." Other factors to consider in either point-to-point or point-to-multipoint connections are the RF band used and the distance, both of which will determine whether a link is feasible for a wireless connection.

Wireless Point-to-Point Connections

As discussed in Chapter 1, connecting at least two wired LANs together is known as a *point-to-point connection*. Wireless point-to-point connections can provide long-range coverage

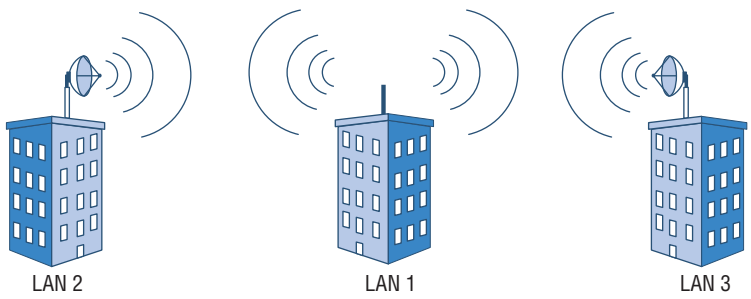
depending on terrain and other local conditions. These links can serve both wired and wireless users on the connected LANs. Wireless point-to-point connections typically call for semi-directional or highly directional antennas. With some regulatory agencies, when an omnidirectional antenna is used in this configuration, it is considered a special case, called a *point-to-multipoint connection*. Correct antenna selection is important and will be discussed in more detail in Chapter 5. Figure 2.1 shows a wireless point-to-point connection.

FIGURE 2.1 A wireless point-to-point connection using directional antennas

Wireless Point-to-Multipoint Connections

As you learned in Chapter 1, a network connecting more than two LANs together is known as a *point-to-multipoint connection*. With wireless networking, this configuration usually consists of one omnidirectional antenna and multiple semi- or highly directional antennas (see Figure 2.2). Point-to-multipoint connections are often used in campus-style deployments where connections to multiple buildings or locations may be required.

FIGURE 2.2 A typical point-to-multipoint connection using omnidirectional and directional antennas



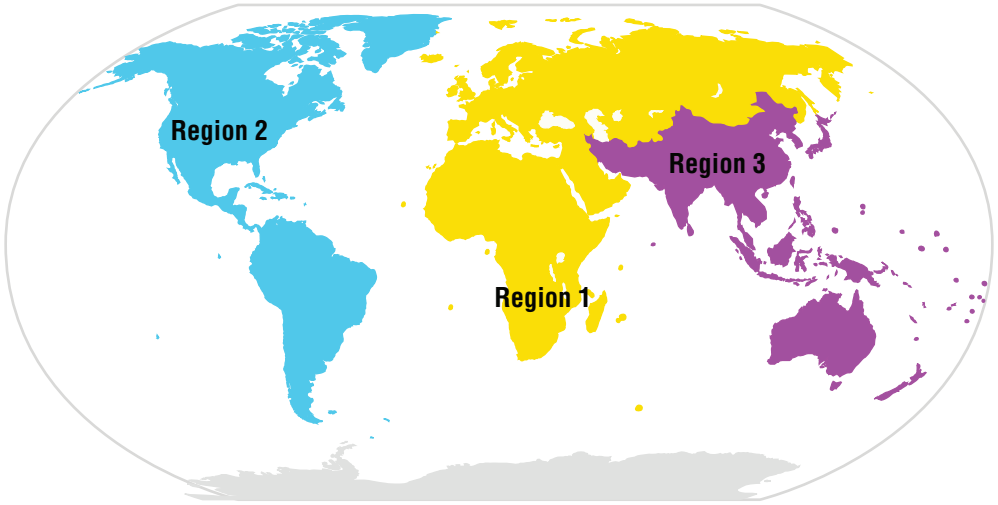
Wireless point-to-point and point-to-multipoint connections are becoming more common with many IEEE 802.11 WLAN deployments, thanks to the low cost of the equipment and the ease of installation. The installation time for a wireless point-to-point connection can be as little as a few hours.

Radio Frequency Regulatory Domain Governing Bodies and Local Regulatory Authorities

Wireless networks use radio frequency (RF) to communicate. The RF spectrum needs to be regulated in order to ensure correct use of the allocated frequency bands. At the global level, the International Telecommunication Union-Radiocommunication Sector (ITU-R) is responsible for global management of RF spectrum, in addition to satellite orbits. This organization currently has more than 700 private sector members and 70 academia members from more than 190 member states. It manages three different administrative regions around the globe.

Figure 2.3 shows the three administration regions and the geographic area they encompass.

FIGURE 2.3 ITU-R administrative region map



For additional information, visit www.itu.int/ITU-R.

Table 2.1 shows the three administrative regions and the geographic areas they cover.

TABLE 2.1 ITU-R regions and geographic locations

Region	Location
Region 1	Europe; Africa; the Middle East west of the Persian Gulf, including Iraq; the former Soviet Union and Mongolia
Region 2	Americas, Greenland, and some of the eastern Pacific Islands
Region 3	Most of non-former-Soviet-Union Asia, east of and including Iran, and most of Oceania

United States: Federal Communications Commission

The *local regulatory authority* that manages RF spectrum for the United States is the Federal Communications Commission (FCC). The FCC, founded in 1934, is (along with other local regulatory authorities) responsible for regulating the licensed and unlicensed RF spectrum. IEEE 802.11 wireless networks may use licensed or unlicensed frequencies for communication between devices. A benefit of using unlicensed RF spectrum is no cost to the end user. The IEEE commonly uses two of three unlicensed RF bands allowed by the FCC:

- 2.4 GHz industrial, scientific, and medical (ISM) band
- 5 GHz Unlicensed National Information Infrastructure (UNII) band

I will further discuss this and other technical details of standards-based wireless communications in Chapter 6, "Communication for Wireless Networking."

The FCC also allows the use of the unlicensed 900 MHz ISM band, but it is currently not used with IEEE 802.11 wireless networking. The 902-928 MHz ISM unlicensed band is not available worldwide and is only available in Region 2 (the Americas), with a few exceptions. Therefore, it was not specified for use with IEEE 802.11 wireless networking. However, this will soon change with the recent ratification of the IEEE 802.11ah amendment, which will allow WLAN use in what is also known as the Sub 1 GHz band.

Licensed RF Bands Used with IEEE 802.11

The following two licensed bands can be used with IEEE 802.11 networking:

- 3.650-3.700 GHz band
- 4.940-4.990 GHz public safety band

In 2008 the IEEE ratified the IEEE 802.11y amendment to the standard. This amendment allows for the use of high-powered WLAN equipment to operate in the 3.650-3.700 GHz band. Within the United States this is a licensed band that requires the user to pay some type of licensing fees.

The IEEE 802.11-2016 standard also specifies the use of the 4.940-4.990 GHz public safety band for use within the United States, consisting of 5 MHz-, 10 MHz-, and 20 MHz-wide channels with both high and low power limits. This is a carry-over from the previous version of the standard.

For additional information regarding RF use in the United States, visit `www.fcc.gov`.

Europe: European Telecommunications Standards Institute

The European Telecommunications Standards Institute (ETSI) is responsible for producing standards for information and communications technologies, including fixed, mobile, radio, converged, broadcast, and Internet technologies in Europe. ETSI was created by the European Conference of Postal and Telecommunications Administrations (CEPT) in 1988.

In Europe, RF use is managed by CEPT, which develops guidelines and provides national administrations with tools for coordinated European RF spectrum management.

The IEEE

The *IEEE* (originally known as the Institute of Electrical and Electronics Engineers), pronounced "eye triple E," is a nonprofit organization responsible for generating a variety of technology standards, including those related to information technology. According to the mission statement on the IEEE's website, its core purpose is to foster technological innovation and excellence for the benefit of humanity. The IEEE is the world's largest technical professional society.

Since 1997 the IEEE has released a series of standards related to wireless local area networking. These standards are all named IEEE 802 followed by combinations of numbers and letters to define specific standards and amendments.

The IEEE consists of working groups that are made up of individual members and experts in the field. With respect to wireless technology, the IEEE working groups are as follows:

- IEEE 802.11 – Wireless local area networking
- IEEE 802.15 – Wireless personal area networking
- IEEE 802.16 – Broadband wireless metropolitan area networks
- IEEE 802.20 – Mobile broadband wireless access
- IEEE 802.22 – Wireless regional area networks

The main focus of this book is related to IEEE 802.11 wireless local area networking.

For additional information about the IEEE, visit www.ieee.org.

The following section describes the IEEE wireless networking standard and the amendments in the order in which they were ratified and released. The IEEE wireless networking standard and its amendments that identify advancements in the technology define the power, range, and speed of RF and WLAN technology. The IEEE 802.11 standard specifies the maximum amount of RF transmit power, the allowed RF spectrum (which is related to the range), and the allowed data rates or speed. All ratified IEEE 802.11 amendments have been incorporated into the IEEE 802.11-2016 standard, including the most recent amendments IEEE 802.11ac, IEEE 802.11ad, and a few others. Even though some are now legacy amendments, it is important to understand the foundation and advancements in standards-based wireless technology that have developed into the current system.

The IEEE 802.11 Standard

The *IEEE 802.11* standard, released in 1997, is what initially defined the WLAN communication standards. The data rates used in this original standard (1 and 2 Mbps) are considered slow compared to today's technology.

As of this writing, the IEEE 802.11-2016 standard is the most current ratified IEEE 802.11 standard. This latest version combines into one document the more recent versions, including the IEEE 802.11-2012 and IEEE 802.11-2007 standards, and outstanding amendments at the time of ratification, such as IEEE 802.11k/n/p/r/s/u/v/w/y/z, and now also IEEE 802.11aa/ac/ad/ae/af/ah. Many in the industry, however, still refer to the original names of the amendments: 802.11b, 802.11a, 802.11g, 802.11n, and so on. The IEEE considers all the previously published amendments and revisions retired as a result of the release of the IEEE 802.11-2016 standard. Device and application requirements for IEEE 802.11 are discussed in Chapter 4, "Radio Frequency Fundamentals for Wireless Networking."

Here are the frequency range, spread spectrum/Physical layer (PHY) technologies, and data rates for the IEEE 802.11-1997 standard:

- 2.4 GHz ISM band
- Frequency-hopping spread spectrum (FHSS)
- Direct-sequence spread spectrum (DSSS)
- Infrared (IR)
- 1 and 2 Mbps

FHSS is considered obsolete technology with regard to IEEE 802.11 wireless networking; however, it is still used in other wireless technologies, such as IEEE 802.15 Bluetooth devices, other wireless devices, and wireless cordless public switched telephone network (PSTN) telephones. References to FHSS were removed from the IEEE 802.11-2016 version of the standard. You will learn more about these Physical layer technologies in Chapter 7.

To see the most up-to-date status of the IEEE 802.11 standard and amendments, visit the Official IEEE 802.11 Working Group Project Timelines web page at `www.ieee802.org/11/Reports/802.11_Timelines.htm`.

The abbreviations described in this section—such as FHSS, DSSS, HR/DSSS, OFDM, ERP, HT, and VHT—are defined to help explain the details of each amendment to the standard. You will learn more about each of these Physical layer technologies in Chapter 7.

The IEEE 802.11a Amendment

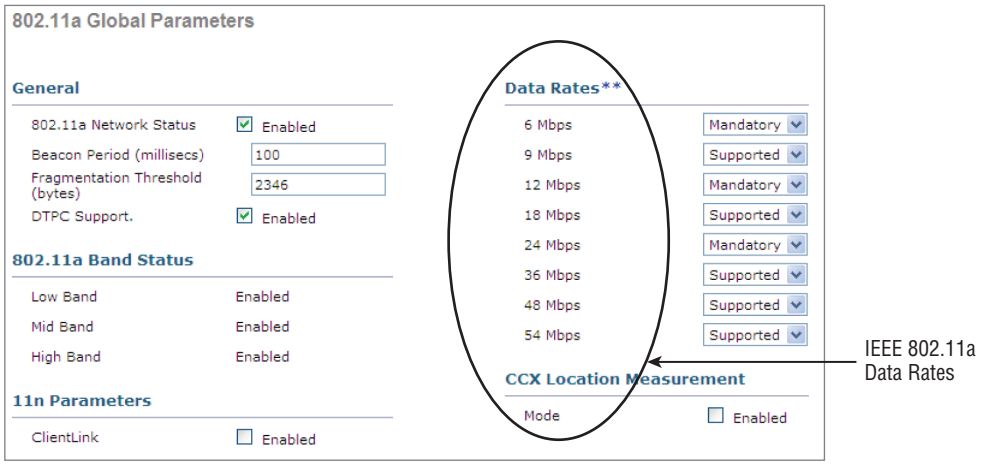
This amendment to the IEEE 802.11 standard defined operation in the 5 GHz UNII band. (UNII stands for Unlicensed National Information Infrastructure.) Released in 1999, this amendment originally defined three frequency ranges in three bands: UNII-1, UNII-2, and UNII-3. The UNII-1 band is intended for indoor use only; the UNII-2 band is for indoor or outdoor use; and the UNII-3 band may be used indoors or outdoors but was most commonly used outdoors. The data rates for IEEE 802.11a are up to 54 Mbps using orthogonal frequency division multiplexing (OFDM). OFDM and other Physical layer technologies will be discussed in Chapter 7. Although this amendment was released in 1999, devices were not widely available until 2001.

Following are the frequency ranges, PHY technology, and data rates as specified in the original *IEEE 802.11a* amendment. (Keep in mind that due to relaxed local regulatory requirements, different data rates are often used and accepted.)

- 5GHz UNII band
  - 5.150-5.250 GHz UNII-1
  - 5.250-5.350 GHz UNII-2
  - 5.725-5.825 GHz UNII-3
- Orthogonal frequency division multiplexing (OFDM)
- 6, 12, 24 Mbps OFDM required data rates
- 9, 18, 36, 48, and 54 Mbps OFDM data rates supported but not required

Figure 2.4 shows the data rates available on a WLAN controller for IEEE 802.11a.

FIGURE 2.4 WLAN controller showing the IEEE 802.11a data rates



A benefit to using the 5 GHz UNII band is that more bandwidth is available compared to the 2.4 GHz ISM band and there is less interference because not all wireless devices support operation in this band. The 5 GHz UNII band supports up to 25 non-overlapping 20 MHz-wide channels compared to only three non-overlapping channels in the 2.4 GHz ISM band, thus providing more available and usable 5 GHz frequency. Currently, fewer devices use the 5 GHz UNII license-free band than use the 2.4 GHz ISM license-free band, including non-802.11 devices. However, the number of wireless devices that operate in the 5 GHz band is always increasing. Fewer devices using the band means less interference, which allows for increased performance and reliability. With the introduction of the IEEE 802.11ac amendment, the number of devices using the 5 GHz band will continue to grow, because this is the only band supported for that technology. IEEE 802.11ac is discussed later in this chapter.

Since the IEEE 802.11a amendment was ratified, some changes have been implemented and are now addressed in the IEEE 802.11-2016 standard and previously the 802.11-2012 standard. They include a new frequency range (5.470-5.725 GHz) that is allowed by some local regulatory agencies and is known as the *UNII-2e band*. This extra frequency space allows for 11 additional 20 MHz-wide non-overlapping channels. The new IEEE 802.11ac amendment added one more channel (channel number 144) to the 5 GHz UNII band, which now provides a total of 25 non-overlapping channels, including channel number 165 (Americas only), which was previously identified as an ISM channel.

The IEEE 802.11b Amendment

The IEEE 802.11b amendment to the 802.11 standard works in the 2.4-2.5 GHz ISM band. This amendment, released in 1999, specifies high rate DSSS (HR/DSSS) for 5.5 and 11 Mbps.

The IEEE 802.11b amendment was released before the IEEE 802.11a amendment, although both were released in 1999.

Here are the frequency range, Physical layer (PHY) technology, spread spectrum technology, and data rates for the *IEEE 802.11b* amendment:

- 2.4 GHz ISM band
- 2.4 GHz-2.4835 GHz in North America, China, and Europe (excluding Spain and France)
- Direct-sequence spread spectrum (DSSS)
- High rate-direct sequence spread spectrum (HR/DSSS)
- 5.5 and 11 Mbps
- Backward compatible to 802.11 DSSS for 1 and 2 Mbps

With the release of the IEEE 802.11b amendment, WLAN technology became more affordable and mainstream. This amendment introduced two higher-rate data speeds, 5.5 and 11 Mbps, making the technology more desirable. Today, wireless infrastructure device manufacturers still support IEEE 802.11b wireless technology; however, it is highly unlikely you would be able to purchase any new devices that support only IEEE 802.11b technology. As wireless technologies continue to evolve, it is doubtful that there are any IEEE 802.11b-only networks, and many organizations are no longer supporting this legacy technology at all and are disabling the capability within their systems. Devices sold today that operate in the 2.4 GHz ISM band will support IEEE 802.11b/g/n and may be marketed as such or as IEEE 802.11g/n, which implies support for IEEE 802.11b.

The IEEE 802.11g Amendment

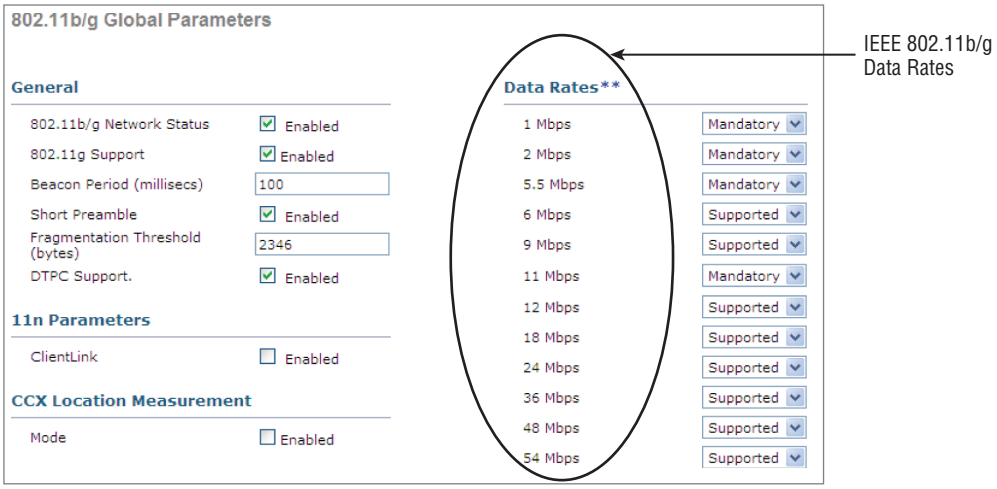
This amendment to the IEEE 802.11 standard was released in 2003. Like 802.11 and 802.11b, it operates in the 2.4 GHz ISM band. This amendment addresses extended data rates with OFDM technology and is backward-compatible to 802.11 and 802.11b.

Here are the frequency range, PHY technology, spread spectrum technology, and data rates for the *IEEE 802.11g* amendment:

- 2.4 GHz ISM band
- 2.4 GHz-2.4835 GHz in North America, China, and Europe (excluding Spain and France)
- Direct-sequence spread spectrum (DSSS)
- High rate-direct sequence spread spectrum (HR/DSSS)
- Extended rate physical-orthogonal frequency division multiplexing (ERP-OFDM)
- Packet binary convolutional code (PBCC; optional)
- 1 and 2 Mbps (compatible with DSSS)
- 5.5 and 11 Mbps complementary code keying (CCK; compatible with HR/DSSS)
- 6, 12, 24 Mbps OFDM required data rates
- 9, 18, 36, 48, and 54 Mbps OFDM data rates supported but not required

Figure 2.5 shows the data rates for IEEE 802.11g available on a WLAN controller.

FIGURE 2.5 WLAN controller showing the IEEE 802.11g data rates



IEEE 802.11g is backward-compatible to 802.11 and 802.11b because it operates in the same 2.4 GHz ISM license-free band and supports the same access methods or technology as 802.11b. One benefit of IEEE 802.11g compatibility was that many established network infrastructures and devices have used 802.11 and 802.11b for years. This allowed them to continue to operate as normal with upgrades or replacement as appropriate or necessary.

To allow the slower DSSS and HR/DSSS data rates of 1, 2, 5.5, and 11 Mbps to operate in an IEEE 802.11g/n network, the amendment addresses the use of "protection mechanisms." These protection mechanisms will decrease the throughput of IEEE 802.11g/n clients to some degree when IEEE 802.11b radios are present in the basic service area (BSA). This is because when 802.11b and 802.11g/n devices are connected to the same access point, RTS and CTS or CTS-to-self-control frames are used to lessen the chances of data collisions by reserving the medium for a specific period of time.

Many organizations have dropped support for IEEE 802.11b devices completely. This is accomplished by disabling the 802.11b data rates on the infrastructure devices—access points, controllers, cloud managed solutions, and so on. They do this to minimize performance issues such as throughput when IEEE 802.11b devices are present in the IEEE 802.11g/n BSA. In some deployment scenarios, such as public wireless hotspots or areas with wireless guest networks, it would be difficult to disallow the use of IEEE 802.11b devices. However, this is becoming more common and strictly a decision to be made by the organization and information technology staff.

Real World Scenario

Maximizing Throughput in an IEEE 802.11g/n Network

In certain cases, the only way to maximize the throughput of an 802.11g/n network is to set the data rates of the access points to support 802.11g/n data rates only. The trade-off is that 802.11b devices will not be able to connect to the network, because the access point will not recognize the 802.11b data rates. With the newer technology available today, turning off support for 802.11b is becoming less of a concern. This would work well where backward compatibility to 802.11b is not required and all equipment in use supports 802.11g/n. An analogy would be a group of individuals all speaking one language. They all understand the same language, so they have no need to accommodate a second language.

Because of protection mechanisms defined in the 802.11g amendment, throughput will degrade in an 802.11b/g/n mixed mode environment when 802.11b devices are present. The 802.11b devices have a maximum data rate of 11 Mbps (HR/DSSS), and they share the medium with the 802.11g/n devices that have a maximum data rate of 54 Mbps (ERP-OFDM) or higher. Think of the language analogy. If a group of individuals is speaking two different languages, a translator may be required for complete communication. A discussion among the group would take longer, because the translator would need to translate the languages. Likewise, protection mechanisms will have an impact on the throughput for the 802.11g/n devices, since the 2.4 GHz medium is shared. If there are no 802.11b devices in the radio range of an access point in an 802.11b/g/n mixed mode environment, protection mechanisms should not affect throughput since the access point will not have to share the medium with the two different technologies, ERP-OFDM and HR/DSSS.

If you do not have any 802.11b devices on your network, you can set your access point to 802.11g/n mode by disabling the 802.11b data rates. In this configuration, your 802.11g/n devices will perform better, because protection mechanisms will not be enabled. However, if there are any 802.11b devices that don't belong to your network in the "listening" range of the access point, data collisions will increase at the access point. This is because 802.11b and 802.11g/n operate in the same RF range, and the 802.11g/n (ERP-OFDM) access point would stop listening to the 802.11b (HR/DSSS) transmissions. (It would simply see them as RF noise.) In this configuration, overall throughput will still exceed that of an access point set to 802.11b/g/n mixed mode in the presence of 802.11b devices. The access point will hear the 802.11b transmissions, but they will not be serviced since they are only seen as RF noise; thus, they will have less impact on throughput. Also, when an 802.11g/n access point "hears" beacon management frames from a neighboring access point that is either an 802.11b access point or 802.11g/n access point in protection mode, it will cause the access point to also enter a protection mode state. This is because a "non-member" protection mode caused by neighboring access points on the same RF channel containing the protection mode requirements in their beacon frames will force the access point to also be in a protection mode state.

The IEEE 802.11n Amendment

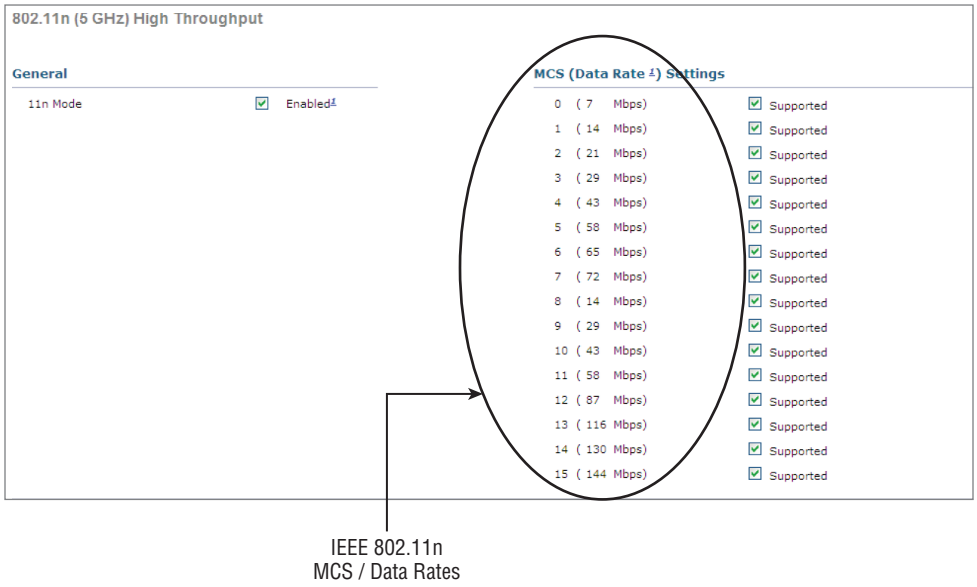
After several years of drafts, the IEEE 802.11n amendment was finally approved in September 2009. The release of this document opened the doors for manufacturers of IEEE 802.11 WLAN equipment, giving them the opportunity to move forward with new technology that allows for better performance, higher throughput, and several other benefits. Wi-Fi certified devices under 802.11n draft 2.0 were available for several years prior to the ratification of IEEE 802.11n. Most if not all enterprise manufacturers had at least one wireless infrastructure device certified under draft 2.0 by the Wi-Fi Alliance prior to the release of the new amendment.

Here are the frequency ranges, PHY technologies, data rates, and other details for the IEEE 802.11n amendment:

- 2.4 GHz ISM band
- 5 GHz UNII band
- Multiple-input multiple-output technology (MIMO)
- High-throughput orthogonal frequency division multiplexing (HT-OFDM)
- Physical layer (PHY) layer enhancements
- Data Link layer (MAC) layer enhancements
- Data rates up to 600 Mbps

Figure 2.6 shows the modulation and coding scheme (MCS) and data rates available on a WLAN controller for IEEE 802.11n operating on the 5 GHz band.

FIGURE 2.6 WLAN controller showing the IEEE 802.11n MCS and data rates for the 5 GHz band



IEEE 802.11n devices are capable of operating in both unlicensed frequency bands, the 2.4 GHz ISM band and the 5 GHz UNII band. This means that they must be backward-compatible with previous technologies, such as IEEE 802.11b/g devices that operate in the 2.4 GHz ISM band and IEEE 802.11a devices that operate in the 5 GHz UNII band.

Multiple-input multiple-output (MIMO) is a big part of what makes IEEE 802.11n such an amazing technology. Prior to 802.11n, IEEE 802.11a/b/g devices used a single radio to transmit and receive radio signals. This is known as *single-input single-output* (SISO) technology. MIMO uses multiple radios or "radio chains" to transmit and receive radio signals. SISO systems are subject to a phenomenon called *multipath*, in which several wavefronts of a signal would be received out of phase because of reflections. This is a problem for IEEE 802.11a/b/g systems, whereas MIMO actually uses the reflections from either a transmitter or a receiver to help enhance the performance and throughput using several radio chains in 802.11n. Multipath is discussed in more detail in Chapter 5. MIMO consists of several types of new technologies that include the following among others:

- Transmit beamforming (TxBF)
- Maximal ratio combining (MRC)
- Spatial multiplexing (SM)
- Space-time block coding (STBC)

It is best to check with the specific manufacturers of the wireless equipment to determine how they implement MIMO technology. The details of the types of MIMO technologies listed here are beyond the scope of the objectives of this book but can be found in other CWNP study guides and training materials.

IEEE 802.11n provides many enhancements to the Physical Layer 1, including the following:

- 40 MHz channels through the use of channel bonding
- More subcarriers for higher data rates
- Optional short guard intervals to provide more potential throughput in less reflective environments
- Varying modulation types for data rates of up to 600 Mbps

The Media Access Control (MAC) sublayer of the Data Link layer also provides enhancements to improve performance and throughput with IEEE 802.11n. These include but are not limited to the following:

- Frame aggregation for less 802.11 overhead
- Block acknowledgments (block ACKs)
- Reduced interframe spacing (RIFS)
- Spatial multiplexing power save (SMPS) to help conserve the battery life of the receiver
- Power save multi-poll (PSMP) for devices enabled for QoS devices

The IEEE 802.11ac Amendment

The IEEE 802.11ac amendment is an exciting step forward with standards-based WLAN technology. This new gigabit wireless networking technology is used with wireless local area networking for both home and enterprise applications. As technology continues to

advance, the users of the connected devices want more data, they want it faster, and they want it available everywhere. Like the IEEE 802.11a amendment to the standard, 802.11ac technology operates in the 5 GHz band only and is a Physical layer extension of IEEE 802.11n, providing backward compatibility with that technology in the 5 GHz frequency band. IEEE 802.11ac brings the following enhancements:

Data Rates up to 6.93 Gbps IEEE 802.11ac, Very High Throughput (VHT), provides the capability of up to 6.93 Gbps of aggregate throughput. The actual amount of throughput will vary and can be affected by several factors, including the number of radio chains/spatial streams and antennas.

256-QAM (Quadrature Amplitude Modulation) The modulation and coding scheme (MCS) concept was introduced with the IEEE 802.11n amendment. Basically, MCS is a way to represent the data transfer rates with the newer, more sophisticated technology. The MCS index will vary based on the technology in place, such as the number of spatial streams, the channel width, and the short guard interval. IEEE 802.11ac allows for 256-QAM up from 64-QAM in 802.11n.

Wider Channels Bandwidth with respect to RF can be considered to be a range of frequencies used for a specific application. IEEE 802.11n increased the RF channel width from 20 MHz to 40 MHz. This newest amendment to the standard allows for 80 MHz- and even 160 MHz-wide channels. Wider channels mean more bandwidth per channel and therefore higher throughput.

More Spatial Streams The IEEE 802.11n amendment allowed for a possible maximum of four spatial streams; however, most manufacturers utilized only three. IEEE 802.11ac will allow for up to eight spatial streams. More spatial streams means a higher data rate, and this will parlay into higher throughput.

Multi-user MIMO (MU-MIMO) Until now, IEEE 802.11 technology was based on unicast communication between two stations, such as a client device and an access point, or broadcast/multicast communication, such as an access point to many or all connected stations. IEEE 802.11ac provides multi-user MIMO (MU-MIMO) for communication. MU-MIMO will allow different stations (client devices) to send or receive independent data streams simultaneously using multiple antennas/radio chains.

IEEE 802.11ac is backward-compatible with devices operating in the 5 GHz band only and will be beneficial for certain types of applications, such as streaming video and/or areas that may need additional capacity, and for minimizing issues in high-density deployments. One thing that is often overlooked is the actual physical wired infrastructure in which the wireless access points are connected. It is important to be certain that the wired infrastructure capacity is available to handle these faster speeds.

The IEEE 802.11ad amendment (Very High Throughput 60 GHz) was ratified in December 2012. This technology operates in the unlicensed 60 GHz frequency band and is not backward-compatible with IEEE 802.11a/b/g/n/ac technology. Because 802.11ad operates at such a high frequency, it has many limitations and does not propagate well, and communications may be limited to a very small physical space, such as a single room. There are

a limited number of IEEE 802.11ad chipsets available that will provide this technology. However, they currently are not big within the WLAN market or widely available. Some manufacturers produce network adapters that will work within the 2.4 GHz, 5 GHz, and 60 GHz frequency ranges, but it is important to understand that even though these adapters will work in all three frequency ranges, the 802.11ad technology is not backward-compatible with 802.11a/b/g/n/ac. The use of 802.11ad wireless technology includes peer-to-peer or ad hoc communications for streaming video and other multimedia type uses within a smaller physical area.

The IEEE 802.11ah amendment allows for wireless LAN operation in frequency bands below 1 GHz (also called the Sub 1 GHz band), allowing for long-range, low-power connections using unlicensed frequency, including the 900 MHz frequency band. The driving force behind this amendment is the Internet of Things (IoT) devices.

Summary of IEEE 802.11 Communications Standards and Amendments

It is beneficial to understand all the frequencies, PHY technology, spread spectrum technologies, and data rates for all the IEEE 802.11 standards and amendments mentioned in this chapter. This will help for certification exam purposes as well as for basic knowledge of the technology. Table 2.2 provides a summary and comparison of the currently released IEEE 802.11 communication standards and amendments.

TABLE 2.2 Summary of 802.11 communication standards and amendments

Details	802.11	802.11a	802.11b	802.11g	802.11n	802.11ac
2.4 GHz ISM band	✓		✓	✓	✓	
5 GHz UNII bands		✓			✓	✓
FHSS	✓					
DSSS	✓		✓	✓	✓	
HR/DSSS			✓	✓	✓	
OFDM		✓			✓	
ERP-OFDM				✓	✓	
HT-OFDM					✓	✓

Details	802.11	802.11a	802.11b	802.11g	802.11n	802.11ac
VHT-OFDM						✓
1 and 2 Mbps	✓		✓	✓	✓	
5.5 and 11 Mbps			✓	✓	✓	
6, 9, 12, 18, 24, 36, 48, and 54 Mbps		✓		✓	✓	✓
Up to 600 Mbps					✓	✓
Up to 6.93 Gbps						✓

Additional IEEE 802.11 Amendments

In addition to communications, the IEEE creates amendments defining specific functionality, including QoS and security. We will look at those functions next.

The IEEE 802.11e Amendment

The original IEEE 802.11 standard lacked QoS functionality features. In the original IEEE 802.11 standard, point coordination function (PCF) mode provided some level of QoS. PCF mode is a function of the access point and allows for polling of connected client devices. This creates a contention-free period for data transmissions and provides QoS-like functionality. However, few if any 802.11 wireless manufacturers implemented this mode of operation.

The IEEE 802.11e amendment defined enhancements for QoS in WLANs. 802.11e introduced a new coordination function, the *hybrid coordination function* (HCF). HCF defines traffic classes and assigns a priority to the information to be transmitted. For example, voice traffic is given a higher priority than data traffic, such as information being sent to a printer. The IEEE 802.11e amendment was incorporated into the IEEE 802.11-2007 standard and is now part of the IEEE 802.11-2016 standard. The Wi-Fi Alliance created a proactive interoperability certification for 802.11e called *Wi-Fi Multimedia* (WMM). The Wi-Fi Alliance and interoperability certifications are discussed later in this chapter.

The IEEE 802.11i Amendment

The IEEE 802.11i amendment addresses advanced security solutions for WLANs, since the original IEEE 802.11 standard was known for security weaknesses. Manufacturers of IEEE 802.11 WLAN equipment addressed the following:

- Wired Equivalent Privacy (WEP)
- Service set identifier (SSID) hiding
- Media access control (MAC) address filtering

Wired Equivalent Privacy (WEP) was defined by the IEEE 802.11 (1999) standard intended to prevent casual eavesdropping. WEP was compromised early on, making WLANs vulnerable to intrusion and providing little if any security. This issue was addressed by stronger security mechanisms (mainly CCMP/AES, which stands for Counter Mode with Cipher-Block Chaining Message Authentication Code Protocol /Advanced Encryption Standard) that became available with the introduction of the IEEE 802.11i amendment to the standard.

Service set identifier (SSID) hiding and media access control (MAC) address filtering are both manufacturer-implemented features that may be used by some for "pseudo" security. It is important to understand that neither of these provides any kind of security for an IEEE 802.11 wireless network. MAC address filtering provided a user the ability to allow or disallow device access to a wireless network based on the assigned Layer 2 address of the device.

WEP, SSID hiding, and MAC filtering all have known security vulnerabilities, allowing for security weaknesses in IEEE 802.11 WLANs. The IEEE 802.11i amendment addressed security weaknesses with WLANS by including several enhancements, all of which will be discussed in Chapter 8, "Security Fundamentals for Wireless Networking." The IEEE 802.11i amendment was incorporated into the IEEE 802.11-2007 standard and is now part of the IEEE 802.11-2016 standard.

The IEEE 802.11r Amendment

The IEEE 802.11r amendment was approved in May 2008. The 802.11r amendment specifies fast secure roaming or fast transition (FT) technology. The IEEE 802.11 standard did not address standards-based transition (roaming) mechanisms, so manufacturers used proprietary methods. The IEEE attempted to standardize transition techniques for WLAN technology with the ratification of a recommended practice, IEEE 802.11F. This recommended practice was never implemented by many (if any) manufacturers and was eventually withdrawn by the IEEE.

The main goal of IEEE 802.11r was to provide fast transition for voice over IP (VoIP) with WLAN technology. Although this amendment has been ratified for some time and most enterprise equipment manufacturers support it, they still rely on the use of proprietary methods for fast transition. This is partly because there was no interoperability certification from the Wi-Fi Alliance until recently. Additionally, there are other technical requirements such as support on both infrastructure and the client device sides for this technology to operate correctly. The IEEE 802.11r amendment was incorporated into the IEEE 802.11-2012 standard and is now part of the IEEE 802.11-2016 standard.

The IEEE 802.11k Amendment

IEEE 802.11k is the amendment to the IEEE 802.11 standard that addresses radio resource management. This amendment was approved in May 2008, the same day as the IEEE 802.11r amendment. 802.11k and 802.11r work together to form fast, secure basic service set (BSS) transition for mobile devices. IEEE 802.11k aids the wireless device in locating the best access point to transition to, by defining the technology to be used to manage the RF. The IEEE 802.11k amendment was incorporated into the IEEE 802.11-2012 standard and is now part of the IEEE 80211-2016 standard.

The IEEE 802.11v amendment, now part of IEEE 802.11-2016 standard, addresses management of devices that are connected to a wireless network and are part of a basic service set. Along with IEEE 802.11r and IEEE 802.11k, IEEE 802.11v is required by the Wi-Fi Alliance to qualify for Wi-Fi certified voice certifications. It is also important to note both the access point and client device need to be Wi-Fi certified for voice in order to benefit from the technology.

The IEEE 802.11w Amendment

WLAN management frames—such as the 802.11 authentication frames and 802.11 association frames used in IEEE 802.11 WLANs—are susceptible to intrusion and can cause security issues. This is because the IEEE 802.11 standard did not provide any protection for management frame information that traverses the air. With some basic knowledge of the technology and the correct software tools, an intruder can perform a denial-of-service (DoS) or hijacking attack. When implemented, technology specified in the IEEE 802.11w amendment helps to mitigate these types of attacks or security issues. This technology is still not yet implemented by most organizations mostly due to the requirements and other technical issues such as the effect on wireless intrusion prevention systems (WIPS) mitigation features. The IEEE 802.11w amendment was incorporated into the IEEE 802.11-2012 standard and is now part of the IEEE 802.11-2016 standard.

The IEEE 802.11s Amendment

The IEEE 802.11s amendment specifies wireless mesh networking. Mesh networking with wired networking has been available for many years. Wireless mesh networking started with military deployments but has evolved into the public sector. Mesh networking allows infrastructure devices such as wireless access points or mesh routers to create a self-forming, self-healing and intelligent network infrastructure. A wireless mesh network is sometimes referred to as a *wireless distribution system* (WDS). Most manufacturers of enterprise wireless equipment have been using mesh technology for years with proprietary protocols. Although the IEEE has ratified the standard for this technology, most manufacturers still use proprietary methods. Mesh technology will be discussed further in Chapter 3, “Infrastructure and Client Devices for Wireless Networking.” The IEEE 802.11s amendment was incorporated into the IEEE 802.11-2012 standard and is now part of the IEEE 802.11-2016 standard.

Interoperability Certifications

By creating standards, the IEEE is encouraging technological progress. Manufacturers often implement wireless devices and networks in a proprietary manner, within or outside the standard. The proprietary approach often leads to a lack of interoperability among devices. In the wireless community, such practices are not widely accepted. Users want all their devices to function well together. The combination of proprietary implementations and user dissatisfaction fostered the creation of interoperability testing and certifications.

This section discusses manufacturer interoperability certifications related to IEEE 802.11 standards-based WLAN equipment. These certifications address communications, QoS, and security.

The Wi-Fi Alliance

The IEEE is responsible for creating the standards for wireless networking. Equipment manufacturers, however, are not required to provide proof that their equipment is compliant with the standards. Starting with the release of the IEEE 802.11b amendment, several early WLAN equipment manufacturers—including Symbol Systems, Aironet, and Lucent—formed an organization known as *Wireless Ethernet Compatibility Alliance* (WECA) to promote the technology and to provide interoperability testing of WLAN equipment manufactured by these and other companies. In 2000, WECA was renamed the *Wi-Fi Alliance*. The term *Wi-Fi* represents a certification and is often misused by people in the industry. Wi-Fi is a registered trademark, originally registered in 1999 by WECA and now registered to the Wi-Fi Alliance. People often use the term Wi-Fi synonymously with WLAN technology; in fact it means wireless technology certified to be interoperable.

For additional information about the Wi-Fi Alliance, visit `www.wi-fi.org` or `www.wi-fi.com`.

Figure 2.7 shows an example of a Wi-Fi certified logo, showing the device has met the interoperability testing criteria.

FIGURE 2.7 Wi-Fi Certified logo for devices that are Wi-Fi certified

The Wi-Fi Protected Access Certification

The *Wi-Fi Protected Access (WPA)* certification was developed by the Wi-Fi Alliance because security in the original IEEE 802.11 standard was weak and had vulnerabilities. This certification was designed as an interim solution until an amendment to the IEEE 802.11 standard addressing security improvements was released. The IEEE 802.11i amendment addressed security for the IEEE 802.11 family of standards. The bottom line is that WPA is a pre-802.11i certification, introducing more advanced security solutions such as Temporal Key Integrity Protocol (TKIP), passphrase, and 802.1X/EAP.

This pre-802.11i certification addressed two options for WLAN security: personal mode and enterprise mode. Personal mode is intended for small office/home office (SOHO) and home users. Enterprise mode is intended for larger deployments. Personal mode allows for a user to enter an 8- to 63-character passphrase (password) on either the access point or another infrastructure device, such as a WLAN controller and all the devices that are connected to the infrastructure device. Enterprise mode, on the other hand, provides user-based authentication utilizing 802.1X/EAP. Both personal and enterprise modes are discussed in more detail in Chapter 8.

The Wi-Fi Protected Access 2 Certification

The WPA certification by the Wi-Fi Alliance worked out so well that the alliance decided to certify WLAN hardware after the IEEE 802.11i amendment was released. This new certification, known as *Wi-Fi Protected Access 2 (WPA 2.0),* is a post-802.11i certification. Like WPA, WPA 2.0 addresses two options for WLAN security: personal mode and enterprise mode. This certification addresses more advanced security solutions and is backward-compatible with WPA. The following is a preview of its key points; we will look at both WPA and WPA 2.0 in more detail in Chapter 8.

- The personal mode security mechanism uses a passphrase for authentication, which is intended for SOHO and personal use. The use of a passphrase to generate a 256-bit pre-shared key provides strong security. Personal mode may also be identified as pre-shared key (PSK).
- The enterprise mode security mechanism uses 802.1X/EAP for user-based authentication, which is port-based authentication and is designed for enterprise implementations. 802.1X/EAP provides strong security using external authentication and Extensible Authentication Protocol (EAP). 802.1X/EAP uses an authentication server for the user authentication. Remote Authentication Dial-In User Service (RADIUS) is a common authentication server. This works well as a replacement for legacy IEEE 802.11 security solutions.

Table 2.3 provides a high-level description of the WPA and WPA 2.0 certifications.

TABLE 2.3 Details of the WPA and WPA 2.0 certifications

Wi-Fi Alliance Security Mechanism	Authentication Mechanism	Encryption Mechanism/Cipher
WPA - Personal	Passphrase	TKIP/RC4
WPA - Enterprise	802.1X/EAP	TKIP/RC4
WPA 2.0 - Personal	Passphrase	CCMP/AES or TKIP/RC4
WPA 2.0 - Enterprise	802.1X/EAP	CCMP/AES or TKIP/RC4

Temporal Key Integrity Protocol (TKIP)
Rivest Cipher 4 (RC4) named after Ron Rivest of RSA Security
Counter Mode with Cipher-Block Chaining Message Authentication Code Protocol (CCMP)
Advanced Encryption Standard (AES)

Encryption mechanisms and ciphers will be discussed further in Chapter 8.

The Wi-Fi Multimedia Certification

The *Wi-Fi Multimedia (WMM)* certification was designed as a proactive certification for the IEEE 802.11e amendment to the 802.11 standard. The 802.11e amendment addresses QoS in WLANs. The WMM certification verifies the validity of features of the 802.11e amendment and allows for a manufacturer-neutral approach to QoS.

QoS is needed to ensure delivery of information for time-sensitive, time-bounded applications, such as voice and real-time streaming video. If a wireless network user were to send a file to a printer or save a file to a server, it is unlikely they would notice any minor delay, or latency. However, in an application that is tuned to the human senses such as hearing or eyesight, latency would more likely be noticeable.

Wi-Fi Multimedia Power Save Certification

Wi-Fi Multimedia Power Save (WMM-PS) is designed for mobile battery-powered devices and specific uses of WLAN technology that require advanced power-save mechanisms for extended battery life. Here are some of these devices and technology that benefit from WMM-PS:

- Voice over IP (VoIP) phones
- Notebook computers
- Tablet devices

Power-save mechanisms allow devices to conserve battery power by "dozing" for short periods of time. Depending on the application, performance could suffer to some degree with power-save features enabled. WMM-PS consumes less power by allowing devices to spend more time in a "dozing" state—an improvement over legacy power save mode that at the same time improves performance by minimizing transmission latency. Unlike the early standard-based power save mode, which uses a scheduled timing process to doze, a device that is WMM PS-enabled will doze based on whether it needs to send or receive data frames. This is known as a trigger and delivery method where the client device will be in an "awake" state as needed to either send or receive data frames to and from an access point.

Wi-Fi Protected Setup Certification Overview

Wi-Fi Protected Setup (WPS) was defined because SOHO users wanted a simple way to provide the best security possible for their installations without the need for extensive technical knowledge of wireless networking. WPS provides strong out-of-the-box setup adequate for many SOHO implementations.

The WPS certification requires support for two types of authentication that enable users to automatically configure network names and strong WPA2 data encryption and authentication:

- Push-button configuration (PBC)
- PIN-based configuration, based on a personal identification number

Support for both PIN and PBC configurations is required for access points; client devices at a minimum must support PIN. A third, optional method, near field communication (NFC) tokens, is also supported.

Security Hole with WPS

In December 2011 a security flaw was reported with WPS. This allegedly allowed an intruder to recover the personal identification number (PIN) used to create the 256-bit pre-shared key. Acquiring the PIN would allow access to the wireless network. Wherever possible, it is recommended that users disable certain features in the wireless router or access point that allow this to happen. A firmware update may also be available to provide adequate protection. Keep in mind that this solution to the issue may only be possible with newer-model wireless routers. You should check with the manufacturer to determine if a solution (either a software setting or firmware upgrade) is available for a specific device. Otherwise, consider a different method such as WPA2.0 to secure the wireless router. Upgrading to a newer wireless router is another possible solution.

Common Wireless Local Area Network Deployment Scenarios

The availability and technology enhancements of IEEE 802.11 wireless networking have increased while the cost continues to decrease, making WLANs a viable solution for many business models, including personal use, home offices, small offices, and enterprise organizations. This section looks at various scenarios in which this type of wireless networking is used. We'll explore some of the following more common deployment scenarios that utilize WLANs:

- Small office/home office (SOHO)
- Enterprise deployments: corporate data access and end-user mobility
- Extension of existing networks into remote locations
- Public wireless hotspots (public Wi-Fi) and hospitality

- Office (carpeted) deployments
- Educational institution deployments
- Industrial deployments
- Healthcare deployments
- Last-mile data delivery: wireless ISP
- High-density deployments including conference centers
- Other deployments, including municipal, law enforcement, and transportation networks

Small Office/Home Office

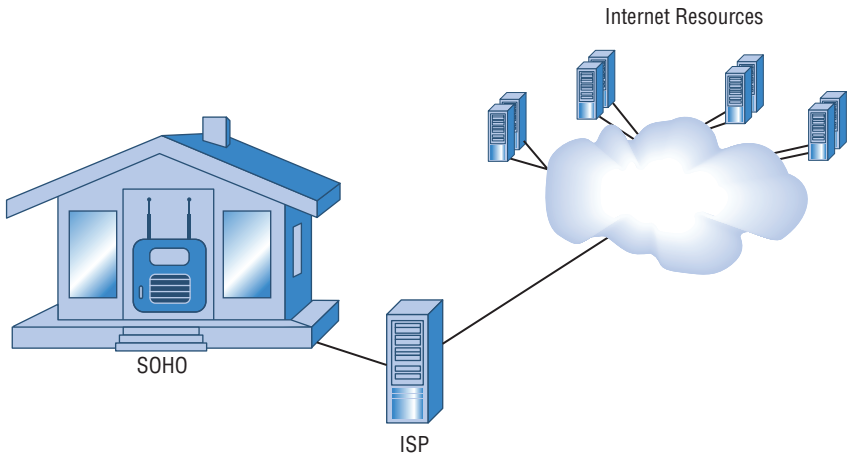
Many small office/home office (SOHO) businesses have the same needs as those of larger businesses with regard to technology, computer networking, and communication. These common needs, regardless of the network size, include access to a common infrastructure for resources such as computer data (files), printers, databases, other networks, and the Internet. Computer networking technology is common regardless of the size of the business. Whether there are 1 or 100 employees, many are categorized as small businesses. WLANs now play a major role in small businesses. Many of these locations have a high-speed Internet connection such as DSL (digital subscriber line) or cable modem for access outside the LAN.

With the number of work-at-home professionals continuing to grow at a very high rate, the need for wireless networking in this environment is also continuing to grow. The same goes for the small office environment. Deployments such as these typically involve a smaller number of users. Therefore, the equipment used may be consumer models sold in consumer electronics department stores and online retailers.

In addition, many companies or organizations now allow for employees to work remotely part or full time. In these cases the company network is now extended to the remote location, which, whether it is a home office or other location, may be considered a branch office of the company's corporate network. When WLAN technology is used at a remote location, new concerns arise, such as data security and network availability. Depending on the size of the small office/home office and the number of potential users and devices, a WLAN RF site survey may be required. A site survey will help determine areas of RF coverage and interference as well as the number and placement of access points. Even if the small office/home office will only require a single access point, it is still beneficial to know what other wireless networks or devices are in the same coverage area that may cause RF interference.

Figure 2.8 shows a SOHO configuration with a WLAN router connected to an Internet service provider allowing access to the necessary network/Internet resources.

FIGURE 2.8 Example of a SOHO WLAN configuration



Enterprise Deployments: Corporate Data Access and End-User Mobility

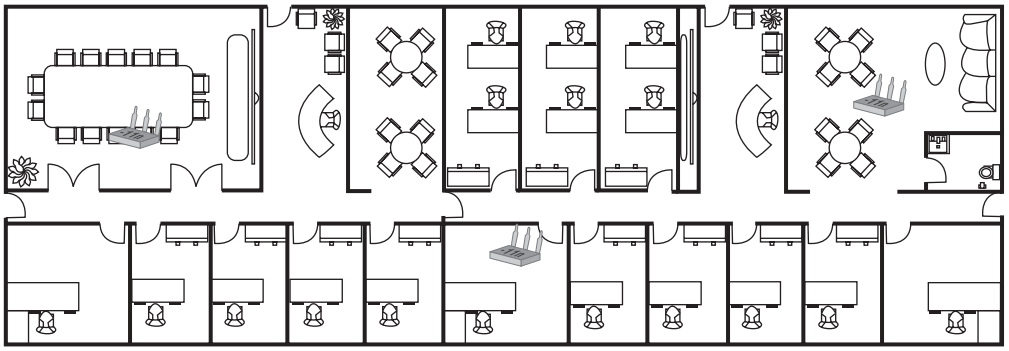
Enterprise organizations have used wired LAN technology for decades. With the increased need for mobility, WLANs within enterprise organizations have also increased in popularity. In earlier years, due to lack of interoperability and security features, many enterprise organizations limited WLAN deployments to extensions of networks where wired connectivity was either not feasible or too costly. Because of advancements in WLAN technology over the recent years, IEEE 802.11 deployments in enterprise organizations are continuing to grow at a rapid pace.

WLANs in the enterprise are used with—but not limited to—client workstation connectivity (desktop, notebook, and tablet devices), printers, barcode scanners, voice handsets, and location services. The cost of this technology has decreased, whereas capabilities, performance, speed, and security have increased, making wireless an attractive solution for many enterprise organizations. The cost savings over hardwired solutions such as Ethernet are enormous, adding to the attractiveness. Finally, wireless connectivity is the only option in some cases, such as mobile Voice over Wi-Fi handsets for voice communications.

Figure 2.9 shows a floor plan drawing of an office area that may include a wireless deployment. Each individual or shared office would contain one or two networked desktop computers and phones, and many would also have laptops. Printers might be located in centrally located common areas accessible to the individuals who have permissions to use them. The conference room might contain a videoconferencing system and an access point depending on the number of available seats, and the reception area might have wireless guest access for vendors or other visitors not belonging to the company or organization. Connecting all these networked devices to each other and the outside world are the wireless

access point and other WLAN infrastructure discussed in Chapter 3; these will be located throughout the facility based on the wireless network design to provide coverage and capacity for all wireless devices.

FIGURE 2.9 Floor plan of a typical office area that may use IEEE 802.11 WLAN technology



Extension of Existing Networks into Remote Locations

In its early days, wireless networking technology was typically deployed as an extension of an existing wired network infrastructure. For example, some users who required access to the computer network were farther than the physical limit of 100 meters that the IEEE 802.3 Ethernet standard allows for a copper-wired connection, so other solutions were needed to provide this connectivity. Other wired technology, such as fiber optics and leased lines, was sometimes cost-prohibitive or not logistically feasible. WLANs were an excellent alternative.

Now IEEE 802.11 WLANs are a major part of every network, including home, corporate, and branch/remote locations. Remote network locations may include the SOHO, branch office locations, public wireless hotspots, and wireless Internet service providers (WISPs). When a user connects to a corporate office network from any of these scenarios, the network is basically being extended to a remote location. This extension should be treated as such with regard to network, security, availability, and performance. This chapter discusses each of these deployment scenarios in more detail.

Public Wireless Hotspots (Public Wi-Fi) and Hospitality

Portability and mobility are major benefits of wireless networking. Portability allows users to access information from a variety of locations, either public or private. Mobility allows the continuous connection to a wireless network while a device is on the move. One example of portability is the wireless hotspot. In today's world, it is rare to visit any public location, whether a restaurant, hotel, coffee shop, or airport, and not be able to find a public wireless hotspot.

A *wireless hotspot* is defined as a location that offers wireless network connectivity for free or for-profit public or patron services. It allows a variety of mobile devices (computers,

tablets, smart phones, and so on) to connect to and access public Internet and private network resources. Many users work from remote locations and require Internet access as part of their job. This can include access from a wireless hotspot.

A typical wireless hotspot will be configured with at least one WLAN router connected to an ISP. In some cases, this setup could be as simple as a location offering free Wi-Fi Internet access for its customers. More sophisticated hotspots will have several wireless access points or a complete wireless infrastructure and will be connected to a remote billing server that is responsible for collecting revenue from the user.

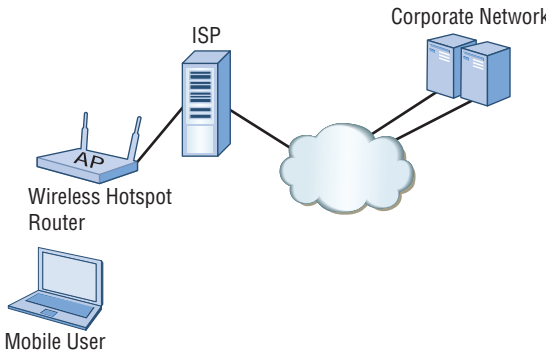
In many cases, when a user connects to the hotspot router, they will be prompted with a web page for authentication. At this point they might be asked to enter information such as an account number, username and password, or a credit card number to allow usage for a limited period of time. In the case of a free hotspot, typically this web page lists terms and conditions the user agrees to prior to accessing the Internet. This type of web page configuration is known as a *captive portal*. Captive portals are discussed in more detail in Chapter 8.

Wireless hotspots can raise security concerns for the user. Without a secure connection in place, information is passed in cleartext through the air via RF, potentially allowing an intruder to capture usernames, passwords, credit card numbers, or other information that could lead to identity theft. Most hotspots do not have the capability to provide a secure wireless connection from the user's computer or wireless device to the wireless router or network. The secure connection then becomes the responsibility of the user. Since many corporations allow employees to work remotely from wireless hotspot connections, extra security measures need to be explored and implemented. In this case, usually a *virtual private network* (VPN) is used to ensure security. A VPN creates a secure tunnel between the user and the corporate network, allowing for a secure encrypted connection for the user from the wireless hotspot to their corporate network over the Internet or public network.

For users who connect to wireless hotspots, it is very important for their wireless devices to be secured with the appropriate antivirus software, firewall software, and up-to-date operating system patches or service packs. Following these guidelines can help protect the user from attacks when they are connected to and using a wireless hotspot.

Figure 2.10 shows a simple wireless hotspot implementation.

FIGURE 2.10 Wireless hotspot allows users to connect to the Internet from remote locations.



Office (Carpeted) Deployments

Computer networking in traditional office space (or "carpeted offices") now relies on wireless technology to a large extent. This is for several reasons:

- Cost
- Portability
- Mobility
- Convenience

Many offices have an existing wired network infrastructure, and I do not expect that to go away any time soon. In most cases copper wire for Ethernet connectivity is already in place and is adequate for the intended use. However, the cost to upgrade the copper wiring or install new wired network drops can be expensive. Therefore, WLAN technology is an attractive alternative to wired networks in many office deployment scenarios. What we are now seeing in the enterprise is a new era of wireless networks by default and wired networks only as required. Depending on the use of the network—that is, the types of software applications and the number of devices requiring connectivity—wireless may be the best solution simply because of the cost.

Without trying to set firm limits, it is common to connect as many as 20–25 users/devices to a single wireless access point. However, the maximum size depends on the software or other applications and the number of devices connected. A major benefit of IEEE 802.11 WLAN technology is that an access point will require only a single Ethernet drop to support all the devices or users. Of course, don't forget that an access point is part of a shared medium for everything that connects, and performance and throughput can be an issue if proper design practices are not used.

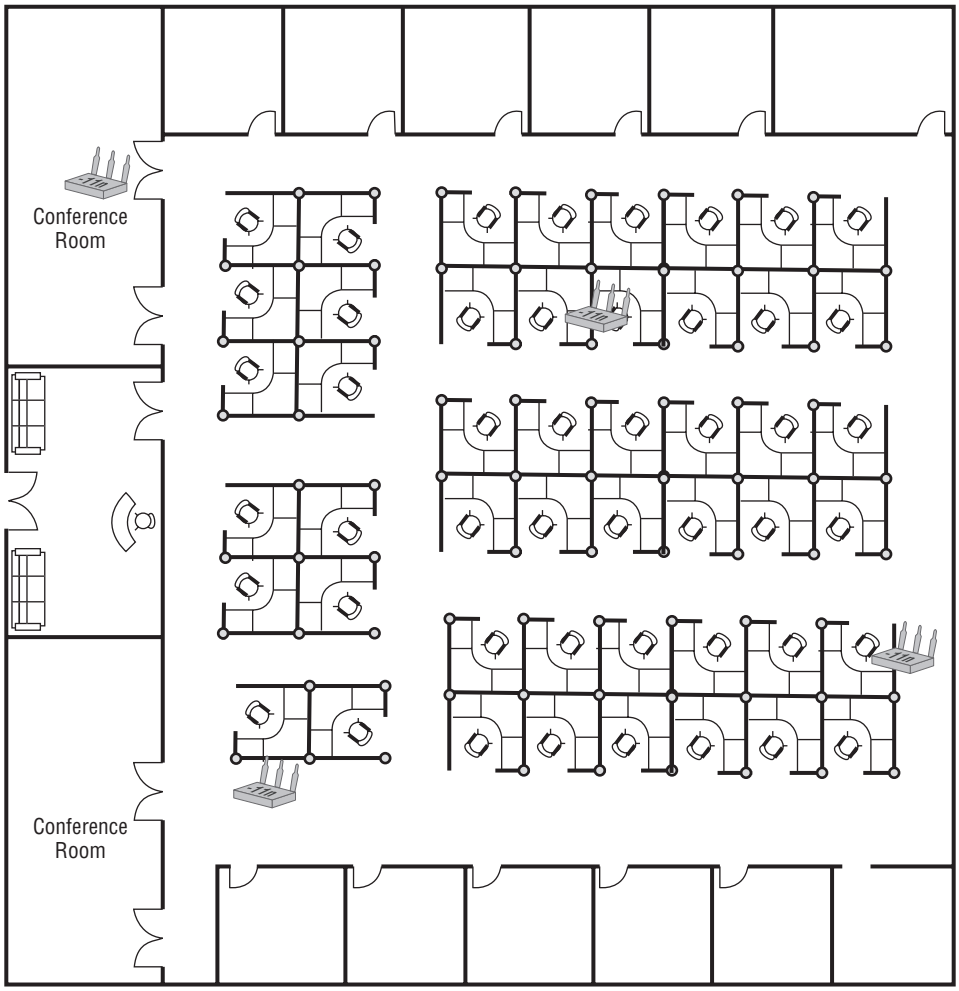
Again, remember the difference between portability and mobility. Portability allows users to access information from a variety of set locations, and mobility allows a continuous connection to a wireless network while the device is moving. Carpeted offices may have a need to provide support for both portability and mobility. For the user who moves from an office cubicle to a conference room to attend a meeting, portability will be sufficient. In this situation they will probably shut down their mobile device, such as a laptop computer, and carry it to a conference room for the meeting. Restarting the computer will then require the device to reconnect to the wireless network—hence, portability.

Devices such as mobile phones using VoIP or tablet devices usually require continuous connectivity to the wireless network while the user/device is in motion. This mobility feature allows uninterrupted communications and a pleasant experience for the user. Both portability and mobility provide the convenience network that people desire. Figure 2.11 shows a common office scenario.

Educational Institution Deployments

Educational institutions can benefit from wireless networking in many ways. WLAN deployments are common in elementary and high schools both public and private. Universities deploy campus-wide WLANs amounting to thousands of access points servicing tens of thousands of users on a single campus.

FIGURE 2.11 Office with conference area and cubicle offices



WLAN technology allows for increased mobility in the educational environment, providing huge cost savings when technology needs to be refreshed. Mobile carts with notebook computers are one example. A high school can deploy wireless infrastructure devices such as access points in classrooms and purchase several mobile carts with notebook or tablet computers to be used when and where needed. This is beneficial since it will save on supplying many classrooms with computers when continuous need for the computers or devices may be low. Some school buildings may be older or historic buildings and installing cabling is impossible or cost-prohibitive. Wireless provides the solution. The architecture of many school buildings may also pose concerns that need to be

addressed with many wireless network deployments. These include building materials, such as the following:

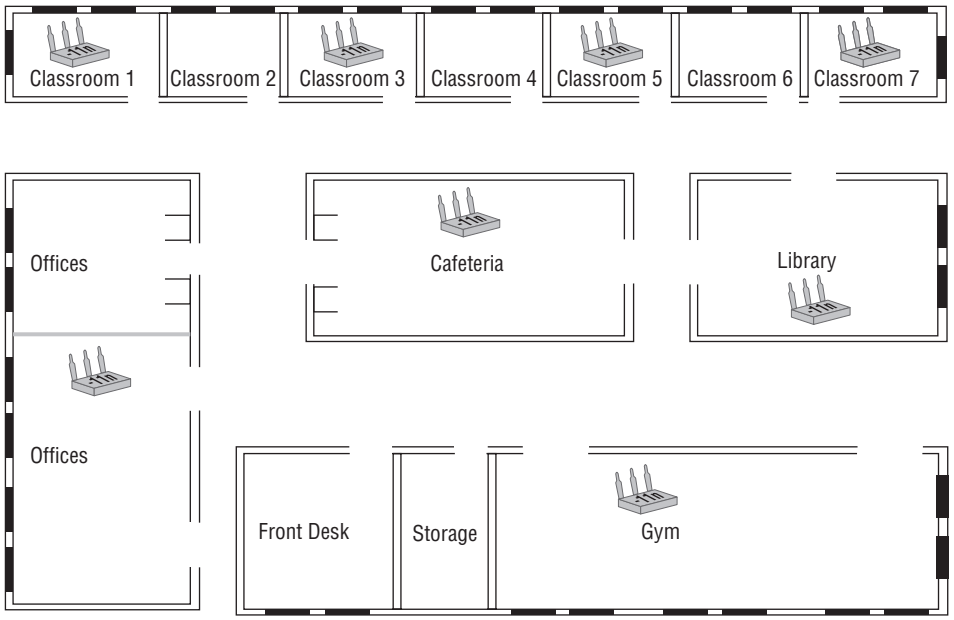
- Brick and concrete walls
- Lath and plaster walls
- Inconsistent materials due to building additions

These materials may cause issues because the RF may not propagate well depending on the density and composition of the building materials. This means potentially additional wireless access points and extra design considerations.

In addition, there may be modular or temporary classrooms; the issue with these is the density of devices and users, which will affect the wireless network capacity and may result in performance issues. Also, the location and distance from the main building should be taken into consideration because this equates to a point-to-multipoint connection, and line of sight needs be taken into account.

Some educational institutions are implementing a "one-to-one" initiative—in other words, the goal is to have one Internet-accessible device for every one student. This type of initiative will introduce density concerns because of the potentially high number of students in a single classroom. Educational institutions, whether an elementary school, a high school, or a college campus, should always consider starting with an RF wireless site survey and follow best practices from the equipment manufacturer to ensure a successful deployment. Figure 2.12 shows a typical small school environment.

FIGURE 2.12 Classrooms for WLAN deployment



Industrial Deployments

Some industrial organizations have been using WLAN technology for many years, even prior to the development of IEEE 802.11 wireless standards-based solutions. Examples of these deployments include barcode and scanning solutions for manufacturing, warehousing, inventory, and retail. Although this type of deployment may not be very dense, coverage is very important. Many businesses of this type include the following building characteristics:

- High ceilings
- Tall storage racks
- Large inventory of product
- Forklifts

These building characteristics can cause issues with wireless networks because of the way RF propagates. With high ceilings, various antennas will need to be tested and coverage verified throughout the facility. Tall storage racks may have varying levels of inventory or product, resulting in poor propagation. Depending on what the products are made of, this will have a direct impact on the RF behavior. For example, a high density of water products and paper products will absorb RF. In many cases, forklifts will be outfitted with wireless barcode scanners or other mobile devices that require the ability for fast secure transition capabilities.

In this type of environment, it is important to understand that RF will behave in ways that could impact the performance of the wireless network. Chapter 4 will explain the behaviors of RF in more detail. These behaviors can lead to coverage issues for the devices in use. Careful evaluation of this type of environment is essential, and an RF site survey is highly recommended to ensure proper RF coverage.

The physical characteristics of this type of environment are fairly static, although additional racks or shelving may occasionally be added. However, product inventory is dynamic and may change constantly. Moreover, forklifts and other product-moving equipment are constantly moving and in different locations. These are some of the factors that must be taken into consideration when deploying wireless networking in an industrial environment. Figure 2.13 shows a typical warehouse facility with 35-foot-high ceilings.

Healthcare Deployments

The growth of WLAN deployments in the healthcare industry is quite impressive. Today, healthcare is one of the fastest-growing sectors of the U.S. economy. Healthcare environments pose many challenges for the design, deployment, and support of wireless networking.

FIGURE 2.13 Warehouse facility with high ceilings and storage shelving inside

Hospitals in most cases run 24 × 7 × 365 days a year. WLANs have numerous applications in hospitals, including these:

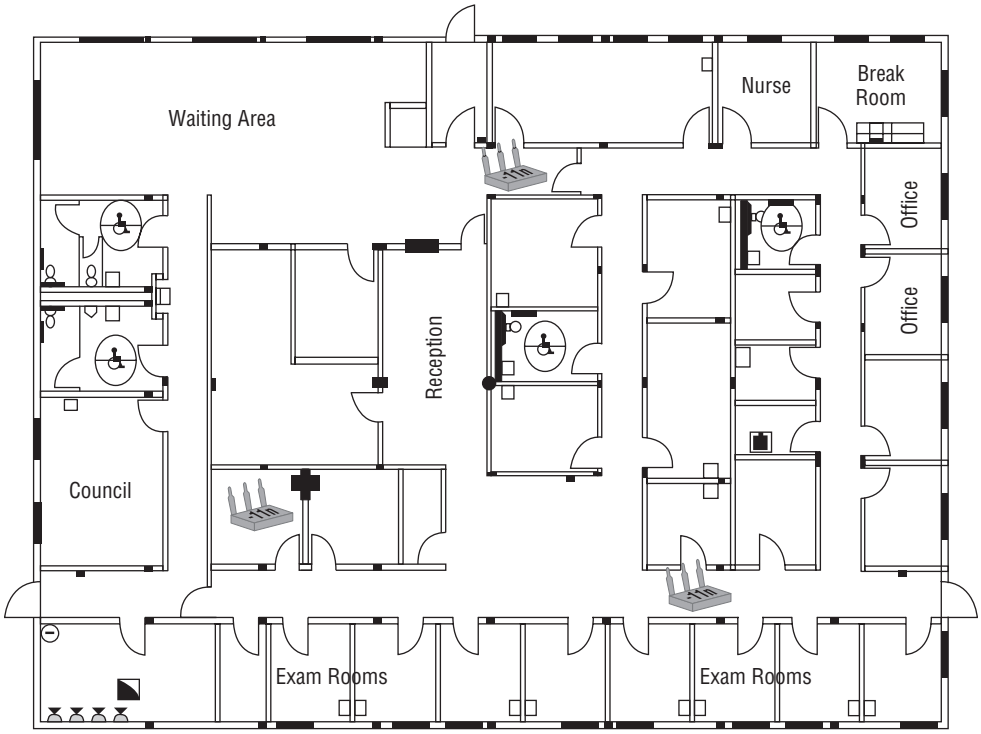
- Patient registration
- Patient charting
- Prescription automation
- Treatment verification
- Inventory tracking
- Electronic medical records
- Location services
- Electronic imaging
- Voice (VoWLAN)
- Patient monitoring devices

One of the obstacles to take into consideration for wireless networking is interference. Hospitals use many devices that operate in the unlicensed ISM RF band. This can create challenges for design and reliability of the wireless network. Licensed and unlicensed RF bands are discussed in the "Licensed RF Bands Used with IEEE 802.11" section in this chapter. Other potential issues for healthcare deployments to be aware of include the following:

- Building materials that can hinder RF propagation, such as lead-lined walls used in radiology areas to protect people from X-rays
- Identical floor layouts above and below, which leads to stacking access point issues
- Limited accessibility to areas such as surgery and patient care rooms
- Aesthetics of the installed equipment

Compliance with legislation such as the Health Insurance Portability and Accountability Act of 1996 (HIPAA) also needs to be taken into consideration when designing wireless installations for healthcare. Security concerns and different legislations will be discussed in Chapter 8. Figure 2.14 illustrates a common medical office that uses WLAN technology.

FIGURE 2.14 Medical offices often use WLAN technology

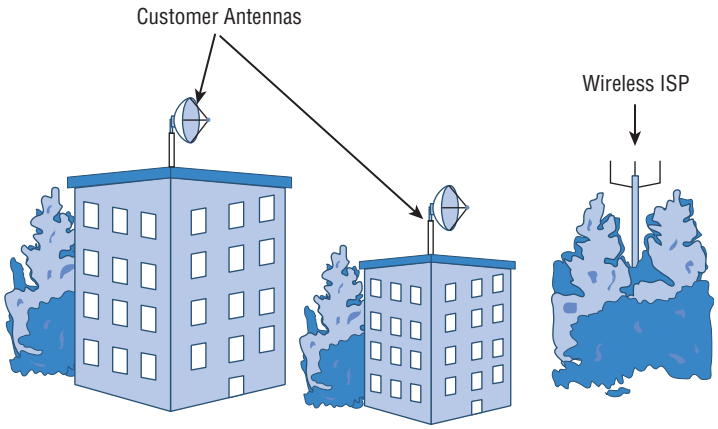


Last-Mile Data Delivery: Wireless ISP

Last-mile data delivery is a term commonly used in telecommunications to describe the connection from a provider to an endpoint such as a home or business. (Last-mile is not necessarily a mile in distance.) This can be a costly solution in many applications, since each endpoint needs a separate physical connection. Wireless technology provides a more cost-effective solution for last-mile data delivery.

Some communication technologies, such as DSL, have physical limitations that prohibit connections in some cases. It may not be cost-effective for telecommunication service providers to supply connections in rural or semi-rural areas. WLANs can service areas that may not be part of a last-mile run. Providing Internet access from a wireless ISP is one application. Things to consider for feasibility are line of sight, obstacles, and RF interference. Figure 2.15 shows an example of wireless last-mile data delivery.

FIGURE 2.15 Wireless last-mile data delivery



In December 2009, the 802.11 task group TGaf was formed to define the 802.11af amendment (not to be confused with IEEE 802.3af for Power over Ethernet). This amendment to the 802.11 standard addresses the use of "TV White Space" frequency bands for use with wireless networking technology. These lower frequencies propagate well over longer distances and may be ideal to provide Internet connectivity for rural or semi-rural areas as well as other types of wireless technology innovation.

High-Density Deployments Including Conference Centers

What does the term "high-density Wi-Fi deployment" really mean? People have differing opinions on this, as it can be subjective. Some industry experts claim that in the next few years the number of installed wireless devices will exceed the number of installed wired devices. When you think about it, this projection may be realistic. Take a moment and count the number of wireless devices that you have in your possession, at your home, the classroom, and the office. This includes notebook computers, smart phones, tablets, and broadband Internet devices. The average person may have between one and five separate wireless devices, many of which include IEEE 802.11 wireless technology. This gives an idea of how the density of WLAN devices in all environments—home, office, education, and industrial—will continue to increase in the coming years.

Some high-density deployments have been discussed in this chapter and include educational institutions and medical facilities such as hospital environments. Issues to consider in this type of environment are the frequency band to use, co-channel interference, cell sizing, and access point capacity.

A future amendment to the standard (IEEE 802.11ax) is intended for high density deployments and will allow for better performance and higher signaling rates to provide faster data transfers and higher throughput using 1024-QAM technology.

Municipal, Law Enforcement, and Transportation Networks

WLANs are valuable technology in the industrial, municipal, and law enforcement fields, and in transportation networks.

Federal and local law enforcement agencies frequently maintain state-of-the-art technology utilizing computer forensics and WLAN technology. Technologies that use 19.2 Kbps connectivity are obsolete because of their slower data transfer rates. Municipal deployments, which include police, fire, utilities, and city or town services, are often all connected to a common WLAN.

Transportation networks are no exception. WLAN installations are becoming more common in places like commuter buses, trains, airplanes, and automobiles. Users can connect for free or by paying a nominal fee. This type of connectivity now allows a user to better employ idle time. This is especially helpful to the mobile user or "road warrior" who needs to make the best use of available time.

Summary

This chapter discussed wireless networks, including the wireless personal area network (WPAN), the wireless local area network (WLAN), the wireless metropolitan area network (WMAN), and the wireless wide area network (WWAN), showing the many ways wireless networks can be implemented.

The IEEE is an organization that creates standards and amendments used for IEEE 802.11 WLAN technology. This chapter described the released communication standards, including:

- IEEE 802.11a
- IEEE 802.11b
- IEEE 802.11g
- IEEE 802.11n
- IEEE 802.11ac
- IEEE 802.11ad
- IEEE 802.11ah

Amendments that addressed QoS, security, fast transition, radio resource management, and management frame protection were also discussed. The IEEE creates standards based on RF regulations. We also looked at RF regulatory domain governing bodies and their role in regulation of the RF spectrum used for IEEE 802.11 wireless networking.

The Wi-Fi Alliance is an organization addressing interoperability testing for equipment manufactured to the IEEE standards. This testing results in a variety of certifications for

- Communication
- QoS
- Security

This chapter also discussed many applications in which WLANs are currently used, from SOHO to corporate deployments and last-mile connectivity. Standards-based wireless deployments continue to grow at a fast pace, adding new installations or replacing proprietary and legacy-based implementations.

Exam Essentials

Understand the function and roles of organizations that are responsible for the regulation and development of WLAN technology. The IEEE, FCC, ETSI, ITU-R, and Wi-Fi Alliance play important roles with wireless technology. Know the function and role of each organization.

Know the frequency ranges, data rates, spread spectrum, and PHY technologies for IEEE 802.11 communication standards. Understand the details of the 802.11, 802.11b, 802.11a, 802.11g, 802.11n, and 802.11ac standards and amendments. It is important to know the supported data rates and operating RF of each.

Know the purpose of IEEE specific-function amendments. Be familiar with the details of 802.11e and 802.11i function amendments. Know that 802.11e is for QoS and 802.11i addresses security.

Understand the differences among interoperability certifications by the Wi-Fi Alliance. Know the purpose of the WPA, WPA 2.0, WMM, WMM-PS, and Wi-Fi Alliance certifications. Understand which address security, QoS, and power-save features.

Understand details of common WLAN applications. These common WLAN applications can include SOHO, corporate data access, end-user mobility, and building-to-building connectivity.

Review Questions

1. Point-to-point links typically use which antenna types? (Choose two.)
   - **A.** Semidirectional
   - **B.** Omnidirectional
   - **C.** Highly directional
   - **D.** Long-range omnidirectional

2. Point-to-multipoint links consist of _____ or more connections.
   - **A.** Two
   - **B.** Three
   - **C.** Four
   - **D.** Five

3. IEEE 802.11ac devices use an enhanced radio technology known as multiple-input multiple-output (MIMO). Which statement correctly describes a benefit of MIMO?
   - **A.** MIMO uses reflections to allow for increased throughput.
   - **B.** MIMO rejects reflections to allow for increased throughput.
   - **C.** MIMO uses a single radio with diversity technology for increased throughput.
   - **D.** MIMO rejects data rates less than 54 Mbps for increased throughput.

4. What organization is responsible for unlicensed frequency band regulation in the United States?
   - **A.** ETSI
   - **B.** Wi-Fi Alliance
   - **C.** IEEE
   - **D.** FCC
   - **E.** WPA

5. IEEE 802.11g WLANs operate in what frequency range?
   - **A.** 900 MHz
   - **B.** 5.15-5.25 GHz
   - **C.** 5.25-5.35 GHz
   - **D.** 2.4-2.5 GHz

6. Which of the following organizations is responsible for validating WLAN standards interoperability testing?
   - **A.** FCC
   - **B.** ETSI
   - **C.** IEEE
   - **D.** WPA2
   - **E.** Wi-Fi Alliance

7. IEEE 802.11a uses which PHY technology?
   - **A.** ERP-OFDM
   - **B.** HR/DSSS
   - **C.** OFDM
   - **D.** FHSS

8. 802.11b is capable of which of the following data rates? (Choose three.)
   - **A.** 1 Mbps
   - **B.** 6 Mbps
   - **C.** 5.5 Mbps
   - **D.** 11 Mbps
   - **E.** 12 Mbps

9. 802.11g is backward-compatible with which of the following IEEE WLAN standards? (Choose two.)
   - **A.** 802.11 DSSS
   - **B.** 802.11a OFDM
   - **C.** 802.11a ERP-OFDM
   - **D.** 802.11b HR/DSSS
   - **E.** 802.3af

10. In the 802.11a amendment, the UNII-3 band is intended to be used for which of the following WLAN applications?
    - **A.** Indoor and outdoor.
    - **B.** Outdoor only.
    - **C.** Indoor only.
    - **D.** The UNII-3 band cannot be used for WLANs.

11. The 802.11i amendment to the standard addresses which of the following technologies?
    - **A.** QoS
    - **B.** DSSS
    - **C.** Security
    - **D.** MIMO

12. Which of the following best describes the Wi-Fi Alliance?
    - **A.** U.S.-based standards organization
    - **B.** Interoperability testing organization
    - **C.** Works with the FCC to verify compliance
    - **D.** Local regulatory body for Europe

13. Which of the following is addressed by the Wi-Fi Multimedia (WMM) certification?
    - **A.** Security/encryption
    - **B.** Fast transition
    - **C.** Management frame protection
    - **D.** QoS

14. Wi-Fi Protected Setup was designed for which of the following wireless applications?
    - **A.** SOHO organizations
    - **B.** Enterprise organizations
    - **C.** FCC interoperability
    - **D.** Security organizations

15. The 802.11g amendment to the standard uses which two Physical layer technologies? (Choose two.)
    - **A.** FHSS
    - **B.** OFDM
    - **C.** ERP-OFDM
    - **D.** DSSS
    - **E.** MIMO

16. WPA was developed as an interim solution for which amendment to the 802.11 standard?
    - **A.** 802.11a
    - **B.** 802.11n
    - **C.** 802.11e
    - **D.** 802.11i
    - **E.** 802.11g

17. Which of the following is correct regarding 802.11e?
    - **A.** Operates only in the 5 GHz frequency range
    - **B.** Operates only at 1, 2, 5.5, and 11Mbps
    - **C.** Addresses wireless security
    - **D.** Addresses wireless QoS

18. According to the 802.11a amendment, which of the following data rates are mandatory?
    - **A.** 1, 2, 5.5, and 11 Mbps
    - **B.** 6, 24, and 54 Mbps
    - **C.** 6, 9, 12, 18, 24, 36, 48, and 54 Mbps
    - **D.** 6, 12, and 24 Mbps
    - **E.** 1, 6, 12, and 24 Mbps

19. You support a wireless network for an office of five employees. The installation consists of one access point, three notebook computers, and two desktop computers. The access point and computers in the office have wireless adapters that are Wi-Fi WPA 2.0 certified. You want to use the highest level of security possible without additional cost or administration. Which of the following solutions would be best for this deployment? (Choose two.)

A. WEP

B. WPA 2.0 personal

C. WPS

D. WMM

E. WPA 2.0 enterprise

20. Which two of the following options are available for Wi-Fi Protected Access 2 (WPA 2.0)?

A. Personal mode

B. Protection mode

C. Professional mode

D. Enterprise mode

E. WPA 2 mode

Chapter

3

Infrastructure and Client Devices Used with Wireless Networking

THE FOLLOWING CWTS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **2.1 Identify the purpose, features, and functions of wireless network components. Choose the appropriate installation or configuration steps in a given scenario.**
- ✓ **2.2 Choose the appropriate installation or configuration steps in a given scenario.**

THE FOLLOWING CWS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **3.1 Identify AP features and capabilities**
- ✓ **3.2 Describe AP management systems**
- ✓ **3.3 Determine capabilities of client devices**
- ✓ **3.4 Identify when Power over Ethernet (PoE) should be used**
- ✓ **4.4 Discover client devices and applications in use**
- ✓ **4.5 Determine the need for outdoor coverage networks and bridge links**

THE FOLLOWING CWT EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **2.1 Describe client types and varying capabilities**
- ✓ **2.5 Configure client devices**
- ✓ **3.1 Identify AP features and capabilities and understand configuration options related to them**
- ✓ **3.3 Ensure proper PoE provisioning when required**
- ✓ **3.4 Configure APs as standalone devices**
- ✓ **3.6 Validate proper AP WLAN configuration**

Choosing the correct network infrastructure devices to be installed as part of a computer network (both wired and wireless) is a critical element of a successful wireless LAN (WLAN) deployment. In this chapter, we will look at a variety of infrastructure devices, including wireless access points, wireless bridges, wireless repeaters/range extenders, WLAN controllers, and cloud-managed wireless systems. Cloud-managed WLAN deployments are growing at a fast pace in all markets. Whereas some manufacturers specialize in only cloud-managed solutions, most manufacturers of enterprise wireless equipment utilize cloud-managed access points to some extent. You will learn about the features and benefits of these and other wireless network infrastructure devices. Power over Ethernet (PoE) is an extension to the IEEE 802.3 Ethernet standard that allows direct current (DC) voltage to be supplied over Ethernet cable to wireless access points, VoIP telephones, Ethernet security cameras, and other PoE-capable devices. PoE consists of two ratified amendments and is heavily used in enterprise WLAN deployments. This chapter will discuss the concepts involved in PoE, including both of its amendments to the IEEE 802.3 standard.

Client devices were often thought of as computers—either desktop or notebook—connected to a computer network. Now many other devices, both wired and wireless, however, can connect to a network. WLAN client devices include various types of computers, tablets, smartphones, scanners, print servers, cameras, and other devices that are used to send data across the network. This chapter will look at the features of various WLAN client adapter types and the software for configuration and management of these devices.

Devices that connect to wireless networks use various types of adapters. Which adapter is used depends on the device that it connects to. You can connect wireless adapters to such devices as a notebook computer, tablet, desktop computer, or barcode scanner. WLAN adapters are available in various types, both external and internal to the device. External adapters will connect to an available interface in the device, such as a USB port. Some devices use internal adapters that may require some level of disassembly or removal of a cover panel prior to the installation. Examples of internal adapter types are PCI, Mini-PCI, Full Mini-PCIe, and Half Mini-PCIe.

WLAN client adapters differ from other networking adapters (such as Ethernet adapters) because they contain radio hardware and use radio frequency (RF) to send the computer data over the air. Chapter 4, “Radio Frequency Fundamentals for Wireless Networking,” will discuss RF fundamentals in more detail. A WLAN design should be partly based on the needs of the client applications, client device types to be supported, and the environment where they will be used.

The Wireless Access Point

The *wireless access point* is an integral component of a WLAN infrastructure. Wireless access points allow a variety of wireless client devices access to any network resources that the device or user may have permissions for. The access point provides computers, VoWLAN phones, smartphones, tablets, and other wireless client devices access to a WLAN, using radio frequency (RF) as the communication mechanism and free space (air) as the communication medium.

Wireless access points are available in three common types: autonomous, controller-managed, and cloud-managed (or "controller-less"). Autonomous access points are self-contained units and can function as independent network infrastructure devices. Controller-managed access points, by contrast, function in conjunction with a hardware WLAN controller. Cloud-managed access points provide a wireless network infrastructure without the use of a hardware controller and are software-managed devices.

One manufacturer of cloud-managed solutions (Aerohive Networks) pioneered a technology known as *cooperative control architecture*, which is used with their cloud-managed infrastructure devices.

When a wireless device is connected to an access point, it is known to be in *infrastructure mode*. In this operation mode, all wireless data traffic is passed through the access point to the intended destination, whether that is a file server, a printer, the Internet, another wireless client device, or anything else capable of receiving network data.

An access point can operate as a stand-alone network device, configured independently to allow wireless devices to connect. It can also operate as part of a larger wireless network by sharing some of the same parameters, such as the service set identifier (SSID). The SSID is the logical name, or identifier, of the WLAN; all wireless client devices connected to an access point will share the same SSID setting. Figure 3.1 shows an example of an access point connected to an Ethernet network with several wireless network client devices.

In addition to providing access through a shared medium, wireless access points are *half-duplex* devices. Half-duplex is defined as two-way communication that occurs in only one direction at a time. (By contrast, *full-duplex*, the other communication method used in computer networking, allows two-way communication to occur between devices simultaneously.) Communication only one way at a time means less data throughput for the connected device. An access point is a network infrastructure device that can connect to a distribution system (DS)—typically an Ethernet segment or Ethernet cable—and allow wireless devices to access network resources with the appropriate access permissions. According to the IEEE 802.11 standard, all wireless devices, including access points, are considered stations (abbreviated *STA*). However, per the standard, an access point is identified as AP/STA (access point station). In a completely Ethernet-switched network, devices will communicate directly with the Ethernet switch. Figure 3.2 illustrates half-duplex communication using a wireless access point.

FIGURE 3.1 Access point connected to an Ethernet network

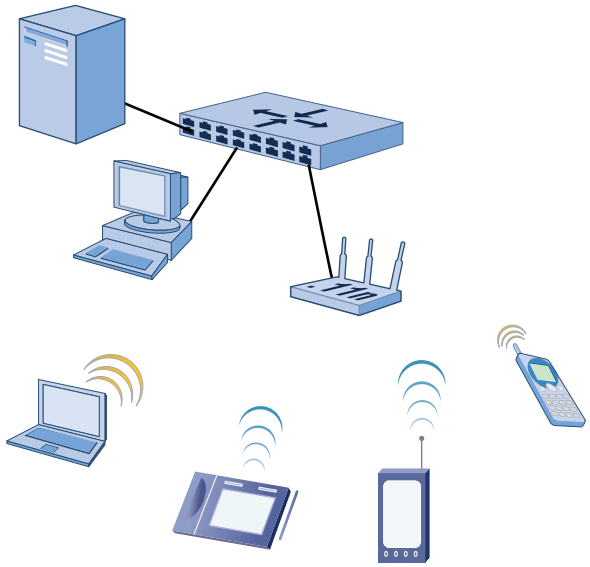
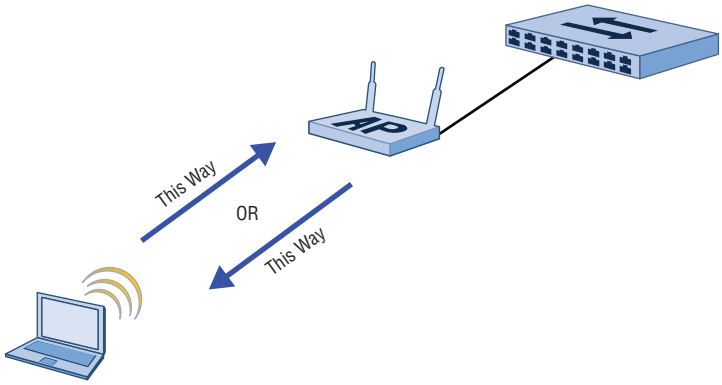


FIGURE 3.2 Half-duplex communication one direction at a time



This book uses the terms *autonomous access point*, *controller-managed access point*, and *cloud-managed access point* to describe the devices. In the industry, they are also known as *intelligent access point*, *split MAC architecture*, *remote MAC*, and *thin access point*. Manufacturers may also use various other terms to identify them.

Autonomous Access Points

Autonomous access points are self-contained units with all the intelligence necessary to provide devices with wireless access to a wired network infrastructure, and access to the resources the devices have permission to use. There are three popular types of autonomous access points: consumer-grade; small office, home office-grade (SOHO-grade); and enterprise-grade. Not surprisingly, the enterprise type generally offers the most robust feature set. The autonomous access point is best suited for small networks with only a few access points or wireless hotspots, because they must be managed independently, and therefore the scalability is somewhat limited.

The industry terminology for access points is not clearly defined. What might be considered a consumer-grade or SOHO-grade access point from one vendor might be considered the opposite from another vendor. In fact, some access points might even be considered both consumer-grade and SOHO-grade access points.

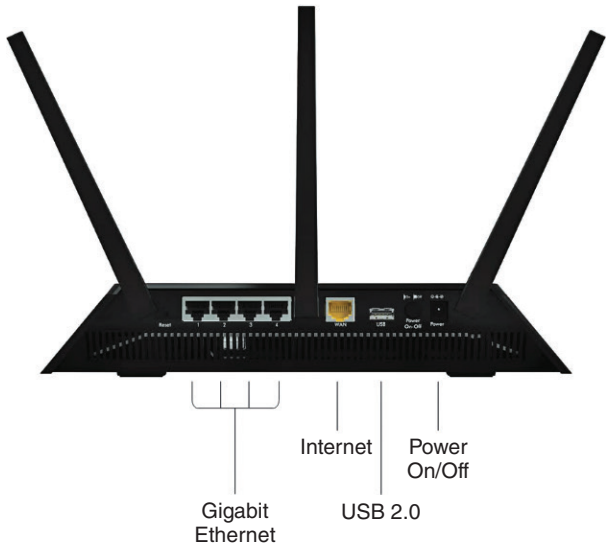
The Consumer-Grade Access Point

Consumer-grade access points, or home broadband wireless routers, are usually equipped with an Internet port, several ports for Ethernet connections, and a wireless access point. The routers are configured through a web browser using either the HTTP or HTTPS protocol. Configuration of the devices is fairly simple for the novice user using a web browser via a built-in web server. In most cases, a broadband wireless router connects to either a cable modem or a digital subscriber line (DSL) connection, available from an Internet service provider (ISP). In this configuration, a router is able to accept wired and wireless connections for computers and other devices, providing them with access to the LAN or the Internet. A wireless broadband router usually includes the following features:

- Network Address Translation (NAT)
- Dynamic Host Configuration Protocol (DHCP) server
- Internet Protocol (IP) routing
- Domain Name System (DNS) services
- Built-in firewall

A wireless broadband router has many of the same features a SOHO-grade access point has. Although consumer-grade access points contain a number of features, they do not have the same hardware capabilities that the more expensive enterprise-grade access points contain, such as processing power and random access memory (RAM). Therefore, they usually support a lesser number of associated client stations. An example of an IEEE 802.11ac dual-band Gigabit wireless broadband router is shown in Figure 3.3.

FIGURE 3.3 NETGEAR Model R7000 AC1900-Nighthawk Smart Wi-Fi dual-band IEEE 802.11ac Gigabit router



Notice in Figure 3.3 that this device contains a Gigabit Ethernet switch, an Internet WAN port, a USB 2.0 port, and a wireless access point all in one self-contained unit. This is a very common configuration with the wireless broadband router.

The SOHO-Grade Access Point

Although they are powerful devices, *SOHO-grade access points* usually have a less extensive feature set than enterprise-grade access points. However, all newer-model consumer-grade, SOHO-grade, and enterprise-grade access points now support the highest standards-based security options available, including IEEE 802.11i or Wi-Fi Protected Access 2.0 (WPA 2.0) certifications. SOHO-grade access points are best used in the SOHO or home environment and usually have a limited number of connections for computers and devices. SOHO-grade access points typically have the following features:

- IEEE 802.11 standards support
- Wi-Fi Alliance interoperability certifications
- Removable antennas
- Static output transmit power
- Advanced security options
- Wireless bridge functionality
- Wireless repeater functionality
- Dynamic Host Configuration Protocol (DHCP) server
- Configuration and settings options

Figure 3.4 shows an example of a SOHO-grade access point. You will notice that one difference between a SOHO-grade access point and a consumer-grade wireless broadband router is the available connection ports. Whereas the broadband router is usually equipped with an Internet port and several ports for Ethernet connections, the SOHO-grade access point typically has only one Ethernet port to connect to a LAN.

FIGURE 3.4 D-Link DAP-2590 AirPremier N dual-band PoE SOHO-grade access point, front and end views

In Figure 3.4, notice that unlike the consumer-grade access point, this device has only a single PoE-capable Ethernet connection and no Internet WAN connection or USB port.

IEEE 802.11 Standards Support

All later-model SOHO-grade access points support the current IEEE 802.11 standard. Some older devices may not have firmware updates available, which can cause implementation challenges where interoperability between newer and legacy devices is required. In this case, I recommend replacing older equipment with the most current, state-of-the art models. The 802.11 standard and amendments that are supported will vary based on several factors, including the cost and complexity of the unit. The most common consumer-grade and SOHO-grade access points support the IEEE 802.11b, IEEE 802.11g, IEEE 802.11n, and now IEEE 802.11ac communication amendments. Most equipment manufacturers make dual-band models, but the cost is normally higher than single-band (IEEE 802.11b/g/n) access points. See Chapter 2, "Wireless Local Area Networking, Standards, and Certifications," if you need to review these 802.11 amendments to the standard.

Wi-Fi Alliance Interoperability Certifications

Interoperability certifications from the Wi-Fi Alliance are a common feature of SOHO-grade access points. As mentioned in Chapter 2, these certifications include WPA/WPA 2.0 and WPS for security, and WMM and WMM-PS for QoS (Quality of Service). Selecting a SOHO-grade access point that is Wi-Fi certified ensures compliance with IEEE standards and interoperability with other IEEE 802.11 wireless devices.

In December 2011, a security flaw was reported with WPS and should be considered before using this feature. See the warning in the section "Wi-Fi Protected Setup Certification Overview" in Chapter 2 and check the device manufacturer's website for more information.

Removable Antennas

Some SOHO-grade access points are equipped with removable antennas. This allows the end user to change to a larger (higher-gain) antenna, thereby allowing an RF to cover a wider area. Conversely, connecting a smaller (lower-gain) antenna will decrease the coverage area. Many SOHO-grade access points have fixed or non-removable antennas, so you cannot add a higher-gain antenna.

The RF coverage area of an access point can be increased by adding a higher-gain antenna to the access point. For more information on this and other antenna-related information, see Chapter 5, "Antenna Technology for Wireless Networking."

Static Output Transmit Power

Occasionally an end user will have the ability to adjust the transmit output power in a SOHO-grade access point. If this is available, the settings are usually very basic, such as low, medium, and high. With enterprise access points, you can change the power in increments of a milliwatt (mW) or a decibel milliwatt (dBm). The transmit output power of the access point will determine in part the area of RF coverage, also known as the *RF cell* or *basic service area* (BSA). A cell is the area of RF coverage of the transmitter—in most cases, a wireless access point. The typical RF transmit power of a SOHO-grade access point is about 15 dBm, or 32 mW, although this will vary with the manufacturer. An access point model with static output power settings cannot be adjusted, which will limit your ability to decrease or increase the size of the RF cell. Changing the RF cell size will allow the access point to cover a larger area in the home or small office where the device is installed. In this case, the only way to change the RF cell size is to change the gain of the antenna in models that have the removable antenna feature. Note that replacing the antenna will also change the vertical and horizontal beamwidths, which is the electromagnetic radiation pattern that propagates away from it.

Advanced Security Options

All newer-model SOHO-grade access points support the highest security features, including the IEEE 802.11i amendment and WPA 2.0 personal and enterprise operation modes. These security features give users with limited technical knowledge the ability to provide the most up-to-date security for their wireless network. For those users who have greater technical know-how, SOHO-grade access points also provide more advanced security features, such as user-based authentication IEEE 802.1X/EAP and VPN pass-through. Users can find more information about these advanced features in most user guides provided with the access point or online at the device manufacturers' websites.

Wireless Bridge Functionality

SOHO-grade access points can sometimes be configured in wireless bridge mode. Both point-to-point and point-to-multipoint settings are available. This enables administrators to connect two or more wired LANs together wirelessly using IEEE 802.11 equipment. You learned about point-to-point and point-to-multipoint settings in Chapter 1, "Computer Networking Fundamentals." Wireless bridging is discussed later in this chapter.

Wireless Repeater Functionality

Some SOHO-grade access points can be configured to function as wireless repeaters. Configuring an access point as a repeater enables administrators to extend the size of the RF cell so that devices not in hearing range of an access point can connect to the wireless network. The cost, however, is reduced throughput for other devices accessing the network through a wireless repeater, in addition to more contention. Wireless repeaters are discussed later in this chapter.

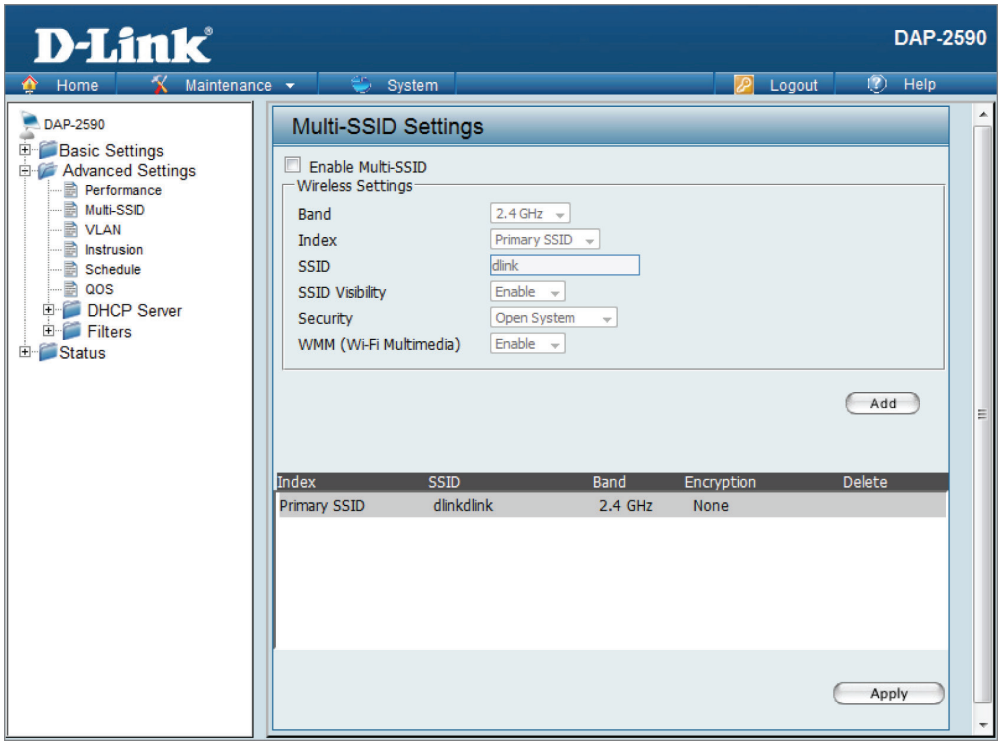
Dynamic Host Configuration Protocol Server

It is also common for SOHO-grade access points to be able to act as DHCP servers. A DHCP server will automatically issue an IP address (logical address) to allow upper-layer communication between devices on the network. IP addresses are a function of Layer 3 of the OSI model, as outlined in Chapter 1. A built-in DHCP server will ease the installation and support of the access point, providing a much better overall user experience.

Configuration and Settings Options

SOHO-grade access points are configured via a web browser, using either HTTP (Hypertext Transfer Protocol) or HTTPS (Hypertext Transfer Protocol Secure). This type of browser-based configuration is an easy way for the novice administrator to make all the necessary settings based on the application in which the access point will be used. SOHO-grade access points rarely offer configuration from the command-line interface (CLI), which allows for more extensive configuration parameters. Figure 3.5 shows an example of a configuration page from a SOHO-grade access point.

FIGURE 3.5 D-Link DAP-2590 AirPremier N dual-band PoE SOHO-grade access point configuration screen



For security reasons, it is best practice to configure access points from the wired side of the network infrastructure whenever possible. Configuration of an access point should only be done wirelessly if absolutely necessary. If configuring this device from the wireless side of the network is the only option, a secure connection such as HTTPS or SSH2 should be in place to prevent potential compromise of administration user credentials and unauthorized access of the wireless device.

Some manufacturers of consumer-grade and SOHO-grade wireless equipment have online emulators that allow customers to view a sample of the configuration process for a device. This allows users to sample the configuration settings and become familiar with the device before making a purchase.

The Enterprise-Grade Access Point

Enterprise-grade access points typically have a much more extensive feature set than the previously mentioned SOHO-grade access points. Taking this into consideration, the price

point can be significantly higher for enterprise-grade access points. Figure 3.6 shows an example of an enterprise-grade access point.

FIGURE 3.6 The Aruba Networks 220 series IEEE 802.11ac dual-band access point

Enterprise-grade access points can include the following features:

- IEEE 802.11 standards support
- Wi-Fi Alliance interoperability certifications
- Removable or expandable antennas
- Adjustable output transmit power
- Advanced security options
- Multiple operation modes, including root access point, wireless bridge, wireless repeater, and mesh capabilities
- Graphical user interface (GUI) and command-line interface configurations

In addition to the items listed here, enterprise-grade access points have various other features that put them a notch above consumer-grade and SOHO-grade access points. Some of these features are outdoor use, plenum ratings, industrial environment ratings, more memory, and faster processors to help handle the load and various environmental conditions.

IEEE 802.11 Standards Support

Like the other access point types discussed in this chapter, enterprise-grade access points support IEEE standards. Enterprise-grade access points have a more extensive feature set than SOHO-grade access points and, depending on the manufacturer and model, will support all communication standards by using the 5 GHz IEEE 802.11a/n/ac and the 2.4 GHz IEEE 802.11b/g/n dual-band radios. Enterprise-grade access points can include support for some amendments to the standard not supported by SOHO-grade access points. Examples include support for IEEE 802.11e QoS, Wi-Fi multimedia certifications, IEEE 802.11r fast BSS transition (FT), and IEEE 802.11w for the security of management frames, to name a few.

Wi-Fi Alliance Interoperability Certifications

Certifications by the Wi-Fi Alliance are an important feature of enterprise-grade access points. These certifications include WPA/WPA 2.0 for security and WMM and WMM-PS for QoS. Selecting an enterprise-grade access point that is Wi-Fi certified ensures compliance with IEEE standards and interoperability with other IEEE 802.11-compliant devices.

Removable or Expandable Antennas

Many enterprise-grade access points have removable or expandable antenna capabilities. These antenna configurations provide a lot of flexibility, because an installer can choose the appropriate antenna based on the deployment scenario. Omnidirectional, semi-directional, and highly directional antennas are all types of antennas commonly used in the enterprise environment. Enterprise-grade access points that use internal antennas can offer options for connecting external antennas, should they be required for the specific installation. Antennas will be discussed in more detail in Chapter 5.

Adjustable Output Transmit Power

Unlike consumer-grade and some SOHO-grade access points, the RF output power of the radio can be adjusted with enterprise-grade access points. This feature allows an installer to select the correct amount of transmit power based on the installation needs of the access point. One benefit of having adjustable output power is that an installer can adapt to the environment in which the access point is installed. If the RF dynamics of an area change, the ability to change access point settings such as output transmit power without physical intervention is beneficial.

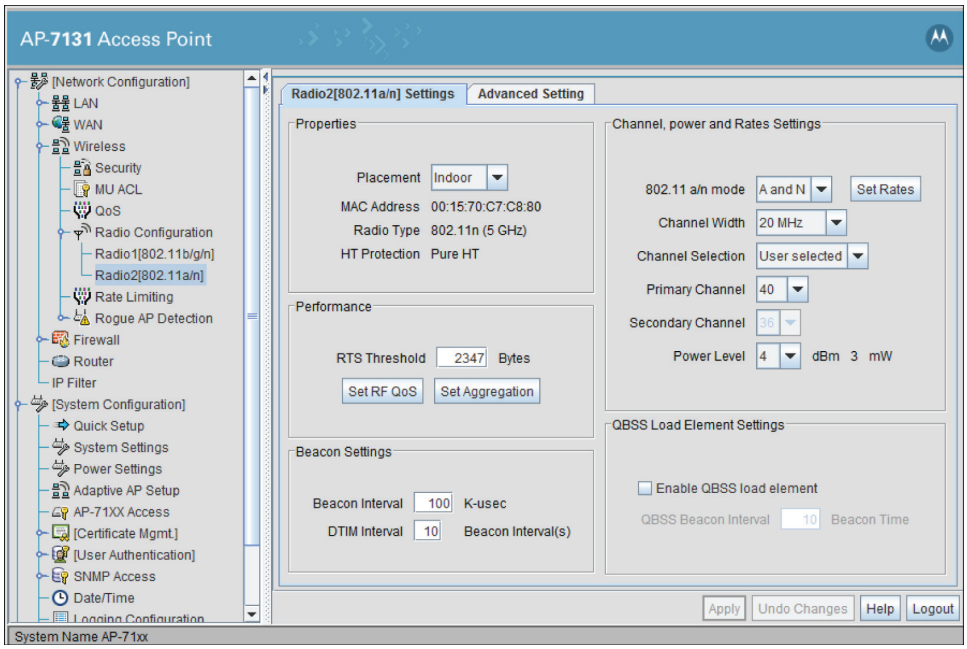
Advanced Security Options

Compared to access points used in the consumer and SOHO environments, enterprise-grade access points typically have more advanced security features. In addition to IEEE 802.11i, WPA/WPA 2.0, passphrase and user-based authentication, and IEEE 802.1X/EAP modes, features such as a built-in user database for local *Remote Authentication Dial-In User Service* (RADIUS) authentication are included. Local RADIUS authentication allows small- to medium-sized businesses to provide their own advanced authentication features without the need of external RADIUS authentication services. This reduces costs and lowers administration overhead.

RADIUS is just one example of the more advanced security features available in enterprise-grade access points. Another advanced security feature that may be available is some level of a wireless intrusion prevention system (WIPS). A WIPS will help determine and have the potential to mitigate certain levels of wireless intrusions or attacks on the network. One example is the detection of a rogue (unknown) access point.

Advanced security features are discussed in more detail in Chapter 8, “Security Fundamentals for Wireless Networking.” Some of the common configuration options available for one model of enterprise access point are shown in Figure 3.7.

FIGURE 3.7 Extreme Networks AP-7131 enterprise-grade access point configuration page in a web browser



Multiple Operation Modes

In addition to the features just discussed, enterprise-grade access points typically have several operation modes:

Root Access Point Mode (the most common configuration) What some in the industry refer to as *root access point mode* is typically the default operation mode in which an enterprise-grade access point operates. Root access point mode involves connecting the access point to a distribution system (DS), such as an Ethernet segment or a network infrastructure of some sort. This mode allows computers and other wireless devices to connect to the access point and use network resources based on the assigned permissions of the user, computer, or other wireless device.

Wireless Bridge Mode (for connecting LANs together) This configuration allows an access point to be set in *bridge mode* for wireless point-to-point or point-to-multipoint configurations connecting two or more LANs. Benefits of using wireless access points to bridge LANs together include cost savings and high data transfer rates compared to some other wired connectivity options.

Wireless Repeater Mode (to extend the RF cell) An access point configured in wireless *repeater mode* can act to extend the RF cell. This allows wireless client devices outside the

radio hearing range of an access point to still be able to connect to the network and access network resources via the wireless repeater. This operation mode does have the downside of reduced throughput and should be used only if justified because of no wired connectivity that allows the access point/repeater to connect to the network.

Mesh Mode (for connecting access points together wirelessly) If an access point has mesh capability, it can be configured to connect access points together without using a wired infrastructure. This is useful in areas where the physical distance from the network segment to the access points exceeds the 328-foot or 100-meter limitation. This is what was formerly known as a *wireless distribution system* (WDS). The term WDS is now considered obsolete and has been removed from the latest revision of the IEEE 802.11 standard.

If an enterprise-grade access point is configured for an operation mode other than an access point, it is no longer considered an access point. Typically an access point can be configured to operate in only one mode at any one time. Also, if an enterprise-grade access point is dual-band capable, it may be possible to configure each band (radio) as a different operation mode.

Access Point Configuration Methods

Enterprise-grade access points can commonly be configured, or "staged," two different ways:

Graphical User Interface (GUI) Configuration Enterprise-grade access points can be configured using a GUI configuration from a web browser using HTTP or HTTPS. This is a convenient way to configure and change settings on the access point using a common graphical interface tool, a web browser. If the access point is configured using a wireless connection, using HTTPS is recommended for security at a minimum, but an SSH or IPsec VPN connection is highly recommended.

Command-Line Interface (CLI) Configuration Most if not all enterprise-grade access points have *command-line interface (CLI)* capabilities to allow extensive and detailed configuration of the device. In some cases, the CLI command set provides higher-level commands that allow an administrator to perform additional configuration tasks that aren't available using the web browser method. This allows consistency in configuring other network infrastructure devices, because many manufacturers share common commands among devices. CLI capabilities vary depending on the manufacturer, but most enterprise models have an extensive set of commands. Access points with CLI capabilities may have a special console port on the device, allowing a direct serial connection to a computer to access for configuration purposes.

Controller-Managed Access Points

Controller-managed access points differ from autonomous access points in that they are used with hardware WLAN controllers, not as stand-alone devices. An autonomous access

point is a self-contained unit that has all the intelligence needed to provide computer and device access to a wireless network. In contrast, controller-managed access points have shifted some of the intelligence to the hardware WLAN controller. Since a controller-managed access point may contain less intelligence than an autonomous access point, the cost of a controller-managed access point may be lower, depending on the local MAC capabilities.

Controller-managed access points are centrally managed from the hardware WLAN controller. The extent of how this is accomplished depends on the type of architecture that is in use: local MAC, split-MAC, or remote-MAC. Split-MAC is the most commonly used architecture, with the controller handling the management and control planes and the access point taking care of the real-time MAC functionality and the Physical layer communications. How manufacturers implement the technology varies. Typically, communication between the access point and the controller is handled by an IP or proprietary tunnel that is built from the access point to the controller. Depending on the manufacturer, they may have a more extensive feature set than autonomous access points, while also including many of the features of those devices. Figure 3.8 shows front and rear views of a controller-managed access point.

FIGURE 3.8 Cisco Aironet 3500e CleanAir IEEE 802.11n access point

The benefits of controller-managed access points are similar to those of autonomous access points, including RF management, security, and QoS. With remote MAC controller-managed access points, very little or no intelligence is contained within the devices. Controller-managed access points are PoE capable for ease of deployment in either mid-sized or large organizations. One thing to keep in mind is that if a controller-managed access point is unable to communicate with the WLAN controller for some reason, the access point may be able to still provide communications to the associated client devices. How this is achieved widely varies, based on how the manufacturer implements the technology.

Cloud-Managed Access Points

Cloud-managed access point technology provides another solution for deploying WLAN infrastructures. The architecture for networks that use this type of access point is sometimes referred to as a "controller-less" architecture, because the device intelligence has been pushed back out to or distributed to the access point edge, similar to that of the autonomous access point, but with much more intelligence and capabilities. The access points are managed through a "cloud" software configuration tool, eliminating the need for a hardware controller. This type of management tool can be accessed from any computer with an Internet connection, assuming the user has appropriate permissions to manage the devices. Some manufacturers also have "software appliances," eliminating the reliance on the cloud server because the software is contained locally with the organization's datacenter network. Figure 3.9 shows an example of a cloud-managed access point.

FIGURE 3.9 ADTRAN/Bluesocket 2030 IEEE 802.11ac (3x3:3) indoor access point

Cloud-managed access points provide many of the same benefits and features of a WLAN controller solution without the need and extra expense of a hardware controller. This technology is

scalable and performs well without relying on a "tunnel" from the access point to a controller through which some or all of the network traffic can be forwarded. This distributed intelligence allows the cloud-managed access point to make decisions about how frames traverse both the wired and wireless network without relying on the hardware controller.

Some manufacturers of controller-managed solutions provide a variant of the cloud technology by allowing autonomous access points to be "adopted" by a controller in a large enterprise environment. These access points are then site survivable, meaning they will still be able to function on their own should connectivity with the controller be temporarily lost. The description of this technology includes the term *adaptive access point*.

Wireless Branch Router/Remote Access Point

A *wireless branch router*, or *remote access point*, can be used to extend a corporate network to a remote location, such as a home, conference room, or branch office, through a secure connection using a WAN or the Internet. This type of device typically has three interfaces available:

- Ethernet port(s) to connect to a LAN
- Internet port to connect to the WAN or to an Internet connection
- Wireless port to allow IEEE 802.11 computers and devices to connect to a network through a wireless connection

Wireless branch routers are usually compact and lightweight, making them easy for sales representatives and other corporate employees to travel with. They also have a more extensive feature set than wireless broadband routers, including the capability of building a Layer 3 VPN tunnel between devices in which the router on each side will act as a VPN endpoint. They can also be configured as a VPN pass-through device, allowing another device on the network, such as a VPN concentrator, to act as the VPN endpoint. They also include these features:

- Point-to-Point Tunneling Protocol (PPTP)
- Layer 2 Tunneling Protocol/Internet Protocol Security (L2TP/IPsec)
- SSH2
- Advanced IP networking services
- Edge router capability

Figure 3.10 shows an example of a wireless branch router.

FIGURE 3.10 Aerohive BR200 wireless branch router

Wireless Mesh

Wireless mesh networking continues to grow at a steady pace. The concept of mesh networking has been in existence for many years. In a full mesh network, all nodes connect together with at least two paths for every node. This allows for reliable communication in the event of a device or path failure.

Wireless mesh networking is popular in the outdoor market space. Most outdoor mesh infrastructure devices provide the highest levels of wireless security and are usually inside a rugged weatherproof enclosure for protection from the elements. Wireless mesh networks are currently utilized in places such as metropolitan areas, university campuses, and amphitheaters, as well as for applications used with public safety, transportation, and government organizations.

Currently, many WLAN manufacturers use proprietary mechanisms and protocols for wireless mesh networking. IEEE 802.11s is an amendment to the IEEE 802.11 standard to include wireless mesh networking and was ratified in 2011. Many enterprise-grade access points have the ability to operate in mesh mode, whereas others have a dedicated mesh function.

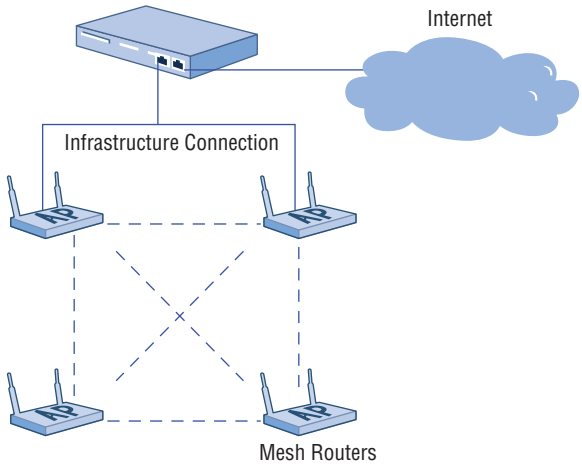
Wireless mesh networking for indoor deployments is starting to appear as a viable solution for some WLAN infrastructure deployments.

Manufacturers commonly recommend using two unlicensed RF bands for a wireless mesh operation. One common solution is to use the 2.4 GHz ISM band for wireless client device access and the 5 GHz UNII band for mesh device infrastructure connectivity. The use of a third radio may be an option in some cases. Using two different RF bands reduces contention on a single band and increases the overall performance of the network.

Mesh can also be used in the event of Ethernet loss to an access point. Some cloud-managed access points are able to automatically mesh together when they suffer an Ethernet loss. By default, they typically support clients in both bands, but they can mesh in 5 GHz if an Ethernet connection fails.

Figure 3.11 illustrates mesh access points connected to a wired infrastructure.

FIGURE 3.11 Mesh access points/routers connected to a common infrastructure and to the Internet



Some manufacturers may provide as many as four radios in a mesh access point. The fourth radio could utilize the 4.94–4.99 GHz licensed band, which is restricted to public safety use only (in the United States).

Wireless Bridges

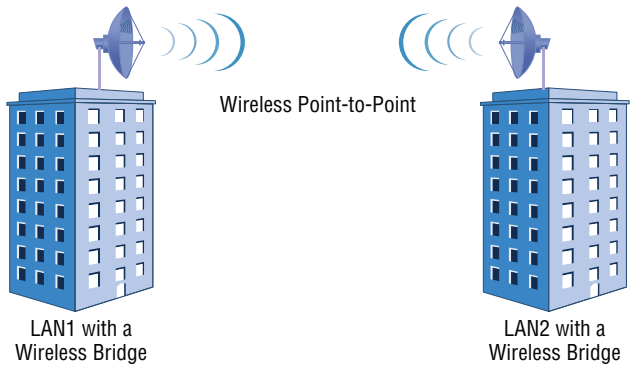
Wireless bridges connect two or more wired LANs. As discussed in Chapter 1, typically there are two configurations for wireless bridges: point-to-point and point-to-multipoint. A wireless bridge is a dedicated device that functions in much the same way as an access point in bridge mode. Wireless bridges have many of the same features as enterprise-grade access points, including removable antennas and selectable power levels.

Connecting locations together using wireless bridging has many benefits, including fast installation, cost savings, and high data transfer rates. Depending on the circumstances, a wireless bridge can be installed in as little as one day or even several hours. Cost savings can be enormous compared to installing and maintaining a physical wired connection between locations, whether it is copper, fiber optics, or a leased line from a service provider.

Most wireless bridges can work in either the 2.4 GHz ISM or 5 GHz UNII unlicensed band. Keep in mind, however, that bridges using wireless technology can also consist of proprietary technology using licensed frequency bands, which may be capable of greater distances and faster speeds than wireless bridges that use IEEE 802.11 devices. The connection can span long distances, so it is important to take security and environmental conditions into consideration, as well as the proper antenna selection.

Figure 3.12 illustrates wireless bridges connecting two LANs in two separate buildings.

FIGURE 3.12 Wireless bridges connecting two LANs



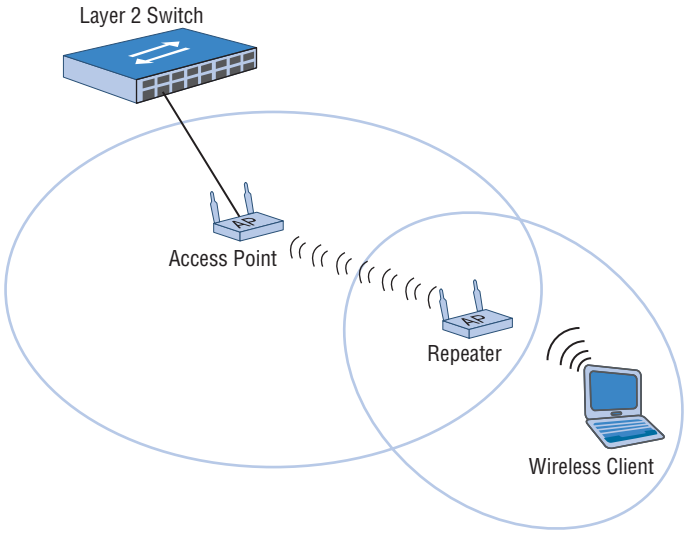
When LANs are connected using wireless bridges, the bridges must be set to the same RF channel and have the same SSID.

Wireless Repeaters/Range Extenders

Wireless repeaters are used to extend the RF cell. In a wired Ethernet network, repeaters function at Layer 1 of the OSI model to extend the Ethernet segment. An Ethernet repeater lacks intelligence—that is, it cannot determine data traffic types and simply passes all data traffic across the device. Since wireless infrastructure devices, including repeaters, are Layer 2 devices, they have more intelligence than Ethernet repeaters.

An Ethernet segment has a maximum distance for successful data transmission, and WLANs do as well. This distance depends on several factors, including the transmit power of the access point and the gain of the antenna. Like an access point, the wireless client device is also a transmitter and a receiver and will have an RF range limited by the transmit power and gain of the antenna. A wireless repeater provides the capability for computers and other devices to connect to a WLAN even when outside the normal hearing range of the access point connected to the network. Figure 3.13 illustrates how a wireless repeater can extend the range of a wireless network.

FIGURE 3.13 A wireless repeater extends the range of a wireless network.



As illustrated, the wireless client device is not within hearing range of the access point, so adequate communication is not possible between these devices. In order for WLAN devices to communicate effectively with an access point, the transmitter must be able to hear the receiver, and the receiver must be able to hear the transmitter. It is a two-way radio communication. A wireless repeater will allow this communication to occur where the wireless client is outside the RF cell or BSA of the access point. The wireless client will send information, or frames, to the repeater, and the repeater will forward them to the

access point, and vice versa. The downside of this configuration is that it will reduce the overall throughput. The wireless repeater may be named differently by the manufacturer and include the term *wireless range extender*.

Real World Scenario

Using Wireless Repeaters Reduces Throughput

Before using a wireless repeater, consider whether it would be the best solution. Since WLANs are half-duplex (two-way communication but only one way at a time), data throughput will suffer when repeaters are used. When data traverses a wireless link between devices that are set to the same RF channel, the data throughput can be reduced by up to 50 percent. If a physical wired connection is available, it should be used for an access point connection rather than a wireless repeater. For security purposes, the Ethernet port on a wireless repeater should be disabled because it is not connected to a wired network infrastructure.

Wireless LAN Controllers and Cloud-Managed Architectures

The *WLAN hardware controller* is a main component in many WLAN deployments. WLAN controllers range from branch office models with a few controller-managed access points to large-scale enterprise devices with hundreds or even thousands of controller-managed access points. The branch office models are typically used in remote office installations or small/medium business (SMB) applications with a limited number of access points. The controller-less, or cloud-managed, architecture is growing at a fast pace and provides another option for enterprise WLAN deployments. The following sections discuss some of the many benefits and features available on both WLAN controllers and cloud-managed controller-less solutions:

- Centralized administration
- Virtual LANs (VLANs)
- PoE capability
- Improved mobile device transition
- WLAN profiles and virtual WLANs
- Advanced security features
- Captive web portals
- Built-in RADIUS services

- Predictive modeling site survey tools
- RF spectrum management
- Firewalls
- QoS
- Infrastructure device redundancy
- WIPS
- Direct and distributed access point connectivity
- Layer 2 and Layer 3 access point connectivity
- Distributed and centralized data forwarding

Centralized Administration

WLAN controllers and cloud-managed, controller-less solutions provide *centralized administration* and give an administrator complete control over the wireless network from a single physical location. Unlike autonomous access points, which require intervention at each device for configuration, these solutions can be a "one-stop shop" for configuration and management of the wireless network. A wireless network management system (WNMS) can be used as a centralized tool to manage WLAN infrastructures. A WNMS can be used to help scale the access point architecture as well but is not required.

Virtual Local Area Networks

According to the IEEE 802.1Q standard, VLANs define broadcast domains in a Layer 2 network by inserting VLAN membership information into Ethernet frames. Layer 2 Ethernet switches can create broadcast domains based on how the switch is configured, by using VLAN technology. This allows an administrator to separate physical ports into logical networks to organize traffic according to the use of the VLAN for security profiles, QoS, or other applications. The concept of a Layer 2 wired VLAN is extended to IEEE 802.11 WLANs. Both hardware controller and controller-less solutions have the ability to configure broadcast domains and segregate broadcast and multicast traffic between VLANs.

Power over Ethernet Capability

WLAN controllers and cloud-managed solutions support PoE, allowing DC voltage and computer data to be sent over the same cable. (The details of PoE are discussed later in this chapter, in the section "Power over Ethernet.") Some hardware controllers provide direct access point connectivity to the controller at the device connection layer and will provide the PoE. For hardware controllers that do not support direct connectivity and cloud-managed solutions, the access points will receive their PoE from the Layer 2 Ethernet switch.

Improved Mobile Device Transition

Fast, seamless Layer 2 and Layer 3 *transitioning* or *roaming* between access points is another common feature of hardware wireless controllers and cloud-managed solutions. This feature makes it possible for computers and other wireless devices connected to the WLAN to maintain a connection while physically moving throughout the wireless network. The IEEE 802.11r amendment specifies fast transition (FT), and the IEEE 802.11k helps with this functionality. Transitioning is more often than not an enterprise network requirement and exists in very few SOHO deployments.

Wireless LAN Profiles and Virtual Wireless LANs

Both the WLAN controller and controller-less cloud-managed solutions can give network administrators the ability to create a variety of configuration profiles. These profiles can work in conjunction with VLANs to allow or deny access based on requirements for the computer, device, or user. Profiles can be configured for various situations, including different SSIDs for guest, corporate, and voice networks; security configurations; and QoS support. Each WLAN profile will create a virtual access point with its own BSSID and will act as though it is a separate physical device. This includes all the wireless management traffic that works with WLAN technology.

Although Wired Equivalent Privacy (WEP) is now rare and not recommended to be used in any WLAN, it may still exist in deployments that use legacy devices, such as wireless bar code scanners or wireless print servers. Using WLAN profiles, you can allow this type of legacy device to be located on a separate wireless VLAN without compromising the security of the entire network. However, if WEP is still used, I highly recommend moving away from it as soon as possible by upgrading legacy devices.

Advanced Security Features

Like autonomous access points, hardware wireless controller and cloud-managed solutions provide advanced security options. These include security options based on IEEE 802.11i and WPA/WPA 2.0, with both passphrase and enterprise configuration capabilities, allowing for the most secure mechanisms available for WLAN technology, including IEEE 802.1X/EAP, RADIUS, and certificates as used in most enterprise deployments.

Captive Web Portals

Captive web portal capability is a common feature in hardware WLAN controllers and cloud-managed systems. A *captive web portal* will intercept a user's attempt to access the network by redirecting them to a web page for authorization of some sort. This web page may request account credentials, payment information from a user, or a simple agreement to terms and conditions before granting access to the wireless network. One common

example of where you will see a captive portal is in a paid or free wireless hotspot. The captive portal can be hosted by an outside service provider, by an autonomous access point, by a hardware wireless controller, and in a cloud-managed system on the access point. It is important to note that some mobile devices may experience issues while connecting to a wireless network with captive web portal technology enabled.

Built-in RADIUS Services

Another common feature of WLAN controllers and cloud-managed systems is RADIUS services for 802.1X/EAP authentication, which is supported by WPA and WPA 2.0. Built-in RADIUS allows a network administrator to utilize the most advanced security features available today to secure the wireless network. Built-in RADIUS servers typically limit the number of users that can be created in the user database, which means that built-in RADIUS is a good solution for SMB or remote office locations but not for very large organizations. Larger networks can use external RADIUS services for scalability. See `www.gnu.org/software/radius` for more about this server.

Predictive Modeling Site Survey Tools

Predictive modeling site survey tools assist in the placement of access points and other wireless infrastructure devices. These tools are sometimes a feature of a hardware WLAN controller. Performing a predictive modeling site survey will assist in planning to determine coverage and capacity for data and voice for both indoor and outdoor deployments. Some manufacturers of cloud-managed enterprise solutions have web-based online predictive modeling site survey tools. Aerohive is one example of a manufacturer that provides these online wireless network planning tools. Visit the following website for more information and instructions on how to access this tool:

```
www.aerohive.com/planner
```

Radio Frequency Spectrum Management

Keeping an eye on the RF environment is another responsibility of the wireless network administrator. RF spectrum management consists of adjusting RF parameters such as the RF channel (frequency) and the RF transmit power after deployment. This allows the network to adapt to changes in the environment and assist in the event of hardware failures.

Firewalls

An integrated stateful firewall feature helps protect a network from unauthorized Internet traffic but still allows authorized traffic. Firewalls can be hardware-based, software-based, or a combination of the two. Stateful firewalls, which keep records of all connections passing through them, help protect against broadcast storms, rogue DHCP server attacks, Address Resolution Protocol (ARP) poisoning, and other potential attacks against the WLAN.

Quality of Service

QoS features help time-critical applications, such as voice and video communications, minimize latency and allow for traffic prioritization. With the continual expansion of voice and video technology in the WLAN arena, QoS is becoming an increasingly important component in the wireless network.

Infrastructure Device Redundancy

Infrastructure device *redundancy* allows for fault-tolerant deployments and provides uninterrupted access in the event an access point or WLAN controller fails. Complete redundancy will prevent a major outage caused by hardware failure for mission-critical or other deployments. Coverage is maintained by alternating access points between the redundant infrastructure devices, minimizing interruption for user access in the event of a hardware failure. Cloud-managed systems eliminate the need of redundant hardware WLAN controllers, and the technology allows for redundancy in the event of an access point failure.

Wireless Intrusion Prevention System

A WIPS monitors all activity across the wireless network for potential intrusion and malicious activities. A WIPS can take appropriate action to mitigate an attack based on the type of intrusion. WIPS will be discussed further in Chapter 8.

Direct and Distributed Access Point Connectivity

Connecting access points that are not directly plugged into a port on the WLAN controller is a feature known as *distributed access point connectivity*. It's beneficial in large-scale deployments, and almost all manufacturers support it. *Direct access point connectivity* is defined as a direct connection to ports on the switch and is typically used with device connection layer hardware wireless controllers.

Layer 2 and Layer 3 Access Point Connectivity

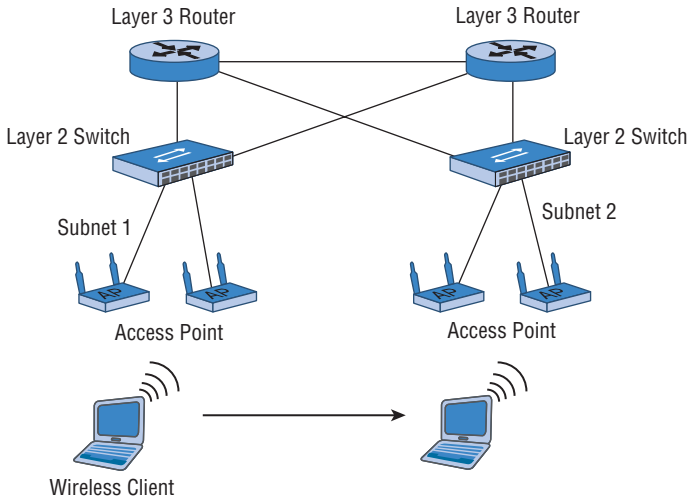
Early wireless network implementations were built with dedicated Layer 2 connectivity, which meant limited wireless mobility. Layer 2 transition (roaming) occurs when a computer or other wireless client device moves out of the radio cell of the currently associated access point and connects to a different access point maintaining Layer 2 connectivity.

As wireless networking technology evolved, so did the need for Layer 3 connectivity and transition. IP addresses are logical Layer 3 addresses that identify devices on a network. All IP devices on the same network or subnet are considered to be in the same IP boundary. Layer 3 roaming occurs when a client moves to an access point that covers a different IP subnet. After a transition, the client will no longer have a valid IP address from the original

subnet, and the device will be issued an IP address from the new subnet while maintaining Layer 3 connectivity.

Figure 3.14 illustrates Layer 2 and Layer 3 connectivity and wireless transition.

FIGURE 3.14 Wireless client device roaming across Layer 2 and Layer 3 boundaries



Distributed and Centralized Data Forwarding

WLAN controller solutions consist of two common types of architectures: centralized and distributed. Early WLAN controller solutions supported the centralized architecture (split-MAC architecture). This design separated the intelligence from the access point and placed it into the wireless controller to allow for centralized management and control of the wireless network. The access point, for the most part, was just a radio and antenna, and traffic decisions were sent to the controller through an Ethernet cable. This technique is also known as *centralized data forwarding*. Depending on where the controller was placed, it could cause bottlenecks and other issues in the case of an overloaded or poorly designed network infrastructure. With the data rates possible with IEEE 802.11n and now IEEE 802.11ac, the aggregate throughput could be too much for the network to handle, resulting in poor performance.

Distributed data forwarding reduces the amount of infrastructure traffic because the controller-managed access point is able to make more decisions, taking some of the load away from the wireless controller. Moving some of the intelligence back to the edge (the wireless access point) minimizes the bottlenecks and other potential issues such as latency. This is also true in a cloud-managed or controller-less architecture, thus eliminating the need for the data to be sent to the controller for handling.

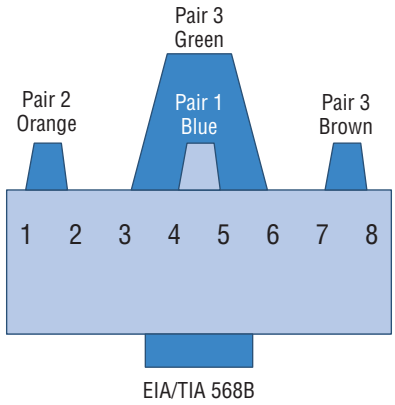
Most enterprise WLAN equipment manufacturers now support both the centralized and distributed WLAN architectures.

Power over Ethernet

PoE sends DC voltage and computer data over the same Ethernet cable, enabling a device to receive DC power and computer data simultaneously. This eliminates the need for an external alternating current (AC) power source to be near the Ethernet device.

An Ethernet cable has four copper wire pairs, or eight copper wires. Depending on the technology in use, either two or all four wired pairs may be used to carry data traffic. Figure 3.15 shows an example of a standard Ethernet cable pin assignment.

FIGURE 3.15 Standard Ethernet pin assignment



PoE now consists of two ratified amendments to the IEEE 802.3 standard. They are defined in *802.3-2012 Clause 33*, also known as *IEEE 802.3af*, and *IEEE 802.3at*, sometimes called *PoE+*. These amendments define the specifications for devices used in wired or wireless networking to receive DC power from the Ethernet connection without the need for an external DC power source. The PoE amendments to the Ethernet standard allow electrical power to be supplied in one of two ways, either over the same wired pairs that carry computer data or over the wired pairs that do not carry data. 10BaseT and 100BaseT (Fast Ethernet) implementations use only two wired pairs (four wires) to carry data. 1000BaseT (Gigabit Ethernet) may use all four pairs (eight wires) to carry computer data. The standard defines which wire pairs are allowed to carry the DC power based on whether the network is 10BaseT, 100BaseT, or 1000BaseT, and whether the power is sourced from an endpoint or midspan injector. Both midspan and endpoint injectors are explained later in this chapter.

The nominal voltage for PoE is 48 volts of *direct current (VDC)*, but the amendments allow for a range of 44 to 57 VDC at the power source. The PoE amendments address two types of devices: *power sourcing equipment* (PSE), the device that provides of the DC power, and the *powered device* (PD), the device that receives the DC power.

Before PoE was standardized, some manufacturers used proprietary implementations. These solutions used various voltages, polarities, and pin assignments and may still be on the market today. I recommend that you verify PoE standard compliance before using this technology to prevent potential hardware or device failures.

The IEEE 802.3-2012 Clause 33 (802.3af) amendment was released in 2003 and allocates 15.4 watts (W) of power maximum per port. This amendment has been incorporated into the IEEE 802.3-2012 standard. The IEEE 802.3at amendment, PoE+, was released in 2009 and includes changes to add to the capabilities of the IEEE 802.3-2008 standard, with higher power levels and improved power management information. IEEE 802.3at allows for 34.2 W of power per port maximum, a big increase over IEEE 802.3af, which allowed for 15.4 W per port. IEEE 802.3af PoE will work with access points from all manufacturers of enterprise-grade IEEE 802.11n access points. Using IEEE 802.3af will make it easier for organizations to transition from older-model access points to the newer 802.11n technology, which will improve their client service and provide overall better performance without having to immediately upgrade their PoE infrastructure to IEEE 802.3at.

Power Sourcing Equipment

The *power sourcing equipment* (PSE) is the device that supplies the DC voltage to the end devices that receive the DC power. The DC voltage (power) can be delivered to the device in one of two ways:

- An *endpoint injector* (usually a WLAN controller or a Layer 2 Ethernet switch) delivers DC power directly over the same wire pairs that carry data over the unused wire pairs.
- A *midspan injector* (usually a single-port or multiple-port injector) injects DC power into the Ethernet cable over the unused wire pairs or over the data pairs, depending on the version of the standard in use.

Midspan Injectors

Midspan PoE injectors provide the required DC voltage (48 VDC) into the Ethernet cable, allowing the access point, bridge, or other PD to receive electrical power and computer data. There are two types of midspan devices: single-port injectors and multiport injectors. A single-port injector supplies power to a single device. This is useful in an implementation that may have only a few PoE devices. A single-port injector is an in-line device that adds DC power to the Ethernet cable. A multiport injector can supply DC power to many devices simultaneously. It is an in-line device that functions like a patch panel. Two ports on this device are required to supply both DC power and computer data to a single PD, such as an access point, bridge, or IP camera. Therefore, a 24-port injector will allow connectivity for only 12 devices.

Endpoint Injectors

Endpoint PoE injectors supply DC power and computer data directly at the Ethernet port, rather than relying on an intermediate device to supply the power. WLAN controllers and Ethernet switches are examples of endpoint devices. A benefit of endpoint PoE is that no intermediate adapter to inject power is necessary.

Powered Devices and Classification Signatures

The *powered device* (PD) is defined as the device receiving DC power, such as a wireless access point, wireless bridge, IP camera, IP phone, and so on. The IEEE 802.3 standard defines the maximum cable length of an Ethernet cable to be 328 feet, or 100 meters. Because of line loss, the standard specifies less maximum power than what is available at the port. Table 3.1 shows the maximum power allowed for both the PSE and the PD.

TABLE 3.1 Maximum power supplied by PSE and drawn by PD for both amendments to the IEEE 802.3 Ethernet standard

Specification	802.3af	802.3at
PSE power maximum	15.4 W	34.2 W
PD power draw maximum	12.95 W	25.5 W

Equipment manufacturers have the option of defining a *classification signature*. The classification signature determines the maximum amount of power a device requires, thereby allowing the PSE to better manage the amount of power delivered to a specific port. The PoE amendments make five classes of powered device available (class 0 through class 4). Table 3.2 shows the available classes and the amount of power in watts for each class for IEEE 802.3-2012 Clause 33 devices.

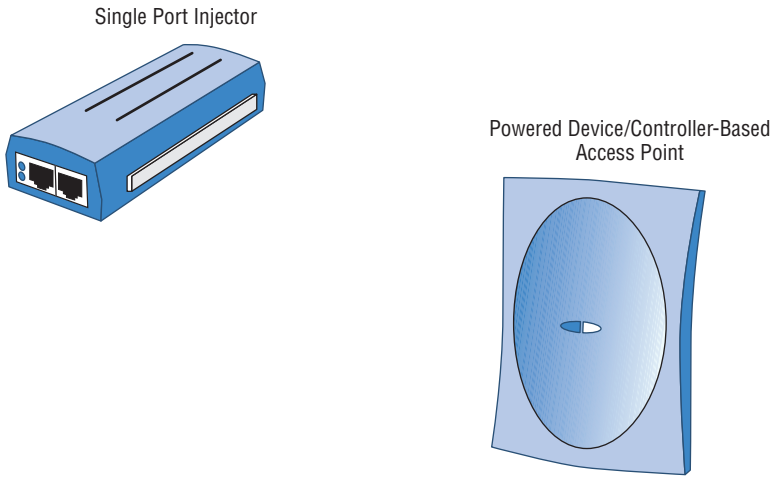
TABLE 3.2 Classes of powered device described in the PoE amendment to the Ethernet standard, 802.3-2012 Clause 33

Class	Use	PSE Power Output, in Watts	PD Max Levels, in Watts
0	Default	15.4 W	0.44 W to 12.95 W
1	Optional	4.0 W	0.44 W to 3.84 W
2	Optional	7.0 W	3.84 W to 6.49 W
3	Optional	15.4 W	6.49 W to 12.95 W
4	Type 2 PoE devices	30.0 W	12.95 W to 25.5 W

It is important to note that the "power budget" of the power source equipment must be considered. The total amount of DC current a PSE can supply will determine how many devices that draw the power can be connected to the power source. This may cause some design constraints, and you may not have enough DC power to supply to all of the connected devices. Understand that each device will draw the required amount of DC power for it to operate. For example, all dual-band, enterprise-grade 802.11n access points can now operate in 3x3:3 MIMO mode using 802.3af power, which allows a maximum of 15.4 watts per port. However, the access points may only draw approximately 12 watts of power. If the total maximum amount of power available in a 24-port switch is 185 watts (the power budget), that would allow only 12 access points to be connected, assuming the ports are allowing 15.4 watts each. Twelve ports multiplied by 15.4 watts each is 184.8 watts of available power. IEEE 802.3at PoE can be used for devices that may require more DC power, such as some IEEE 802.11ac access points, which would qualify as Class 4 devices, shown in Table 3.2.

Figure 3.16 shows an example of PSE and a PD.

FIGURE 3.16 PSE single-port injector and PD access port



Benefits of PoE

There are many benefits to using devices that support PoE, including cost savings and convenience. The IEEE 802.3 standard (Ethernet) specifies a maximum distance of 100 meters, or 328 feet, for unshielded twisted-pair (UTP) Ethernet cable. PoE enables a PoE device to receive DC power and computer data at this distance without the need for electrical power at the point where the device is installed or located. This can amount to a big cost savings if a voltage source is not available where the device is located, because there is no need to install electrical power at that point.

Radio Hardware Used with Wireless LAN Technology

WLAN client devices require some type of radio hardware or chipset to send the digital data (all the ones and zeros) across the air using RF. It is important to understand that based on the IEEE 802.11 standard, every addressable unit used in a WLAN is considered a station (STA). This includes both client devices that connect to the network and wireless access points that allow devices to connect to and use network resources.

Another point to consider is that with the recent advancements in WLAN technology, including the release of the IEEE 802.11n/ac amendments, client device selection will need to be carefully considered. Although it is beneficial to use 802.11n/ac-capable client devices along with the newer 802.11n/ac multiple-input multiple-output (MIMO) access points, radio technology used in 802.11a/b/g devices may benefit from MIMO technology as well. Selecting the correct wireless adapter will allow a user to take advantage of the newest WLAN technology available.

Many organizations now have to deal with the Bring Your Own Device (BYOD) subject. This is a trend in which employees bring their own personal electronic wireless devices, such as tablets and Wi-Fi-enabled smartphones, to the office or place of business. These devices will then have access to company resources, including email services, file servers, computer data, and printers. This may create problems for technical support and security issues. BYOD is forcing organizations to address this in corporate policies.

USB 1.0, USB 1.1, USB 2.0, and USB 3.0

Introduced in 1995, the *Universal Serial Bus* (USB 1.0) standard was designed as a replacement for legacy serial and parallel connections.

Serial communication is the process of transmitting one data bit at a time. *Parallel communication* has the capability of transmitting several data bits at a time. Imagine a single-lane road compared to a four-lane highway. On a single-lane road, only one car at a time can travel, whereas on a four-lane highway, many cars can traverse the same path at the same time.

USB allows connectivity for various devices that once used serial and parallel data connection ports. These devices include but are not limited to the following:

- Keyboard
- Mouse
- Digital camera
- Printer
- Computer networking adapter
- HDMI video using a converter adapter

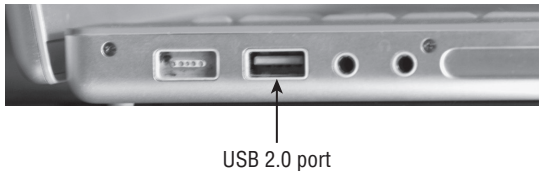
USB 1.0 specified data rates from 1.5 Mbps to 12 and was replaced by USB 1.1 in 1998. Devices using this version of the standard were more common in the market.

USB standards are implemented by the USB Implementers Forum (USB-IF). This organization consists of companies from the computer and electronics industries, including Intel, Microsoft, NEC, and HP.

The *USB 2.0* specification was released in April 2000. The first revision appeared in December 2000, and the standard has been revised several times since. USB 2.0 incorporates several changes, including connector types. Data rates now allow for a maximum speed of up to 480 Mbps. (USB 1.0 supported a maximum of 12 Mbps.)

Figure 3.17 shows an example of a USB 2.0 port.

FIGURE 3.17 USB 2.0 port on notebook computer panel



USB 3.0 technology was introduced in early 2010 and is commonly available to the point of being included on newer system boards. USB 3.0 devices have faster transfer rates and use a wider bandwidth, and they allow multiple logical streams and improved bus use with asynchronous readiness notification without polling. USB 3.0 greatly increases the transmission speed from the 480 Mbps of USB 2.0 up to 4.8 Gbps. This is more than 10 times that of the earlier standard, and as a result USB 3.0 is known as *SuperSpeed*. In addition to speed, the new USB 3.0 specification addresses improvements to the technology, including bandwidth, by using bidirectional data paths, power management, and improved bus utilization.

Features of USB

USB uses a standard connector that replaces 9-pin serial, 25-pin parallel, and various other connector types. External configuration allows the user to plug in the USB device and power it with a single USB port. The computer operating system will guide the user through the device driver installation process. External installation minimizes the need to open up a computer case and make adjustments within the computer, such as switch or jumper settings. USB also supports hot-swapping of devices, allowing connection and disconnection without the need to power down the device or the computer. In some cases, USB allows for power to be delivered to the peripheral device, eliminating the need for an external power supply. Rarely will you see a device with PC card or ExpressCard interfaces, and most use only USB ports for adding peripheral devices.

For additional information and specifications regarding the USB standards, visit the USB Implementers Forum (USB-IF) at `www.usb.org`.

Installation and Configuration of USB Devices

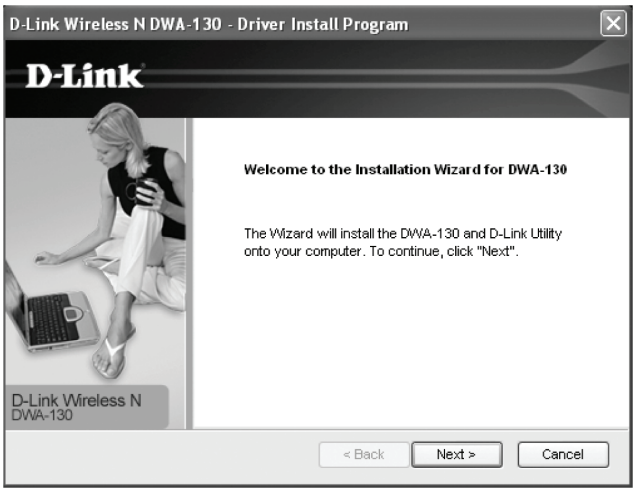
Exercise 3.1 walks you through the steps to install the D-Link Wireless N USB 2.0 Adapter. Many USB WLAN adapters use installation procedures similar to this one. Installation steps are specific to the manufacturer, and I recommend that you follow the manufacturer's installation instructions. Always read the manufacturer's manual regarding installation and safety before attempting installation.

EXERCISE 3.1

Installing a USB 2.0 Wireless LAN Adapter

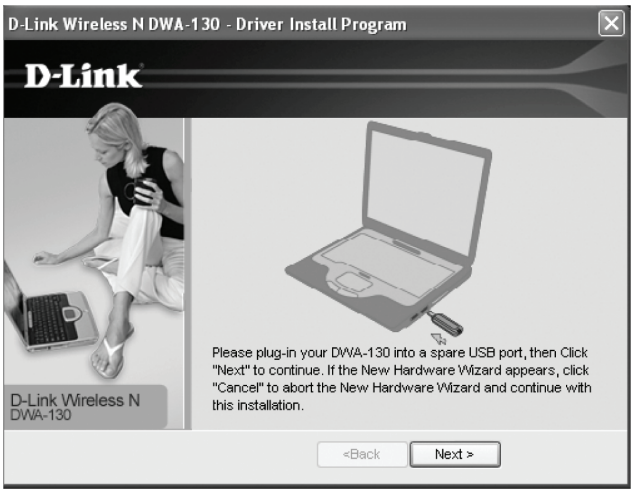
To install the D-Link Wireless N USB 2.0 Adapter on a computer running Microsoft Windows, follow these steps:

1. Visit the D-Link website at `http://support.dlink.com` to get the most current installation files and device driver. You can search the support website by entering the model number of the adapter into the search bar. If an Internet connection is not available, you can use the setup CD that comes with the adapter to install the client utility. Execute the setup program you downloaded or insert the setup CD into the CD-ROM drive. The program should start automatically, and an Autorun screen will appear. Click to start the installation, and the Installation Wizard window will appear.



2. Accept the default location to install the files or browse for an alternate file location.

3. When prompted, insert the USB adapter into an available USB port on your computer.



4. When prompted, enter the network name (SSID) manually. If you don't know the SSID, click Scan to see the site survey page.

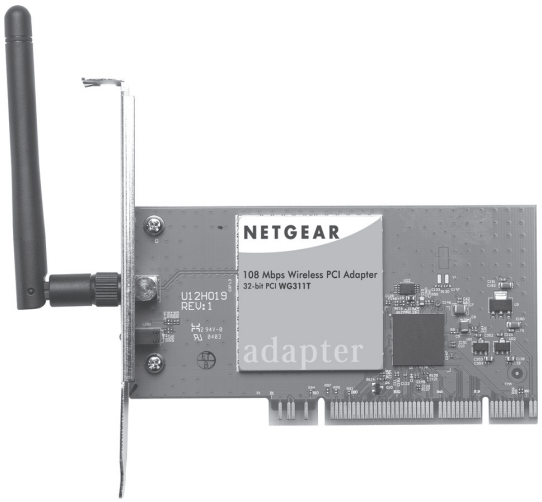
The site survey page will also appear if the SSID is entered incorrectly. Click the network name (SSID) and click Next.

5. Click Finish to continue. If prompted to restart the computer, select Yes, Restart The Computer Now.

Peripheral Component Interconnect

PCI is the acronym for *Peripheral Component Interconnect*, a standard for computer interface cards that was developed by Intel. A PCI card is inserted into a slot in the main board or motherboard of a desktop computer, allowing for the attachment of peripheral devices. Installing a PCI card may require basic tools such as a screwdriver, and the installer usually will need to remove the cover from the desktop computer case. Figure 3.18 shows an example of an IEEE 802.11 wireless PCI card.

FIGURE 3.18 NETGEAR WG311T IEEE 802.11g wireless PCI adapter



Features of PCI

A PCI adapter connects to what is known as a *data bus* in a desktop computer. In basic terms, a data bus allows connection of devices to the computer's processor or "brain." In the early days of personal computers, many devices used a data bus. These devices included video, hard disks, serial ports, Ethernet adapters, and parallel ports for printers. These interfaces connected to what is known as an *Industry Standard Architecture* (ISA) bus.

Modern computers have integrated many of these interfaces directly into the motherboard, system board, or main board. As PC technology evolved, so did the data bus architecture, going to 32-bit and now 64-bit bus. Wireless networks are no strangers to PCI. Even though wireless is often thought of as portable or mobile, in many cases stationary desktop computers can utilize WLAN connectivity through the use of wireless PCI interface cards.

PCI-SIG (Peripheral Component Interconnect-Special Interest Group) is the industry organization for development and management of the PCI standards. For additional information, visit `www.pcisig.com`.

Installation and Configuration of PCI Cards

Back in 1995, Microsoft introduced a feature in the Windows 95 operating system called *Plug and Play* (PnP). This new feature accelerated the interest in PCI. PnP made installing a PCI card a snap. All that was required was for the installer to plug the card into the motherboard, and it would be recognized and automatically work with the operating system. However, this process still required user intervention to open the case in order to physically install the card. Exercise 3.2 describes the steps for installing a PCI card in a desktop computer.

EXERCISE 3.2

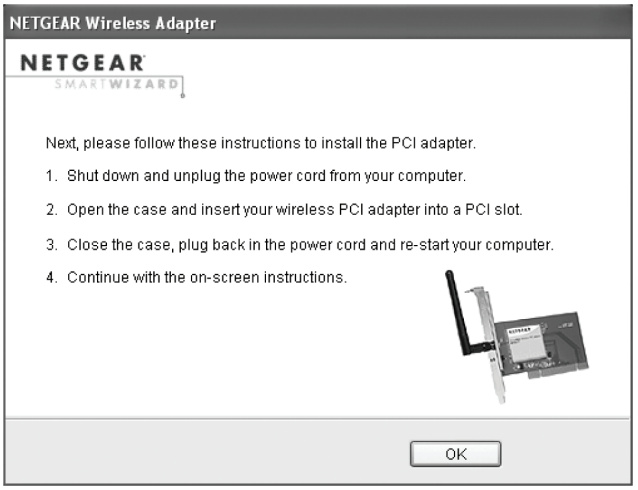
Installing a PCI Card

The following steps are typical for installation of a PCI WLAN card. Exact installation steps are specific to the manufacturer, and I recommend that you follow the manufacturer's setup instructions. Always read the manufacturer's manual regarding setup and safety before attempting installation.

1. Visit the NETGEAR website at `https://www.netgear.com/support/` to get the most current installation files and device driver. You can search the support website by entering the model number of the adapter into the search bar. If an Internet connection is not available, you can use the setup CD that comes with the adapter to install the client utility. Execute the setup program you downloaded or insert the setup CD into the CD-ROM drive. The program should start automatically, and a welcome or Autorun screen may appear. When the screen appears, click Next to continue and follow the instructions to install and configure the wireless PCI adapter. The Installation Wizard will appear on the screen.

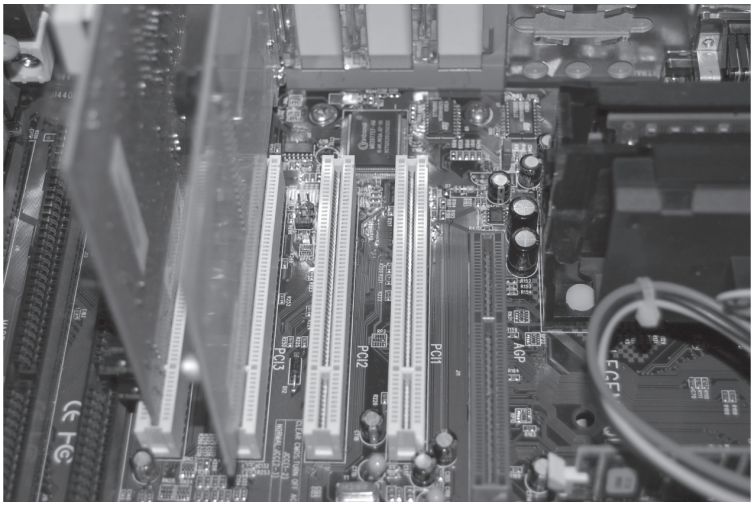
EXERCISE 3.2 *(continued)*

2. The setup program will copy the required files to the desktop computer.



Turn off the computer to install the card. Once the computer is turned off, unplug the power cord from the wall jack.

3. Open the case and identify an available PCI slot in the motherboard. Using the appropriate tool, remove the cover over the slot. Insert the wireless PCI adapter into the available PCI slot and securely fasten it in place. The following image shows an available PCI slot in a desktop computer.



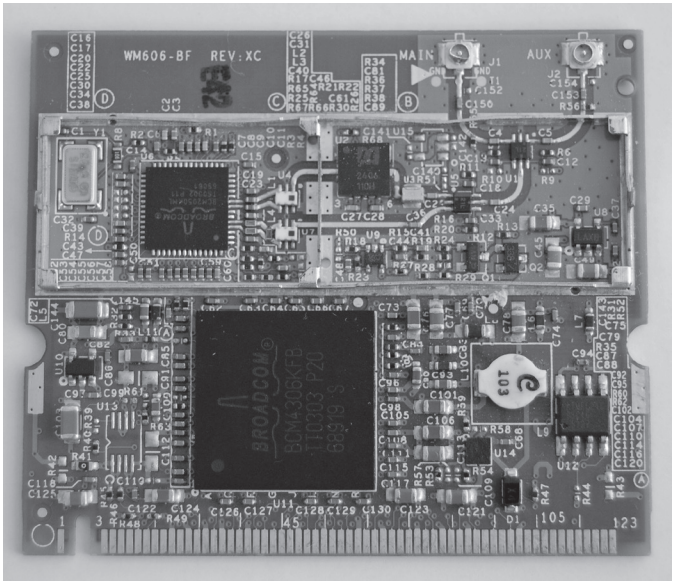
4. Once the card is securely mounted, close the case and insert the power cable into the wall jack. Turn on the computer.
5. The setup program will appear on the screen. Follow the onscreen instructions to complete the installation.

In some cases, the installation and setup may require the computer to be restarted in order for the adapter to operate correctly. Follow the manufacturer's recommendations.

Mini-PCI, Mini-PCIe, and Half Mini-PCIe

Mini-PCI is a variation of the PCI standard, designed for laptops and other small-footprint computer systems. One common example of a Mini-PCI card is the IEEE 802.11 Mini-PCI adapter shown in Figure 3.19.

FIGURE 3.19 IEEE 802.11 Mini-PCI adapter



Mini-PCI cards are common in many devices, such as Fast Ethernet networks, Bluetooth, modems, hard drive controllers, and WLANs. In the wireless world, Mini-PCI cards are used in access points and client devices such as laptop or notebook computers.

Mini-PCI Express (*Mini-PCIe*) cards are a replacement for the Mini-PCI card and are based on PCI Express.

Many notebook and portable computers with built-in WLAN use either Mini-PCI or Mini-PCIe or now Half Mini-PCIe cards for wireless IEEE 802.11 WLAN connectivity.

Features of Mini-PCI, Mini-PCIe, and Half Mini-PCIe Cards

Mini-PCI cards are available in three types: Type I, Type II, and Type III. Types I and II cards use a 100-pin stacking connector. Type III cards use a 124-pin edge connector. Type II cards have RJ11 and RJ45 connectors for telephone and Ethernet network connections. These cards are commonly located at the edge of the computer or docking station so that the connectors can be mounted for external access, such as to a modem or computer network.

Mini-PCIe cards are 30 mm × 56 mm and have a 52-pin edge connector, consisting of two staggered rows on a 0.8 mm pitch. These cards are 1.0 mm thick excluding components. Table 3.3 summarizes the features of Mini-PCI and Mini-PCIe cards.

TABLE 3.3 Features of Mini-PCI, Full Mini-PCIe, and Half Mini-PCIe cards

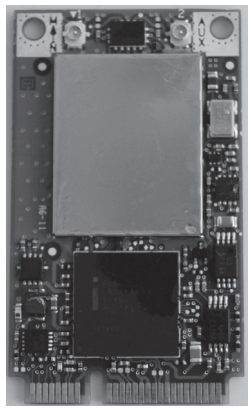
Card Type	Connectors	Size
Mini-PCI Type IA	100-pin stacking	7.5 mm × 70 mm × 45 mm
Mini-PCI Type IB	100-pin stacking	5.5 mm × 70 mm × 45 mm
Mini-PCI Type IIA	100-pin stacking, RJ11, RJ45	17.44 mm × 70 mm × 45 mm
Mini-PCI Type IIB	100-pin stacking, RJ11, RJ45	5.5 mm × 78 mm × 45 mm
Mini-PCI Type IIIA	124-pin edge	5 mm × 59.75 mm × 50.95 mm
Mini-PCI Type IIIB	124-pin edge	5 mm × 59.75 mm × 44.6 mm
Full Mini-PCIe	52-pin edge, two staggered rows on 0.8 mm pitch	30 mm × 31.90 mm × 1 mm (excluding components)
Half Mini-PCIe	52-pin edge, two staggered rows on 0.8 mm pitch	30 mm × 56 mm × 1 mm (excluding components)

The *Half Mini-PCIe* cards are 30 mm × 31.90 mm. The main difference between this card and the Mini-PCIe card is the length. The length of this new form factor is about half of the Mini-PCIe card.

With the introduction of the Half Mini-PCIe card form factor, the Mini-PCIe card is now called the *Full Mini-PCIe* card.

Figure 3.20 shows a Mini-PCIe adapter.

FIGURE 3.20 Full Mini-PCIe adapter



Installation and Configuration of Mini-PCI, Full Mini-PCIe, and Half Mini-PCIe Cards

As with the PCI card installation process, Mini-PCI and Mini-PCIe installation may require the user to physically install hardware in the computer. Location of the Mini-PCI or Mini-PCIe interface varies depending on the computer manufacturer. On some computers, you just have to remove a cover panel on the bottom of the notebook. On others, you need to disassemble the computer case. Exercise 3.3 describes the typical installation steps.

EXERCISE 3.3

Installing Mini-PCI and Mini-PCIe Cards

The following steps are typical for the installation of a Mini-PCI and Mini-PCIe WLAN card on a notebook computer. Exact installation steps are specific to the manufacturer, and I recommend that you follow the manufacturer's setup instructions.

1. Shut down the computer. Verify that the computer is not in Hibernation mode. If it is, turn on the computer and perform a complete shutdown.
2. Disconnect the AC power cord from the wall jack.
3. Disconnect all connected peripherals and remove the battery pack.

EXERCISE 3.3 *(continued)*

4. Remove the panel covering the Mini-PCI—Mini-PCIe compartment. (Details of this step will depend on the computer model.)
5. Insert the Mini-PCI or Mini-PCIe card into the correct slot. Note the correct pin orientation.
6. Connect the wireless antenna cables to the Mini-PCI or Mini-PCIe card.
7. Replace the panel for the Mini-PCI—Mini-PCIe compartment.
8. Replace all peripheral devices and battery pack. Plug in the AC power cord to the wall jack.
9. Visit the manufacturer's support website to get the most current installation files and device driver. You can search the support website by entering the model number of the adapter into the search bar. If an Internet connection is not available, you can use the setup CD that comes with the adapter to install the client utility. Power on the computer and execute the setup program you downloaded or insert the Setup CD-ROM into the CD-ROM drive. The program should start automatically, and a welcome or Auto-run screen may appear. When the screen appears, click Install Drivers and follow the onscreen instructions to install and configure the wireless Mini-PCI or Mini-PCIe card.

Always read the manufacturer's manual regarding installation and safety before attempting installation.

Real World Scenario

Replacing a Full Mini-PCIe with Half Mini-PCIe Adapter

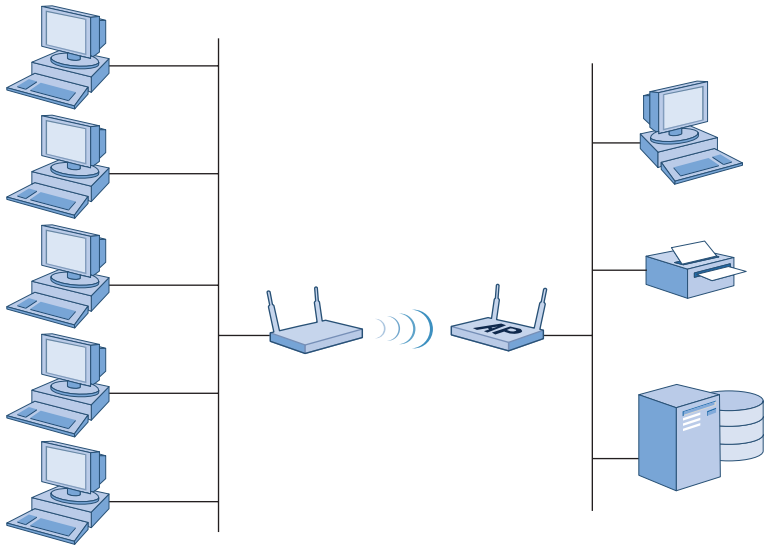
Upgrading an IEEE 802.11g wireless Full Mini-PCIe card to a newer IEEE 802.11n/ac Half-Mini PCIe card may require the use of a special adapter or bracket. Keep in mind that the Half Mini-PCIe card is about half the length of the Full card, and you may not be able to install the card securely. Therefore, you may need to purchase a special bracket in order for the new Half Mini-PCIe card to be securely mounted in the notebook computer or other device where the card is to be installed.

Wireless Workgroup Bridges

A *wireless workgroup bridge* (WWB), also known as a *wireless client bridge*, is a wireless device acting as a client device that will allow potentially several Ethernet devices on an Ethernet segment (devices connected to a common Physical layer boundary) to connect to

an infrastructure through a wireless access point. This is accomplished without the need to upgrade each wired device on the Ethernet segment to wireless. Figure 3.21 illustrates an application of a WWB.

FIGURE 3.21 Typical application for an enterprise WWB



Features of Wireless Workgroup Bridges

The WWB can be used in a variety of business or SOHO applications, including enterprise, medical, retail, education, and warehouse. Supported devices include computers, printers, scales, medical equipment, barcode readers, and point-of-sale machines, such as cash registers. Although the WWB may have the appearance and features of an infrastructure device, such as a wireless access point, it is considered a client device. A WWB will allow for a limited number of wired client devices to connect to and use network resources. A wireless access point sees a WWB as a single station even if several wired stations are connected, because the WWB multiplexes the signal to a single wireless connection. In other words, it is basically a multiplex device.

WWBs may include the following features:

- Fixed or detachable antennas
- Advanced security features
- Web browser and/or command-line interface management utilities
- MAC filtering options
- Multiple connectivity modes
- PoE
- Support for connection of a limited number of client devices

Installation and Configuration of Wireless Workgroup Bridges

The following are the steps usually necessary for installing and configuring a WWB:

1. Connect the WWB to the Ethernet segment that needs to have a wireless connection.
2. If PoE is not a feature of the device, connect the bridge power adapter to the wall jack.
3. Using a web browser, connect to the assigned IP address. In some cases it may be necessary to assign an IP address to the WWB from a CLI prior to configuring the bridge.
4. From the web management interface, assign the correct SSID and RF channel in order to associate to the correct access point.
5. Configure the correct security settings, either WPA or WPA2 and Personal or Enterprise mode.
6. Verify association of the WWB to the desired access point.

Always read the manufacturer's manual regarding installation and safety before attempting installation.

Another form of WWB is one that is designed to allow a variety of single Ethernet devices, not just computers, to connect to and use wireless networks. These devices will have an Ethernet port but are not wireless-capable. This type of client bridge also has characteristics similar to some infrastructure devices, such as wireless access points. One benefit is that in most cases no software is required—that is, you will not have to install device driver or client utility software on the client Ethernet device. These devices are seen by the access point as a single wireless client. Devices that can benefit from this type of client bridge are printers, DVD/media players, and game consoles. Figure 3.22 shows a wireless client bridge.

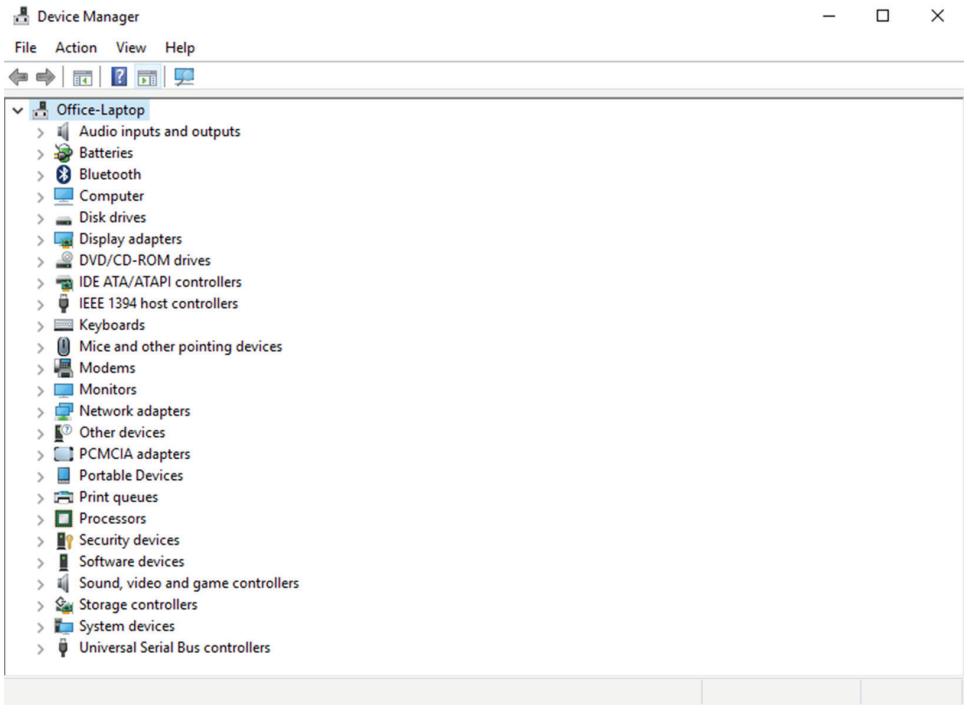
FIGURE 3.22 EnGenius Technologies ECB3500 802.11g High Power 600mW wireless access point/bridge/repeater/router

Client Device Drivers

All devices connected to a computer require a device driver. Components requiring drivers include keyboards, mice, video cards, USB ports, printers, wired network interface cards, IEEE 802.11 WLAN cards, and many others. The device driver is software that allows the installed device to communicate with or take instructions from the computer operating system in order to provide correct functionality.

It is important to verify the latest revision of the device driver from the client device manufacturer. Having the latest revision installed will ensure correct operation and sometimes add additional features. Figure 3.23 shows a device listing in the Windows 10 Professional operating system.

FIGURE 3.23 Microsoft Windows 10 Professional Device Manager utility



Client Utility Software

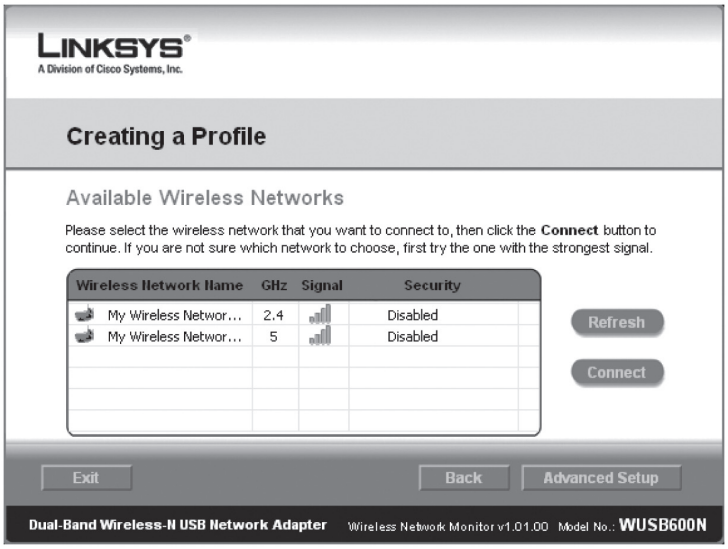
All IEEE 802.11 WLAN cards require configuration in order to connect to a wireless network. The configuration capabilities of device drivers are usually very limited. Therefore, a user needs additional configuration software. The user can choose from either manufacturer-specific utilities or third-party client utilities built into some operating systems.

When IEEE 802.1X port-based authentication is used, the client device is known as the *supplicant*. The supplicant will provide authentication credentials to the authenticator, which in wireless networking is the access point. 802.1X authentication will be discussed in more detail in Chapter 8. Regardless of the client utility installed, a user has the capability to create a profile that will retain the connection/session parameters. A profile will contain information regarding a specific connection, including network name or SSID and security settings.

Manufacturer-Specific Client Utilities

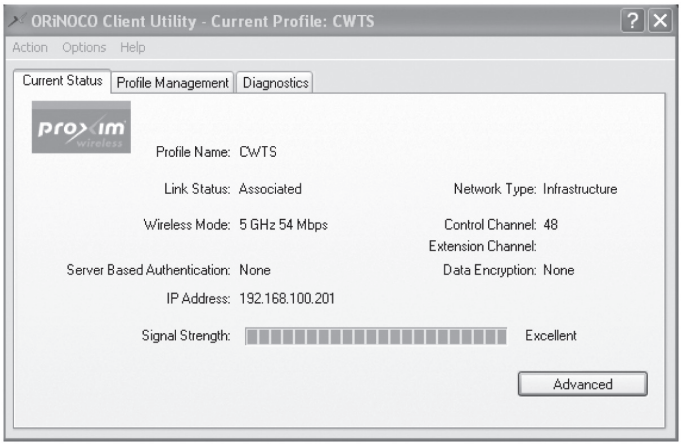
Most manufacturers of WLAN adapters provide a software client utility for the wireless adapter. The features of the utility depend on whether the client is SOHO-grade or enterprise-grade. SOHO-grade client utilities have basic connection and security parameters. The client software installation usually is part of the adapter install process and is typically performed through a setup wizard. Figure 3.24 shows a screenshot from a SOHO-grade client utility.

FIGURE 3.24 Linksys Dual-Band Wireless-N USB client utility



Enterprise-grade client utilities may have a more advanced feature set, including connection statistics and site survey. Typically, a user can install the device driver and client utility simultaneously or will be able to choose separate installation procedures. In most enterprise-grade client utilities, profile setup is a manual process requiring a user to have a basic understanding of the adapter's capabilities as well as the network configuration. Figure 3.25 shows an enterprise-grade client utility.

FIGURE 3.25 Proxim Client Utility for 8494-US 802.11a/b/g/n USB adapter

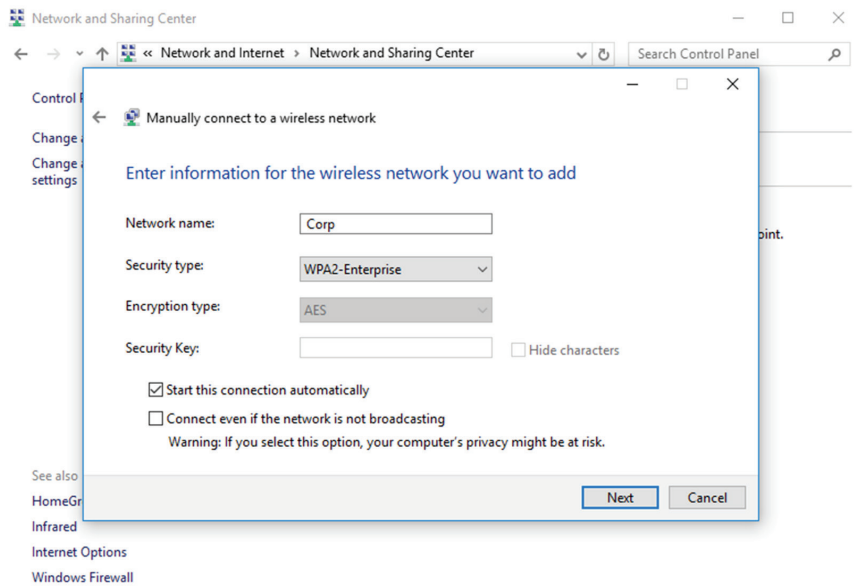


Third-Party Client Utilities

Another option for a WLAN adapter client utility is a third-party utility built into a computer operating system. Recent versions of the Microsoft Windows operating system—Windows 7, Windows 8, and Windows 10, for example—have a client utility built in and running as a service.

In later versions, such as Windows 10, the service is now called the *WLAN AutoConfig*. After the wireless adapter is installed, a user may select a wireless network to connect to and supply security parameters if required. Figure 3.26 shows the Windows 10 Professional client utility using the Microsoft *AutoConfig service*.

FIGURE 3.26 Microsoft Windows 10 Professional client utility



Summary

This chapter discussed network infrastructure devices, which are commonly used to provide wireless connectivity to a computer network for computers and other wireless client devices. The infrastructure devices include the access point (an integral part of the WLAN and available as a self-contained intelligent, or autonomous, device), a controller-managed device for use with hardware WLAN controllers, and a cloud-managed access point that provides user and client device access to network resources. Other infrastructure devices include wireless broadband routers for SOHO or home use, wireless bridges for connecting LANs together, and wireless repeaters for extending an RF cell.

This chapter also explored some of the features, benefits, and applications of these infrastructure devices. In addition, we took a look at the two PoE amendments (IEEE 802.3-2012 Clause 33, also referred to as 802.3af, and IEEE 802.3at), components, the DC voltage and amount of DC power supplied to devices (in watts), and how the power may be delivered to a PD.

Many types of WLAN client devices are used in various applications. These device types include desktop and notebook computers, printers, and barcode scanners, to name a few. A wireless client adapter uses radio hardware or chipset to send the digital data (all the ones and zeros) across the air using RF. This chapter looked at some of the various IEEE 802.11 WLAN adapter types, explaining the features, common hardware, software, and configuration procedures. External adapters with WLAN functionality include the following:

- USB 2.0
- USB 3.0

WLAN adapters are also available as internal adapters. These adapters may require some disassembly or removal of a panel for installation. Internal adapter types include the following:

- PCI
- Mini-PCI
- Full Mini-PCIe
- Half Mini-PCIe

WLAN adapters require a device driver in order to communicate with the operating system, and in most cases software utilities may be installed and/or configured in order to connect the wireless network. This chapter described several installation scenarios for various types of WLAN adapters, including USB and PCI. We also looked at how a WWB can be used to connect computers and other devices on an Ethernet segment to a network by connecting to an access point.

Finally, this chapter showed how WLAN client utilities simplify the process of connecting to a wireless network. Client utilities are sometimes supplied by the manufacturer of the adapter or may part of the operating system. WLAN AutoConfig (Windows 10) is a commonly used operating system client utility.

Exam Essentials

Remember the function and features of the different access point technologies. Compare and contrast the features of autonomous, controller-managed, and cloud-managed access points. Know that autonomous access points are self-contained units, and controller-managed access points work with WLAN controllers. Cloud-managed access points do not require a hardware controller but use cloud-managed software for configuration and management.

Understand differences between various infrastructure devices. Identify the features and applications of wireless access points, wireless bridges, wireless repeaters, and the WLAN controller, and how they differ from one another.

Explain the function and implementation of wireless infrastructure devices such as wireless bridges and wireless repeaters. Understand the different modes in which wireless infrastructure devices operate, as well as the uses for specific devices such as wireless bridges and wireless repeaters.

Explain the differences between PoE devices. Know the differences between power sourcing equipment (PSE) and powered devices (PDs), and know how they are used in wireless networking. PSE devices will supply the DC voltage, and PDs will receive the DC voltage.

Know the details of the IEEE 802.3-2012 Clause 33 (802.3af) and 802.3at PoE amendments to the Ethernet standard. Know that the nominal voltage for PoE is 48 VDC. Identify the different classifications signatures. Understand the difference between midspan and endpoint PoE solutions. IEEE 802.3at allows 34.2 W maximum power per port, while IEEE 802.3-2012 Clause 33 (802.3af) allows for 15.4 W of power maximum.

Know the various types and features of external client adapters used in WLAN clients. Understand the features and function of external client adapters, including USB 2.0 and USB 3.0.

Know the various types and features of internal client adapters used in WLAN clients. Be familiar with internal adapter cards used with 802.11 WLAN technology, including PCI, Mini-PCI, Full Mini-PCIe, and Half Mini-PCIe cards. Understand the installation factors involved with internal network adapters.

Understand the installation process of client adapters and client software. USB 2.0, USB 3.0, PCI, Mini-PCI, and Full and Half Mini-PCIe cards require software components such as a device driver and client utility software to be installed in order to function correctly.

Explain the function and features of specialty client devices. Specialty client devices such as a WWB can be used to connect devices on a common Physical layer cable to a wireless network.

Know the differences among software components of wireless client adapters. Device drivers, client utility software, and third-party client software all play important roles in the successful installation of a wireless client adapter. Understand the details of software components used in wireless networking.

Review Questions

1. In computer network terminology, the definition of half-duplex is closest to which of the following?
   - **A.** One-way communication only
   - **B.** One-way communication one way at a time
   - **C.** Two-way communication both directions simultaneously
   - **D.** Two-way communication one way at a time

2. A self-contained intelligent access point is _____.
   - **A.** Controller-managed
   - **B.** Heavyweight
   - **C.** Autonomous
   - **D.** Thin

3. Wireless bridges must be configured with _____ and _____. (Choose two.)
   - **A.** A null SSID
   - **B.** The same SSID
   - **C.** The same RF channel
   - **D.** Channel scanning
   - **E.** Wired Equivalent Privacy

4. Which of the following are benefits of a wireless repeater? (Choose two.)
   - **A.** Higher data transfer rate.
   - **B.** Larger cell size allows more devices to access the medium.
   - **C.** Smaller cell size allows fewer devices to access the medium.
   - **D.** Less data throughput.
   - **E.** Extends cell size.

5. Which of the following devices is an in-line device that will inject DC voltage into the Ethernet cable?
   - **A.** Midspan
   - **B.** Midpoint
   - **C.** Endspan
   - **D.** Endpoint

6. Access points work at which layers of the OSI model? (Choose two.)
   - **A.** Layer 1
   - **B.** Layer 2
   - **C.** Layer 3
   - **D.** Layer 4
   - **E.** Layer 5
   - **F.** Layer 6
   - **G.** Layer 7

7. Enterprise access points may contain which of the following features? (Choose three.)
   - **A.** WPA 2.0 support
   - **B.** RADIUS server
   - **C.** Static output power
   - **D.** Repeater mode
   - **E.** Power sourcing equipment

8. A controller-managed access point connected to a port on the WLAN controller and not to an intermediate device is considered to have which of the following?
   - **A.** Direct connectivity
   - **B.** Distributed connectivity
   - **C.** Decentralized connectivity
   - **D.** Centralized connectivity

9. Which access point mode involves connecting the access point to a distribution system for user access to the LAN?
   - **A.** Bridge-only mode
   - **B.** Repeater-only mode
   - **C.** Root access point mode
   - **D.** Access mode

10. WLAN controllers may contain which of the following features? (Choose three.)
    - **A.** Centralized administration
    - **B.** Captive portal
    - **C.** Network Address Translation (NAT)
    - **D.** Built-in RADIUS services
    - **E.** IP routing

11. You have a notebook computer and wish to connect to an IEEE 802.11ac wireless network. The computer does not have a built-in WLAN card or a PC card interface. You do not want any peripherals connected to the notebook that use wires and do not want to disassemble the computer. Which wireless adapter would be the best solution?

A. Wireless PCI

B. Wireless PCMCIA

C. Wireless Full Mini-PCIe

D. Wireless USB 2.0

12. Which component is required for a successful installation and operation of an 802.11ac wireless USB adapter?

A. Device driver

B. Client utility

C. Profile software

D. Windows AutoConfig

13. You want to connect a desktop computer to an IEEE 802.11ac wireless network. Which WLAN adapter would be the best solution if you do not want to disassemble the computer?

A. Mini-PCI

B. USB 3.0

C. Half Mini-PCIe

D. PCMCIA

14. How many data bits does serial communication transmit at a time?

A. 1

B. 3

C. 4

D. 8

15. Most manufacturers recommend installing a wireless IEEE 802.11ac USB adapter at what point?

A. When the computer is not powered on

B. When instructed by the setup utility

C. After calling technical support

D. Before starting the setup process

16. Enterprise-grade IEEE 802.11n/ac client utilities typically contain which advanced feature?

A. PCI configuration

B. Spectrum analyzer

C. Setup wizard

D. Site survey

17. A wireless workgroup bridge will allow you to do which of the following?
    - **A.** Connect two WLAN NICs together
    - **B.** Connect a wired LAN to an access point
    - **C.** Connect a PCI card to a WLAN
    - **D.** Connect two client bridges

18. Which WLAN adapter can be installed in a computer without the need to disassemble the computer in any way?
    - **A.** PCI
    - **B.** USB 3.0
    - **C.** PCIe
    - **D.** Mini-PCI

19. A device driver can be used in wireless networking. Which is an example of a device driver?
    - **A.** Software to control a wireless NIC
    - **B.** Software to control the operating system
    - **C.** Hardware to install a PCI card
    - **D.** Hardware to install a client bridge

20. Which is required in order to successfully install an IEEE 802.11ac WLAN adapter?
    - **A.** Security profile
    - **B.** Device driver
    - **C.** Third-party client utility
    - **D.** SOHO utility

Chapter

4

Radio Frequency Fundamentals for Wireless Networking

THE FOLLOWING CWTS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ 1.2 Define basic characteristics of and concepts relating to Wi-Fi technology
- ✓ 3.1 Define the basic concepts and units of RF measurements, identify when they are used, and perform basic unit conversion
- ✓ 3.2 Identify and explain RF signal characteristics
- ✓ 3.3 Identify factors which affect the range and rate of RF transmissions

THE FOLLOWING CWS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ 1.1 Identify RF characteristics
- ✓ 1.2 Explain basic RF behaviors
- ✓ 2.1 Know the frequency bands used
- ✓ 2.3 Select appropriate channels
- ✓ 3.3 Determine capabilities of client devices

THE FOLLOWING CWT EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ 1.1 Describe RF signal characteristics
- ✓ 1.2 Explain RF behaviors and signal propagation

- ✓ **1.3 Understand how to detect RF signal factors**
- ✓ **1.4 Create basic RF channel plans**
- ✓ **2.4 Determine the channels and streams supported by client devices**
- ✓ **5.2 Troubleshoot performance problems**

Radio frequency (RF) plays an essential role in wireless LAN (WLAN) technology. Radio waves are passed through the air (which is the medium) and are used to get information from one wireless device to another. Technically speaking, with respect to WLANs, RF consists of high-frequency alternating current (AC) signals passing over a copper cable connected to an antenna. The antenna then transforms the signal into radio waves, which propagate through the air from a transmitter to a receiver.

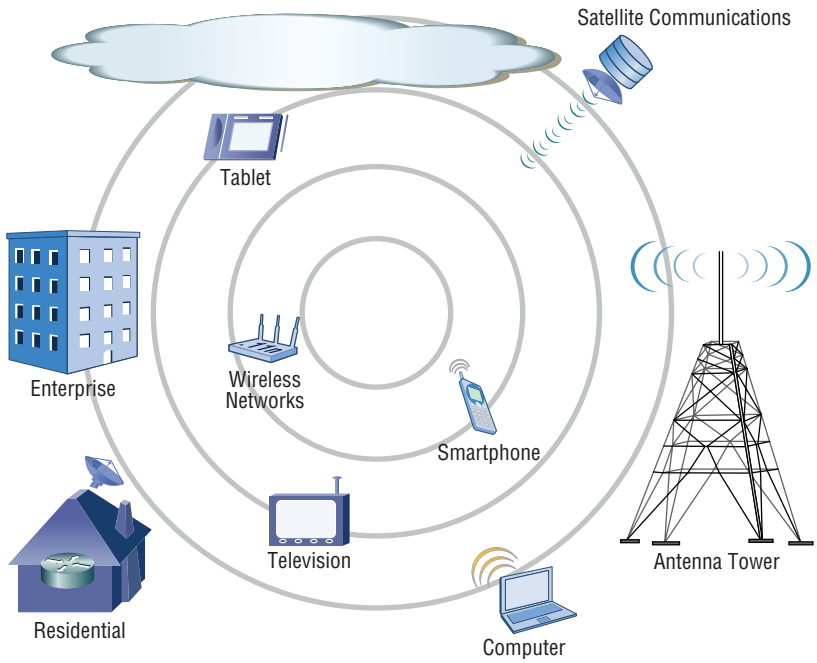
Unlike wired devices, which use physical cable to communicate, WLANs use the radio waves and the air to communicate. This chapter will discuss the characteristics of RF and explain how far a radio signal will travel depending on various factors, the area covered by the RF propagation, and some of the factors determining how many clients or devices can use the RF signals for data communications. This chapter will also explain the range and speed of RF transmissions. Range (how far radio waves will travel) and speed can be affected by several environmental conditions or behaviors, such as reflection and refraction. Additionally, this chapter will examine some of the conditions that affect the transmission of information across the air, including interference.

Understanding RF units of measure, such as watts (W), milliwatts (mW), and decibels (dB), is important to RF work, just as understanding denominations of money is an important part of daily life. We will discuss RF signal measurements, including receiver sensitivity, received signal strength indicator (RSSI), and signal-to-noise ratio (SNR).

Understanding Radio Frequency

Radio frequency (RF) waves are used in a wide range of communications, including radio, television, cordless phones, WLANs, and satellite communications. RF is around everyone and everything, and comes in many forms. RF energy is emitted from the numerous devices that use it for various types of communications. For the most part, it is invisible to humans. There is so much of it around that if you could actually see RF, it would probably scare you. Don't let it scare you, however, because the amount of regulated RF power transmitted from the devices used with wireless computer networking is harmless. Figure 4.1 shows some of the many ways RF is used. Studies have shown that the amount of power emitted from many of these devices, such as cordless telephones or wireless network adapters, will not cause any physical harm if the devices are manufactured not to exceed the maximum regulated power allowed for the device.

FIGURE 4.1 Radio frequency is used in many different devices to provide wireless communications.



Remember, RF consists of high-frequency alternating current (AC) signals passing over a copper cable connected to an antenna. This antenna will then transform the received signal into radio waves that propagate through the air. The most basic AC signal is a *sine wave*, which is the result of an electrical current varying uniformly in voltage over a period of time. This sine wave cycle will repeat a specific number of times (cycles) over a period of one second. The number of cycles per second will result in different frequencies. Figure 4.2 shows a basic sine wave.

Successful radio transmissions consist of a minimum of two components, a *transmitter* and *receiver* (see Figure 4.3). With IEEE 802.11 wireless networking, a wireless station can transmit and receive and is known as a transceiver. These two components work together: For every radio transmitter, there must be one or more radio receivers. It is important to understand the basic characteristics of RF transmissions. These characteristics work together to form AC signals and include the wavelength, frequency, amplitude, and phase. The antenna will transform these signals into radio waves that travel through the air carrying information from the transmitter to the receiver. This is accomplished in different ways, depending on the wireless technology in use. This theory will be discussed more in Chapter 5, "Antenna Technology for Wireless Networking."

FIGURE 4.2 A basic sine wave, one complete cycle varying voltage at a point in time

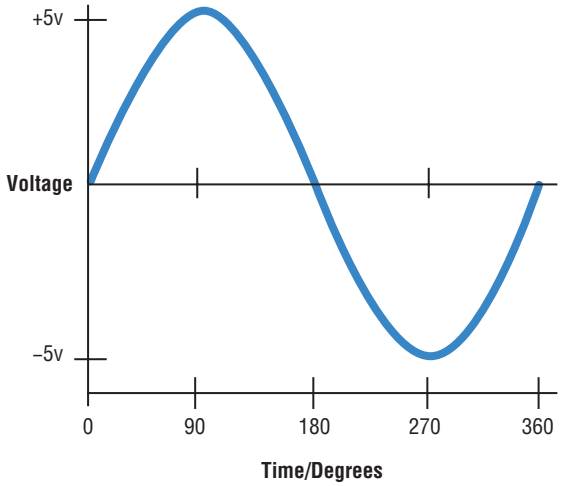
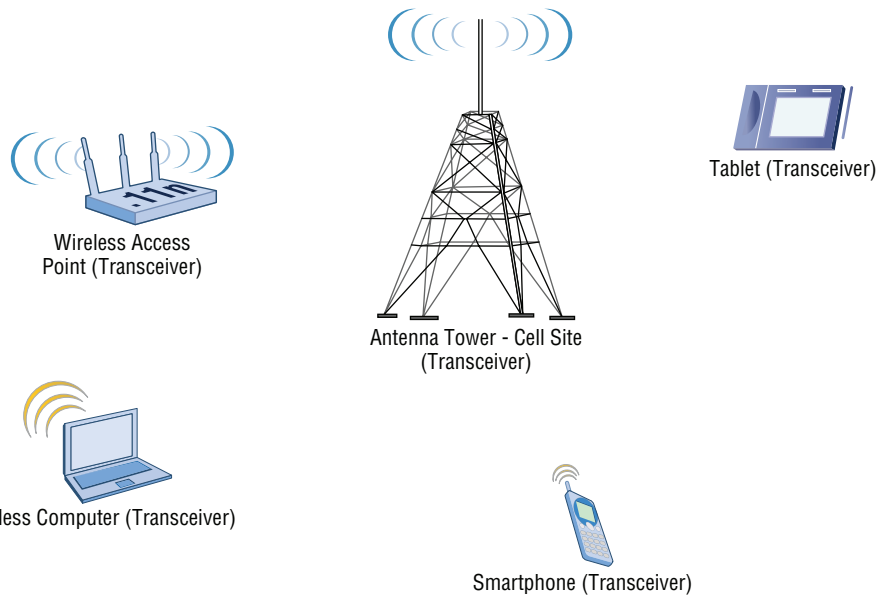


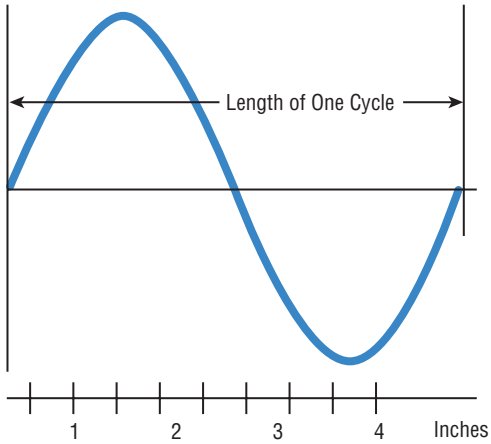
FIGURE 4.3 RF transmitter and receiver. In a WLAN, the transmitter and receiver could be an access point and client device, respectively.



Wavelength in Wireless LANs

The *wavelength* is the distance of one complete cycle, or one oscillation, of an AC signal. Wavelength is typically identified by the Greek symbol lambda, λ, which is used in formulas for calculations. This distance is usually measured in centimeters or inches. Figure 4.4 shows an example of a wavelength.

FIGURE 4.4 The wavelength is the distance of one complete cycle, measured in centimeters or inches.



2.437 GHz Channel 6 ISM Band, Approximately 4.85 Inches

IEEE 802.11 WLANs currently use both the 2.4 GHz and 5 GHz unlicensed frequency ranges for transmission. The IEEE 802.11-2016 standard also specifies some additional frequency ranges in which WLANs can operate. Although these do not fall under the "unlicensed" category, 4.9 GHz public safety and 3.650 GHz (IEEE 802.11y amendment) can also be used for IEEE 802.11 WLAN communications. Table 4.1 lists some examples of wavelengths for IEEE 802.11 WLANs using unlicensed frequencies.

TABLE 4.1 Typical radio transmission wavelengths for WLANs

RF Channel	Frequency (GHz)	Length (in)	Length (cm)
6	2.437 GHz	4.85 in	12.31 cm
40	5.200 GHz	2.27 in	5.77 cm
153	5.765 GHz	2.05 in	5.20 cm

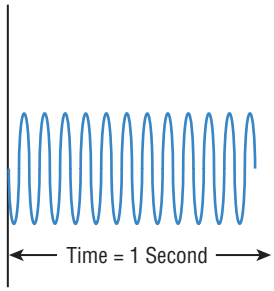
The IEEE 802.11ah amendment (also known as *Wi-Fi HaLOW*) allows for WLAN operation in frequency bands below 1 GHz (also called the *Sub 1 GHz band*, or S1G). This allows for long-range, low-power connections using an unlicensed frequency, including the 900 MHz frequency band. The actual frequency ranges used vary based on regulatory domains. The driving force behind this amendment is the Internet of Things (IoT) devices.

Frequency in Wireless LANs

Frequency is defined as the number of complete cycles in one second. Low frequencies correspond to long waves, and high frequencies to short waves; so, the higher the frequency, the shorter the wavelength (range). From a WLAN perspective, if all things were equal, such as radio transmit power and antenna gain, the range of a 2.4 GHz signal would be approximately twice as far as a 5 GHz signal because of the difference in wavelengths. In formulas, frequency is typically identified by the lowercase letter *f*.

Figure 4.5 shows an example of frequency.

FIGURE 4.5 Frequency is the number of complete cycles in one second.



How Far Can a Signal Travel?

A few years back, 900 MHz cordless telephones were very popular. Cordless telephones were introduced in the 1970s, and in 1990 the FCC opened the 900 MHz range for these telephones. With a 900 MHz phone, you could hypothetically go up to 500 feet away from the cordless phone's base station before losing the signal and no longer being able to make a phone call. In the past few years, higher-frequency phones have increased in popularity. After upgrading to a 2.4 GHz phone, you may have noticed you can get only about 250 feet away (half the distance compared to a 900 MHz phone) in the same environment before losing the signal. This is because the 2.4 GHz wavelength is about half the distance of a 900 MHz wavelength, assuming both phones are operating at the same output power. With 5.8 GHz cordless telephones, the range is still less, assuming the same amount of transmit power.

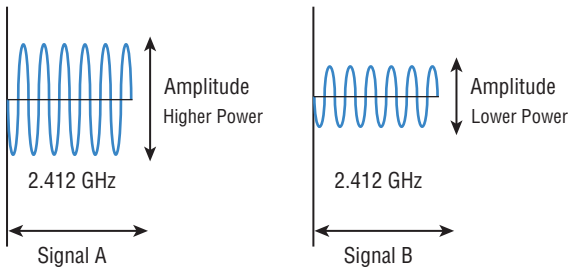
IEEE 802.11 WLANs work in several unlicensed frequency ranges. The unlicensed ranges used for WLANs are from 2.4 GHz to 2.5 GHz and from 5.15 GHz to 5.875 GHz. There are some areas in the 5.15 GHz to 5.875 GHz range that are not used for standards-based wireless networking. With respect to wireless networking, think of the wavelength and frequency as the range or distance a signal will propagate.

Amplitude in Wireless LANs

From a WLAN perspective, the *amplitude* is the strength or the amount of power of an RF signal. This is calculated from the height (in a two-dimensional view), on the y-axis of the sine wave, representing the voltage. A basic sine wave is a change in voltage over a period of time. Using a formula, the voltage at the peak of the signal can be used to calculate the amount of RF power. So an increase in amplitude is equal to an increase in RF power. An increase in power is also known as *gain*. Conversely, any decrease in amplitude will be a decrease in power. A decrease in power is known as *loss*. If a transmitter outputs a certain amount of RF power (for example, 100 mW0, then it has a specific amplitude of some value. As this signal travels through an RF cable, it will have a specific level of loss based on the type and length of cable in use, resulting in attenuation. Therefore, the result will be less amplitude at the end of the cable due to the loss value of the cable.

Figure 4.6 shows two signals operating at the same frequency with different amplitudes. The signal with the higher amplitude (Signal A) is more powerful than the signal with the lower amplitude (Signal B). With respect to wireless networking, think of the amplitude as the amount of transmitted or received RF power.

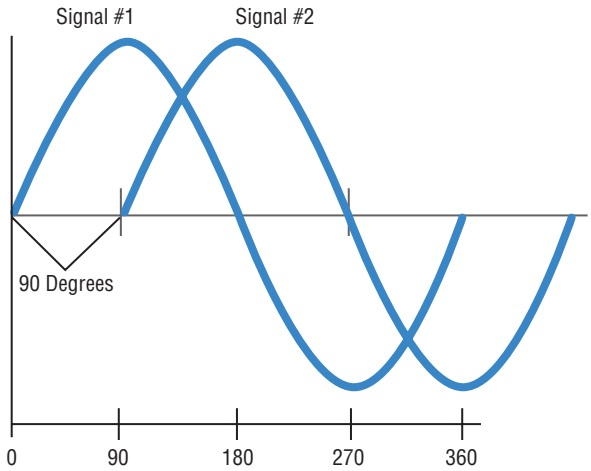
FIGURE 4.6 Two signals at the same frequency with different amplitudes



Phase in Wireless LANs

Phase is the difference in degrees at a particular point in the time of a cycle, measured from some arbitrary zero and expressed as an angle. For example, if a second sine wave starts a quarter of a wavelength after the first sine wave, it is considered to be 90° out of phase with the first sine wave. Figure 4.7 shows an example of the phase relationship between two AC signals. Two radio waves that have the same frequency but start at different times are known to have a *phase difference* and are considered out of phase with one another. The amount of the phase difference is typically measured in degrees, ranging from 0° to 360°.

FIGURE 4.7 Phase is the difference in degrees between two signals.



Waves that arrive at a receiver out of phase will experience some level of distortion, which will cause corruption in a single radio system. This is known as *multipath*. The difference in time of arrival of the main signal and a reflected signal that causes the multipath problem is called the *delay spread*. If two waves arrive at a receiver 180° out of phase, this will usually result in a cancellation effect or nullify the two signals. Conversely, two waves that arrive in phase are additive, and this will result in an increase in signal strength known as *upfade*. Keep in mind, however, that the amplitude of the waves that experience the upfade effect will never be higher than the wave transmitted. With respect to wireless networking, think of the signal phase as it pertains to interference (multipath) and the modulation of an RF signal.

Radio Frequency Used in Wireless LANs

As discussed in Chapter 2, "Wireless Local Area Networking, Standards and Certifications," RF *spectrum* is governed by local regulatory agencies. The country where the RF is used determines the regulations, such as frequency use and maximum power. Table 4.2 illustrates examples of local RF regulations.

TABLE 4.2 Examples of local RF regulations

Location	Regulation
Canada	ISC RSS-210
China	RRL/MIC Notice 2003-13

TABLE 4.2 Examples of local RF regulations *(continued)*

Location	Regulation
Europe (ETSI)	ETS 300.328ETS 301.893
Israel	MOC
Japan (MKK)	TELEC 33BTELEC ARIB STD-T71
Singapore	IDA/TS SSS Issue 1
Taiwan	PDT
United States	FCC (47 CFR) Part 15C, Section 15.247FCC (47 CFR) Part 15C, Section 15.407

U.S. (FCC) Unlicensed Frequency Bands

In the United States, the Federal Communications Commission (FCC) is the local regulatory agency responsible for regulating licensed and unlicensed radio spectrum. Listed are the unlicensed RF bands available in the United States for use with wireless communications:

- ISM (Industrial, Scientific, and Medical):
  - 902–928 MHz
  - 2.400–2.4835 GHz
  - 5.725–5.875 GHz
- UNII (Unlicensed National Information Infrastructure):
  - 5.15–5.25 GHz: UNII-1, lower
  - 5.25–5.35 GHz: UNII-2, lower middle
  - 5.470–5.725 GHz: UNII-2e, upper middle
  - 5.725–5.825 GHz: UNII-3, upper

The 5.725–5.875 GHz UNII band is used in the United States for a single channel (165). The IEEE 802.11-2016 Standard Clause 17 section 17.3.8.4.1 reads, "The OFDM PHY shall not operate in frequency bands not allocated by a regulatory body in its operational region. Regulatory requirements for a given frequency band are set by the regulatory authority responsible for spectrum management in a given geographic region or domain." The FCC allows this frequency for IEEE 802.11 wireless networking. It is important to note that as of April 2014, the FCC rules changed and channel 165 (5.825 GHz), which was previously categorized as an ISM channel, now falls under the UNII band.

The IEEE 802.11 standard addresses the 2.4 GHz ISM band and the 5 GHz UNII band. In the United States, the 2.4 GHz ISM band allows for 11 of 14 total channels to be used for WLAN communications. The 5 GHz UNII band consists of four bands utilizing four frequency ranges: UNII-1, the lower band; UNII-2 and UNII-2e, the middle bands; and UNII-3, the upper band. Table 4.3 shows unlicensed frequency bands and channels used by IEEE 802.11 WLAN technology. Keep in mind that the 5.725–5.875 GHz UNII band is used where allowed by the regulatory agency.

TABLE 4.3 IEEE 802.11 frequency and channel allocations

Band	Frequency	Number of Channels
ISM	2.400–2.500 GHz	14
UNII-1	5.150–5.250 GHz	4
UNII-2	5.250–5.350 GHz	4
UNII-2e	5.470–5.725 GHz	12
UNII-3	5.725–5.825 GHz	5

A chart of the United States frequency allocations is available from the National Telecommunications and Information Administration. To view this chart, visit `www.ntia.doc.gov/osmhome/allochrt.pdf`.

Radio Frequency Channels

As you have seen, RF is divided into bands. These bands can be further separated into *channels*. A channel is a smaller allocation of a RF band. One familiar application in which this is accomplished is television. Until over-the-air television became available in digital format, television was allocated certain frequency ranges. Common television channels operated in the very high frequency (VHF) band—for example, channels 2 through 13 operated from 54 through 216 MHz. This frequency range was divided into 12 channels, allowing optimal use of the frequency range for the application—in this case, television signals.

A viewer can change channels on a television to watch different programs running simultaneously. Only one program can be viewed at any one time, however, depending on which channel is currently selected. (Picture-in-picture televisions can show two or more channels at once on the screen, but each picture is still being received on a different channel.)

WLANs use channels in the same way. Certain unlicensed frequency ranges are allocated for wireless networking, and those frequency ranges are subdivided into channels. In order for a transmitter and receiver to communicate with one another, they must be on the same channel. The 2.4 GHz ISM band has a total of 14 channels available for wireless networking. The locale where they are used will determine which of the 14 channels can be legally used for wireless networking. In the United States, IEEE 802.11b/g/n wireless networks use 11 of the 14 channels available in the 2.4 GHz ISM band. Each of these 11 channels for DSSS or HR/DSSS technology is 22 MHz wide, and for OFDM technology it is 20 MHz wide. Understand that these channels are further defined by their center frequency; for example, Channel 1 in the 2.4 GHz ISM band has the center frequency at 2.412 GHz. Simple arithmetic shows there will be overlap in order to accommodate all of the 20 MHz or 22 MHz wide channels in this frequency range. Table 4.4 shows the 14 available channels in the 2.4 GHz range.

TABLE 4.4 Channels in the 2.4 GHz ISM band

Channel Number	Center Frequency in GHz	United States	Europe	Israel*	China	Japan
1	2.412	✔	✔	✔	✔	✔
2	2.417	✔	✔	✔	✔	✔
3	2.422	✔	✔	✔	✔	✔
4	2.427	✔	✔	✔	✔	✔
5	2.432	✔	✔	✔	✔	✔
6	2.437	✔	✔	✔	✔	✔
7	2.442	✔	✔	✔	✔	✔
8	2.447	✔	✔	✔	✔	✔
9	2.452	✔	✔	✔	✔	✔
10	2.457	✔	✔	✔	✔	✔
11	2.462	✔	✔	✔	✔	✔
12	2.467		✔	✔		✔
13	2.472		✔	✔		✔
14	2.484					✔

*Israel allows only channels 5–13 outdoors, but 1–13 indoors.

The 5 GHz UNII band is also divided into channels. This band consists of four bands—lower, lower middle, upper middle, and upper. These four bands consist of four different frequency ranges. Since there are fewer channels in the same amount of space, channels in the UNII band do not overlap. In the 5 GHz UNII band, channels are 20 MHz wide. Table 4.5 shows the 5 GHz UNII band for the FCC and ETSI locales.

TABLE 4.5 Number of available channels in the 5 GHz band

Locale	Frequency Range	Number of Channels
Americas/EMEA	UNII-1 band (5.15–5.25)	4
Americas/EMEA	UNII-2 band (5.25–5.35)	4
Americas/EMEA	UNII-2e band (5.470–5.725)	12
Americas/EMEA (with restrictions)	UNII-3 band (5.725–5.825)	5

Radio Frequency Range

RF *range* for WLANs is based on the wavelength or distance of a single cycle—the higher the RF, the shorter the range of the signal; and the lower the frequency, the longer the range of the signal. At the same output power level (amplitude), a 2.4 GHz signal will travel almost twice as far as a 5 GHz signal. If the transmit power of a 2.4 GHz or 5 GHz device were increased or decreased, the range of the signal would also be affected. If a network design is planning to use dual-band access points, range will need to be considered to ensure proper coverage for both the 2.4 GHz ISM and 5 GHz UNII bands. A wireless site survey will help determine the usable range an access point will produce. A survey can involve physically walking around the proposed space and/or predictive modeling using one of many software programs. This process is discussed further in Chapter 9, "Design for Wireless Networking."

Wireless LAN Coverage and Capacity

Coverage and capacity are two key factors to take into consideration when designing and implementing an IEEE 802.11 WLAN. During the design phase of an IEEE 802.3 wired network, the design engineer will take capacity into account, verifying and validating that there are enough capacity switches, ports, and so on, for the user base of the network. The same is true for a wireless network. The number of devices/users connected to an access point and the applications they perform need to be carefully considered. The fact that wireless networks use a shared medium is an issue, because the more devices that are connected to an access point, the lower the performance may be, depending on what the devices are

doing. This capacity consideration will ensure satisfied end users and excellent network performance—proof of a successful wireless network design and deployment.

In wireless networks, coverage also needs to be considered. Coverage is determined by the RF cell size. In IEEE 802.11 wireless networks, a cell is the area of RF coverage of the radio transmitter—in most cases, an access point. Depending on implementation, wide coverage or large cell size may not be the best solution. A large space covered by a single access point could result in less than adequate network performance based on factors such as the user's distance from the access point. The farther away from an access point, the less throughput a device or user will experience. This is because a weaker received signal will use a lower signaling rate due to the ability of a receiver to effectively demodulate the signal. The proprietary dynamic rate switching (DRS) process will allow an associated wireless device to adapt to the RF signal strength and signal quality in a particular location of the basic service area. As a wireless device moves away from an access point, the amount of received signal will decrease because of the free space path loss. When this occurs, the modulation type will change because the RF signal quality is less and thus a lower data rate will be realized. If users will be scattered throughout a large space, it will be best to have several access points covering the space to allow for optimal performance.

The term *cell* has several different meanings, depending on the context. In the world of IEEE 802.11 wireless networks, a cell is the radio coverage area for a transmitter such as an access point or a client device.

Wireless LAN Coverage

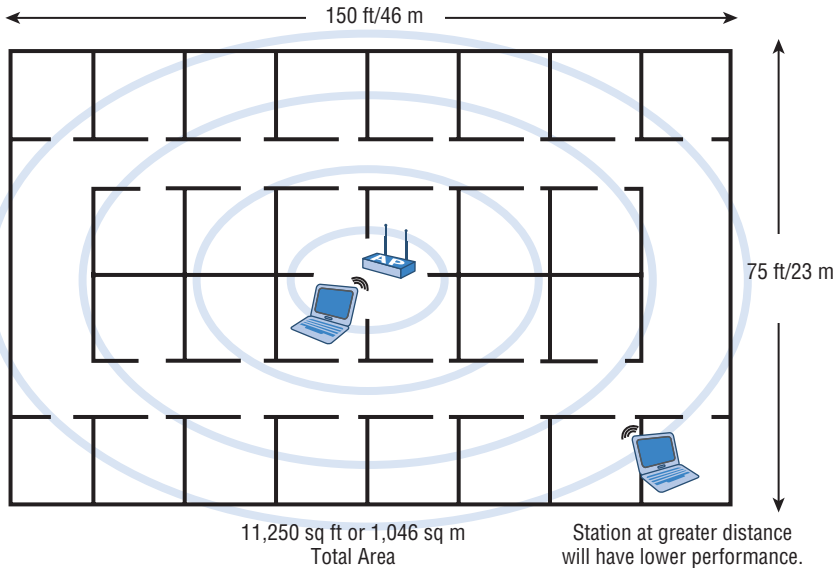
The term *coverage* has different meanings, depending on the context in which it used. For example, if you buy a gallon of paint, the label will specify the approximate coverage area in square feet (sq ft). If one gallon of paint covers 300 sq ft and the room you wish to paint is 900 sq ft, simple arithmetic shows at least three gallons of paint would be needed to effectively cover the room.

The concept is similar in IEEE 802.11 wireless networking. Unlike with paint, however, there is no simple rule that determines how much space an access point will cover with the RF energy it is transmitting. This coverage will depend on many factors, some of which include:

- Physical size of the area
- Bandwidth-intensive software applications in use or hardware applications, which may negatively impact the performance, thereby requiring smaller RF coverage cells
- Obstacles, including building materials and propagation (the way radio waves spread through an area)
- RF range
- WLAN hardware in use, which affects coverage because higher frequencies, such as 5 GHz, do not travel as far as lower frequencies, such as 2.4 GHz
- Transmitter output power

You might initially assume that you want the RF signal to propagate over the largest area possible. But this may not be the best solution. A very large cell may allow too many devices to connect to a single access point, causing a decrease in overall performance. For those client devices connected at a greater distance, the performance will be lower than for stations closer to the access point. Figure 4.8 shows a large coverage area, approximately 11,250 sq ft (1,046 sq m) covered with a single access point. This is an example of too large an area for a single access point.

FIGURE 4.8 Wide coverage with only a single access point is not recommended.



Physical Size of the Area

Rarely, if at all, will a manufacturer of enterprise-grade IEEE 802.11 WLAN hardware commit to the amount of area an access point will cover. There are too many variables to take into consideration, which makes it difficult to specify an exact number. Some manufacturers, however, may estimate the effective range of the device or access point. A site survey of the area will help determine the coverage area of an access point. A manual survey will allow for testing to verify the distance a signal will travel. A predictive site survey will model the environment and determine the signal propagation. Chapter 9 discusses this concept further.

Applications in Use

The application types in use—either software or hardware—can affect the bandwidth of an access point. If the devices connected to an access point use bandwidth-intensive applications, such as a computer-aided design/computer-aided manufacturing (CAD/CAM)

application, it could result in poor throughput for all devices or users connected to that access point due to device contention and the shared medium. This is another example of where more access points, with each covering a smaller area, could be a better solution than a single access point covering a large area. Multiple access points could allow the high-bandwidth users to be separated from other parts of the network, increasing overall performance of the network.

Obstacles, Building Materials, Propagation, and Radio Frequency Range

Obstacles in an area, including building materials such as walls, doors, windows, and furnishings, as well as the physical properties of these obstacles—thickness of the walls and doors, density of the windows, and type of furnishings—can also affect coverage. The RF used, either 2.4 GHz or 5 GHz, will determine how well a signal will propagate and handle an obstacle.

For example, a wall made from sheetrock or drywall materials may have an attenuation value of about 3 dB to 4 dB, whereas a wall made of concrete may have an attenuation value of about 12 dB. Keep in mind that a 3 dB loss is actually one half of the amount of RF power. Therefore, the sheetrock wall would have less impact on the RF propagation than the concrete wall. Partitions, walls, and other obstacles will also determine the coverage pattern of an access point because of the way RF behaves as it travels through the air. Behaviors of RF will be discussed later in this chapter in the section "Environment: Radio Frequency Behavior."

Wireless LAN Hardware and Output Power

The WLAN hardware in use can also have an impact on the coverage area. Examples include the antenna type, antenna orientation, and gain of the antenna. The higher the gain of an antenna, the greater the coverage area can be; conversely, the lower the gain of an antenna, the smaller the coverage area. The polarization of an antenna (horizontal vs. vertical) will also have an effect on the coverage area because of the different shapes of the radiation patterns. The output power of the transmitter or access point will also have an effect on coverage. The higher the RF transmit power, the greater distance a signal will propagate. A higher power signal will provide more coverage. Most enterprise-grade access points provide the capability to control or adjust the output power.

Wireless LAN Capacity

One definition of *capacity* is the maximum amount that can be received or contained. An example of this would be an elevator in a building. An elevator typically will have a maximum number of people or amount of weight it can hold; this is usually stated on a panel within the elevator. To ensure safety, the elevator may have a safety mechanism to prevent overloading. Likewise, a restaurant has a certain number of chairs to hold customers; therefore, they would have a maximum capacity of customers who can be served at any one time. Does this mean that when a restaurant fills its seats to capacity, the doors close

and no other customers can enter the building? Not necessarily. In some cases, a restaurant could have customers standing and waiting to be seated.

Just as an elevator or a restaurant has a limited number of people they can accommodate comfortably, wireless access points also have a limited number of devices and bandwidth they can handle, known as *capacity*. The capacity of an access point is how many devices or users the AP can service effectively, offering the best performance. This capacity depends on several factors, including:

- Software and hardware applications in use
- Desired throughput or performance
- Number of devices/users

The following sections discuss how these factors affect the capacity of an access point.

Real World Scenario

What Happens When an Access Point Is Overloaded?

If the capacity of a single access point has exceeded the maximum number of users or devices based on the performance metrics, access points may need to be added. If a wireless network is installed correctly, an access point will not be overloaded with an excessive number of users. An overloaded access point will result in poor performance and therefore unhappy users.

Consider the restaurant example. If a restaurant seats 20 customers and all 20 seats are taken, the restaurant has reached its capacity. Let's say the restaurant is short-staffed because two servers did not show up for work. The servers who did show up will have to work extra hard to handle the customers. This may cause delays in service because the servers need to handle more than their normal number of tables. The delays may result in unhappy customers.

The same is true for wireless access points. If a wireless access point has reached its capacity, it could get overloaded. This would result in its taking longer to handle any individual request for access. The delays may result in unhappy users. This situation could justify adding another access point in the area to handle the additional users. Just as a restaurant will not close its doors when all seats are taken, an access point will continue to accept users to connect unless restrictions, such as load balancing, are implemented.

Software and Hardware Applications in Use

The software and hardware applications in use may affect the capacity of an access point. Some applications are more bandwidth-intensive than others. For example, word processing applications may not require much bandwidth, whereas database or CAD/CAM applications may require much more bandwidth than other applications. If high-bandwidth

applications are in use, the contention among the connected users will increase because they are using a shared medium (air and RF). Therefore, performance will potentially be reduced for all users connected to the access point. The access point is providing the same amount of bandwidth, but the overall performance has been decreased for the connected users because the software applications are all using a lot of bandwidth.

The use of Voice over Wireless LAN (VoWLAN) technology continues to increase in many wireless network deployments. This is an example of a hardware application. Voice technology on wireless networks is subject to latency. Therefore, depending on the number of voice client devices connecting to an access point, the network must be carefully planned. Capacity planning and quality of service (QoS) features are important when it comes to deploying voice technology on wireless networks.

Desired Throughput or Performance

The desired *throughput* or performance can also affect capacity. A large number of users connected to an access point using a bandwidth-intensive application will cause poor performance. Therefore, it may be necessary to limit the capacity to a certain number of users to give the connected users the best performance possible. Any software application that is bandwidth-intensive, such as CAD/CAM, streaming video, or File Transfer Protocol (FTP) downloads, can affect overall performance. One way to help resolve this would be to use a load-balancing method to limit the number of users who can connect to an access point. Another way would be to create RF cells with smaller coverage areas and add more access points.

Number of Devices/Users

The number of connected devices in an area will also affect the access point capacity. A single access point covering a large area will potentially allow for a large number of devices connecting to the access point. For example, an office of 8,000 sq ft may consist of 100 people, each with their own wireless device. This is an example of wide coverage and large capacity. The software applications in use on the wireless network will have an impact on the overall performance. If all 100 devices connected are using a CAD/CAM application, which is a bandwidth-intensive application, the overall performance will be poor because this type of application requires a lot of resources. Therefore, more access points, each covering less space and less capacity, would parlay into better overall performance for all of the users.

Wide coverage in a densely populated area may allow too many devices to connect to a single access point, resulting in poor performance overall. WLANs use what is known as a *shared medium*. In other words, all devices users connected to an access point will share the available bandwidth. Too many devices using powerful applications will overload the access point, adding to the poor performance issues. This scenario is considered a capacity issue. In this situation, more access points with each AP covering a smaller area and a lower number of devices or less capacity would be a better solution. As you learned in Chapter 3, "Infrastructure and Client Devices Used with Wireless Networking," many organizations now have to deal with the "bring your own device" (BYOD) issue.

In addition to potential problems with technical support and security, WLAN capacity is also a major concern. The BYOD expansion of Wi-Fi devices is causing a wireless client

device density issue within the enterprise market. If a company's corporate policy allows employees to bring their own wireless capable devices, then WLAN capacity needs to be carefully evaluated to address this potential issue.

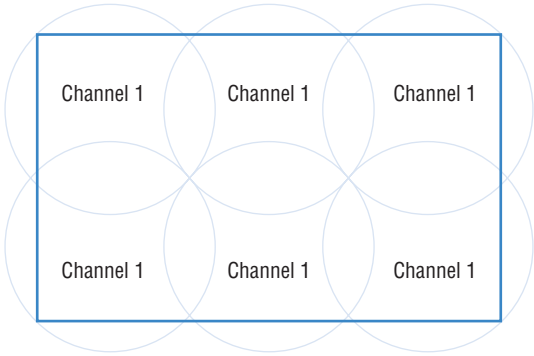
Radio Frequency Channel Reuse and Device Co-location

The 2.4 GHz ISM band has a total of three nonoverlapping channels. In the U.S. FCC implementation of this band, the three nonoverlapping channels are 1, 6, and 11. This means there must be a separation of five channels in order for them to be considered nonoverlapping. In the 2.4 GHz ISM band, channels are separated by 5 MHz on center. Taking this into consideration, channels must be separated by 25 MHz or greater in order to be considered nonoverlapping (IEEE 802.11-2016, Clause 16). This is calculated from five channels of separation multiplied by 5 MHz on center (5 × 5 = 25). With deployments larger than a few access points, a channel plan may be necessary. A channel plan will minimize the chance of interference caused by two transmitters (access points) set to the same or adjacent overlapping channels.

The IEEE 802.11-2016 Clause 15 specifies 30 MHz or greater of separation to be considered nonoverlapping: "Adjacent channel rejection is defined between any two channels with ≥ 30 MHz separation in each channel group defined in 15.4.4.3." Keep in mind that this specification is for 802.11 DSSS. For HR/DSSS (IEEE 802.11-2016, Clause 16), channels must be separated by 25 MHz or greater in order to be considered nonoverlapping.

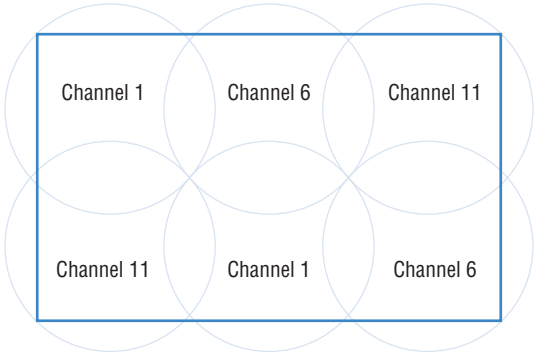
Figure 4.9 illustrates a 2.4 GHz deployment with no channel planning. Users in the areas where the circles overlap will experience interference. This interference will result in lower overall throughput for the connected users because of the Physical layer (PHY) technologies that WLANs use. This interference basically has the same effect as collisions in an Ethernet network, resulting in retransmissions of data.

FIGURE 4.9 Users of these access points will experience overlapping channel interference in a multichannel architecture because they are all set to the same channel.



A correct channel plan will implement channel reuse and ensure that overlapping cells will not use overlapping channels. Channel reuse is using nonoverlapping channels—for example 1, 6, and 11 in the 2.4 GHz range—in such a way that the overlapping cells are on different RF channels. Figure 4.10 shows a 2.4 GHz deployment utilizing proper channel reuse. Channel reuse may be accomplished by mapping out the access points on a floor plan and minimizing the chances that the RF cells propagated by the access points do not overlap on the same RF channels. This type of channel plan can be done manually or with site survey software applications. Site survey applications will be discussed in more detail in Chapter 9. In parts of the world where the regulatory agency allows WLAN use of channels 12, 13, and 14 in the 2.4 GHz ISM band it may be possible to utilize four channels (1, 5, 9, and 13) instead of the more common three non-overlapping channels of 1, 6, and 11.

FIGURE 4.10 Co-location of access points with proper channel reuse. Overlapping areas use different channels in a multichannel architecture to prevent interference.



Radio Frequency Range and Speed

How far and fast a RF signal travels depends on a variety of factors, including line of sight, RF interference, and the types of materials within the environment. This section discusses these factors.

Line of Sight in Wireless Networking

RF communication between devices in 802.11 wireless networking uses different types of line of sight. There are two types of line of sight to take into account when planning, designing, and installing wireless networks:

- Visual line of sight
- Direct link RF line of sight

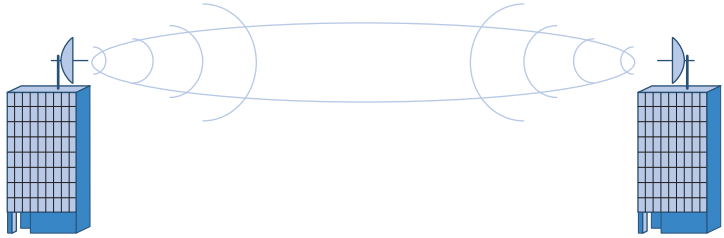
Visual line of sight is when a transmitter and receiver can "see" each other. In order for wireless networking direct link communication to be successful in an outdoor wireless link, there should be a clear, unobstructed view between the transmitter and receiver. An

unobstructed line of sight means few or no obstacles blocking the RF signal between these devices.

In an outdoor WLAN installation, *direct link RF line of sight* is an unobstructed line between a radio transmitter and receiver. This line will be surrounded by an area of RF transmissions known as the *Fresnel zone*. The Fresnel zone consists of a number of concentric ellipsoidal volumes that surround the direct RF line of sight between two points, such as an RF transmitter and receiver or two wireless bridges.

In outdoor WLAN installations, the RF line of sight, and therefore the radio transmissions between a transmitter and receiver, could be affected if the total area of the Fresnel zone is blocked by more than 40 percent. This blockage can come from a variety of sources, such as trees, buildings, terrain, or other obstacles, including the curvature of the earth over a distance of 7 miles (11.2 km) or greater. Figure 4.11 illustrates a Fresnel zone.

FIGURE 4.11 The oval area represents the Fresnel zone RF coverage area between a transmitter and receiver, two wireless bridges in a point-to-point connection.



One way to think about line of sight is by the analogy of two people looking at each other. If two people about the same height standing some distance apart are making direct eye contact, they have a good visual line of sight. In addition to being able to see directly in front of them, people have peripheral vision. This peripheral vision gives people the ability to see movement and objects outside of their direct line of sight or direct eye contact. This peripheral vision or side vision is analogous to the Fresnel zone theory. Exercise 4.1 provides a fun way to conceptualize a Fresnel zone on your own.

EXERCISE 4.1

Demonstrating Fresnel Zone and Blockage

Here is one way to demonstrate the Fresnel zone. Focus your eyes at a location on a wall. Make sure there are obstacles or movement off to both left and right sides of your view. Hold your hands down to your sides. Continue to focus your eyes for a minute or so, and then take your right, left, or both hands and slowly raise them from your sides toward the side of your head while blocking your peripheral vision. You'll notice as your hands get closer to the side of your head, the view of the objects or movement to the sides will be blocked by your hands. This is an example of a blocked Fresnel zone.

Sixty percent at a minimum of the total area of the Fresnel zone must be clear of obstacles in order to have RF line of sight.

Because of the low transmit and receive power and the short distance, a visual line of sight is not required for an indoor WLAN deployment. An indoor access point may cover areas that are divided by walls, ceilings, and other obstacles. With this short range and if the RF is able to penetrate the obstacles, wireless communication between a transmitter and a receiver will be successful even when the devices do not have a visual line of sight.

Wi-Fi and Non–Wi-Fi Interference

Interference, from a RF point of view, occurs when a receiver hears two different signals on the same or close frequency. *Interference* causes received RF signals to be distorted. In WLANs, this interference can have a severe impact on the quality of signal received by a wireless device. This distorted or corrupted signal will decrease the amount of data a device can effectively receive, thereby causing less data throughput.

A WLAN receiver has similar characteristics to the human ear. Both can hear a range of frequencies. If one person is speaking and a number of people are listening, that is analogous to a single transmitter and multiple receivers. If a second person started to speak at the exact same time, people listening might not be able to understand either speaker. In a sense, they are experiencing interference.

An IEEE 802.11 wireless network may use the unlicensed 2.4 GHz industrial, scientific, and medical (ISM) band. This band is also used for many other devices, including:

- Cordless phones
- Microwave ovens
- Medical devices
- Industrial devices
- Baby monitors
- Other IEEE 802.11 wireless networks
- Some IEEE 802.15 devices

Because these devices also use RF to operate and the frequency is in the same unlicensed band as IEEE 802.11 wireless networks, they have the potential to interfere with one another. Although they may coexist in the same RF space, the interference factor needs to be taken into consideration. This can be done as part of the site survey process.

Adjacent Channel and Co-channel Interference

Adjacent channel and co-channel interference occurs when two devices in the same physical area are tuned to close RF channels or the same channel. For example, an access point on channel 1 and another access point on channel 2 in close or hearing range of each other

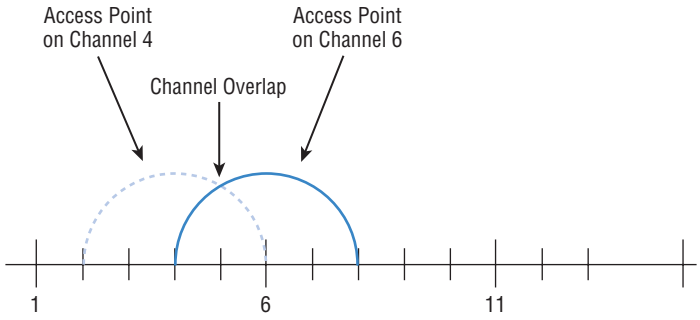
will experience adjacent channel interference. Some of the symptoms of adjacent channel interference are reduced throughput and the equivalent of collisions causing data retransmissions. Co-channel interference is when two or more independently coordinated access point radios are providing RF coverage to the same physical area using the same 802.11 channel such as Channel 1 and Channel 1. Another term used for co-channel interference is "co-channel cooperation," since it is not really interference but rather an increase in the size of the contention domain.

Co-channel interference is defined as two different radio transmitters using the same frequency. The IEEE 802.11-2016 standard, however, defines interference between channels 1 and 2 as co-channel interference caused by overlapping channels. According to the standard, adjacent channel interference for HR/DSSS and ERP in the 2.4 GHz ISM band is caused by frequencies of greater than or equal to 25 MHz separation, such as channels 1 and 6. The terms *co-channel* and *adjacent* are used loosely in the WLAN industry. Please consult specific manufacturers' documentation for their definition. The CWNP program complies with the IEEE standards definition.

Overlapping interference is defined as two devices (such as access points) on the same frequency overlapping one another. For example, two access points on the 2.4 GHz ISM band in close proximity to each other, one on channel 1 and the other on channel 3, might interfere with each other.

Both adjacent channel interference and co-channel channel interference will cause poor performance and throughput on a wireless network. In a wireless network, co-channel or adjacent channel interference can have the same impact. Figure 4.12 shows that 2.4 GHz ISM band channel 4 and channel 6 overlap.

FIGURE 4.12 Channel overlap in the 2.4 GHz ISM band

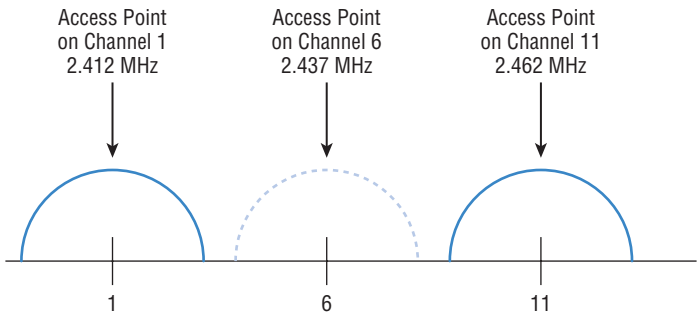


Representation of 2.4 GHz ISM band consisting of 14 channels.
Channels 1, 6, and 11 are labeled.

A properly designed WLAN will have overlapping RF cells. Overlapping cells provide continuous coverage and channel reuse for the entire area where the access points are placed.

Overlapping cells allow devices to move from one access point to another and maintain a constant connection. A well-designed WLAN will also minimize or eliminate overlapping and co-channel interference. This design includes assigning nonoverlapping RF channels to cells that do overlap with each other. In practice, an overlapping cell design will include approximately a 20 percent overlap to encourage better transitioning for the connected devices. Wireless repeaters require a 50 percent overlap to be effective. The frequency in use is determined by how many nonoverlapping channels are available in the band. For example, in the United States, the 2.4 GHz band used for 802.11b/g/n has three nonoverlapping channels: 1, 6, and 11. Figure 4.13 shows 2.4 GHz ISM band with these three nonoverlapping channels.

FIGURE 4.13 Five channels of separation and 25 MHz of separation between nonoverlapping channels



Representation of 2.4 GHz ISM band consisting of 14 channels.
Channels 1, 6, 11 are non-overlapping.

WLAN/WPAN Interference

The performance of IEEE 802.11 wireless networks can be affected when they are co-located with IEEE 802.15 wireless personal area networks (WPANs). Bluetooth is an example of a WPAN. Like 802.11, Bluetooth devices operate in the 2.4 GHz frequency range and use frequency-hopping spread spectrum (FHSS) technology. This functionality in older Bluetooth devices could potentially interfere with IEEE 802.11 wireless networks. Newer versions of Bluetooth that use adaptive frequency hopping (AFH) have less chance of interfering with other wireless networks, including 802.11 wireless networks. AFH allows devices such as Bluetooth to adapt to the RF environment by seeking areas of interference and not operating in those specific frequency ranges. This will lessen the chances of 802.15 WPAN devices interfering with 802.11 WLAN devices. This newer technology is proven such that WLAN 802.11 and WPAN 802.15 Bluetooth devices may coexist in the same physical radio chipset. Keep in mind, however, that a high density of Bluetooth-enabled devices may still cause interference with IEEE 802.11 wireless networks in the 2.4 GHz ISM band.

Environment: Radio Frequency Behavior

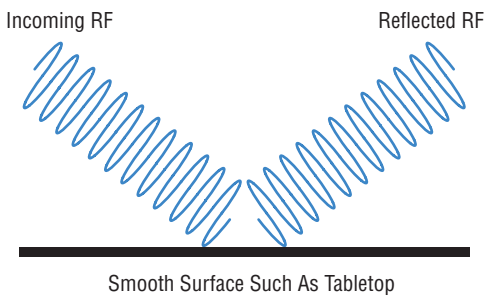
In addition to various types of RF interference, the interaction between RF and the surrounding environment can also affect the performance of IEEE 802.11 wireless networks. RF behavior is the result of environmental conditions, including:

- Reflection
- Refraction
- Diffraction
- Scattering
- Absorption
- Diffusion

Reflection

Reflection occurs when an RF signal bounces off a smooth, nonabsorptive surface, such as a tabletop, and changes direction. Reflections can affect indoor WLAN installations fairly significantly in certain cases. Depending on the interior of the building—such as the type of walls, floors, or furnishings—there could be a large number of reflected signals. If not properly handled, reflections could cause a decrease in throughput and poor network performance in IEEE 802.11a/b/g (non-MIMO) wireless networks. Furnishings, metal beams, walls, ceilings, shelving, and roofing can all cause reflections. Figure 4.14 illustrates reflection.

FIGURE 4.14 Radio frequency reflection

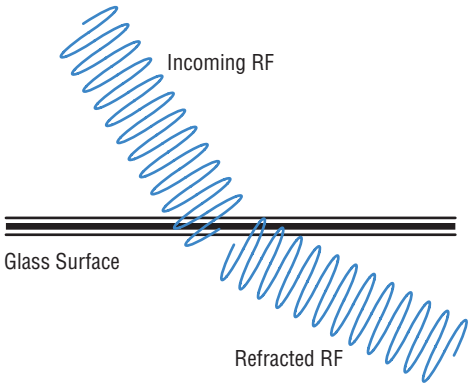


When it comes to reflection, think of a ping-pong game. When a ping-pong ball is served or hit, it comes in contact with the table—a smooth, hard surface—and bounces off in a different direction. This is similar to how reflection works with radio frequency.

Refraction

When an RF signal passes between mediums of different densities, it may change speeds and also bend. This behavior of RF is called *refraction*. Glass is an example of material that may cause refraction. When an RF signal comes in contact with an obstacle such as glass, the signal is refracted (bent) as it passes through, and some of the signal is lost. The amount of loss depends on the type of glass, its thickness, and other properties. Figure 4.15 shows refraction.

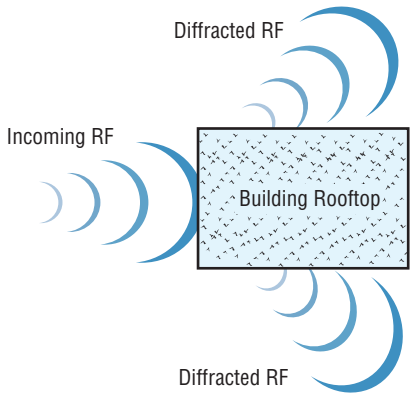
FIGURE 4.15 Radio frequency refraction



Diffraction

When an RF signal passes an obstacle, the wave changes direction by bending around the obstacle. This RF behavior is called *diffraction*. A building or other tall structure could cause diffraction, as could a column in a large open area or conference hall. When the signal bends around a column, building, or other obstacle, the signal weakens, resulting in some level of loss. Figure 4.16 illustrates diffraction.

FIGURE 4.16 Radio frequency diffraction



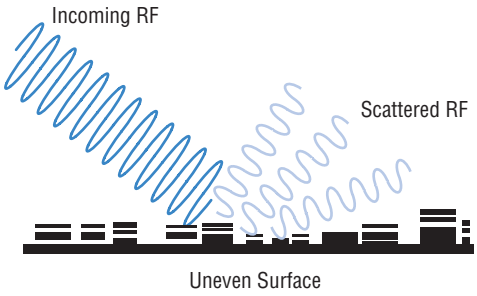
Demonstrating Diffraction: A Rock in a Pond

You can demonstrate diffraction by using a pond of still water. Place a large object, such as a two-by-four piece of lumber, in a pond of still water. After the water settles, try to drop a pebble or small rock off to the side of the piece of lumber. Watch closely and you will see the ripple of the water bend around the lumber, resulting in a diffraction effect. It is easy to confuse the term *diffraction* with *diffusion*. Note that diffusion is the natural widening (spreading) of an RF signal as it leaves an antenna element. This is the premise of free space path loss (FSPL), which is discussed further in the "Diffusion" section.

Scattering

When an RF signal strikes an uneven surface, wavefronts of the signal will reflect off the uneven surface in several directions. This is known as *scattering*. Scattering, illustrated in Figure 4.17, is another form of loss that may severely degrade the RF signal. The difference between scattering and reflection is the surface with which the RF comes in contact. As with reflection, furnishings, metal beams, walls, ceilings, shelving, and roofing all can cause scattering.

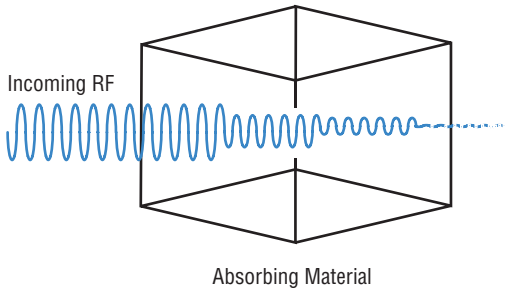
FIGURE 4.17 Radio frequency scattering



Absorption

Absorption is the conversion of the RF signal energy into heat. This occurs because the molecules in the medium through which the RF signal is passing do not travel as fast as the RF waves, resulting in a loss of signal. There are many materials to consider with absorption, including brick, concrete, windows, doors, water, drywall, wood, and people. When material absorbs an RF signal, it may significantly affect the signal as it penetrates through the material. One example of absorption is the human body, which has a high liquid content and will absorb RF signals. This type of absorption can be a problem for wireless network deployments in certain environments. Absorption should be considered when designing a WLAN for densely populated areas such as stadiums, airports, and conference halls. Figure 4.18 shows absorption.

FIGURE 4.18 Radio frequency absorption



Diffusion

Diffusion occurs when the RF signal naturally widens as it leaves an antenna element. As a result of this widening effect, the transmitted RF signal will decrease in amplitude and be less powerful at any distance from the antenna. This is known as *free space path loss* (FSPL). FSPL is the greatest form of loss factor in a RF link. FSPL is calculated using frequency and distance as variables and entered into a mathematical formula. The receiving antenna is only able to receive a small amount of the transmitted signal because of this widening effect of the diffused signal as it propagates through the air. Any signal that is not received by the intended device is considered loss.

Basic Units of Radio Frequency Measurement

If a person were given a dollar bill, they would be one dollar richer. If this person were given 100 cents, they would still be one dollar richer. From this example, we see 1 dollar = 100 cents, and 1 cent = 1/100th of a dollar. One dollar and 100 cents are the same net amount, but a cent and a dollar are different units of currency.

The same is true for RF measures of power. The basic unit of measure for RF is the watt (W). A wireless access point may be set to an output of 30 mW (milliwatts) of power. A milliwatt is 1/1000 of a watt. Just as in currency cents and dollars are both denominations of money, watts and milliwatts are measurements of RF power. Other units of measurement for RF are dB, dBi, dBd, and dBm.

Absolute Measurements of Radio Frequency Power

The amount of power leaving a wireless access point is one example of an *absolute* measure of power. This is an actual power measurement, not a ratio or a relative value. In other words, this is a measurable amount of power and can be determined with the proper

instrument, such as a watt meter. A typical maximum amount of transmit output power from an access point is 100 mW.

The measure of AC power can be calculated using the following basic formula:

$$P = E \times I$$

Power (P) equals voltage (E) multiplied by current (I).

A simple example would be to calculate the power from 1 volt and 1 amp. Using the given variables, the formula is as follows:

$$P = 1 \text{ volt} \times 1 \text{ amp}$$

The answer would be power = 1 watt.

The formula P = E × I is shown here for reference only to demonstrate the calculation of RF power. You will not need to know this formula for any of the associated certification exams.

Watt

The *watt* (W) is a basic unit of power measurement. It is an absolute value, which is a measurable amount of power. Most indoor wireless networks function in the milliwatt range. Power level in watts is a common measurement in long distance point-to-point and point-to-multipoint connections.

Milliwatt

One milliwatt (mW) is 1/1000 of a watt. This is a common value used in RF work and indoor IEEE 802.11 WLAN deployments. The output power of an access point typically ranges from 1 mW to 100 mW. Most enterprise-grade access points allow you to change the output power. Most SOHO-grade access points have a fixed output power, typically about 30 mW. The milliwatt is also an absolute unit of power measurement.

Decibel Relative to a Milliwatt

dBm is the power level compared to 1 milliwatt. This is based on a logarithmic function. A good rule to remember is 0 dBm = 1 mW. This value is considered as absolute zero. Using a formula or basic RF calculation rules, you can easily convert any milliwatt value to decibels: 100 mW = 20 dBm, for example.

The dBm is also an absolute unit of power measurement. A dB is an example of a change in power or relative measurement of power where dBm is measured power referenced to 1 milliwatt or an absolute measure of power. The next section discusses relative measurements of power.

Remember, absolute values are measurable values of power, such as watt, milliwatt, and decibel milliwatt.

Relative Measurements of Radio Frequency Power

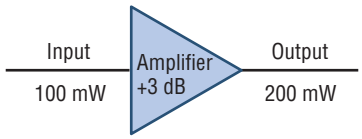
Changes in RF power are known as *relative*. dB and dBi are relative measurements of power. An example would be an RF amplifier. If the input power to an amplifier is 10 mW and the output power is 100 mW, the gain of the amplifier is 10 dB—a change in power.

If the input RF power to an antenna is 100 mW and the theoretical amount of RF output power is 200 mW, the gain of the antenna is 3 dBi—a change in power. Both of these are examples of changes in power and are known as *relative expressions* of RF power.

Decibel

The decibel (*dB*) is a ratio of two different power levels caused by a change in power. Figure 4.19 shows how an amplifier will provide an increase or change in power.

FIGURE 4.19 Output doubled in power from 100 mW to 200 mW from amplifier with a gain or change in power of +3 dB



Basic RF Math: The 3s and 10s Rule

This section is beyond the scope of the exam objectives and is for informational purposes only.

There is a simple way to perform any RF math calculation without having to use logarithms and mathematical formulas. This method is known as the *3s and 10s Rule* (or sometimes referred to as the *10s and 3s Rule*). If you remember five basic steps, you can perform any RF math calculation. The five basic steps are as follows:

- 0 dBm = 1 mW (starting point)
- Increase by 3 dBm and power in mW doubles or × 2
- Decrease by 3 dBm and power in mW is cut in half or ÷ 2
- Increase by 10 dBm and power in mW is multiplied by 10 or × 10
- Decrease by 10 dBm and power in mW is divided by 10 or ÷ 10

Decibel Isotropic

Decibel isotropic (*dBi*) is the unit that represents the gain or increase in signal strength of an antenna. The term *isotropic* in the RF world means energy broadcast equally in all

directions in a spherical fashion. An imaginary, perfect antenna is known as an *isotropic radiator*. This is a theoretical concept and is used as a reference and in calculations. dBi will be discussed and used in more detail in Chapter 5. Table 4.6 shows a summary of absolute and relative power measurements.

TABLE 4.6 Absolute and relative measures of power

Absolute Power Units	Relative Power Units
Watt	dB
Milliwatt	dBi
dBm	dBd

Remember, relative values are changes in power from one value to another value. dB, dBi, and dBd measure relative power.

Decibel Dipole

The gain of some antennas may be measured in decibel dipole (*dBd*). This unit of measurement refers to the antenna gain with respect to a reference dipole antenna. The gain of most antennas used in WLANs is measured in decibel isotropic (dBi); however, some manufacturers may reference the gain of an antenna in dBd. The following simple formula derives the dBi value from the dBd value:

$$dBi = dBd + 2.14$$

This formula converts from dBi to dBd:

$$dBd = dBi - 2.14$$

Real World Scenario

dBd vs. dBi

You are a procurement agent working for a manufacturing company. An engineer orders some antennas to be used in a WLAN deployment. The part number you received from the engineer on the bill of materials is for antennas that are currently out of stock at your normal supplier. The order has to be placed as soon as possible, but technical support for the vendor is gone for the day, and you are not able to get any assistance.

You found what appears to be a reasonable alternative for the requested antennas. However, the gain of the antennas does not exactly match what the engineer documented on the bill of materials. The engineer requested omnidirectional antennas with a gain of 6 dBi. You found what appears to be a comparable alternate with a gain of 6 dBd. It will be necessary for you to determine whether these antennas will work. Not quite understanding the difference, you do some research to determine the difference between dBd and dBi. After searching various websites, you find a formula to convert the two different units:

$$dBi = dBd + 2.14$$

Using your calculator, you enter the value from the specification sheet for the alternate antennas:

$$6\ dBd + 2.14 = 8.14\ dBi$$

Unfortunately, the antennas found will not be good alternates in this example. Back to the drawing board!

Radio Frequency Signal Measurements

It is important to understand the various signal measurements of RF used in WLAN technology. Using tools like a wireless adapter client utility or a *spectrum analyzer* will allow you to view different statistics that pertain to a wireless network. Some of these statistics are

- Receiver sensitivity
- RF noise
- Received signal strength indicator (RSSI)
- Signal-to-noise ratio (SNR)

Receiver Sensitivity

The basic definition of *receiver sensitivity* is the measurable amount of RF signal usable by a receiver. More complex modulation and coding types will require better signals and are directly related to which signaling rate will be used to transfer the data. This is also determined by how much RF noise is in the area of the radio receiver. Figure 4.20 shows a data sheet of a wireless access point that displays the minimum receiver sensitivity required to achieve a specific data rate.

It is important to note that data sheets from wireless equipment manufacturers show the minimum amount of receive signal to achieve the listed data rates. You can see in Figure 4.20 that this specific access point requires a minimum of –75 dBm receiver sensitivity in order to get the data rate of 54 Mbps. Most industry best practices recommend a minimum of –65 dBm to –67 dBm in order to achieve the highest data rate and best possible performance. There is a lack of industry standards for calculating the RSSI value. Manufacturers

may derive the same or similar values but use different proprietary calculations to do so. Two devices from different manufacturers having equal distance from the transmitting device and subjected to the same interference sources may calculate different RSSI values. So, when conducting a physical site survey, if possible it is recommended to use the same type of wireless devices that will be deployed in the environment to sample RSSI and SNR values.

FIGURE 4.20 Data sheet from an Aruba Networks IEEE 802.11ac AP 330 wave 2 wireless access point showing the mapping of minimum receiver sensitivity in dBm to data rates in Mbps

RF PERFORMANCE TABLE

	Maximum transmit power (dBm) per transmit chain	Receiver sensitivity (dBm) per receive chain
802.11b 2.4 GHz		
1 Mbps	18.0	-96.0
11 Mbps	18.0	-89.0
802.11g 2.4 GHz		
6 Mbps	18.0	-91.0
54 Mbps	18.0	-75.0
802.11n HT20 2.4 GHz		
MCS0/8/16	18.0	-90.0
MCS7/15/23/31	17.0	-71.0
802.11n HT40 2.4 GHz		
MCS0/8/16/24	18.0	-88.0
MCS7/15/23/31	16.0	-68.0
802.11a 5 GHz		
6 Mbps	18.0	-88.0
54 Mbps	16.0	-73.0

Minimum Receive Sensitivity of –75.0 dBm for 54 Mbps

Radio Frequency Noise

Radio frequency noise is the term for RF signals from sources other than the transmitter and receiver that are in communication. Here is an analogy to help explain. You and a guest are in a crowded open-space restaurant for dinner. There are many unrelated conversations occurring at the same time at the various tables throughout the restaurant. If you and your dinner guest momentarily paused in your conversation, you would hear these other conversations, as well as the noise from equipment, telephones, and tables that are being cleared. This would be the restaurant equivalent of RF noise, as shown in Figure 4.21.

In a WLAN environment, several RF devices may be operating in the same physical space as the wireless transmitter (access point) and receiver (client device). Depending on the level of this RF noise, it may be difficult for the transmitter and receiver to understand each other because the signal level may be too close to the noise floor and the receiver will have a difficult time determining the difference between signal and the RF noise. In Figure 4.22, a screen capture from a spectrum analyzer utility shows a wireless basic service set on channel 161 in the 5 GHz UNII-3 band. Also shown is the RF noise floor of about –98 dBm.

FIGURE 4.21 Restaurant analogy example of radio frequency noise

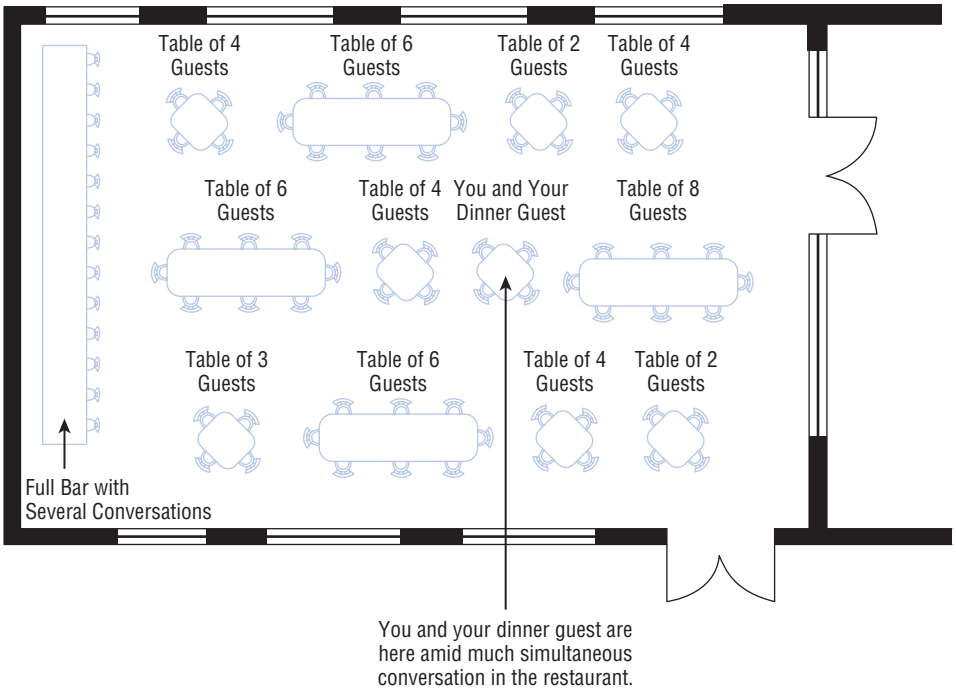
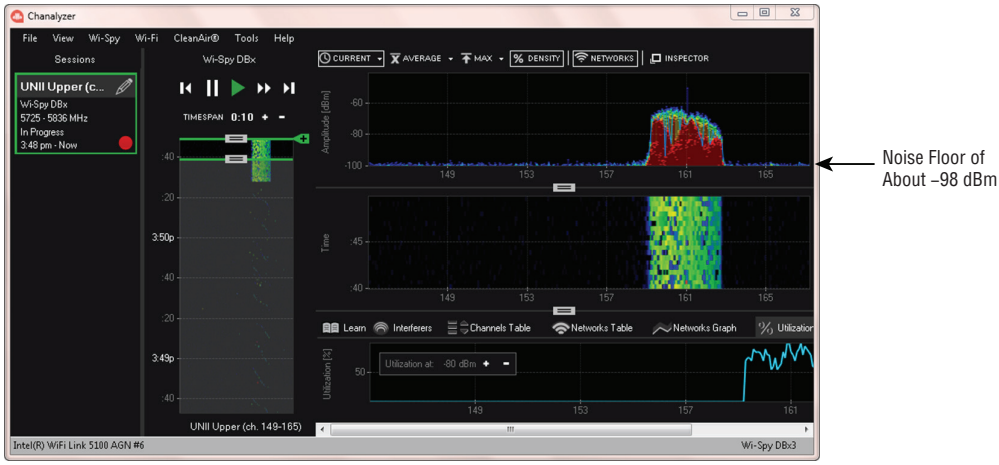


FIGURE 4.22 The MetaGeek Chanalyzer spectrum analyzer utility shows a noise floor for the tested site of about –98 dBm.



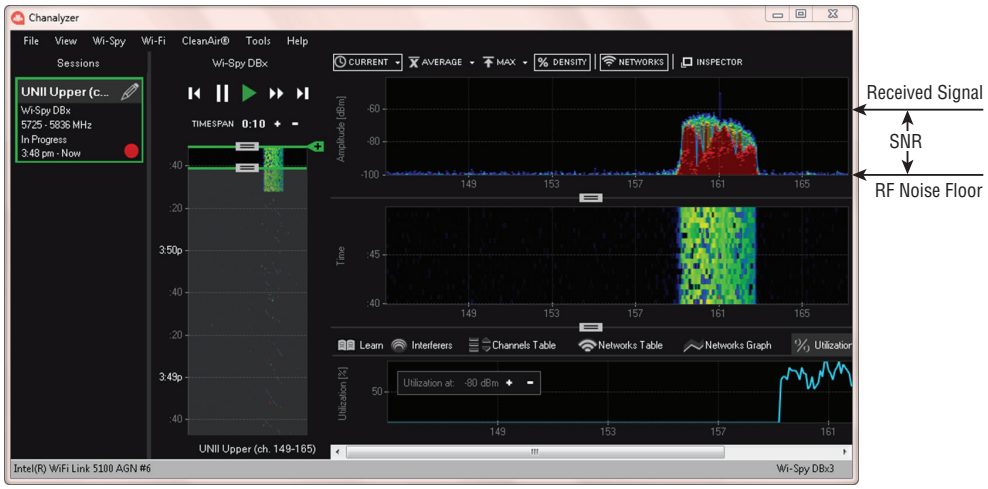
Received Signal Strength Indicator

Received signal strength indicator (RSSI) is an arbitrary number assigned by the radio chipset or device manufacturer, and it will not be comparable between devices from different manufacturers. As stated in the standard, the RSSI may be averaged over time using a vendor-specific smoothing function. The calculation of the RSSI value is done in a proprietary manner, and a wireless device from one manufacturer may indicate different signal strength than that indicated by another, even though they both are receiving the exact same signal and at the same actual amount of RF power. This value is a key determinant of how well the WLAN device will perform. How the device is used with the network will determine the required levels of signal for optimal connectivity. Most wireless client device manufacturers allow their chipsets to access the higher data rates as long as they are getting a –70 dBm signal or stronger. Wireless VoIP manufacturers recommend deploying so that the client devices can receive a –67 dBm or better signal from the access point, a strength that is double the –70 dBm required for higher data rate use due to the need for better signaling in QoS communications.

Signal-to-Noise Ratio

The *signal-to-noise ratio* (SNR) is the difference between the amount of received signal and the noise floor. Looking back at the restaurant analogy, if you were to continue your conversation and the tables surrounding yours were all speaking at higher volumes, you might not be able to hear your dinner guest very well because of the amount of noise created in the open area of your table. Looking at this from a WLAN perspective, if a client device records a received signal of –85 dBm and the noise floor is –95 dBm, the SNR will be 10 dB. This value is calculated by subtracting the received signal from the noise. In this case –85 dBm – (–95 dBm) = 10 dB. This would not be an adequate SNR, because the receiver would have a difficult time determining the difference between the wanted RF signal and the surrounding RF noise. On the other hand, if the received signal is –65 dBm and the noise floor is –95 dBm, then the SNR will be 30 dB. This value again is calculated by subtracting the received signal from the noise—in this case, –65 dBm – (–95 dBm) = 30 dB. This would be an excellent SNR because the receiver would easily be able to determine the intended RF signal from the surrounding RF noise. The SNR is a very important metric used with WLAN design. This value is used to determine the minimum received signal strength required for optimal performance of a WLAN system. Current best practices recommend a minimum SNR of 25 dB. Figure 4.23 illustrates the SNR as seen in a spectrum analyzer tool.

FIGURE 4.23 Graph showing the received signal strength vs. noise floor and the SNR using the MetaGeek Chanalyzer spectrum analyzer utility



Summary

This chapter explored RF basics and the essential role RF plays in the world of IEEE 802.11 wireless networking. You learned the definition of RF as it pertains to wireless networking and the basic characteristics or properties of RF, including:

- Wavelength
- Frequency
- Amplitude
- Phase

Then we described devices such as transmitters and receivers and how they communicate. In WLAN technology, an example of a transmitter and receiver is an access point and client device. We also discussed the unlicensed RF bands and channels used in the 2.4 GHz ISM and 5 GHz UNII ranges for WLAN communications, as well as other frequency ranges that may be allowed for use with IEEE 80211 wireless networking depending on the local regulatory agency. RF coverage and capacity are two important areas that should be considered closely to ensure that a wireless deployment will offer reliable connectivity and perform well for the user base.

We then explained correct channel reuse to minimize interference from the co-location of access points. This chapter explored the cause and effect of co-channel interference from sources other than wireless networks operating in the ISM and UNII bands. We also looked at RF behaviors such as reflection, refraction, and absorption, and the impact of

building materials on the propagation of radio waves. We discussed RF units of measure, both absolute and relative, including the watt, milliwatt, dB, and dBi. Finally, we covered various types of RF signal measurements used with IEEE 802.11 wireless networking. These topics included:

- Receiver sensitivity
- RF noise
- Received signal strength indicator (RSSI)
- Signal-to-noise ratio (SNR)

Exam Essentials

Know the basic characteristics or properties of RF. Understand the characteristics of RF, such as wavelength, phase, frequency, and amplitude.

Be familiar with the frequencies used for wireless networks. Know the unlicensed ISM and UNII bands available for use with wireless networks.

Understand wireless network coverage and capacity. Know the difference between coverage and capacity and the factors that will have an impact on both.

Know what RF factors will affect the range and speed of wireless networks. Understand the effects of interference and the devices that cause interference. Be familiar with the environmental conditions that cause reflection, refraction, diffraction, scattering, and absorption. Understand their impact on the propagation of RF signals.

Identify basic RF units of measurement. Understand the difference between absolute and relative measures of RF power. Define W, mW, dB, dBm, and dBi.

Identify RF signal measurements Understand receiver sensitivity, radio frequency noise, RSSI, and SNR.

Review Questions

1. What is the term defining the number of times a cycle of an RF signal will oscillate in one second?
   - **A.** Phase
   - **B.** Frequency
   - **C.** Amplitude
   - **D.** Wavelength
2. How many nonoverlapping channels are available in the unlicensed 2.4 GHz ISM band?
   - **A.** 1
   - **B.** 3
   - **C.** 6
   - **D.** 11
3. The capacity of an access point is dependent on which factors? (Choose two.)
   - **A.** Number of devices
   - **B.** Channel reuse
   - **C.** Co-location
   - **D.** Software applications
   - **E.** Frequency
4. When an RF signal passes between media of different densities and may change speeds and bend, the behavior is known as:
   - **A.** Refraction
   - **B.** Reflection
   - **C.** Scattering
   - **D.** Diffraction
5. What two devices use RF to communicate? (Choose two.)
   - **A.** Transmitter
   - **B.** Transistor
   - **C.** Reactor
   - **D.** Reflector
   - **E.** Receiver
6. Which are relative measures of RF power? (Choose two.)
   - **A.** mW
   - **B.** dB
   - **C.** dBm
   - **D.** dBi
   - **E.** Watt

7. In the 2.4 GHz range, what distance between the center frequencies (in megahertz) is required for two channels to be considered nonoverlapping for HR/DSSS?
   - **A.** 5 MHz
   - **B.** 22 MHz
   - **C.** 25 MHz
   - **D.** 30 MHz

8. Two characteristics of RF signals are
   - **A.** Amplitude
   - **B.** Reflection
   - **C.** Phase
   - **D.** Refraction
   - **E.** Diffraction

9. How many channels are available for WLANs to use in the unlicensed UNII-1 band?
   - **A.** 2
   - **B.** 4
   - **C.** 6
   - **D.** 11

10. Which are absolute measures of RF power? (Choose two.)
   - **A.** Watt
   - **B.** dB
   - **C.** mW
   - **D.** dBi
   - **E.** dBd

11. Which two channels are considered nonoverlapping in the 2.4 GHz band?
   - **A.** 1 and 6
   - **B.** 2 and 6
   - **C.** 6 and 10
   - **D.** 11 and 13

12. How many channels are available for WLAN use in the unlicensed 2.4 GHz ISM band?
   - **A.** 8
   - **B.** 10
   - **C.** 11
   - **D.** 14

13. The range of a 2.4 GHz signal is mostly dependent on which RF characteristic?
   - **A.** Frequency
   - **B.** Wavelength
   - **C.** Amplitude
   - **D.** Phase

14. Which item has an effect on RF line of sight?

- **A.** Phase
- **B.** Obstacles
- **C.** Interference
- **D.** Amplitude

15. How many channels are available for WLAN use in the unlicensed middle UNII-2e band?

- **A.** 4
- **B.** 6
- **C.** 12
- **D.** 14

16. As seen in a two-dimensional (X/Y) view, the amplitude of an RF signal is:

- **A.** Height
- **B.** Length
- **C.** Shift
- **D.** Width

17. An 802.11b channel is how wide in MHz?

- **A.** 5 MHz
- **B.** 22 MHz
- **C.** 25 MHz
- **D.** 30 MHz

18. When an RF signal bounces off a smooth, nonabsorptive surface, the behavior is

- **A.** Refraction
- **B.** Reflection
- **C.** Scattering
- **D.** Diffraction

19. What is the gain of an antenna measured in?

- **A.** dB
- **B.** dBc
- **C.** dBi
- **D.** dBm

20. When RF passes or bends around an obstacle such as a building or column, the behavior is:

- **A.** Reflection
- **B.** Refraction
- **C.** Scattering
- **D.** Diffraction

Chapter

5

Antenna Technology for Wireless Networking

THE FOLLOWING CWTS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **2.3 Identify the purpose, features, and proper implementation of antennas**
- ✓ **2.4 Describe the proper locations and methods for installing RF antennas**
- ✓ **3.6 Understand and apply basic RF antenna concepts**
- ✓ **3.7 Identify the use of WLAN accessories and explain how to select and install them for optimal performance and regulatory domain**

THE FOLLOWING CWS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **1.3 Understand antenna types**
- ✓ **2.1 Know the frequency bands used**
- ✓ **2.4 Identify factors impacting wireless LAN (WLAN) performance**
- ✓ **4.8 Match organizational goals to WLAN features and functions**

THE FOLLOWING CWT EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **1.5 Describe the basic differences among antenna types**
- ✓ **1.6 Select the appropriate external antenna when required**
- ✓ **3.2 Select appropriate mounting kits for a specified installation location**

Antennas are an essential part of a successful wireless LAN (WLAN) deployment. From the transmitter perspective, an antenna takes the modulated RF energy from the transmission system, transforms it into radio waves, and propagates it through the free air. From the receiver perspective, an antenna performs the opposite task—it receives the modulated radio waves, transforms them back to AC signals, and, finally, sends the information to a computer or other wireless device.

Many factors are involved in determining the proper antenna to be used in an application or deployment of a WLAN. These factors include

- Indoor or outdoor installation
- Distance between transmitter and receiver
- Frequency to be used
- Horizontal or vertical orientation/polarization
- Aesthetics
- Cost
- Manufacturer
- Intended use
- Mounting brackets
- Electrical characteristics
- Height
- Location
- Local ordinances

Basic Radio Frequency Antenna Concepts

It is important to understand some of the basic theory, characteristics, and terminology associated with antennas prior to learning how they operate. Becoming familiar with this will help in making decisions when it comes to sales and support of antennas and WLAN systems. Some of the terminology for characteristics of antennas is listed here:

- **Radio frequency lobes**: Shape of the radiation patterns
- **Beamwidth**: Horizontal and vertical angles

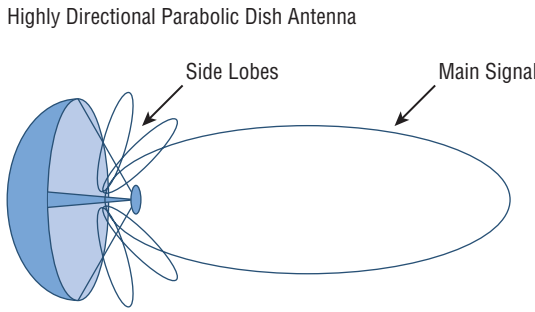
- **Antenna charts**: Azimuth and elevation
- **Gain**: Changing the RF coverage pattern (beamwidths)
- **Polarization**: Horizontal or vertical orientation

Radio Frequency Lobes

The term *lobe* has many meanings, depending on the context in which it is used. Typically, it is used to define the projecting part of an object. In anatomical terms, an example would be part of the human ear known as the ear lobe. In botanical terms, a lobe is the divided part of a leaf. As an RF antenna technology term, lobe refers to the shape of the RF energy emitted from an antenna element. RF lobes are determined by the physical design of the antenna. The antenna design also determines how the lobes project from an antenna element.

The effect of antenna design, particularly the shape of the RF lobes, is one reason why choosing the correct antenna is a critical part of a WLAN design. Antennas may project many lobes of RF signal, some of which are not intended to be usable areas of coverage. The RF lobes that are not part of the main or intended lobe coverage—that is, the rear and side lobes—contain usable RF but are not intended to be used to provide coverage for the WLAN cell. They are, for the most part, unintentional coverage areas and are *not* part of a good WLAN design and planned coverage area. The type of antenna utilized—omnidirectional, semidirectional, or highly directional—will determine the usable lobes. These antennas as well as the RF radiation patterns they project will be discussed in more detail later in this chapter. Figure 5.1 shows an example of RF lobes emitted from an antenna element. The "main signal" is the lobe intended to be used.

FIGURE 5.1 RF lobes' shape and coverage area are affected by the type and design of an antenna.



Antenna Beamwidth

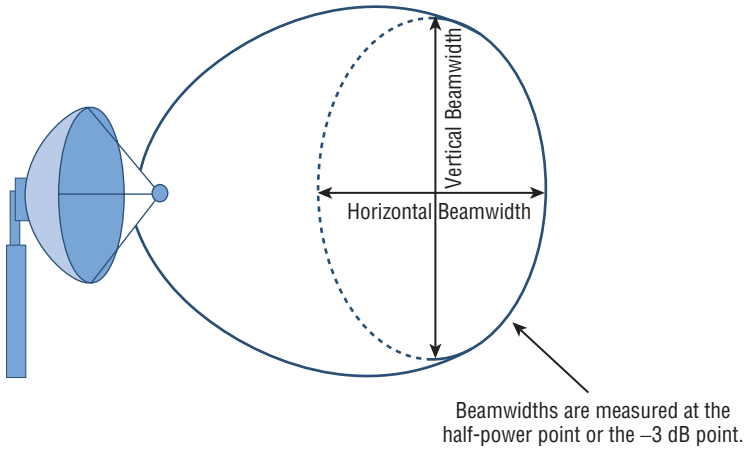
The design of an antenna will determine how RFs propagate and the specific patterns in which the RF energy propagates from an antenna element. As mentioned earlier, the patterns of energy emitted from an antenna are known as *lobes*. For antennas, the

beamwidth is the angle of measurement of the main RF lobe measured at what is called the *half-power point*, or – *or power*. This is where the RF power decreases by 50 percent. Antenna *beamwidth* is measured both horizontally and vertically, in degrees. It is important to understand that antennas shape the RF coverage or isotropic energy that radiates from the antenna element. Changing types or remaining with the same type of antenna but changing the gain will also change the coverage area provided by the WLAN system.

Documents or antenna specifications are available to illustrate the horizontal and vertical beamwidths. Azimuth and elevation charts available from the antenna manufacturer will show the beamwidth angles.

The *azimuth* refers to the horizontal RF coverage pattern, and the *elevation* is the vertical RF coverage pattern. The azimuth is the view from above, or the "bird's-eye view" of the RF pattern; in some cases it will be 360°. Think of the elevation as a side view. If you were to look at a mountain from the side view, it would have a certain height or elevation measured in feet or meters. For example, Pikes Peak, a mountain in the front range of the Rocky Mountains, has an elevation of 14,115′ (4,302 meters). Figure 5.2 shows a representation of horizontal and vertical beamwidths. Some predictive modeling site survey software programs will allow the WLAN designer to adjust the azimuth and elevation of the antennas used in the predictive modeling design to more closely depict the real-world coverage of the WLAN system. WLAN site surveys and predictive modeling will be discussed in more detail in Chapter 9, "Design for Wireless Networking."

FIGURE 5.2 Horizontal (azimuth) and vertical (elevation) beamwidths measured at the half power, or –3 dB point

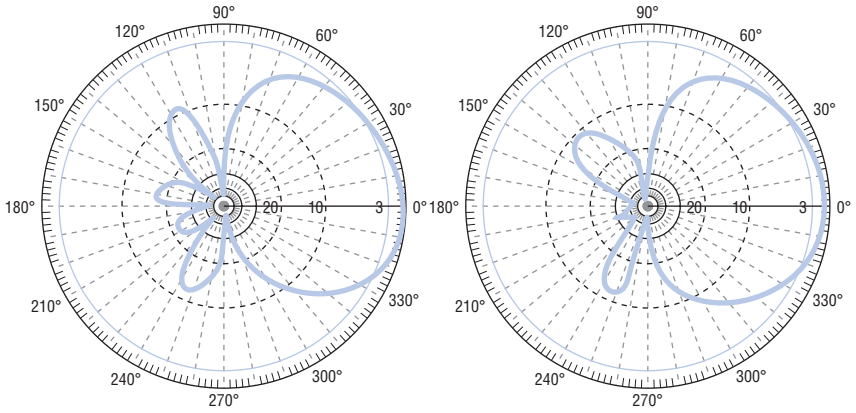


Real World Scenario

Reading Azimuth and Elevation Charts

Understanding how to read an azimuth and elevation chart is useful from a technical sales, design, or integration perspective. Knowing these patterns will help when making hardware recommendations for customers based on needed coverage and device use. These charts show the angles of RF propagation from both the azimuth (horizontal or looking down, top view) and the elevation (vertical or side view). They give a general idea of the shape of the RF propagation lobe based on antenna design.

Antenna manufacturers test antenna designs in a laboratory. Using the correct instruments, an engineer is able to create the azimuth and elevation charts. These charts show only approximate coverage area based on the readings taken during laboratory testing and do not take into consideration any environmental conditions such as obstacles or interference. The following image shows an example of an azimuth and elevation chart for a semidirectional antenna.

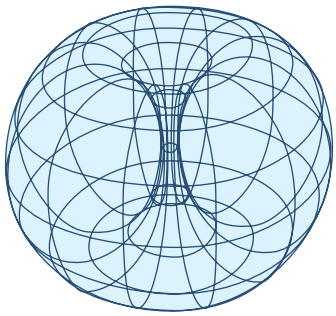


Understanding how to read one of these charts is not complicated. Notice that the chart is a circular pattern with readings from 0° to 360°, and there are many rings within these charts. The outermost ring shows the strongest signal from the testing process of this antenna. The inner rings show measurements and dB ratings less than the strongest measured signal from the outside ring. A good chart will show the most accurate readings from the testing process. A sales or technical support professional can use these charts to get an idea of how the radiation pattern would look based on a specific antenna type and model.

Antenna Gain

The *gain* of an antenna provides a change in a coverage pattern that is a result of the antenna focusing the area of RF propagation. This gain is produced from the physical design of the antenna element. In Chapter 4, "Radio Frequency Fundamentals for Wireless Networking," we looked at various characteristics of RF. One of these characteristics is amplitude, which is defined as the height (voltage level) or the amount of power of a sine wave. The amplitude is created by varying voltage over a period of time and is measured at the peaks of the signal from top to bottom. Amplification of an RF signal will result in gain. An antenna is a device that can change the RF coverage area, thus propagating an RF signal further. Antenna gain is measured in *decibels isotropic* (dBi), which is a change in intensity as a result of increasing the isotropic energy. *Isotropic energy* is defined as energy emitted equally in all directions. The sun is a good example of isotropic energy, emitting energy in a spherical fashion equally in all directions. Figure 5.3 illustrates energy being emitted from an isotropic radiator.

FIGURE 5.3 A perfect isotropic radiator emits energy equally in all directions.

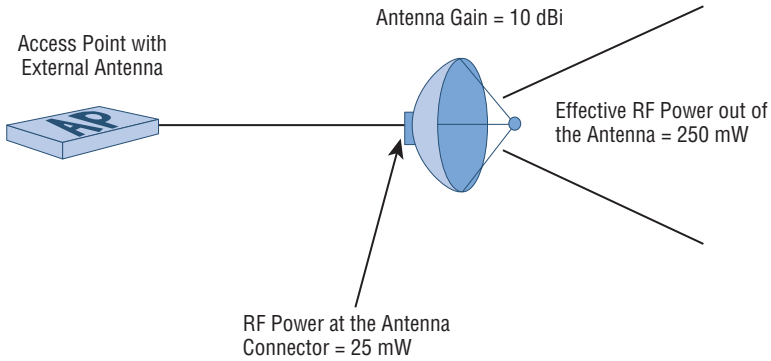


Passive Gain

It's quite intriguing how an antenna can provide *passive gain*, a change in coverage without the use of an external power source. Because of their design, antennas focus isotropic energy into a specific radiation pattern. Focusing this energy increases coverage in a particular direction. A common example used to describe passive gain is a magnifying glass. If a person is standing outside on a beautiful sunny day, the sun's energy is not intense because it is being diffused across the entire earth's hemisphere. Thus, there is not enough concentrated energy to cause any harm or damage in a short period of time. If this person were to point one side of a magnifying glass toward the sun and the other side toward a piece of paper, however, more than likely the paper would start to heat quickly. This is because the convex shape of the magnifying glass focuses, or concentrates, the sun's energy into one specific area, thus increasing the amount of heat to that area.

Antennas are designed to function in the same way by focusing the energy they receive from a signal source into a specific RF radiation pattern. Depending on the design of the antenna element, as the gain of an antenna increases, both the horizontal and vertical radiation patterns (beamwidths) will decrease or create narrower beamwidths. Conversely, as the gain of an antenna decreases, the beamwidths will increase, making a larger radiation pattern. One exception to this behavior is the omnidirectional antenna. This type of antenna has a horizontal beamwidth of 360°. When the gain is increased or decreased, the beamwidth will remain 360° but the size of this coverage area will increase or decrease depending on the change in the gain. Omnidirectional antennas are discussed in more detail later in this chapter. Figure 5.4 shows a drawing of a WLAN system with 25 mW (milliwatts) of RF power at the antenna. Because of passive gain, the antenna has the effect of emitting 250 mW of RF power.

FIGURE 5.4 An access point supplying 25 mW of RF power to an antenna with a gain of 10 dBi for an output at the antenna of effectively 250 mW of RF power



It is important to understand that many local RF regulatory domains or agencies restrict the amount of RF power that can be emitted from an unlicensed RF system. This "system" includes all the components certified by the local regulatory agency and may include the transmitter (access point), the connectors, and the antenna. Changing and increasing the gain of an antenna will increase the amount of effective RF energy leaving the antenna and may violate the regulations set forth by the local regulatory agency and void the certification. The Federal Communications Commission (FCC) has modified what it allows several times, to the point of much confusion for installers trying to remain compliant with the regulations. Additionally, altering the original design in any way may require the entire system to be recertified based on the regulations in each RF agency and that agency's interpretation of the term licensed system.

Exercise 5.1 provides a simple way to demonstrate passive gain.

EXERCISE 5.1

Demonstrating Passive Gain

You can demonstrate passive gain by using a standard 8.5″ × 11.0″ piece of notebook paper or cardstock.

1. Roll a piece of paper into a cone or funnel shape.
2. Speak at your normal volume and notice the sound of your voice as it propagates through the air.
3. Hold the cone-shaped paper in front of your mouth.
4. Speak at the same volume.
5. Notice that the sound of your voice is louder. This occurs because the sound is now focused into a specific area or radiation pattern, and passive gain occurs.

Active Gain

Active gain will also provide an increase in signal strength. In a WLAN system, *active gain* is accomplished by providing an external power source to an installed device. An example of such a device is an amplifier. An amplifier is placed in series in the WLAN system and will increase the signal strength based on how much gain it provides.

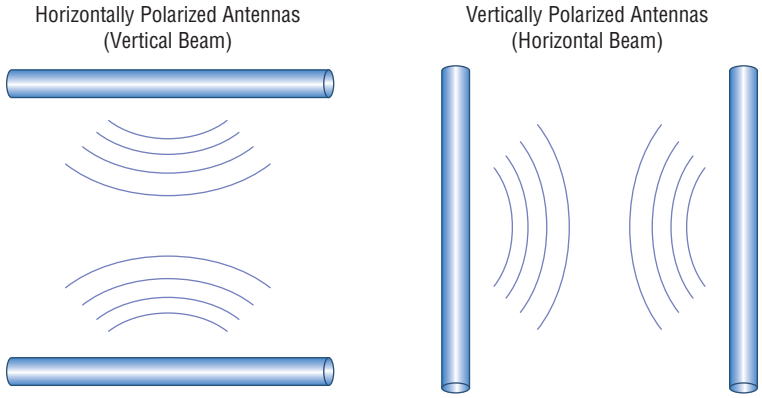
If an amplifier is used in a WLAN system, certain regulatory domains require that the amplifier be certified as part of the system. It is best to carefully consider whether an amplifier is necessary before using such a device in an IEEE 802.11 WLAN system. Using an amplifier may nullify the system's certification and potentially exceed the allowed RF limit. Therefore, it is important to stay within the rules of the regulatory agency that governs the use of RF when adding amplifiers, changing antennas, or changing transmit power settings in any WLAN deployment.

Antenna Polarization

Antenna *polarization* describes how a wave is emitted from an antenna and the orientation of the electrical component or electric field of the waveform. To maximize RF signals, the transmitting and receiving antennas should be polarized in the same direction or as closely as possible. Antennas polarized the same way ensure the best possible RF signal.

If the polarization of the transmitter and receiver are different, the power of the RF signal will decrease depending how different the polarization is. Figure 5.5 shows an example of horizontal and vertical polarized antennas.

FIGURE 5.5 Horizontally and vertically polarized antennas



With the large number of WLAN devices available, it is a challenging task to accomplish the same polarization for all devices on the network. Performing a WLAN site survey will show signal strength based on several factors, including polarization of access point antennas. This survey will help determine the received signal strength of the WLAN devices. Site surveys and antenna polarization are discussed in more detail in Chapter 9.

Real World Scenario

Antenna Polarization Example

It is fairly simple to demonstrate antenna polarization with a notebook computer or other WLAN device and either a wireless network adapter client utility or other third-party software that shows signal strength and/or signal-to-noise ratio. One such utility is Acrylic WiFi Home, a free Wi-Fi network scanning utility for various operating systems. You can download and install the program from the Acrylic WiFi website, at `https://www.acrylicwifi.com/en/wlan-software/wlan-scanner-acrylic-wifi-free`. Acrylic WiFi Home displays the received signal strength from the access points in the receiver area.

You can visualize polarization by performing the following steps. This experiment should be performed using a notebook computer or mobile device within close proximity to an access point.

1. Verify that you have a supported wireless network adapter.
2. Install and launch the Acrylic WiFi Home program or other utility that shows signal strength.

3. Monitor the received signal strength indicator (RSSI) value.
4. While monitoring the RSSI value, change the orientation of the notebook computer.
5. Notice the change in the RSSI value (either an increase or decrease) when the orientation of the computer changes with respect to the access point.

This demonstrates how polarity can affect the received signal of a device.

Wireless LAN Antenna Types

The type of antenna that is best for a particular installation or application will depend on the desired RF coverage pattern. Making the correct choice is part of a good WLAN design. Using the wrong type of antenna can cause undesirable results, such as interference to neighboring systems, poor signal strength, or incorrect coverage pattern for your design.

The following are three common types of antennas for use with WLANs:

- Omnidirectional/half wave dipole antennas
- Semidirectional antennas
- Highly directional antennas

This section describes each type of antenna in more detail and provides specifications and installation or configuration information about these antennas.

Omnidirectional Antennas

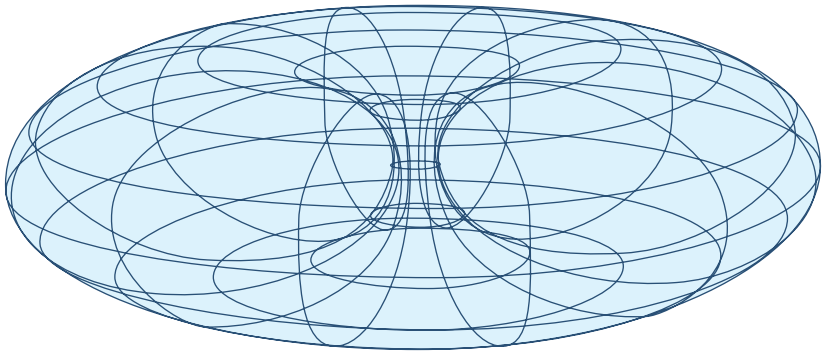
Omnidirectional antennas are common on most access points of either SOHO (Small Office Home Office) or enterprise grade. An *omnidirectional antenna* has a horizontal beamwidth (azimuth) of 360°. This means that when the antenna is vertically polarized (perpendicular to the earth's surface), the horizontal radiation pattern is 360° and will propagate RF energy in every direction horizontally. The vertical beamwidth (elevation) will vary depending on the antenna's gain. As the gain of the antenna increases, the horizontal radiation pattern will increase, providing more horizontal coverage. Keep in mind the beamwidth is still 360°, but it will be a larger 360° area that is covered because of the higher gain of the antenna. The vertical radiation pattern will decrease, however, thus providing less vertical coverage.

The shape of the radiation pattern from an omnidirectional antenna looks like a donut and is known as a *torus*. Figure 5.6 shows an example of the toroidal radiation pattern of an omnidirectional antenna.

Omnidirectional antennas are one of the most common types of antenna for indoor WLAN deployments. Most access points use omnidirectional antennas. Access points come with fixed, removable, or integrated antennas. If the antenna is removable, the installer can replace it with one of different gain. Enterprise-grade access points typically have removable antennas that are sold separately.

Some regulatory domains require the use of proprietary connectors with respect to antennas. These connectors limit access points to the specific antennas tested with the system. Therefore, it is best to consult with the manufacturer of the access point or other WLAN transmitting device to determine which antennas may be used with the system.

FIGURE 5.6 The omnidirectional radiation pattern has a toroidal shape.



The most common type of omnidirectional antenna used indoors is known as the *rubber duck antenna*. This type of antenna typically has a low gain of 2 dBi to 3 dBi and connects directly to an access point. Rubber duck antennas usually have a pivot point so the polarization can be adjusted vertically or horizontally regardless of how the access point is mounted.

Some antennas will operate in both the 2.4 GHz ISM band and the 5 GHz UNII band and can thus work with a multiband wireless device.

Figure 5.7 shows a dual-band rubber duck omnidirectional antenna.

FIGURE 5.7 2.4–2.5 GHz and 5.1–5.8 GHz dual-band rubber duck antenna

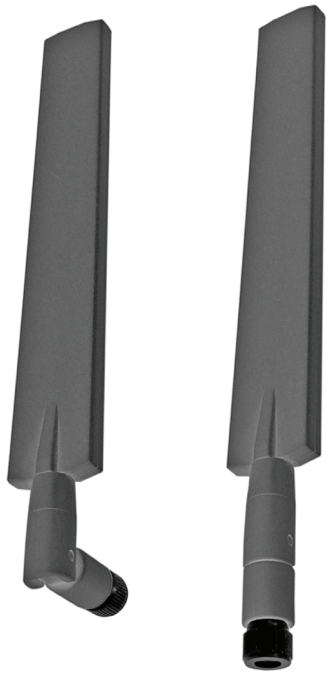


Image provided by www.L-com.com.

Omnidirectional Antenna Specifications

In addition to the beamwidth and gain, omnidirectional antennas have various other specifications to be considered, including the following:

- Frequency range
- Voltage standing wave ratio (VSWR)
- Polarization
- Attached cable length
- Dimensions
- Mounting requirements

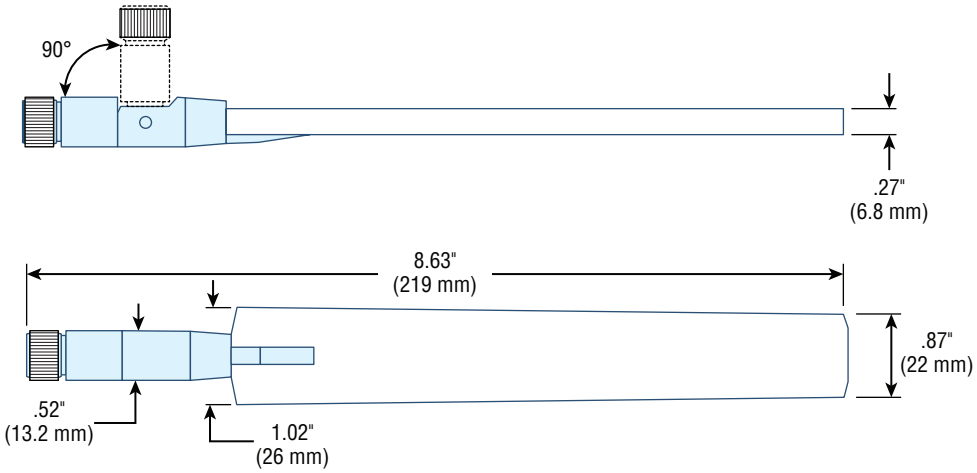
Table 5.1 is an example of a specification sheet for a rubber duck omnidirectional antenna.

TABLE 5.1 Omnidirectional antenna specifications

Electrical Specifications	
Frequency ranges and gain	2400-2483 MHz @ 3 dBi 5150-5900 MHz @ 5 dBi
Horizontal beamwidth	360°
Impedance	50 ohm
VSWR	<2:1
Mechanical Specifications	
Weight	0.18 lb (.07 kg)
Length	10.1″ (256 mm)
Base diameter	1.6″ (40.6 mm)
Finish	Matte black
Connector	Reverse polarity SMA plug
Operating temperature	–30°C to 60°C (–22°F to 140°F)
Polarization	Vertical
RoHS-compliant	Yes

A physical representation of the antenna is also helpful for sales and integration professionals. Figure 5.8 shows the physical specifications diagram for a rubber duck omnidirectional antenna.

FIGURE 5.8 Omnidirectional 2.4–2.5 GHz and 5.1–5.8 GHz dual-band rubber duck antenna physical specifications



Azimuth and elevation charts are usually available to allow visualization of the RF radiation pattern emitted from the antenna. This is useful for a WLAN professional to determine the approximate RF propagation pattern. The purpose of these charts, and how to read them, was explained in "Reading Azimuth and Elevation Charts" earlier in this chapter. Figure 5.9 shows the charts for a rubber duck omnidirectional antenna.

FIGURE 5.9 Vertical (elevation) and horizontal (azimuth) charts for omnidirectional antenna

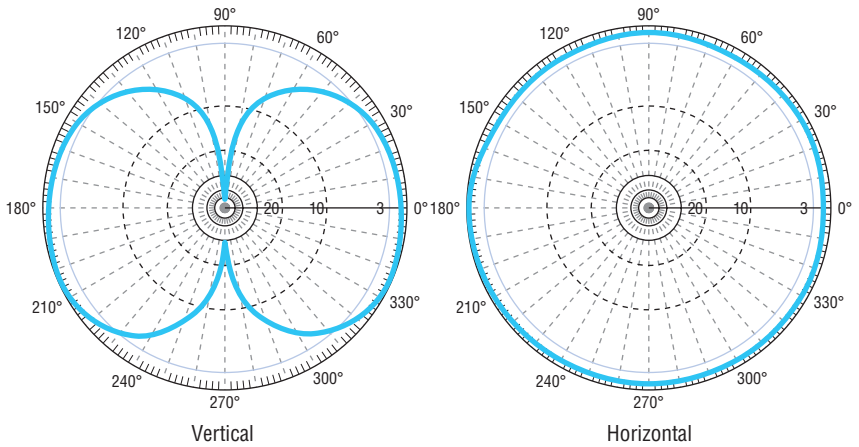


Image provided by www.L-com.com.

Semidirectional Antennas

Semidirectional antennas take RF power from the transmitting system and focus it into a more specific pattern than an omnidirectional antenna offers. *Semidirectional antennas* are available in various types, including patch, panel, sector, and Yagi. These antennas, manufactured for either indoor or outdoor use, are designed to provide more specific coverage by focusing the horizontal radiation pattern to a value of less than 360°. A semidirectional antenna will allow the WLAN designer to provide RF coverage to a specific area within a deployment. This coverage area may consist of rooms or areas in which an omnidirectional antenna might not be the perfect solution. For indoor installations, such areas include rectangular rooms or offices, hallways, and long corridors. For outdoor deployments, they include point-to-point and point-to-multipoint bridging installations.

Patch/Panel Antennas

In the WLAN world, the terms *patch* and *panel* are commonly used to describe the same type of antenna. The intended use will affect the choice of patch/panel antenna to be used in a specific application. Choosing the correct patch/panel antenna will require knowing the dimensions of the physical area to be covered as well as the amount of gain required. A patch/panel antenna can have a horizontal beamwidth of as high as 180°, but usually the horizontal beamwidth is between 35° and 60°. The vertical beamwidth usually ranges between 30° and 80°. Figure 5.10 shows a 2.4 GHz MIMO/802.11n flat panel antenna. Sector antennas are a type of semidirectional antenna that can be configured in an array to provide omnidirectional coverage. Sector antennas are covered in more detail later in this chapter.

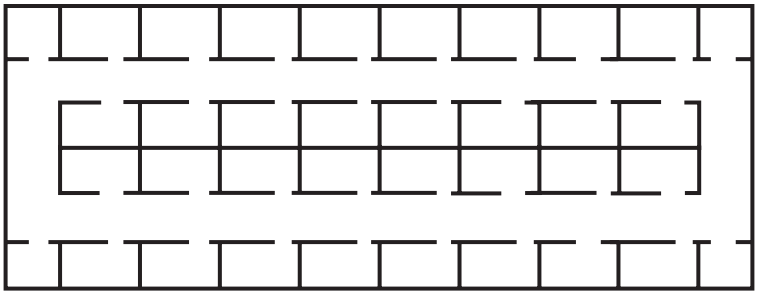
FIGURE 5.10 2.4 GHz 11 dBi dual polarization diversity/MIMO/802.11n flat panel antenna

Image provided by www.L-com.com.

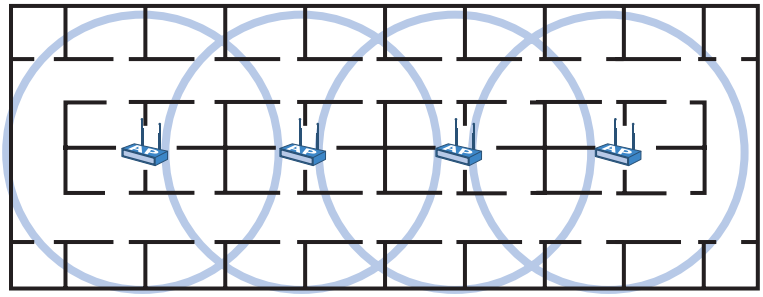
Real World Scenario

Appropriate Use of a Semidirectional Antenna

A small business consultant is tasked with providing WLAN access to several offices in a multi-tenant building. The client wants to provide adequate coverage for the offices but would like to minimize the number of access points. The client wishes to use access points and antennas that are aesthetically pleasing, since these offices allow public access. The areas to be covered are rectangular, as shown here:



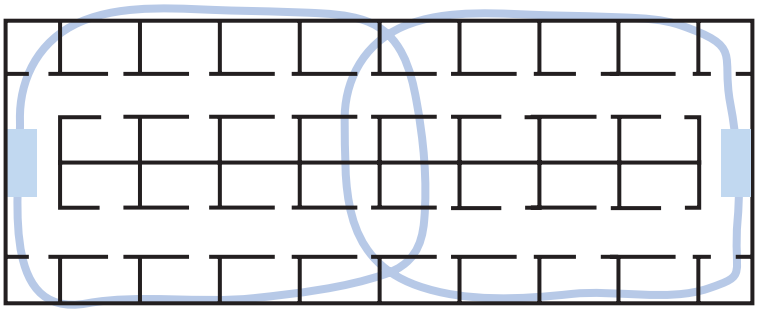
One solution would be to provide several access points using low-gain omnidirectional antennas. The following image illustrates how several access points could be used to provide coverage to this area.



The consultant believes, however, that if low-gain rubber duck omnidirectional antennas were used, an access point with significant output power would be required to cover the length of the rooms. In addition, the client wants to minimize the number of access points and make the installation aesthetically pleasing.

An alternate solution is to use a patch antenna on both sides of the office, thereby providing adequate coverage and minimizing the use of access points. The following image

shows patch antennas mounted at both ends of the office area as well as the projected coverage area of both antennas.



Patch/Panel Antenna Specifications

The specifications for semidirectional antennas such as patch or panel vary based on the design of the antenna. Semidirectional antennas are available in single- or dual-band capability. Semidirectional antennas may be used indoors or outdoors, depending on the application. Table 5.2 is an example of a specification sheet for a 2.4 GHz flat patch antenna.

TABLE 5.2 2.4 GHz 11 dBi dual-polarization diversity/MIMO/802.11n flat patch antenna specifications

Electrical Specifications	
Frequency ranges	2400–2500 MHz
Gain	11 dBi
Horizontal beamwidth (Antennas 1 & 2)	60°
Vertical beamwidth (Antennas 1 & 2)	30°
Impedance	50 ohm
Maximum power	25 W
VSWR	<1.5:1 avg
Mechanical Specifications	
Weight	0.95 lb (0.43 Kg)
Dimensions	8.5″ × 8.5″ × 1″ (216 × 216 × 26 mm)

Mechanical Specifications	
Radome material	UV-inhibited polymer
Connector	RP SMA
Operating temperature	–40°C to 85°C (–40°F to 185°F)
Mounting	Four 1/4″ (6.3 mm) holes
Polarization	Horizontal (Left antenna lead) Vertical (Right antenna lead)
Flame rating	UL 94HB
RoHS-compliant	Yes
Wind survival	>150 mph (241 kph)

A radome cover will protect an antenna from outdoor elements and certain weather conditions. Attenuation from the materials that the radome covers are constructed of will be minimal. They mainly protect the antenna from the collection of elements such as snow and hail.

Azimuth and elevation charts are also available for patch/panel antennas. Figure 5.11 shows the charts for the 2.4 GHz 11 dBi flat patch antenna.

FIGURE 5.11 Vertical (elevation) and horizontal (azimuth) charts for 2.4 GHz 11 dBi dual polarization diversity/MIMO/802.11n flat patch antenna

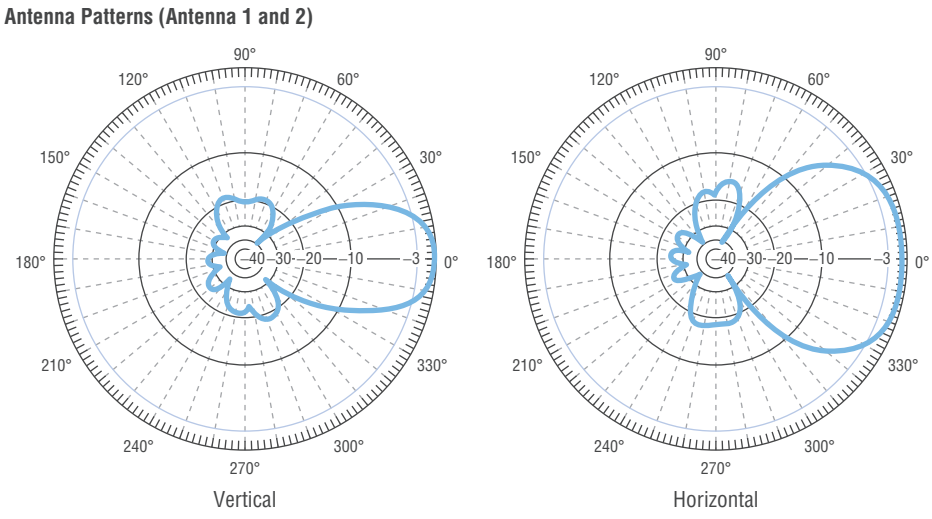


Image provided by www.L-com.com.

Sector Antennas

Sector antennas can be used to create omnidirectional radiation patterns using semidirectional antennas. These antennas are often used for base station connectivity for point-to-multipoint connectivity. *Sector antennas* have an azimuth that varies from 90° to 180°. These are typically configured to offer a total azimuth of 360°. For example, using sector antennas with an azimuth of 120° each would require three antennas in order to get omnidirectional or 360° coverage. This is a common configuration used with cellular phone technology. Figure 5.12 shows a sector panel antenna.

FIGURE 5.12 2.4 GHz and 4.9 to 5.8 GHz dual-feed dual-band 90° sector panel antenna

Image provided by www.L-com.com.

Sector Antenna Specifications

As mentioned earlier, sector antennas are commonly configured in an array to allow semidirectional antennas to provide omnidirectional coverage. This is useful in a campus environment or community arrangement to provide WLAN access such as Internet access. Sector antennas will usually have wide horizontal beamwidth (azimuth) and a narrow vertical beamwidth (elevation). Table 5.3 is an example of a specification sheet for a dual-band 14 dBi 90° sector panel WLAN antenna.

TABLE 5.3 90° sector panel WLAN antenna specifications

Electrical Specifications	
Frequency ranges	2400–2500 MHz 4900–5900 MHz
Gain	14 dBi
Horizontal beamwidth	90°
Vertical beamwidth	16° (2400–2500 MHz) 8° (4900–5900 MHz)
Impedance	50 ohm
Maximum input power	50 W
VSWR	<1.5:1 avg
Front-to-back ratio	>21 dB
Lightning protection	DC ground
Mechanical Specifications	
Weight	4.4 lb (2 kg)
Dimensions	24 × 6.3″ × 2.3″ (620 × 160 × 60 mm)
Radome material	UV-inhibited fiberglass
Connector	(2) Integral N-female
Operating temperature	–40°C to 60°C (–40°F to 140°F)
Mounting	1.5–2 in (40–53 mm) dia. mast max.
Polarization	Vertical
RoHS-compliant	Yes
Rated wind	>130 mph (210 Km/h)

TABLE 5.3 90° sector panel WLAN antenna specifications *(continued)*

Wind Loading Data	
Wind Speed (mph)	**Loading**
100	34 lb
125	54 lb

Figure 5.13 shows the charts for the 2.4 GHz and 4.9 to 5.8 GHz dual-feed dual-band 90° sector antenna.

FIGURE 5.13 Vertical (elevation) and horizontal (azimuth) charts for 2.4 GHz and 4.9 to 5.8 GHz dual-feed dual-band 90° sector panel antenna

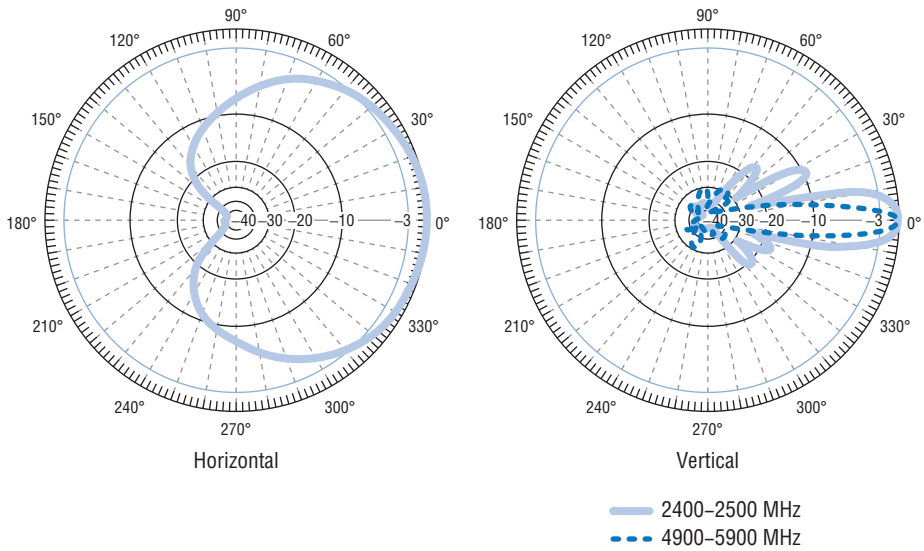


Image provided by www.L-com.com.

Yagi Antennas

Yagi antennas are designed to be used indoors in long hallways and corridors, or outdoors for short-range bridging (typically less than two miles). Yagi antennas have vertical and horizontal beamwidths ranging from 25° to 65°. The radiation pattern may look like a funnel or a cone. As the signal propagates away from the antenna, the RF coverage naturally widens (diffuses). The aperture of the receiving antenna is much narrower than the signal at that point. This is a result of diffusion, which is the biggest form of loss in an RF link. Figure 5.14 shows a Yagi antenna.

FIGURE 5.14 2.4 GHz 15 dBi Yagi antenna

Image provided by www.L-com.com.

Yagi Antenna Specifications

Table 5.4 is an example of a specification sheet for a 2.4 GHz 15 dBi Yagi WLAN antenna.

TABLE 5.4 15 dBi Yagi antenna specifications

Electrical Specifications	
Frequency ranges	2400–2500 MHz
Gain	14.5 dBi
–3 dB beamwidth	30°
Impedance	50 ohm
Maximum power	50 W
VSWR	<1.5:1 avg
Lightning protection	DC short
Mechanical Specifications	
Weight	1.8 lb (.81 kg)
Dimensions – Length × diameter	18.2″ × 3″ (462mm × 76mm)
Radome material	UV-inhibited polymer

TABLE 5.4 15 dBi Yagi antenna specifications *(continued)*

Mechanical Specifications	
Connector	12″ N-female
Operating temperature	–40°C to 85°C (–40°F to 185°F)
Mounting	1-1/4″ (32mm) to 2″ (51mm) diameter masts
Polarization	Vertical and horizontal
Flame rating	UL 94HB
RoHS-compliant	Yes
Wind survival	>150 mph (241 kph)
Wind Speed (mph)	**Loading**
100	12 lb
125	19 lb

Figure 5.15 shows the charts for the 2.4 GHz 14 dBi Yagi antenna.

FIGURE 5.15 Vertical (elevation) and horizontal (azimuth) charts for 2.4 GHz 14 dBi Yagi antenna

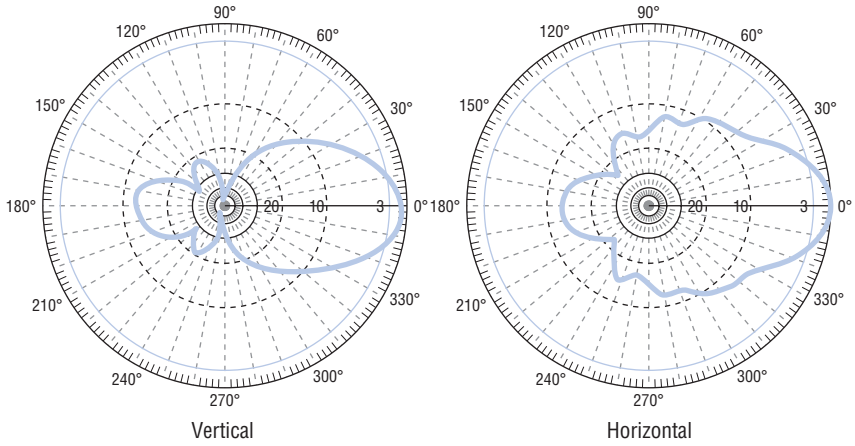


Image provided by www.L-com.com.

Outdoor Installation of Yagi Antennas

A Yagi antenna may be in a weatherproof enclosure. This is not required but may be useful in outdoor installations. The weatherproof enclosure will prevent collection of certain elements such as snow and ice. Radome covers are available for parabolic dish antennas for the same purpose.

Highly Directional Antennas

Highly directional antennas are typically *parabolic dish antennas* used for long-range point-to-point bridge connections. These antennas are available with a solid reflector or a grid. Some manufacturers of parabolic dish antennas advertise long ranges depending on the gain and the environmental conditions. Parabolic dish antennas have very narrow horizontal and vertical beamwidths. This beamwidth can range from 3° to 15° and has a radiation pattern similar to that of a Yagi, with the appearance of a funnel. The beamwidth starts very narrow at the antenna element and naturally widens because of diffusion. Because these antennas are designed for outdoor use, they need to be manufactured to withstand certain environmental conditions, including a wind rating and appropriate mounting. Grid antennas can provide similar coverage and are less susceptible to wind loading. Figure 5.16 shows a parabolic dish antenna.

FIGURE 5.16 Front and back views of a 5.8 GHz 29 dBi ISM / U-NII band parabolic dish antenna

Image provided by www.L-com.com.

Highly Directional Antenna Specifications

Table 5.5 is an example of a specification sheet for a 5.8 GHz 29 dBi solid parabolic dish antenna. Notice that the vertical and horizontal beamwidths of this antenna are 6°, very narrow compared to other antenna types.

TABLE 5.5 5.8 GHz 29 dBi solid parabolic dish antenna specifications

Electrical Specifications		
Frequency ranges	5725–5850 MHz	
Gain	29 dBi	
Horizontal beamwidth	6°	
Vertical beamwidth	6°	
Impedance	50 ohm	
Maximum power	100 W	
VSWR	<1.5:1 avg	
Mechanical Specifications		
Weight	13.2 lb (6 kg)	
Dimensions	23.6″ diameter (600 mm)	
Grid material	Galvanized steel	
Operating temperature	–40° C to 85° C (–40° F to 185° F)	
Mounting	1.5″ (38 mm) to 3″ (76 mm) dia. masts	
Lightning protection	DC Short	
Wind Speed (mph)	**Loading**	**With Radome**
100	113 lb	75 lb
125	177 lb	116 lb

Figure 5.17 shows the charts for a 5.8 GHz solid parabolic dish antenna.

FIGURE 5.17 Vertical (elevation) and horizontal (azimuth) charts for a 5.8 GHz 29 dBi ISM/U-NII band solid parabolic dish antenna

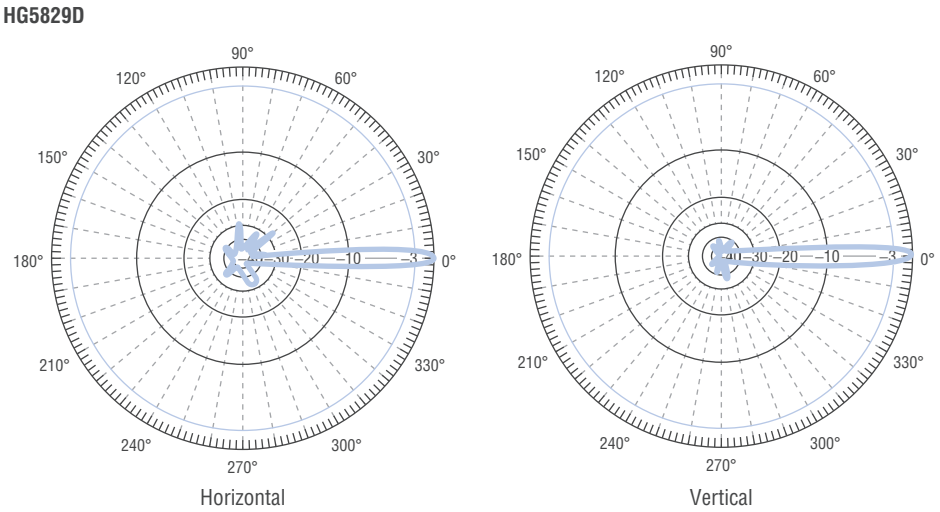


Image provided by www.L-com.com.

Shipping a Parabolic Dish Antenna

One thing to consider regarding the sale and procurement of a highly directional parabolic dish antenna is the size and shipping weight. Since these antennas are much larger and heavier than other antennas used in WLANs, shipping cost may be a factor. Some specification sheets will detail shipping information for this reason.

Radio Frequency Cables and Connectors

Radio frequency cables play a role in various WLAN deployment situations. For example, cables may be used to connect access points and client devices to antennas or to connect other devices that may be used in wireless networking. Several factors need to be taken into consideration when using cables in a WLAN system, including these:

- Type of cable
- Length of cable
- Cost of cable
- Impedance rating

Choosing the correct cable for use in WLAN systems is an important part of a successful WLAN deployment. The right cable for the right job will help ensure that *signal loss*—a decrease in signal strength—is minimized and performance is maximized.

Radio Frequency Cable Types

The type of cable used will depend on the application. Many systems use cables to extend from the wireless device such as an access point to an antenna located outside of a building. It is important to choose the correct type of cable in order to optimize the performance of the WLAN system. Cables vary in diameter, and the application will determine the type of cable to use. For example, connecting a WLAN adapter on a notebook computer to an external antenna requires a specific type of cable that should be short and flexible. Thick, rigid cables are best used for longer runs.

The RF range in which the cable will be used also is important to consider. Where the cable is used will determine the RF rating of the cable. For example, WLANs use cable rated at 50 ohms, whereas television (such as satellite and cable) use cable rated at 75 ohms. Using cable with the correct rating will minimize voltage standing wave ratio (VSWR), a phenomenon discussed in the section "Impedance and VSWR." Figure 5.18 shows a spool of high-quality 50 ohm cable.

FIGURE 5.18 L-com spool of low-loss 400-series coaxial bulk cable

Image provided by www.L-com.com.

Radio Frequency Cable Length

The length of a cable used in a WLAN system is another factor to consider. A cable of even a very short length will have some level of attenuation or loss. As a reminder, loss is a decrease in signal strength. This decrease in signal strength means less overall performance and throughput for users of the WLAN. Professionally manufactured cables typically are

available in many standard common lengths. Best practices recommend using the correct length and minimizing connections. For example, if a run from an access point to an external antenna is 27′, it would be best to use a single cable as close to that length as possible. Connecting two or more pieces of cable together will increase the loss to the system. One might be tempted to use a longer piece, such as 50′, but this is not recommended since the extra length will add loss to the system.

Figure 5.19 shows a short length of cable, known as a *pigtail*, used to connect a standard cable to a proprietary cable. If an RF cable is used or extended, the attenuation that is introduced can be offset with the use of an amplifier or with a higher-gain antenna. An amplifier will provide active gain, and an antenna will provide passive gain. Keep in mind that using an incorrect amplifier may void the system certification and that using a higher-gain antenna may exceed the rules set by the local RF regulatory agency.

FIGURE 5.19 Short pigtail adapter cable

Image provided by www.L-com.com.

Radio Frequency Cable Cost

Cable cost may also play a role in the type of cable to be used. The old saying "you get what you pay for" is true with cables as well. I recommend using high-quality name-brand RF cables to optimize the performance of your system. Premium cables may come at a higher price, but the benefit of better quality signal is the main advantage.

Impedance and VSWR

Impedance is the measurement of alternating current (AC) resistance. It is normal to have some level of impedance mismatch in a WLAN system, but the impedances of all components should be matched as closely as possible in order to optimize performance of the system. Impedance mismatches can result in what is called *voltage standing wave ratio (VSWR)*. A large impedance mismatch can cause higher than desired levels of VSWR and will have an impact on the WLAN system and transmitted or received signal.

Electrical resistance is measured in ohms. IEEE 802.11 WLAN devices have an impedance of 50 ohms. This includes antennas, cables, connectors, and other accessories.

Radio Frequency Connectors

In a WLAN system, RF connectors are used to join devices together, allowing the RF signal to transfer between the devices. These devices may connect access point to antenna, antenna to cable, cable to cable, or various other components to each other. RF connectors also cause an impedance mismatch to some degree and increase the level of VSWR. To minimize the effects of VSWR, best practices suggest keeping the use of connectors to a minimum. Using connectors can also result in *insertion loss*. Insertion loss is usually minor by itself, but it can contribute to overall loss in a system, thereby resulting in less RF signal and less throughput.

Using Proprietary Connectors for Regulatory Domain Compliance

Some regulatory domains require the use of *proprietary connectors* on antennas and antenna connections in WLAN systems. These proprietary connectors prevent an installer or integrator from unintentionally using an antenna that might exceed the maximum amount of power allowed for the transmission system. Although these connectors are considered proprietary, many manufacturers share proprietary connectors.

Standard RF connectors may be used in WLAN systems to connect devices that are not part of the point connecting to the antenna. For example, an access point connecting to a length of cable that is then connected to an amplifier could use a standard RF connector. The cable connecting the amplifier to the antenna would require a proprietary connector. Figure 5.20 shows examples of common RF connectors.

FIGURE 5.20 Several common RF connectors used with WLANs

Image provided by www.L-com.com.

Factors in Antenna Installation

Several factors are important to consider when you are planning to install an antenna in a WLAN environment. These include earth curvature, multipath, and RF line of sight. This section includes information about how to take these factors into account when planning a wireless installation.

Addressing the Effects of Earth Curvature

Beyond seven miles (11.2 km), the curvature of the earth will have an impact on point-to-point or point-to-multipoint WLAN connections. Therefore, it is important to add height to the antenna in order to compensate for the *earth curvature*, sometimes referred to as *earth bulge*. A formula is used to calculate the additional height of antennas when a link exceeds seven miles. However, this is beyond the scope of the exam objectives and is not discussed in this book.

Antenna Placement

The installation location and placement of antennas depend on the type of antenna and application in which it will be used. When installing antennas, consider both the placement based on the design of the WLAN and the intended use of the antenna. When antennas are used outdoors, lightning arrestors, grounding, and adherence to local codes, laws, and government regulations must be followed, as well as good RF design. Increasingly, local ordinances dictate how or if outdoor antennas can be mounted for looks as well as safety. Lightning arrestors and grounding methods are discussed later in this section.

Omnidirectional Antenna Placement

Placement of an omnidirectional antenna will depend on the intended use. Some omnidirectional antennas can be connected directly to an access point or may be integrated within the access point. The installation is fairly straightforward; it involves simply attaching the antenna to the access point or using the integrated antenna. Omnidirectional antennas are usually placed in the center of the intended coverage area. High-gain omnidirectional antennas are typically used in outdoor installations for point-to-multipoint configurations. This configuration is more complex because more than likely it requires mast or tower mounting. The exact placement depends on the intended coverage area as well as the gain of the antenna.

Semidirectional Antenna Placement

Semidirectional antennas may be used for either outdoor or indoor installations. When mounted indoors, a patch/panel antenna typically will be mounted flat on a wall, with the connector upward for connections to a cable or directly to an access point. A template with the mounting hole placement may be included for ease of installation. These antennas

usually will use four mounting holes (one in each corner) to fasten the antenna to the wall securely. Yagi antennas can also be mounted either indoors or outdoors. The most common installation is outdoors for short-range point-to-point or point-to-multipoint bridging solutions. This will require a mounting bracket such as a tilt and swivel for wall mounting or U-bolts and plate for mast or pole mounting.

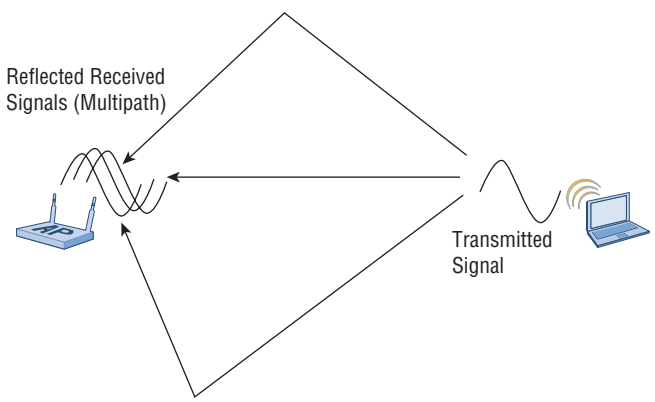
Highly Directional Antenna Placement

Highly directional antennas such as a parabolic dish are almost always used exclusively in outdoor installations. This type of antenna is used mostly for long-range point-to-point bridging links and will require installation on building rooftops or antenna towers. Alignment for long-range links is critical for reliable communications. Software and hardware tools are available for the installer to use for accurate alignment. As with other outdoor installations, secure mounting is essential in order to maintain safety and link reliability.

Minimizing the Effects of Multipath Using Antenna Diversity

In Chapter 4, we discussed some of the behaviors of RF, including reflection, refraction, scattering, and diffraction. To review, reflection is caused by an RF signal bouncing off a smooth, nonabsorptive surface and changing direction. Indoor environments are areas that are prone to reflections. Reflections are caused by the RF signal bouncing off walls, ceilings, floors, and furniture; thus, some installations will suffer from reflection more than others. The effect of reflection will be a decrease in signal strength due to a phenomenon called *multipath*. Multipath is the result of several wavefronts of the same transmission signal received out of phase at slightly different times. This can cause the receiver to be confused about the received signals. The result is corrupted signal and less overall throughput. Figure 5.21 illustrates multipath.

FIGURE 5.21 Effects of multipath



Think of multipath as an echo. If you were to stand near a canyon and speak to somebody at a high volume some distance away, the other person would notice an echo. This echo is due to the fact that the sound of your voice is reflecting off the canyon walls. Therefore, the other person is hearing variations of your voice at slightly different times—as with RF multipath, several wavefronts of the same signal are arriving out of phase.

Antenna diversity is one way to help reduce the effects of multipath. *Antenna diversity* is a technology used in IEEE 802.11a/b/g WLANs; a station (access point or client device) will utilize two antennas combined with one radio to decrease the effects of multipath. Using multiple antennas and some additional electronic intelligence, the receiver will be able to determine which antenna will receive and send the best signal. In diversity systems, two antennas are spaced at least one wavelength apart. This allows the receiver to use the antenna with the best signal to transmit and receive. With respect to RF diversity, the antennas are required to be of the same design, frequency, gain, and so on. Newer IEEE 802.11 technologies (802.11n and 802.11ac, for example) are capable of high throughput (HT) multiple-input, multiple-output (MIMO), which uses radio chains to transmit and receive radio signals. IEEE 802.11a/b/g devices used a single radio to transmit and receive radio signals, which is known as *single-input, single-output* (SISO) technology. SISO systems are subject to multipath. This is a problem for IEEE 802.11a/b/g systems, whereas MIMO actually uses the reflections (multipath) to help enhance the performance and throughput using several radio chains and additional electronics in newer WLAN technology. You can read more about MIMO in Chapter 2, "Wireless Local Area Networking, Standards, and Certifications," in the section "The IEEE 802.11n Amendment."

Diversity Antenna Orientation

When you are using a diversity system such as an access point, it is important to have both antennas oriented the same way. They cannot be used to cover different areas. Using diversity antennas in an attempt to provide coverage for different areas will defeat the purpose of the diversity design.

Combating Effects of Wind and Lightning in Wireless LAN Installations

Weather conditions such as rain, snow, and sleet typically do not affect WLAN communications unless the conditions are extreme or snow and sleet collect on antenna elements. However, some weather conditions that can affect wireless communication are wind and lightning.

Most outdoor antennas that can be affected by wind will have wind-loading data in the specification sheet. *Wind loading* is the result of wind blowing at high speeds and causing the antenna to move.

Lightning can destroy components connected to a network if the antenna takes either a direct or an indirect lightning strike. A properly grounded lightning arrestor will help protect WLAN and other networking equipment from indirect lightning strikes.

Lightning Arrestors

Transient or induced electrical currents are the result of an indirect lightning strike in the area of a WLAN antenna system. *Lightning arrestors* are an in-series device installed after the antenna and prior to the transmitter/receiver. Although this device will not provide protection from a direct lightning strike, it will help protect against an indirect lightning strike, which can damage electronics at distances away from the source of the strike. When the induced electrical currents from a lightning strike travel to the antenna, a lightning arrestor shunts this excess current to ground, protecting the system from damage. Figure 5.22 shows a lightning arrestor.

FIGURE 5.22 Phoenix Contact 2.4–5.9 GHz surge protection device

Image provided by www.phoenixcontact.com.

Grounding Rods

A *grounding rod* is a metal shaft used for grounding a device, such as an antenna used in wireless networking. The rod should be driven into the ground at least 8′ deep. Grounding rods are available in various types of steel, including stainless, galvanized, and copper clad. They are also available in a variety of diameters and lengths. Depending on the local electrical code, the grounding system should measure resistance between 5 and 25 ohms. Local code should also be consulted regarding material, diameter, and length of grounding rods. You should not share grounding rods with other equipment because interference or damage may occur.

It is imperative to install a grounding rod properly to ensure correct operation. If installing a grounding rod and other lightning protection equipment is beyond the knowledge level of the wireless engineer or installer, it is best to have a professional contractor perform the job.

Installation Safety

Professional contractors should be considered in the event you are not comfortable with performing the installation of a WLAN antenna yourself. Installing antennas may require bonded or certified technicians. Be sure to check local building codes prior to performing any installation of a WLAN antenna. Never underestimate safety when installing or mounting antennas. All safety precautions must be adhered to while performing an installation. The following are some general guidelines and precautions to be considered for a WLAN antenna installation:

- Read the installation manual from the manufacturer.
- Always avoid power lines. Contact with power lines can result in death.
- Always use the correct safety equipment when working at heights.
- Correctly install and use grounding rods when appropriate.
- Comply with regulations for use in the area and for the use of towers.

Antenna Mounting

In addition to choosing the correct antenna to be used with a WLAN system, you must take into account the antenna mounting. The required antenna mounting fixture will depend on the antenna type, whether it will be used indoors or outdoors, and whether it will be used for device/client access or bridging solutions such as point-to-point or point-to-multipoint. It is best to consult with the antenna or device manufacturer to determine

which mounting fixture is appropriate for use based on the intended deployment scenario. The following are several mounting types that may be used for a WLAN antenna solution:

- Internal and external (to the access point) antennas
- Pole/mast mount
- Ceiling mount
- Wall mount

Internal and External (to the Access Point) Antennas

Some wireless access points allow the use of either integrated or external antennas. Most modern controller-managed and cloud-managed access points provide integrated antennas, and some have connectors to allow for the use of external antennas. Integrated antennas may be a better solution, mostly to match the aesthetics requirements of the organization where the access point will be used. Integrated antennas make an access point less noticeable if it is hanging from a standard 8′–10′ high ceiling. Integrating them will also prevent individuals from tampering with antennas that if external might be within a person's reach. Tampering could be an issue in areas that are accessible to the general public, such as installations in educational, library, and medical environments.

It is important to take the mounting orientation into consideration when using access points with integrated antennas. The access point may be designed to be mounted on a ceiling. If you were to mount this type of access point on a wall, the radiation patterns would change, and this might create a coverage problem, especially with omnidirectional antennas.

One disadvantage of access points with integrated antennas is that the antennas cannot be changed to any other type. Basically you would be committed to using the antennas that are part of the access point and would be unable to add an antenna with higher gain or a different radiation pattern. Access points that have external antenna connectors allow the user to add different antennas that may be better suited to the environment or installation location. The external antennas will allow for a higher gain and possibly a different radiation pattern. Using an external antenna usually requires a software configuration that will disable the integrated antenna when external antennas are installed. You should not be able to use both the integrated and external antennas simultaneously. Many indoor access point models that use internal antennas offer the same coverage as their external antenna model counterparts This, however, will vary based on the manufacturer.

When using wireless access points with integrated antennas, it is important to take the mounting into consideration. Some access points of this style are intended to be mounted on a ceiling or a wall, possibly both. Mounting an antenna in a way it is not designed for will produce undesirable results, including RF coverage problems.

Pole/Mast Mount

Pole/mast mounts typically consist of a mounting bracket and U-bolt mounting hardware. The mounting bracket is commonly L-shaped. One side of the bracket has a hole to mount an omnidirectional or similar antenna. The other side of the bracket has predrilled holes for fastening the bracket to a pole using U-bolts. Figure 5.23 shows an example of a mast mount bracket.

FIGURE 5.23 Stationary antenna mast mounting kit with U-bolts

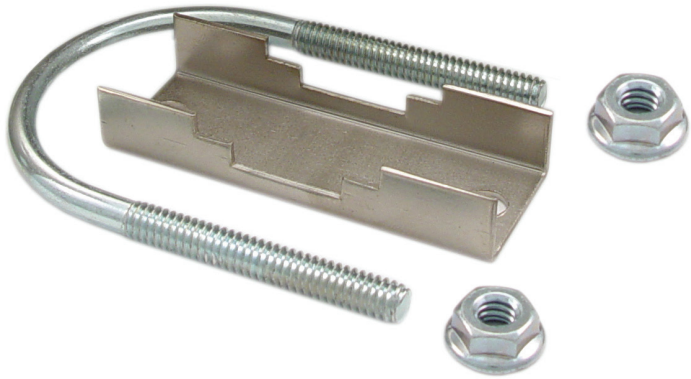


Image provided by www.L-com.com.

Exercise 5.2 describes the basic steps for installing an omnidirectional antenna using a mast mount adapter.

EXERCISE 5.2

Installing a Pole/Mast Mount

1. Attach the mounting bracket to the mast using the supplied hardware.
2. Remove the antenna mounting bolt and washer from the base of the antenna.
3. Insert the antenna into the hole in the top of the mounting bracket. Without overtightening, securely fasten the antenna to the mounting bracket using the washer and antenna mounting bolt.
4. For outdoor installations, remember to use the proper sealant for weatherproofing when connecting the cable to the antenna.

Ceiling Mount

It may be necessary to mount certain antennas or access points with attached or integrated antennas from a ceiling. Many antennas can be mounted directly to a hard ceiling made from concrete, drywall, or similar material. Another possibility is a drop ceiling with acoustic tiles. Regardless of the type of ceiling in question, follow the manufacturer's instructions on the appropriate fixture to be used for mounting and detailed instructions for ceiling mounts. Figure 5.24 shows an example of a ceiling mount antenna.

FIGURE 5.24 L-com 2.3 GHz to 6 GHz 3 dBi omnidirectional ceiling mount antenna

Image provided by www.L-com.com.

Wall Mount

Antennas or access points with attached antennas may need to be mounted to a wall based on the use or site survey results. Just as with a ceiling mount, follow the manufacturer's instructions on the appropriate fixture for wall mounting. When mounting an antenna to the wall, consider the polarization of the antenna. Keep in mind that some antennas are designed to be mounted on the ceiling; these types should not be mounted on a wall. This is especially true for access points with integrated antennas. It is best to try to match the polarization of the access points and the wireless client devices. In other words, if the access point's antennas are vertically polarized, the wireless client devices should be polarized in the same manner to promote better connectivity. With the wide variety of newer wireless client devices available, however, this is getting harder to achieve. Choosing the correct antenna and mounting position is typically part of a WLAN site survey. Site surveys will be discussed in more detail in Chapter 9.

Maintaining Clear Communications

Several factors affect whether two wireless devices can communicate with each other. These factors include line of sight (both visual and RF) and Fresnel zone. Indoor WLAN installations use a low amount of RF transmit power, usually around 30 mW to 50 mW,

and will be able to communicate effectively even if the client device does not have a line of sight with an access point. This is because the RF will be able to penetrate obstacles such as walls, windows, and doors. Outdoor installations usually use a much higher output transmit power and will require an RF line of sight for effective communication.

Visual Line of Sight

Visual *line of sight* (LoS) is defined as the capability of two points to have an unobstructed view of one another. A visual LoS is usually not necessary for communications using indoor IEEE 802.11 WLAN systems; it is implied with RF LoS. If a WLAN engineer were planning to connect two buildings together using WLAN technology, one of the first things the engineer would do is to verify that there is a clear, unobstructed view between the planned locations in order to provide an RF LoS.

Radio Frequency LoS

For two devices to communicate successfully at a distance via RF, including a point-to-point or point-to-multipoint connection, a clear path for the RF energy to travel between the two points is necessary. This clear path is called *RF LoS*. This RF LoS is the premise of the Fresnel zone.

Fresnel Zone

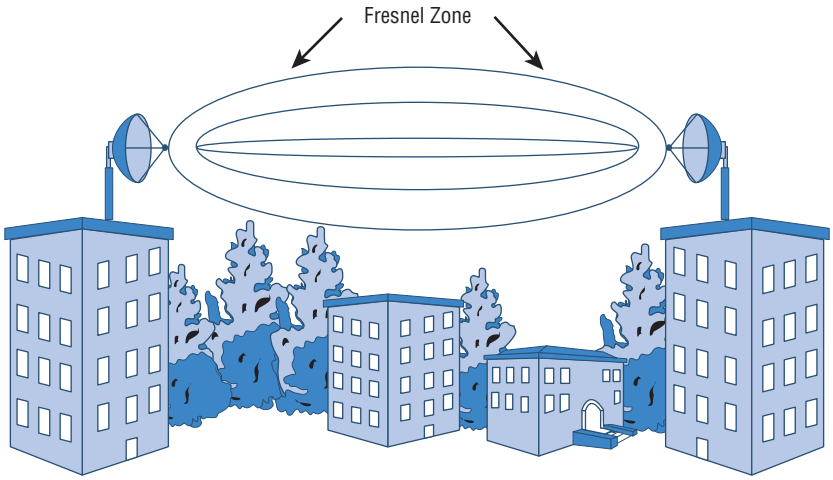
The *Fresnel zone* for an RF signal is the area of RF coverage surrounding the visual LoS. The width or area of the Fresnel zone will depend on the specific RF used as well as the length or distance of the signal path. There is a formula used to calculate the width of the Fresnel zone at the widest point; however, that is beyond the scope of the exam objectives and is not shown in this book.

In an outdoor point-to-point or point-to-multipoint installation, it is important for the Fresnel zone to be clear of obstructions for successful communications to take place between a RF transmitter and receiver. Best practices recommend maintaining an obstruction-free clearance of the least 60 percent for the Fresnel zone in order to have acceptable RF LoS. Maintaining a clear RF LoS becomes more difficult as the distance between two points increases. Obstructions can cause the Fresnel zone to be blocked enough for communications to suffer between a transmitter and receiver. Such obstructions include

- Trees
- Buildings or other structures
- Earth curvature
- Natural elements such as hills and mountains

Figure 5.25 illustrates the Fresnel zone between two highly directional antennas.

FIGURE 5.25 Visualization of the Fresnel zone



In order for your antennas to stay clear of obstructions, carefully plan their placement and height. Keep in mind that a WLAN link may cross public areas in which an integrator or installer will have no control over the environment. There is a possibility, depending on the environmental conditions, that an IEEE 802.11 WLAN link may not be a feasible solution due to the inability to maintain an RF LoS. You should perform an outdoor site survey prior to the procurement and installation of WLAN hardware to ensure the installation and operation of the WLAN will be successful.

Summary

Antennas are a critical component in a successful operation of a WLAN. In this chapter, you learned about RF signal characteristics and basic RF antenna concepts, including the following:

- RF lobes
- Beamwidth (horizontal and vertical measurements)
- Passive and active gain
- Horizontal and vertical polarization of antennas

By understanding these characteristics and concepts, a sales engineer, integrator, or other WLAN professional can help choose the best antenna to be used for a specific use.

Understanding the RF propagation patterns of various antenna types as well as the recommended use of an antenna will assist in deciding which antenna is best suited for the desired application. As discussed in this chapter, antennas are available in various types:

- Omnidirectional
- Semidirectional
  - Patch/panel
  - Sector
  - Yagi
- Highly directional
  - Parabolic dish

Omnidirectional antennas are one of the most common types of antenna used for indoor applications of wireless networking. Omnidirectional antennas provide a horizontal radiation pattern of 360°. Other antennas, such as patch/panel, Yagi, or parabolic dish, can be used if justified by the intended use. You learned about the radiation patterns of each of these types of antennas as well as how each may be used.

A proper mounting fixture is required to ensure safety and correct operation of the antenna and wireless network. This chapter looked at various methods for mounting antennas, including integrated and external (to the access point), pole/mast mount, ceiling mount, and wall mount.

Finally, you learned about the following other factors to be considered when choosing and installing an antenna for use with WLANs:

- Visual line of sight
- RF line of sight
- Fresnel zone

Understanding these concepts will help you achieve more successful deployment, operation, and use of antennas in WLANs.

Exam Essentials

Understand RF signal characteristics and basic RF concepts used with antennas. Know the difference between passive and active gain. Understand that antennas use passive gain to change or focus the RF radiation pattern. Understand the difference between beamwidth and polarization.

Know the different types of antennas used in wireless networking. Be familiar with different types of antennas used with wireless networking, including omnidirectional antennas, semidirectional antennas, and highly directional antennas. Understand the various radiation patterns each of these antennas is capable of.

Identify various RF cables, connectors, and accessories used in WLANs. Understand that, depending on the local regulatory body, proprietary connectors may be required for use with antennas. Know that cables will induce some level of loss in a WLAN system. Be familiar with the types of connectors available.

Identify the mounting options of antennas used in wireless networking. Antennas may be integrated or external to the wireless access point. Identify different types of antenna mounts, including internal and external (to the access point), pole/mast, ceiling, and walls.

Understand additional concepts regarding RF propagation. Understand and know some of the additional concepts when choosing and installing antennas used with WLANs. These concepts include visual line of sight, RF line of sight, and Fresnel zone.

Review Questions

1. Omnidirectional antennas have a horizontal beamwidth of _____ degrees.
   - **A.** 90
   - **B.** 180
   - **C.** 270
   - **D.** 360

2. Antennas provide an increase in RF coverage by using _____ gain.
   - **A.** Active
   - **B.** Passive
   - **C.** Positive
   - **D.** Maximum

3. Horizontal beamwidth is _____ to the earth's surface.
   - **A.** Parallel
   - **B.** Perpendicular
   - **C.** Positive
   - **D.** Negative

4. IEEE 802.11a/b/g access points require _____ antennas on each radio for diversity functionality.
   - **A.** One
   - **B.** Two
   - **C.** Three
   - **D.** Six

5. What device is used to shunt transient current to ground in the event of an indirect lightning strike?
   - **A.** Lightning striker
   - **B.** Lightning arrestor
   - **C.** Lightning prevention
   - **D.** Lightning breaker

6. Powered amplifiers provide an increase in signal strength by using _____ gain.
   - **A.** Active
   - **B.** Passive
   - **C.** Positive
   - **D.** Maximum

7. Highly directional antennas are typically used for _____ connectivity.

A. Short-range

B. Omnidirectional

C. Long-range

D. Dipole

8. You are a network engineer troubleshooting a WLAN weak signal complaint. While moving a handheld WLAN device, you notice that the signal strength increases when the device is moved from a horizontal to a vertical position. This is because the _____ is changing.

A. Polarization

B. Wavelength

C. Frequency

D. Diffusion

9. RF line of sight is required for which type of IEEE 802.11 WLAN installation? (Choose two.)

A. Point-to-point

B. Scattered

C. Point-to-multipoint

D. Reflected

E. Refracted

10. Which can cause a loss of signal strength? (Choose two.)

A. Antenna

B. Amplifier

C. Cable

D. Connector

E. Transmitter

11. An IEEE 802.11g access point requires a minimum of how many antennas to move data?

A. One

B. Two

C. Four

D. Six

12. 802.11a access points support which antenna technology to help reduce the effects of multipath?

A. Adjustable gain

B. Antenna diversity

C. Adjustable polarization

D. Antenna multiplexing

13. The following graphic shows which type of antenna?

A. Omnidirectional
B. Yagi
C. Patch/panel
D. Parabolic dish

14. Which weather element would commonly have an effect on a WLAN system?
A. Rain
B. Snow
C. Wind
D. Hail

15. Wireless network cables and devices have impedance (AC resistance) of _____ ohms.
A. 10
B. 25
C. 50
D. 75

16. The curvature of the earth will have an impact on the WLAN signal after how many miles?
A. 2
B. 7
C. 10
D. 25

17. A patch antenna is an example of which type of antenna?

- **A.** Semidirectional
- **B.** Omnidirectional
- **C.** Highly directional
- **D.** Dipole-directional

18. An azimuth chart shows which RF radiation pattern?

- **A.** Vertical
- **B.** Horizontal
- **C.** Positive
- **D.** Negative

19. A point-to-point wireless link requires what percent of the Fresnel zone to be clear in order to be considered to have an acceptable RF line of sight?

- **A.** 0
- **B.** 20
- **C.** 40
- **D.** 60

20. The following image shows which type of antenna?

- **A.** Highly directional
- **B.** Dipole-directional
- **C.** Omnidirectional
- **D.** Semidirectional

Chapter

6

Communication for Wireless Networking

THE FOLLOWING CWTS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

✓ **1.2 Define basic characteristics of and concepts relating to Wi-Fi technology**

THE FOLLOWING CWS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

✓ **2.6 Describe features of enhanced 802.11 functions**

THE FOLLOWING CWT EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

✓ **2.2 Explain the basic WLAN location processes**

✓ **2.3 Describe the basic steps required in the WLAN connection process**

✓ **2.5 Configure client devices**

✓ **4.2 Identify legacy security technologies that should not be used**

This chapter will look at terminology and basic communication used in 802.11 wireless networking. IEEE 802.11 wireless LANs (WLANs) can be configured in one of two operation methods: ad hoc or infrastructure mode. We will discuss both of these methods, as well as how the technology is applied and its advantages and disadvantages. In addition, we will examine some of the technical aspects, such as naming the WLAN and identifying the devices through Layer 2 MAC addressing or logical names. You will also learn about the methodologies a WLAN device or client station uses to locate and connect to the wireless network. (These include passive and active scanning as well as the authentication and association processes.)

It is important to know how IEEE 802.11 WLAN infrastructure devices such as access points are connected using a common distribution system. This distribution system allows access points to communicate with each other and enables the associated and connected WLAN devices to roam or move between access points and maintain consistent connectivity across the WLAN.

Other WLAN technology factors are important to understand when studying IEEE 802.11 wireless networking. This chapter will discuss the differences between data rates, modulation, coding schemes, and throughput. A sales or technical support specialist should be able to understand and explain why, for example, an IEEE 802.11ac access point advertises a maximum aggregate signaling rate of up to 6,933.3 Mbps (6.93 Gbps), but in many cases the data transfers are much less than the advertised rate.

Finally, we will look in depth at IEEE 802.11 protection mechanisms and explain why they are needed for backward compatibility and the effect they may have on the data transfer rate.

Some of the topics you will see in this chapter have been briefly touched on in earlier chapters. One of the objectives of this chapter is to tie the terminology and topics together. It can be somewhat challenging to cover certain parts of the WLAN technology without touching lightly on some other topics. This chapter will tie some of the loose ends together and help you to better understand how IEEE 802.11 wireless networks operate.

Wireless LAN Operation Methods

WLANs can be configured to operate in different modes for device and user access. Two common modes for access are ad hoc mode and infrastructure mode. These two modes can be broken down into the following three different configuration sets:

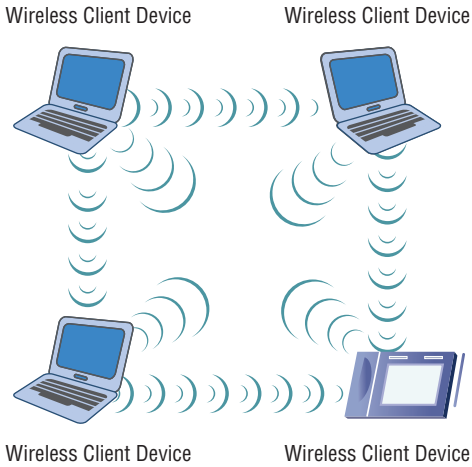
- Independent basic service set (IBSS)
- Basic service set (BSS)
- Extended service set (ESS)

Each of these configurations will be discussed in more detail in this chapter. The application/deployment scenario for a WLAN is the determining factor for the best mode to use. The IBSS configuration does not require the use of an access point and, unless specifically justified, is not commonly used in enterprise WLAN deployments. In addition, if not properly implemented, the IBSS can introduce security vulnerabilities, such as potentially bridging the wired network infrastructure to an unsecured wireless network. The most common configuration for an IEEE 802.11 WLAN is infrastructure mode, which uses at least one access point. Infrastructure mode requires a minimum of one access point but can consist of up to thousands of access points. The access points are connected by a common medium known as the *distribution system* (DS). We will look at each of these modes and the details of how they are configured.

The Independent Basic Service Set

It is important to understand what the *independent basic service set* (IBSS) is, how it works, and its potential uses, advantages, and disadvantages. An IBSS network is also known as an *ad hoc* or *peer-to-peer* network. This WLAN operation mode uses no access points and consists of only wireless devices or client computers. Communication occurs only among devices that are part of the same IBSS. Unlike an access point, this mode has no centralized control or manageable security or accounting features. Figure 6.1 shows devices in an IBSS.

FIGURE 6.1 Example of an independent basic service set (IBSS)



Certain parameters must be set on the devices that wish to participate in an IBSS. These parameters must be the same on all the devices in order for them to effectively communicate with one another. The following are three common parameters set on devices that belong to the same IBSS:

- Service set identifier (SSID)
- Radio frequency (RF) channel
- Security configuration

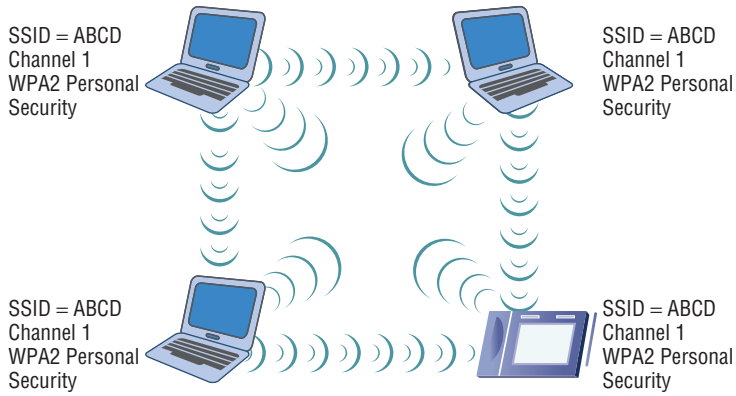
The Service Set Identifier

The *service set identifier* (SSID) is a common parameter used in all WLAN operation configurations. Although it is discussed here, it also pertains to the other configurations discussed later in this chapter, such as the basic service set (BSS) and extended service set (ESS). The SSID is the logical name of the service set used to identify the wireless network. The SSID is used by devices to select a wireless network to join. This is accomplished through processes that are known collectively as the *discovery phase* and include passive and active scanning, both of which will be discussed later in this chapter.

In some cases, naming a wireless network can be a tough decision. Organizations that deploy a wireless network may already have a naming convention in place for such scenarios. If not, a decision will need to be made regarding the wireless network names (SSIDs) used for access points and other devices to identify the WLAN.

Every device that wishes to be part of the same WLAN IBSS, BSS, or ESS will use a common network name, the SSID. (See Figure 6.2 for an IBSS example.) For infrastructure devices such as access points, the SSID parameter is manually set on the access point. From the client access side, the SSID is a user-configurable parameter that can be set manually in the wireless client software utility or received automatically from networks that broadcast this information element.

FIGURE 6.2 IBSS, ad hoc, or peer-to-peer network using common configuration parameters



The SSID name should be unique and should not divulge who you are or the location of the WLAN devices, unless you are trying to create a wireless hotspot or a public accessible IEEE 802.11 wireless network. For example, if a fictitious bank by the name of ABC Bank used an SSID that included ABC_Bank, it would tell an intruder where the wireless network is and could be a potential security threat because a financial institution is a target. It is important to understand if the proper WLAN security is enabled, the SSID name should not be an issue, but there is no point in broadcasting certain types of information. Rather than using the bank name in the SSID, consider a unique name that does not describe the business or location.

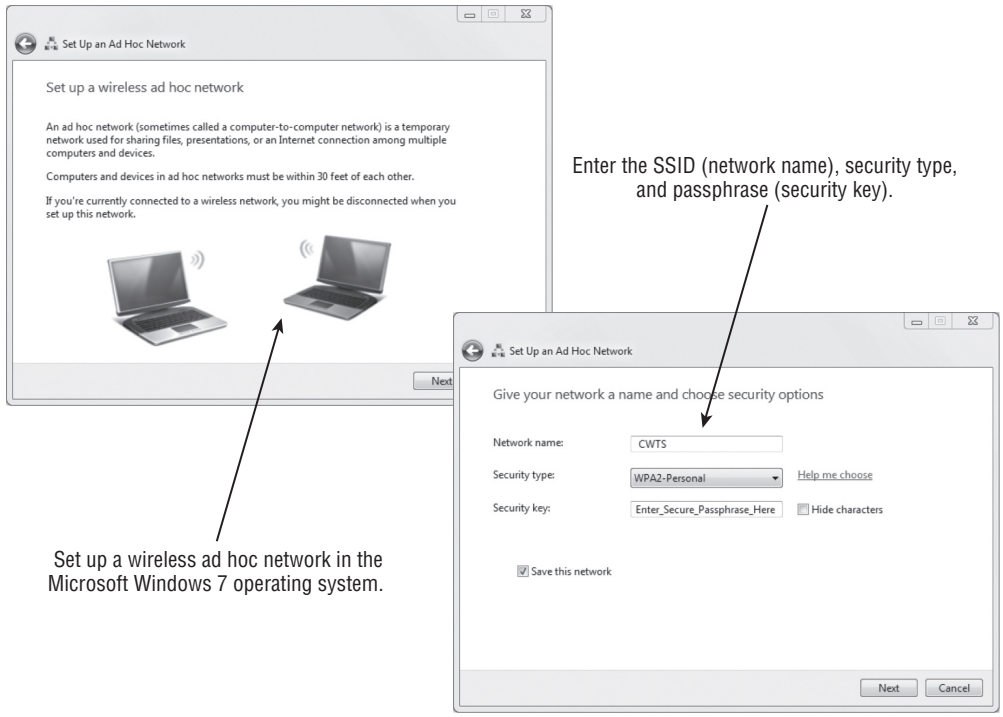
The SSID is case sensitive, must consist of at least one ASCII character, and has a maximum limit of 32 characters or, as specified in the IEEE 802.11 standard, 32 octets.

SSID Hiding

Most manufacturers of small office, home office (SOHO) and enterprise-grade access points allow the SSID to be hidden from view for devices attempting to locate a wireless network. In this case, a client device would need to know and specify the SSID in the client utility profile in order to connect to the network. Even though this is not an effective way to secure a wireless network and should not be used to do so, it is a practice some choose to use for various reasons. Some disadvantages to not broadcasting the SSID are that it may cause an increase in roaming times in an enterprise deployment, and in a SOHO deployment cause neighbors to deploy on the same channel that you are using because they are unable to see your network. *SSID hiding* (also known as a *closed network*) will be discussed in more detail in Chapter 8, "Security Fundamentals for Wireless Networking."

Figure 6.3 shows an example of entering the SSID in the Microsoft Windows 7 AutoConfig wireless configuration client utility for an ad hoc network. First you select "Set up a wireless ad hoc (computer-to-computer) network" in the Set Up A Connection Or Network dialog box; then you enter the SSID on the "Give your network a name and choose security options" Properties page.

FIGURE 6.3 Entering the SSID and other parameters in the Microsoft Windows 7 wireless configuration client utility



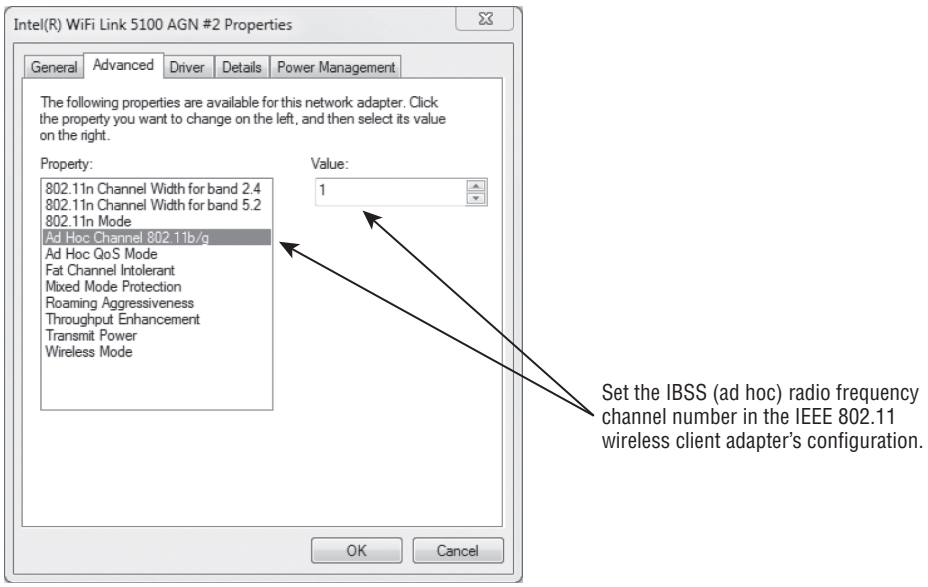
Microsoft Windows operating systems after version 8.1 no longer allow for an ad hoc network to be created from the graphical user interface. However, there are some command-line settings that can be used to allow wireless ad hoc connections from other devices.

The Radio Frequency Channel

The IBSS wireless network configuration requires a user to set the specific RF channel that will be used by all devices that are part of the same IBSS network. This is accomplished in the client utility software for the network adapter. Some client software utilities set this automatically, in which case the IBSS will use the channel automatically specified. You may also be able to specify the RF channel in the advanced properties of the wireless network adapter device driver properties.

It is important to understand that all wireless devices in any common IBSS must be communicating on the same RF channel. If the client utility does allow a channel to be set, the channel chosen is up to the user but based on the local regulatory domain in which the network is used. Additional devices wishing to join the IBSS must do so by scanning, either passively or by use of active scanning. Figure 6.4 shows an example of setting the RF channel on a notebook computer.

FIGURE 6.4 Setting the RF channel for an IBSS, ad hoc wireless network in a wireless network adapter driver advanced settings page



IBSS Security

With IBSS networks, there is no centralized control and no security management features. Security is left up to the individual user or wireless device. If a user inadvertently shares a resource, it could expose sensitive information and pose security threats. This can be a concern for many enterprise installations, and therefore the use of an IBSS is against corporate security policy in many organizations.

IBSS Terminology

The WLAN industry uses several different terms to identify an IBSS. The term used is up to the manufacturer or a specific implementation. An IBSS is usually identified by one of following three terms:

- Independent basic service set (IBSS)
- Ad hoc
- Peer-to-peer

Regardless of the terminology used—*IBSS*, *ad hoc*, or *peer-to-peer*—it comes down to WLAN devices connecting to each other without the use of an access point or other wireless infrastructure device. All devices in an IBSS network work independently of one another, and there is no centralized management or administration capability. This type of connection may be useful in homes or small offices for ease of installation but is rarely if at all used with enterprise or corporate wireless networks.

Advantages and Disadvantages of an IBSS

The advantages and disadvantages of an IBSS network will vary depending on the application.

Some of the advantages of IBSS are as follows:

Easy to Configure To create an IBSS, the user only needs to specify an SSID, set the RF channel, and enable the security settings.

No Investment in Access Point Hardware An IBSS can be created with the IEEE 802.11 WLAN adapter that is built into the wireless computer or other device. No infrastructure device such as an access point is required to connect the WLAN devices together.

Some disadvantages of IBSS are as follows:

Limited Radio Frequency Range and Interference Because radio communications is two-way, all devices need to be in a mutual communication range of one another in order to operate effectively. Interference may also be an issue if the RF channel is not configured correctly.

No Centralized Administration Capability In many large or enterprise deployments, IBSS connectivity is against corporate security policy because it is impossible to manage such networks centrally.

Not Scalable There is no set maximum number of devices that can be part of an IBSS network, but the capacity of such networks is low compared to other types of networks.

Difficult to Secure Some computer operating systems have made the setup of an IBSS wireless network very easy for any type of user. These users may inadvertently share or allow access to sensitive or proprietary information. This security threat is worse if an IBSS wireless network is also physically connected to a wired network and provides a connection from an unsecured or unmanaged wireless network to a company's wired network infrastructure.

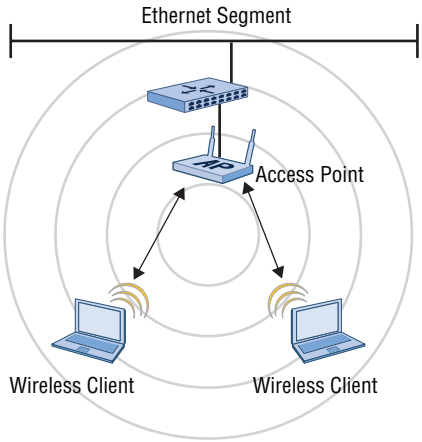
A WLAN device such as a notebook computer configured as an IBSS device can be a potential security threat if it is also connected to a wired network infrastructure. It could provide a bridge for unsecured wireless access to the company's wired network. In this configuration, potential intruders would have access to information from a corporate network by connecting to the unsecured ad hoc network. For this reason, this type of configuration is against written corporate security policies of many organizations and is strictly enforced. Organizations may use wireless intrusion prevention systems to detect and shut down wireless ad hoc networks. It is important to inform visitors and contractors who may be physically connected to the company's infrastructure when ad hoc networks are against the corporate security policy to prevent potential security issues.

Setting up an IBSS network is similar to setting up a workgroup for an operating system such as Microsoft Windows. All devices with the same workgroup name will be able to communicate with each other sharing resources such as files, printers, and so on.

The Basic Service Set

The *basic service set* (BSS) is the foundation of the wireless network. This mode consists of an access point connected to a network infrastructure and its associated wireless devices. This is considered the foundation because it may be one of many access points that form a wireless network. With a BSS setup, each access point is connected to a network infrastructure, also known as the *distribution system* (DS), which allows connected WLAN devices to access network resources based on the appropriate permissions the wireless device or user has access to. The RF area of coverage, known as the *basic service area* (BSA), depends on several factors, such as the antenna gain and RF output power settings. Any IEEE 802.11 wireless device in radio range and part of the BSA with the correct configuration parameters, including the SSID and security settings, will be able to connect to the access point. Figure 6.5 shows an example of a BSS.

FIGURE 6.5 Basic service set consisting of a single access point connected to a distribution system and associated devices



Infrastructure mode consists of a wireless access point connected to a DS. The BSS consisting of one access point is a common implementation in many homes, SOHO, or small to medium businesses (SMBs). The decision to use a single access point depends on several factors, among them the size of the location, how the wireless network is used, and how many wireless devices will be connected.

Just as in an IBSS configuration, several parameters need to be configured for a BSS. These include the SSID or name of the network, the RF channel to be used, and any security parameters that are set on the BSS. The access point will broadcast these and other parameters about the wireless network to devices that want to connect to the BSS, thus requiring minimal configuration on the wireless client side. Unlike the IBSS, in a BSS the RF channel is set on the access point and not on the wireless client device.

Advantages and Disadvantages of a BSS

A BSS has many benefits, advantages, and disadvantages. Some of the advantages are as follows:

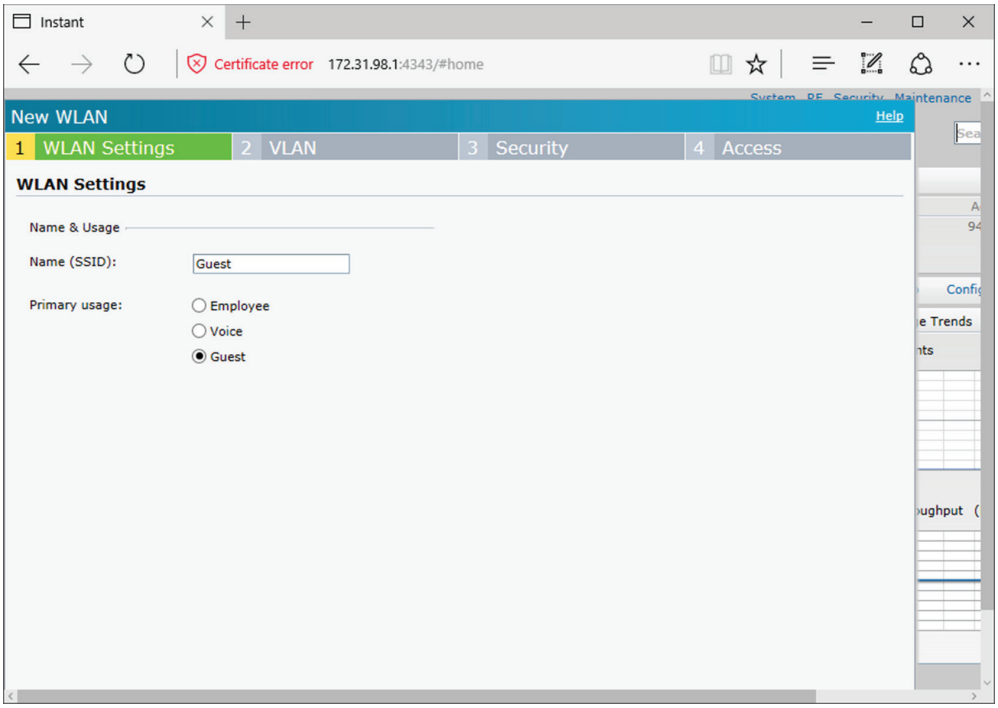
- Uses intelligent devices with a large feature set to provide users with consistent, reliable, and secure communications to a wireless network.
- Useful in a variety of situations: homes, SOHO, and small to large businesses.
- Very scalable; you can increase the coverage and capacity of a BSS by adding more access points.
- Centralized administration and control.
- Security parameters and specific access can be set centrally.

Some of the disadvantages of a BSS are as follows:

- Incurs additional hardware costs compared to IBSS.
- Usually will require a site survey to determine RF coverage and capacity requirements.
- Must be connected to a network infrastructure known as the distribution system, either wired or wireless mesh.
- Requires additional knowledge for configuration and deployment.

Figure 6.6 shows configuring the SSID on an access point.

FIGURE 6.6 Graphical user interface for an Aruba Networks access point configuring the SSID

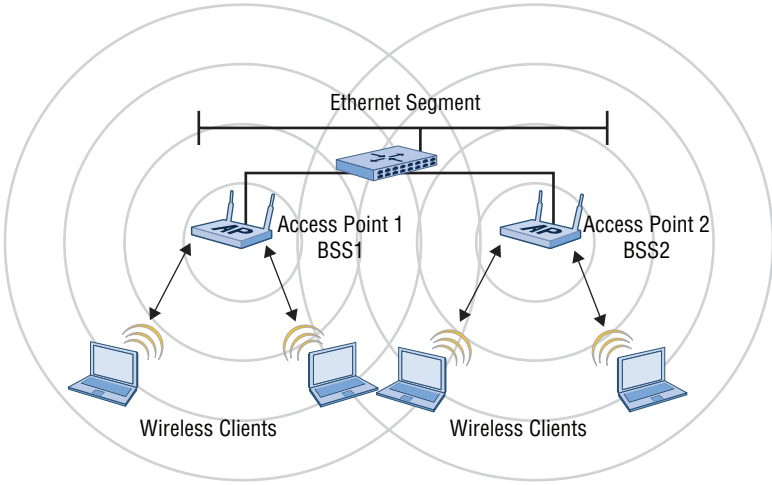


The Extended Service Set

As stated in the IEEE 802.11-2016 standard, an *extended service set* (ESS) is defined as a "set of one or more interconnected basic service sets (BSSs) that appears as a single BSS to the Logical Link Control (LLC) layer at any station (STA) associated with one of those BSSs." In basic terms, this can be one or more access points connected to a common wired or wireless DS. An ESS is a common configuration in most WLAN deployments for small to medium businesses as well as large enterprise organizations.

In most cases, an ESS would be used to provide consistent and complete coverage across an entire organization. An ESS can be thought of as several basic service sets (BSSs) that must have matching parameters, such as SSID and security settings. If the SSIDs of two access points do not match, then they are considered separate BSSs, even though they are connected by a common network infrastructure. It is the DS connecting these together and a common network name (SSID) that makes up the ESS. In most if not all cases, the BSA for each BSS will overlap to allow transition (roaming) from one BSS to another. Figure 6.7 shows an example of an ESS.

FIGURE 6.7 Two basic service sets connected by a common distribution system, making an extended service set



Roaming between access points is a critical component of WLAN technology in most modern wireless network deployments. This is because the WLAN is now a major part of every corporate network. Many envision a complete wireless network for all communications, including data, voice, and video. Roaming is so important that the IEEE added the 802.11r amendment to provide a standardized methodology for client station roaming and fast secure transition within the WLAN. Recall that roaming within an IEEE 802.11 WLAN is always decided by the client device with the exception of single channel architecture (SCA). IEEE 802.11r provides the fast secure transition between access points. Keep in mind that IEEE 802.11k and IEEE 802,11v work with IEEE 802.11r to provide more information to the wireless device so it can make a more intelligent roaming decision based on the RF environment.

The Basic Service Area

The *basic service area* (BSA) is the area of RF coverage or the RF cell that encompasses a wireless access point and its associated stations. A wireless client device will be contained in the BSA as long as it has enough required receive signal strength to maintain an association state with the wireless access point.

Know Your Abbreviations: SSID vs. ESSID vs. BSSID

It is easy to confuse the abbreviations for several of the WLAN terms we have learned. This sidebar summarizes the differences.

SSID (Service Set Identifier)

SSID (service set identifier) is the network name and provides some segmentation of the wireless network.

ESSID (Extended Service Set Identifier)

Although not defined by the IEEE 802.11 standard or amendments, *extended service set identifier* (ESSID) is a term that some manufacturers use in place of SSID. For the most part, ESSID and SSID are synonymous terms for the name or segmentation of a wireless network. The term used will vary among manufacturers. The term ESSID was adopted by some manufacturers because it implies more than one access point is using the same SSID and security settings connected to a common DS.

BSSID (Basic Service Set Identifier)

It is sometimes easy to confuse the *basic service set identifier* (BSSID) with the SSID or name of the network. The BSSID is defined as the unique identifier, Media Access Control (MAC) address of the basic service set. It is important to note that some manufacturers may allow for several BSSIDs to be connected to a single access point radio or for a single common BSSID to be shared among many access points.

To review, the MAC address is the unique identifier of a network adapter or what is known as the *hardware address*. The radio in an access point is also a network adapter. The difference between a wired and a wireless network adapter is simply that no Ethernet jack is available on a wireless adapter. Instead, a radio is used for Layer 1 communications.

The MAC address is a 48-bit, IEEE 802 format address that uniquely identifies the network interface adapter—or, in this case, radio. The format of the BSSID is *XX:XX:XX:YY:YY:YY*, where *X* is the number assigned to a manufacturer, and *Y* is the unique hardware address of the device.

Although the BSSID uniquely identifies the access point's radio using a MAC address, the SSID is broadcast as the name of the network in order to allow devices to connect. Some devices allow for multiple SSIDs, which use multiple BSSIDs for a single radio. This lets a single access point connected to a wired infrastructure provide multiple WLANs.

In an ad hoc or IBSS network there is no access point for centralized communication. Instead, WLAN devices communicate directly with each other. Because there is no access point in this configuration, the BSSID is a randomly generated number that has the same format as the 802 MAC address and is generated by the first ad hoc wireless device at startup.

Connecting to an IEEE 802.11 Wireless Network

In order for a device to successfully connect to a wireless network, several different frame exchanges must take place. Various frame types allow for specific functions to occur. They include the authentication and association process, reserving the medium, exchanging data, and power save functions. The following section introduces some of the frame types and the roles they play in wireless networking.

IEEE 802.11 Frame Types

As discussed in Chapter 4, "Radio Frequency Fundamentals for Wireless Networking," devices communicate by sending RF waves to each other through the air. These RF waves carry the digital data from one device to another. At this stage, the information traveling through the air is organized into what are known as *frames*. These frame types play various roles depending on the information being sent. WLANs use three different frame types.

Management Frames

Management frames are used to manage the network. Management frames assist WLAN devices in finding and connecting to a wireless network. This includes advertising the capabilities of the WLAN and allowing connections by the authentication and association process. Management frames are exchanged only between immediate wireless devices, such as an access point and client device, and never cross the Data Link layer (Layer 2) of the OSI model. It is important to understand that management frames are always transmitted at the lowest mandatory data rate of the service set so that all stations on the same RF channel in the BSA can understand them. The following are examples of common management frames:

- Beacon
- Probe request
- Probe response
- Authentication
- Association request
- Association response

Control Frames

Control frames are used to control access to the wireless medium by allowing devices to reserve the medium and acknowledge data. In addition, some control frames are used to request data from the access point after returning from a power save state and with

IEEE 802.11 protection mechanisms to allow wireless device coexistence. Some examples of control frames are as follows:

- RTS
- CTS
- CTS to Self
- PS-Poll
- ACK

Data Frames

As their name implies, *data frames* are used to carry data payload or Layer 3 information between wireless devices.

A special type of data frame is the null data, or null function, frame, which helps implement power save features and is not used to carry any data payload. There is also a variant of the null frame called the *QoS null frame*, which is used with quality of service power save mode. The following are examples of data frames:

- Data
- QoS data
- Null data

The details of the specific functions of each of these frame types are beyond the scope of this book and the exam objectives; however, some of these frames needed to be briefly introduced in order to explain upcoming topics. These include a wireless device "listening" for a network to join, supplying the appropriate credentials, and finally connecting to send data to the network infrastructure.

Wireless Network Discovery

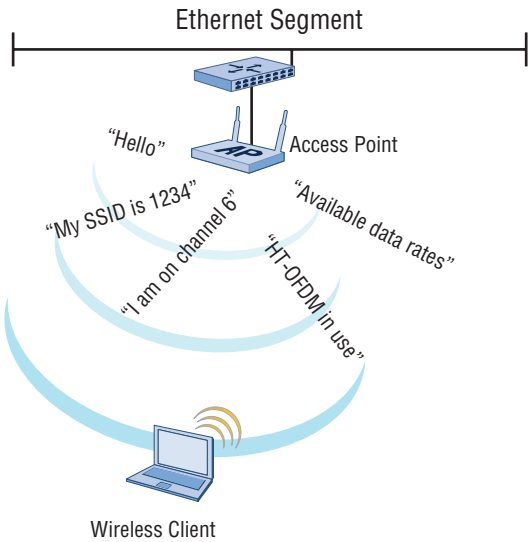
Wireless network discovery is the process of a client device scanning for wireless networks and identifying the parameters of the network, including the SSID, supported data rates, and security settings. The discovery phase consists of the passive scanning and active scanning processes. Wireless network discovery prepares a wireless client device to perform an IEEE 802.11 authentication and association, which will allow a device access to the wireless network.

Passive Scanning

The first part of the discovery phase in IEEE 802.11 wireless networking is known as *passive scanning*. This process allows WLAN devices to "listen" for information about wireless networks in the radio receiving area of the wireless network or the BSA. During the passive scanning process, WLAN devices will listen for specific information to make them aware of networks in the area. An analogy to this process would be using an FM radio tuner to scan through the entire band listening for a station to tune in to. The radio will scan through the band listening for different stations. Once a desired station is heard, the person listening can stop on that specific radio station.

Management frames assist WLAN devices in finding and connecting to a wireless network. An example of a management frame that works in the discovery phase or passive scanning is a *beacon frame*. This frame, for the most part, is an advertisement of the wireless network. It carries specific information about the access point or basic service set such as the SSID, the RF channel that it is operating on, the available data rates it is configured for, the security parameters, and much more. During the passive scanning phase, wireless devices listen for beacons advertising the details about the wireless networks in the area or radio range of the client device. WLAN devices are constantly listening for beacon frames. Figure 6.8 shows a WLAN client passively scanning and listening for an access point to connect with.

FIGURE 6.8 An example of passive scanning with a WLAN client listening for access points in the BSA



By default, beacons for most access points broadcast at about 10 times a second. This value is actually 1024 microseconds and is identified as the *target beacon transmission time* (TBTT). Although this interval can be changed, it is recommended to do so only if necessary or recommended by the manufacturer. In some cases, manufacturers may suggest specific timing intervals for such frames as beacons.

Figure 6.9 shows a protocol analyzer capturing beacon frames generated from an access point.

FIGURE 6.9 Packet capture of beacon frames

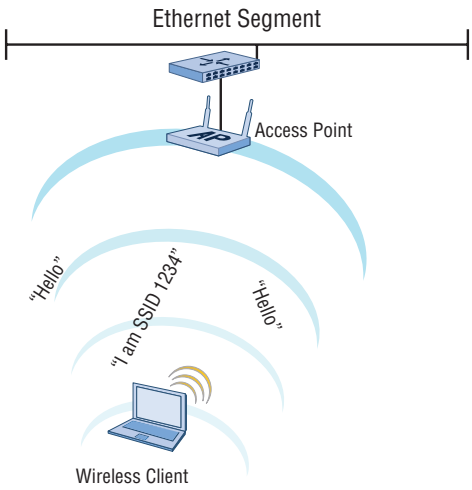
00:14:A8:53:5F:C0	Ethernet Broadcast	00:14:A8:53:5F:C0	47%	802.11 Beacon
00:14:A8:53:5F:C0	Ethernet Broadcast	00:14:A8:53:5F:C0	45%	802.11 Beacon
00:14:A8:53:5F:C0	Ethernet Broadcast	00:14:A8:53:5F:C0	44%	802.11 Beacon
00:14:A8:53:5F:C0	Ethernet Broadcast	00:14:A8:53:5F:C0	44%	802.11 Beacon
00:14:A8:53:5F:C0	Ethernet Broadcast	00:14:A8:53:5F:C0	44%	802.11 Beacon
00:14:A8:53:5F:C0	Ethernet Broadcast	00:14:A8:53:5F:C0	44%	802.11 Beacon
00:14:A8:53:5F:C0	Ethernet Broadcast	00:14:A8:53:5F:C0	45%	802.11 Beacon
00:14:A8:53:5F:C0	Ethernet Broadcast	00:14:A8:53:5F:C0	47%	802.11 Beacon

Active Scanning

Active scanning is the second part of the WLAN discovery phase. In *active scanning*, WLAN devices wishing to connect to a network send out a management frame known as a *probe request*. The function of this management frame is to find a specific wireless access point to connect with. Depending on the wireless client utility software used, if an SSID is specified in the client utility software active profile, the device will join only a network with the matching SSID that is specified. An exception to this is a probe request that contains a "wildcard SSID" or a "null SSID." The IEEE 802.11 standard requires all access points to respond to a broadcast probe request that contains a null SSID value. This type of probe request frame will not specify an SSID value and will rely on the access points to provide the SSID in the probe response frame.

Access points constantly listen for probe request frames. Any access point within hearing range of the wireless device and having a matching SSID sends out a probe response frame to the wireless device. If more than one access point responds, the device selects the "best" access point to connect with based on certain factors, such as signal strength and signal quality. Figure 6.10 illustrates the active scanning process.

FIGURE 6.10 Wireless client device sending a probe request frame to access points in radio range



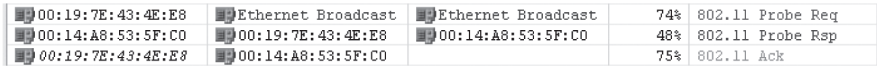
Frames Used for Active Scanning

During the active scanning process, two frames are exchanged between the device and the access point.

1. The WLAN device sends a broadcast probe request frame to all devices, including access points within radio range.
2. The access point(s) sends a probe response frame to the device so that it can identify the parameters of the network before joining.

Figure 6.11 shows a protocol analyzer capturing frames of the active scanning process.

FIGURE 6.11 Packet capture of probe request and probe response frames



The IEEE 802.11 standard requires access points to respond to devices that are sending a null or blank SSID. The standard refers to this as a wildcard SSID. It is important not to confuse this with disabling the SSID broadcast on an access point. Most wireless equipment manufacturers provide the capability to set the access point not to respond to a probe request with a null or wildcard SSID. If the AP is set not to respond to such probe requests, the wireless device is required to have the SSID specified in the client utility in order to connect to the BSS.

IEEE 802.11 Authentication

Authentication in general is defined as verifying or confirming an identity. We use a variety of authentication mechanisms in our daily lives, such as logging onto a computer or network at home or at the office, accessing secure sites on the Internet, using an ATM machine, or showing an identification badge to get access to a building.

IEEE 802.11 devices must use an "authentication process" in order to access network resources. This IEEE 802.11 authentication process differs from conventional authentication methods such as providing credentials, such as a username and password, to gain access to a network. The *authentication* discussed here is wireless device or IEEE 802.11 authentication, required in order for the device to become part of the wireless network and participate in exchanging data frames by creating a connection to the access point. (Providing credentials such as a username and password or a preshared key is a different type of authentication, to be discussed in Chapter 8.) The IEEE 802.11 standard addresses two types of IEEE 802.11 authentication methods: open system and shared-key.

IEEE 802.11 Open System Authentication

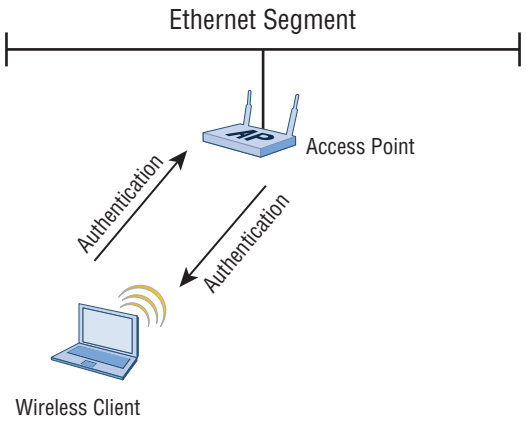
This 802.11 authentication method is defined by the IEEE 802.11 standard as a null authentication algorithm and is a two-step authentication process. Two management frames are exchanged between the device and the access point during open system authentication. For the most part, open system authentication cannot fail unless other security measures such as MAC address filtering are put in place that will prevent the device from accessing the network. Keep in mind that IEEE 802.11 open system authentication always exists, even with the most secure WLANs. It is used to allow the wireless station to connect to the access point and then after association use additional credentials such as a passphrase or username and password pair for authentication. If the wireless station did not perform an open system authentication and association first, there would be no way to use additional security mechanisms. IEEE 802.11 open system authentication is the only valid authentication process allowed with newer WLAN security

amendments and interoperability certifications for the network to be considered a robust security network (RSN).

Open system authentication is a very simple process. A WLAN device will ask an access point, "Can I be a part of this network?" and the access point will respond, "Sure, come join the party." So there really is no validation of identity. Open system authentication is considered a two-way frame exchange because two authentication frames are sent during this process. It is not a request and response situation; it is authentication and success.

Figure 6.12 illustrates open system authentication.

FIGURE 6.12 A wireless client authenticating to an access point using open system authentication



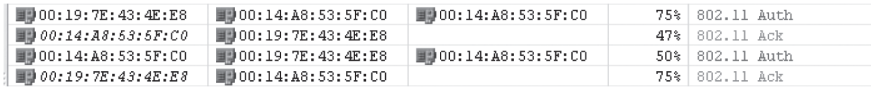
Open system authentication does not provide any type of data encryption. With open system authentication, optional security solutions can be used for data encryption as required. Wireless security solutions will be discussed in more detail in Chapter 8.

Two steps are used for open system authentication. One management frame is sent in each step.

1. The WLAN device wanting to authenticate sends an authentication frame to the access point. This frame is acknowledged by the access point.
2. The access point accepting the authentication sends a successful authentication frame back to the device. This frame is acknowledged by the authenticating device.

Figure 6.13 shows a packet capture of the two-way, open system authentication frame exchange.

FIGURE 6.13 Packet capture of open system authentication



00:19:7E:43:4E:E8	00:14:A8:53:5F:C0	00:14:A8:53:5F:C0	75%	802.11 Auth
00:14:A8:53:5F:C0	00:19:7E:43:4E:E8		47%	802.11 Ack
00:14:A8:53:5F:C0	00:19:7E:43:4E:E8	00:14:A8:53:5F:C0	50%	802.11 Auth
00:19:7E:43:4E:E8	00:14:A8:53:5F:C0		75%	802.11 Ack

IEEE 802.11 Shared-Key Authentication

IEEE 802.11 shared-key is another authentication method defined by the 1997 release of the original IEEE 802.11 standard. It is a little more complex than open system authentication. This IEEE 802.11 authentication method is a four-way frame exchange. During *shared-key authentication*, four management frames are sent between the wireless device wanting to join the wireless network and the access point. Shared-key authentication differs from open system authentication in that shared-key authentication is used for both IEEE 802.11 authentication and data encryption.

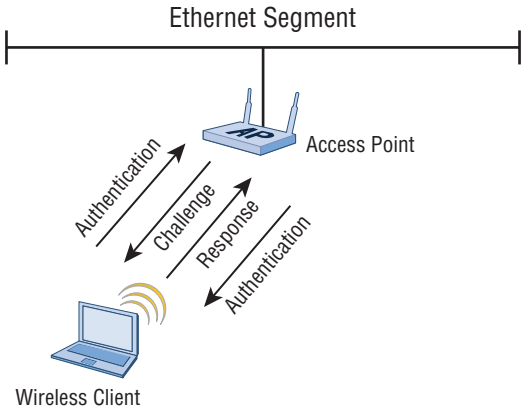
It is important not to confuse the IEEE 802.11 standard shared-key authentication described here with newer authentication and encryption methods defined in the IEEE 802.11i amendment to the standard, which includes passphrase/pre-shared key authentication. IEEE 802.11i, WPA/WPA2 pre-shared key authentication, will be discussed further in Chapter 8.

IEEE 802.11 shared-key authentication is considered flawed because information is sent across the air in cleartext that relates to the authentication key and therefore the encryption key that is used and could be captured by an intruder. If an intruder were to capture the four wireless frames used during the IEEE 802.11 shared-key authentication process, they would be able to use this information with the appropriate software and extract the security (WEP) key. The original IEEE 802.11 shared-key authentication requires the use of Wired Equivalent Privacy (WEP) for both wireless device authentication and data encryption. Because WEP is mandatory with IEEE 802.11 shared-key authentication, an intruder could potentially identify the WEP key used for the network by capturing the authentication process using a wireless protocol analyzer. Shared-key authentication, therefore, should always be avoided and is not allowed when using newer IEEE 802.11i, WPA, or WPA2 security methods.

Some manufacturers have removed the option to set IEEE 802.11 shared-key authentication, both in infrastructure devices such as access points and bridges and in client software utilities. If legacy devices are in use on the network and still use shared-key authentication as the only authentication option, steps need to be taken to protect the integrity of the network and also to identify an appropriate upgrade path for the devices using this authentication.

Figure 6.14 illustrates the four frames exchanged during the shared-key authentication process.

FIGURE 6.14 Shared-key authentication uses a four-way frame exchange.



Because WEP is mandatory with IEEE 802.11 shared-key authentication, it makes a system vulnerable to intrusion. Therefore, open system authentication is considered more secure than shared-key authentication when WEP was used with open system authentication. This is because WEP was used to encrypt the data only and not used for the IEEE 802.11 authentication process. WEP was designed as a way to protect wireless networking users from casual eavesdropping. The IEEE 802.11-2016 standard states, "The use of WEP for confidentiality, authentication, or access control is deprecated. The WEP algorithm is unsuitable for the purposes of this standard."

Frames Used for Shared-Key Authentication

An 802.11 wireless device must perform an IEEE 802.11 authentication to the wireless network prior to associating according to the 802.11 standard. The following steps show the four-way frame exchange used for shared-key authentication. This method should not be used but is shown here to illustrate the process.

1. The WLAN device wanting to authenticate sends an authentication frame to the access point. This frame is acknowledged by the access point.
2. The access point sends a frame back to the WLAN device that contains a challenge text. This frame is acknowledged by the WLAN device.
3. The WLAN device sends a frame back to the access point containing an encrypted response to the challenge text. The response is encrypted using the device's WEP key. This frame is acknowledged by the access point.
4. After verifying the encrypted response, the access point accepts the authentication and sends a "successful authentication" frame back to the device. This final frame is acknowledged by the device.

Figure 6.15 shows the four authentication frames used in shared-key authentication.

FIGURE 6.15 Packet capture of a four-frame exchange 802.11 shared-key authentication

00:19:7E:43:4E:E8	00:14:A8:53:5F:C0	00:14:A8:53:5F:C0	88%	802.11 Auth
00:14:A8:53:5F:C0	00:19:7E:43:4E:E8		44%	802.11 Ack
00:14:A8:53:5F:C0	00:19:7E:43:4E:E8	00:14:A8:53:5F:C0	45%	802.11 Auth
00:19:7E:43:4E:E8	00:14:A8:53:5F:C0		84%	802.11 Ack
00:19:7E:43:4E:E8	00:14:A8:53:5F:C0	00:14:A8:53:5F:C0	88%	802.11 Auth
00:14:A8:53:5F:C0	00:19:7E:43:4E:E8		42%	802.11 Ack
00:14:A8:53:5F:C0	00:19:7E:43:4E:E8	00:14:A8:53:5F:C0	44%	802.11 Auth
00:19:7E:43:4E:E8	00:14:A8:53:5F:C0		87%	802.11 Ack

IEEE 802.11 Association

IEEE 802.11 *association* takes place after a wireless device has been successfully 802.11 authenticated either by open system authentication or by shared-key authentication. In the association state, the authenticated device can pass traffic across the access point to the network infrastructure or other associated wireless devices, allowing access to resources that the device or user has permissions to access. After a device is authenticated and associated, it is considered to be part of the BSS. A device must be 802.11 authenticated before it can be associated. Figure 6.16 illustrates the association process, and Figure 6.17 shows frames used during the association process.

FIGURE 6.16 IEEE 802.11 authentication and association

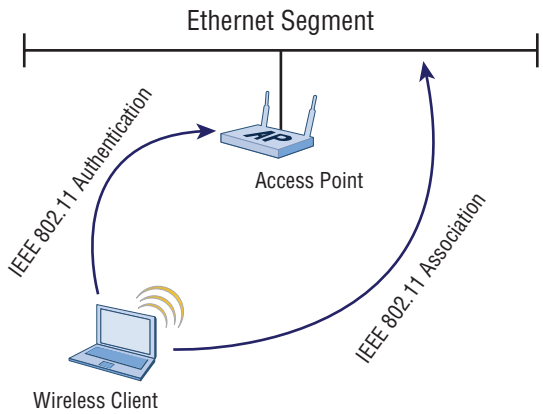


FIGURE 6.17 Packet capture of the IEEE 802.11 association request and association response process

00:19:7E:43:4E:E8	00:14:A8:53:5F:C0	00:14:A8:53:5F:C0	78%	802.11 Assoc Req
00:14:A8:53:5F:C0	00:19:7E:43:4E:E8		44%	802.11 Ack
00:14:A8:53:5F:C0	00:19:7E:43:4E:E8	00:14:A8:53:5F:C0	50%	802.11 Assoc Rsp
00:19:7E:43:4E:E8	00:14:A8:53:5F:C0		71%	802.11 Ack

After successful association, the IEEE 802.11 authentication and association process is complete. Keep in mind that this is very basic access to the network using either open system authentication or WEP for authentication and encryption. After this process is

complete, more advanced authentication mechanisms, such as IEEE 802.1X/EAP (which provides user-based authentication) or preshared key (passphrase), can be used to secure the wireless network. These and other security components will be discussed in more detail in Chapter 8.

Frames Used for IEEE 802.11 Association

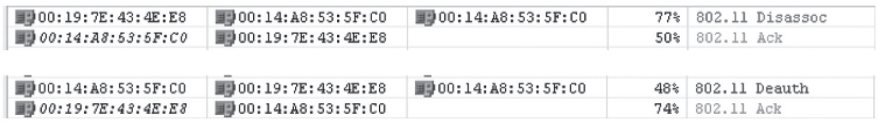
After a successful 802.11 authentication, the association process will begin. Association allows a wireless device to send information across the access point to the network infrastructure or other wireless devices connected to the access point.

1. A WLAN device sends an association request frame to the access point. This frame is acknowledged by the access point.
2. The access point sends an association response frame to the device. This frame is acknowledged by the associating device.

IEEE 802.11 Deauthentication and Disassociation

It is worthwhile to understand that the opposite of authentication and association can occur in a WLAN. These events are known as *deauthentication* and *disassociation*. Deauthentication occurs when an existing authentication is no longer valid. This can be caused by a WLAN device logging off from the current connection or transitioning to a different BSS. A disassociation occurs when an association to an access point is terminated. This may occur when the associated WLAN device roams from one BSS to another. Both deauthentication and disassociation are notifications, not requests. Since neither can be refused by either side, they are both considered automatically successful from the sender's perspective. Unless IEEE 802.11w (management frame protection) is implemented, deauthentication can also be a security issue. These frames can be used for denial of service (DoS) attacks or to hijack a wireless device. Both deauthentication and disassociation frames are management frames. Figure 6.18 shows how disassociation and deauthentication frames would look on a protocol analyzer.

FIGURE 6.18 Packet capture of disassociation and deauthentication frames

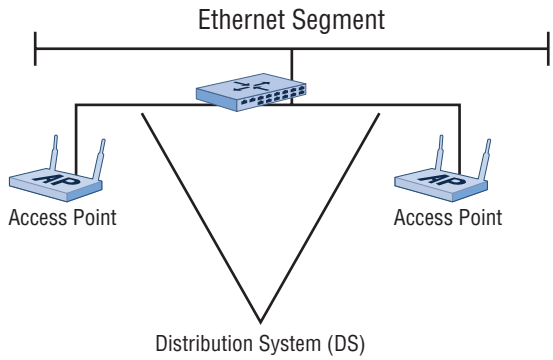


Tools are available that will continuously send deauthentication frames to a device. Use of this type of tool can be considered a DoS attack. An intruder may also use a deauthentication frame to force a device to reauthenticate to an access point, causing the device to be hijacked. This as well as other possible intrusion techniques will be discussed in Chapter 8. The 802.11w amendment provides enhancements to the IEEE 802.11 standard that enables data integrity, data origin authenticity, replay protection, and data confidentiality for selected IEEE 802.11 management frames, including authentication and association.

The Distribution System

In WLAN technology, the *distribution system* (DS) is the common network infrastructure to which wireless access points are connected; it can be wired or wireless mesh. In most cases this would be an Ethernet segment. In this capacity, the access point acts like a Layer 2 translational bridge. A *translational bridge* is defined as a device used to connect two or more dissimilar types of LANs together, such as wireless (IEEE 802.11) and Ethernet (IEEE 802.3). From a receiver's perspective, this allows an access point to take information from the air (the communication medium in wireless networking) and make a decision either to send it back out to the same wireless radio or to forward it across to the DS. An access point can do this because it has enough intelligence to determine if a data frame is destined to be sent to the DS or if it should stay on the originating wireless side of the network. This is possible because the access point knows whether a device is part of the WLAN side through the authentication and association methods mentioned earlier. Figure 6.19 shows an example of a DS.

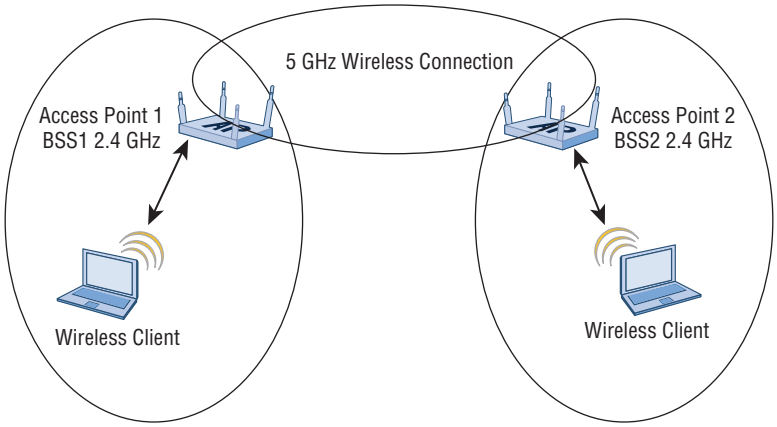
FIGURE 6.19 Two access points connected to a common distribution system—in this case, IEEE 802.3, Ethernet



The DS is a network segment that consists of one or more connected basic service sets. According to the original IEEE 802.11 standard, one or more interconnected basic service sets make up an ESS. The DS allows WLAN devices to communicate with resources on a wired network infrastructure or to communicate with each other through the wireless medium. Either way, all wireless frame transmissions will traverse through an access point.

In some cases it may be feasible and justified to use a *wireless mesh distribution system*. Unlike the wired distribution system, a wireless mesh will connect basic service sets together using WLAN technology. Typically the best way to use a wireless mesh is to use two different radio technologies in the same access point. For example, using the 2.4 GHz band for wireless client device access and the 5 GHz band for the wireless mesh will limit contention and provide associated devices a better experience because one radio is used for device access and the other creates the mesh network. Figure 6.20 shows an example of a wireless DS.

FIGURE 6.20 Two dual-band access points used to create a wireless mesh distribution system



Data Rates

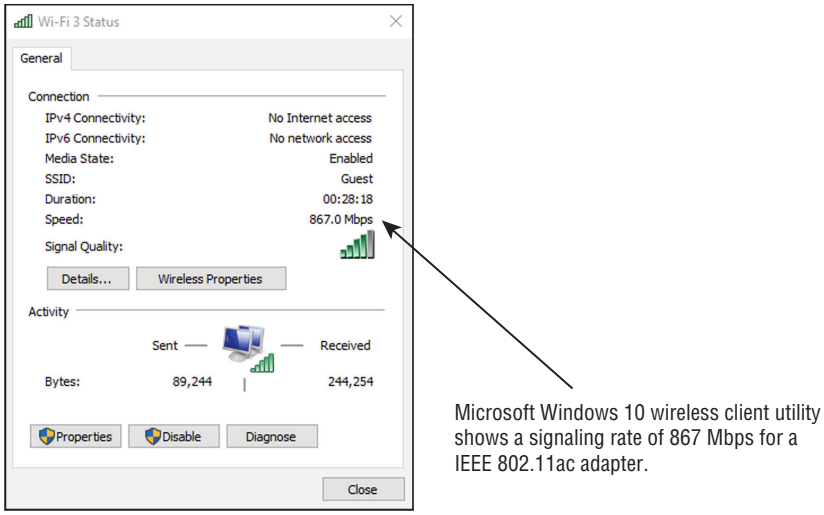
The speed at which wireless devices are designed to exchange information is known as the *data rate*. As you will see in Chapter 7, "Modulation Technology for Wireless Networking," these rates will differ depending on the wireless standard, amendment, spread spectrum type, or Physical layer technology in use. Table 6.1 shows data rates for various WLAN technologies. Data rates do not accurately represent the amount of information that is actually being transferred between devices and a wireless network. Figure 6.21 shows an

IEEE 802.11ac WLAN adapter in a notebook computer reading a data rate of 867 Mbps. To learn more about the actual amount of information transferred, see the next section, "Throughput."

TABLE 6.1 Data rates and modulation and coding schemes based on spread spectrum type

Standard/Amendment	Technology	Data Rates
802.11	FHSS	1 and 2 Mbps
802.11	DSSS	1 and 2 Mbps
802.11b	HR/DSSS	5.5 and 11 Mbps; 1 and 2 Mbps from DSSS
802.11a	OFDM	6, 9, 12, 18, 24, 36 and 48 Mbps
802.11g	ERP-OFDM	6, 9, 12, 18, 24, 36 and 48 Mbps
802.11n	HT-OFDM	Up to 600 Mbps
802.11ac	VHT-OFDM	Up to 6.93 Gbps aggregate

FIGURE 6.21 Windows 10 wireless configuration utility showing a data rate of 867 Mbps for an IEEE 802.11ac WLAN adapter



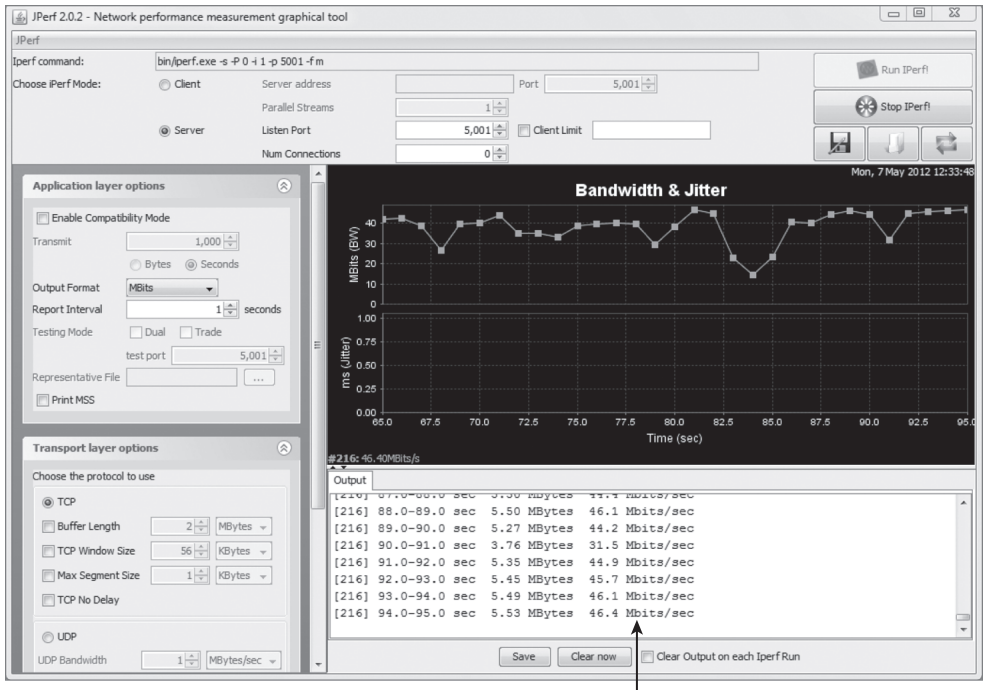
Throughput

Unlike data rate (the maximum amount of information theoretically capable of being sent), *throughput* is the amount of information actually being correctly received or transmitted. Many variables affect the throughput of information being sent. Some of these include

- Spread spectrum or Physical layer technology type in use
- RF interference
- Number of wireless devices connected to an access point

An 802.11a/g/n wireless access point, for example, has a theoretical maximum signaling rate of 600 Mbps, depending on the data rate or modulation and coding scheme in use. With one user connected to this access point, chances are the best throughput that could be expected is less than 50 percent of the maximum advertised rate. If more users connect to the same access point, the throughput for each user would be even less, because of the contention between users sharing the same wireless medium. Figure 6.22 shows an example of actual throughput for an 802.11a/g/n WLAN adapter.

FIGURE 6.22 Actual throughput of an IEEE 802.11a/g/n 300 Mbps WLAN adapter



JPerf performance test utility shows an average throughput of about 44 Mbps using an IEEE 802.11a/g/n wireless adapter.

Packing and Shipping Data: A Throughput Analogy

Packing and shipping an item in a cardboard box is a way of looking at data rate versus throughput. You have a cardboard box that is rated to have a maximum capacity of two cubic feet. You want to send a fragile item such as a vase to somebody else. The vase, if measured, would really take only about one cubic foot of space. This is a very fragile item, however, and you want to make sure it gets to the destination without any damage. Rather than just put the vase by itself in a box with a capacity of one cubic foot, you want to protect it with some packing material, such as bubble wrap. Wrapping the vase in bubble wrap will take an additional one cubic foot of space.

The data rate is analogous to the box capable of holding two cubic feet of material. The one-cubic-foot vase is analogous to the actual data being sent. The packing material is analogous to the contention management and other overhead that causes the throughput to be less than the theoretical capacity of the WLAN device.

In Exercise 6.1 you will measure the throughput of your own wireless network.

EXERCISE 6.1

Measuring Throughput of a Wireless Network

In this activity, you will measure throughput of a wireless network. If you have the proper equipment, it is not too difficult. If you already have an existing wireless network set up with a computer connected to the wired side or DS, you have a good part of the setup done. This exercise uses the JPerf software program for Microsoft Windows. JPerf is a graphical front-end program for IPerf from SourceForge. JPerf does require that Java be installed on the computer. The following step-by-step instructions assume a wireless access point already configured with TCP/IP settings as well as SSID. To perform this exercise, you will need the following equipment:

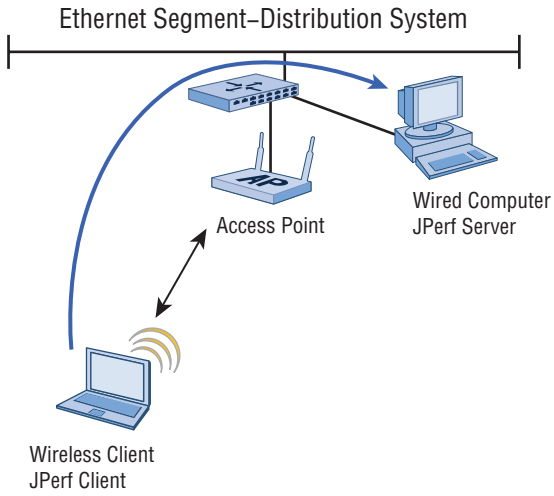
- Two computers, both with Java installed
- One wireless access point
- One Ethernet cable
- One wireless network adapter
- JPerf software (`jperf-2.0.2.zip`)

The JPerf software is available from `code.google.com/p/xjperf`. Click the Downloads link to complete the download.

EXERCISE 6.1 *(continued)*

Complete the following steps to measure throughput:

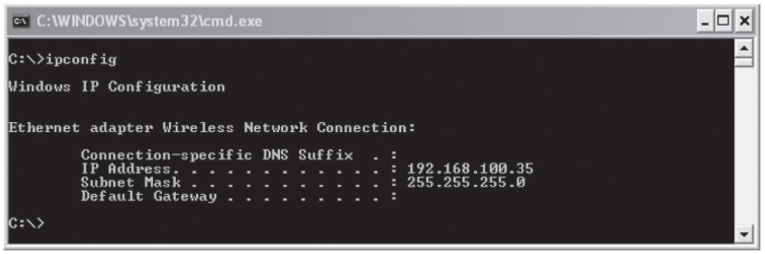
1. Connect the required equipment as shown in the following graphic.



2. Create a folder named Jperf on the `C:\` drive on both computers and extract the contents of the `jperf-2.0.2.zip` file you downloaded to the Jperf folder you created. This folder needs to be created at the root or `C:\` in order for the remaining steps to work as written.

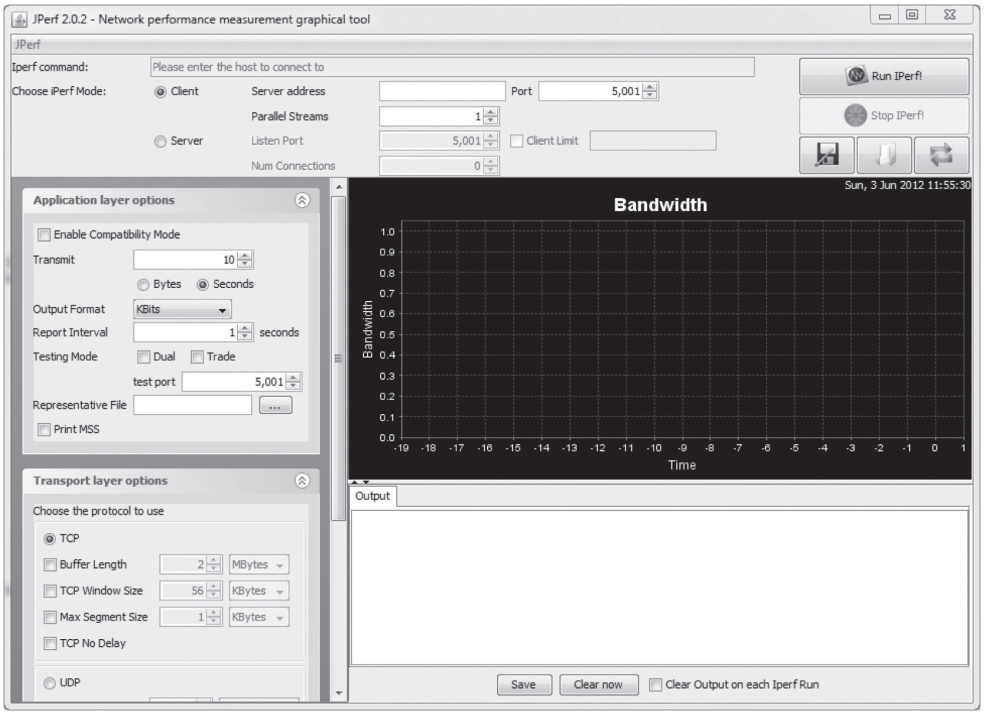
3. On the computer connected to the wired DS, open a command prompt. This will vary based on the operating system in use. For example, if you are using Windows 7, select Start ➢ All Programs ➢ Accessories ➢ Command Prompt. If you are using Windows 10, press and hold the Windows and X keys to open the Programs menu and then click Command Prompt. Steps for other operating systems may vary slightly.

4. In the command prompt window, type the command **`ipconfig`** at the `C:\` prompt and note the IP address of this computer.



5. This computer will act as the JPerf server. In the open command window, type **`cd\Jperf`** at the `C:\` prompt and press the Enter key. This will put you in the proper location of the JPerf program you copied to this computer in step 2.

6. Enter the following command to start the JPerf server: **`jperf.bat`**. After a few seconds, the JPerf 2.0.2 - Network Performance Measurement Graphical Tool window will appear.

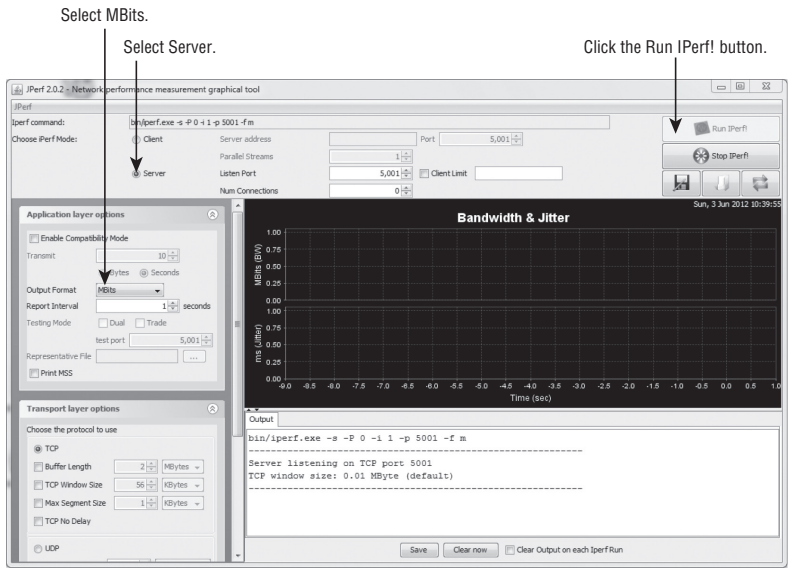


7. In the Application Layer Options section, click the Output Format drop-down box and select the MBits option. This will show the results in megabits per second.

8. Click the Server radio button.

9. Click the Run IPerf! button in the upper-right corner of the window.

EXERCISE 6.1 *(continued)*



10. The JPerf server is now ready for throughput testing.

11. On the computer with a wireless network adapter, connect to your access point using the wireless network adapter. This computer will act as the JPerf client for throughput testing.

12. On this same computer, open a command prompt.

13. In the command prompt window, type the command **`ipconfig`** at the `C:\` prompt and verify the IP address of this computer.

14. Verify connectivity to the JPerf server by typing the following command: **`ping {`***IP address***`}`**.

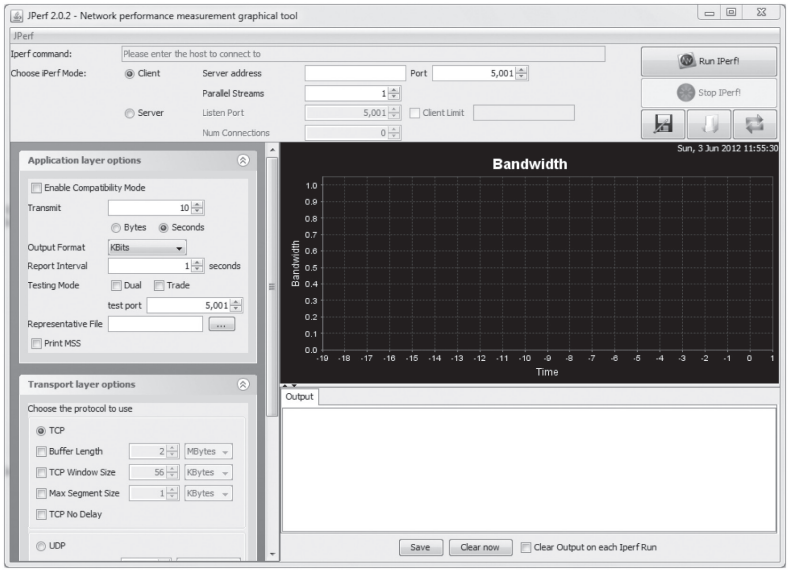
    You will need to replace {*IP address*} with the server address you recorded in step 4. You should see several replies if you are correctly connected to the server through the access point.

15. This computer will act as the JPerf client. In the open command window, type the command **`cd\jperf`** at the `C:\` prompt and press Enter.

    This will put you in the proper location of the JPerf program you copied to this computer in step 2.

16. In the command prompt window, type the following command to launch the JPerf graphical program: **`jperf.bat`**.

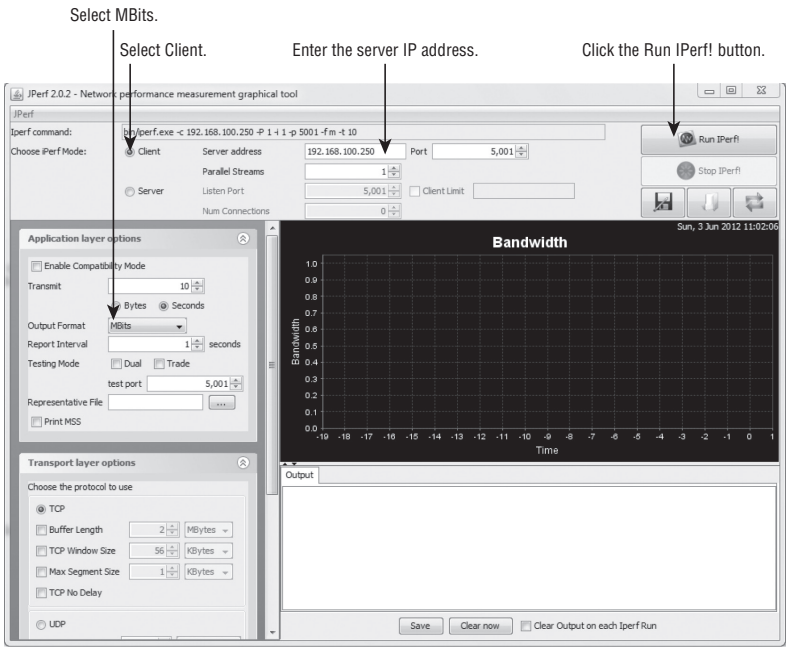
    After a few seconds the JPerf 2.0.2 - Network Performance Measurement Graphical Tool window will appear.



17. In the Application Layer Options section, click the Output Format drop-down box and select the MBits option. This will show the results in megabits per second.

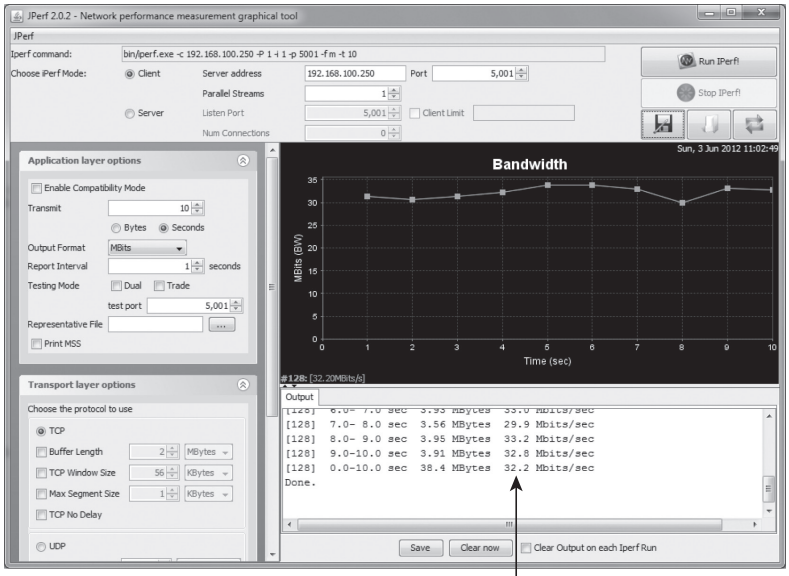
18. Click the Client radio button, and in the Server Address field enter the IP address of the server that you recorded in step 4.

19. Click the Run IPerf! button in the upper-right corner.



EXERCISE 6.1 *(continued)*

20. After 10 seconds the test will be complete and in the program window you will see the actual throughput recorded using the JPerf program.



Test shows 32 Mbps of data throughput.

21. Close the JPerf program window on both computers.

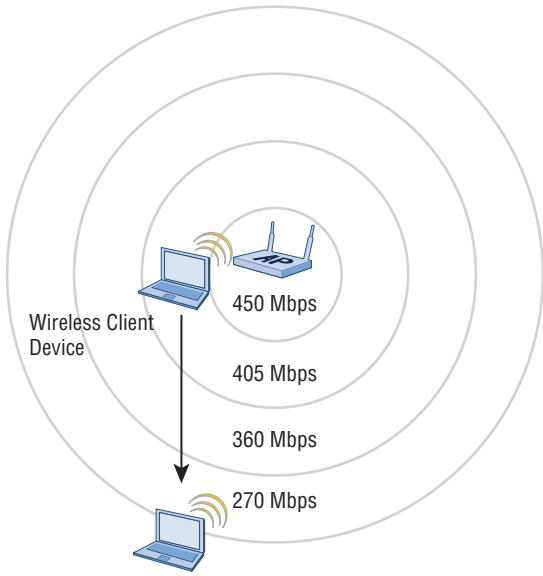
When you are finished, you can delete the JPerf program and folder you created in step 2.

Dynamic Rate Switching

When a wireless device moves through the BSA or as the distance from the access point increases, the data rate will decrease. Conversely, as the wireless device moves closer to the access point, the data rate can increase. This is called *dynamic rate switching* (DRS), also known as *dynamic rate shifting* and even *dynamic rate selection*. This process allows an associated wireless device to adapt to the RF signal strength and signal quality in a particular location of the BSA. DRS typically is accomplished through proprietary mechanisms set by the manufacturer of the wireless device. The main goal of DRS is to improve performance for the wireless device connected to an access point. As a wireless device moves away from an access point, the amount of received signal will decrease because of the free space path loss. When this occurs, the modulation type will change because the RF signal quality is less, and thus a lower data rate will be realized.

You will see in Chapter 7 that different data rates use different modulation technologies. Using a less complex modulation type at a lower data rate will provide better overall performance as the station moves away from the access point. Figure 6.23 illustrates how DRS works. As the wireless device moves away from the access point, the data rate will decrease. Keep in mind the opposite is true as well. As a wireless device moves closer to an access point, the data rate will increase.

FIGURE 6.23 A graphical representation of dynamic rate switching



Wireless LAN Transitioning/Roaming

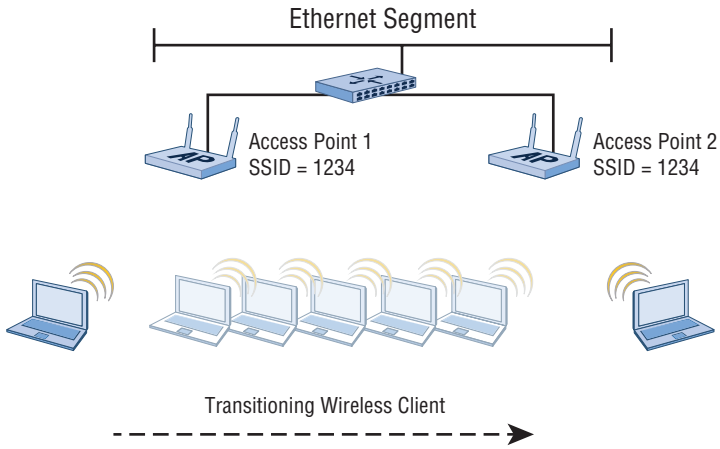
In WLAN technology, *transitioning* (also referred to as *roaming*) is the term for what happens when a wireless device moves from one BSS or access point to another. Standards-based transitioning was not addressed in the original IEEE 802.11 standard but was specified in later amendments. This process is typically accomplished in a proprietary manner based on how the manufacturer chooses to implement it. Manufacturers use different criteria to initiate roaming from one access point to another. There was an amendment to the IEEE 802.11 standard (IEEE 802.11F, Inter-Access Point Protocol) that was ratified in June 2003 as a recommended practice intended to address multivendor access point interoperability. This recommended practice was implemented by few if any manufacturers, however, and was withdrawn by the IEEE 802 Executive Committee in February 2006. The next attempt to standardize transitioning between access points was IEEE 802.11r, which was ratified in 2008. The driving force behind this amendment to the standard was to allow for fast secure transition with voice devices over a wireless network. Keep in mind that IEEE 802.11r is used in conjunction with IEEE 802.1X/EAP and requires CCMP/AES support for both the infrastructure and client devices.

When a WLAN device moves through a BSA and receives a signal from another access point, it needs to decide whether to stay associated with the current access point or to reassociate with the new access point. This decision when to roam is proprietary and based on specific manufacturer criteria. Some of these criteria manufacturers use include

- Signal strength
- Signal-to-noise ratio
- Error rate
- Number of currently associated devices

The most common metric used is received signal strength. When a WLAN device chooses to reassociate to a new access point, the original access point will hand off the association to the new access point as requested from the new access point. Keep in mind it is the wireless client device that initiates the move to a new access point. This move is done over the wired network or DS based on how the manufacturer implemented the roaming criteria. Figure 6.24 illustrates a notebook computer roaming from one access point to a new access point.

FIGURE 6.24 The roaming process for a WLAN



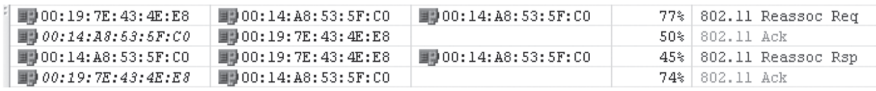
Frames Used for Reassociation (Roaming)

When a device transitions or "roams" to a new access point, it needs to associate to the new access point. Because the device is already associated, in order to connect to the new access point it must complete a reassociation process.

1. A WLAN device sends a reassociation request frame to the new access point. This frame is acknowledged by the new access point.
2. The new access point sends a reassociation response frame to the wireless device after handoff across the DS from the original access point has occurred. This frame is acknowledged by the reassociating wireless device.

Figure 6.25 shows reassociation request and response frames in a protocol analyzer.

FIGURE 6.25 Packet capture of the reassociation process



The 802.11r amendment to the standard was ratified in 2008 and is now part of the IEEE 802.11-2016 standard. This amendment specifies fast BSS transition (FT) and allows for fast secure roaming for devices between basic service sets. The main objective of this amendment is to support wireless voice over IP (VoIP) technology allowing for a consistent secure connection to the wireless network.

IEEE 802.11 Power Save Operations

Many WLAN devices are portable and use DC battery power to some degree. A wireless network adapter uses DC power to operate, and in some cases this could be a significant drain on the battery in the device. This is especially true with newer IEEE 802.11n/ac wireless adapters that support MIMO technology. The original IEEE 802.11 standard addresses a power save operation designed to allow a WLAN radio to enter a dozing state in order to conserve DC power and extend battery life. If the WLAN device is plugged into a consistent power source such as an AC outlet, there is no reason to implement power save features. However, portable devices that are mobile and may not have access to an AC power source should consider using power save operations. The original IEEE 802.11 standard specified two different power save modes: active mode (AM) and power save (PS) mode. The PS mode is considered legacy because the IEEE 802.11e amendment for quality of service addresses new, more efficient power save mechanisms. Although the original PS mode may be considered legacy, it still may be used in some devices. As mentioned earlier in this chapter, in the section "IEEE 802.11 Frame Types," a data frame known as a *null function frame* is used with power management and does not carry any data but is used to inform the access point of a change in power state. This is a non-standard variant that is more efficient than the original power save mode because it does not use a PS-Poll frame to retrieve buffered data frames from an access point.

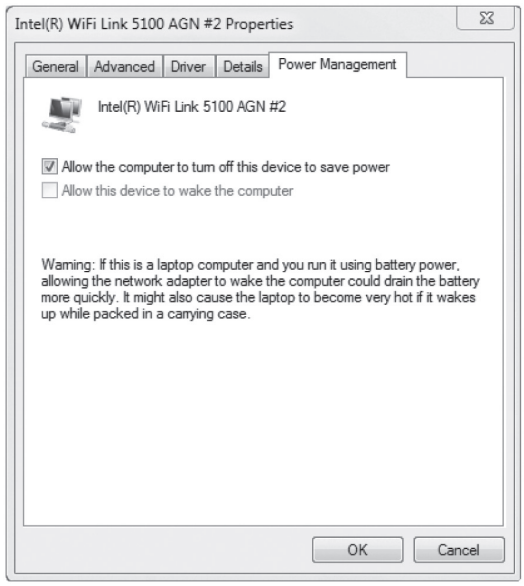
Active Mode

In *active mode* (AM) a WLAN device or station (STA) may receive frames at any time and is always in an "awake" state. In this case, the WLAN device is not relying on battery power; thus, there is no reason for the device to assume a low power state, and it will never doze. Some manufacturers refer to active mode as *continuous aware mode* (CAM).

Power Save Mode

In *power save* (PS) mode, the WLAN device or station (STA) will doze or enter a low power state for very short periods of times. At specific time intervals, the device will "listen" for selected beacons and determine if any data is waiting for it (buffered) at the access point. The beacon frame contains information for associated devices regarding power save. When a WLAN device associates to an access point, the device receives what is known as an *association ID* (AID). The AID is a value that will represent that device in various functions, including PS mode. The beacon frame contains an indicator for each AID associated device to let wireless devices know whether they have data waiting for them or buffered at the access point. If it is determined that the access point does have data buffered for a specific device, the device will send a control frame message (PS-Poll frame) to the access point to request the buffered data. Figure 6.26 shows where power save mode can be set in the advanced settings of the wireless adapter device driver.

FIGURE 6.26 The driver settings for a wireless adapter in a laptop computer and power save mode setting



Power save mode may cause some amount of overhead for the WLAN device, and there is a trade-off in performance. With power save mode enabled, the battery life will be extended; however, performance will suffer to some degree because the device will not be available to receive data continuously. The device will be able to receive buffered data only during the "awake" state. Power save mode is common in applications where battery conservation is important, such as barcode scanners, voice over Wi-Fi-enabled phones, and other handheld devices.

Real World Scenario

Use of Power Save Mode in Barcode Scanners

Organizations such as retail, manufacturing, and warehousing have been using 802.11 WLAN technologies for many years. Many of these businesses use WLAN devices such as barcode scanners in addition to notebook computers and other portable devices. Barcode scanners are used heavily for inventory and asset tracking purposes. These devices must run for many hours at a time, typically in 8- or 10-hour shifts for individuals who may be using them. Applications such as this greatly benefit from using IEEE 802.11 power save features and extending battery life of WLAN devices. This minimizes down-time because batteries in these devices don't have to be changed or recharged as often during a work shift.

Automatic Power Save Delivery

The IEEE 802.11e Quality of Service amendment to the standard fueled the need for more efficient power save mechanisms in wireless networking. Depending on the implementation and requirements, legacy power save modes may not be efficient enough to work with applications that use QoS, such as voice and video. *Automatic power save delivery* (APSD) differs from the original power save mode in that a trigger frame will wake a device in order to receive data. APSD is a more efficient way of performing power save functions. It works well with time-bound applications that are subject to latency, such as voice and real-time video.

IEEE 802.11 Protection Mechanisms

In order to allow newer, faster WLAN technology such as 802.11g and 802.11n devices to communicate with older, slower wireless devices, technology called *protection mechanisms* was designed to allow for backward compatibility. The mechanisms available depend on which amendment to the standard is used. Protection mechanisms will provide the backward compatibility needed to allow different technologies to coexist in the same RF space.

There are two broad categories of protection mechanism:

- Extended rate physical (ERP) protection mechanism for IEEE 802.11g networks
- High-throughput (HT) protection mechanism for IEEE 802.11n networks

Each category includes several modes for specific situations.

IEEE 802.11g Extended Rate Physical Protection Mechanisms

In order for IEEE 802.11g and IEEE 802.11b devices to coexist in the same BSA, the wireless access point must use *extended rate physical (ERP) protection*. Most manufacturers of IEEE 802.11 WLAN equipment will provide options when it comes to coexistence. These options usually include the capability to set an access point to one of three operation modes:

- IEEE 802.11b-only mode: DSSS and HR/DSSS
- IEEE 802.11g-only mode: ERP-OFDM
- IEEE 802.11b/g/n mixed mode: DSSS, HR/DSSS, and ERP-OFDM

IEEE 802.11b-Only Mode

This operation mode requires setting an access point to operate in 802.11b-only mode. This involves disabling all the IEEE 802.11g ERP-OFDM data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbps and allowing only DSSS data rates of 1 and 2 Mbps and HR/DSSS rates of 5.5 and 11 Mbps. Enabling this mode limits the maximum data rate to 11 Mbps. Setting an access point to this mode has limited applications, such as using legacy IEEE 802.11b-only capable devices.

IEEE 802.11g-Only Mode

This operation mode is the opposite of 802.11b-only mode. It disables all of the IEEE 802.11b DSSS and HR/DSSS data rates of 1, 2, 5.5, and 11 Mbps, and it allows the IEEE 802.11g ERP-OFDM data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbps. This operation mode is useful in an environment where backward compatibility to 802.11b is not required, such as an environment where all devices connecting have IEEE 802.11g capability, and the throughput needs to be maximized; thus, there are no IEEE 802.11b devices in use.

IEEE 802.11b/g/n Mixed Mode

Most deployments in the 2.4 GHz ISM band use this mode for communications. This allows devices that support the IEEE 802.11g/n amendments and IEEE 802.11b devices to operate together in the same BSA and be associated to the same access point. As mentioned in Chapter 2, "Wireless Local Area Networking, Standards, and Certifications," throughput will decrease when IEEE 802.11b devices and IEEE 802.11g/n devices are both associated to the same access point.

Extended Rate Physical (ERP) mixed mode uses control frames to reserve the wireless medium. Two options are available:

Request to Send/Clear to Send (RTS/CTS) One option of control frames that are used as a protection mechanism to reserve the RF medium.

Clear to Send (CTS) to Self A single frame used as a protection mechanism. This is a common implementation used by WLAN equipment manufacturers. A benefit of using this frame is less overhead than the RTS/CTS process.

Both RTS/CTS and CTS-to-Self control frames allow wireless devices using different Physical layer technologies to share the wireless medium and help to avoid collisions. These control frames specify how much time is needed for a frame exchange between the transmitter and a receiver to complete. This time value is processed by all devices in the BSA that are not part of the frame exchange. Once this time has expired, the wireless medium is considered clear.

Although administrators of many wireless networks now disable IEEE 802.11b functionality, it is important to note that in some industries this operation mode is still required for legacy device support. This is most common in warehousing, manufacturing, and retail environments.

IEEE 802.11n High-Throughput Protection Mechanisms

IEEE 802.11n devices operate in either the 2.4 GHz or the 5 GHz band. Backward compatibility for IEEE 802.11a/b/g devices needs to be taken into consideration. The IEEE 802.11n amendment identifies several different modes for high-throughput (HT) protection mechanisms. These mechanisms, known as *HT protection modes*, are a set of rules that devices and access points will use for backward compatibility:

- Mode 0–No protection mode
- Mode 1–HT nonmember protection mode
- Mode 2–HT 20 MHz protection mode
- Mode 3–Non-HT mixed mode

These modes are constantly changing based on the RF environment and associated wireless devices. The goal with IEEE 802.11n wireless networks is to get to Mode 0 (no protection mode). With today's wireless networks and WLAN technology, we are more than likely at Mode 3 (non-HT mixed mode) or possibly even one of the other two modes in most cases.

Mode 0–No Protection (AKA Greenfield) Mode

Mode 0, or *no protection mode*, allows for HT devices only. These HT devices must also share operational functionality and they must match; for example, they must all support 20 MHz or 20/40 MHz channels only. If an IEEE 802.11n (HT) access point is set to 20/40 MHz channel width and a client capable of only 20 MHz wide channels associates, the connection is not considered no protection mode. Mode 0 does not allow IEEE 802.11a/b/g devices using the same RF channel. IEEE 802.11a/b/g devices will not be able to communicate with an access point in Mode 0. Transmissions from these devices will cause collisions at the access point, causing some degradation in throughput because it is seen by the HT system as RF interference.

Mode 1–HT Nonmember Protection Mode

All devices in Mode 1, or *HT nonmember protection mode*, must be HT-capable. When a non-HT device—that is, an IEEE 802.11a/b/g access point or wireless client device—is

within the hearing range of the HT access point and on the same 20 MHz channel or one of the 20/40 MHz wide channels, this protection mode will be activated.

Mode 2–HT 20 MHz Protection Mode

All devices in Mode 2, or *HT 20 MHz protection mode*, must be HT-capable as well. The operation of this protection mode is based on the fact that 802.11n devices can use 20 MHz or 20/40 MHz wide channels. Mode 2 means that at least one 20 MHz HT station is associated with the HT 20/40 MHz access point and that the access point provides compatibility for 20 MHz devices.

Mode 3–Non-HT Mixed Mode

Mode *3*, or *non-HT mixed mode*, is used if one or more non-HT stations are associated in the BSS. This mode allows backward compatibility with non-802.11n or IEEE 802.11a/b/g wireless devices. This is the likely the most common mode for IEEE 802.11n HT networks today because of the need for backward compatibility and the legacy IEEE 802.11 wireless devices that are still in use on most wireless networks.

Additional HT Protection Modes

Two other HT protection modes are also available:

- Dual CTS is a Layer 2 protection mechanism that is used for backward compatibility between IEEE 802.11n HT and IEEE 802.11a/b/g devices.
- Phased coexistence operation (PCO) is an optional BSS mode with alternating 20 MHz and 20/40 MHz phases controlled by a PCO-capable access point.

Summary

WLANs can operate in one of two methods: either ad hoc mode, which means no access points are used, or infrastructure mode, where an access point provides a central point of communication for the WLAN devices. In this chapter, we looked at these modes of operation as well as the service sets IEEE 802.11 networks use. We looked at the following three configurations for WLANs:

- Independent basic service set (IBSS)
- Basic service set (BSS)
- Extended service set (ESS)

We explained the configuration of each, along with some of the advantages and disadvantages of each configuration—from an IBSS, which uses no access points, to a BSS or ESS, which uses one or many access points. Some of the configuration parameters, such as SSID and RF channel, and how they are used were also explained. Some of these

abbreviations are very close in spelling and sound similar when spoken. It is important to understand the differences among the following abbreviations:

- Service set identifier (SSID)
- Extended service set identifier (ESSID)
- Basic service set identifier (BSSID)
- Independent basic service set (IBSS)
- Basic service set (BSS)
- Extended service set (ESS)
- Basic service area (BSA)

For example, SSID is the name of the wireless network, and the BSSID is the unique identifier MAC address of the AP radio.

In addition to explaining the different configurations and terminology used, we looked at the processes wireless devices use to connect to and become part of a WLAN, including:

- Wireless discovery
- Passive scanning
- Active scanning
- IEEE 802.11 authentication
- IEEE 802.11 association

The discovery processes of passive scanning (listening for beacons) and active scanning (joining a WLAN) are important parts of starting the connection process. This continues with 802.11 authentication—in most cases open system—and the 802.11 association process. Once these processes are complete, the device finally becomes part of the wireless network, enabling it to pass traffic across to the access point to the network infrastructure.

You also learned about the components and technology that play a role with IEEE 802.11 wireless networks, such as:

- Distribution system (DS)
- Data rate (what is advertised)
- Throughput (what is actual)

Both a wired DS, in most cases Ethernet, and a wireless DS using radios and access points provide connectivity for wireless infrastructure. We looked at the differences between data rate and throughput. It is important to understand that an access point may have a data rate of 54 Mbps or even up to 6933.3 Mbps, but throughput (the actual data transmission rate) is typically less than half of the data rate. Because WLANs are contention based, data throughput will be even less when more devices connect to the network.

Dynamic rate switching (DRS)—a client transferring more or less data depending on the proximity from an access point as well as roaming or moving through the BSAs and being able to maintain connectivity—was also discussed in this chapter. Finally, the chapter covered the important topics of power save mode and protection mechanisms. With power

save mode, a WLAN device is able to extend battery life by entering into a low-power state or "doze" for very short periods of time. This permits the device to consume less battery power, therefore allowing connectivity for longer periods of time without changing or recharging the battery. The modes discussed were

- Active mode
- Power save mode (PS)
- Automatic power save delivery (APSD)

It is beneficial to understand the differences in power save capabilities among these modes.

Lastly, we discussed the following IEEE 802.11 protection mechanisms and the importance of these methods to provide backward compatibility and coexistence to older technology devices:

- Extended rate physical (ERP) protection for IEEE 802.11g
- High-throughput (HT) protection for IEEE 802.11n

We looked at some highlights of both protection mechanism technologies for IEEE 802.11g and 802.11n networks.

Exam Essentials

Understand the different operation methods for IEEE 802.11 wireless networks. Know the difference between infrastructure and ad hoc mode as well as the use of both.

Be familiar with the different service sets used with wireless networking. Understand the differences among IBSS, BSS, BSA and ESS.

Identify the terminology used with IEEE 802.11 wireless networking. Understand the differences among SSID, ESSID, and BSSID. Know which one identifies the name of a network and which one identifies the physical address of an access point.

Know the process that devices use to join a WLAN. Understand the process and operation of discovery, passive scanning, active scanning, IEEE 802.11 authentication, and IEEE 802.11 association.

Understand the differences between distribution systems as well as data transfer. Identify the differences as well as the function of a wired DS and wireless DS and roaming between each. Know the differences between data rate and throughput as well as DRS.

Identify the power-save capabilities of IEEE 802.11 wireless networks. Know the various power save modes of both legacy and Wi-Fi Multimedia (WMM), including active mode, power save mode, and APSD.

Know the various protection mechanisms available for both IEEE 802.11g and 802.11n wireless networks. Be familiar with the two protection mechanisms: ERP protection mechanisms and HT protection mechanisms. Understand that these mechanisms provide coexistence for newer and legacy WLAN devices.

Review Questions

1. When a WLAN device listens for beacon frames, it is participating in which phase?
   - **A.** Power save
   - **B.** Passive scanning
   - **C.** Active scanning
   - **D.** Authentication

2. You are a sales engineer connected to an IEEE 802.11ac access point with a mobile computer. As you move away from the access point, the connection speed slows to the next lowest supported data rate. The change in data rate is described by which term?
   - **A.** Dynamic frequency selection
   - **B.** Transmit power control
   - **C.** Dynamic rate switching
   - **D.** Transmit save mode

3. An independent basic service set (IBSS) consists of how many access points?
   - **A.** 0
   - **B.** 1
   - **C.** 2
   - **D.** 4

4. WLAN devices in an 802.11a peer-to-peer network will connect to which device(s)?
   - **A.** An access point
   - **B.** 802.11g client devices
   - **C.** 802.11a client devices
   - **D.** A wireless switch

5. As a device moves away from an access point, which of the following is true regarding dynamic rate switching?
   - **A.** Data rate decreases
   - **B.** Output power decreases
   - **C.** Data rate increases
   - **D.** Output power increases

6. A service set identifier (SSID) has a maximum limit of how many characters or octets?
   - **A.** 8
   - **B.** 16
   - **C.** 32
   - **D.** 128

7. You are a technical support engineer and receive a call from a customer regarding a problem with their wireless network connection. The building has an ESS network with five 802.11ac access points. The customer claims that when they move from their office to a conference room using the 802.11ac network they lose their connection and cannot connect to the access point in the conference room. Which is the most likely cause for this user to lose their connection when they roam on the wireless network?
   - **A.** Different RF channel
   - **B.** Mismatched SSID
   - **C.** Different BSSID
   - **D.** Mismatched association

8. A beacon frame advertises information about the wireless network. A beacon frame is what type of frame?
   - **A.** Data
   - **B.** Control
   - **C.** Management
   - **D.** Detail

9. In order for a wireless client to become completely part of the basic service set, it must first _____ and then _____.
   - **A.** Associate, authenticate
   - **B.** Authenticate, associate
   - **C.** Deauthenticate, authenticate
   - **D.** Disassociate, authenticate

10. The process in which a WLAN client connection moves from one access point to another is called _____.
   - **A.** Reauthentication
   - **B.** Roaming
   - **C.** Rebuilding
   - **D.** Roving

11. In order to set up an ad hoc network, a user must know which two parameters? (Choose two.)
   - **A.** SSID
   - **B.** BSSID
   - **C.** Channel
   - **D.** MAC address
   - **E.** Protection mode

12. The open system authentication process uses how many frames?

A. One

B. Two

C. Three

D. Four

13. You are a help desk support technician at a retail department store, and you receive a call from a manager in the administrative offices. He complains that the performance of his 802.11g/n notebook computer decreases several times throughout the day. Upon visiting the customer, you realize several people are performing inventory using 802.11b barcode scanners in the adjacent room. What is most likely the cause of the poor performance for the manager's notebook computer?

A. Association

B. Authentication

C. ERP protection

D. HT protection

14. Which items describe a service set identifier (SSID)? (Choose two.)

A. 32 characters maximum

B. 64 characters maximum

C. Is case sensitive

D. Is not case sensitive

15. A basic service set identifier (BSSID) is the unique identifying MAC address of the _____.

A. AP radio

B. AP Ethernet port

C. Router

D. Client

16. When an IEEE 802.11g WLAN consists only of wireless client stations, the network is operating as which type of basic service set?

A. Active

B. Independent

C. Passive

D. Infrastructure

17. You are a technical support engineer and provide help desk support for the network in a manufacturing company. You receive a call from the sales manager who wants to know how power save operations should be set up on her notebook computer to optimize the system performance. The notebook computer is plugged into an AC power source and rarely used on battery. Which mode would you recommend her to set on the wireless adapter?

A. Power save mode

B. Association mode

C. Active mode

D. Passive mode

18. According to the IEEE 802.11 standard, an extended service set (ESS) consists of how many interconnected basic service sets?

A. One or more

B. Two or more

C. Three or more

D. Four or more

19. The IEEE 802.11 association process happens after which phase?

A. Authentication

B. Distribution

C. Deauthentication

D. Reauthentication

20. A basic service set (BSS) consists of how many access points?

A. Zero

B. At least one

C. At least two

D. At least four

Chapter 7

Modulation Technology for Wireless Networking

THE FOLLOWING CWTS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **3.4 Define and differentiate between Physical layer wireless technologies**
- ✓ **3.5 Define concepts that make up the functionality of RF and spread-spectrum communication**

THE FOLLOWING CWT EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **3.1 Identify AP features and capabilities and understand configuration options related to them**
- ✓ **5.2 Troubleshoot performance problems**

THE FOLLOWING CWS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **3.1 Identify AP features and capabilities**
- ✓ **3.3 Determine capabilities of client devices**

In computer networking it is important to understand how digital data is sent from one device to another. Whether on a wired network or a wireless network, an *access method* is used to transfer this type of electronic information. Two common access methods are CSMA/CD and CSMA/CA. The type of medium in use—wired or wireless—will determine which of these two access methods is best suited for the application. You saw in previous chapters that wireless LANs (WLANs) use radio frequencies (RFs) with air as the communication medium. This chapter will discuss the various techniques and methods used to get digital computer data from one device to another using spread-spectrum and other Physical layer modulation technologies.

It is important to understand that different WLAN spread-spectrum technologies such as DSSS HR/DSSS will allow for various data rates. The spread-spectrum or other Physical layer technology in use, such as orthogonal frequency-division multiplexing (OFDM) or high throughput orthogonal frequency division multiplexing HT-OFDM, will determine the maximum amount of data transfer as well as the resilience to noise and other interfering sources. We will look at the 802.11 channels, the number of channels available, channel spacing, and frequencies of the unlicensed RF bands used with wireless networking. We will also discuss the implications of overlapping channels and interference. Finally, this chapter will discuss co-location of different technologies used in various amendments to the standard as well as interference from WLANs and other sources, including WPANs.

The IEEE 802.11-2016 standard has been officially released. This standard includes all communication amendments that were outstanding or part of the IEEE 802.11-2012 standard, including IEEE 802.11a/b/g/n/ac. Even though these amendments are incorporated into the newest version of the standard, we will discuss the technology using the original amendment names, 802.11b, 802.11a, and so on, because these names are still commonly used in the industry.

Network Access Methods

Network access methods enable devices connected to a common infrastructure to communicate and transmit data across a network medium from one device to another. Several different types of network access methods are used in computer networks. The following two types are discussed in this chapter:

- Carrier Sense Multiple Access/Collision Detection (CSMA/CD)
- Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)

Because Ethernet networks use a bounded wired medium and have the capability to detect collisions, 802.3 Ethernet networks use *CSMA/CD* as the access method. Devices on a WLAN do not have the capability to detect collisions due to the use of an unbounded medium; therefore, 802.11 WLANs use *CSMA/CA* for the access method. Since multiple wireless devices can use an access point at the same time, wireless devices that connect to an access point are competing to share the medium; therefore, it is important to control the medium in order to minimize collisions. The CSMA/CA process provides this control.

Detecting Network Traffic Collisions with CSMA/CD

802.3 Ethernet networks use CSMA/CD to share the medium. The name of this access method describes how it functions.

The abbreviation CSMA/CD is broken down as follows:

- **Carrier Sense**—Devices sense the medium (in this case, Ethernet cable) to see if it is clear (no data being transmitted).
- **Multiple Access**—Many devices accessing the medium at the same time.
- **Collision Detection**—Detecting collisions that occur on the medium during the transmission of data.

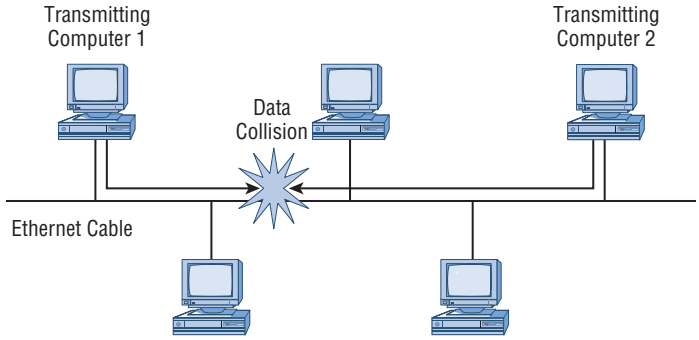
CSMA/CD is a contention-based media access control method that Ethernet devices use to share the medium. This method allows only one device to transmit at any one time.

In computing terminology, *contention* is defined as multiple devices competing for a chance to send data on the network. CSMA/CD functions like this:

1. A device with data to transmit checks whether any data is being transmitted on the Ethernet cable (sensing).
2. If the device senses that the medium is clear and no data is being transmitted, it transmits its own data.
3. If more than one device transmits simultaneously, a collision occurs and the data is lost. The devices detect the collision and each will back off for a random amount of time.
4. After the random amount of time expires, the device checks the cable and attempts to send the data again.

This contention of the Ethernet segment is one reason for decreased data throughput of the transmitting devices. Figure 7.1 demonstrates CSMA/CD with desktop computers connected to an Ethernet segment.

FIGURE 7.1 Computers connected to Ethernet cable using CSMA/CD



Conversation as a Form of CSMA/CD

An analogy for CSMA/CD is a conversation among a group of people in which all the individuals in the group would like a chance to speak. Everyone is listening to each other (sensing the medium). Only one person at a time gets a chance to say something. This is an example of a multiple access (MA) shared medium. If there is a pause in the conversation, two or more people listening may notice the opportunity and may say something at the exact same time, in which case neither may be heard by the rest of the group. This is an example of a collision. At this point, the collision is detected (CD), and those involved in the failed communication wait a few seconds and attempt to speak again later—hence, CSMA/CD.

Avoiding Network Traffic Collisions with CSMA/CA

WLANs use CSMA/CA to share the medium. The main difference from CSMA/CD is the CA—collision avoidance. Just as in CSMA/CD, the abbreviation CSMA/CA gives an idea of how it functions:

- **Carrier Sense**—Sensing the medium, in this case the air
- **Multiple Access**—Many devices accessing the medium at the same time
- **Collision Avoidance**—Avoiding collisions that may occur on the medium during transmission

Because WLAN devices have no way to detect collisions, the CSMA/CD access method is not an adequate solution for WLAN communications. If WLANs were to use CSMA/CD, collisions would occur at the wireless access point, and all data would be lost. At this point, a transmitting device would not know that it should retransmit the information, because the receiving device would be unaware that a collision occurred; the result would be very poor performance.

Instead of detecting transmission collisions, CSMA/CA uses mechanisms that attempt to avoid collisions. Although these mechanisms impose some overhead, the overall benefit is better data throughput because data collisions are minimized. This overhead occurs because devices use "countdown timers" that require them to wait for periods of time before they are able to transmit again. This helps to avoid data collisions.

Lecture Q&A as a Form of CSMA/CA

An analogy for CSMA/CA is the question-and-answer period following a lecture. The lecture hall is filled with many people (multiple access). A presenter has finished giving a speech, and it is now question-and-answer time. The presenter shouts out, "Does anyone have a question?" An attendee named Marvin listens (sensing the carrier). He does not hear anyone speaking, so he yells out a question. Although many people are in the room (again, multiple access), they can hear that Marvin has the floor and this time is dedicated to him. So they defer and do not ask their question until Marvin's question has been answered by the speaker (collision avoidance); hence, CSMA/CA.

Reserving Time for Data Transmission Using Distributed Coordination Function

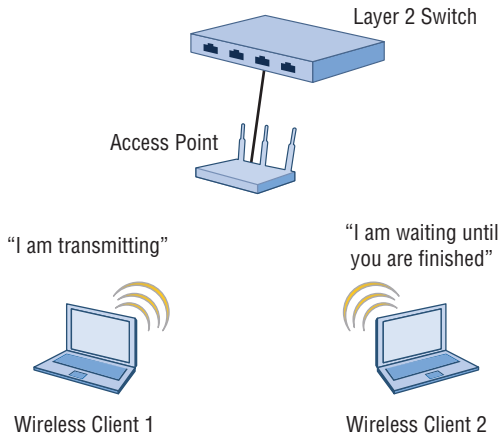
One of the access methods WLAN devices use to communicate is known as *distributed coordination function* (DCF). This method of access employs a contention period for devices competing to send data on the network. This collision avoidance mechanism is part of a detailed process requiring certain criteria to be met in order for a frame (a Layer 2 digital transmission unit) to be transmitted across the medium. In the case of WLAN technology, this medium is the air, using RFs. The IEEE 802.11 standard requires all service set types to support the DCF mode of operation.

To avoid collisions, the devices are required to

- Detect the RF energy of other devices transmitting, a technique known as *Clear Channel Assessment* (CCA), which is the physical carrier sense.
- Announce how much time is required for the frame exchange to occur, allowing other stations to read the duration field and set their Network Allocation Vector (NAV), which is the virtual carrier sense.
- Wait for a predetermined period of time between frames, a technique known as *interframe spacing*.
- Back off and retry if the medium is busy, a technique known as the random backoff timer via the contention window.

In short, these devices are reserving the medium so that transmissions can take place and avoid collisions. Figure 7.2 illustrates WLAN devices using CSMA/CA for an access method.

FIGURE 7.2 Wireless LAN devices using CSMA/CA and DCF



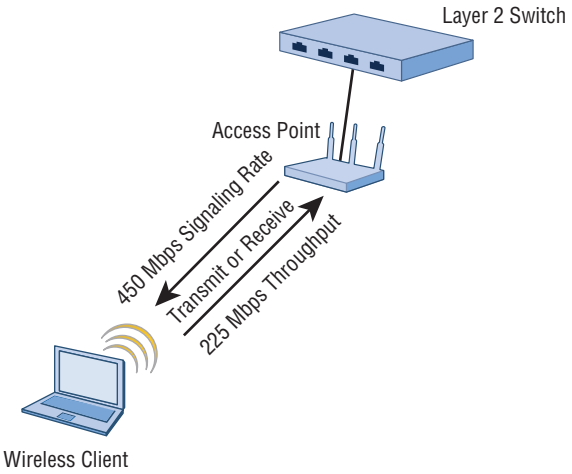
The 802.11 standard also specifies two other access methods used with wireless networking. *Point coordination function* (PCF) mode is a contention-free mode that works by polling stations and giving them an opportunity to send information without contending with other devices. PCF mode was optional and never implemented by any manufacturers. The IEEE 802.11-2016 standard states, "The PCF mechanism is obsolete. Consequently, this subclause might be removed in a later revision of the standard." Another access method, *Hybrid coordination function* (HCF) mode, was introduced with 802.11e for quality of service (QoS) technology.

Effects of Half-Duplex on Wireless Throughput

As discussed in Chapter 3, "Infrastructure and Client Devices Used with Wireless Networking," WLANs use half-duplex communication. To review, *half-duplex* in computer terminology is defined as two-way communication that occurs in only one direction at a time. Communication only one way at a time means less data throughput for the connected device(s). Half-duplex communication is part of the reason why in WLANs the amount of data being transferred is sometimes less than half of the advertised data rate; collisions and additional overhead are other factors to consider. An 802.11b/g/n device may only get 95 Mbps or less data transfer even though this technology is rated at 195 Mbps, assuming a 3×3:3 multiple input/multiple output (MIMO) 802.11n access point using a 20 MHz–wide channel. On a good day, devices will also average less than half of the advertised data rates due to the associated overhead and the use of half-duplex shared medium technology.

Figure 7.3 shows the half-duplex communication method and some of the effect it has on throughput. The data rate in this example is 450 Mbps, but the throughput is less than half of that, about 225 Mbps. The newest IEEE standards-based technology, 802.11ac, uses MIMO technology and has a potential maximum signaling rate of up to 6933.3 Mbps. However, many of the client devices available today are capable of a maximum of about 450–866.7 Mbps. The actual throughput can be much less than the advertised signaling rate.

FIGURE 7.3 Half-duplex operation has some effect on overall data throughput.



Narrowband vs. Spread-Spectrum Communication

Narrowband and spread-spectrum are two examples of how devices can communicate using RF.

One example of narrowband communication is an FM radio station. FM radio stations use licensed frequency ranges that are tuned to a specific RF in the FM band. A radio station can transmit a signal at a high power of tens of thousands of watts in a very narrow frequency. Depending on the conditions, a receiver can hear the station for tens or even possibly hundreds of miles.

Figure 7.4 shows the high amount of output power over a narrowband frequency of a potential FM radio station.

In contrast, spread-spectrum technology uses low power over a wider range of frequency. Figure 7.5 illustrates how a spread spectrum–capable access point uses low power over a wide frequency range.

FIGURE 7.4 Narrowband frequency—high power, narrow frequency

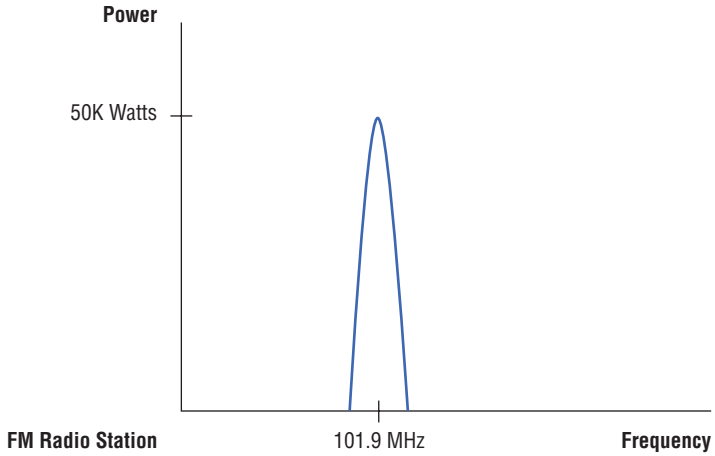
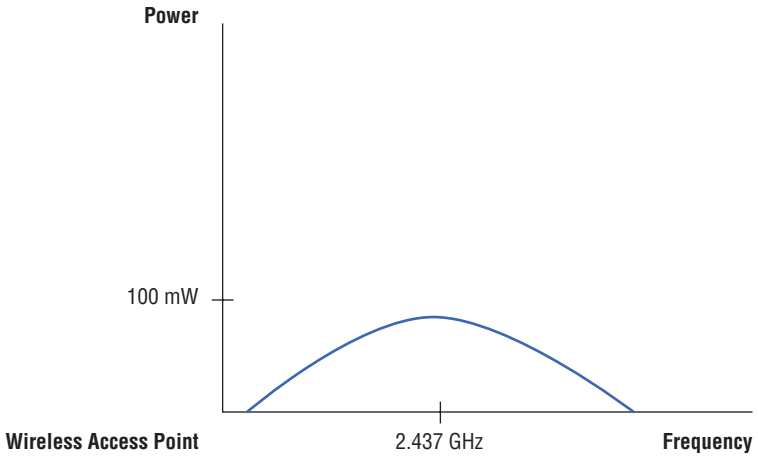


FIGURE 7.5 Spread-spectrum technology—low power, wide frequency



Lecturer vs. Breakout Discussions

Narrowband communication is similar to a lecture presented in a large room filled with several hundred attendees. The presenter may have a microphone connected to an amplifier or PA system to address the large audience. All attendees at this event will pay attention to the presenter, who will get the message across to the entire audience in this very large venue.

Spread-spectrum communication is similar to what happens when the same audience breaks out into small groups in which each member is communicating only with other members of that group. These groups of individuals will be speaking at a much lower volume without the help of a high-power microphone, and the conversation volume will not exceed the area in which this group is contained.

Spread-Spectrum Technology

Two types of *spread-spectrum* technology were specified in the original IEEE 802.11 WLAN standard ratified in 1997:

- Frequency-hopping spread spectrum (FHSS)
- Direct-sequence spread spectrum (DSSS)

These spread-spectrum technologies communicate in the 2.4 GHz industrial, scientific, and medical (ISM) frequency range. There are advantages and disadvantages to each of these spread-spectrum types.

Spread-spectrum technologies take the digital information generated by a computer (ones and zeros) and, through the use of modulation technologies, send it across the air between devices using RF.

In order for devices to communicate effectively and understand one another, they must be using the same spread-spectrum and modulation technology. This would be analogous to two people trying to talk with each other. If the two people don't know the same language, they will not be able to understand each other and a conversation could not take place.

Frequency-Hopping Spread Spectrum

Frequency-hopping spread spectrum (FHSS) is used in a variety of devices in computer technology and communications. FHSS was used by many early adopters of wireless networking, including computers, barcode scanners, and other handheld or portable devices. Although defined in the original IEEE 802.11 standard, this technology is considered obsolete in IEEE 802.11 wireless networking. However, FHSS is still used in devices such as cordless telephones and IEEE 802.15 wireless personal area networks (WPANs), including Bluetooth mice, cameras, phones, and wireless headsets.

FHSS is now considered obsolete with respect to 802.11 wireless networking and has formally been removed from the newest version of the standard (IEEE 802.11-2016). However, it is important to understand that some other wireless technologies still use FHSS as a communication mechanism and may cause interference with WLAN devices that use the same 2.4–2.5 GHz ISM frequency band.

802.11 Direct-Sequence Spread Spectrum

Direct-sequence spread spectrum (DSSS) is a spread-spectrum technology used with WLANs and defined by the original IEEE 802.11 standard. DSSS supports data rates of 1 and 2 Mbps and is considered very slow by today's computer networking requirements.

DSSS uses special techniques to transmit digital data (ones and zeros) across the air using RF. This is accomplished by modulating or modifying the RF characteristics, such as phase, amplitude, and frequency (see Chapter 4, "Radio Frequency Fundamentals for Wireless Networking").

In addition to modulation, DSSS uses technology known as a *spreading code* to provide redundancy of the digital data as it traverses through the air. The spreading code transmits information on multiple *subcarriers*, and the redundancy helps the receiver detect transmission errors due to interference. Subcarriers are smaller segments of the RF channel that is in use. This spreading of information across the 22 MHz–wide RF channel is what helps makes DSSS resilient to interference. This spreading code technology allows the receiver to determine if a single bit of digital data (symbol) received is a binary 0 or binary 1. Depending on the data rate, the transmitter and receiver understand the spreading code in use and therefore are able to communicate.

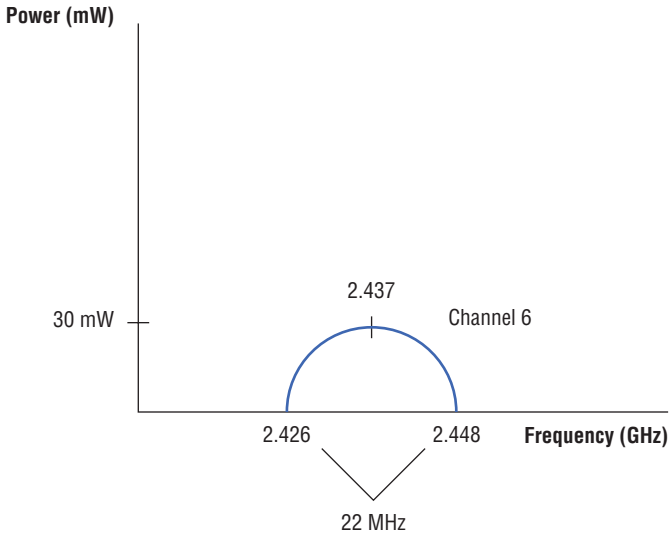
An example of a coding technique is Barker code. Barker code is used as the spreading code for DSSS at the data rates of 1 and 2 Mbps. IEEE 802.11 WLANs can use this 11 "chip" spreading code for communications. Each digital data bit (binary 1 or 0) is combined with the set Barker code through what is called an *exclusive OR* (XOR) process. XOR is a way of combining binary data bits in digital electronics. The result then spreads the binary 0 or 1 over a 22 MHz–wide channel, helping to make it resilient to RF interference. Since both the transmitter and receiver understand the same code, they would be able to determine the information that was sent across the air.

DSSS operates within a range of RF frequency also known as a *channel*. The channel is defined by its center frequency; that is, Channel 1 is 2.412 GHz on center, Channel 2 is 2.417 GHz on center, and so on. Each channel in the 2.4 GHz ISM band is separated by 5 MHz on center. Unlike narrowband communication, which operates on a single narrow frequency, a DSSS channel is 22 MHz wide and is one of 14 channels in the 2.4 GHz to 2.5 GHz ISM band. The country and location of the device will determine which of the 14 channels are available for use in that specific area.

Figure 7.6 shows that channel 6 is 22 MHz wide in the ISM unlicensed RF band.

FHSS and DSSS both operate in the same frequency range. If devices that use both technologies are occupying the same physical area, the devices may encounter some interference. Therefore, RF interference may occur from either IEEE 802.11 WLAN devices using the same channel or non-IEEE 802.11 WLAN devices that are using the same RF channel. This includes anything wireless that does not adhere to the IEEE 802.11 protocol rules but is operating in the same frequency range, such as 2.4 GHz wireless cameras, 2-way radios or radio monitors, and even microwave ovens.

FIGURE 7.6 DSSS is limited to a 22 MHz–wide channel in the 2.4 GHz ISM band. Each channel for DSSS is 5 MHz on center.



802.11b High Rate/Direct-Sequence Spread Spectrum

High rate/direct-sequence spread spectrum (HR/DSSS) was defined in the IEEE *802.11b* amendment to the IEEE 802.11 standard. HR/DSSS (802.11b) introduced higher data rates of 5.5 and 11 Mbps. At the time the amendment was released, because of the higher data rates this technology helped fuel the acceleration of IEEE standards based on WLAN technology. The desire for 802.11 technology grew as the availability became greater and the cost decreased.

Like DSSS, HR/DSSS uses one of fourteen 22 MHz–wide channels to transmit and receive digital computer data. The main difference between these two technologies is that HR/DSSS supports higher data rates of 5.5 Mbps and 11 Mbps.

HR/DSSS (802.11b) also uses a different spreading code or an encoding technique from DSSS. HR/DSSS uses complementary code keying (CCK) for transmitting data at 5.5 and 11 Mbps. The detailed operation of CCK is beyond the scope of this book.

IEEE 802.11 DSSS and HR/DSSS Channels

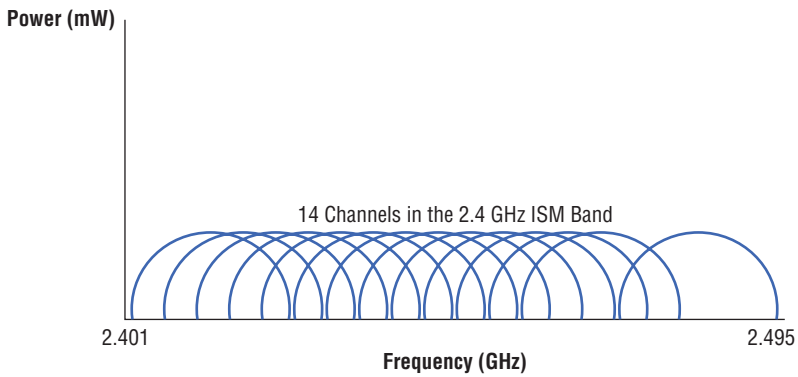
DSSS and HR/DSSS operate in the 2.4 GHz industrial, scientific, and medical (ISM) license free band. This band has 14 available channels. Depending on the country and location, all 14 channels may not be available. Table 7.1 shows the 14 available channels in the 2.4 GHz ISM band for a few different countries.

TABLE 7.1 14 available channels in 2.4 GHz ISM band

Channel	Frequency (GHz)	Americas	EMEA	Israel	China	Japan
1	2.412	✓	✓	✓	✓	✓
2	2.417	✓	✓	✓	✓	✓
3	2.422	✓	✓	✓	✓	✓
4	2.427	✓	✓	✓	✓	✓
5	2.432	✓	✓	✓	✓	✓
6	2.437	✓	✓	✓	✓	✓
7	2.442	✓	✓	✓	✓	✓
8	2.447	✓	✓	✓	✓	✓
9	2.452	✓	✓	✓	✓	✓
10	2.457	✓	✓	✓	✓	✓
11	2.462	✓	✓	✓	✓	✓
12	2.467		✓	✓		✓
13	2.472		✓	✓		✓
14	2.484					✓

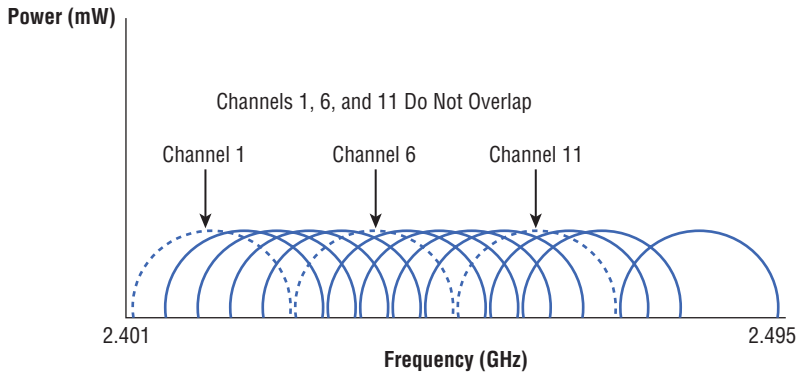
Figure 7.7 shows the 14 available channels and the amount of overlap in the 2.4 GHz ISM band.

FIGURE 7.7 The 2.4 GHz ISM band allows 14 channels.



Of these 14 channels, mathematically there are only 3 adjacent nonoverlapping channels, with the exception of channel 14. According to the IEEE 802.11-2016 standard, "Channel 14 shall be designated specifically for operation in Japan." Channel 14 is separated by 12 MHz on center from Channel 13, whereas Channels 1–13 are separated by 5 MHz on center of each channel. There are 3 MHz of separation where the RF of one channel ends and the next adjacent nonoverlapping channel begins. For example, Channel 1 and Channel 6 are adjacent nonoverlapping channels. Channel 1 ends at 2.423 GHz, and Channel 6 begins at 2.426 GHz. Mathematically this is a separation of 3 MHz. This means that three access points can be co-located in the same physical space without overlapping channel interference. However, there is still theoretically a small amount of overlapping RF or harmonics between these two channels. This small level of overlap is not large enough to cause any real interference issues because the signal becomes weaker as it spreads further away from the channel's center frequency. Figure 7.8 illustrates 3 of the first 14 channels that do not overlap in the 2.4 GHz ISM band.

FIGURE 7.8 3 nonoverlapping channels possible in the 2.4 GHz ISM band



Each DSSS channel is 22 MHz wide. Using spread-spectrum technology, a 22 MHz–wide channel helps add resiliency to interference for data transmissions and gives the capability to move large amounts of data with a small amount of RF power. Some early IEEE 802.11 devices included barcode scanners, and they worked with limited battery life. Using a spreading technology instead of narrowband technology (which would be higher RF transmit power) helped to conserve battery life and increased the use of IEEE 802.11 devices as a whole.

IEEE 802.11g Extended Rate Physical

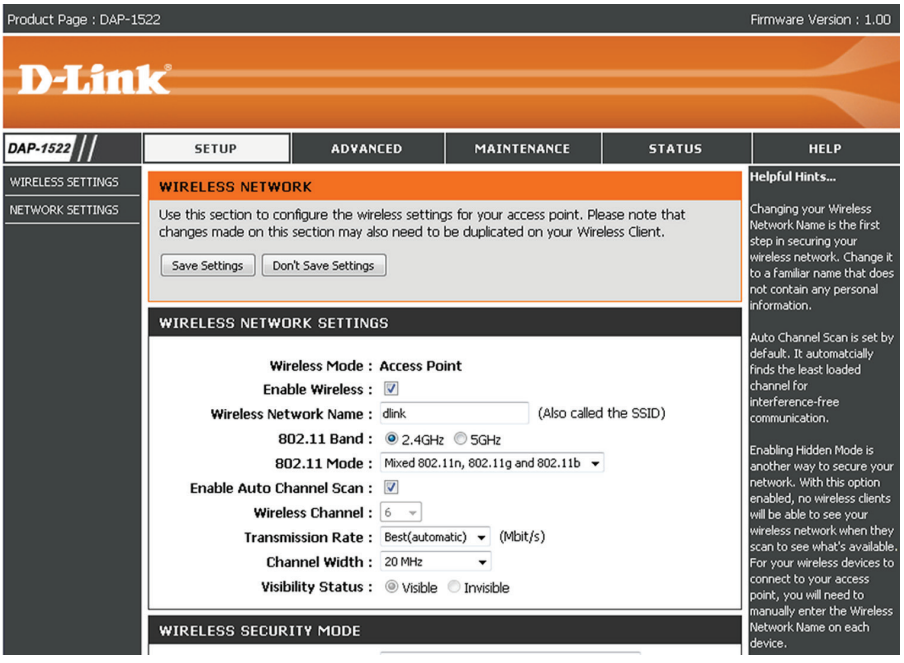
The IEEE 802.11g amendment was released in 2003 and introduced technology that allowed for higher data rates for devices and operation in the 2.4 GHz ISM band. The objective of this amendment was to allow for these higher data rates (up to 54 Mbps) using orthogonal frequency-division multiplexing (OFDM) and still maintain backward

compatibility with existing 802.11b technology and devices. This technology, known as *Extended Rate Physical* (ERP), builds on the data rates of 1, 2 Mbps DSSS (802.11) and 5.5, 11 Mbps HR/DSSS (802.11b). The 802.11g amendment introduced several compatibility operation modes:

- ERP-DSSS
- ERP-CCK
- ERP-DSSS/CCK
- ERP-OFDM

The *802.11g* amendment required support for ERP-DSSS/CCK and ERP-OFDM. This allowed for both the 802.11b data rates of 1, 2, 5.5, and 11 Mbps and the newer OFDM data rates of 6, 9,12, 18, 24, 36, 48, and 54 Mbps. Manufacturers of WLAN equipment implement this in various ways. In a graphical user interface, there may be a drop-down menu that allows a user to select a specific operation mode, such as mixed mode, b/g mode, b-only mode, and so on. Another possibility is to select the individual data rates using radio buttons. For manufacturers that provide a command-line interface (CLI) option, the appropriate commands would need to be executed in order to enable or disable the desired data rates. Figure 7.9 illustrates an example of how manufacturers allow a user to select the ERP operation mode on an access point.

FIGURE 7.9 Selecting an operation mode on a dual-band IEEE 802.11a/b/g/n SOHO access point



IEEE 802.11n High Throughput

The IEEE 802.11n amendment was ratified in September 2009. This high throughput (HT) Physical layer (PHY) technology is based on the OFDM (PHY) in Clause 17 (802.11a) PHY. 802.11n HT allows extensibility of up to four spatial streams, using a channel width of 20 MHz. Also, transmission using one to four spatial streams is defined for operation in 20/40 MHz channel width mode. This technology is capable of supporting data rates up to 600 Mbps using four spatial streams with a 20/40 MHz channel. IEEE 802.11n HT provides features that can support a throughput of 100 Mbps and greater. Other optional features on both the transmit and receive sides include but are not limited to the following:

- HT No Protection (also known as *greenfield mode*)
- Optional short guard interval (GI), 400 ns
- Transmit beamforming (TxBF)
- Space-time block coding (STBC)

The *802.11n* amendment allows for operation in both the 2.4 GHz ISM and 5 GHz Unlicensed National Information Infrastructure (UNII) bands with either 20 MHz– or 40 MHz–wide channels. Although 40 MHz–wide channels are allowed in the 2.4 GHz ISM band, best practices recommend against it. Using a 40 MHz channel in this band would only equate to a single channel without any channel overlap.

It is important to understand the difference between data rate and throughput. Data rates are what a station is capable of exchanging information, whereas throughput is the rate at which the information is actually moving. Data rate and throughput are compared in more detail in Chapter 6, "Communication for Wireless Networking."

IEEE 802.11a, 802.11g, 802.11n, and 802.11ac OFDM

Orthogonal frequency-division multiplexing (OFDM) is used by the IEEE 802.11a (OFDM), IEEE 802.11g Extended Rate Physical Orthogonal Frequency-Division Multiplexing (ERP-OFDM), IEEE 802.11n High Throughput (HT-OFDM), and IEEE 802.11ac Very High Throughput (VHT) amendments to the IEEE 802.11 standard. OFDM allows for much higher data rate transfers than DSSS and HR/DSSS, up to 54 Mbps for 802.11a and 802.11g, potentially up to 600 Mbps for 802.11n, and theoretically up to 6.933 Gbps for 802.11ac.

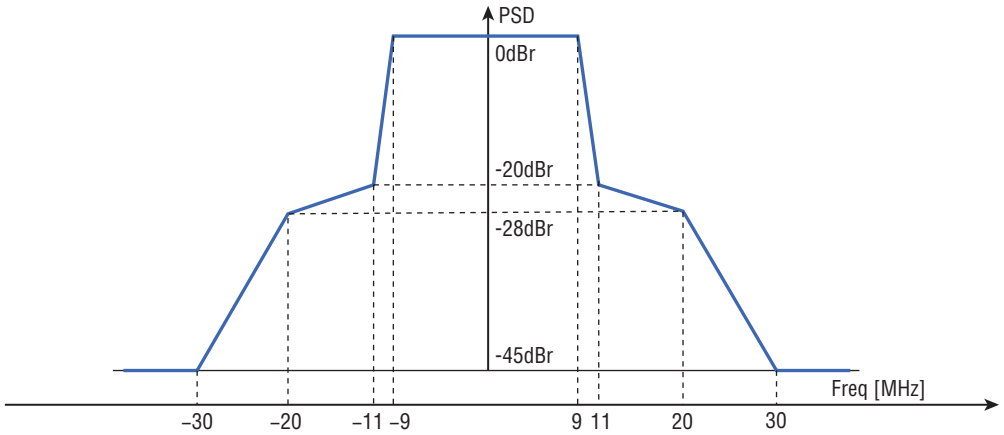
OFDM is a technology designed to transmit many signals simultaneously over one transmission path in a shared medium and is used in wireless and other transmission systems.

Every signal travels within its own unique frequency subcarrier (a separate signal carried on a main RF transmission). IEEE 802.11a and 802.11g OFDM distribute computer data over 52 subcarriers equally spaced apart, and 4 of the 52 subcarriers do not carry data and are used as pilot channels. IEEE 802.11n/ac allows for 56 subcarriers of which 52 are usable for data with a 20 MHz–wide channel, and 114 subcarriers of which 108 are usable for data with a 40 MHz–wide channel. Having many subcarriers allows for high data rates in WLAN IEEE 802.11a and IEEE 802.11g devices. 802.11n/ac devices (HT-OFDM) may use a MIMO technology known as *spatial multiplexing* (SM), which uses several radio chains to transmit different pieces of the same information simultaneously, greatly increasing throughput. In addition to high data rates, OFDM helps provide resiliency to interference from other wireless devices.

IEEE 802.11a, 802.11g, 802.11n, and 802.11ac OFDM Channels

OFDM functions in either the 2.4 GHz ISM or the 5 GHz UNII bands. The channel width is smaller than DSSS or HR/DSSS. The width of an OFDM channel is only 20 MHz compared to 22 MHz for DSSS. Figure 7.10 shows a representation of a 20 MHz–wide OFDM channel.

FIGURE 7.10 OFDM transmit spectral mask for 20 MHz transmission



Like DSSS, when OFDM is used in the 2.4 GHz ISM band there are at most, in the same physical area, only three non-overlapping adjacent channels for use. This will limit the use of "bonded" channels (20/40 MHz–wide channels) in IEEE 802.11n (HT-OFDM) deployments that are located in the same RF physical area. In the 5 GHz UNII bands, the channel spacing is such that there is no overlap. The frequency range used will determine how many nonoverlapping channels are available for use. In the lower UNII band, 4 non-overlapping

channels are available. With the ratification of IEEE 802.11ac, the middle UNII band now has a possible16 nonoverlapping channels available. The upper UNII band now provides a possible 5 non-overlapping channels. All UNII band channels are 20 MHz wide and separated by 20 MHz from the center frequencies of each channel. Certain regulatory domains, including the United States Federal Communication Commission (FCC) and the European Telecommunications Standards Institute (ETSI), require the use of dynamic frequency selection (DFS) support for wireless devices such as access points that operate in the middle 5 GHz (5.250 GHz–5.725 GHz) UNII band. DFS will allow an access point to change the RF channel it is operating on in order to avoid interfering with certain type of radar systems. Table 7.2 shows the 25 available channels, center frequency, and channel number in the 5 GHz UNII band. Also displayed is a single 5 GHz ISM channel that is available by some regulatory agencies for use with wireless networking.

TABLE 7.2 5 GHz UNII band channels

Regulatory Domain	Frequency Band (GHz)	Frequency Center (GHz)	Channel Number
4 channels	5.150–5.250	5.180	36
		5.200	40
		5.220	44
		5.240	48
4 channels	5.250–5.350	5.260	52
		5.280	56
		5.300	60
		5.320	64
12 channels	5.470–5.725	5.500	100
		5.520	104
		5.540	108
		5.560	112
		5.580	116
		5.600	120
		5.620	124
		5.640	128
		5.660	132
		5.680	136
		5.700	140
		5.720	144

TABLE 7.2 5 GHz UNII band channels *(continued)*

Regulatory Domain	Frequency Band (GHz)	Frequency Center (GHz)	Channel Number
5 channels	5.725–5.825	5.745	149
		5.765	153
		5.785	157
		5.805	161
		5.825	165

Some regulatory agencies allow the use of the 5.725–5.850 GHz band for wireless networking, including but not limited to the United States, Europe, Singapore, and China. This frequency range is specified in the IEEE 802.11-2016 standard for use with WLAN technology. The use of this frequency range is regulated separately with some similarities to the 2.4 GHz ISM band and allows for the use of more devices such as cordless telephones.

IEEE 802.11n/ac Multiple Input/Multiple Output Technology

Multiple input/multiple output (MIMO) is a technology used by IEEE 802.11n and 802.11ac devices. MIMO technology is capable of signaling rates up to 600 Mbps for 802.11n devices and 6,933.3 Mbps (6.93 Gbps) for 802.11ac devices. MIMO provides users with a better overall experience for data, voice, and video communications with throughput faster than 802.11 a/g, *single input/single output* (SISO) networks.

SISO is the most basic wireless antenna technology used in a WLAN system. One antenna is used at the transmitter to transmit data, and one antenna is used at the receiver to receive the data. Some SISO systems support a technology known as *diversity*, which uses two antennas with a single radio. Diversity technology will help to lessen the effects of multipath, which is caused by reflections. Diversity and multipath are discussed in more detail in Chapter 5, "Antenna Technology for Wireless Networking." Coverage is more predictable and consistent with MIMO networks because devices using this technology are able to utilize reflected signals, which are a problem for wireless networks using other WLAN technologies.

MIMO also allows 802.11n/ac networks better throughput than DSSS or OFDM-based networks at the same distance. IEEE 802.11n MIMO-based networks offer backward compatibility with 802.11a/b/g networks and devices in both the 2.4 GHz ISM and the 5 GHz UNII bands, allowing for deployments to continue using their existing hardware. IEEE 802.11ac MIMO-based networks offer backward compatibility with 802.11a/n

networks and devices because 802.11ac technology is designed to operate only in the 5 GHz UNII band.

Some of the benefits of 802.11n/ac MIMO networks include throughput, reliability, and predictability:

- More throughput than SISO technology
- Enhanced file transfer and download speeds for large files
- More reliable performance than SISO technology
- Lower latency for mobile communications
- More predictable coverage compared to SISO technology
- More consistent coverage and throughput for mobile applications compared to SISO technology

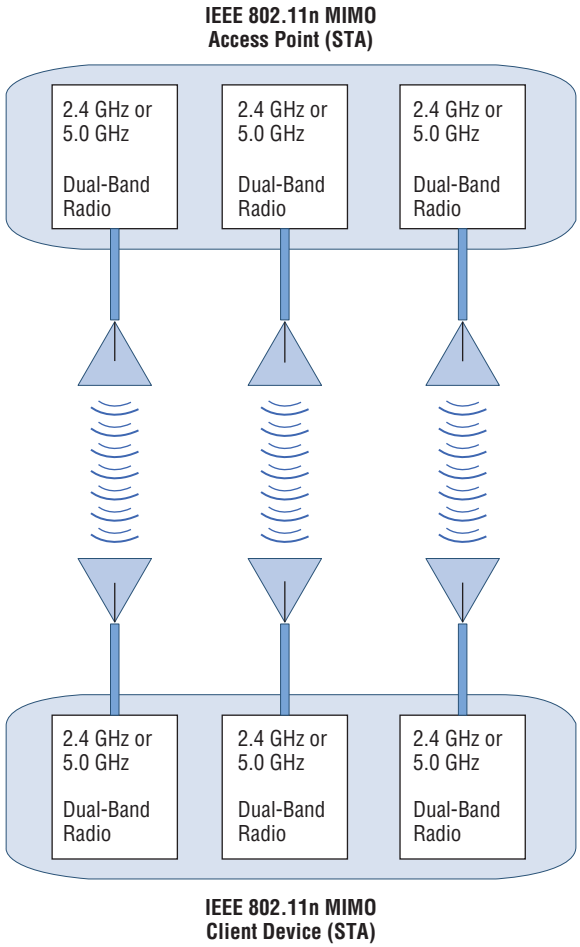
Unlike IEEE 802.11b (HR/DSSS) and IEEE 802.11a/g (OFDM) access points, MIMO access points use multiple radios with multiple antennas. The multiple radio chains and some additional intelligence are what give 802.11n/ac MIMO access points the capability to process reflected signals. Since 802.11n MIMO works with both the 2.4 GHz ISM and the 5 GHZ UNII bands, a dual-band IEEE 802.11n MIMO access point will have up to eight radio chains (four for 2.4 GHz and four for 5 GHz) and eight antennas (one for each radio) for data rates of up to 600 Mbps. Keep in mind that 802.11n MIMO technology is capable of up to four radio chains in a single band; however, until the release of 802.11ac technology, no enterprise equipment manufacturer produced such a device. Dual-band 802.11n/ac devices may provide 4×4:4 technologies in the 2.4 GHz ISM band. 802.11ac devices are capable of up to eight radio chains in the 5 GHz band, but current devices support up to four radio chains. Figure 7.11 shows that MIMO uses multiple radio chains and multiple antennas to transmit and receive data.

802.11n/ac systems use MIMO technology. They have more receivers and are much more sensitive than the average 802.11a or 802.11g radio. The following techniques are what allow for better performance and much higher data rates up to 450 Mbps with 3×3:3 IEEE 802.11n MIMO and up to 600 Mbps with 4×4:4 IEEE 802.11ac MIMO:

- Maximal ratio combining (MRC)
- Transmit beamforming (TxBF)
- Spatial multiplexing (SM)
- Multi-user MIMO (MU-MIMO)

802.11a/b/g networks are known as *single input/single output* (SISO) systems, which means that performance can degrade as a result of multipath, poor reception because of obstacles, and RF interference sources. 802.11n/ac MIMO networks can take advantage of multipath to help increase throughput at a given range, providing much higher throughput at the same range.

FIGURE 7.11 MIMO hardware uses separate radio chains for each band and one antenna for each radio.

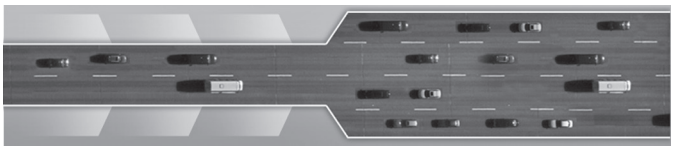


IEEE 802.11n/ac MIMO Channels

IEEE 802.11n MIMO networks can operate in both the 2.4 GHz ISM and 5 GHz UNII bands and are capable of either 20 or 20/40 MHz–wide channels. Even while 802.11n MIMO networks are operating in 20/40 MHz channel width mode, many frames such as beacon management frames are still transmitted with a 20 MHz channel width. The 20 and 20/40 MHz channel widths are defined by the IEEE for the transmission of OFDM modulated data. As you would expect, wider channels mean more data can be transmitted over the RF medium simultaneously. Therefore, wider channels allow higher data

throughput. Think of this like cars traveling on a two-lane or a four-lane highway. A 20 MHz–wide channel can be looked at as the two-lane highway, and a 40 MHz–wide channel as the four-lane highway. More cars can pass through four lanes in the same amount of time than can pass through two lanes. Figure 7.12 illustrates this point.

FIGURE 7.12 More lanes, more cars—wider channels, more data

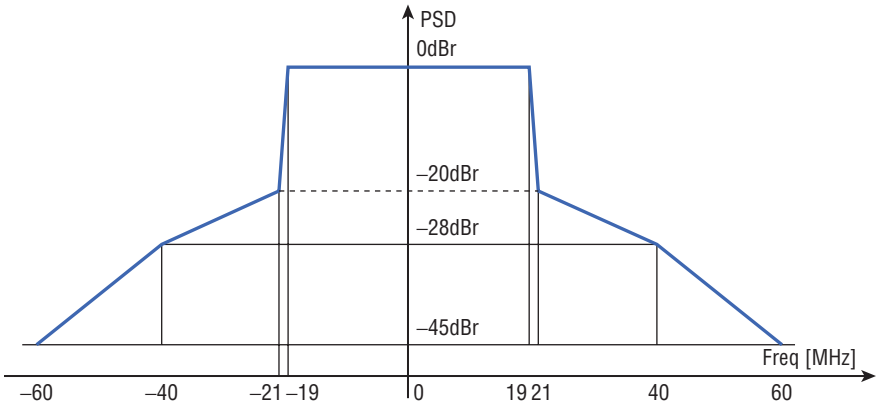


A 40 MHz wide channel is like moving from 2 to 4 lanes.

The 20 MHz or 20/40 MHz channels can be used in either the 2.4 GHz or 5 GHz frequency ranges. Because of the limited amount of frequency space in the 2.4 GHz ISM band, there is only one 20/40 MHz–wide channel without any adjacent-channel overlap. Figure 7.13 shows a 40 MHz–wide channel as specified in the 802.11 standard.

Although most enterprise-grade access points support bonded (20/40 MHz–wide) channels, there are still some wireless client devices, both new and legacy, that do not support this technology. To achieve the higher data rates that IEEE 802.11n offers, both the client and the access point must support the newer technologies. If the wireless client device does not support the bonded channels, the access point will be able to adapt, allowing for coexistence.

FIGURE 7.13 OFDM transmit spectral mask for 40 MHz transmission



In addition to the 20 MHz or 20/40 MHz channel widths that are available with 802.11n MIMO, 802.11ac allows for additional channel widths, 80 MHz– and 160 MHz–wide channels in the 5 GHZ UNII band. Although using wider channels will allow for much higher data rates and throughput, the use of such channels should be carefully considered. Using wider channels will lessen the number of available non-overlapping channels and will limit the types of networks that will be able to utilize the wider channel plan deployments. In many cases, higher-density deployment scenarios such as stadium venues will benefit from more channels with smaller 20 MHz channel widths. Home and small office deployments may benefit from using the wider 80 MHz or 160 MHz channel widths.

Co-location of IEEE 802.11b HR/DSSS and IEEE 802.11a/g/n OFDM Systems

Now we will look at the co-location of different 802.11a/b/g/n/ac devices. One thing to understand is that many consider 802.11b systems to be legacy devices that are on the verge of becoming obsolete. However, this may not be the case in all installations. Mostly because of legacy hardware and depending on the type of WLAN installation (typically public guest networks and the retail environment), support for 802.11b networks may still be required. Additionally, the latest revision of the 802.11 standard (IEEE 802.11-2016) still addresses this technology, and therefore it is important to understand the implications of co-location of 802.11b devices.

All IEEE-based WLANs can be *co-located*—that is, they can function in the same RF space. The technologies that the devices use determine how well they work together. Both HR/DSSS (802.11b) and ERP-OFDM (802.11g/n) networks operate in the 2.4 GHz frequency range ISM band. 802.11g-compliant devices are backward compatible with 802.11b-compliant devices. However, this backward compatibility comes at a price: reduced data throughput. Because of protection mechanisms, ERP-OFDM devices used in 802.11g/n will suffer in performance when an HR/DSSS device is in the same radio or hearing range of the ERP-OFDM device.

HR/DSSS and ERP-OFDM systems have many common features:

- Both operate in the 2.4 GHz ISM band.
- Both have three nonoverlapping channels.
- Both are subject to interference from other devices operating in the same frequency range.

HR/DSSS and ERP-OFDM (802.11b-compliant and 802.11g/n-compliant) devices are backward compatible. ERP-OFDM is rated at 6, 9, 12, 18, 24, 36, 48, and 54 Mbps. Actual throughput in an environment relatively free of interference will be about 15 to 24 Mbps. If a DSSS or HR/DSSS device is introduced in the radio range of the ERP-OFDM device, the throughput will decrease significantly because of protection mechanisms. How much of an impact this makes depends on many factors in the environment. Typically, the decrease in throughput is about 25 percent to 30 percent. It is important to understand that this is not just limited to a single wireless access point or the basic service area. If an

802.11g/n access point can "hear" another 802.11g/n access point on the same RF channel that is in ERP protection mode, then that access point will also enter a protection mode state. This is known as what some call the *ripple effect*. The same holds true for access points that support 802.11n technology in the 2.4 GHz ISM band. With the higher data rates of potentially up to 600 Mbps using a 4×4:4 MIMO system, any 802.11b device introduced into the basic service set will have an adverse effect on the amount of data throughput for the 802.11n network.

Just as co-location of 802.11b/g/n EPR-OFDM systems needs to be taken into consideration, the same holds true with 802.11a/n/ac OFDM systems. The real difference is the frequency band that 802.11a/n/ac systems operate in. IEEE 802.11 devices operate in the 5 GHz UNII band. The IEEE 802.11n High Throughput (HT) amendment to the standard addresses different protection mechanisms. This is because 802.11n devices can operate in both the 2.4 GHz ISM and 5 GHZ UNII bands. Therefore, an 802.11n/ac access point will need to allow 802.11a/n devices to utilize the network along with 802.11ac devices, both types in the 5 GHz UNII band.

802.11a OFDM, 802.11n HT-OFDM, and 802.11ac VHT systems have several common features:

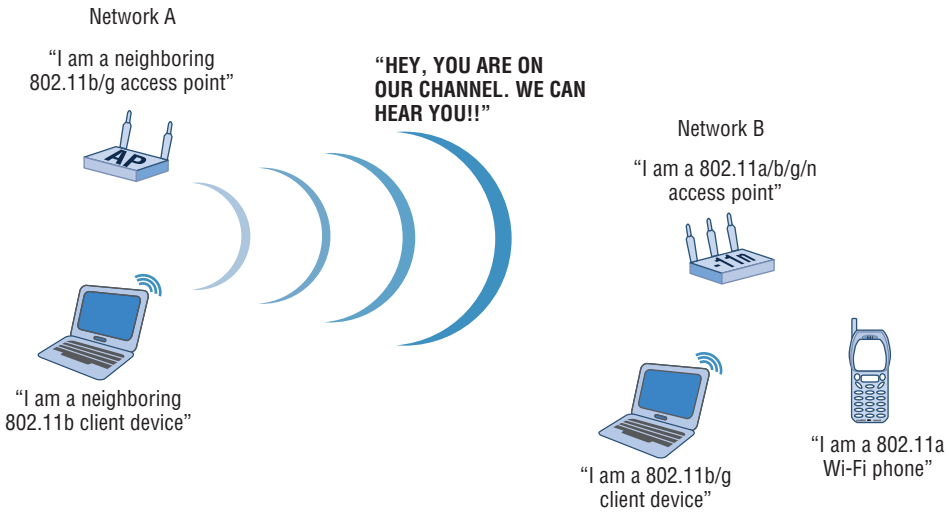
- All operate in the 5 GHz UNII band.
- They have up to 25 nonoverlapping channels (depending on the regulatory agency and whether 802.11ac is supported).
- All are subject to interference from other devices operating in the same frequency range.

802.11n HT networks offer various protection mechanisms to ensure interoperability and co-location.

OFDM, HT-OFDM, and VHT (802.11n/ac-compliant and 802.11a-compliant) devices are backward compatible. OFDM is rated at 6, 9, 12, 18, 24, 36, 48, and 54 Mbps. Actual throughput in an environment relatively free of interference may be a little higher than an 802.11g/n environment, about 18 to 26 Mbps. Networks that operate in the 5 GHz UNII band are not subject to co-location issues with DSSS or HR/DSSS, because they operate in different frequency ranges. The 802.11n amendment introduced a new concept called the *modulation and coding scheme* (MCS). This is a different way to represent the data rates that are available with 802.11n technology. Previously, the IEEE 802.11 standard and amendments specified data rates as individual values—1 Mbps, 2 Mbps, 5.5 Mbps, and 11 Mbps in IEEE 802.11b technology, for example. The IEEE 802.11n amendment to the standard refers to this as the *modulation and coding scheme* (MCS). This is because depending on the technology enabled or used, a single MCS may support multiple data rates. For example, an MCS Index 7 will support either 65.0 Mbps or 72.2 Mbps, depending on whether short guard interval is enabled. The same is true with 802.11 ac devices.

802.11n devices have a maximum data rate or MCS of up to 600 Mbps. Just as devices that operate in the 2.4 GHz ISM band must be able to coexist, devices that operate in the 5 GHz band must be able to coexist as well. Co-location of 802.11a/n/ac devices is possible through the use of additional protection mechanisms. (ERP and HT protection mechanisms will be discussed in more detail in Chapter 6.) Figure 7.14 illustrates co-location of various 802.11 technologies.

FIGURE 7.14 Co-location of various IEEE 802.11 devices/technologies



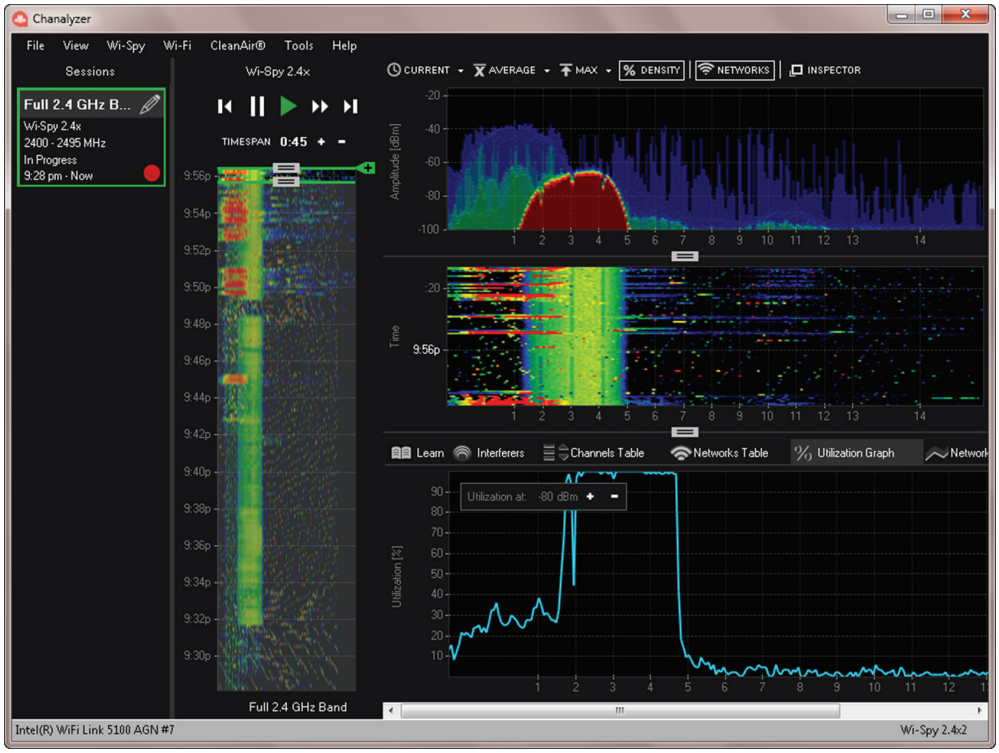
Adjacent-Channel and Co-channel Interference

Adjacent-channel and *co-channel* interference (two or more RF signals interacting with each other and causing a degradation of performance) are concerns in the design, development, and deployment of IEEE 802.11-based wireless networks. This is because the wireless devices are contending to use the medium rather than just being seen as RF noise to each other. These types of interference will have an impact on the amount of actual throughput between devices over a wireless network. The definition of adjacent-channel interference is when two or more access point radios are providing RF coverage to the same physical area using overlapping frequencies, such as Channel 1 and Channel 3. Co-channel interference is when two or more independently coordinated access point radios are providing RF coverage to the same physical area using the same 802.11 channel, such as Channel 1 and Channel 1. The 2.4 GHz ISM band has only three nonoverlapping channels. Careful channel planning is required when designing or implementing a wireless network. This type of planning will minimize issues such as poor throughput as a result of adjacent-channel and co-channel interference. *Channel planning* involves designing wireless networks so that overlapping RF cells are on different (nonoverlapping) channels—for example, channels 1, 6, and 11 in the 2.4 GHz ISM band. This will help optimize performance and minimize degradation of throughput because of adjacent-channel and co-channel interference.

With the advancements in 802.11 technologies, channel planning is more "automated" by the use of spectrum management technology and the IEEE 802.11 standard. It is still important, however, to understand the concept of channel planning. RF energy propagates in several directions simultaneously. A well-designed wireless network will account

for a three-dimensional propagation. In other words, in a three-story building, the RF from an access point on the second floor building may pass through to the first and third floors; therefore, interference could be an issue if the network is not planned properly. Figure 7.15 illustrates overlapping channel interference with two access points in the 2.4 GHz ISM band.

FIGURE 7.15 Two access points on overlapping channels as seen in MetaGeek's Chanalyzer. The "Data" access point is on channel 1, and the "Guest" access point is on channel 3 in the 2.4 GHz ISM band.



WLAN/WPAN Coexistence

Wireless personal networks (WPANs) typically consist of portable devices such as personal digital assistants (PDAs), cell phones, headsets, computer keyboards, mice, and now tablet devices. In Chapter 4, you saw how the performance of IEEE 802.11 WLANs can be affected when co-located with WPAN devices. The IEEE 802.15 standard addresses WPANs and includes Bluetooth and Zigbee networks. Bluetooth is one of the most popular WPAN network technologies and operates in the 2.4 GHz ISM band using FHSS technology.

Early Bluetooth devices could cause significant interference while operating in close proximity to IEEE 802.11 WLANs. Bluetooth was designed to hop at a rate of 1,600 times per second across the entire 2.4 GHz band, potentially causing significant interference with 802.11 wireless networks. Bluetooth-capable devices now use adaptive frequency hopping (AFH) and thus are less likely to interfere with IEEE 802.11 wireless networks, even though they still operate in the 2.4 GHz ISM band. Devices that use AFH will try to avoid using the same frequencies, decreasing the chance of interference. Since these devices operate at low power, most WPANs communicate in small, close-range, peer-to-peer networks.

Real World Scenario

Taking Adjacent-Channel and Co-Channel Interference into Consideration When Planning a New Wireless Network

As a wireless network engineer, you are tasked with deploying a new wireless network in a multitenant building. The area to be covered is approximately 50,000 square feet.

Your first task, prior to the procurement and deployment of the wireless network, should be to perform a spectrum analysis and site survey. This will help determine the best frequency and channels to be used in the new deployment.

A survey reveals that tenants on the floors above and below where the new deployment is to be installed are also using IEEE 802.11b/g/n networks, with many access points on channels across the entire 2.4 GHz ISM band. A situation such as this may make the deployment difficult. There is an increased possibility of adjacent-channel and co-channel interference.

Upon further evaluation, it is determined that the lower band of the 5 GHz UNII band is not being utilized to any large extent. Since this is a new deployment, you have the opportunity to purchase equipment that will utilize the 5 GHz UNII band as well as the 2.4 GHz ISM band. The following are some of the questions that need to be evaluated:

- Are any devices limited to 802.11b/g/n capability only?
- Does the network require backward compatibility to 802.11b/g/n?
- Does the network need to support guest access?
- What impact would a network using only 5 GHz 802.11a/n/ac have on the business?
- Is it possible to utilize both frequency bands in this deployment to maximize throughput while limiting interference?
- Is a single channel architecture (SCA) technology system that will allow for backward compatibility to existing wireless client devices a possible solution?

These are just some questions that need to be considered prior to making any final decisions on the network to be installed and the equipment to be purchased.

Summary

In this chapter, we looked at access methods used to get data from one device to another when multiple users share the medium. These access methods consist of collision avoidance and collision detection:

- CSMA/CD—Carrier Sense Multiple Access/Collision Detection
- CSMA/CA—Carrier Sense Multiple Access/Collision Avoidance

WLANs have no way of detecting collisions, so they must use collision avoidance (CSMA/CA). WLANs use half-duplex communication, which limits the communication for a data transfer.

This chapter also looked at the spread-spectrum and Physical layer (PHY) technologies used with WLANs and the differences among them. The IEEE standard and various amendments use different spread-spectrum and PHY technologies and unlicensed radio spectrum allowing for data rates up to 6,933.3 Mbps. These Physical layer (PHY) technologies include:

- DSSS—For data rates of 1 and 2 Mbps
- HR/DSSS—For data rates of 5.5 and 11 Mbps
- OFDM—For data rates up to 54 Mbps
- HT-OFDM—For data rates of up to 600 Mbps
- VHT-OFDM—For a theoretical maximum of up to 6,933.3 Mbps

Even though FHSS is now an obsolete technology for WLANs, it is still important to understand some of the basics of this technology since it is still in use today in many industries in various types of wireless technologies, including IEEE 802.15 personal area networking (PAN), Bluetooth, and cordless telephones.

We looked at the different channel sets used with 802.11 wireless networks and some of the co-location considerations.

Some of the Physical layer technologies discussed in this chapter are more susceptible to interference than others. This can make installations in some industries challenging. We also looked at co-location of HR/DSSS and ERP-OFDM systems and some of the challenges it can pose. Finally, this chapter discussed the coexistence of WPANs and WLANs and the various devices and technology that can cause interference when working in the same RF space.

Exam Essentials

Know the frequencies and channels HR/DSSS and OFDM use. Understand that HR/DSSS operates in the 2.4 GHz ISM band and can use 14 channels depending on the country/location used. Know that ERP-OFDM is used for the 2.4 GHz band; OFDM is used for the 5 GHz band; and HT-OFDM is used in either band. Know the four UNII

bands OFDM uses for the 802.11a and 802.11n amendments. Understand that MIMO systems may use HT-OFDM and can operate in either the 2.4 GHz ISM band or the 5 GHz UNII band.

Understand the difference between CSMA/CD and CSMA/CA. Know the differences between access methods and that they can either detect or attempt to avoid collisions. Also understand that IEEE 802.11 wireless networks use distributed coordination function (DCF) mode as a contention method to send data.

Know the differences among various Physical layer wireless technologies, such as DSSS, HR/DSSS, OFDM, ERP-OFDM, and MIMO. The uses of Physical layer technologies vary depending on RF, applications, and desired data rates. Understand the standard or amendment each Physical layer technology uses as well as advantages and disadvantages of each, including co-location and interference.

Understand that co-location of WPAN and WLAN devices may cause interference and affect performance. WPAN and WLAN devices might be co-located in the same RF space. Know the potential impact of co-location on performance and other factors. Some WPAN and WLAN devices use the same frequency and spread-spectrum technology. Understand that this can cause interference.

Review Questions

1. IEEE 802.11a/b/g/n/ac devices use what type of communication?
   - **A.** Half-diplex
   - **B.** Full-diplex
   - **C.** Half-duplex
   - **D.** Full-duplex

2. HR/DSSS devices operate in which frequency range?
   - **A.** 2.400 GHz ISM
   - **B.** 5.250 GHz UNII
   - **C.** 5.350 GHz UNII
   - **D.** 5.750 GHz UNII
   - **E.** 5.725 GHz ISM

3. How many access points can be co-located without channel reuse in the same RF area to maximize total system throughput while minimizing RF interference in an IEEE 802.11g/n network?
   - **A.** Two
   - **B.** Three
   - **C.** Four
   - **D.** Six

4. Devices compliant with which two amendments to the IEEE standard use multiple radio chains and multiple antennas? (Choose two.)
   - **A.** 802.11a
   - **B.** 802.11b
   - **C.** 802.11g
   - **D.** 802.11n
   - **E.** 802.11/ac

5. What technology is used to send WLAN data over a wireless medium using many subcarrier frequencies?
   - **A.** Wireless broadband
   - **B.** Narrowband
   - **C.** Spread-spectrum
   - **D.** Spectral masking
   - **E.** Wideband

6. Which two channels could be used so that the access points do not interfere with each other in an 802.11g/n wireless network? (Choose three.)
   - **A.** Channel 1 and channel 5
   - **B.** Channel 3 and channel 9
   - **C.** Channel 6 and channel 11
   - **D.** Channel 2 and channel 8
   - **E.** Channel 4 and channel 7

7. Which network access method attempts to avoid collisions?
   - **A.** CSMA/CA
   - **B.** CSMA/CD
   - **C.** CSMA/CR
   - **D.** CSMA/DSSS

8. DSSS uses which spreading code at 1 Mbps?
   - **A.** Barker
   - **B.** CCK
   - **C.** DBPSK
   - **D.** DQPSK

9. FM radio stations use what type of RF communication?
   - **A.** High power, narrow bandwidth
   - **B.** High power, wide bandwidth
   - **C.** Low power, narrow bandwidth
   - **D.** Low power, wide bandwidth

10. An HR/DSSS channel is how wide?
    - **A.** 1 MHz
    - **B.** 5 MHz
    - **C.** 20 MHz
    - **D.** 22 MHz
    - **E.** 40 MHz

11. Bluetooth devices use _____, which can potentially cause interference with WLANs.
    - **A.** Bluetooth spread spectrum (BTSS)
    - **B.** Orthogonal frequency division multiplexing (OFDM)
    - **C.** Direct-sequence spread spectrum (DSSS)
    - **D.** Frequency-hopping spread spectrum (FHSS)

12. OFDM that is used with 802.11a and 802.11g stations (STA) supports a maximum data rate of _____ Mbps.

A. 11

B. 22

C. 33

D. 54

13. Which WLAN technology can be used to obtain the highest data transfer rate possible?

A. DSSS

B. Ethernet

C. HT-OFDM

D. OFDM

14. Which frequency ranges are used in an IEEE 802.11a-compliant WLAN? (Choose two.)

A. 900 MHz ISM range

B. 2.40 GHz ISM range

C. 5.25 GHz UNII range

D. 5.35 GHz UNII range

15. Stations (STA) operating in which two IEEE 802.11 amendments are interoperable?

A. 802.11 and 802.11a

B. 802.11a and 802.11b

C. 802.11a and 802.11g

D. 802.11b and 802.11g

16. Without any regulatory domain taken into consideration, the 2.4 GHz frequency range allows for how many channels using 802.11b/g/n?

A. 3

B. 6

C. 11

D. 14

17. OFDM uses which communication channel width to exchange data?

A. 1 MHz–wide channel

B. 20 MHz–wide channel

C. 22 MHz–wide channel

D. 80 MHz–wide channel

18. What is the maximum data rate of HR/DSSS 802.11b devices?

A. 5.5 Mbps

B. 11 Mbps

C. 24 Mbps

D. 54 Mbps

19. Which IEEE 802.11 PHY technology specifies an 80 MHz–wide channel for transmitting and receiving data?

A. DSSS

B. OFDM

C. VHT-OFDM

D. ERP-OFDM

20. Which WLAN technology in wireless networking uses the effects of multipath to provide data rates of 600 Mbps in the 2.4 GHz ISM band?

A. OFDM

B. HR/DSSS

C. HT/DSSS

D. MIMO

Chapter

8

Security Fundamentals for Wireless Networking

THE FOLLOWING CWTS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **6.1 Identify and describe legacy WLAN security technologies**
- ✓ **6.2 Understand the basic operation of and implementation best practices for WLAN security technologies**
- ✓ **6.3 Understand the basic functions and implementation best practices for WLAN security technologies**

THE FOLLOWING CWS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **2.5 Explain the basic differences between WPA and WPA2 security**
- ✓ **3.1 Identify AP features and capabilities**
- ✓ **4.8 Match organizational goals to WLAN features and functions**

THE FOLLOWING CWT EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **2.3 Describe the basic steps required in the WLAN connection process**
- ✓ **4.1 Understand the basics of 802.11 standard security solutions**
- ✓ **4.2 Identify legacy security technologies that should not be used**
- ✓ **4.3 Configure security parameters in an AP**
- ✓ **4.4 Configure security parameters in a client device**

Security in many ways means defining your level of acceptable risk and protecting yourself to at least that level. This can vary greatly based on industry, budget, and the types and ages of devices supported. Security is a very important part of wireless networking, just as it is in any other type of computer networking or information technology. When the IEEE 802.11 standard was first ratified back in 1997, it addressed a basic security concept called *Wired Equivalent Privacy* (WEP). However, this security solution was considered weak and was easily compromised early on. In this chapter, we will look at some of what are considered legacy wireless LAN (WLAN) security technologies used with standards-based wireless networking, including the following:

- Service set identifier (SSID) hiding
- Media access control (MAC) address filtering
- Wired Equivalent Privacy (WEP)

We will also take a look at some of the vulnerabilities of these legacy technologies and why they should not be used for securing a WLAN. You will learn about some of the newer security methods available based on the IEEE 802.11i amendment and included in the IEEE 802.11-2016 standard. These security methods are also part of the Wi-Fi Alliance certifications, WPA and WPA 2.0. We will explore small office/home office (SOHO) security solutions and enterprise-level security solutions. These include the following:

- Preshared key/passphrase
- User-based authentication
- IEEE 802.1X/EAP
- Remote Access Dial-In User Service (RADIUS)
- Authentication, authorization, and accounting (AAA)

In Chapter 2, "Wireless Local Area Networking, Standards, and Certifications," we discussed some of the certifications available from the Wi-Fi Alliance that pertain to WLAN security. This chapter will explore further some of the concepts of passphrase, preshared key, and 802.1X/EAP. Also explained will be encryption methods such as Temporal Key Integrity Protocol (TKIP) and Cipher-Block Chaining Message Authentication Code Protocol (CCMP), which are ways to scramble computer data and are used with WLANs. One thing that is often overlooked is security from a remote location, such as a wireless hotspot. In this chapter, you will learn about virtual private networking (VPN) solutions and how they can be used to secure wireless connections for users connecting to the corporate network from a remote wireless network. Wireless intrusion prevention systems

(WIPS) are also part of the technology used in today's WLAN world. If a WIPS is implemented correctly, it can provide a wealth of information as well as protection for your network infrastructure and wireless devices. Finally, we will look at basic functions and implementation best practices for role-based access control (RBAC), captive portals, and network management and monitoring systems.

Introducing IEEE 802.11 Wireless LAN Security

The importance of computer network security is often underestimated, and WLAN security is no different. "I don't understand why I need to secure my access point." "I don't have anything on my computer that would be of interest to anyone else." "I tried to enable security on my wireless but couldn't get it to work, so I just turned it off." These are some of the common excuses many technical support engineers or consultants heard from people when it came to wireless security. In the early days of IEEE 802.11 wireless networking, security was weak. This led to much vulnerability, which in turn made wireless networking not a very attractive solution for many enterprise deployments, especially those concerned about security.

With the improvements in standards-based WLAN security, partly thanks to the Wi-Fi Alliance certifications as well as the IEEE 802.11i amendment to the standard, WLANs have become a major part of many enterprise networks in all industries and businesses. Because wireless networks are inherently unbounded, it is possible to have more security protecting wireless communication than what is used to secure most wired LANs. This is the case in many WLAN implementations.

Wireless LAN Threats and Intrusion

Computer networks have always been the target of various types of intrusion techniques. Wireless networks are no different—in fact, wireless networks are more vulnerable to intrusion because the communication is not bounded by any physical media, such as an Ethernet cable. This key vulnerability in wireless networking is the use of the air, a shared unbounded medium. The level of security applied to a wireless network will depend on the following factors:

- What are you trying to protect?
- What are you trying to prevent?

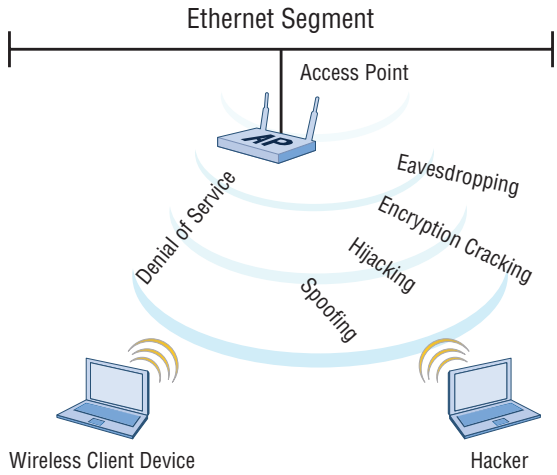
There are many security concerns related to wireless networking. Some of these concerns arise because WLANs use radio frequency (RF) for communication and the open air as the

medium. Others are a threat to either wired or wireless networks. The following list identifies some of these concerns and threats:

- Eavesdropping
- RF denial-of-service (DoS) attacks
- Media access control (MAC) address spoofing
- Hijacking
- Man-in-the-middle attacks
- Peer-to-peer attacks
- Encryption cracking

Although many of these threats or methods of intrusion are common, advanced security solutions such as wireless intrusion prevention systems (WIPS) are available to help discover and mitigate some of them. Figure 8.1 illustrates some of the vulnerabilities with wireless networking.

FIGURE 8.1 WLANs are subject to many potential security threats.



Real World Scenario

Locking the Door of Your Automobile

Let's take a quick look at an analogy that may make network security easier to understand. You need to run some errands on a Saturday afternoon and decide to go to the market to pick up some supplies. When you arrive at your destination, you leave your automobile but do not lock the door. Who could potentially enter your vehicle? The

answer is anybody who attempts to open the door. Locking the door of your vehicle will prevent the casual intruder from being able to enter through the door. Therefore, the lock on your door is one layer of security that could be used to prevent a potential intruder from entering your vehicle.

So, with the door locked, now who could potentially get into your vehicle? The answer is two different individuals: first, you (because you have the key to the door); second, a potential intruder who could compromise the lock on the door. As you can see, locking the door provides a layer of security and will prevent the casual intruder from entering your vehicle, but it will not prevent a determined intruder.

Now let's add a second layer of security. In addition to locking the door you set an alarm on your vehicle. You now have two layers of security: the door lock and the alarm. For an intruder to gain access to your vehicle, they would now need to have the knowledge and the ability to overcome two layers of security. First, they would need the ability to compromise the lock on the door, and then they would need the knowledge to disable the alarm, both without being noticed. The number of potential intruders has decreased significantly, from those who can just open the unlocked door to those who have the knowledge to not only compromise the door lock but also disable the alarm.

IEEE 802.11 Standard Security

Even though WLAN security has greatly increased over the years, it is important to understand the original IEEE 802.11 standard as it relates to WLAN security. It is important to be aware of some of the basics or building blocks prior to getting into more sophisticated areas of security. From a security viewpoint, the original standard addressed two areas of security: authentication and data privacy. Both of these are common components of computer network security. In computer networking, *authentication* is defined as a way of confirming an identity; basically, it determines that you are who you say you are. Data privacy is ensuring that information or data is understandable only by the individuals or groups it is intended for, the sender and the intended receiver.

One way many people may think of authentication is to supply a username and password in order to log onto a computer. Another would be to supply the appropriate logon before performing an activity like Internet banking. To review from Chapter 6, "Communication for Wireless Networking," the original IEEE 802.11 standard addresses two types of authentication: IEEE 802.11 open system authentication and IEEE 802.11 shared-key authentication. IEEE 802.11 authentication is performed by the WLAN protocol and, except for IEEE 802.11 shared-key authentication, does not require user intervention. It is important not to confuse IEEE 802.11 shared-key authentication with preshared-key authentication, as defined in the IEEE 802.11i amendment to the standard.

IEEE 802.11 Open System Authentication

To review from Chapter 6, open system authentication is a two-step process, a two-frame exchange, and is one of the simplest ways to provide an authentication process. IEEE 802.11 open system authentication cannot fail except for circumstances such as a network adapter having a bad device driver. This authentication is what is known as a *null authentication*, which for the most part means it doesn't really authenticate anything at all. For example, if a wireless client device such as a notebook computer wants to join the wireless network, it will "ask" the access point if it can authenticate, and the access point will always accept.

IEEE 802.11 Shared-Key Authentication

Also discussed in Chapter 6, IEEE 802.11 shared-key authentication is a four-step process, not to be confused with IEEE 802.11i, WPA, or WPA2 personal mode, which uses a 256-bit preshared key for authentication. The main difference between IEEE 802.11 open system and IEEE 802.11 shared-key authentication is that with shared-key authentication, WEP is required in order for it to function correctly. This is because IEEE 802.11 shared-key authentication uses WEP for both 802.11 authentication and for data payload encryption. But WEP is not secure, so it makes shared-key authentication weak and vulnerable to intrusion. WEP was intended only to protect wireless network users against casual eavesdropping and for authentication that is used with shared key.

Early Wireless LAN Security Methods

Because of the way security was defined in the original IEEE 802.11 standard, manufacturers of WLAN equipment were able to design different ways a user could secure a WLAN. But even though these methods looked good on paper, they did not do much to provide a good security solution. This section discusses the following common WLAN security methods and legacy security solutions:

- Service set identifier (SSID) hiding (closed network)
- Media access control (MAC) address filtering
- Wired Equivalent Privacy (WEP)

If some of these are considered legacy WLAN security methods, why is it important to discuss them? You need to understand these solutions because there are still some wireless network implementations that may use some or all of them as part of a wireless security solution. Because standards-based WLAN technology has been around for two decades, many early adopters had no choice but to use these security techniques. Over the years, WLAN security has improved tremendously; however, it is a fact that some of these early adopters still have legacy wireless devices that will not support the latest and greatest security technology, such as WPA2. Therefore, these solutions may still currently play a role in the wireless network infrastructure.

The Service Set Identifier

As you'll recall from Chapter 6, the service set identifier (SSID) is a logical name for the wireless network and was designed to be used for wireless device segmentation. The SSID allows WLAN-capable devices to identify and connect to a WLAN using the discovery phase, which includes the passive and active scanning processes. There are a couple of ways this connection can be accomplished. Passive scanning occurs when the wireless client device listens for beacons frames. The SSID is specified in a beacon frame in the SSID information element. As discussed in Chapter 6, the beacon frame is an advertisement of the wireless network. The beacon frame by default is set to broadcast at about 10 times a second. The beacon frame will advertise the SSID of the wireless network during this interval.

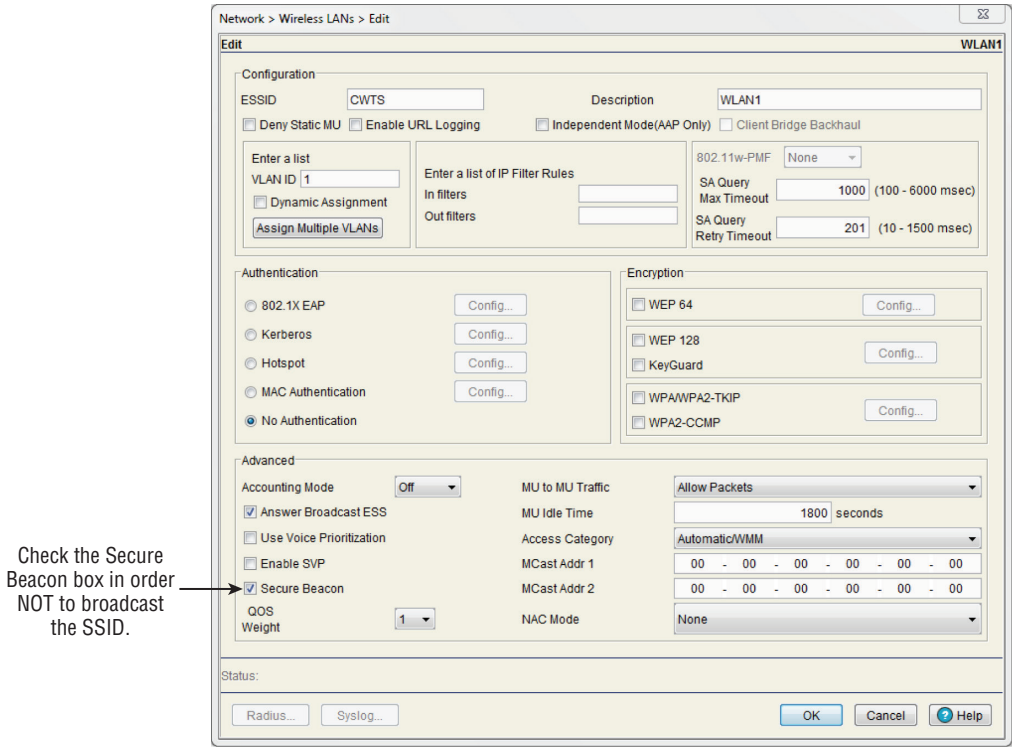
You can specify that the SSID of the WLAN be joined in the wireless client software utility of the connecting wireless device. In this case, a wireless client will send a probe request frame with the intent of joining that particular network. The IEEE 802.11 standard requires access points to respond to all probe requests that have a matching SSID or what is known as a *wildcard SSID* (an SSID with a value of 0), also referred to as a *null SSID*. A wildcard SSID is used when a client device does not specify the SSID in the wireless client software utility. If a wireless client device is scanning or looking for a wireless network to join, it will see the wireless network because the beacon frame is broadcasting the SSID. Most manufacturers of SOHO and enterprise access points provide the option not to broadcast the SSID in beacon frames. This is commonly known as disabling the SSID broadcast, SSID hiding, or a closed network, and is discussed in the next section.

SSID Hiding

Manufacturers of IEEE 802.11 WLAN equipment provide the capability to disable SSID broadcasting, as shown in Figure 8.2. Another term for this process is *SSID hiding*. SSID hiding allows a user to remove the SSID that would normally appear in broadcast beacon frames. If the SSID is not being broadcast, the wireless network will not be seen by the wireless client devices that do not have that wireless network's SSID specified in their client software utility. If somebody knows the SSID, they would be able to enter it into their wireless client device software and then be able to connect to the wireless network.

In the early days of wireless networking, people would hide the SSID, believing that would secure the network because it was not visible to devices passively scanning for a network to join. This was a misconception, because even though the SSID is not being broadcast in these beacon frames, it can still be identified in other wireless frames, such as the probe request frames, probe response frames, association request frames, and re-association request frames. This means that anyone with a wireless scanning utility, such as a packet analyzer, would be able to determine the SSID of a wireless network by monitoring the frames that are sent through the air. Therefore, hiding the SSID should *not* be used as a way to secure a wireless network.

FIGURE 8.2 A WLAN controller allowing you to disable SSID broadcast



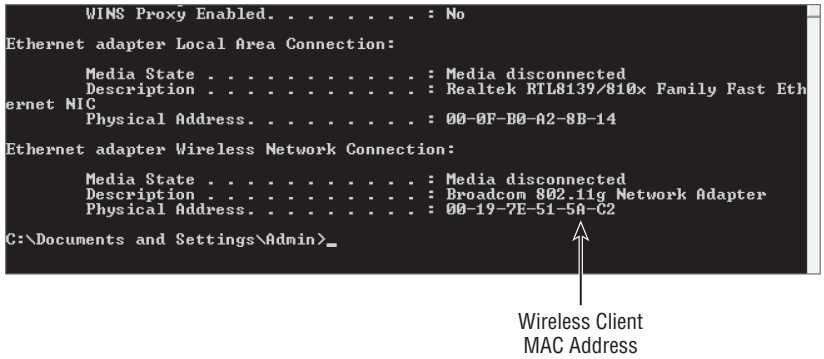
Check the Secure Beacon box in order NOT to broadcast the SSID.

Hiding the SSID is sometimes used to prevent the wireless network from being seen by those who should not be connecting to it. Many organizations will hide the SSIDs of all the wireless networks except for the open guest network. This is sometimes done to help reduce unnecessary technical support calls from someone who may try to connect to a WLAN that they do not have access to. However, this method is not intended to secure the wireless network.

The Media Access Control Address

To review, the media access control (MAC) address is a unique hardware identifier of a computer network device. This 6-byte address is the Layer 2 address that allows frames to be sent to and received from a device. Figure 8.3 shows the MAC address of a wireless network adapter viewed with `ipconfig.exe`. An important point here is that the MAC address is unique, and no two network devices should ever have the same Layer 2 MAC address. In a wireless network, MAC addresses are easily visible to anyone using a wireless packet analyzer or wireless network scanning software utility. These addresses are required for a network device to send and receive information; therefore, they cannot be encrypted and are visible to anyone with the knowledge to view them.

FIGURE 8.3 The Windows command-line utility `ipconfig.exe` will display MAC addresses.



MAC Address Filtering

Since IEEE 802.11 WLAN device technology operates at the lowest two layers of the OSI model, the Physical layer and the Data Link layer, the MAC address plays a big role in wireless networking. Manufacturers of WLAN equipment provide a feature known as *MAC address filtering*. Its purpose is to either allow or disallow access to the wireless network by restricting which MAC addresses can IEEE 802.11 authenticate and associate to a wireless network. Figure 8.4 is an example of how to apply a MAC address filter on an access point.

FIGURE 8.4 A MAC address filter table on a SOHO access point

This looks great on paper but is a weak security feature, because it can be easily compromised. Remember, wireless networks use the air as their access medium to communicate, and RF is what exchanges the information between devices. So if someone were to monitor the air with a tool such as a wireless packet analyzer or wireless scanning utility software program, they would be able to see all the wireless traffic within hearing range of their wireless device. Because WLAN devices communicate with each other using MAC addressing, all of these addresses would be visible to whoever wants to see them.

MAC Address Spoofing

Because MAC addresses are visible to anyone who wants to take the time to see them by using the correct software utility, they create a potential problem for those who implemented MAC address filtering. An intruder can easily perform a task called *MAC address spoofing*. This involves tricking the wireless device into thinking its unique MAC address is something other than what is encoded in the actual network card.

There are several ways for an intruder to accomplish MAC address spoofing. It can be done with software programs, such as SMAC, or within the computer operating system—for example, in the Microsoft Windows Registry. All options and configuration settings in the Windows operating system are stored in this hierarchical database known as the *Windows Registry*. If someone wanted to spoof the MAC address of a wireless network adapter using this database, they might (depending on the adapter) be able to enter a new MAC address value in the device driver's configuration, which would then be stored in the Windows Registry. Another option is to change the Windows Registry value directly using the Registry Editor tool built into Windows. This would be considered a modifiable MAC address. MAC addresses may also be stored in a configuration file, and in nonvolatile memory. Keep in mind that changing the MAC address in the Registry or in a configuration file changes only the software reference that the operating system sees and uses. It does not change what is known as the *burned-in address* (BIA) or the *hard-coded address*, which is unmodifiable.

IEEE 802.11 Authentication and Data Encryption

Authentication is defined as validating an identity. Authentication also gives the capability to control access to a system. In the original IEEE 802.11 standard, this is accomplished by using either IEEE 802.11 open system or shared-key authentication. Since open system authentication is a null authentication method and, except for special circumstances, cannot fail, the wireless device will always authenticate. IEEE 802.11 shared-key authentication, on the other hand, uses WEP for wireless device authentication as well as for data payload encryption. Encryption is the process of modifying information from its original

form to make it unreadable except by those who know the technique or the method in which the data was modified. In the original IEEE 802.11 standard, data encryption was accomplished by using WEP. In order for a device to pass information across an access point, it must first IEEE 802.11 authenticate and then associate.

About Wired Equivalent Privacy

From a security perspective, one major drawback to any wireless network is the fact that all information, including data payload, travels through the air from one device to another. This makes WLANs vulnerable to eavesdropping and inherently less secure than bounded networking using other networking technology, such as Ethernet. With IEEE 802.11 open system authentication, all information is broadcast through the air in plain text after a connection to the wireless access point is created. This means that anyone with knowledge of how to use a wireless packet analyzer or other wireless scanning software program can easily see all the information that is passing between devices through the air.

WEP was designed as a way to protect wireless networking from casual eavesdropping. The original IEEE 802.11 standard states that the use of WEP is optional. The manufacturer supplies the capability, but it was up to the user of the wireless device to implement it.

In WLANs, WEP can be used in one of two ways: with IEEE 802.11 open system authentication to encrypt the data only or with shared-key authentication, which is used for wireless device authentication and for data encryption. The original standard specified only 64-bit WEP, which consists of a 40-bit key plus 24-bit WEP initialization vector (IV).

How Wired Equivalent Privacy Was Used

WEP was fairly simple to implement. It requires all wireless devices to have the same WEP key. The WEP key can be either 64-bit or 128-bit; however, the standard required only 64-bit WEP. One disadvantage to WEP is that it uses static keys, which means all wireless devices—access points, bridges, and client stations—must have the same key and the key must be manually entered into them. Any time the key is changed, it must be changed on all the wireless devices that are on the same SSID. No matter which you use, 64-bit WEP or 128-bit WEP, you are still only using a 24-bit IV. 64-bit WEP uses a 40-bit secret key and a 24-bit IV. 128-bit WEP uses a 104-bit secret key but still only the 24-bit IV, making both vulnerable to the same attacks. Gathering a number of these IVs allows an attacker to crack your key in very little time.

Some governing bodies no longer allow the use of WEP. Payment Card Industry (PCI), for example, no longer allows the use of WEP for securing wireless networks. If you are still using WEP, it should be a high priority to move away from this legacy security technology as quickly as possible.

Table 8.1 describes the characteristics of the two types of WEP keys.

TABLE 8.1 Characteristics of the two types of WEP keys

Key Length	Number of ASCII Characters	Number of Hex Characters
64-bit	5	13
128-bit	10	26

One major disadvantage of using WEP is that it was compromised early on and is therefore not secure. It is easy to capture data using a wireless packet analyzer; with a little knowledge and correct software utilities, cracking a WEP key is a simple feat. This made WEP a weak security solution, but it was pretty much the only solution available at the time of early IEEE 802.11 wireless networking.

With today's newer and more sophisticated software tools and technology, WEP can be cracked easily and quickly. WEP will be discussed in more detail in the section "IEEE 802.11 Encryption Methods" later in this chapter.

IEEE 802.11 SOHO and Enterprise Security Technologies

The IEEE 802.11i amendment to the standard provided much improvement in the ways WLANs can be secured. Enterprise-based WLANs are now capable of the most up-to-date security solutions available in the industry. This amendment to the standard introduced what is known as the *Robust Security Network* (RSN). In order for WLAN equipment to create an RSN, it must be RSN capable or 802.11i compliant, which means it will optionally support Temporal Key Integrity Protocol (TKIP) and it must also support Counter Mode with Cipher-Block Chaining Message Authentication Code Protocol (CCMP). The Wi-Fi Alliance released several certifications that pertain to wireless networking: WPA and WPA 2.0 for SOHO and enterprise deployments, and WPS for the home user.

The following section discusses Wi-Fi Protected Setup (WPS). This topic is not included in the exam objectives but is explained here for your reference.

Wi-Fi Protected Setup PIN-Based or Push-Button Configuration Wireless Security

Many manufacturers of SOHO-grade WLAN equipment have adopted either PIN-based or push-button wireless security. Both of these solutions simplify the process of securing a

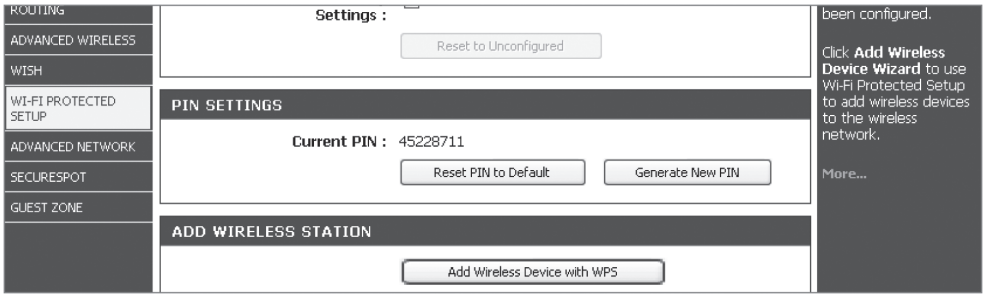
wireless network either for the SOHO environment or for home-based users. As discussed in Chapter 2, the Wi-Fi Alliance has branded a certification for push-button and PIN-based security called *Wi-Fi Protected Setup*. The Wi-Fi Protected Setup certification (WPS) addresses both of these solutions.

In December 2011 a security flaw was reported with WPS. This allegedly allowed an intruder to recover the personal identification number (PIN) used to create the 256-bit preshared key. Disabling certain features or a firmware update may be available to provide adequate protection. Keep in mind that these solutions to the issue may only be possible with newer-model wireless routers. You should check with the manufacturer to determine if a solution (either a software setting or firmware upgrade) is available for a specific device.

PIN-Based Security

Personal identification number functionality is required in order for a wireless device to be WPS certified. PIN-based security requires a unique PIN to be entered on all devices that will be part of the same secure wireless network. A PIN will come as either a fixed label or sticker on a device, or it can be dynamically generated in the setup utility and shown on the computer screen. It is important to understand the difference between a PIN and a passphrase, password, shared key, or preshared key. A PIN is a number; the acronym spelled out means "personal identification number." Therefore, a PIN will consist only of numbers. Passphrases and the others may contain combinations of numbers, letters, and special characters. The registrar device in the case of a WLAN is the access point. The access point will detect when a new wireless device that supports WPS is in radio range. When this device tries to join the network, the registrar will prompt the user to enter the unique PIN. Once the PIN is entered, the process authenticates the device and encrypts the network data sent to and from the device. Figure 8.5 shows an example of PIN-based wireless security.

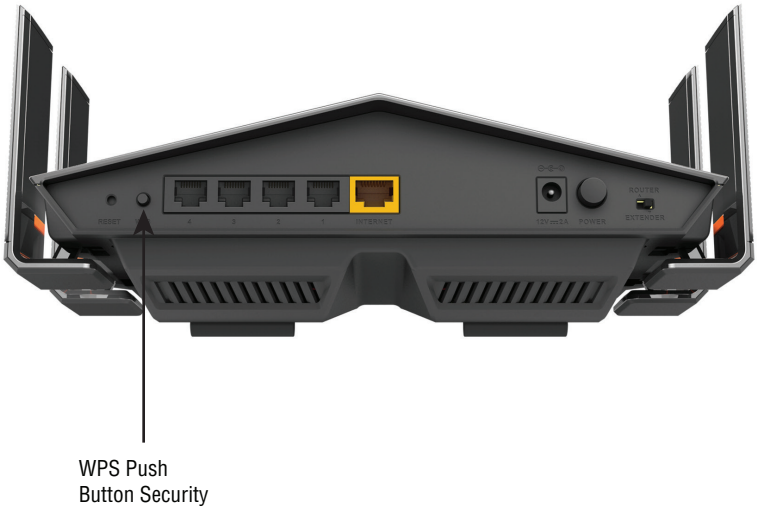
FIGURE 8.5 SOHO wireless access point with PIN-based security



Push-Button Configuration Security

Push-button security or push-button configuration (PBC) allows users to configure WLAN security with "the push of a button," making setting up wireless security a simple process. When a user pushes a hardware button on the wireless router and clicks a software button in the software utility for the network adapter installed in the client device wanting to associate, push-button security creates a connection between the devices, configures the network's SSID, and turns on security. This allows a secure connection among all devices that are part of the wireless network. Figure 8.6 shows an example of WPS push-button security.

FIGURE 8.6 D-Link wireless router with push-button security



In order to use push-button security, all devices—including the wireless router and the wireless client adapters—must support the feature. First a button is pushed on the wireless router; then a button (a software setting in the wireless client utility) is clicked on the wireless device(s). Usually in less than a minute the process is complete and all devices have a secure connection. Only those devices that are within RF hearing range and are participating in the process will become part of the secure network.

Support for both PIN and PBC configurations is required for access points; client devices at a minimum must support PIN. A third, optional method, near field communication (NFC) tokens, is also supported. A USB flash drive (memory card or solid-state storage drive with a USB interface) may be used to store and transfer credentials. Many SOHO equipment manufacturers have WPS-certified devices on the market today. Some include the following:

- Belkin
- Broadcom
- D-Link

- Linksys
- Netgear
- TRENDnet
- ZyXEL

For these and other manufacturers that support WPS, visit the Wi-Fi Alliance website at `www.wi-fi.org`.

Wi-Fi Protected Access and WPA2 Personal Security

Passphrase-based security was designed with the SOHO or home-based user in mind. This type of security allows a user to create a very secure WLAN solution without the experience or knowledge necessary to configure enterprise-level components such as an 802.1X/EAP and a RADIUS server. Passphrase-based security requires all wireless devices that are part of the same wireless network to have the same 256-bit preshared key (PSK) in order to securely communicate. The capability to derive a secure key of this length would be a daunting task; to ease the burden of having to create a long secure key, the passphrase was introduced. This works by requiring the user to enter a strong passphrase on all wireless devices that are part of the same WLAN to be secured. The benefit of a passphrase is it can be a sequence of words or other text that is memorable only to the user who created it. After the passphrase is entered into the device, with the help of an electronic algorithm from the IEEE 802.11i amendment, it will create a 256-bit preshared key.

Passphrase Characteristics

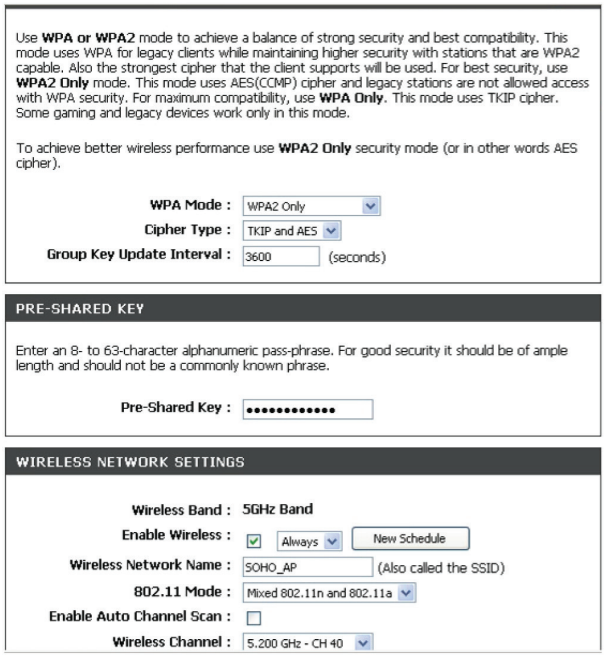
The characteristics of the passphrase are as follows:

- It consists of 8 to 63 ASCII (case sensitive) or 64 hexadecimal characters.
- It creates a 256-bit preshared key.
- The longer and more random the passphrase, the more secure it will be.
- Weak passphrases can be compromised.

Several software programs and websites have random password generators to aid in the generation of strong passphrases. One such website is Gibson Research Corporation. Their Ultra High Security Password Generator can be found at `www.grc.com/passwords.htm`.

Figure 8.7 shows how to configure a passphrase on a SOHO access point.

FIGURE 8.7 D-Link wireless access point preshared key passphrase settings



WPA and WPA2 Enterprise Security

Concerned about problems connected with MAC address filtering and WEP, the industry drove the development of additional, improved wireless security solutions. One of these solutions also operates at Layer 2 and is an IEEE standard. This advanced enterprise-level solution is known as *IEEE 802.1X* (also called *user-based security*). User-based security allows an administrator to restrict access to a wireless network and its resources by creating users in a centralized database. Anyone trying to join the network will be required to authenticate as one of the users by supplying a valid username and password. After successful authentication, the user will be able to gain access to resources for which they have permissions. This type of mutual authentication is more secure than the previously mentioned passphrase security method.

IEEE 802.1X/EAP

IEEE 802.1X/EAP consists of two different components used together to form an enterprise computer network security solution. IEEE 802.1X/EAP is defined in the IEEE 802.11-2016 standard but was originally part of the IEEE 802.11i amendment. We'll first discuss the IEEE 802.1X standard and then Extensible Authentication Protocol (EAP). Then we'll combine the technology and terms to form IEEE 802.1X/EAP.

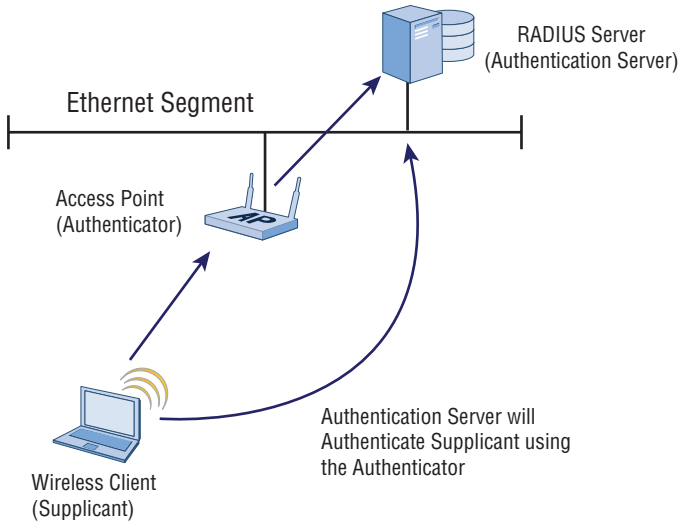
IEEE 802.1X

IEEE 802.1X is a port-based access control method designed to work with IEEE 802.3 Ethernet wired networks. However, this standard was adapted into the wireless world as an alternative, more powerful solution to legacy 802.11 WLAN security technologies. Wireless devices that use 802.1X technology are identified using different terminology from that used in IEEE 802.11 standards-based wireless networking:

- Supplicant (wireless client device)
- Authenticator (wireless access point)
- Authentication server (RADIUS or AAA)

Figure 8.8 illustrates the 802.1X/EAP process for a WLAN.

FIGURE 8.8 WLAN client authenticating to a RADIUS server using IEEE 802.1X/EAP



Supplicant The supplicant is another name for the wireless client device attempting to connect to the wireless network. This typically is the software security component of the wireless client device and the IEEE 802.1X terminology.

Authenticator The authenticator is the IEEE 802.1X term for the wireless access point or WLAN controller. The authenticator acts as a middleman between the wireless supplicant and the authentication server. When the supplicant requests to join the wireless network, the authenticator passes the authentication information between the two devices.

Authentication Server The term "authentication server" is used by the IEEE 802.1X standard to identify the server that will authenticate the wireless supplicant. The authentication server receives all information from the authenticator. The authentication server may be an AAA or a RADIUS server; both are explained later in this chapter.

Extensible Authentication Protocol

IEEE 802.1X is a framework that allows for an authentication process. The authentication process used with IEEE 802.1X is *Extensible Authentication Protocol* (EAP). The IEEE 802.1X standard will employ some EAP type to complete this process. Many types of EAP that can be used with IEEE 802.11 WLANs are available in the industry. These vary from proprietary solutions to very secure standard solutions. Following are some popular examples of EAP types:

- EAP-TLS
- TTLS (EAP-MSCHAPv2)
- PEAP (EAP-MSCHAPv2)
- EAP-FAST

These and other EAP types allow a user to authenticate to a wireless network in several ways, including credentials such as username/password or certificate-based authentication.

The details of EAP and how it works are beyond the scope of the exam objectives. For more information, refer to other CWNP materials.

IEEE 802.1X and EAP Together: IEEE 802.1X/EAP

Now it is time to put these two parts together to form the IEEE 802.1X/EAP authentication process. This authentication process is typically used for enterprise-level security but can be and is sometimes used in smaller wireless installations. A variety of EAP types that work very well with IEEE 802.11 WLAN deployments are available. The EAP type chosen will depend on the environment in which the WLAN is used. EAP types vary in specifications, costs, and complexity. Figure 8.9 shows IEEE 802.1X/EAP configuration on a cloud-based wireless network management system.

Remote Authentication Dial-In User Service

Remote Authentication Dial-In User Service (RADIUS) is a networking service that provides centralized authentication and administration of users. RADIUS started as a way to authenticate and authorize dial-up networking users. A remote user would dial up to a network using the public switched telephone network (PSTN) and a modem. A modem from a modem pool on the receiver side would answer the call. The user would then be prompted by a remote access server to enter a username and password in order to authenticate. Once the credentials were validated, the user would then have access to any resources for which they had permissions. Figure 8.10 illustrates the remote access service authentication mechanism.

FIGURE 8.9 Aerohive HiveManager Online cloud-based IEEE 802.1X/EAP configuration screen

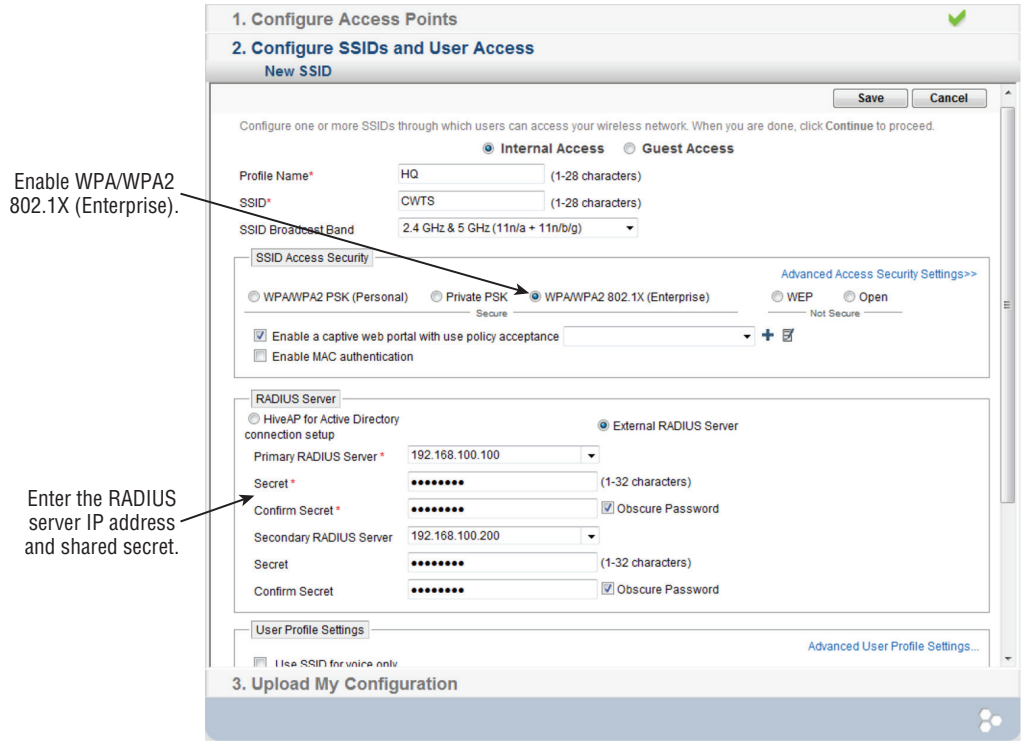
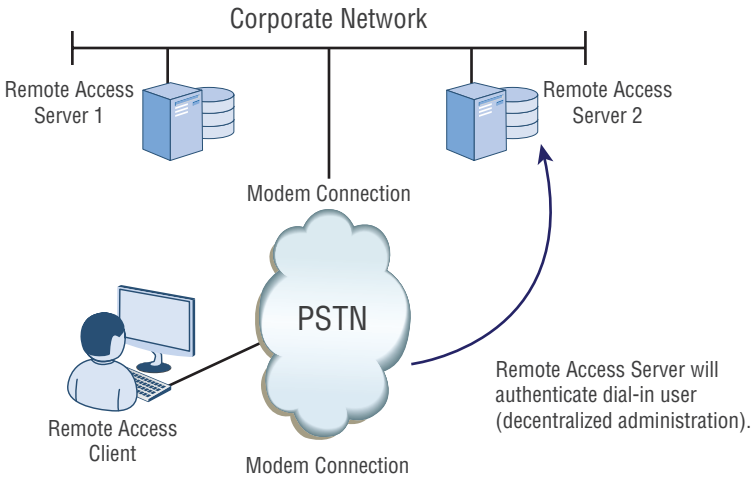


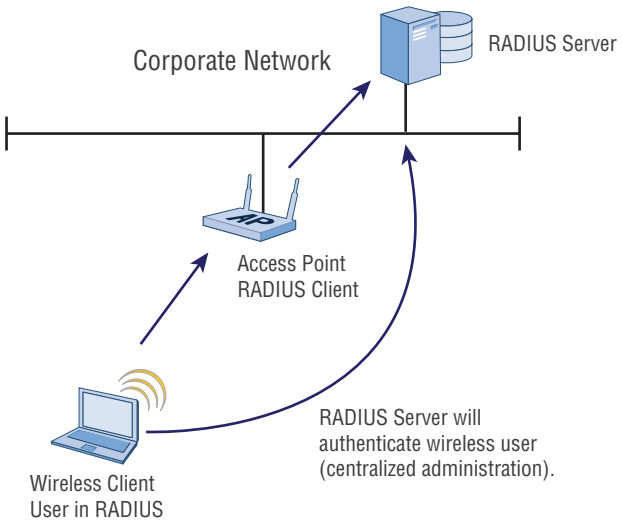
FIGURE 8.10 Remote user authenticating to a remote access server



In this example, the remote access client would be the computer dialing into the network, and the remote access server would be the one performing the authentication for the dial-up user. As computer networks grew in size and complexity and remote access technology improved, there was a need to optimize the process on the remote access server side. This is where RADIUS provides a solution. RADIUS combined decentralized remote access services databases into one central location, allowing for centralized user administration and centralized management. It eased the burden of having to manage several databases and optimized administration of remote access services.

A company does not need a large number of RADIUS servers. For a small to medium-sized company, one RADIUS server should be sufficient (with a backup, if possible). Larger enterprise organizations may need several RADIUS servers across the entire wide area network. In wireless networking, the wireless access point can act as a RADIUS client, which means it will have the capability to accept requests from wireless client devices and forward them to the RADIUS server for authentication. Figure 8.11 shows this configuration.

FIGURE 8.11 Wireless access point configured as a RADIUS client device



As Figure 8.11 shows, the remote access client is now the wireless access point. The wireless client device is authorized as a user in the database of the RADIUS server. The RADIUS server is the authenticating server or database. A RADIUS server may also be known as an authentication, authorization, and accounting (AAA) server. In this configuration, it will authenticate users and provide access to the resources for which they have permissions. In addition, it will keep track of all transactions by accounting.

Authentication, Authorization, and Accounting

The *Authentication, Authorization, and Accounting* (AAA) protocol provides a framework to allow secure access and authorization as well as keep track of the user's activities on a

computer network including wireless networks. AAA is commonly part of a RADIUS server's functionality. The three components that work together in the AAA protocol are:

- Authentication
- Authorization
- Accounting

The First Part of AAA—Authentication Authentication is defined as a way of confirming or validating an identity. Basically, it validates that you are who you say you are. Enterprise IEEE 802.11 wireless networks commonly use IEEE 802.1X/EAP or user-based authentication technology. In addition to username and passwords, wireless networks may also use other authentication methods, including digital certificates and smart cards, to name a few.

The Second Part of AAA—Authorization For wireless networking, authorization provides access to network resources that a wireless device or user has the appropriate permissions or rights to use. These permissions could be tied to an individual user object but can also be tied to a group object. After a user authenticates, the AAA protocol will then allow for the authorization process. Authorization can be on a per-user or per-group basis. In IEEE wireless networking technology, authorization is commonly used for WLAN functionality, including bandwidth controls, time restrictions/controls, and quality of service (QoS) policies.

The Third Part of AAA—Accounting Accounting is the last part or third "A" in the AAA protocol. Accounting will keep track of every place on the network a user visits or everything done on the network. Basically, it monitors all network activity. This can be used for something as simple as tracking resource usage for software or hardware upgrade purposes or for technology budgeting purposes. Accounting can be used to determine what technology different areas of the organization are using and how they will be able to contribute to the cost of this technology.

IEEE 802.11 Encryption Methods

In the most basic sense, encryption consists of taking information and scrambling it so only the sender and intended recipient that know the encryption method are able to decipher the encrypted information. In addition to authenticating and verifying an identity, encryption also needs to be considered for wireless networking. In the IEEE 802.11 standard, the following three encryption mechanisms could be used on a wireless network to protect data traffic:

- Wired Equivalent Privacy (WEP)
- Temporal Key Integrity Protocol (TKIP)
- Counter Mode with Cipher Block Chaining Message Authentication Code Protocol (CCMP)

Wired Equivalent Privacy

Wired Equivalent Privacy (WEP) was an optional encryption method specified in the original IEEE 802.11 standard. WEP was only intended to protect wireless network users against casual eavesdropping and for IEEE 802.11 shared-key authentication. As discussed previously, this encryption method is considered legacy and was compromised early on, making it a weak solution to use with modern wireless networks. With early deployments of standards-based wireless networking, WEP was the only solution available, which made it very popular. At that time, the capability to crack WEP was available, but that did not mean anyone could do it. Initially, cracking WEP required a large amount of data, some knowledge of the process, and usually a software program to extract the WEP key. Newer technology has made cracking WEP a simple process. WEP can be cracked in minutes rather than hours, days, or weeks, and almost anyone can do it. The fact that WEP is available in two key lengths—64-bit or 128-bit—makes no difference to the experienced intruder. WEP uses the RC4 stream cipher for bit-level encryption. The problem with WEP does not lie in RC4 but in how it was used in the encryption process. One reason WEP is vulnerable to intrusion is because of something called an *initialization vector* (IV). The 24-bit IV is broadcast in the clear or unencrypted. This being the case, it exposes a weakness in the way WEP was designed, thereby allowing it to be compromised.

Is WEP Still Used?

WEP is weak and its vulnerabilities can be cracked, so it is not a recommended solution to secure wireless computer data. Many countries have not fallen under PCI's scrutiny yet and still use WEP to protect wireless networks. Older voice over Wi-Fi phones and barcode scanners may still use WEP.

As a general rule, it is best not to use WEP as a security measure for protection of a wireless network and its users. However, there are still some deployments that use devices with wireless networking that have limited capabilities when it comes to security. WEP may be the only security option they have. If upgrading the devices to something that supports higher-level security is not an option, the organization may have no choice but to use WEP. If this is the case, it is important for the network administrator to use appropriate device segmentation for the WEP-enabled devices in order to not compromise the entire network infrastructure. One way to do this is to consider the use of a virtual local area network (VLAN). This enables the administrator to separate wireless devices that may be potentially compromised because of WEP from other devices that are capable of more advanced security solutions.

Many software programs are available to allow someone with limited knowledge to be able to crack WEP. Newer, more sophisticated tools allow WEP to be cracked in minutes. If a wireless network has the capability of more advanced security, such as 802.11i or WPA 2.0, one of those should be used instead of WEP. An appropriate device upgrade path should be evaluated in order to eliminate the use of WEP in any capacity on the wireless network.

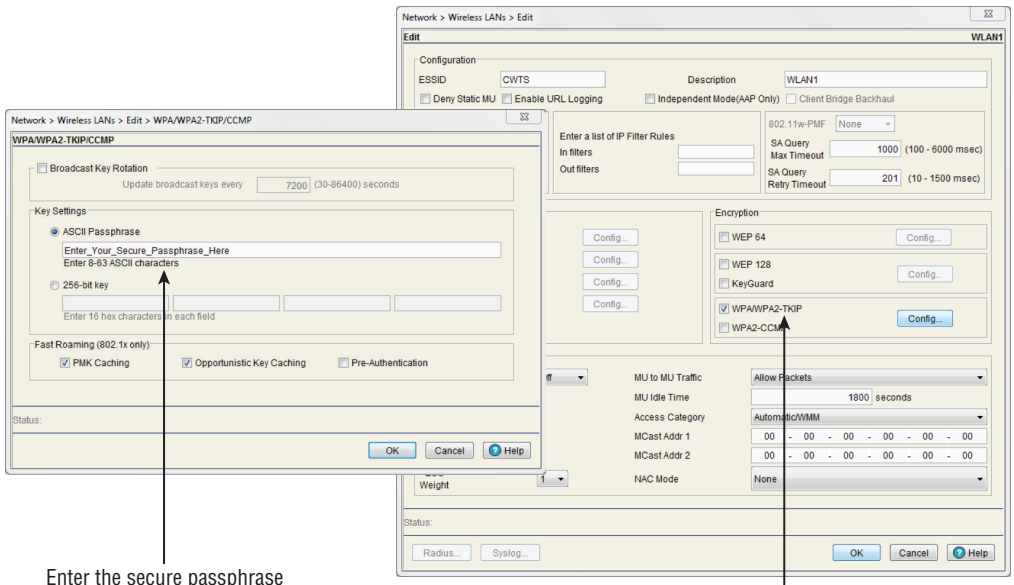
Temporal Key Integrity Protocol

Temporal Key Integrity Protocol (TKIP) was designed as a firmware upgrade to WEP. TKIP added several enhancements to the WEP algorithm and was the foundation for the Wi-Fi Protected Access (WPA) certification from the Wi-Fi Alliance. These enhancements include the following:

- Per-packet key mixing of the IV to separate IVs from weak keys
- A dynamic rekeying mechanism to change encryption and integrity keys
- 48-bit IV and IV sequence counter to prevent replay attacks
- Message Integrity Check (MIC) to prevent forgery attacks
- Use of the RC4 stream cipher, thereby allowing backward compatibility with WEP

Configuring a wireless network to use TKIP was a fairly straightforward process. It can be accomplished either by using the web interface available on most SOHO access points or by using the web interface or command-line interface for enterprise-level access points. For the wireless client devices, TKIP will be configured through the client software utility. Some older wireless hardware devices may not support TKIP. If this is the case, replacement of the hardware will be necessary in order to take advantage of newer security solutions. Figure 8.12 shows how to configure TKIP using WPA on a WLAN controller.

FIGURE 8.12 WLAN controller security configuration screen



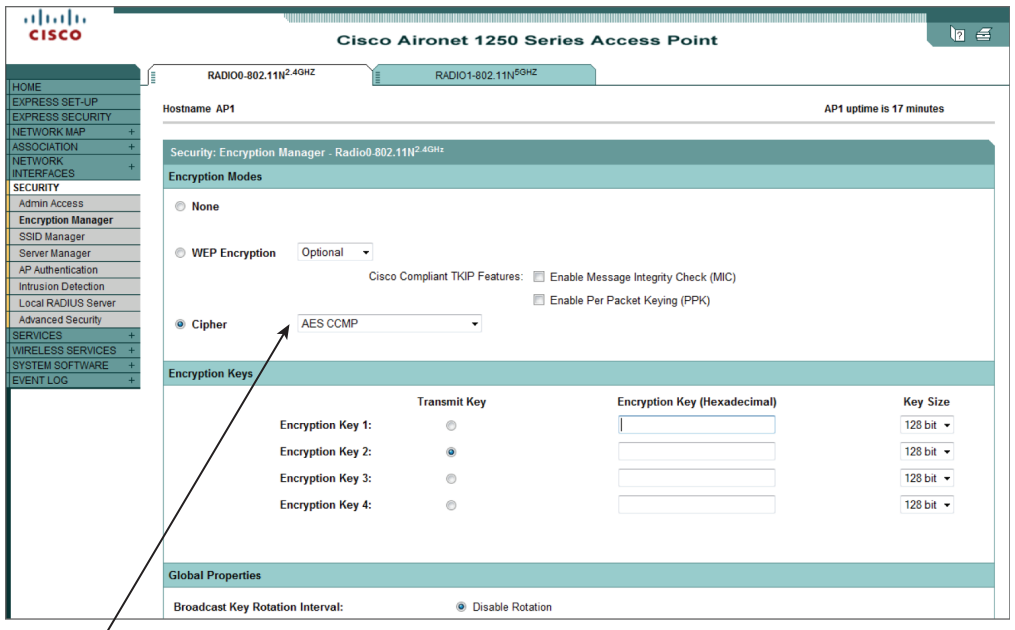
TKIP/RC4 uses a 48-bit IV and can be compromised in the same way as WEP if a weak key is used. Using a stronger technique such as CCMP/AES is a better solution. It is also important to note that if TKIP is implemented, IEEE 802.11n/ac MCS rates will not be utilized. In other words, the highest data rate achievable will be only 54 Mbps if TKIP is in use.

Counter Mode with Cipher Block Chaining Message Authentication Code Protocol

Counter Mode with Cipher Block Chaining Message Authentication Code Protocol (CCMP) is a mandatory part of the IEEE 801.11i amendment and is in the IEEE 802.11-2016 standard and part of Wi-Fi Protected Access 2.0 (WPA2) certification from the Wi-Fi Alliance. CCMP uses the *Advanced Encryption Standard* (AES) algorithm block cipher. CCMP is mandatory for RSN compliance. If an RSN is required to comply with an industry or governmental regulation, CCMP must be used. CCMP is also intended as a replacement to TKIP. Because of the strong encryption CCMP provides, it may require replacement of legacy hardware. In some cases, it may use a separate chip to perform computation-intensive AES ciphering.

Configuration of CCMP is similar to that of TKIP, discussed earlier. The main difference with CCMP is that older hardware may not support it and it is a stronger encryption solution. Figure 8.13 shows configuring the CCMP method using WPA2.

FIGURE 8.13 Wireless access point security configuration selection



Upgrading the Firmware on Wireless LAN Devices

In some cases, it may be necessary to upgrade the device firmware in order to get either TKIP or CCMP capability. It is important to follow the manufacturer's instructions when upgrading firmware to prevent damage to the device. Improper firmware upgrades or a loss of power during the upgrade process may render the device unusable or require the device to be sent back to the manufacturer for repair.

Some of the security technologies we just discussed are part of the Wi-Fi Alliance interoperability testing for standards-based WLAN equipment. As mentioned in Chapter 2, equipment certified for both WPA and WPA2 can function in either personal or enterprise modes. Table 8.2 shows the details of both WPA and WPA 2 certifications.

TABLE 8.2 Details of the Wi-Fi Alliance WPA and WPA 2 certifications

Wi-Fi Alliance Security Method	Authentication Method	Encryption/Cipher Method
WPA - Personal	Passphrase	TKIP/RC4
WPA - Enterprise	IEEE 802.1X/EAP	TKIP/RC4
WPA 2 - Personal	Passphrase	CCMP/AES or TKIP/RC4 (optional)
WPA 2 - Enterprise	IEEE 802.1X/EAP	CCMP/AES or TKIP/RC4 (optional)

Role-Based Access Control

Role-based access control (RBAC) is a way of restricting access to only authorized users. This access is from authentication based on specific roles rather than user identities. It was designed to ease the task of security administration on large networks. RBAC has characteristics similar to those of a common network administration practice: the creation of users and groups. RBAC may also fit well under the authorization part of AAA because it has very similar characteristics.

To give a user on a computer network access to a network resource, best practices recommend creating a group object, assigning the group permissions to the resource, and then adding the user object to the group. This method allows any user who is a member of the group to be granted access to the resource. RBAC can be used for various activities users may perform while connected to a WLAN, including limiting the amount of throughput, enforcing time restrictions, or controlling access to specific resources such as the Internet.

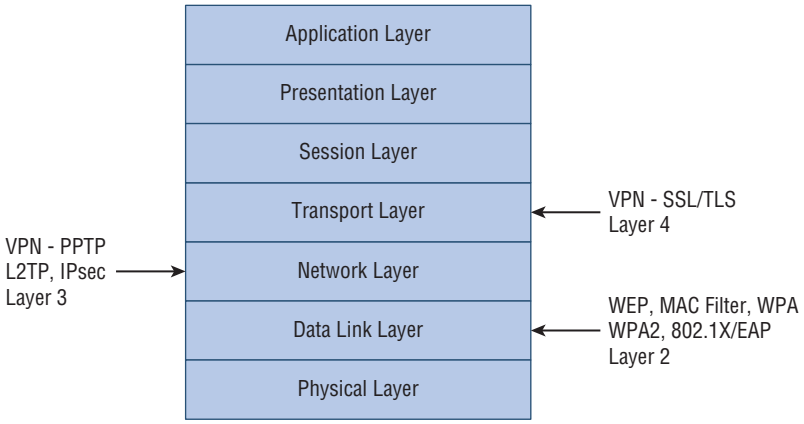
Let's look at an example. Your organization consists of several departments that use resources available on the wireless network. The departments are sales, engineering, and

accounting. Each department has specific requirements for what and when they need to access from the WLAN. This is where RBAC would be a great fit. If the network administrator wanted to restrict access to the WLAN for the sales department from 8 a.m. to 5 p.m., she could create a role using this feature. If the engineering department was using too much bandwidth, a role could be created to restrict throughput for that department. These are a couple of examples where RBAC can work with a WLAN.

Virtual Private Networking

Virtual private networking (VPN) is the capability to create private communications over a public network infrastructure such as the Internet. The security solutions discussed earlier in this chapter are Layer 2 security solutions—that is, all such solutions work at Layer 2 of the OSI model. By contrast, VPNs are Internet Protocol-based; they typically operate at Layer 3 of the OSI model but some will work at Layer 2. Figure 8.14 illustrates VPN technology in relationship to the OSI model.

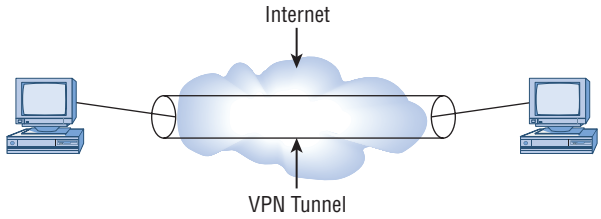
FIGURE 8.14 OSI model representation of a Layer 3 VPN security solution



Prior to the ratification of the IEEE 802.11i amendment to the standard, VPN technology was prevalent in enterprise deployments as well as in remote access security. Since Layer 2 security solutions have become stronger (mostly thanks to the 802.11i amendment and the Wi-Fi Alliance WPA and WPA2 certifications), VPN technology is not as widely used within enterprise LANs. However, VPN still remains a powerful security solution for remote access in both wired and wireless networking.

VPNs consist of two parts: tunneling and encryption. Figure 8.15 illustrates a VPN tunnel using the Internet. A standalone VPN tunnel does not provide data encryption, and VPN tunnels are created across IP networks. In a very basic sense, VPNs use encapsulation methods where one IP frame is encapsulated within a second IP frame. The encryption of VPNs is performed as a separate function.

FIGURE 8.15 Representation of a VPN tunnel



Real World Scenario

Shipping a Crate Using VPN Technology

An analogy for the VPN process is shipping a locked crate from one location to another. You are a technical support engineer for the headquarters office of a company that has five offices in different locations around the world. You get a telephone call from a co-worker at one of the remote offices. She needs to replace an access point with a newer model at the remote office. You need to ship the preconfigured replacement access point to her using a common carrier. You want to ensure that the access point arrives at the destination location without coming into physical contact with anybody other than the intended recipient.

The access point is analogous to the *IP frame*. You put the access point into a crate that has a combination lock to secure it. This crate containing the access point is analogous to the *second IP frame*, or the one that *encapsulates* the original IP frame.

You ship the crate to the destination using a common carrier, which would be analogous to the *public infrastructure* over which the encrypted data is sent. Many other packages are shipped by this common carrier, but no one will be able to see the contents of the crate because they do not know the combination to the lock (the encryption method).

When the access point arrives at the destination, the recipient (the technical support engineer for the remote office) must know the combination of the lock on the crate in order to open it to retrieve the access point. So you tell her the combination over the telephone. This is analogous to the *encryption method*. Over a secure telephone line, only you (the sender) and she (the recipient) know the combination to the lock. The tech support engineer will be able to unlock the crate using the combination you supplied her, and she will be able to retrieve the access point.

The following are two common types of VPN protocols:

- Point-to-Point Tunneling Protocol (PPTP)
- Layer 2 Tunneling Protocol (L2TP)

Point-to-Point Tunneling Protocol

Developed by a vendor consortium that included Microsoft, *Point-to-Point Tunneling Protocol* (PPTP) was very popular because of its ease of configuration and was included in all Microsoft Windows operating systems starting with Windows 95. PPTP uses Microsoft Point-to-Point Encryption (MPPE-128) Protocol for encryption. This process provides both tunneling and encryption capabilities for the user's data.

If the PPTP configuration uses MS-CHAP version 2 for user authentication on a wireless network, it can be a security issue. This authentication process can be captured using a wireless protocol analyzer or other scanning software program and potentially allow someone to perform a dictionary attack, enabling them to acquire a user's credentials and eventually giving them the capability to log on to the network. A dictionary attack is performed by software that challenges the encrypted password against common words or phrases in a text file (dictionary). Therefore, using PPTP on a wireless network should be avoided. Keep in mind that the security vulnerability is not PPTP itself; it is that the authentication frames on a WLAN can be captured by an intruder, who can then acquire user credentials (username and password) and be able to gain access to the VPN.

Layer 2 Tunneling Protocol

Layer 2 Tunneling Protocol (L2TP) is the combination of two different tunneling protocols: Cisco's Layer 2 Forwarding (L2F) and Microsoft's Point-to-Point Tunneling Protocol (PPTP). L2TP defines the tunneling process, which requires some level of encryption in order to function. With L2TP, a popular choice of encryption is Internet Protocol Security (IPSec), which provides authentication and encryption for each IP packet in a data stream. Since L2TP was published in 1999 as a proposed standard and because it is more secure than PPTP, L2TP has gained much popularity and for the most part is a replacement for PPTP. L2TP/IPSec is a very common VPN solution in use today. PPTP should not be used when L2TP is available.

Components of a VPN Solution

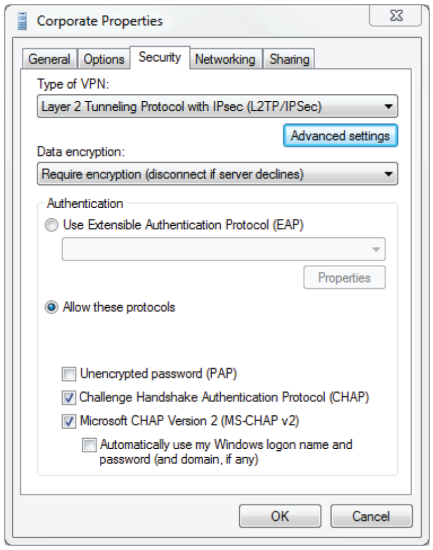
A VPN solution consists of the following three components:

- Client side (endpoint)
- Network infrastructure (public or private)
- Server side (endpoint)

In many cases, both the client side and server side are known as VPN endpoints. The infrastructure often is a public access network, such as the Internet. Some firewall manufacturers' security solutions allow the application of advanced security policies, such as web content filtering, anti-virus, botnet detection, and other security features to be applied directly to wireless traffic. This enables VPNs to secure various types of network traffic very easily for both wireless client devices and access points to wireless controller connections. The client-side endpoint typically consists of software, allowing it to be configured for the VPN. This software is available at a nominal cost from a variety of manufacturers.

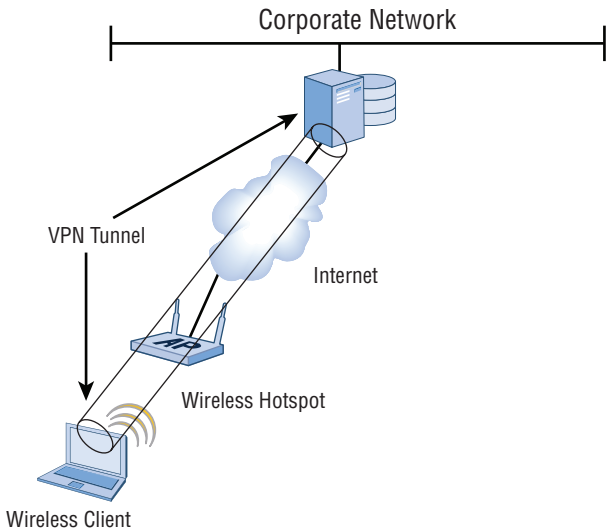
Newer Microsoft Windows operating systems include VPN client software for both PPTP and L2TP. Figure 8.16 shows a VPN client configuration screen.

FIGURE 8.16 Microsoft Windows 7 Professional built-in VPN client utility configuration



WLAN client devices have the capability to be a VPN client endpoint. The VPN can terminate either at an access point or across the Internet to the corporate network. Figure 8.17 shows a common example of a wireless client device connecting to a wireless hotspot to access the corporate network.

FIGURE 8.17 WLAN client using a wireless hotspot to connect to a corporate office using VPN technology



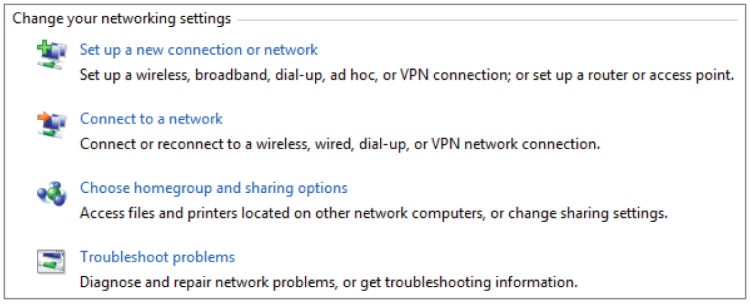
In Exercise 8.1, you will explore the built-in VPN client software utility in Microsoft Windows 7 Professional. Exercise 8.2 is another way to create a VPN connection using the built-in VPN client software utility in Microsoft Windows 10 Professional.

EXERCISE 8.1

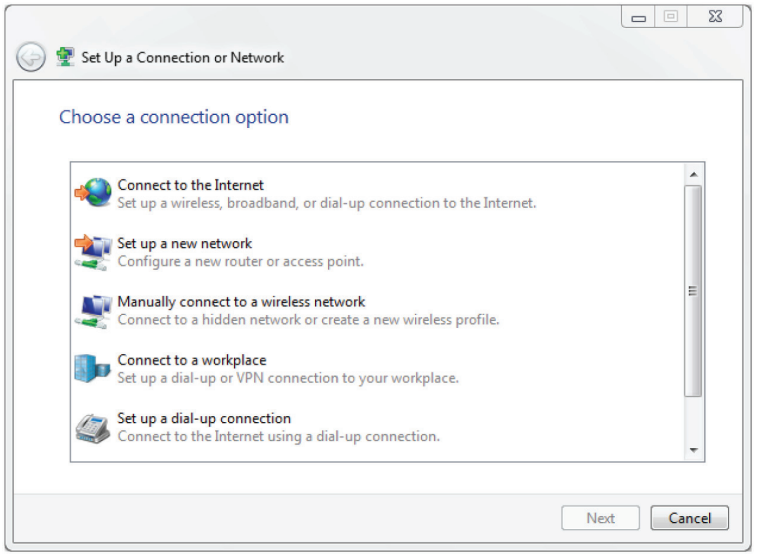
Setting Up a VPN

In this exercise, you will set up a VPN connection using the built-in VPN client utility in Microsoft Windows 7 Professional.

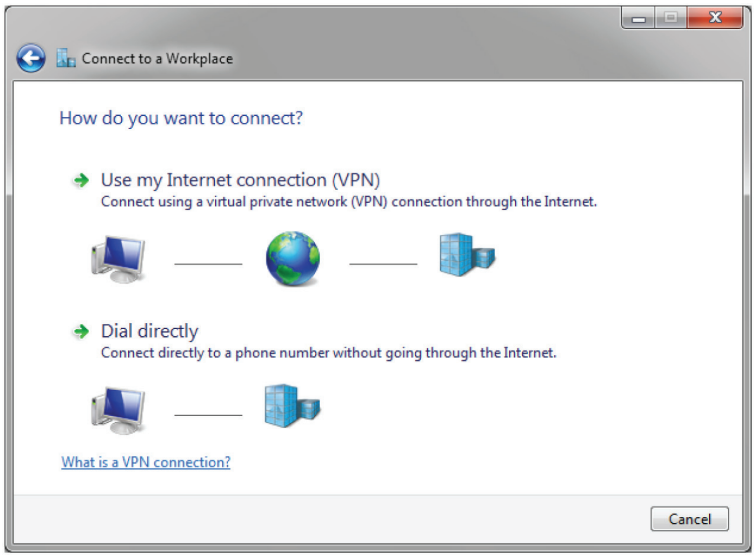
1. Click Start ➢ Control Panel. The Control Panel window appears.
2. Click the View Network Status And Tasks link under the Network And Internet heading in the Control Panel window. The Network and Sharing Center window appears.



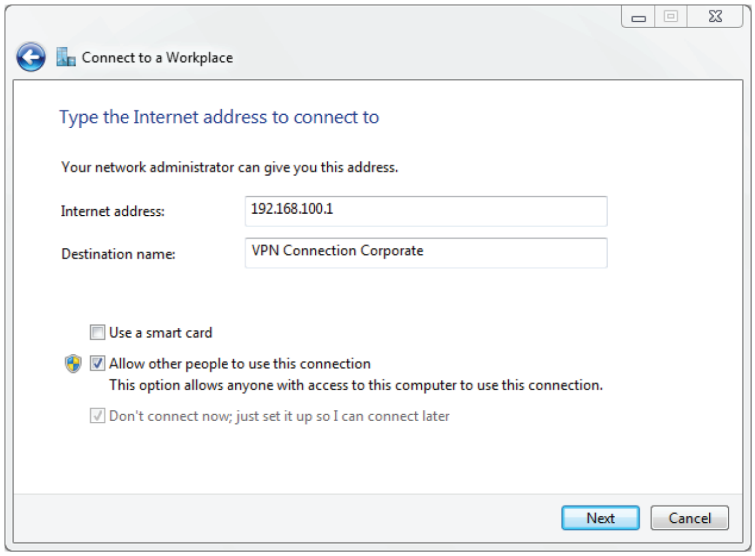
3. In the Change Your Network Settings menu, click the Set Up A New Connection Or Network link. The Set Up A Connection Or Network - Choose A Connection screen appears.



4. Select Connect To A Workplace - Set Up A Dial-Up Or VPN Connection To Your Workplace, and click Next. The Connect To A Workplace - How Do You Want To Connect? screen appears.

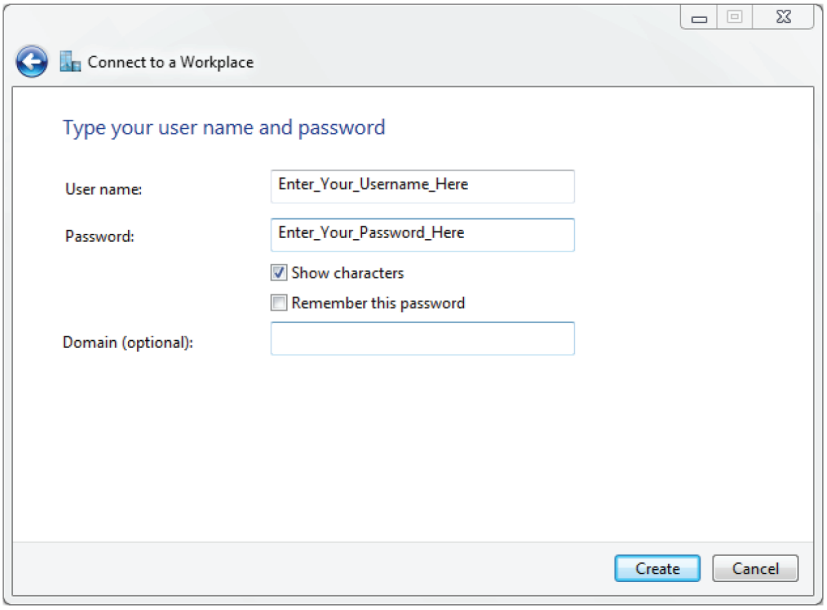


5. Click Use My Internet Connection (VPN). The Connect To A Workplace - Do You Want To Set Up An Internet Connection Before Continuing? screen appears. Click I'll Set Up An Internet Connection Later. The Connect To A Workplace - Type The Internet Address To Connect To screen appears.



EXERCISE 8.1 *(continued)*

6. In the Internet Address text box, type the IP address or hostname of the remote VPN server you want to connect to. In the Destination Name text box, type your selected name for the VPN connection, and click Next. The Connect To A Workplace - Type Your User Name And Password screen appears.



7. In the User Name and Password text boxes, enter a valid username and password, and click Create.
8. The Connect To A Workplace - The Connection Is Ready To Use screen appears; click Close. The Network and Sharing Center appears.
9. To use your VPN connection, click the Connect To A Network link. The Currently Connected To screen appears. Click the name of the VPN connection you created in step 6. The Connect VPN Connection dialog box appears, prompting for a username and password.

10. Enter a valid username and password (and also domain, if required), and click Connect to connect to your VPN server. Once your credentials have been validated by the VPN server, you will have access to the network through the VPN you created.

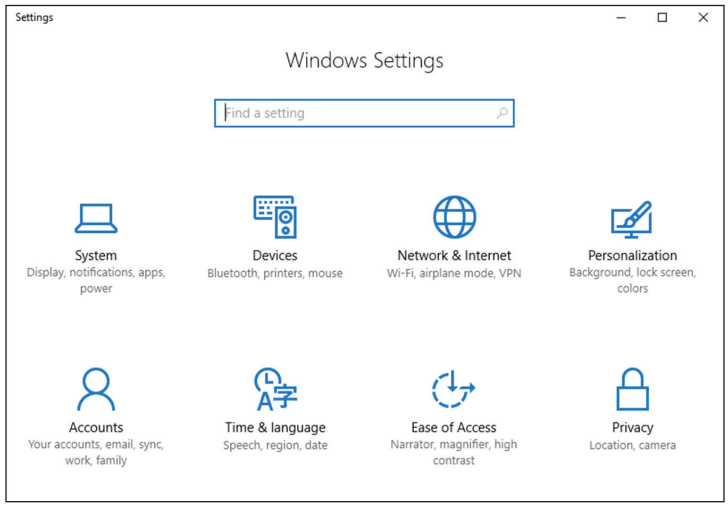
In Exercise 8.2, you will explore the built-in VPN client software utility in Microsoft Windows 10 Professional.

EXERCISE 8.2

Setting Up a VPN

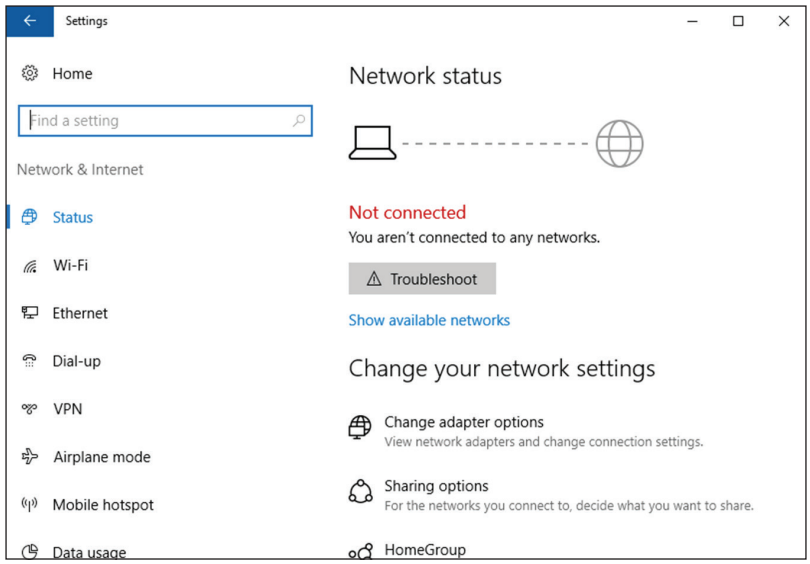
In this exercise, you will set up a VPN connection using the built-in VPN client utility in Microsoft Windows 10 Professional.

1. Click Start ➢ Settings (the gear symbol). The Windows Settings dialog box appears.

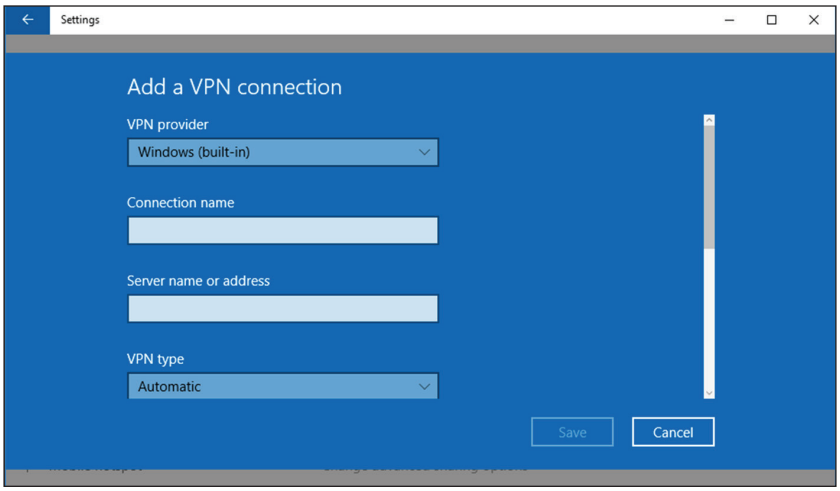


EXERCISE 8.2 *(continued)*

2. Click the Network and Internet Wi-Fi, airplane mode, VPN icon in the Windows Settings page. The Network status home page appears.

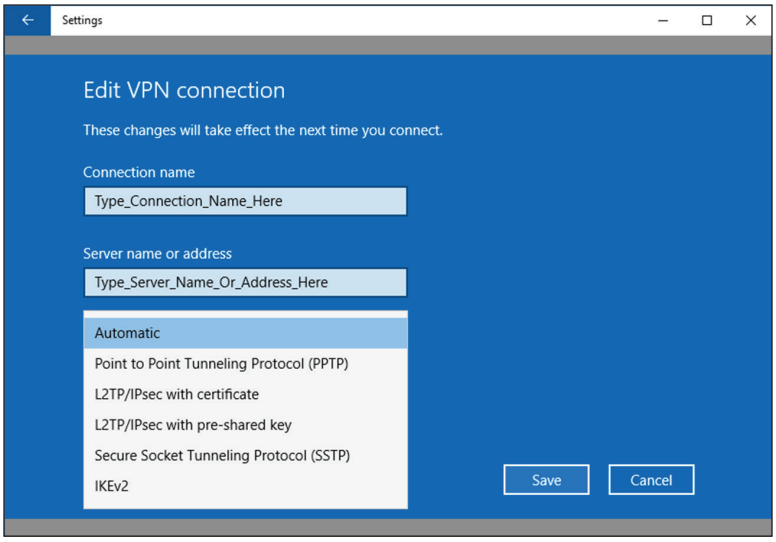


3. Click VPN under the Network & Internet column, and then click the Add a VPN connection under VPN on the right side of the dialog box. The Add a VPN Connection dialog box appears.

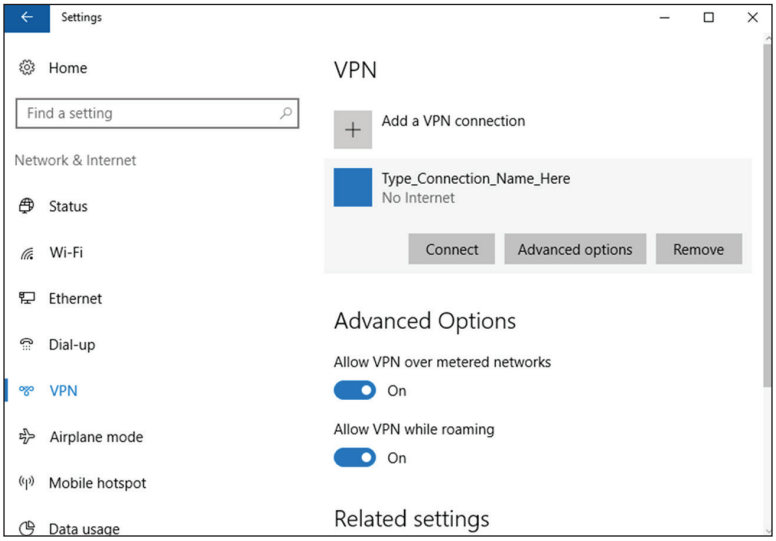


4. Click the drop-down arrow under VPN Provider and select the Windows (built-in) option. Enter the additional information, including Connection Name and Server Name or Address.

5. Click the drop-down arrow under the VPN Type box. Leave the default Automatic or select the appropriate option. Fill in the remaining fields as required.

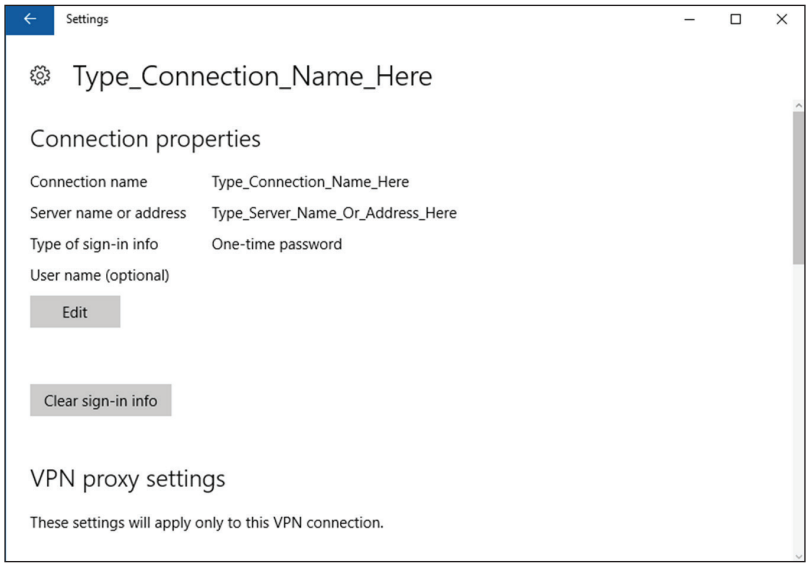


6. Click the Save button. A dialog box with the VPN profiles will appear.



EXERCISE 8.2 *(continued)*

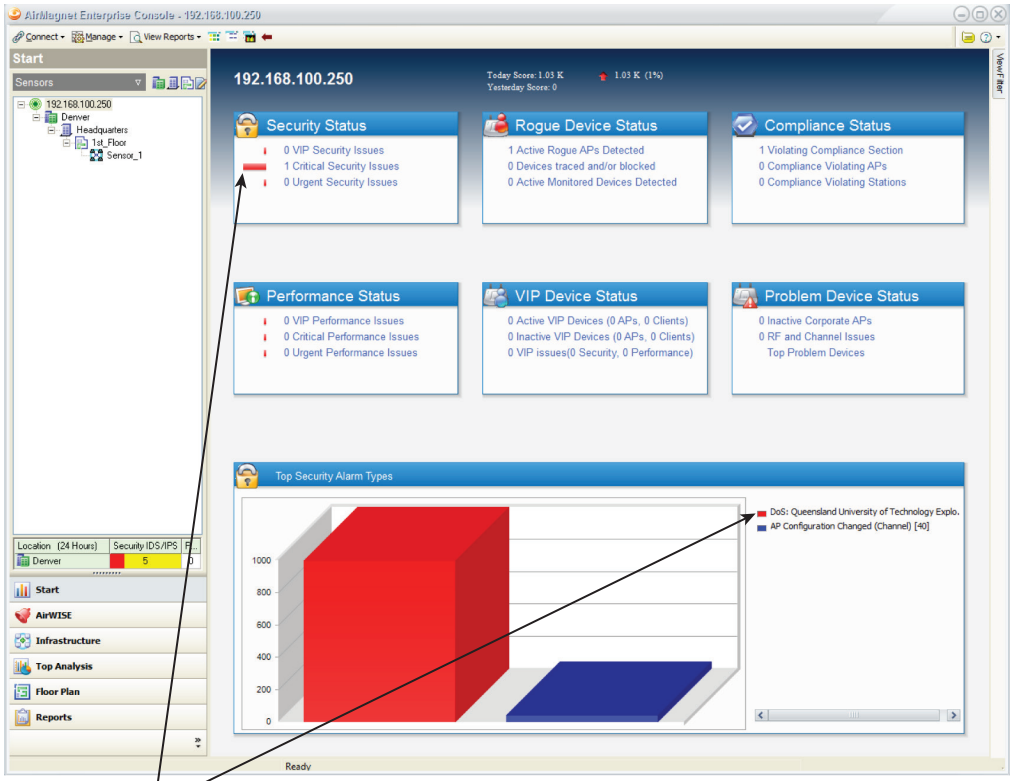
7. Click the profile you created, enter your credentials, and test the VPN connection. You can also click the Advanced Options button to edit the profile and view additional details about the profile you created.



The Wireless Intrusion Prevention System

In wireless networking, a *wireless intrusion prevention system* (WIPS) is a software/hardware solution that monitors the radio waves and, using a wireless hardware sensor, can report captured information to software to be recorded in a server database. (This differs from other network monitoring and management systems discussed later in this chapter.) The WIPS solution will then be able to take the appropriate countermeasures to prevent wireless network intrusions. These countermeasures are based on identifying the intrusion by comparing the captured information to an intrusion signature database within the WIPS server. Figure 8.18 shows a WIPS dashboard that displays a Layer 1 RF jamming DoS attack that was recorded.

FIGURE 8.18 A WIPS dashboard



AirMagnet Enterprise detects an RF denial-of-service (DoS) attack that was reported.

There are many advantages to using a WIPS. Some of them include:

- Captures information by 24×7 monitoring
- Detects threats to the wireless infrastructure, such as DoS attacks and rogue access points
- Notifies you about threats through a variety of mechanisms
- Supports integrated spectrum analysis
- Includes elaborate reporting systems
- Ensures compliance with corporate security policy and legislative compliance
- Retains data for forensic investigation
- Uses hardware sensors for monitoring

Let's look at these in a little more detail.

24/7/365 Monitoring With a WIPS, monitoring of the wireless network can be accomplished 24 hours a day, seven days a week, to help identify potential attacks, including DoS, either from Layer 1 RF or from Layer 2 software such as a deauthentication storm. A WIPS also finds rogue (unauthorized) access points and misconfigured wireless devices.

Detection and Mitigation Unlike many wireless intrusion detection systems (WIDS), WIPS has the capability to detect and react. WIPS solutions will automatically respond to threats against a WLAN by stopping the device or process that contains the threat before it has a chance to cause any damage to the wireless network.

Notification of Threats WIPS solutions have the capability to provide notifications to network administrators based on alerts and alarms of potential threats that the WIPS encounters during monitoring. These notifications can be provided in a variety of ways, such as email or pager.

Integrated Spectrum Analysis This feature allows an administrator to view the state of a remote radio environment at a branch office or remote location. This allows the accurate diagnosis of radio spectrum problems, including Layer 1 DoS attacks.

Elaborate Reporting Systems In addition to standard reports, most WIPS solutions allow network administrators to create their own customized reports in a short period of time. These reports will enable an organization to meet the specific requirements of audit groups, either internal or external to the organization.

Regulatory Policy Compliance A WIPS will have the capability to help ensure that an organization maintains the necessary legislative compliance. Compliance requirements include Health Insurance Portability and Accountability Act (HIPAA) and Payment Card Industry (PCI).

Retains Data for Forensics Many WIPS solutions can retain data that may be used in forensics investigations. The WIPS will provide the documented proof an organization may require to take the appropriate action based on events recorded. WIPS solutions will require fine-tuning to some degree to eliminate misrepresentation of the threat signatures the system will detect. This starts with a baseline of the environment, allowing the administrator to gauge the levels of detection and reaction.

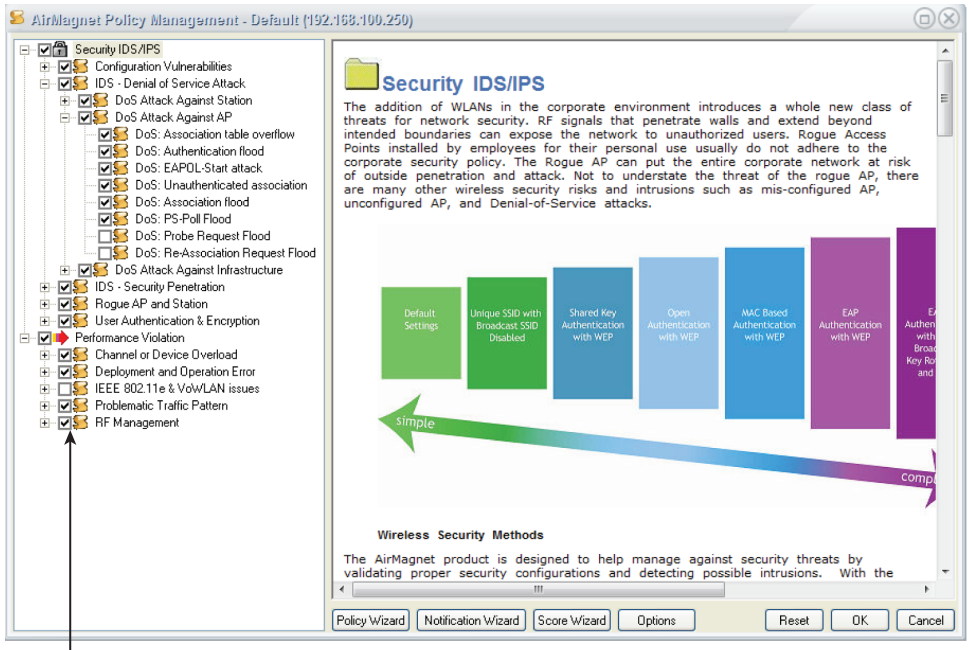
Uses Hardware Sensors for Monitoring WIPS solutions will use either dedicated hardware sensors or share the sensor functionality with access points. These sensors will collect data by monitoring the air 24×7 and allowing information to be reported to a server database.

WIPS Configuration and Maintenance

Although a WIPS solution is a valuable tool to use for WLAN monitoring and detection/mitigation of wireless intrusions, it needs to be set up, configured, and maintained correctly. Installing a WIPS system without setting the appropriate thresholds and baselines may result in unreliable or unusable collections of information. For example, if an organization is concerned about deauthentication attacks, such as forcing a "deauthentication

storm" (sending many consecutive deauthentication frames), this setting will need to be enabled on the WIPS system with the appropriate threshold setting in order to be detected. Remember from Chapter 6 that deauthentication occurs when an existing authentication is no longer valid, and it can be caused by a WLAN device logging off from the current connection or roaming to a different basic service set (BSS). If an intruder sends just a couple of deauthentication frames to a wireless device in an attempt to force them to reauthenticate, and thus perform a hijack attack, the activity may fall under the threshold set for the deauthentication frames that are monitored and could be missed. The bottom line is that proper setup, configuration, and maintenance of a WIPS system all need to be carefully considered. Figure 8.19 shows the policy setup screen for a WIPS.

FIGURE 8.19 WIPS policy configuration



Airmagnet Enterprise Policy Components Selection and Threshold Settings

Overlay and Integrated WIPS Technology

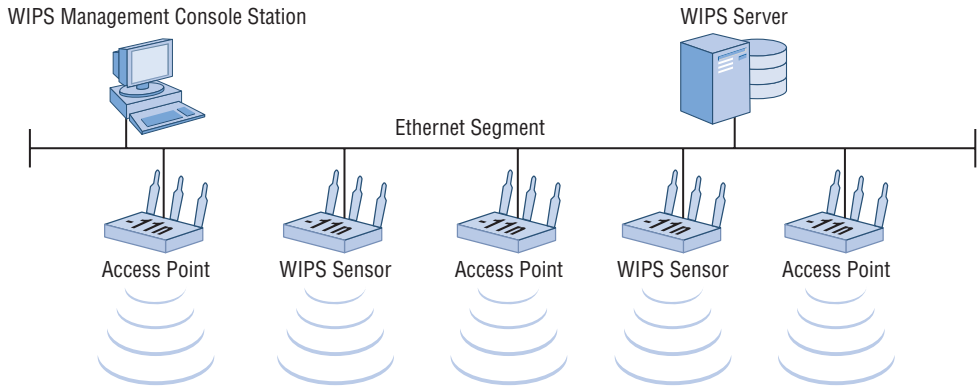
A WIPS requires hardware sensors for monitoring and sending the data to the WIPS server. These sensors can be dedicated devices (only used for monitoring) or they can share functionality with the wireless access points. The terminology used for these WIPS sensors is

- Overlay WIPS sensors
- Integrated WIPS sensors

Overlay WIPS Sensors

Overlay WIPS sensors are dedicated wireless devices that have physical characteristics similar to those of wireless access points but are only used for scanning the air and sending data to a WIPS server. These devices are passive and will not interfere with other WLAN devices such as access points. This type of sensor does not need to be implemented on a 1:1 deployment. In other words, you do not need one WIPS sensor with every access point. WIPS sensors are commonly installed in a 1:3 or 1:4 ratio. Figure 8.20 shows how a WIPS overlay solution uses dedicated sensors.

FIGURE 8.20 The WIPS overlay installation uses separate devices.



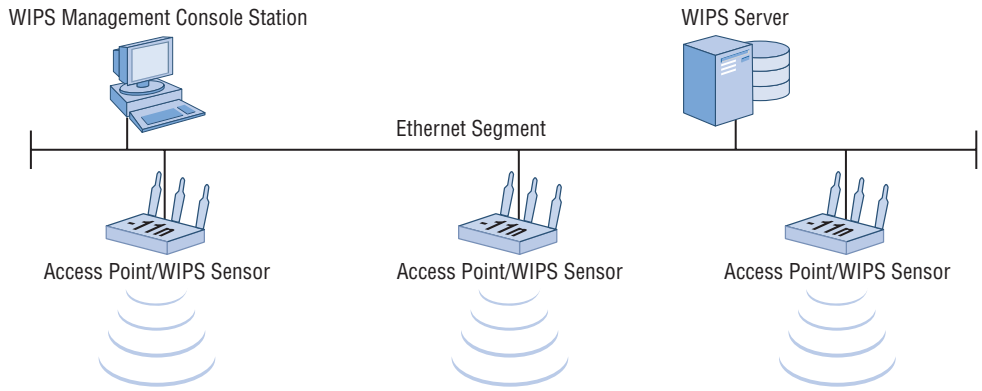
It is best to check with the WIPS manufacturer to determine the recommended number of dedicated sensors. Some wireless site survey software tools will specify the number and locations of the sensors required, based on the wireless network design. One disadvantage to the overlay solution is the extra cost for the dedicated sensors. Some manufacturers allow a wireless access point to run as a dedicated sensor; for these, the cost would be the same as the wireless access point.

Integrated WIPS Sensors

Integrated WIPS sensors are part of a wireless access point's functionality. An integrated sensor may have a dedicated radio for full-time WIPS monitoring, or it may share a radio with the access point for part-time WIPS monitoring. A dedicated WIPS radio that is built into the wireless access point will be able to monitor the air and send data directly to the WIPS server full time. This would be the radio's only function. One benefit to this type of sensor is that the cost will be less than that of the overlay system, because it does not requires separate dedicated WIPS sensors. However, the cost may be a little higher than if it were only an access point because of the additional radio for the WIPS capability. The other type of integrated WIPS sensor is the one that shares a radio with the access point. The downside to this is that the WIPS monitoring will only be part-time

and will not be able to capture everything that is going on. Figure 8.21 shows a WIPS integrated solution, consisting of a WIPS sensor and access point in the same device (wireless access point).

FIGURE 8.21 WIPS integrated solution sensor radio built into a wireless access point



Real World Scenario

Integrated WIPS Sensor Analogy

Think about this analogy. An after-hours security officer is sitting at a desk watching the security monitors for any unauthorized access or other activities that could be a security violation. The officer hears a noise down the hall and leaves his post to investigate. Because he has stepped away from the desk, he cannot be watching the security monitors at the same time; therefore, an unauthorized person may be able to enter the area without being noticed by the security officer. This is similar to the way an access point that is a part-time integrated WIPS sensor and that is servicing wireless client devices may not be able to see and detect potential WIPS violations. For example, if the wireless access point is providing voice over wireless access, because of QoS features the access point will prioritize the wireless voice frames and may forgo the WIPS monitoring. This will result in the WIPS server not being able to capture potential wireless intrusions or other wireless security violations.

The decision to use an overlay or integrated WIPS can be a tough one. It may come down to what you are trying to prevent and what you are trying to protect. It may also come down to cost. The bottom line is this: If you are planning to install a WIPS, evaluate the advantages and disadvantages of each type carefully. One of the main goals of a WIPS is to enforce functional (technical) corporate security policy 24/7/365.

The Captive Portal

A *captive portal* is a process that redirects a user to an authentication source of some type before they will be allowed wireless network access. This authentication source in the form of a web page will require a user to "authenticate" in some way and may include the following:

- Enter user credentials (username and password).
- Input payment information.
- Agree to terms and conditions.

When one or more of these methods is complete, a wireless device will then be able to access the network and use whatever resources they have permission to access. Most if not all public access wireless networks should have some type of captive portal enabled. This will help to protect both the provider (host) and the user of the wireless network. At a minimum, requiring the user to agree to terms and conditions via a captive portal should be implemented.

Most enterprise-grade wireless access points, including cooperative access points and WLAN controllers, have built-in captive portal capabilities that are fairly straightforward to implement.

Wireless Network Management and Monitoring Systems

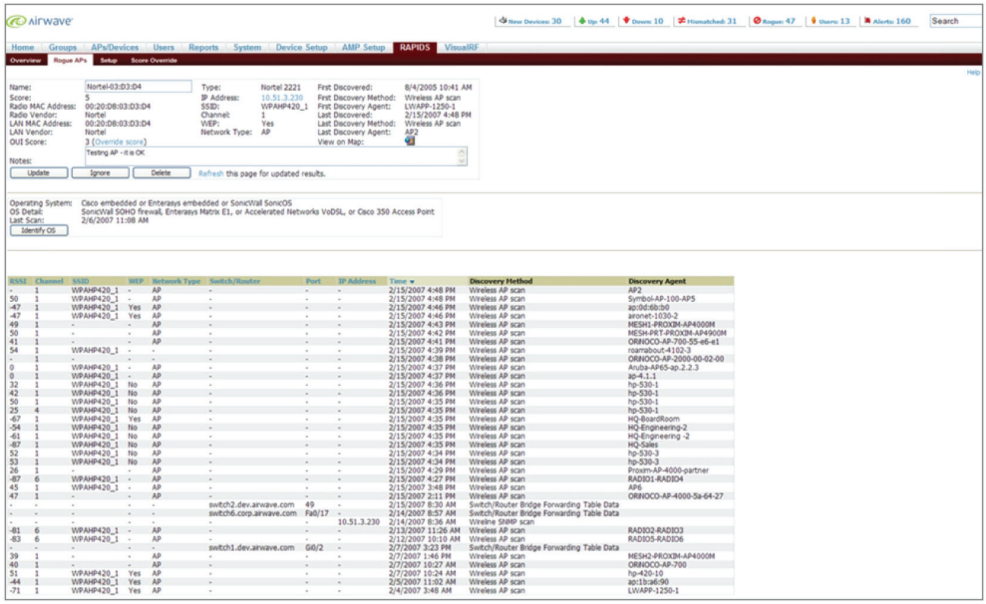
Wireless network management and monitoring systems are software- or hardware-based solutions that allow a wireless network engineer to both control and administer wireless infrastructure devices and collect information that may be used to troubleshoot and resolve WLAN issues. The information collected may consist of either Physical layer information (RF) or Data Link layer information (WLAN frames).

In the early days of standards-based IEEE 802.11 wireless networking, only autonomous access points for the most part were available; there was no centralized management or control. (Autonomous access points are discussed in Chapter 3, "Infrastructure and Client Devices Used with Wireless Networking.") To manage these infrastructure devices, you would need to configure each device separately. This could be done by connecting either through the command-line interface or a web-based interface, and individual configuration worked well if only a few infrastructure devices were installed.

As the need for WLAN technology grew, however, so did the number of devices or access points. Managing a large number of infrastructure devices manually was not feasible. This is where the *wireless network management system* (WNMS) evolved.

The WNMS is a centralized solution that was originally available in either software form to run on a server or hardware form to run as a standalone network appliance. (We'll look at a third option, cloud-based WNMS solutions, next.) A WNMS would allow a network engineer to manage and control the entire WLAN centrally. These centralized management systems are available from many manufacturers for use with their own infrastructure devices and are available as vendor-neutral solutions to work with many different manufacturers' equipment. A WNMS may also incorporate WIPS technology for a complete wireless network management, monitoring, and security solution. Figure 8.22 shows a WNMS dashboard.

FIGURE 8.22 Aruba Networks Airwave wireless network management software platform



WNMS: Software, Hardware, or Cloud?

As you just learned, a WNMS is available in different forms: software that will run on a server, hardware that will run on a dedicated appliance, and now cloud-based WNMS solutions. This newest option is growing in popularity. With the evolution of standards-based WLAN technology, the WLAN controller worked as a substitute for WNMS, offering control and management of the complete WLAN infrastructure. However, as the wireless networks continued to grow, so did the need for a WNMS. Figure 8.23 shows a cloud-based wireless network management system.

FIGURE 8.23 Aerohive HiveManager NMS cloud-based WNMS

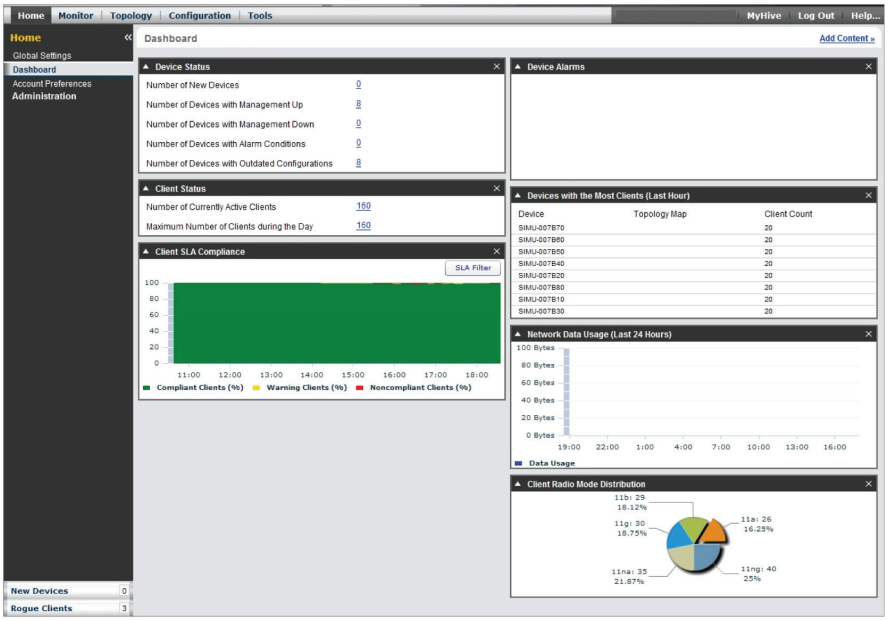


Table 8.3 shows some of the WNMS solutions available from various manufacturers.

TABLE 8.3 WNMS solutions

Manufacturer	Solution	Description
Aerohive	HiveManager NMS	Cloud-based, public or private cloud using a virtual machine
Aruba Networks (HPE)	AirWave network management	Also vendor-neutral or multivendor
Cisco Systems	Cisco Prime	Cisco's network management software suite
Cisco Meraki	Systems Manager	Cloud-based
Extreme Networks	Extreme AirDefense Services Platform (ADSP)	Hardware appliance or virtual machine
Fortinet	Fortinet Wireless LAN Manager	Flexible Appliance, physical, virtual and cloud
Ruckus Wireless (Arris Group)	Flexmaster	Web-based management platform
Xirrus	Xirrus Management System-Cloud (XMS-Cloud)	Software-, appliance-, or cloud-based

Keep in mind that some manufacturers allow management of both wireless and wired infrastructures from one platform, creating a "unified" management of the entire network.

Wireless Network Monitoring

In addition to wireless network management solutions, you need to understand wireless network monitoring solutions. These monitoring solutions are in addition to the WIPS you learned about earlier in this chapter. They allow a wireless network engineer to monitor the performance of a wireless network at the Physical layer and the Data Link layer for both troubleshooting and security information gathering purposes.

Physical Layer Monitoring

Physical layer monitoring allows the wireless network engineer to see what is happening in the air as it relates to RF. This is usually accomplished with the use of a spectrum analyzer, which allows an engineer to "see" the RF and thus detect potential interference issues and also security issues. Interference from both WLAN devices and other wireless devices such as two-way radios or microwave ovens will be visible with the help of a spectrum analyzer. The spectrum analyzer will also detect Layer 1 security issues such as a narrow-band or wide-band RF DoS attack. Figure 8.24 shows how a spectrum analyzer can see the Physical layer information and detect potential security threats.

FIGURE 8.24 The MetaGeek Chanalyzer spectrum analyzer shows an RF DoS attack using a narrow-band jamming device.

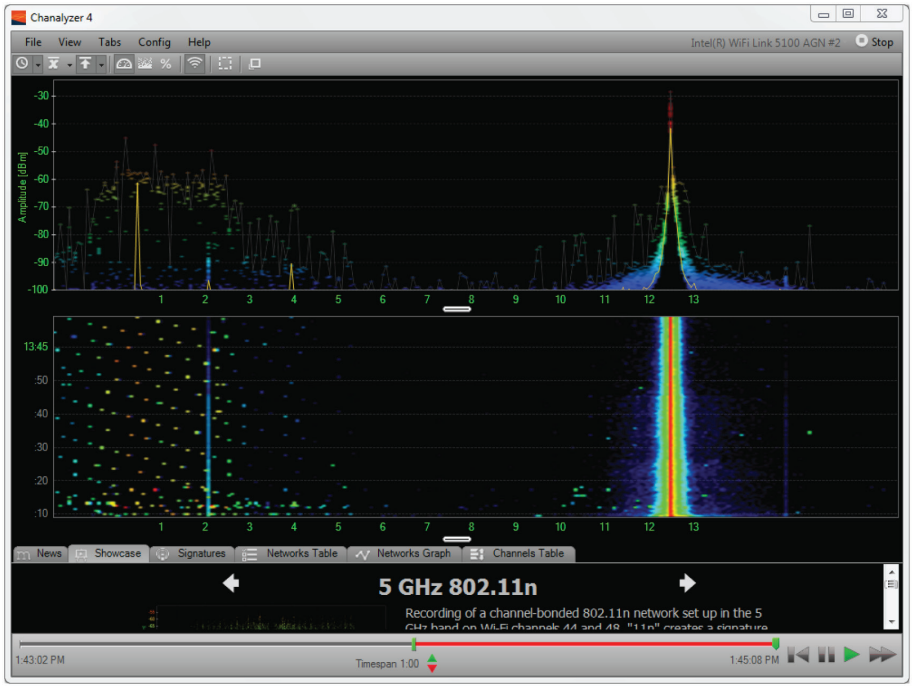


Table 8.4 shows some manufacturers of WLAN-centric spectrum analyzers.

TABLE 8.4 WLAN-centric spectrum analyzers

Manufacturer	Solution	Comments
NetScout/AirMagnet	Spectrum XT	
Cisco Systems	Cisco Spectrum Expert	Formerly Cognio
NetScout	AirCheck G2WirelessTester	Handheld device
MetaGeek	Chanalyzer	

Data Link Layer Monitoring

Data Link layer monitoring means looking at the Layer 2 information; it allows a network engineer to view the WLAN frames that traverse the air and provides the opportunity to view both potential performance and security issues. Protocol analysis tools allow the engineer to view both frame exchanges and frame decoding by expanding on the captured wireless frames. From a security point of view, these tools can provide valuable wireless network information for both the wireless network engineer as well as a potential intruder. The wireless network engineer will be able to find potential security configuration issues that could open the door to intruders. If an intruder were to capture wireless frames, such as the pre-shared key 4-way handshake, they might (depending on how strong the passphrase is) be able to use a dictionary attack software program and determine the passphrase. This would allow them to gain access to the wireless network and potentially see a user's encrypted data.

Some WLAN analyzers are able to capture and reconstruct TCP/IP frames and reconstruct a session and allow web pages to be seen or email messages to be read directly from the captured wireless frames. Keep in mind that this is possible on an open wireless network or one on which the intruder has been able to capture the frames that allow them to access the WLAN and to decode the data frames. Table 8.5 provides some common WLAN protocol analyzers.

TABLE 8.5 Common WLAN protocol analyzers

Manufacturer	Solution	Comments
NetScout/AirMagnet	WiFi Analyzer	
MetaGeek	Eye P.A.	
Tamosoft	Commview for WiFi	
Savvius	OmniPeek Network Analyzer	
Wireshark		Formerly Ethereal

Some of these packet analyzers (among others) will perform WLAN analysis and work with wired LANs.

Many manufacturers of WLAN packet analyzers offer trial versions of their software to allow you to "try before you buy." Visit the manufacturers' websites for more information on how to obtain a trial version of their software.

The topic of regulatory compliance, discussed next, is not included in the exam objectives but is explained here for your own reference.

Industry Regulatory Compliance

It is very important for companies, organizations, and businesses that collect private or personal information from individuals to secure that information appropriately. In recent years, there have been several legislative regulations that various businesses are required to conform to. This legislation regulates how data is handled for businesses such as health care, retail, financial, and others. Plans for complying with them are known as *legislative compliances*. When using wireless networks, companies must verify any additional requirements from a security perspective that may be needed when dealing with regulatory compliance. This section briefly describes some of the more popular legislative compliance requirements.

PCI Compliance

PCI stands for Payment Card Industry and is a regulation requiring companies to adhere to security standards created to protect card information pertaining to financial transactions. According to the PCI Security Standards Council, in order to be PCI-compliant a company must meet the following six requirements:

- Build and maintain a secure network.
- Protect cardholder data.
- Maintain a vulnerability management program.
- Implement strong access control measures.
- Regularly monitor and test networks.
- Maintain an information security policy.

For more information on PCI, visit the PCI Security Standards Council website at `www.pcisecuritystandards.org`.

HIPAA Compliance

HIPAA is the abbreviation for the United States Health Insurance Portability and Accountability Act of 1996. The goal of HIPAA is to provide standardized mechanisms for electronic data exchange, security, and confidentiality of all health care-related computer information and data. HIPAA consists of two parts:

- HIPAA, Title I
- HIPAA, Title II

If someone loses or changes their job, Title I of HIPAA protects their health insurance coverage.

In the information technology industries, Title II is what most people mean when they refer to HIPAA. It establishes mandatory regulations that require extensive changes to the way that health-care providers conduct business by securing computer information and data.

For more information on HIPAA, visit the U.S. Department of Health and Human Services website at `www.hhs.gov/ocr/hipaa`.

Summary

In this chapter, we briefly discussed network intrusion and the impact it can have on a WLAN. We also took a look at IEEE 802.11 security methods and a quick review from Chapter 6 of the authentication types defined in the IEEE 802.11 standard: open system and shared key. We explored some of the IEEE 802.11 WLAN security technologies, including:

- SSID hiding
- MAC address filtering
- WEP

We discussed the vulnerabilities in each of these solutions. We showed an example of how the SSID could be hidden from view and also discussed why this is not a good security method—because other wireless frames contain the SSID, and it can be found even though it is removed from a beacon frame. You saw how MAC address filtering can be spoofed using freeware utilities downloadable from the Internet or through the computer operating system. We also looked at the last of three security solutions, WEP, and illustrated how it could be compromised; as you learned, it is a weak wireless security solution.

In addition to the legacy security solutions, we explored some of the more modern solutions:

SOHO and home-based solutions

- Passphrase/preshared key
- Push-button or PIN-based configuration

Enterprise-based solutions

- 802.1X/EAP
- RADIUS and AAA

You learned that encryption consists of taking information and scrambling it so that only the sender and the intended recipient, who know the algorithm, will be able to decipher the data. We looked at three types of encryption used in IEEE 802.11 wireless networking:

- WEP
- TKIP
- CCMP

Role-based access control (RBAC) is a component for administration of wireless networks that allows access and authorization based on individual groups and users and other parameters.

We also discussed virtual private networking (VPN), commonly a Layer 3 solution that provides a secure connection over a public infrastructure such as the Internet. You saw how VPN technology can be a solution for wireless network users from a remote location to access corporate or other networks from a hotspot or other unsecured WLAN. We also compared PPTP and L2TP and discussed the differences between them. PPTP using MS-CHAP version 2 is not a good security solution for WLANs, because the authentication can be captured and potentially compromised through a dictionary attack.

You saw how a captive portal can be used to redirect a user to a web authentication page requiring authentication or an agreement of terms and conditions prior to getting network access.

Products are available for enterprise WLANs that will monitor the airwaves 24/7 and record all activity detected by the wireless sensors. We discussed these solutions, known as a wireless intrusion prevention system (WIPS), which have the capability to detect and react to a potential intrusion on the wireless network. You learned that WIPS sensors are available in an overlay or integrated technology. Wireless network management systems (WNMS) are available in software-, hardware-, or cloud-based solutions. A WNMS will allow for centralized management and control of the wireless and possibly wired infrastructure. A WNMS may have some WIPS capability. We also addressed the functionality and features of these solutions.

Finally, we discussed regulatory compliances, including the Health Insurance Portability and Accountability Act (HIPAA) and Payment Card Industry (PCI), and the importance of securing computer data for industries such as health care, retail, and financial.

Exam Essentials

Be familiar with 802.11 legacy security technologies. Know the characteristics and features of security methods, including SSID hiding, MAC address filtering, and WEP, and the weaknesses or vulnerabilities of each.

Understand passphrase-based security. Identify the components of passphrase-based security that are commonly used for SOHO and home wireless networks. Understand that a passphrase will create a 256-bit preshared key for wireless security.

Identify IEEE 802.1X/EAP user-based security components. Know the features and use of IEEE 802.1X port-based access control, EAP, and RADIUS. Understand the components that make up an AAA server.

Understand Layer 3 wireless VPN security solutions. Know how a VPN operates as well as the components of the VPN solution. Understand the differences between PPTP and L2TP.

Be familiar with the WIPS. Know what a WIPS solution is and the benefits it can provide an organization to help manage WLAN security. Understand the differences between overlay and integrated WIPS sensors, including their advantages and disadvantages.

Know the differences between wireless network management and monitoring systems. Identify some of the features and benefits of a WNMS and the different platforms that are available. Understand that a WNMS includes wireless packet analyzers and allows a network engineer to view statistics regarding the network health and security.

Review Questions

1. Which security methods do IEEE 802.11a/b/g/ access points support? (Choose three.)
   - **A.** WPA Enterprise
   - **B.** WEP
   - **C.** PPTP
   - **D.** RBAC
   - **E.** MAC filters
   - **F.** IPSec

2. Both _____ and _____ are WLAN security methods that support shared key security. (Choose two.)
   - **A.** WPA2 Personal
   - **B.** WPA2 Enterprise
   - **C.** 802.1X/EAP
   - **D.** WEP
   - **E.** WPA Enterprise

3. Which security feature provides one of the strongest security methods for a home-based wireless network?
   - **A.** SSID hiding
   - **B.** Passphrase
   - **C.** MAC filters
   - **D.** 128-bit WEP

4. You need to attend a business meeting out of town that requires air travel. You are at the airport and have some extra time. While waiting to board your plane you decide to check your office email using an IEEE 802.11g/n wireless hotspot access point at the airport. In order to provide a secure connection, you would enable your notebook computer to use _____.
   - **A.** Passphrase security
   - **B.** WEP
   - **C.** A VPN to the corporate network
   - **D.** IEEE 802.1X/EAP to the corporate network

5. A _____ filter is used to allow or deny wireless barcode scanners access to an 802.11b/g/n network.
   - **A.** WEP
   - **B.** IPSec
   - **C.** SSID
   - **D.** RF
   - **E.** MAC

6. The security amendment to the IEEE 802.11 standard requires _____.
   - **A.** WEP
   - **B.** CCMP
   - **C.** TKIP
   - **D.** PPTP
   - **E.** VPN

7. Which process is a VPN solution intended to provide for users connecting to a network?
   - **A.** Secure Layer 3 transmissions over a public network infrastructure
   - **B.** Secure Layer 2 transmissions over a public network infrastructure
   - **C.** Secure Layer 3 transmissions over a corporate network infrastructure
   - **D.** Secure Layer 2 transmissions over a corporate network infrastructure

8. Which function does RBAC provide?
   - **A.** Restricts access to authorized users or groups
   - **B.** Provides access to only network administrators
   - **C.** Streamlines hardware installation
   - **D.** Allows users to install software

9. Hiding the SSID of a WLAN will require a user to _____ in order to gain access to the wireless network.
   - **A.** Enter a username and password when prompted
   - **B.** Call the help desk and ask for a new password
   - **C.** Enable the SSID broadcast on the client device
   - **D.** Know the SSID and enter it manually

10. RADIUS requires users on a wireless network to perform what function?
    - **A.** Access the corporate network using only the PSTN and a modem.
    - **B.** Call in to the help desk service and request a username and password.
    - **C.** Enter a username and password that will be centrally administered.
    - **D.** Request remote assistance to help solve a software problem on a computer.

11. The IEEE 802.1X standard identifies the authenticator as another term for the _____ in wireless networking.
    - **A.** Client device
    - **B.** Access point
    - **C.** RADIUS server
    - **D.** EAP server

12. Which data encryption/authentication method is identified in the original IEEE 802.11 standard?

A. TKIP

B. AES

C. CCMP

D. WEP

E. EAP

13. You are a wireless network administrator monitoring the reports for a recently installed wireless intrusion prevention system. You receive an alert notifying you of high levels of RF activity detected from an access point operating as a sensor and currently set to channel 6. Which problem could be causing the alert? (Choose two.)

A. Interference from a neighboring access point

B. RF deauthentication storm

C. RF DoS attack

D. Misconfigured client workstation

E. RF encryption attack

14. The length of a WEP key is typically _____ or _____.

A. 5-bit, 10-bit

B. 13-bit, 26-bit

C. 64-bit, 128-bit

D. 128-bit, 256-bit

E. 192-bit, 256-bit

15. Which security solution is mandatory for client devices in order to be considered Wi-Fi Protected Setup certified?

A. WEP

B. PIN

C. WPA

D. PBC

E. TKIP

16. A newly configured wireless intrusion prevention system will _____.

A. Require a network administrator to monitor for intrusions

B. Automatically monitor the network for potential attacks

C. Require an administrator to manually shut down a rogue access point

D. Automatically notify a network administrator regarding a firmware upgrade

17. You are a network administrator and are asked for a security recommendation regarding older wireless 802.11-compliant VoIP handsets. The company does not have the budget to upgrade the equipment at this time. Which would be the best recommendation you could provide?
    - **A.** Don't worry about securing the handsets because voice transmissions cannot be deciphered.
    - **B.** Carefully plan a strategy using WEP and VLANs.
    - **C.** Use a VPN solution with L2TP/IPSec.
    - **D.** Use a CCMP/AES Layer 2 solution.

18. A weakness with MAC address filtering is that it allows an intruder to _____.
    - **A.** Crack the encryption.
    - **B.** Spoof an address.
    - **C.** Cause an RF DoS attack.
    - **D.** Steal user authentication.

19. What type of wireless network device is PIN-based security most commonly used with?
    - **A.** SOHO brands that support WPA 2.0
    - **B.** Enterprise brands that support WPA 2.0
    - **C.** SOHO brands that support WPS
    - **D.** Enterprise brands that support WPS

20. L2TP commonly uses which encryption method?
    - **A.** IPSec
    - **B.** PPTP
    - **C.** AES
    - **D.** WEP
    - **E.** MPPE

Chapter

9

Design for Wireless Networking

THE FOLLOWING CWTS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **4.1 Understand and describe the requirements to gather information prior to the site survey and do reporting after the site survey**
- ✓ **4.2 Define and differentiate between multiple channel and single channel WLAN system architectures and understand site survey concepts related to each architecture. Identify and explain best practices for access point placement and density.**
- ✓ **4.3 Describe the primary purpose and methodology of manual and predictive site surveys**
- ✓ **4.4 Define the need for and the use of a manual site survey tool and differentiate between active and passive manual site survey types**
- ✓ **4.5 Differentiate between manual and predictive site surveys**
- ✓ **4.6 Define the need for and use of site survey software or a protocol analyzer in a manual site survey as it relates to identifying, locating, and assessing nearby WLANs**
- ✓ **4.7 Differentiate between site survey methods for indoor and outdoor wireless service**
- ✓ **4.8 Define the need for and use of a spectrum analyzer in a site survey**
- ✓ **4.9 Understand industry best practices for optimal use of directional and omni-directional antennas in site surveys**

THE FOLLOWING CWS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **2.4 Identify factors impacting wireless LAN (WLAN) performance**
- ✓ **3.7 Determine the best solution for BYOD and guest access**
- ✓ **4.3 Discover coverage and capacity needs**

THE FOLLOWING CWT EXAM OBJECTIVE IS COVERED IN THIS CHAPTER:

- ✓ **1.4 Create basic RF channel plans**

This chapter discusses the details of WLAN design and site surveys for IEEE 802.11 wireless networking. We will explore site survey planning and the business aspects related to a wireless network site survey, including gathering business requirements, interviewing the appropriate people, and gathering additional information about the location in which the network will be installed.

You will learn about site survey requirements, such as understanding the business requirements for the intended use of the WLAN and asking plenty of questions by interviewing department managers and users to help determine the applications and security requirements for the proposed network. Gathering information is a major part of a site survey to ensure a successful deployment.

You will also learn about the importance of documenting every step, from the design to the installation, and the importance of validating the wireless network, a process commonly known as a *post survey*. It is important to have all the necessary groundwork prior to starting a physical wireless radio frequency (RF) site survey. Having all the correct information in hand will allow for a complete and thorough survey, which in turn will result in a successful wireless network deployment.

In this chapter, you will see some of the components of performing an RF wireless site survey, including determining areas of RF coverage and interference by using a spectrum analyzer. Considering both Wi-Fi and non–Wi-Fi interference sources and understanding how this interference will affect the deployment are also important parts of performing a site survey. We will also look at different types of site surveys, both manual and predictive modeling. You will learn about the two types of manual site surveys, passive and active, and see the advantages and disadvantages of both. Understanding the steps involved and the details of each site survey type will help a wireless engineer determine the best methodology to use. You will see some of the tools that may be used in a wireless site survey, including spectrum analyzers, wireless protocol analyzers, and wireless scanners.

Finally, we will look at the two different types of channel architecture and best practices for hardware placement, including access points and antennas, as well as some of the limitations you may encounter during the physical site survey process.

Wireless Site Surveys

Early WLAN deployments in many cases required only a one-time site survey. This is because wireless networking technology was fairly static and the RF dynamics of the locations in which these networks were installed did not change much. The main goal for early

deployments was to provide adequate RF coverage. Thanks to the rapid pace at which wireless technology is growing and the increasing use of other devices that use unlicensed RF, however, site surveys can be an ongoing process for the areas where these wireless networks are installed. Although there are no set rules about when or how wireless site surveys should be performed, many manufacturers suggest guidelines based on the deployment scenarios for wireless networks using their equipment. Best practices and experience also play a role in the site survey process.

The term *wireless site survey* can be subjective. A site survey may include walking an area to check for RF coverage and interference, planning for network capacity, and designing the wireless network. A wireless site survey includes the following main objectives:

- Evaluate areas for RF coverage.
- Locate and mitigate any sources of RF interference.
- Determine wireless network capacity requirements.
- Decide on locations for hardware infrastructure devices.
- Identify the antenna types to be used.
- Evaluate the environmental conditions including RF propagation and attenuation.

It is important to understand that an RF site survey is not WLAN design, and WLAN design is not an RF site survey. A wireless RF site survey is a combination of processes and procedures used to create a WLAN design.

Site surveys vary in complexity, depending on the type of business or location in which a wireless network will be used. Many organizations are now designing wireless networks based on an average of three to four wireless mobile devices per user. The devices may include computers, smartphones, tablets, and Internet of Things (IoT) devices and can have a major impact on capacity planning.

Although there is no specific set of rules that must be followed, many manufacturers of wireless networking equipment have guidelines and suggestions when it comes to a wireless site survey and where this survey will fit into the process of the design and implementation of a wireless network.

Knowing and understanding the expectations of the client or business in regard to a wireless installation is a critical part of a successful deployment. To understand client expectations, you have to gather much information. This means you will need to participate in interviews and meetings with all those who will be affected by the installation of the wireless network, which, in most cases, encompasses nearly all departments of the company.

The scope of the wireless site survey, capacity planning, and wireless network design is dependent on many factors, including the following:

- Size of the physical location
- Intended use of the wireless network

- Number of wireless mobile devices
- Wireless client device capabilities
- The environment
- The performance expectations
- Bring your own device (BYOD) acceptance
- Building age and construction materials
- Network infrastructure devices

Size of the Physical Location

Depending on the size of the physical location where the wireless network will be installed, a complete wireless site survey may not be necessary, and the design will be straightforward. For example, a small sandwich shop wants to offer free wireless Internet access (a hotspot) as a convenience for its patrons. This sandwich shop is approximately 1,200 square feet (111 square meters), has seating for about 15 people, and is located in a small retail mall. In this case, a single access point would more than likely be sufficient for the number of users who access the wireless network at any one time and the type of data being sent across the access point to the Internet.

Although a full-blown physical site survey determining areas of RF interference, coverage, and capacity would more than likely not be required, it would still be beneficial to visit the location and determine the best place for the access point. In a situation like this, what could be called a "site survey lite" may be all that is necessary. This would include performing some simple tests to determine the best RF channel to use as well as access point mounting, consideration of aesthetics, and connecting to the wired network for access to the Internet.

A larger installation will require a much more extensive site survey and may include either a manual RF site survey or a predictive modeling site survey using elaborate software. Manual and predictive modeling site survey software will be discussed in more detail later in this chapter.

Intended Use of the Wireless Network

Looking at the sandwich shop scenario again, chances are the intended use of this wireless network will consist of patrons staying online for short periods of time and browsing the Internet, interacting with social media, or checking email. It is unlikely that many users would be performing any high-end or bandwidth-intensive applications on this type of connection. Therefore, the single-access point model would be sufficient for this deployment, providing adequate wireless access and capacity. With larger installations, the use of the network may include bandwidth-intensive applications, such as electronic imaging, computer-aided design, graphics design, and database programs, which would impact the number of

access points required to provide adequate performance. Although not bandwidth-intensive, a Voice over Wireless LAN (VoWLAN) application may also have an impact on the number of access points because of the type of wireless traffic that is sent and received.

Number of Wireless Devices

The number of users and their wireless devices that will be accessing a wireless network is also a big factor in determining the number of access points required, which in turn will determine the scope of a site survey and will have an impact on the WLAN design. Many organizations plan on three to five wireless devices per user, including computers, smartphones, tablets, and others. It has already been established that in our sandwich shop example a single access point would be sufficient based on the size of the location and the intended use of the network. However, as the number of actual wireless-enabled devices increases and because of the added capacity requirements, the need for additional access points will also increase. When more than one access point is required, a more extensive wireless site survey is also required.

Wireless Client Device Capabilities

In addition to the number of users and their wireless client devices, it is important to understand the type of client devices that will be connected to the wireless network and what those device capabilities are. For example, notebook computers or handheld devices, such as tablets and smartphones, all have specific functionality and will need to meet certain network requirements. Some client devices are multifunctional and include capabilities such as cellular voice, 3G, 4G, LTE, and Wi-Fi, which will need to be taken into consideration. The devices could be performing tasks as simple as basic web browsing or checking email. Other possible device types include Wi-Fi–enabled voice handsets that may need a dedicated SSID for QoS functionality and may operate in the 5 GHz UNII bands, or even bar code scanners that will be keeping track of product inventory. With the advancements in wireless networking technology, such as the IEEE 802.11ac amendment, the device capabilities including 5 GHz functionality must be closely evaluated.

Part of the wireless site survey planning process is to question the appropriate people regarding the types and capabilities of the wireless devices in use, to ensure that expectations of the users will be met. The following device capabilities are among those that need to be considered:

- IEEE 802.11b/g/n, 2.4 GHz only
- IEEE 802.11a or dual band, 2.4 GHz/5 GHz capable
- IEEE 802.11n capable and the number of transmit and receive radio chains (for example, 2x2 MIMO)
- IEEE 802.11ac capable and the extended features 802.11ac technology provides
- MIMO capabilities, such as the number of spatial streams, channel width, transmit beamforming, or multiuser MIMO

- Notebook computers, desktop computers, multifunction smartphones, or tablets
- Radio frequency identification (RFID) tags for location services
- Wi-Fi–enabled voice handsets and the operating frequency they can be used in

Future mobile device types that will be used with the wireless network must also be evaluated. Keep in mind that more devices are becoming dual band capable and in order to take advantage of newer technology such as IEEE 802.11ac, infrastructure support for the 5 GHz band is mandatory. Expansion of the wireless network, new technology types that may be introduced based on the business model, and BYOD acceptance and use should be considered. Even so, some wireless devices, regardless of how new they are, may not have 5 GHz capability and therefore will not operate in the 5 GHz U-NII bands. This is especially true with less expensive consumer-grade devices.

The Environment

Understanding the environment in which the wireless network will be installed and the wireless mobile devices that will be used within the environment are important factors that are sometimes overlooked. Different environments will have different concerns. For example, areas that may have excess RF noise, areas with harsh environmental conditions (such as temperature fluctuations), or industrial areas have their own set of challenges. Different environments may have distinct types of challenges:

- General office spaces: Walls and attenuation values
- Office cube farms: User and device density
- Health-care environments: Wireless medical and other interfering devices
- Industrial areas: Reflections and machine shop equipment
- Educational environments: High quantity of mobile devices

These are a few examples of different environments that may use IEEE 802.11 wireless networks and the challenges that will need to be considered as part of the wireless site survey. In Chapter 2, "Wireless Local Area Networking, Standards, and Certifications," you learned about some of the various deployment scenarios for common wireless network types.

Performance Expectations

Keep in mind that IEEE 802.11 wireless networks are half-duplex, shared medium, and contention-based and that many factors will affect the performance of a wireless network, including the number and capabilities of wireless and mobile client devices, types of software and hardware applications used, location, and the number of infrastructure devices providing access. These infrastructure devices include wireless access points and bridges. Part of a wireless site survey involves defining what the customer expects for performance of the network. A mutual understanding of the factors that affect performance as well as how they will be dealt with is imperative from the beginning of the wireless site survey process.

Bring Your Own Device Acceptance

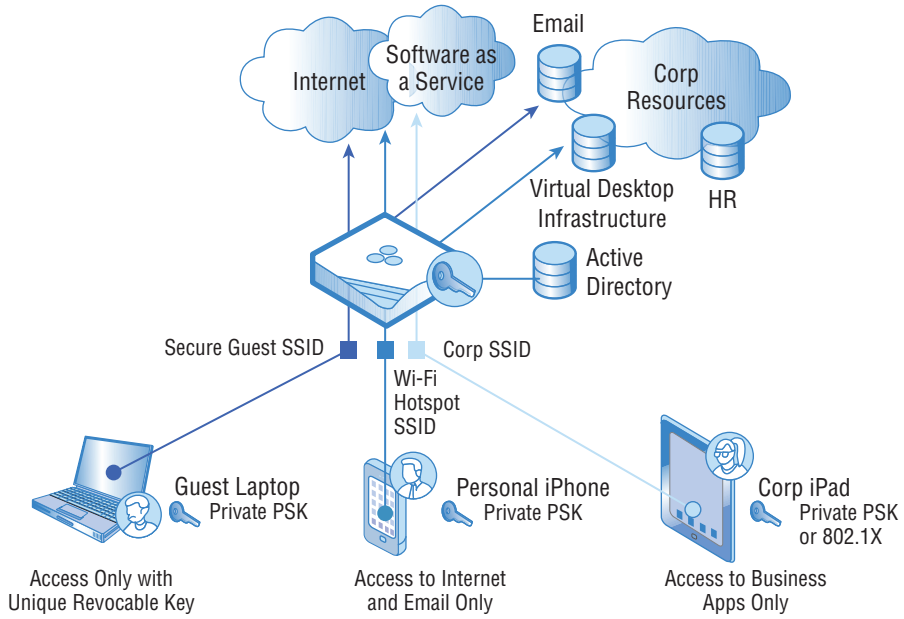
With the number of IEEE 802.11–enabled wireless mobile devices continually growing, the need for increased wireless network capacity is a major concern. *Bring your own device* (BYOD) describes the recent increase in company employees bringing their own personal IEEE 802.11–capable mobile devices, such as smartphones and tablets, to their place of work and using these devices to access company resources, including the Internet, printers, software applications, and file servers. Take a moment and think about the number of IEEE 802.11–enabled mobile devices you may have in your office or home. Any of the following devices would qualify:

- Notebook computers
- Smartphones
- Tablet devices
- Wireless printers
- Wireless video cameras
- Wireless household appliances
- DVD or Blu-ray players
- Wireless-capable gaming devices
- Wireless-capable televisions

These are just some of the devices that are used daily and are now IEEE 802.11 wireless capable. A family of four people may have as many as 20 wireless devices in the home, and this number will likely increase as wireless technology continues to advance due to developments such as IEEE 802.11ah, IoT, and so on. When companies or organizations allow employees to bring their personal wireless devices to the office or place of work, that opens up an entire set of potential issues, including security, technical support, and wireless infrastructure capacity concerns.

If employees are allowed to bring their own devices to their place of business, you must take this into consideration when performing an RF site survey and designing a wireless network. Because IEEE 802.11 wireless networks are contention based and use a shared medium, the added number of devices will impact the performance if the network is not properly designed. Higher density and wireless networks that support BYOD may require smaller RF cells and additional wireless access points in order to offer adequate performance for the number of connected devices. In addition to the load factor, the types of technology used—IEEE 802.11a/b/g/n and IEEE 802.11ac—will have an impact on the need for backward compatibility. Figure 9.1 shows how a number of personal devices can have an impact on the capacity of a wireless network.

FIGURE 9.1 Various personal devices that may be connected to a wireless network



Building Age and Construction Materials

It is important to identify the age of the building and the materials that were used for its construction. RF propagation is required for adequate coverage and desired signal strength. In older buildings it may be difficult to determine what materials the walls consist of based on the building practices at the time of construction. If an RF signal does not propagate sufficiently, additional access points may be required for adequate coverage and capacity requirements. Newer buildings will have lighter and thinner yet stronger construction materials that may make it easier for an RF signal to penetrate. In addition, covering an office with open space and cubicles will be easier than covering a hotel or enclosed areas with many rooms and walls. Coverage is just one part of the equation. Network capacity must also be considered and is discussed later in this chapter.

Network Infrastructure Devices

It is important to factor in network infrastructure devices, such as Ethernet switches. For example, installing 500 access points in a hospital will require 500 Ethernet switch ports to connect the access points. It is unlikely that a hospital or any organization for that matter will have 500 open and available Ethernet ports and therefore will not be capable of supporting the required wired network capacity needed for the wireless network installation.

Also, considering the access points will be installed throughout the building, it is important to note where the wiring closets are and how many Ethernet switches and ports will be required per wiring closet. When you're running twisted-pair Ethernet cabling, the access point must be within 100 meters (328 feet) of the wiring closet. The access points will be powered using Power over Ethernet (PoE), so choosing a proper PoE source is critical. In addition, it is important to ensure that the wiring closets have adequate supply power to support additional Ethernet switches and the PoE they will provide to the connected devices.

A wireless engineer conducting a wireless site survey will also work with the wired network engineers. Adding 500 access points and many additional wireless mobile client devices will increase traffic to and from the WAN and Internet. The network infrastructure devices will need the capacity to handle to additional traffic.

Gathering Business Requirements

Gathering information is typically the first step of wireless network design and implementation. The business model or type of business where the wireless network will be deployed is a major part of deciding the level of a wireless site survey. The type of business will determine the needs and use of a wireless network. Knowing the applications used—both hardware (such as VoWLAN) and software (such as accessing a database)—is a critical part of a wireless deployment because this will affect recommendations, such as the number and locations of access points. Expectations can make or break a wireless deployment. The expectations of the wireless network must be discussed, evaluated, and documented up front. To completely understand what the customer expects, you will need to gather information from various areas of the business. A high-quality site survey requires many questions to be asked and answered, including the following:

Bandwidth and Capacity Needs How much bandwidth will users of the wireless network require? The types of applications in use will have an impact on this. How many wireless devices per user? Most manufacturers have wireless design guides that you can reference for various deployment scenarios.

Coverage Area In what rooms or areas of the buildings is wireless coverage expected? Is coverage limited to indoors only, or will outdoor coverage also be required? Many businesses want coverage over the entire location.

Applications Used What types of applications—either hardware or software—are used at the facility? How will the applications affect the performance? This may include computer-aided design, digital imaging, databases, and VoWLAN.

Wireless Devices Used What types of wireless client devices will be used? Are the devices multifunctional? These include notebook computers, handheld scanners, smartphones, tablets, and other devices, both company owned and employee owned (BYOD).

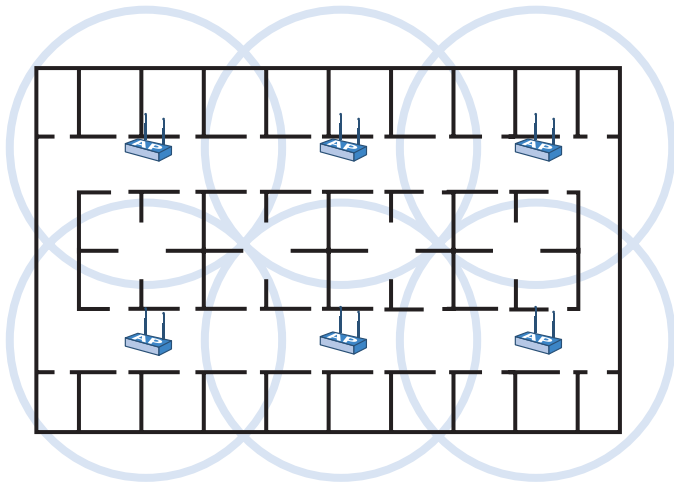
Desired IEEE 802.11 Technologies What type of IEEE 802.11 infrastructure devices (IEEE 802.11a/b/g/n, IEEE 802.11ac, and IEEE 802.11ah) would be best suited to the specific environment and deployment?

IEEE 802.11 wireless networks were once primarily used as extensions of wired networks, providing access to a few users in areas exceeding the physical distance of an Ethernet or other wired medium. IEEE 802.11 wireless technology continues to evolve and is now a major part of every area in a business, corporation, or company's computer network infrastructure. It is difficult to find any business or organization that does not provide some type of IEEE 802.11 wireless network access. Fully understanding the *business requirements* is part of a successful wireless network site survey and deployment.

General Office/Enterprise

Office buildings and other enterprise installation locations may consist of walled offices or open spaces with many cubicles. This type of installation usually will require infrastructure devices to aesthetically fit the environment and may require antennas to be mounted to drop ceilings with the access points located out of sight. Figure 9.2 shows an example of a floor plan for a small office deployment.

FIGURE 9.2 A small office wireless network installation using omnidirectional antennas



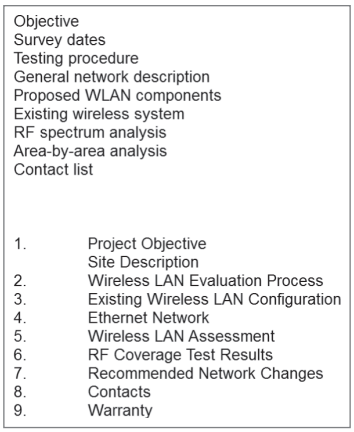
Some installations may have a high density of wireless mobile devices and therefore require more access points to handle the number of wireless devices connected to the network. The software and hardware applications used in these environments will need to be closely evaluated to ensure optimal performance for the user base. Chances are that interference sources in this type of deployment would be limited mostly to computer networking, and RF challenges may be limited.

Interviewing Stakeholders

Understanding the intended use of a wireless network is a critical part of a successful deployment. And who better to explain what the wireless network will be used for than those who will be using it? Those performing a site survey may not necessarily understand the functional aspects of a certain type of business, so it is critical to get input from everyone who will be using the wireless network. Department managers, business unit managers, and team leaders usually know the function of their specific areas of the organization the best. Therefore, they will also know the needs and requirements of users of the wireless network and how a successful deployment will help increase job productivity.

We recommend that you create some type of checklist or formal site survey questionnaire to use during the interview process. This will ensure that specific details about the business and proposed wireless deployment are not missed. The use of such forms helps ensure uniform, repeatable interviews. The forms can also become part of the documentation and final deliverable that will be presented to the customer. Although there are some general questions that can be asked, there will be more specific questions based on the business model of the organization or the wireless network to be installed. Figure 9.3 shows an example of notes that can be taken during the information gathering stage and the wireless site survey specifics.

FIGURE 9.3 Sample checklist showing some information collected for a wireless site survey



The following list includes some generic interview questions that will pertain to most wireless network installations:

Has a site survey ever been performed in the past? It is good to know whether a site survey has previously been performed at a location. Although the previous site survey is only as good as the people who performed it, it may be beneficial and a timesaver to have some

information available. Depending on when it was performed, a previous site survey report may not be accurate because, for example, physical changes to the location may have taken place, such as additions of rooms or walls or changes to the interior design.

Are blueprints, floor plans, or any other site-specific documentation available? Blueprints, floor plans, or other documentation about the location are critical in performing an RF wireless site survey. If this information is not available, it may have to be created, which in turn would create an additional expense for the company or customer. The accuracy of these documents needs to be considered in order to provide ideal site survey results.

How many wireless mobile devices and users will be using the wireless network? What are the bandwidth and capacity requirements? The number of devices expected to be on the wireless network is valuable information to have. Knowing the number of devices and users will help determine the amount of infrastructure equipment, such as access points and wireless bridges, that will be required for the deployment. Discussing with department managers the number of devices and users on the network as well as the number of working shifts will help provide adequate planning. It will also be beneficial to know whether users are allowed to bring their own devices.

Will guest access be required? If guest access to the wireless network is required, that will potentially affect the number of infrastructure devices such as access points required for the deployment. Depending on the type of access, network capacity will need to be considered. In addition to the equipment, you should take into account security, the captive portal, and backward compatibility.

Is there any preference for a specific manufacturer's equipment? It is a recommended practice for a site survey to be performed with the same manufacturer's equipment that will be used in the deployment. Therefore, customer preference for equipment manufacturers must be determined at the initial phases of the site survey. This will ensure good results based on the design of the wireless network.

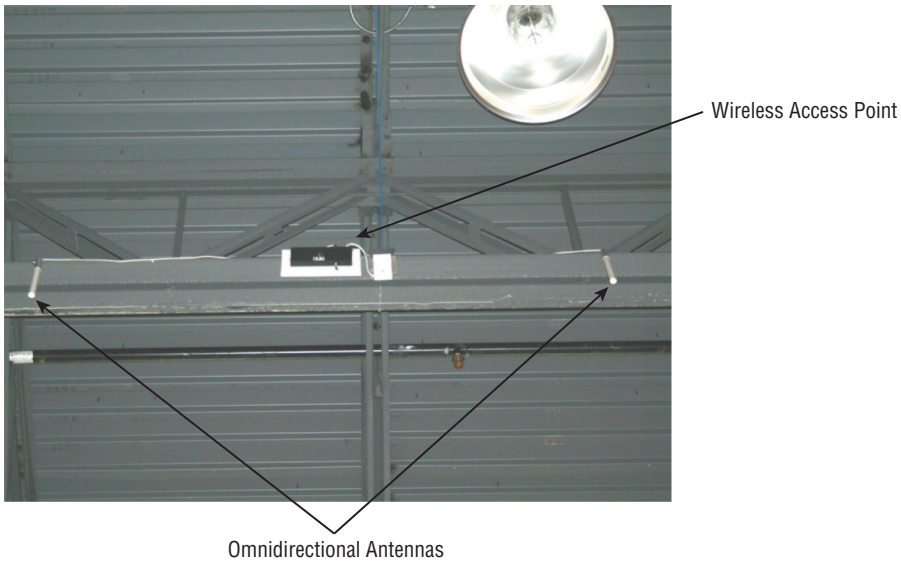
What is the coverage area? The intended coverage area of the facility also needs to be addressed. This helps provide a surveyor with information to accurately estimate how long a physical site survey may take and roughly estimate the amount of hardware required. Knowing the coverage area will also help determine any unexpected obstacles that may occur as part of the site survey process.

Is an existing IEEE 802.11 wireless network in place? If an existing IEEE 802.11 wireless network is in place, it needs to be addressed as part of the site survey process. The following questions need to be asked:

- Which technology is currently in use, IEEE 802.11a, IEEE 802.11b/g, IEEE 802.11n, or IEEE 802.11ac?
- How many wireless devices and users does the network currently support?
- Where are the existing access points located?
- Are the existing access points and external antennas installed correctly?
- What is the wireless network used for?

Knowing the answers to these and other questions will help determine the role, if any, that the existing IEEE 802.11 wireless network will play in the new deployment. Keep in mind that some organizations may have quite an extensive existing wireless network and may be in the process of upgrading to newer or different technology. If this is the case, it will need to be determined whether any of the existing network components can or will be used with the new deployment. Photographs of existing equipment used in a deployment are always useful. Figure 9.4 shows a photograph of an existing IEEE 802.11a/b/g access point with an incorrect installation of diversity antennas. If this were a new or updated installation and external antennas were used, the antennas would need to be set to the proper spacing based on the technology in use such as IEEE 802.11n/ac.

FIGURE 9.4 A legacy IEEE 802.11a/b/g dual-band access point mounted on a ceiling 35 feet high with diversity antennas spaced incorrectly for diversity technology



Are there any known areas of RF interference? Information regarding known areas of RF interference is useful in a site survey. It will save time if previous knowledge of RF interference is made available as part of the site survey process. Keep in mind that interference may change and can be detected only at the time of testing or when a manual site survey is performed.

Are there any known areas that may lack RF coverage? Just as previous knowledge of areas affected by RF interference is valuable, the lack of RF coverage in specific areas is also good to know. This will help a surveyor determine any special situations that may be addressed during the site survey process. Testing of various types of antennas may be required to help provide RF coverage in areas that are currently lacking. Available coverage maps may also be useful.

What type of applications will be used? It is important to know the types of applications that will be used. Applications—either software or hardware—will affect the load and number of access points or other infrastructure devices required. These applications include bandwidth-intensive software, VoWLAN, and so on. The surveyor should also become familiar with any special circumstances that may be required to support these applications—for example, the frequency or IEEE 802.11 technology that may be required for the wireless devices to operate.

Will VoWi-Fi or other real-time applications that require QoS be used? If applications (such as VoWi-Fi handsets) are planned for the location, they will have an impact on the site survey and design of the wireless network. Because this type of application has greater requirements for signal quality, signal strength, and fast transition, this will need to be taken into consideration during the site survey. Additional density and more access points may be required.

Real-time video communications, such as a videoconference calls over a wireless network connection, is another application that may require QoS. Like voice, real-time video is subject to latency and may involve special design requirements. Real-time video over a wireless connection is used in applications ranging from sports venues to security surveillance and monitoring.

Is wireless transition (roaming) required? In most cases, with newer technology, the answer to this question is yes. This is especially true with networks that will be using Wi-Fi-capable voice handsets. Voice handsets are among the most commonly used wireless mobile devices that require seamless roaming and secure transition capabilities. Although notebook computers and tablets may require transitioning, real-time voice and video applications are subject to latency issues. Fast, secure transitions may also be required for roaming. If so, the amount of overlap between RF cells would need to be closely looked at to ensure reliable sessions for the devices connected to the network.

Is PoE required? In all medium-to-large installations, the answer to this question is yes. Understanding the PoE requirements is another essential part of the wireless site survey. The capabilities of the network devices as well as the number of devices expected to use PoE—including wireless access points, hardwired Ethernet IP phones, and security cameras—will play a role in the design and types of equipment used in the wireless network.

What are the wireless security requirements? Although security is not necessarily part of an RF site survey or design, as much information as possible on the security requirements is helpful with the design of the wireless network. Some security solutions may require additional hardware, such as sensors that are used with a wireless intrusion prevention system (WIPS) or software that would have to be taken into account for the network design.

Will an escort and ID badge be required? In many cases, people are not allowed to roam freely throughout a business. An escort might be and usually is needed to walk through a location with an outside contract site surveyor. In addition, the escort and surveyor will need access to areas that may be locked or secure, such as wiring closets and computer rooms. Escorts may be from various parts of the company, hospital, or organization,

including facilities, information technology, medical staff, and security. Depending on the organization, proper paperwork for access may need to be submitted ahead of time to allow for adequate processing time. For example, you don't want to show up on a Monday morning only to find out it will take hours or even days to process the paperwork needed to get an ID badge for access.

Are there any compliance requirements? Depending on the type of business in which the wireless network will be installed, there may be legislative or other compliance requirements. For example, medical institutions may have to meet HIPAA requirements, and retail establishments may require PCI compliance. These need to be taken into consideration as part of a wireless site survey and deployment.

Are you following corporate policies? If one exists, you should use a written corporate policy as a guideline or offer suggestions for changes in the policy to accommodate other wireless requirements. The wireless site survey questioning process should bring any policy-related issues to light for discussion and/or change if needed.

Manufacturer Guidelines and Deployment Guides

The information just presented includes some types of questions that need to be addressed during the site survey process. Keep in mind that the actual questions and details depend on the business model and the implementation of the wireless network. For site survey and deployment guides, check with the manufacturer of the equipment that you will use. These guides will provide additional helpful information for generating a list of questions and concerns that will need to be addressed.

Gathering Site-Specific Documentation

Documentation for the location where a wireless network will be installed will make a surveyor's job much easier and result in a smoother overall deployment. Drawings and other documentation pertaining to the following items can provide valuable information:

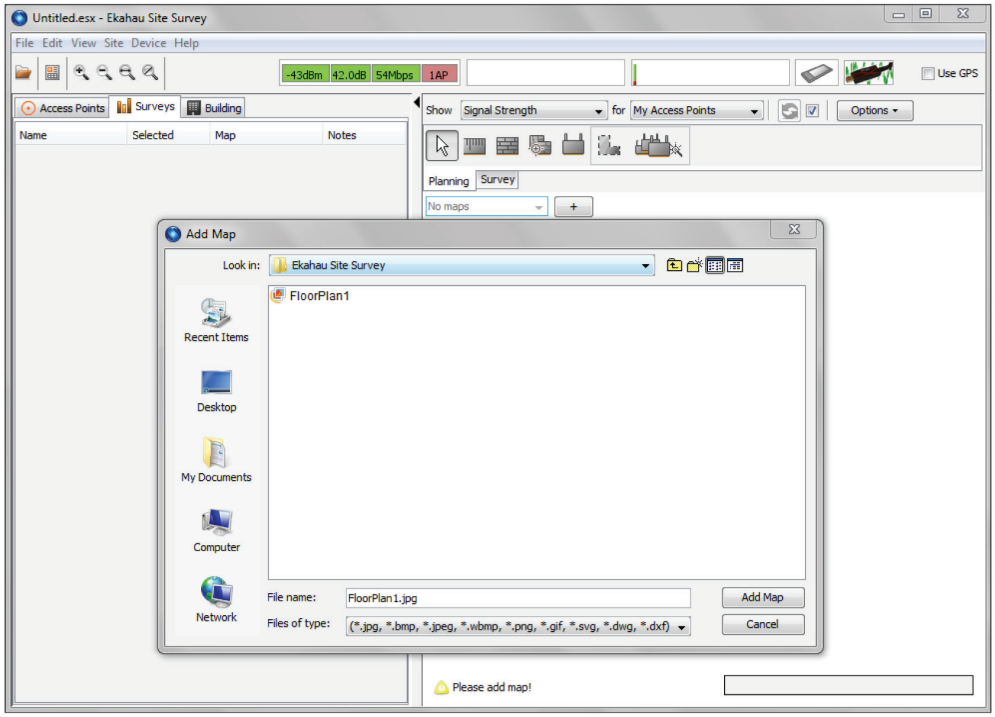
- Floor plans
- Blueprints
- Proposed location of furnishings
- Electrical specifications
- Existing network characteristics

Floor Plans and Blueprints

Gathering any site-specific documentation that exists, such as floor plans or blueprints, is extremely helpful for a site survey. This documentation is useful to a variety of individuals who will be participating in a wireless network design and deployment. The documentation

can be used during a physical or predictive RF site survey and spectrum analysis to note areas of importance and concerns. Having floor plans and blueprints available allows a surveyor to document specific parts of a site survey, such as the location of access points and other wireless devices. If a predictive modeling site survey is used, an electronic version of a floor plan can be imported into the software program to help streamline the surveyor's job. The standard formats for floor plan (map) files vary from product to product for most modeling software, but they typically include DWG, PDF, JPG, PNG, GIF, and TIF. Figure 9.5 shows a site survey software program that allows for various file formats to be imported.

FIGURE 9.5 Importing a floor plan map using the Ekahau Site Survey program



Blueprints or floor plans will also help those who install cable and mount hardware and can be provided to electricians for AC power installation, if necessary.

Furnishings

The proposed types and location of furnishings or other items that may affect RF signal propagation or penetration are also good to know. This will help during the design and site survey phase to determine access point locations and pinpoint other things that may affect RF signals, such as reflection, refraction, diffraction, and absorption. Unfortunately, most floor plan documents do not specify this kind of information, because in many cases furnishings are not permanent fixtures and can change. Some organizations will have this

information stored in asset documentation using spreadsheets or databases. Many times it will be up to the surveyor to determine where the furnishings or equipment are located and the effect it may have on the RF.

Keep the following in mind when gathering information about the types and location of furnishings:

- In an office or enterprise environment, furnishings may consist of desks, cabinets, chairs, and other items.
- In warehousing and retail environments, furnishings will include storage racks and shelving as well as product inventories.
- In manufacturing environments, information should be gathered about the location of industrial equipment used in the manufacturing process and about equipment used to move products throughout the factory.
- In medical environments, furnishings or equipment will include devices that may cause interference and operate in the same RF range as the proposed wireless network. Storage of items used within the hospital or medical environment for patients and employees may also affect RF coverage.
- In educational environments, the location of lockers and internal windows is important to note, as are the types of materials used in the walls, such as concrete blocks with and/or without sound dampening material inside. All these factors will have an effect on the RF propagation.

These are just some examples of the types of furnishings and other items that may affect a wireless network deployment and are factors to consider.

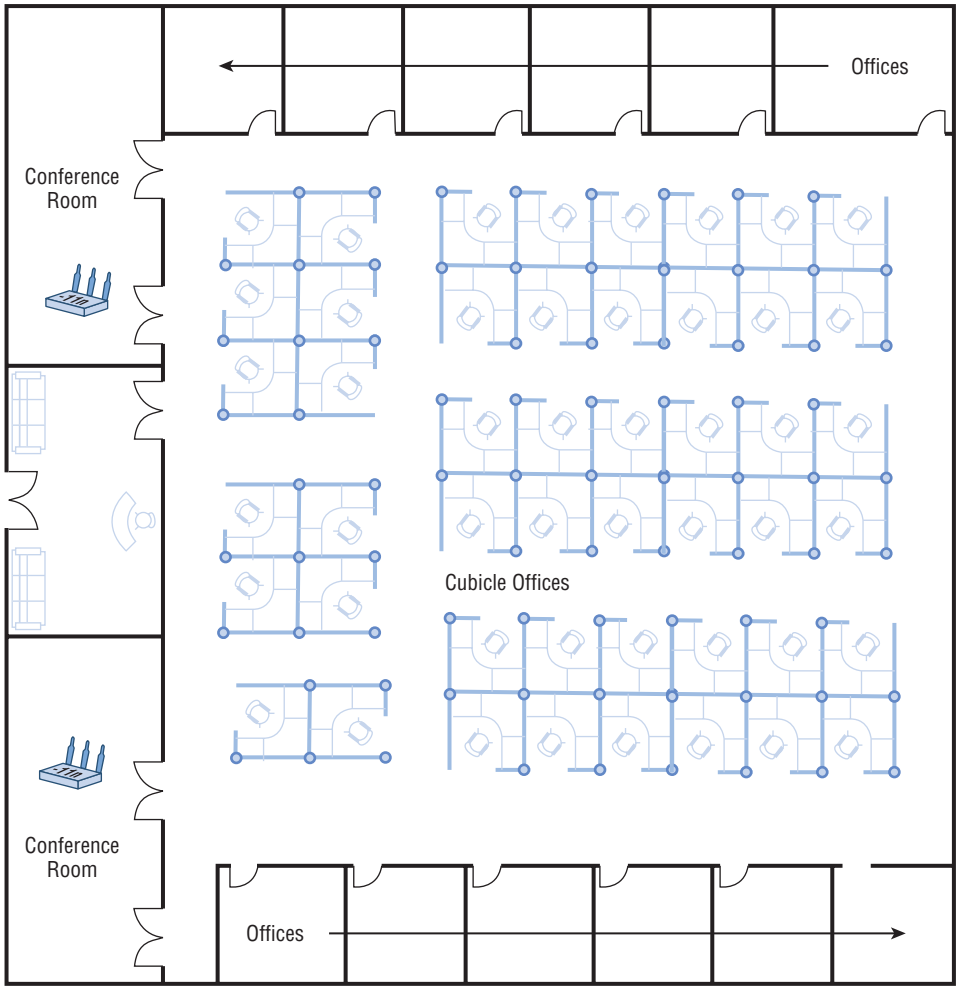
Electrical Specifications

Documentation of the electrical specifications of the environment is helpful in determining whether the current electrical implementation will be sufficient to handle the proposed wireless network deployment. This will allow the site survey process to determine whether any upgrades need to be made to support devices that may be using PoE or whether the existing infrastructure is sufficient. It is best to gather information regarding electrical power sources, electrical panels, existing wiring, and the locations of electrical outlets.

Existing Network Characteristics

Documentation is a major part of any business, including documentation of computer networks. In order to have a successful deployment of a wireless network, it is critical to know the details of the existing network infrastructure as well as future implementations, upgrades, and modifications. These existing infrastructures may include a wired or wireless network already in place and functioning that may be upgraded or in a new deployment. Figure 9.6 shows a floor plan with an existing wireless deployment of only two access points providing wireless access for the conference rooms. This information can be used as part of the new wireless site survey and network design.

FIGURE 9.6 Floor plan with an existing wireless network deployment



The following list includes some of the questions that you should take into consideration when performing a wireless site survey:

- In what RF range will the new wireless network operate?
- Are there any existing IEEE 802.11 wireless networks in the same RF space?
- Will all or part of the existing wireless network be used in the new deployment?
- What effect will the neighboring wireless networks have on this deployment?

Ignoring existing IEEE 802.11 wireless networks will have a significant impact on how a new wireless network will operate and result in poor performance for the clients or devices that will be connecting.

Documentation of networks is usually the responsibility of the IT department. Some organizations may lack good documentation of the existing network infrastructure. If this is the case, additional work may be required prior to starting a wireless site survey.

Existing IEEE 802.11 Wireless Networks The scope of any existing wireless networks must be determined during the interview process. If a wireless network does exist (as it often does), it will need to be dealt with during the site survey and design procedure. The questions that are asked regarding the existing wireless network will help determine the role it is going to play. If the existing network is going to remain in place, understanding its technical details and how to work it into the design of the new or upgraded deployment will help you create a successful and productive wireless network deployment.

Existing IEEE 802.3 or Other Wired Networks In addition to knowing of any existing wireless networks, you should know about the wired network infrastructure. Existing documentation on the wired network infrastructure will help streamline the process for connecting the IEEE 802.11 wireless components of the network. The wired infrastructure is discussed in more detail in the next section of this chapter.

Existing wireless networks play a big role in a new wireless network deployment. Understanding the current location of infrastructure and other wireless network devices is an important part of a wireless site survey. One way to see devices that are part of a wireless network is to use a protocol analyzer. Other programs, such as MetaGeek inSSIDer or Xirrus Wi-Fi Inspector, will also be able to view existing wireless networks. In some cases, these programs may be adequate based on the complexity and size of the site survey. But they typically do not have the extensive feature set that many protocol analyzer packages have.

Identifying Infrastructure Connectivity and Power Requirements

Why are there so many wires in wireless networking? Wireless networks require some type of wired infrastructure for many reasons, including connecting access points together, allowing wireless device and user access to network resources, providing access to a WAN, allowing Internet connectivity, and supplying electrical power.

Network infrastructure connectivity plays a big role in wireless networking. A wireless site survey will require additional information about the network infrastructure and power requirements. In a sense, a wireless site survey also requires a wired or infrastructure survey. A wireless site survey should include information about the wired network, including the location of the wiring closet, the wired infrastructure network devices in use, the connection speed between sites, and the electrical power requirement:

Location of Wiring Closets A *wiring closet* is a room (usually secured) containing electrical power and cabling for voice and data and that is terminated and connected to infrastructure devices, such as switches and routers. In most cases, these locations are noted on

the floor plan or blueprint documents, but that may not always be the case, and you will need to find them if they are not noted. When deploying a wireless network, you should know not only the physical locations of wiring closets but also the capacity of existing infrastructure devices. This is important because wired connections, such as IEEE 802.3 Ethernet, have specific limits for cable lengths, and infrastructure devices, such as access points and bridges, will have to be placed within these physical limits of infrastructure connectivity. For example, the IEEE 802.3 Ethernet standard has a physical maximum cable length of 328 feet (or 100 meters) for unshielded twisted-pair wiring.

In addition to cable length, the feasibility of running the Ethernet cable from the wiring closet to the desired location must be considered. For example, the intended location for an access point may be on a ceiling without any access from above. In this case, the lack of accessibility could pose a problem for the installation of the Ethernet cabling from the wiring closet and/or AC power to the devices.

Wired Infrastructure Network Devices in Use The wired infrastructure devices in use may have an impact on a successful deployment of a wireless network. An evaluation of the infrastructure devices by a WLAN site surveyor or a network infrastructure professional may be required to determine if any additional hardware is needed or if changes must be made prior to deploying a WLAN. If the infrastructure devices, such as Layer 2 switches and routers, are not adequate to support a new wireless deployment, additional hardware may need to be purchased.

Connection Speed between Sites The connection speeds and type of connections between sites should be evaluated to determine if there are any bottlenecks that could affect the overall network performance. The placement of authentication servers and other network resources may be affected by the speed of these links.

Electrical Power Since all wireless network infrastructure devices, including access points, bridges, and wireless switches, require an AC power source, and because these devices may be supplying PoE to the infrastructure devices, verification of an adequate AC power supply must be performed. The AC power sources are sometimes taken for granted or not taken into consideration, which could pose a problem during the installation phase. It is also important to determine what local ordinances may apply and what they allow you to do for a wireless network installation.

Because PoE is used not only in infrastructure devices but also with IP telephones, security cameras, and user devices, it may be necessary to perform calculations and verify that the power supply to the wiring closet will be adequate to support the powered infrastructure (including the PoE devices). Electrical components of a wiring closet may need to be upgraded to support a new wireless network deployment. Newer wireless networking technologies, such as 802.11ac MIMO systems, may require more DC power than is available with the IEEE 802.3af PoE amendment to the Ethernet standard.

If these technologies will be used, the power requirements will need to be carefully considered to verify that enough DC power will be available to the endpoint powered devices. Manufacturers now provide IEEE 802.3at (with new PoE capabilities) endpoint or midspan

devices to provide the necessary amount of DC voltage for certain PoE-capable devices. All manufacturers of enterprise dual-band IEEE 802.11n wireless access points claim their equipment will operate with standard 802.3af power. You should read the specification data sheet for the access point, WIPS sensor, or other wireless infrastructure device to determine the type of PoE required and whether IEEE 802.3af or IEEE 802.3at will be required to provide DC power to the device.

It is important to understand that wireless infrastructure devices require some sort of wired connectivity for data and electrical power. Data access will usually come by way of an Ethernet connection from a wired network infrastructure or backbone. As stated in the IEEE 802.3 Ethernet standard, the maximum length for unshielded twisted-pair Ethernet cable is 328 feet, or 100 meters. This limitation may have an impact on how and where access points and other infrastructure devices are placed.

During the wireless site survey process, the surveyor will need access to wiring closets. This will allow the surveyor to evaluate and perform a survey of the wired network infrastructure as well.

Another consideration is electrical power requirements. Infrastructure devices need electrical power as well as data connectivity to operate. If the electrical power is decentralized and located at each device, an electrician will need to evaluate and determine the requirements.

PoE is an option for supplying electrical power to infrastructure devices. This technology is now very common and is supported by all enterprise device manufacturers. A survey of the wired infrastructure and devices is almost always required to determine if the infrastructure will be capable of handling the new PoE devices that will be installed. Keep in mind that zoning and building regulations, electrical contractors, and labor union requirements may add to the overall cost of wireless deployment. PoE was discussed in Chapter 3, “Infrastructure and Client Devices Used with Wireless Networking.”

Understanding Application Requirements

Understanding the requirements for software applications is another important part of a successful wireless deployment. The types and number of applications used will affect the performance and the capacity of an IEEE 802.11 wireless network. Some software applications are very bandwidth intensive and will require more resources than others to perform effectively as designed. Examples of these applications are streaming video, computer-aided design (CAD), and database programs. By contrast, applications used for email, social media (if policy allows), and casual Internet browsing are not bandwidth intensive.

Because digital imaging, graphic design, CAD, and database applications can have a tremendous effect on the performance of a wireless network, they require special attention when the network is designed. The infrastructure resources that will be impacted include the processing power and memory capacity of the wireless access points, and the speed of the wired infrastructure itself, such as 100 Mbps or 1,000 Mbps (gigabit).

This, in turn, will affect the site survey and network design. The wireless site survey will be impacted because the location where the wireless network is installed may require more infrastructure devices or access points. Other applications, such as VoWLAN, may introduce another entire set of issues. This type of deployment may use only the 5 GHz band for wireless voice technology, and therefore the wireless site survey must be performed accordingly.

Understanding Radio Frequency Coverage and Capacity Requirements

A major aspect of a wireless site survey is to understand and verify the RF coverage and capacity requirements based on the network design. A wireless network site surveyor will need to verify these requirements as part of the site survey. This can be accomplished either manually or automatically through a predictive modeling process, both of which will be discussed in more detail later in this chapter.

To review, the wireless coverage and capacity requirements depend on the following factors:

- Physical size of the area to be covered
- Number of users or devices accessing the wireless network, including BYOD users
- Software or hardware applications in use
- Obstacles and propagation factors based on the environment
- RF range of the network to be installed
- Wireless network hardware to be used
- Output RF power of the transmitters
- Receive sensitivity of the receivers

In addition to an RF coverage analysis, an *RF spectrum analysis* will be beneficial. An RF spectrum analysis allows a site surveyor to view areas of RF coverage as well as interference sources and non-IEEE 802.11 wireless devices. This topic will be discussed later in this chapter. Although a spectrum analysis is not required, it does allow a site surveyor to view sources of RF in the locations where a wireless network will be deployed.

Client Connectivity Requirements

The wireless client devices that will be connecting to the wireless network also need to be considered as part of a site survey. This includes knowing the radio type, antenna type, gain, orientation, portability, and mobility of the devices. Keep in mind that a wireless client device is both an RF transmitter and a receiver. The client (receiver) must be able to

hear the transmitter, and the transmitter must be able to hear the client. The RF cell size will vary from device to device. It is beneficial to survey with the type of devices that will be used with the wireless network whenever possible. Understanding the type and function of client devices will have an impact on the design of the wireless network. The following wireless client devices are commonly used in a wireless network:

- Notebook computers
- Tablets
- Pocket computers
- Smartphones
- Bar code scanners
- Point-of-sale devices
- Voice handsets

Other wireless devices used in various wireless applications include but are not limited to the following:

- Desktop computers
- Printers and print servers
- Manufacturing equipment
- IEEE 802.11–friendly video cameras

Many environments have both desktop and notebook computers as wireless client devices. These devices may or may not require roaming capability. Office and enterprise deployments commonly use handsets for voice communications. Although it is fairly difficult to take all potential wireless client devices into consideration, it is best to understand the types of devices that will be used. This information can be obtained through the interview process and the information gathering stage of the site survey.

Antenna Use Considerations

Chapter 4, "Radio Frequency Fundamentals for Wireless Networking," discussed various types of antennas and accessories. The antenna used in any wireless network installation will depend on the specific scenario. As part of the site survey, various antenna types may need to be used for testing purposes to determine the best antenna for a specific application. In some cases, the customer may want a specific type of antenna, such as an omnidirectional antenna mounted directly to the access points. Others may be using access points without external antenna capabilities.

Some businesses are concerned about aesthetics and are particular about the appearance of an antenna and the mounting location. The proper antenna selection will ensure correct coverage as intended by the design and site survey of the wireless network. The antenna type used will determine the propagation pattern of the RF and is a significant part of a

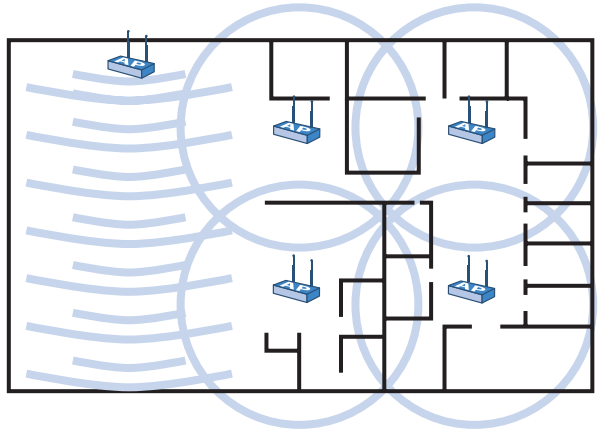
successful wireless deployment. The antenna used in various deployments will depend on the business model in which the network is installed:

General Office/Enterprise General office/enterprise solutions usually require complete coverage throughout the entire location. In many cases, this type of installation will require access points mounted out of sight and aesthetically pleasing antennas. This could be an omnidirectional antenna mounted to a ceiling tile or integrated within an access point.

Manufacturing Manufacturing environments are usually industrial facilities with high ceilings and various types of manufacturing and industrial equipment. These environments may use a combination of omnidirectional and semidirectional antennas due to the physical architecture of the buildings. The antennas also may need to withstand harsh environmental conditions such as extreme temperature fluctuations and dirt.

Warehousing Warehousing implementations have some characteristics in common with manufacturing. The buildings that house this type of business are in many cases large open areas with high ceilings to allow the storage of large volumes of product and equipment. Antenna mounting needs to be looked at very closely to ensure that equipment such as forklifts used to move product do not come in contact and damage antennas. Warehousing also may use a combination of omnidirectional and semidirectional antennas for proper coverage. Figure 9.7 shows a sample floor plan for a combination small office/warehouse deployment using a combination of omnidirectional and semidirectional antennas.

FIGURE 9.7 Small office/warehouse floor plan showing RF coverage using different antenna types



Retail/Point-of-Sale Retail/point-of-sale (PoS) installations may have to accommodate publicly accessible areas as well as warehousing and storage in the back of the buildings. In this type of installation, antennas will be a combination of omnidirectional and semidirectional. The devices may consist of computers as well as other handhelds, such as wireless bar code scanners or portable wireless devices. Appropriate antenna selection and gain

need to be considered to ensure that the devices have good signal connectivity to the infrastructure. In many cases, the public areas will require aesthetics to be taken into account in antenna selection. In the storage part of the building, antennas are similar to those described in "Warehousing."

Health Care and Medical Many health-care and medical deployments are publicly accessible, so aesthetics and security are both important. Antenna types that fit the environment and are not accessible to the public are commonly used. Some health-care facilities, such as hospitals, may require the use of only omnidirectional antennas mounted to the autonomous access point or integrated into an access point. Others may allow semidirectional antennas, such as a Yagi, to cover long hallways and corridors.

Government and Military Government and military wireless environments are usually not publicly accessible and in many cases are campus-based deployments that require outdoor as well as indoor solutions. In these installations, antennas mounted directly to an access point or semidirectional antennas may well fit the environment. For outdoor point-to-point or point-to-multipoint, highly directional antennas, such as parabolic dishes, may be required.

Education Education deployments are typically campus-based deployments and may require the use of outdoor antennas to connect buildings together. However, for indoor solutions, ensuring that the antennas will fit the environment and not be tampered with is important. These deployments may use a combination of omnidirectional and semidirectional antenna types. Some locations may require the use of enclosures for the infrastructure devices to ensure security of the physical devices. In these cases, special connectors and antenna adapters may be required.

Public Access, Hotspot, and Hospitality Public access, hotspot, and hospitality sites are publicly accessible locations that will require aesthetics and security when it comes to antenna selection, as with some of the previous examples. These deployments can use a combination of omnidirectional, semidirectional, and highly directional antennas.

Another consideration when choosing an antenna is that the wireless system must comply with the rules set forth by the local regulatory agency. Before installing an antenna, verify that it will not violate any RF regulations.

Real World Scenario

Typical Steps Used in a Wireless Site Survey

Here are some basic steps to provide an overview of the wireless site survey process. Keep in mind that these steps may vary slightly based on the location and the type of wireless network deployment.

1. **Gathering Information and Discussing Business Requirements**: Determine the need and intended use of the wireless network and interview appropriate individuals.

Explain the site survey process and provide an overview of wireless networking. Doing so will help minimize unnecessary delays caused by people who are not included in the process but should have been and are unaware of the wireless network and site survey.

2. **Project Timeline and Planning:** Understand and document the extent and estimated timeline of the survey process and deployment. This will include all stages of the wireless site survey from start to finish, such as design, deployment, and verification. Because the wireless site survey may include people from many different areas, such as facilities, IT, engineering, and so on, everyone must be on the same track.
3. **Site Visit and Pre-design Audit:** It is a good idea to make a visit to the location to get an idea of any issues that may not be visible on a blueprint or floor plan. This will also allow for checking the RF propagation with a test access point if feasible. Performing a wireless site survey without a site visit—especially a predictive modeling survey—can be done, but that will come with some risks. Knowing what you are dealing with will minimize mistakes caused by not knowing the environment and therefore possibly making inaccurate assumptions.
4. **Wireless Network Design:** Determine areas of RF coverage and interference as well as potential placement of access points and other infrastructure devices. This will be done with an onsite manual site survey, a predictive modeling site survey, or a combination of both. An RF spectrum analyzer can be used to view the air to determine the areas of RF interference.
5. **RF Spectrum Analysis and RF Testing:** Perform testing of the proposed design and verify RF sources of interference. Also verify coverage and lack of coverage. Although an RF spectrum analysis is not a required part of the wireless site survey process, it is highly recommended. Knowing the potential RF interference may impact the wireless network design as a whole. It will be much easier to deal with potential RF issues up front rather than after the wireless network is deployed. Testing specific areas or audit points with an access point will allow the surveyor to determine the coverage and how the RF propagates from the access point.
6. **Deployment of Infrastructure Devices:** Install the infrastructure devices as described by the design. This may or may not be done by the same person who performed the wireless site survey, and in many cases it is not. This means that clear, concise documentation and instructions must be provided to the installer. This will reduce the risk of having to make unnecessary visits back to the location for corrections or adjustments because of mistakes that could have been avoided.
7. **Verification of RF Coverage:** Perform verification testing and spot checks of RF coverage per the design. Make necessary adjustments based on the results of RF testing. Verification testing may consist of spot checks in key areas (audit points) or could include the entire facility. It is important to be certain the wireless network will operate as designed. Sometimes cost or budget may not allow for a verification of the entire location, but I recommend it whenever possible. If the entire area cannot be

checked, determining the audit points should be done carefully and should be completed in the early stages of the site survey. If needed, make adjustments to allow the wireless network to operate as designed.

8. **Support**: Provide technical support for wireless network deployment. This involves maintaining the wireless network infrastructure and includes RF spectrum monitoring and making the necessary adjustments to adapt to the dynamics of environment. This can be done manually or automatically, depending on the capabilities of the technology that is deployed.

The Physical Radio Frequency Site Survey Process

After all the up-front work is completed, such as gathering information (including the business requirements and site-specific documentation), defining physical and data security requirements, and interviewing managers and users, it is time to start the physical RF site survey process and the wireless network design. This is one of the most important parts of a successful wireless network deployment. This process includes locating areas and sources of RF interference as well as RF coverage (or lack thereof) and determining the locations of access points, bridges, sensors, and other infrastructure devices that will be used with the wireless network. Capacity planning is another important part of the process, to ensure that optimal performance is achieved. The following steps detail the entire physical wireless site survey process and guidelines. The RF physical site survey is subjective, and people have different opinions on how the entire process works. In many cases, the process can be tailored based on the individual needs or requirements of the location where the wireless network will be installed. The following steps should be viewed as recommendations or guidelines:

1. Arrange a walk-through of the entire location, which may often require being escorted by an authorized person.
2. Take thorough notes and digital photographs, as needed.
3. Perform an RF spectrum analysis.
4. Determine the preliminary placement of infrastructure devices.
5. Perform onsite testing to verify the design.
6. Determine the actual placement of infrastructure devices.
7. Install infrastructure hardware as specified.
8. Perform onsite verification testing and make adjustments to verify that the design meets the specifications.
9. Deliver the final site survey report.

In today's wireless world, an RF site survey can be considered an ongoing process. Just a few years ago, not nearly as many wireless networks existed as do today, so the interference

factor was not as significant. With the RF dynamics constantly changing and more devices using RF for communications, it is up to the network engineer to take into consideration that site requirements may also be constantly changing. Therefore, the RF site survey may need to be updated periodically.

Radio Frequency Spectrum Analysis

The wireless site survey includes finding areas of RF coverage and RF interference as well as locations for hardware, such as access points, bridges, and other infrastructure devices. Although RF is not visible to the human eye, some tools are available to "see" a visual representation of the RF. One common tool is the RF *spectrum analyzer*. How the analyzer will be used will determine the type of equipment you will need for the job. RF is used as a communications mechanism for many different types of technology:

- Radio
- Television
- Computing
- Cellular voice

In Chapter 4 you learned about the fundamentals, characteristics, and behaviors of RF technology, including various antenna types. You also saw some of the common frequency bands that are used for various types of wireless technologies. Using the correct spectrum analyzer for the job is a key element to collect the data you need. Spectrum analyzers are available in various form factors, and some are designed for a specific purpose, such as wireless networking technology, whereas others can be used for a larger part of the RF spectrum. These tools can be PC based or dedicated instrumentation devices. The following section explores spectrum analysis for IEEE 802.11 wireless networks.

Spectrum Analysis for IEEE 802.11 Wireless Networks

A spectrum analyzer used with IEEE 802.11 wireless networking can be limited to the specific RF bands used with wireless networking. This includes the 2.4 GHz ISM band and the 5 GHz U-NII bands. Figure 9.8 shows a spectrum analyzer view of the 2.4 GHz ISM band with the access points on various channels. Spectrum analyzers vary in cost and complexity, depending on the frequency ranges they are designed to work with.

The spectrum analyzers that are designed specifically for the wireless market usually work only in the license-free radio bands. They are typically less expensive because of spectrum limitations. Spectrum analyzers allow you to view the Physical layer of communication between devices used in wireless networking. Spectrum analyzers that work with IEEE 802.11 wireless networking technology are available in devices that attach to a USB port on the computer and instrumentation-style devices that can be used for applications other than wireless networking. Legacy solutions are PC card–based models, which may still be available in some markets. Figure 9.9 shows an example of a wireless network spectrum analyzer that connects to a USB port on a computer.

FIGURE 9.8 MetaGeek Chanalyzer shows an RF capture of the 2.4 GHz ISM band.

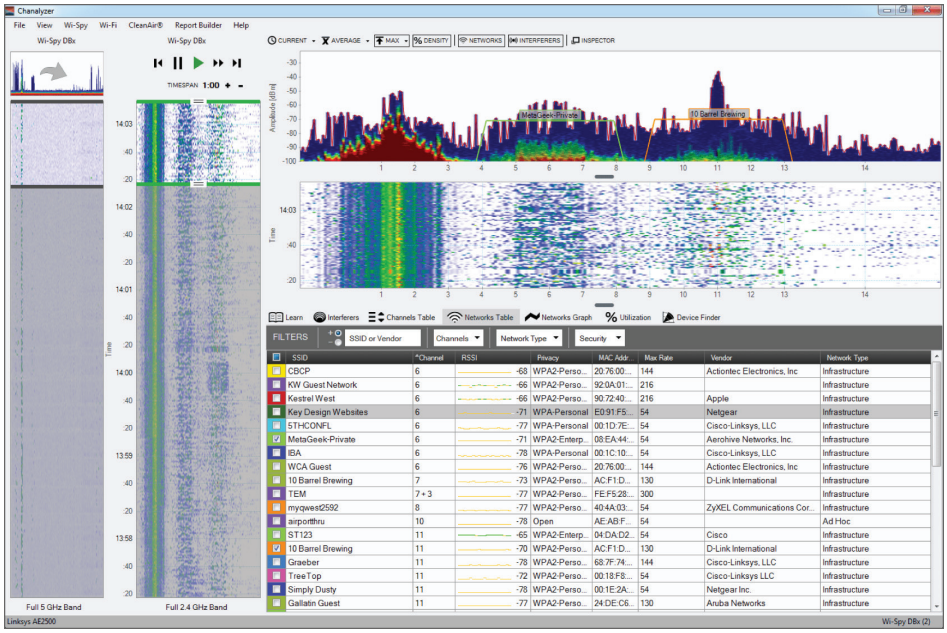


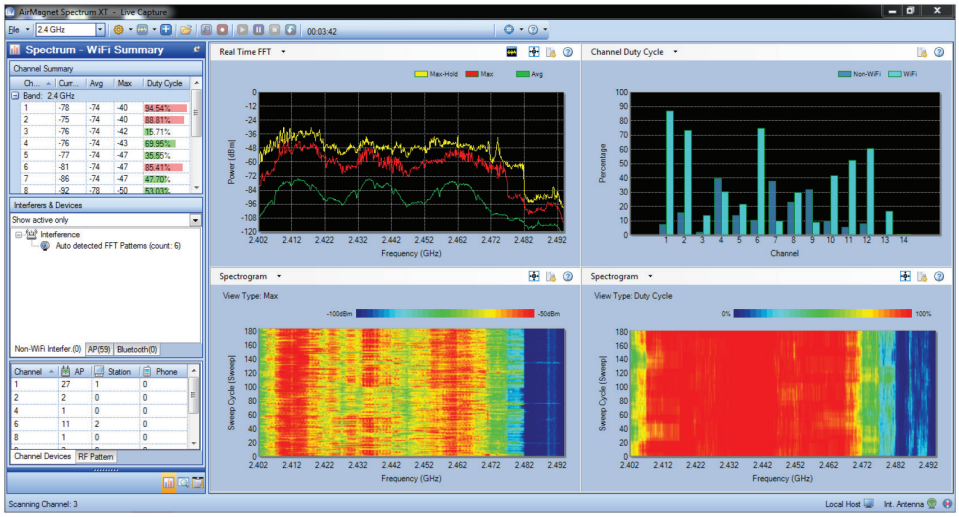
FIGURE 9.9 MetaGeek DBx spectrum analyzer for IEEE 802.11a/b/g/n/ac networks operating in the 2.4 GHz and 5 GHz frequency ranges

Some manufacturers of wireless network equipment integrate spectrum analyzer tools into devices such as wireless access points or WLAN controllers for constant monitoring of the RF. This feature is used for troubleshooting and allows a network administrator to monitor the RF in any part of the company. Some manufacturers offer stand-alone products that can be used to monitor more specific areas. Here are some manufacturers of wireless network spectrum analyzers:

- AirMagnet Spectrum XT: `www.netscout.com`
- BumbleBee Handheld: `www.bvsystems.com`
- Extreme Networks AirDefense: `www.extremenetworks.com`
- Wi-Spy by MetaGeek: `www.metageek.com`

The ability to analyze the RF allows a site surveyor to find areas that lack coverage, also known as *dead spots*, as well as interference caused by other devices and other IEEE 802.11 wireless networks that operate in the same RF range. Although a spectrum analysis is not a requirement for a wireless site survey, it is beneficial in most medium- to large-scale deployments of wireless networks. Because of the vast number of devices that use unlicensed radio bands, spectrum analysis can be considered an ongoing process. Performing regular spectrum analysis enables wireless network engineers to monitor the area in which wireless devices are located for RF interference and other issues. Figure 9.10 shows a screen capture of an RF scan using a USB-based spectrum analyzer designed for IEEE 802.11 wireless networks.

FIGURE 9.10 AirMagnet Spectrum XT USB Spectrum Analyzer screen capture



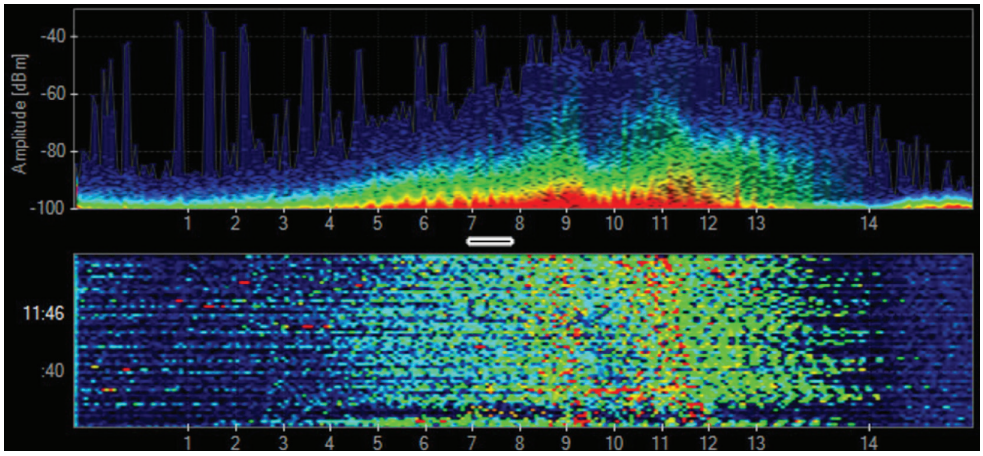
Wi-Fi and Non–Wi-Fi Interference Sources

The performance of a wireless network can be significantly affected by various types of interference sources. Interference may be either intentional or unintentional and caused both by IEEE 802.11 wireless networks and by other devices that also operate in the 2.4 GHz ISM or 5 GHz U-NII band. The use of portable and mobile devices that employ RF for communication continues to rise, so interference from these devices is also more prevalent. These interfering devices typically operate in the unlicensed radio spectrum 2.4 GHz ISM band. Other sources of interference from the Industrial, Medical, and Scientific (ISM) communities will also affect the amount of interference. *Non–Wi-Fi interference* in the ISM band can be caused by devices such as these:

- Microwave ovens
- Cordless telephones
- Medical equipment
- Manufacturing or industrial equipment
- Wireless video cameras
- Radar systems (5 GHz bands)

This is by no means a complete list, but it does contain some of the devices used daily that may cause some level of interference in the world of wireless networking. Figure 9.11 shows an example of interference caused by a microwave oven. Microwave ovens operate in the 2.4 GHz frequency range and, depending on the unit, may cause interference with IEEE 802.11 wireless networks.

FIGURE 9.11 MetaGeek Chanalyzer shows a microwave oven operating at maximum power. These typically create a mountain-like shape, as shown in the waterfall view.



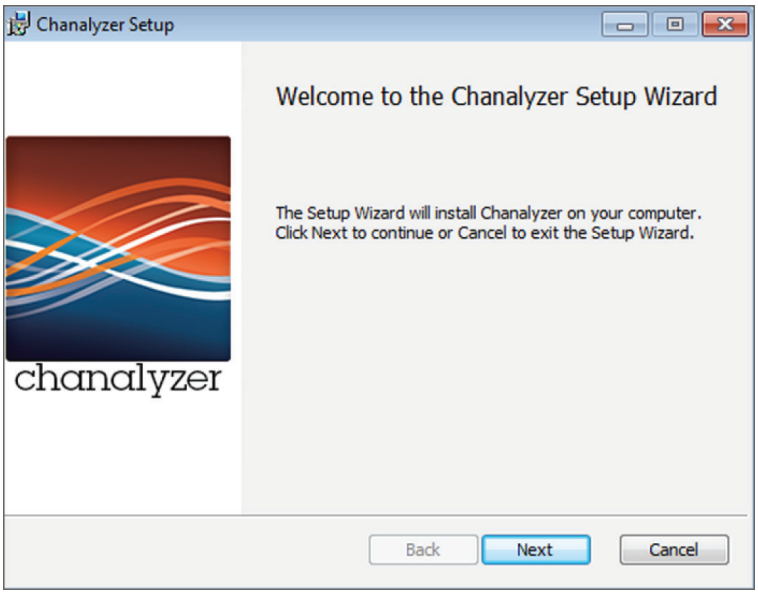
In Exercise 9.1, you will use the Chanalyzer spectrum analysis software from MetaGeek to look at some sample RF captures.

EXERCISE 9.1

Using Spectrum Analysis Tools for Wi-Fi Networks

In this exercise, you will install the Chanalyzer software program by MetaGeek. The seven-day demonstration version of the software allows you to view some predefined RF captures that are available as part of the program. To perform actual captures, you need to purchase the Chanalyzer program and one of the Wi-Spy adapters available at `www.metageek.com`. To perform this exercise, you can download the Chanalyzer program from `www.metageek.com`.

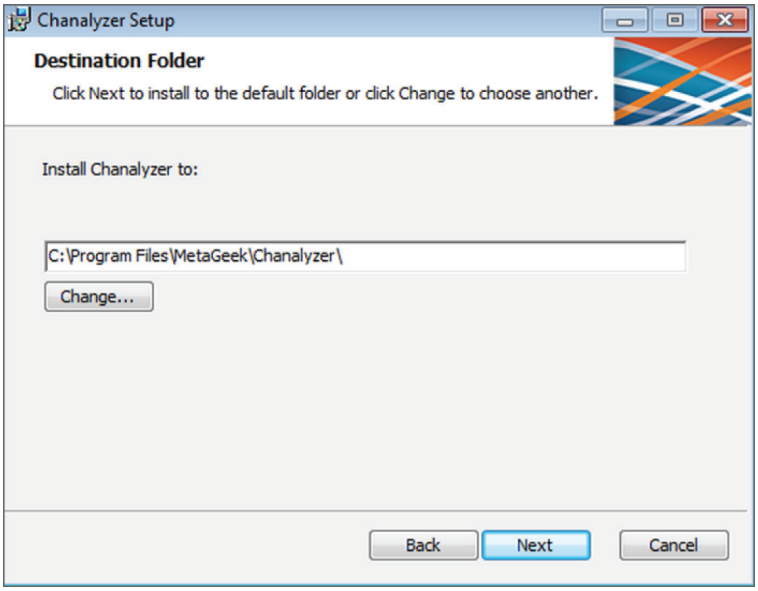
1. Download the Chanalyzer software package. As of this writing, the file is named `Chanalyzer-Installer.msi`. Execute the program. Depending on the version of the Microsoft Windows operating system you are using, you may see an Open File – Security Warning dialog box. Click the Run button to continue. The Setup Wizard will appear.



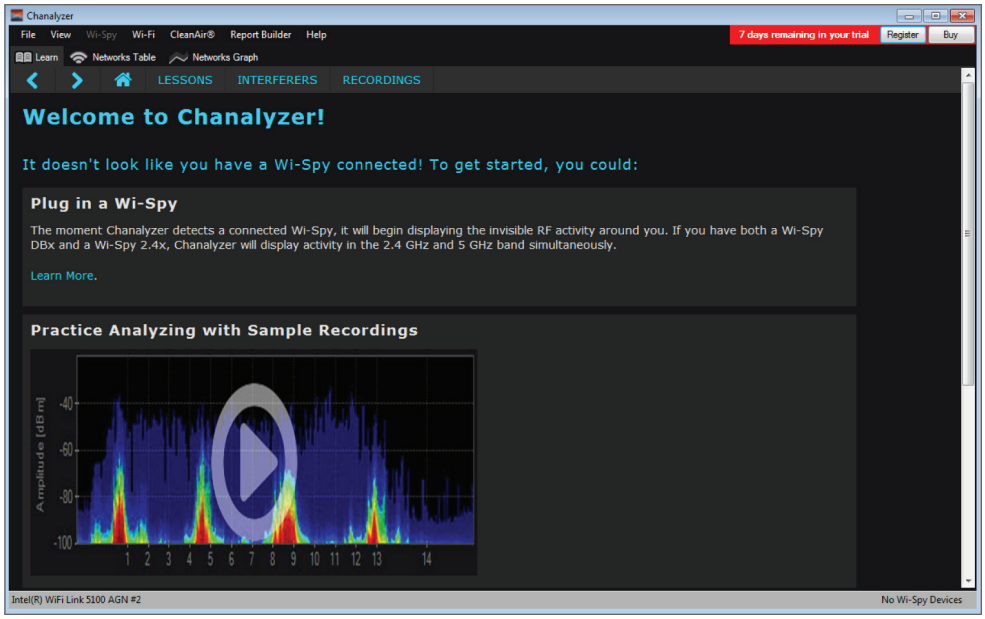
2. Click Next to start the installation process. The license agreement will appear.

EXERCISE 9.1 *(continued)*

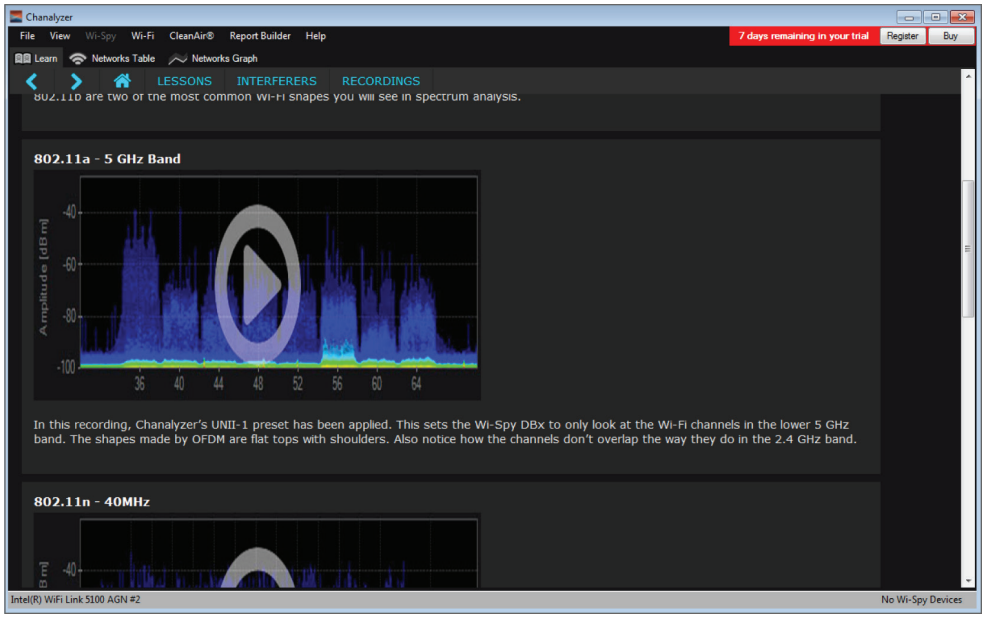
3. Read the license agreement, select the I Agree button, and click Next. The Destination Folder screen will appear.



4. Click Next to accept the default installation folder. The User Experience Improvement Program screen will appear.
5. Click Next to continue the installation. The Ready To install Chanalyzer screen will appear.
6. Click Install on the Ready To install Chanalyzer screen to start the installation process. Depending on the version of the Microsoft Windows operating system you are using, you may see a User Account Control screen. Click Yes to continue the installation. The Chanalyzer program will now be installed on your computer. The Installation Complete screen will appear.
7. Click Finish to complete the installation process and exit the installer program. The Chanalyzer program is now installed on your computer.
8. Start the Chanalyzer program by choosing Windows Start ➢ All Programs ➢ MetaGeek ➢ Chanalyzer. The Welcome To Chanalyzer screen will appear.



9. Click the RECORDINGS tab. Scroll down to the 802.11a - 5 GHz Band recording to view the sample recording for an IEEE 802.11a network 5 GHz capture.



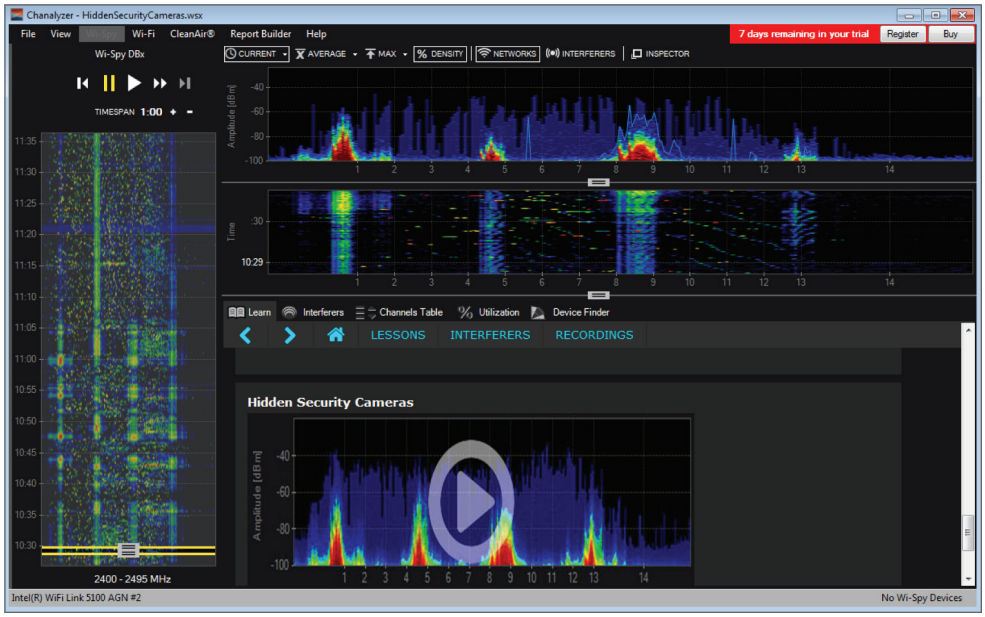
EXERCISE 9.1 *(continued)*

10. Click the large white arrow to start viewing the recording. While observing the screen, let the sample recording run for a few minutes and notice the capture change as the program displays the recorded session. You can pause or rewind the capture by using the controls in the upper-left corner of the Chanalyzer window.

11. Select a new capture by clicking the RECORDINGS tab near the center of the screen. The additional sample captures screen will appear in the recordings window.

12. Use the scroll bar to move down and view the sample recordings. Click the large white arrow on the Hidden Security Cameras recording to view the sample recording of a hidden security cameras capture.

13. While observing the screen, let the sample recording run for a few minutes and notice the capture change as the program displays the recorded session. As with all the sample captures, you can pause, restart, or rewind the capture by using the controls in the upper-left corner of the Chanalyzer window.



14. Use the scroll bar to move down and view the other sample recordings.

15. Continue to view the other sample recordings by clicking the 802.11b and 802.11g - 2.4 GHz Band, 802.11n 40 MHz, and Cisco CleanAir AP recordings, repeating steps 10 and 11.

16. Click the LESSONS and INTERFERERS tabs and explore some of the available features of the program.

After completing this exercise, you can remove the Chanalyzer program from your computer. If you choose to keep and continue to use the program, before the seven-day evaluation period expires, you can click the Buy button in the upper-right corner of the screen or visit the MetaGeek website for instructions on how to purchase the program with the Wi-Spy USB adapter.

The Wi-Spy spectrum analyzer device is available in several models. This device plugs into an available USB port on your computer. The Chanalyzer program used in this exercise is the same you would use to perform actual captures with the Wi-Spy device from MetaGeek.

Wi-Fi Interference

Wi-Fi interference is caused by IEEE 802.11 wireless network devices (also known as *stations* [STA], per the IEEE 802.11 standard) that operate in the 2.4 GHz ISM or 5 GHz U-NII bands. In some cases, this is the largest source of interference for wireless networks. There are two types of Wi-Fi interference: co-channel interference (other devices on the same channel) and adjacent channel interference (other devices on overlapping channels). The following network types will cause Wi-Fi interference:

- FHSS networks: 2.4 GHz (obsolete for IEEE 802.11)
- DSSS networks: 2.4 GHz
- ERP-OFDM networks: 2.4 GHz
- OFDM: 5 GHz
- HT-OFDM: 2.4 GHz and 5 GHz (802.11n)
- VHT-OFDM: 5 GHz (802.11ac)

Wi-Fi devices that cause interference can be operating in either infrastructure mode or ad hoc mode. The number of devices that are part of the wireless network will also determine the extent of the interference. In Chapter 7, "Modulation Technology for Wireless Networking," we discussed different types of spread spectrum technologies that wireless networks use to communicate. FHSS, DSSS, ERP-OFDM, OFDM, HT-OFDM, and VHT-OFDM are technologies used for IEEE 802.11 wireless networking in the 2.4 GHz and 5 GHz bands. However, some of these technologies are used in non–wireless-network devices as well. For example, Bluetooth devices operating in the 2.4 GHz ISM band also use FHSS technology for communication. Zigbee devices operate in the 2.4 GHz band and use DSSS technology for communication. Depending on the manufacturer, 2.4 GHz cordless phones may use either FHSS or DSSS. Performing an RF spectrum analysis is one way you can determine the source of this type of interference. If an instrumentation spectrum analyzer (a calibrated device that has the capability to view entire radio spectrums) is used, it will be necessary to understand how to interpret the data collected as well as how to operate the device.

It is important to note that IEEE 802.11 FHSS WLANs are obsolete networks and unlikely to be found with today's wireless installations. All references to FHSS have officially been removed from the IEEE 802.11-2016 standard. We mention this here because FHSS is used with other wireless technologies, such as Bluetooth devices and cordless telephones.

Standards vs. Industry Definitions of Interference

The 802.11 standard loosely defines an adjacent channel as any channel with nonoverlapping frequencies for the DSSS and HR/DSSS PHYs. With ERP and OFDM, the standard loosely defines an adjacent channel as the first channel with a nonoverlapping frequency space.

This contradicts how the term *adjacent channel interference* is typically used in the marketplace. Most Wi-Fi manufacturers use this term to loosely mean both interference resulting from overlapping cells and interference resulting from the use of overlapping frequency space. For example, manufacturers typically use this term in a case where AP-1 (channel 1) is located near AP-2 (channel 2).

Adjacent channel interference is a performance condition that occurs when two or more access point radios are providing RF coverage to the same physical area using overlapping frequencies. Simultaneous RF transmissions by two or more of these access point radios in the same physical area can result in corrupted 802.11 frames because of the frequency overlap. Corrupted 802.11 frames cause retransmissions, which result in both throughput degradation and latency.

Co-channel interference is a performance condition that occurs when two or more independently coordinated access point radios are providing RF coverage to the same physical area using the same 802.11 channel. Additional RF medium contention overhead occurs for all radios using this channel in this physical area, resulting in throughput degradation and latency.

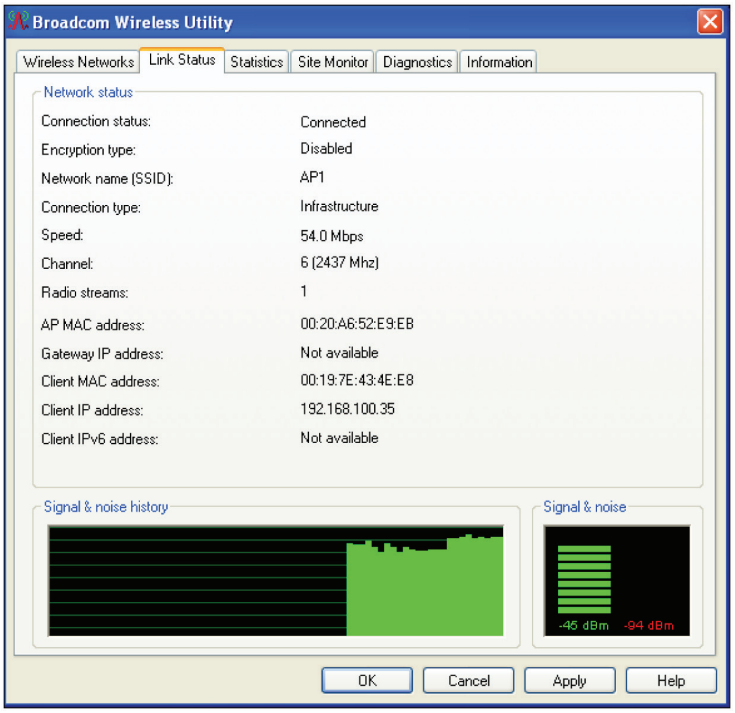
Received Signal Strength

The main objective of a wireless network is to provide access to computer network resources and services for wireless devices that are connected to the network. This means it is essential for wireless client devices to have reliable connectivity to the wireless network infrastructure. To provide this connectivity, the wireless site survey process should include testing to verify that the received signal is adequate for the application of the device.

Devices that communicate wirelessly require two-way communications in order to operate correctly. This means the receiver must be able to receive enough of the signal to determine the data that was sent from the transmitter. Wireless client devices use what is known as the *received signal strength* to show the amount of power received from a transmission. Figure 9.12 shows a client utility that displays specifics regarding the received signal.

The amount of received signal strength required will be determined by the type or application of the wireless device as well as the amount of RF noise in the area. RF noise consists of extraneous undesired radio signals in the area emitted by a variety of devices other than the transmitter. You should check with the device manufacturer to determine the minimum amount of received signal that is acceptable for a specific application. Some applications will require more received signal than others. For example, the manufacturer of a voice handset used with a Wi-Fi network may recommend a minimum of –65 dBm to –67 dBm, whereas a computer network card may require a minimum of –70 dBm.

FIGURE 9.12 A wireless client utility showing signal, noise, and data rate



The *signal-to-noise ratio* (SNR) is the difference between the received signal and the noise floor. For example, if the received signal is –65 dBm and the noise floor is –95 dBm, then the SNR will be 30 dB. This value is calculated by subtracting the received signal from the noise. In this case, –65 dBm – (–95 dBm) = 30 dB.

Most best practices recommend the SNR for wireless networks to be a minimum of 25 dB.

In wireless network technology, the received signal strength indicator (RSSI) value is an arbitrary number assigned by the device manufacturer. There is no standard for this value, and it will not be comparable between devices from different manufacturers. When performing a site survey, whenever possible it is beneficial to survey with the same network adapter model that will be used in the deployment. This will provide more accurate results for the client devices using the network.

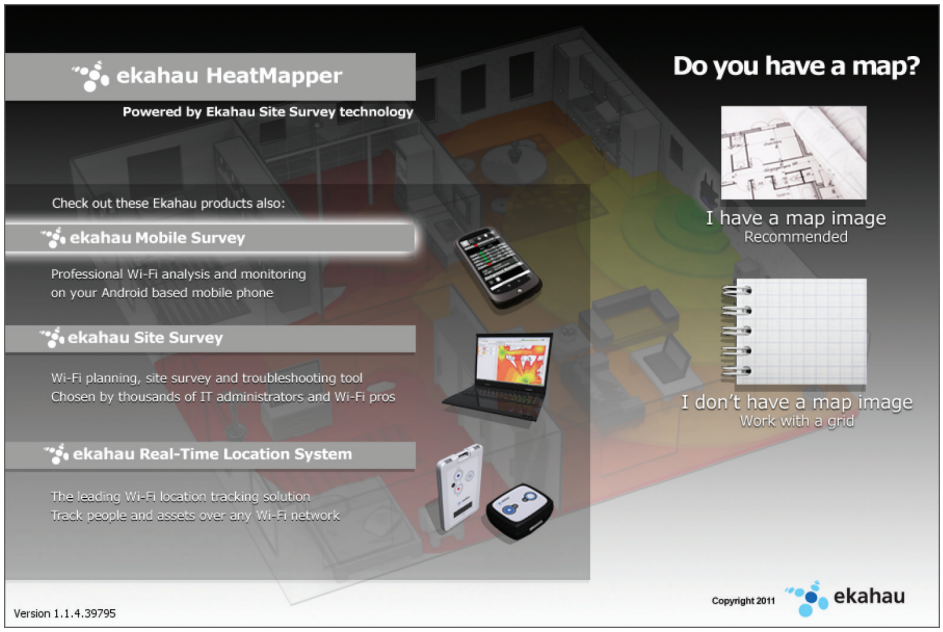
Performing a Manual Radio Frequency Wireless Site Survey

A manual RF site survey can provide some of the most accurate results when it comes to obtaining certain information. A manual site survey requires a physical walk-through of the area, recording information to determine the performance of clients and devices that will be connected to the wireless network. This type of site survey can be very accurate because the surveyor is recording actual statistics, such as the following:

- Signal strength
- SNR
- Data rate of connected devices
- RF interference

These measurements are recorded while the site surveyor is physically moving through the facility or location. Recommended received signal strength and SNR values were discussed earlier in this chapter. Small-scale manual site surveys can be performed inexpensively by using a wireless client adapter with site survey functionality, one of several freeware/shareware utilities, or commercial software designed specifically for this type of application. Figure 9.13 shows an example of a free site survey software program that can be used for very basic measurements.

FIGURE 9.13 Ekahau HeatMapper, a Wi-Fi coverage mapping site survey software utility, is a free download from Ekahau.



The manual site survey process can be used for recording measurements to determine the actual placement of hardware infrastructure devices and for spot checking, locating other IEEE 802.11 wireless networks, or verification after a predictive site survey has determined the placement of these devices. Not too long ago this manual process was the only way to perform a wireless site survey. The main advantage of the manual process is accuracy. One disadvantage is that it can be very time consuming, depending on the extent of the installation.

The process for a manual RF site survey will vary depending on the individual who is performing the survey. However, there are some common components and considerations that may be included:

- Obtaining a floor plan or blueprint
- Identifying existing wireless networks
- Testing access point placement
- Analyzing the results
- Considering the advantages and disadvantages of manual site surveys
- Performing a software-assisted manual site survey
- Using a manual site survey toolkit

Understanding each of these components will help provide a more accurate site survey and successful wireless network deployment.

Obtaining a Floor Plan or Blueprint

The first step in a manual site survey is to review a floor plan or blueprint of the location. Many in the industry refer to a floor plan as a map. This could be a simple sketch and is required to note access point placement as well as readings. The readings to note on the floor plan include signal strength and SNR values from client devices. Figure 9.14 shows a basic floor plan of a small office building. The floor plan should be marked with approximate access point locations. In some cases, a floor plan or CAD drawing of the location may not be available. Depending on the size of the location, a fire evacuation plan could be photographed or scanned in and used as a starting point to create a drawing and may be adequate for the site survey.

The floor plan and approximate access point locations used in these examples are for illustration purposes only.

Identifying Existing Wireless Networks

As part of a manual site survey, you should identify existing wireless networks in the area, noting locations that include possible sources of RF interference and may have an impact on the wireless network that will be installed. Using a device or software program designed specifically for wireless networks would be ideal. However, freeware or shareware programs may be satisfactory. Figure 9.15 shows an example of a software program that can be used to find existing IEEE 802.11 wireless networks.

FIGURE 9.14 Approximate access point locations

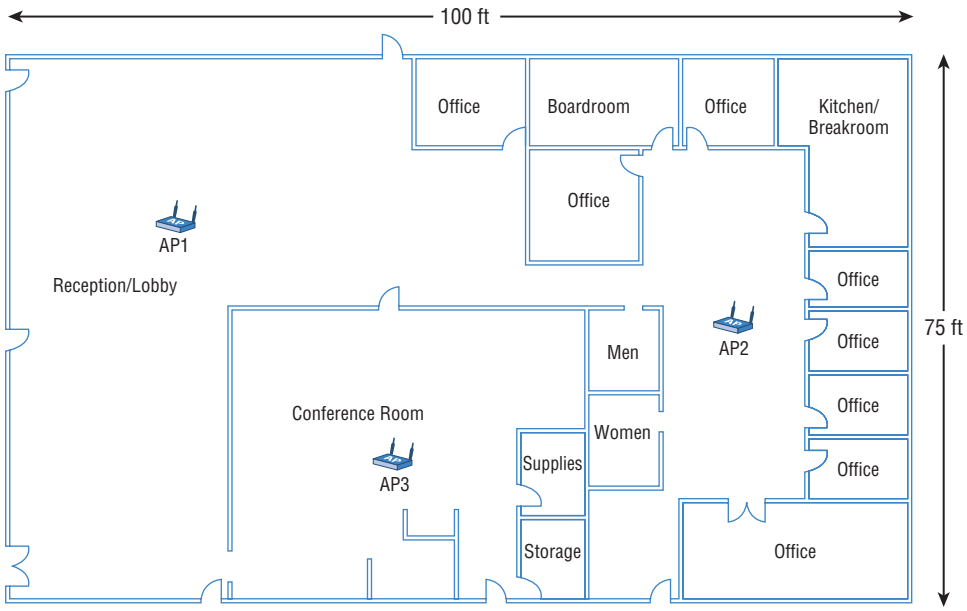
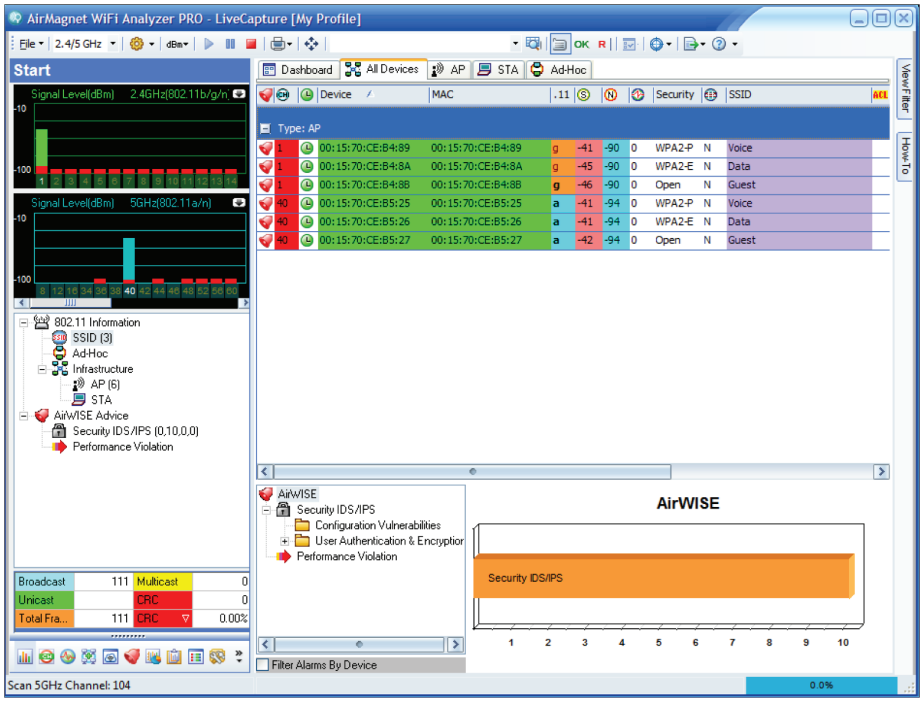


FIGURE 9.15 The AirMagnet Wi-Fi Analyzer can be used to view existing IEEE 802.11 wireless networks.



Testing Access Point Placement

Once you have identified potential locations for access points, you can start testing the proposed access point placement. This can be done by temporarily mounting an access point at the desired location to get the most accurate results. In some cases, a tool or fixture made specifically for wireless site surveys or even a tall ladder could be used as a temporary mounting solution. Refer to the documentation that was created prior to going on site for mounting locations.

It is always best to use test access points from the same manufacturer and, if possible, the same model that will be used in the actual deployment during the pre- and post-deployment manual site survey process. This practice will yield a better outcome than using generic access points during testing. Figure 9.16 shows an example of a temporary mounting solution.

FIGURE 9.16 Access point temporarily mounted using an expandable light pole

Using one or possibly two temporarily mounted access points, document the results of the testing while moving around the facility. One testing method is the active survey process and requires the client device used for the survey to perform an IEEE 802.11 authentication and association to the test access points. This will provide the active connection. The passive survey process (listening to all access points in the area) may also be used for this type of site survey. The area to be tested should include a reasonable proximity around the temporarily mounted access point. The extent should be the desired minimum received signal threshold (for example, –67 dBm). The information recorded and documented will

depend on the surveyor but commonly includes signal strength and SNR. It may be necessary to make adjustments to access point mounting during the testing process, based on the results of the onsite testing process. It would be beneficial to test an actual wireless client device and software application that will be used with the network to see if the performance meets expectations. Software-assisted surveys, as described later in this chapter, are commonly used for a site survey of any size in today's wireless deployments.

Analyzing the Results

Once all the testing is complete, it is necessary to perform an offline analysis to determine the final placement of access points or other infrastructure devices that may be used in the wireless deployment. This may include making adjustments from the original plan or adding and removing access points. The use of various antennas may also need to be analyzed and documented.

Considering the Advantages and Disadvantages of Manual Site Surveys

There are several advantages and disadvantages to the manual site survey process:

- Advantages
  - It is accurate because it is based on actual readings.
  - Characteristics (attenuation values) of the building are physically tested.
  - It allows verification of actual RF signal coverage and interference.
  - It allows marking exact installation locations of infrastructure hardware while onsite.
- Disadvantages
  - It can be time consuming.
  - Usually only one access point is used for testing, so readings will need to be merged.
  - It requires a physical walk-through of entire location.
  - Many areas require an escort and special clearances for access.

WLAN infrastructure equipment used in a manual site survey should be from the same manufacturer as the hardware that will be installed in the actual deployment. Although in some cases it may be difficult to accomplish, using a site survey client device to replicate what will be used in the actual environment is always recommended. This will minimize any potential issues from variations between manufacturers' devices.

Performing a Software-Assisted Manual Site Survey

The manual site survey technique discussed earlier may be adequate for smaller deployments or for organizations that have limited resources and budget. Manual site surveys can also be accomplished with the aid of commercial software programs designed specifically for this process. These programs vary in cost, complexity, and features, and contain many advanced features:

- Capability to perform both passive and active surveys
- Capability to import floor plans with support for many graphic formats, including JPG, BMP, and CAD
- Capability to record critical data, such as signal and SNR
- Visual representation of RF signal propagation of surveyed areas
- Post-survey offline analysis of collected data

The Passive Wireless Site Survey

A *passive site survey* consists of monitoring the air and recording the RF information from all wireless access points and wireless client stations or devices in the "hearing range" of the surveying station, and includes RF information from your own and neighboring devices. This type of site survey does not require an IEEE 802.11 authentication and association to an access point, and no traffic is passed between the survey station and the access point. A passive site survey will provide an overall snapshot of the RF in use in or around the location, including RF noise and other IEEE 802.11 wireless networks in the area. It is used to get an overall picture of the wireless network access points that are transmitting within the area being surveyed. Figure 9.17 shows an example of a commercial site survey application in passive mode.

Since passive site surveys do not require an association to an access point, all RFs will be detected, displayed, and recorded. Most commercial software applications with this functionality will have the capability to filter the coverage map on specific access points from the information that was recorded.

The Active Site Wireless Survey

An *active site survey* consists of a survey device, such as a notebook computer, associating to an access point prior to taking readings and collecting the data. Some claim this type of manual survey will provide more accurate results because of this direct IEEE 802.11 authentication and association to an access point. The association of the survey device to an access point will actively send and receive some basic RF information to and from the access point, allowing the information about signal strength and noise levels to be recorded. Figure 9.18 shows a commercial site survey performing an active site survey.

Performing either a passive or active site survey using software involves many of the same steps discussed in the section "Performing a Manual Radio Frequency Wireless Site Survey" earlier in this chapter. The main difference is the features and capabilities that are available in these commercial software packages. These elaborate features will eliminate the need to manually document and record all the information obtained while walking the area, because the program handles this task for the surveyor.

FIGURE 9.17 Ekahau Site Survey (ESS) showing a passive survey

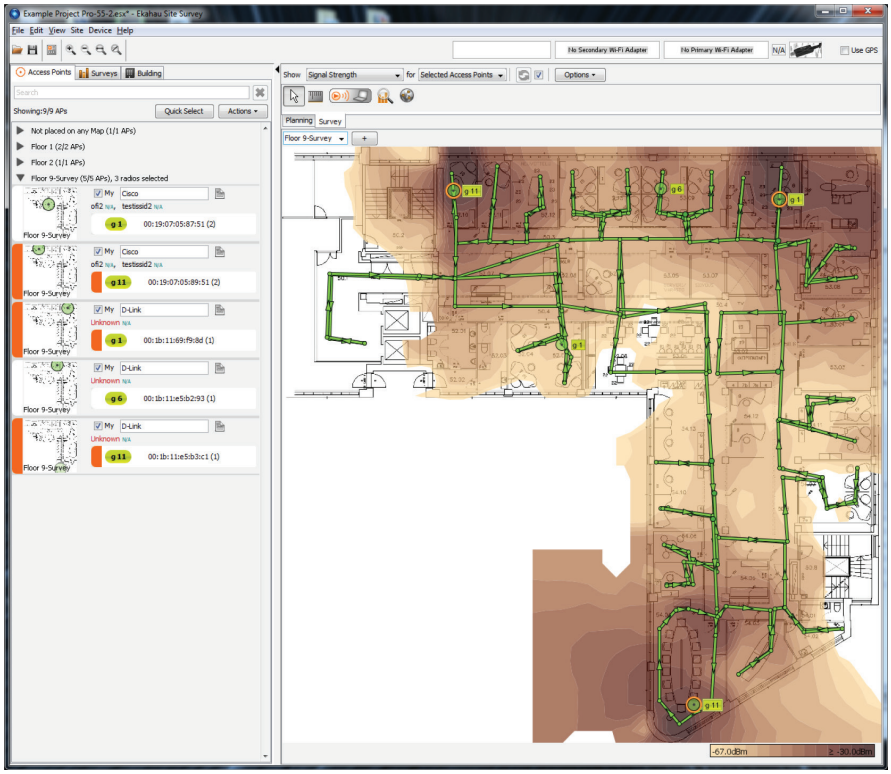
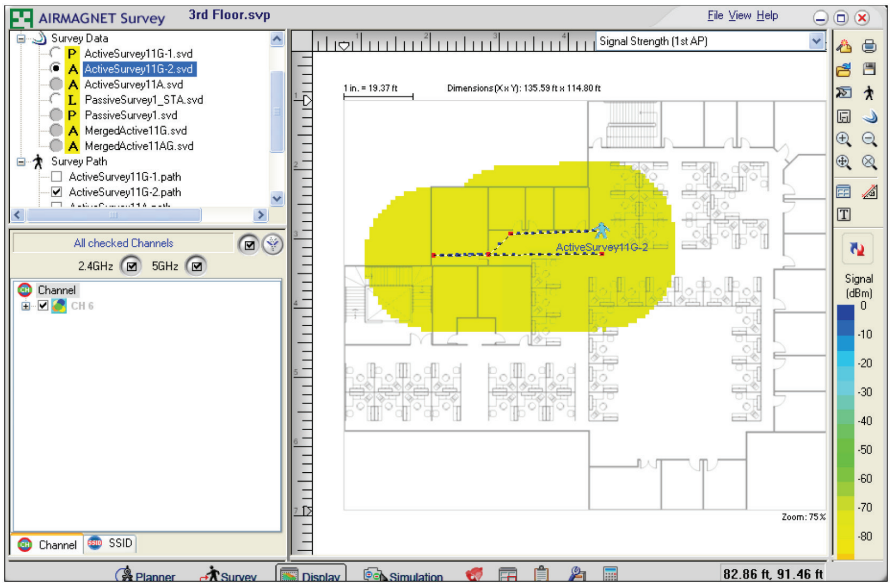


FIGURE 9.18 AirMagnet Survey showing an active site survey



In Exercise 9.2, you will explore the Ekahau HeatMapper site survey program. If you have a floor plan of your area, you can perform an actual manual wireless site survey.

EXERCISE 9.2

Installing Ekahau HeatMapper

In this exercise, you will begin by installing the Ekahau HeatMapper, a free Wi-Fi site survey tool.

Ekahau HeatMapper has the following specifications:

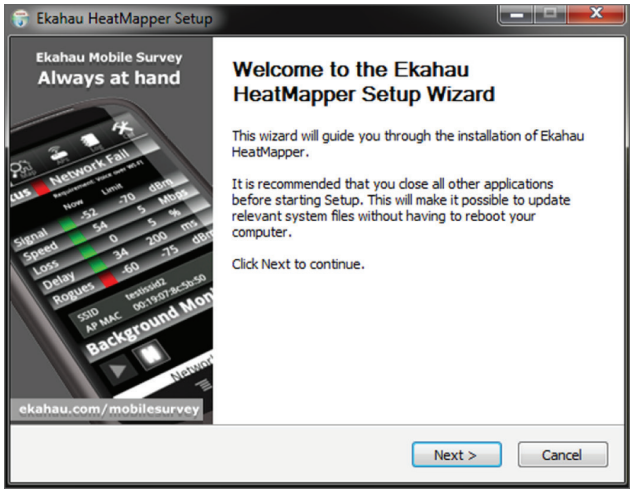
- Wi-Fi coverage mapping tool
- Free of charge
- No official support provided

The requirements for Ekahau HeatMapper are as follows:

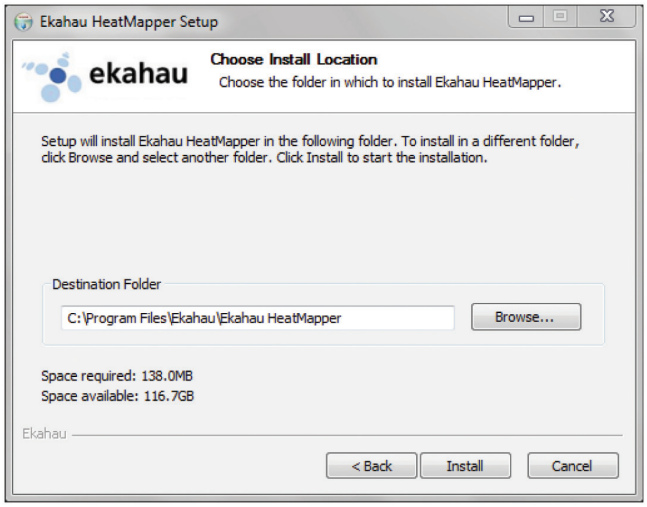
- Laptop computer running Windows Vista, Windows 7 or Windows 8, Windows 10 (64-bit or 32-bit)
- 1 GB of RAM
- 2 GB of hard disk space
- 1 GHz or faster processor
- Wireless network adapter (internal or external)

The Ekahau HeatMapper program is available free of charge from Ekahau at `www.ekahau.com`. It allows you to see your wireless network. It shows the wireless coverage of any access point on the map. It also locates all the audible access points and shows their configurations and signal strength—in real time and on the map (floor plan).

1. Download the Ekahau HeatMapper program, which at the time of this writing has the filename `Ekahau-Heatmapper-Setup.exe`, from the Ekahau website and execute the program. Depending on the version of the Microsoft Windows operating system you are using, you may see a User Account Control dialog box. Click the Yes button to continue. The Ekahau HeatMapper Setup Wizard will appear.

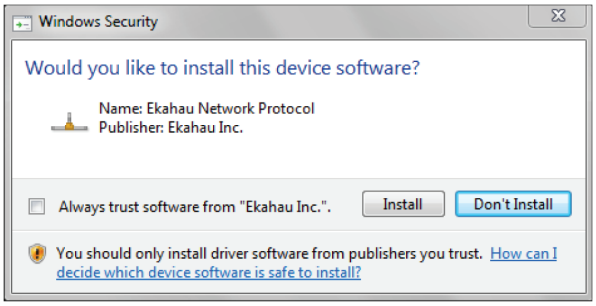


2. Click Next to start the installation process. The license agreement will appear.
3. Read the license agreement and select the I Agree button. The Choose Install Location screen will appear.

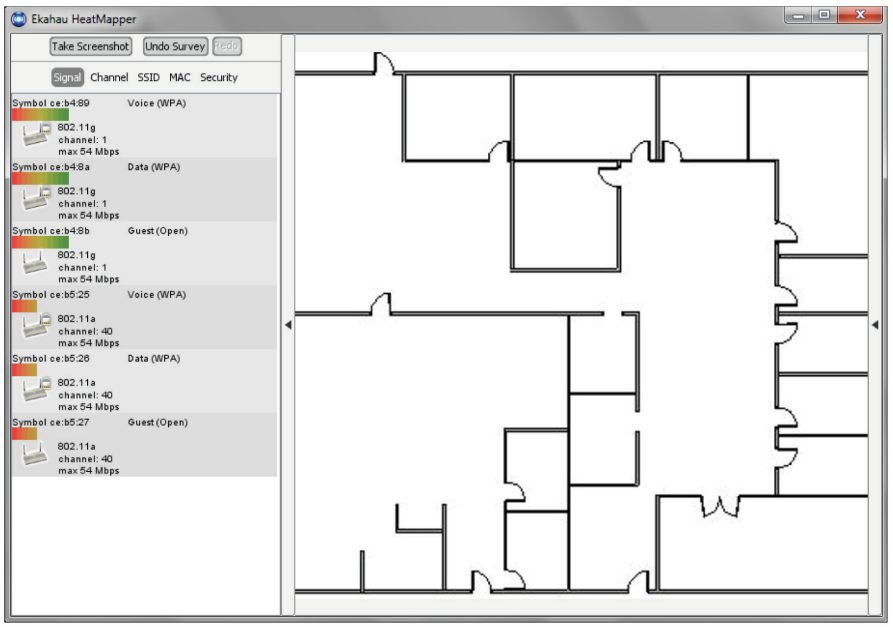


4. Click Next to accept the default installation folder. Depending on the version of the Microsoft Windows operating system you are using, a Windows Security dialog box may appear.

EXERCISE 9.2 *(continued)*

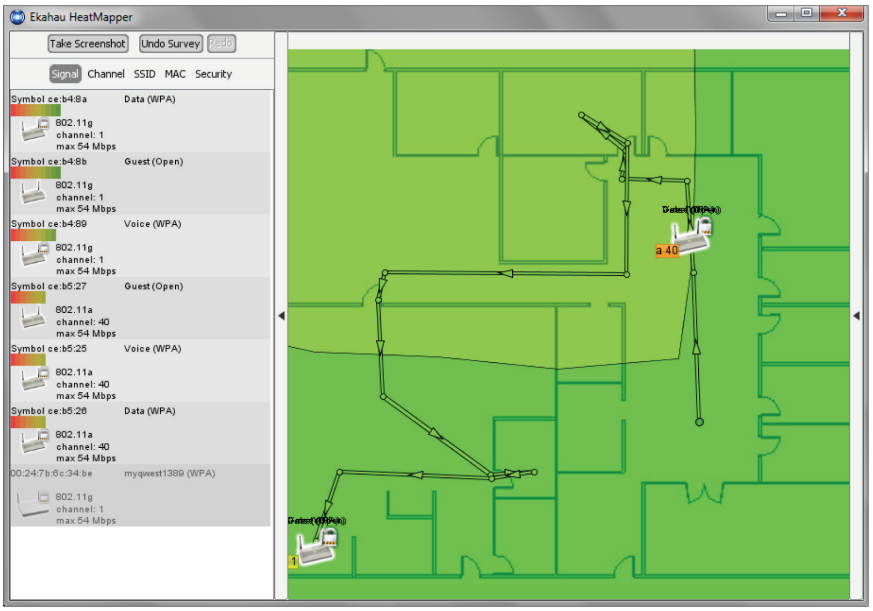


5. Click the Install button to continue. The Ekahau HeatMapper program will now be installed on your computer. The Installation Complete screen will appear.
6. Click Finish to complete the installation process and exit the installer program. The Ekahau HeatMapper program is now installed on your computer, and the program will start. The Ekahau HeatMapper home screen will appear (refer to Figure 9.13).
7. Click the "I have a map image" box to start using the program.
8. Browse to the location containing the floor plan image that you plan to use for the survey.
9. Select the image and click the Choose Image button. The Ekahau HeatMapper home screen will return, displaying the floor plan image you imported. If the Quick Help screen appears, you can click the small arrow button in the right center of the screen to minimize the help window.



10. Click the area of the floor plan where you are currently located. You will notice access points on the left side of the screen that the HeatMapper program detects.
11. Take your laptop and start walking around the facility slowly.
12. Left-click your current location on the map as you walk.

13. Right-click when you stop walking. After right-clicking, you will see the combined coverage heat maps of all access points.



EXERCISE 9.2 *(continued)*

14. Move the mouse over an access point to see the coverage of a single access point.
15. Hide and show the access point list by clicking the small arrow button on the left side center of the screen.
16. Experiment with the HeatMapper program by clicking on the various access point options: Signal, Channel, SSID, MAC, and Security.
17. Click the Take Screenshot button to save an image of the current survey.
18. Close and exit the Ekahau HeatMapper program.

Using a Manual Site Survey Toolkit

To perform a manual site survey, you need a toolkit containing essential components. A floor plan or blueprint is required to record data collected during a manual site survey. If a software program is used, both an electronic version of the floor plan and a paper printout are necessary. Site survey toolkits will vary in complexity and cost. Planning the equipment and tools you will need for a manual site survey is very important. We recommend you take everything you will need and not take items you will not need. Taking items you do not need creates an unnecessary burden. Many times you may be the only person performing the physical survey, and therefore you need to realize your physical and time limitations. You can create your own site survey kit based on what you will need, or you can purchase from a manufacturer a kit that is built specifically for this purpose.

A variety of items might be included in a wireless site survey kit. Now take a look at some of the most common items, and keep in mind that the kit will vary based on the site survey and the person performing the site survey.

Spectrum Analyzer (Optional) A spectrum analyzer is an optional but recommended item that may be used in an RF wireless site survey. This device will sweep the area to look for devices that may cause interference with the deployment and locate all the RF information in the area. Spectrum analyzers vary in cost and features. Although optional, this tool is highly recommended.

Wireless Access Points One or two access points are needed to take signal measurements during the manual site survey process. It is important to use access points from the same manufacturer, and if possible the same model that will be installed, to simulate what will be used in the actual installation. If this cannot be achieved, try to get an access point that is as close as possible to those that will be used in the deployment.

We recommend that you set the test access points' output power level at about 50 percent or less during the site survey. This usually requires lowering the default power, which in many cases is set at maximum. This will allow for adjustments after installation to help compensate for potential differences from when the space was originally surveyed. The output power settings used will be determined by the individual performing the site survey. It is also important to keep in mind that if you are performing a site survey for both the 2.4 GHz and 5 GHz bands, the amount of RF transmit power as well as the gain of the antennas must be taken into consideration because of the difference in wavelength, which will in turn affect the range.

Wireless Client Device A device to take measurements from the client side is an important component of the site survey kit. This can be a Wi-Fi–enabled notebook computer, smartphone, or tablet with appropriate software to take signal measurements. Size and weight should be considered as well. A Wi-Fi, VoIP handset may also be used for locations that are considering VoIP capabilities. It is best to try to match the survey client devices with those that will actually be used in the wireless devices connecting to the wireless network; however, this is not required.

Portable Battery Packs or Extension Cords Portable battery packs to temporarily power the wireless access points are highly recommended. If these are not available, extension cords are a good substitute. The disadvantage of extension cords is that they require accessible AC power outlets, which might not be available at all sites. Also, they may be difficult to use and can be cumbersome. An extra battery pack for the survey device is also recommended. Battery packs specifically designed for wireless site surveys are available from a variety of manufacturers. Most battery packs will last longer than the surveyor.

Various Antennas (If Required) If antennas other than those mounted directly to an access point will be used in the deployment, a variety of them should be on hand for testing during the site survey process. If 802.11n technology will be tested during the site survey, appropriate 802.11n antennas will be required as part of the site survey kit. If you do not plan to use different antennas, there is no value in taking them along during the survey.

Temporary Mounting Hardware Mounting hardware for temporarily mounting access points and antennas should also be considered, including expandable poles, brackets, tape, and nylon tie straps. You may have to be creative when it comes to temporary mounting. It is critical to make safety a number-one priority when performing this task.

Measuring Device, Either Tape or Wheel A measuring tape or wheel is recommended for measuring distance to wiring closets and distance between access points and any other areas where distance is important. Laser measuring tools are also available, but many are capable of only short distances. If possible, it would be beneficial to have both a tape (or wheel) and a laser measuring device.

Digital Camera As they say, a picture is worth a thousand words. Using a digital camera to take photographs of situations that may be difficult to explain in writing is a great help. This also adds quality to wireless site survey reports. Digital camera technology is now inexpensive, and most smartphones and tablets have this capability built in. We recommend taking many digital photographs when possible, especially in areas that may be difficult to describe in writing. It is better to have the photographs if the need arises than to wish you had them. Photographs of potential access point locations are valuable should physical limitations of the facility come into question. Also, photographs of existing devices are useful to determine if they are damaged or poorly deployed and need to be revisited as part of the new device deployment.

Pens, Pencils, Markers, and Paper Documentation is a critical part of wireless site surveys as well as all other areas of the network. Keeping thorough and accurate notes will allow the surveyor to document areas of importance. Even with the advanced portable technology you have in your possession, it is always a good idea to have paper and writing utensils. Markers can also be used to identify the locations where access points will be installed.

Ladders or Lifts Ladders or lifts are required for mounting temporary access points and antennas. The height of the ladder or lift will depend on the mounting locations for the access points. Keep in mind that the surveyor may not be allowed to use a ladder or lift at certain locations or in some areas. You may have to work with the facility manager to get someone who will be able to perform this task.

If heavy equipment is required to install an access point in the final location, several items should be considered. What is the cost of the equipment, and does this cost fit into the budget? Will the equipment physically fit into the area where the access point needs to be installed? Will any special training be required to operate the equipment, or do you need to factor in the cost to hire an experienced operator? In some cases an alternate location to mount the access point may be a more cost-effective solution.

Movable Cart A movable cart or dolly to move all equipment used for the site survey will ease the burden of getting the equipment moved safely around the facility. Depending on the amount of site survey equipment and the number of access points, batteries, poles, ladders, and so on, it can be a cumbersome task to move all this around. This is especially true in larger facilities, and carts make this task much easier.

Performing a Predictive Modeling Site Survey

A predictive modeling site survey can be an accurate way to design a wireless network without having to spend time on site performing a physical walk-through and testing of the entire location. A *predictive modeling site survey* is a software-based site survey in which a

floor plan (map) or drawing of the area to be surveyed is imported into a software program. The program then simulates the RF propagation from access points by using the attenuation properties of various structural components, and provides a coverage map based on the information that was input into the program. The surveyor can trace over walls, windows, doors, and other elements of the physical location in order to estimate the RF attenuation and show how the RF propagates based on the environment. This type of site survey can be performed in several different ways depending on the equipment used. You can use a stand-alone commercial software program designed specifically for this purpose, or in some cases, manufacturers build this site survey functionality directly into a wireless controller. Some manufacturers now have Internet-based wireless site survey programs, and the design is performed online. You will see more information on Internet-based survey tools later in this chapter.

A predictive modeling site survey requires the wireless engineer or surveyor to input a floor plan drawing of the facility, such as a CAD, JPEG, BMP (or other format) file, directly into the software program, in the controller, or to the online program. Then, details such as the attenuation values of the facility are added. The details can include the following information:

- Type of walls, such as drywall, brick, or poured concrete
- Thickness of walls
- Types of windows, including glass, thickness, and coating
- Type of doors, such as hollow core, solid core, fire doors, wood, or steel
- Location of certain types of furnishings, such as cubicle offices
- Height of the ceiling

One thing to keep in mind about a predictive modeling site survey is that the accuracy and final results are only as good as the information that was input into the program. Basically it equates to "garbage in, garbage out." It is essential for the surveyor to use accurate information about the location, including the attenuation value of all the building materials.

Here are some the advantages and disadvantages of using the predictive modeling site survey process:

- Advantages
  - It requires limited time on site.
  - It does not require a complete physical walk-through for testing, though a visit to the site is recommended.
  - It allows for easy adjustment of access point locations and settings.
  - It can model different scenarios.
- Disadvantages
  - The surveyor may be unfamiliar with the location's physical characteristics.
  - The accuracy is limited to the data input into the software program.
  - It requires extensive knowledge of physical properties of the installation area, including attenuation values.

Many different site survey programs are available, both commercial and freeware or shareware. You should compare the programs and determine which would be best suited for your environment based on features, cost, and capabilities. Here are some common stand-alone programs for predictive modeling or manual site surveys that are available on the market today:

Stand-alone Site Survey Program	Website
AirMagnet Survey/Planner	www.flukenetworks.com
Berkeley Varitronics Systems (BV Systems) Swarm	www.bvsystems.com
Ekahau Site Survey	www.ekahau.com
TamoGraph Site Survey	www.tamos.com
VisiWave – AZO Technologies	www.visiwave.com

Some enterprise wireless client adapter utilities can also be used in manual RF wireless site surveys to provide basic information, such as signal strength and SNR.

Internet-Based Predictive Modeling Site Survey

Some manufacturers of wireless network equipment offer Internet- or web-based predictive modeling wireless site survey programs. The manufacturers of these programs assume you will be using their equipment in your wireless deployment. The programs are robust and free to access, and some also provide free online training. The process to use these tools is fairly straightforward. You need to request access or create an account on the manufacturer's website. You will then be able to log in and upload a floor plan map to the website program. Here is a list of such programs:

Internet-Based Site Survey Program	Website
Aerohive Wi-Fi Planner	www.aerohive.com/planner
Meraki WiFi Mapper	meraki.cisco.com
WLAN Coverage Estimator	www. mojonetworks.com

Real World Scenario

Hybrid Approach to Wireless Site Surveys

A surveyor can also use a hybrid approach to wireless site surveys. The hybrid method combines both the physical manual site survey and the predictive model site survey. This method can give "the best of both worlds" and enables the surveyor to check the physical installation location, make notes, place an access point to take signal readings in key areas, and get some spectrum analysis data. The surveyor can then apply the information collected to a predictive model to get more accurate results.

Performing a Post-Deployment Site Survey

Regardless of which survey method is used for the RF wireless site survey, you should conduct a final post-deployment validation site survey. This task should be included in the initial scope of work. The post-site survey can be a walk-through where you make a spot-check of the coverage and signal strength. You should test known or suspected problem areas. This will give you a snapshot of the overall wireless installation. A better and more thorough method would be to do a complete walk-through in every area, checking and recording the coverage and providing a coverage map. Using one of the software-based site survey programs previously discussed will allow you to do a passive, active, or predictive site survey and give you an accurate footprint of the overall wireless coverage. A post-deployment site survey will allow you to test the roaming capabilities of different wireless clients and mobile devices that may be used in the actual wireless installation. This type of survey may be time consuming on a large facility, but it will give you not only a footprint of RF coverage but also a baseline for ongoing monitoring and troubleshooting.

When performing a post-deployment site survey, use the same devices used to perform the initial manual site survey. Include a walkabout on the exterior perimeter of the building in order to record the RF signal around the building. During the post-deployment site survey, not only can you record the RSSI and SNR of the RF signal, you can detect and record any dead spots or areas of RF interference to validate the design. The goal of the post-deployment site survey is to ensure that the signal level meets the design goal. Most industry experts recommend a threshold of –65 dBm to –67 dBm as a minimum for best performance for both data and voice.

Protocol Analysis

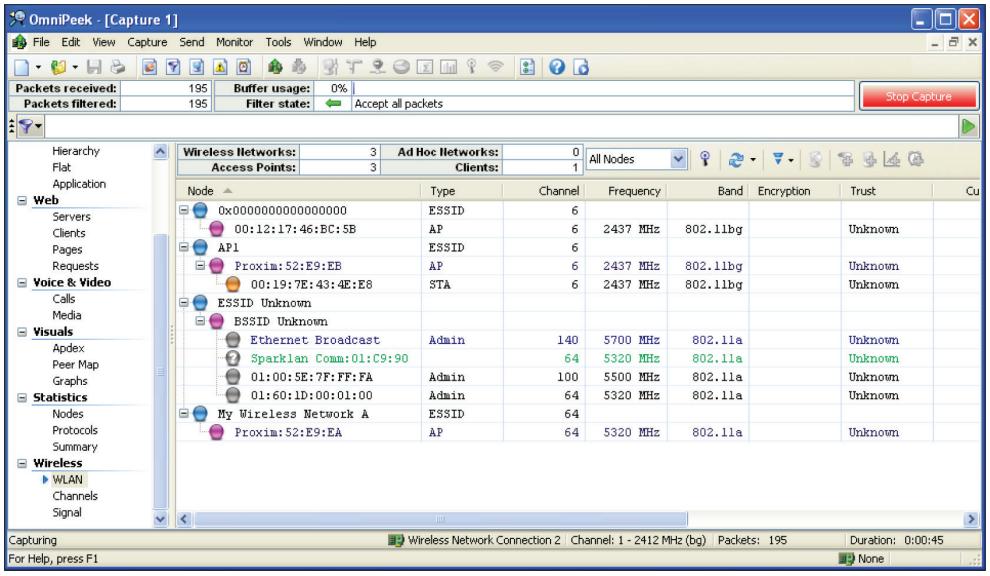
Wireless network protocol analyzers are becoming common tools; many network administrators have one as part of their wireless network toolkit. A *protocol analyzer* allows a network administrator or engineer to view all wireless frames that are traversing across the air within the hearing range of the analysis device. At one time, performing a protocol analysis was a specialty task, and without extensive training few people had the skills to perform it. Along with the evolution of wireless networking technology in recent years, protocol analyzers are becoming more mainstream, more affordable, and easier to use. Many variations of analyzers are available in the market today. Here are some of the manufacturers and their products:

Manufacturer	Product	Website
Berkeley Varitronics Systems	Yellowjacket-BAND Wi-Fi Analyzer	`www.bvsystems.com`
MetaGeek	Eye P.A.	`www.metageek.net`
NetScout	Sniffer	`www.netscout.com`
Netscout	WiFi Analyzer	`www.netscout.com`
Savvius	OmniPeek	`www.savvius.com`
TamoSoft	CommView for WiFi	`www.tamos.com`

Most wireless protocol analyzers require the use of certain network adapters and, in many cases, a special device driver. We recommend that you verify that you have access to an adapter supported by the protocol analyzer's manufacturer.

Protocol analyzers are available in software programs that can be installed on a notebook computer, and they are also available in specialty dedicated handheld devices. Many analyzers are feature rich, with the capability to view security information, perform legislative compliance analysis and reporting, and generate a variety of reports, in addition to performing protocol analysis or frame decoding. Figure 9.19 shows an example of a wireless network protocol analyzer. Some manufacturers of enterprise wireless equipment provide remote packet analysis capability that allows protocol analysis from any location. Most wireless intrusion prevention system (WIPS) sensors also have this capability.

FIGURE 9.19 OmniPeek by Savvius identifies nearby wireless networks.



The main goals of a wireless network analyzer, or any protocol analyzer, are to troubleshoot network problems, gather information about security issues, and optimize the network's performance. When it comes to wireless site surveys, a protocol analyzer is a valuable tool for evaluating which wireless devices are currently in the same RF space where the proposed wireless network will be deployed. They can also be used to view the signal strength, security implementations, network name or SSID, and the channels

on which access points and other devices are currently operating. An analyzer will show not only access points but any wireless device that may have an impact on the site survey and deployment. The following devices are among those an analyzer is able to locate and identify:

- Access points
- Ad hoc networks
- Wireless bridges
- Mesh networks
- Client devices

In Exercise 9.3, you will explore a protocol analyzer.

EXERCISE 9.3

Installing a Protocol Analyzer

In this exercise, you will install the evaluation version of the CommView for WiFi protocol analyzer by TamoSoft.

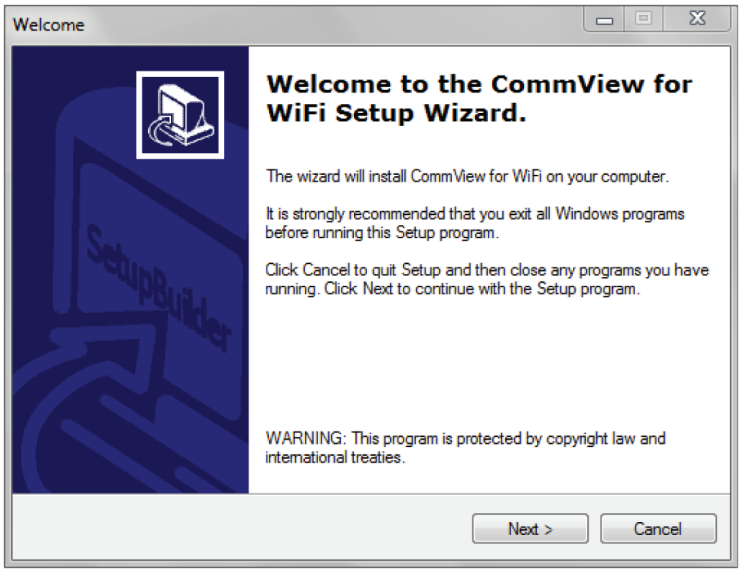
CommView for WiFi has the following system requirements:

- A compatible wireless adapter. For the up-to-date list, visit `www.tamos.com/products/commwifi`.
- Windows XP, Vista, 7, 8, 8.1, 10; Windows Server 2008, 2012 (both 32- and 64-bit versions).
- 10 MB of free disk space.

Microsoft Windows 10 Professional was used for this exercise. The steps may vary slightly depending on the version of the operating system used.

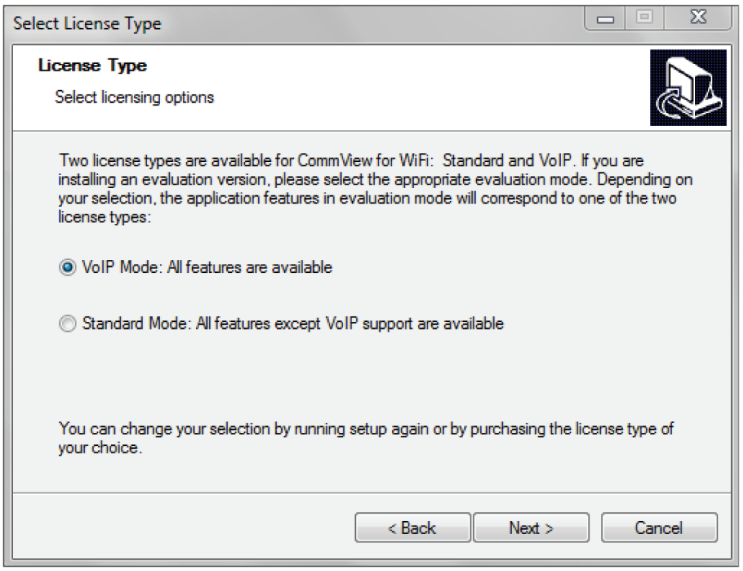
1. Download the CommView for WiFi setup program from the TamoSoft website at `www.tamos.com`. As of this writing, the name of the compressed file is `ca7.zip`.
2. Extract the files to a folder on your computer.
3. Browse to the folder containing the extracted files and open the `readme.txt` file to read the contents.
4. Start the setup process by executing the `setup.exe` program. Depending on the version of the Microsoft operating system you are using, you may see a User Account Control dialog box. Click the Yes button to continue. The CommView for WiFi Setup Wizard will appear.

EXERCISE 9.3 *(continued)*

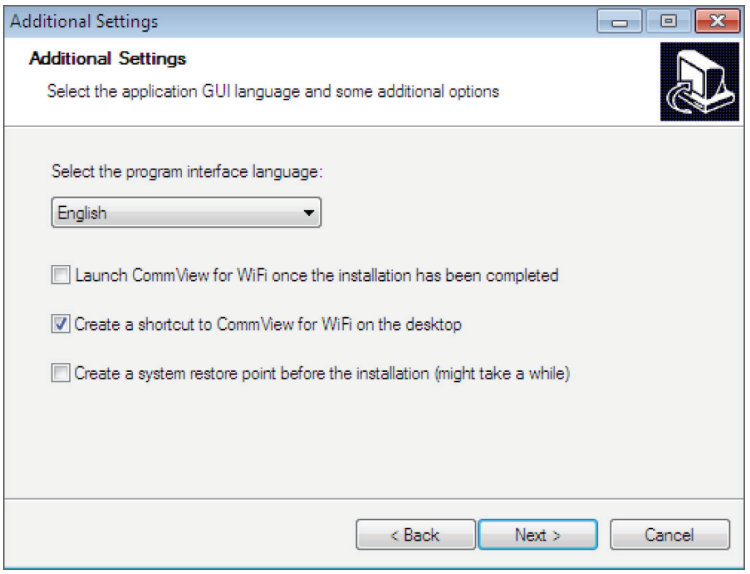


5. Click Next to start the installation process.

6. The license agreement will appear. Read the license agreement, select the "I accept the terms in this license agreement" radio button, and click Next. The Select License Type screen will appear.



7. Accept the default and click Next to continue.
8. The Destination Location screen will appear. Click Next to accept the default location.
9. The Additional Settings screen will appear. Select the appropriate language and deselect the "Launch CommView for WiFi once the installation has been completed" check box.

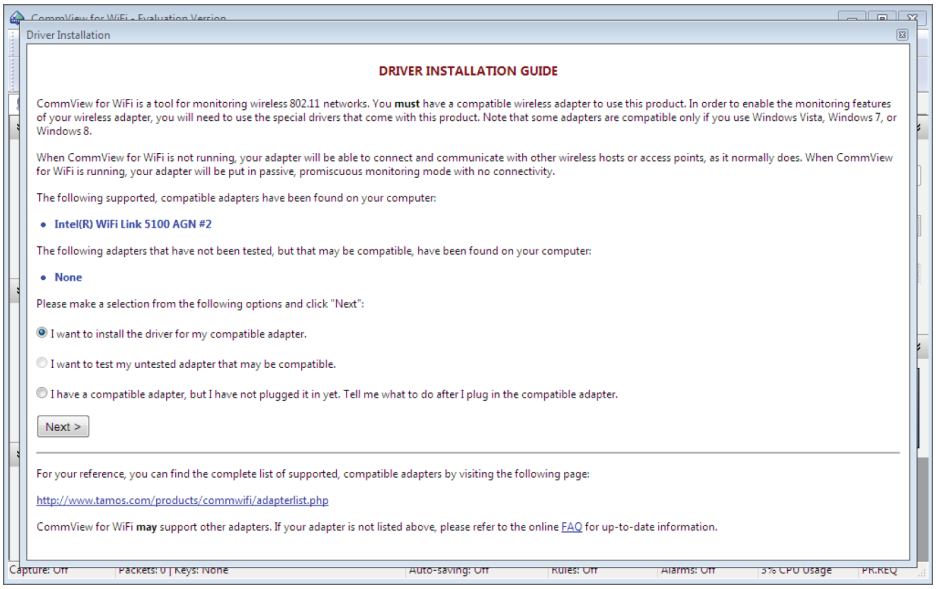


10. Click Next; the Ready To Install screen will appear. Click Next to start the installation.
11. After the installation is complete, the CommView For WiFi screen will appear. Click Finish to complete the installation.

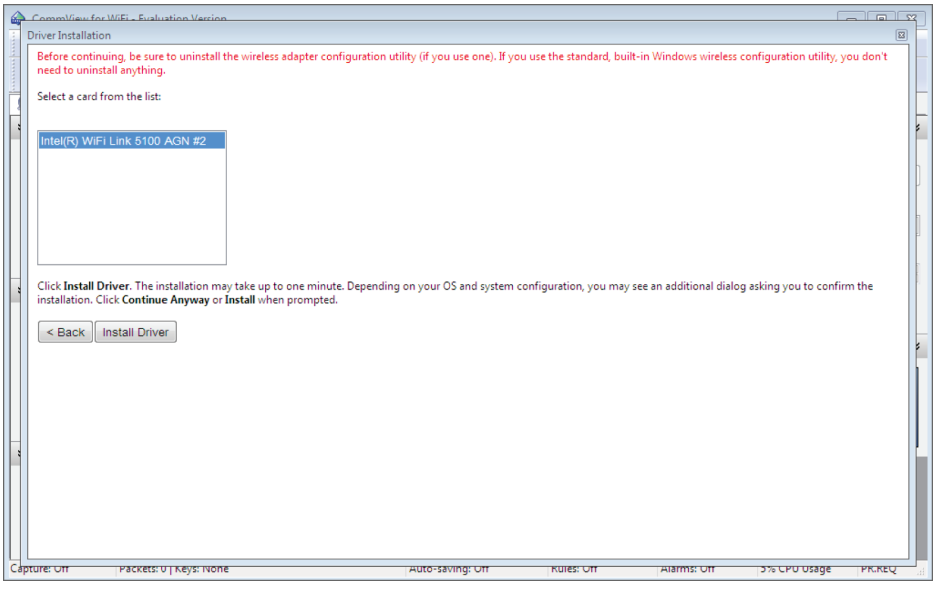
    Note: You should have a Wi-Fi adapter that is on the CommView compatibility list installed prior to completing the next step.

12. Click the CommView for WiFi icon on your Desktop to start the program. Depending on the version of the Microsoft Windows operating system you are using, you may see a User Account Control dialog box. Click the Yes button to continue. The program will start, and the Driver Installation Guide dialog box will appear in the foreground for the driver installation. Verify that the "I want to install the driver for my compatible adapter" radio button is selected.

EXERCISE 9.3 *(continued)*



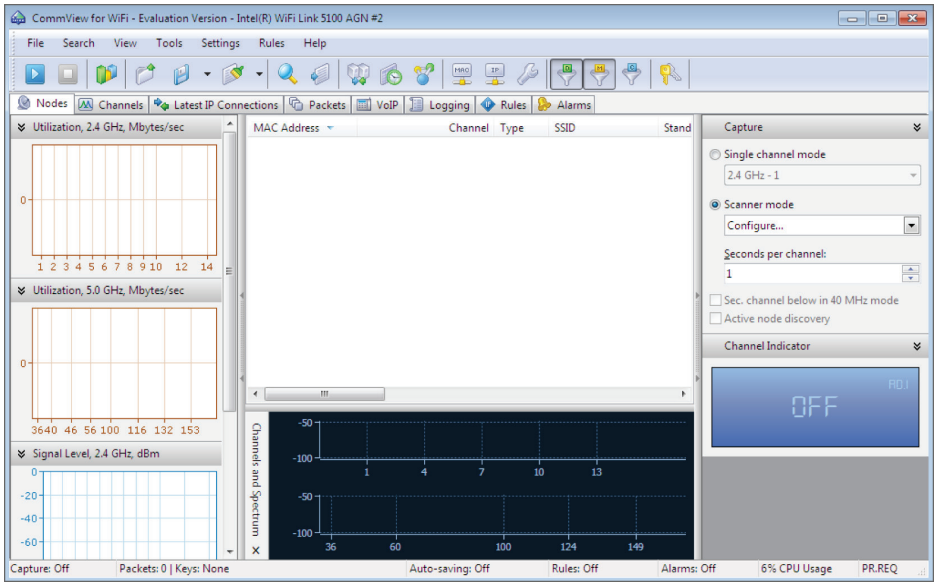
13. Click the Next button to continue if you choose to continue with the installation. The Driver Installation dialog box will appear. Verify that your Wi-Fi adapter is selected.



14. Click the Install Driver button. The program will attempt to install the device driver for your supported wireless network adapter. After the device driver is installed, the CommView for WiFi program will instruct you to restart the application.

15. Click the Close button.

16. Click the CommView for WiFi icon on your Desktop to start the program. Depending on the version of the Microsoft Windows operating system you are using, you may see a User Account Control dialog box. Click the Yes button to continue. The CommView for WiFi home screen will appear.



17. Click the arrow in the upper-left corner of the program window or click the File Menu and select Start Capture to start a capture with the program. The Evaluation Version dialog box will appear.

18. Click the Continue button to use the evaluation version of the program. Select the channel you want to view on the right side of the screen. The screen will show all wireless network devices captured when the channels were scanned.

19. Click various buttons to see the features associated with this program. When you're finished with the demonstration, exit the program by clicking the File drop-down menu and choosing Exit.

20. A "Thank you for trying this evaluation version" dialog box will appear. Click OK to close the program.

21. If necessary, using Device Manager, restore the original device driver for the wireless network adapter used with this demonstration.

After you have completed the exercise, you can remove the software from your computer or continue to use it for the remainder of the evaluation period. You can purchase a license online if you choose to continue using the program prior to the evaluation period ending.

RF Coverage Planning

One goal of a wireless site survey is to determine areas of RF coverage and RF interference. The details of the required coverage and capacity in any wireless network are part of the wireless network design, which involves determining the need, use, and business requirements of the network. This was discussed earlier in this chapter. The following factors need to be taken into consideration during a physical site survey:

- Purpose of wireless network: data, voice, video and/or location services
- Size of the physical location
- Number of users and wireless devices, including BYOD users
- Obstacles that may impact RF signal propagation
- RF range
- Bandwidth requirements of applications to be used
- Selected RF of wireless network hardware

The planning process will provide some of the answers, whereas a site visit and onsite testing will determine others, such as obstacles, signal propagation, and RF range.

Infrastructure Hardware Selection and Placement

In addition to identifying areas of RF coverage and interference, a site survey will determine the best locations for wireless access points and other infrastructure devices. The correct placement of these devices is important in order to allow clients and devices to benefit fully from the deployment of the wireless network. The location of these devices is traditionally based on the following criteria:

- Desired RF coverage
- Required bandwidth
- Aesthetics requirements
- Applications, both hardware and software
- RF cell overlap
- Channel reuse patterns

Mapping out the infrastructure device placement is considered part of the planning and design process. Manual, software-assisted, or predictive modeling site survey processes will help identify the proper locations based on the items mentioned. In most cases, a preliminary visit to the location is highly recommended, regardless of the size and the site survey method that will be used. Knowing the physical location will benefit the entire site survey process because it will help identify areas of concern.

Testing Different Antennas

Chapter 5, "Antenna Technology for Wireless Networking," discussed the characteristics, features, and best uses of various types of antennas, including omnidirectional, semidirectional, and highly directional models. Here we'll consider how best to conduct antenna testing in a wireless site survey.

As part of a manual site survey, it may be necessary to test different antennas to determine the best RF coverage. This usually requires the surveyor to connect and temporarily mount various types of antennas to access points in order to determine the proper radiation pattern and to verify RF coverage within the desired area. Some predictive modeling site survey programs will allow you to change different antennas so you can see how that will change the RF propagation pattern. A temporary antenna mounting example is shown in Figure 9.20.

FIGURE 9.20 Expandable light pole used for temporary mounting and testing of Yagi and patch antennas

Testing Multiple Antenna Types

If different antennas will be used in the deployment, it is important for the surveyor to have several types of antennas as part of the site survey kit. Some organizations that deploy wireless networks are extremely concerned about aesthetics; they will allow only specific types of antennas to be used. For example, if access points with removable antennas are used, in many cases the only type allowed will be omnidirectional antennas that are attached directly to the access point with a gain of about 2 or 3 dBi. Other deployments may use access points in which antennas are permanently attached and cannot be removed or changed.

Polarization of antennas must be taken into consideration during a manual site survey. Polarization of antennas for infrastructure devices is critical, and tests should mimic as closely as possible what will actually be installed. With the variety of wireless client devices that may be used in a wireless network, it is a challenge to predict the polarization of all the devices that might be used. However, it is advisable for the surveyor to take this into consideration during the site survey.

Choosing the Correct Antennas

Choosing the correct antenna to be used in a specific deployment is part of the wireless design and site survey process. Many factors play a role in determining which antenna will be best for the application. Some locations have strict requirements about the type of antenna that may be used. Therefore, the surveyor may have to work with specific antennas to ensure proper RF coverage. Take the following factors into consideration when choosing antennas:

Manufacturer's Recommendations The manufacturer of an access point may recommend only a specific type of antenna. If this is the case, it is important to perform the site survey with the same type of antenna.

Customer Requirements A customer may require that only specific types of antennas be used. In this case, the survey should be performed with the type of antenna required by the customer. For example, a deployment consisting of walled offices may require the use of thin access points. Usually this type of access point uses an omnidirectional internal antenna.

Environmental Conditions The environment where the wireless network is installed may also determine the type of antenna to be used. If the location is a factory with harsh environmental conditions, that could have an impact on the type of antenna and may also call for an enclosure for the access point.

Aesthetics Many organizations are sensitive to the type of devices that are seen by customers and clients. Therefore, aesthetically pleasing antennas may be required by the customer in order to be a good fit for the location in which they will be used.

Required Coverage The required RF coverage and the gain of the antenna will affect the choice of antenna. For example, a large office area may require the use of omnidirectional antennas that are physically attached to access points. A manufacturing facility may require semidirectional antennas to cover areas of the manufacturing floor. Keep in mind that in addition to being passive bidirectional amplifiers, antennas shape the coverage by either an increase or decrease in antenna gain.

Number of Wireless Access Points The number of access points to be installed in a location will also be a determining factor in the type of antenna to be used. An office building with a combination of walled offices and cubicles may have a dense deployment of access points with a limited number of users connecting to any particular access point. Omnidirectional antennas connected directly to the access point may be an adequate solution for this type of deployment. The purpose of the wireless network also affects the number of access points. For example, a wireless network that will support voice clients

will typically require more access points than a network supporting only data. If the wireless network will support location services such as RFID tracking or wireless intrusion prevention mitigation, additional access points with semidirectional antennas may be required due to the design aspects of the technology.

Physical Geometry of Location The attributes of the physical location will have an effect on the type of antenna to be installed and therefore should be tested during the site survey. This includes propagation of the signal and attenuation of obstacles. If a building has long hallways or corridors, a Yagi antenna would be a good candidate for a solution.

Regulatory Agency and Local Codes When selecting antennas, both indoors and outdoors, it is important to completely understand any RF limits or regulations that apply from the governing body or regulatory agency or any local codes that exist. In addition to the RF codes, these may include, for example, height limitations and proximity to airports. Violations of any of these may result in large fines or other penalties.

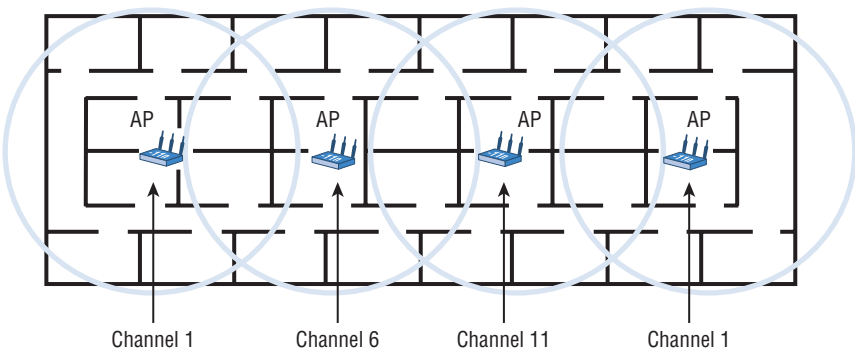
Wireless Channel Architectures

In wireless technology, *channel architecture* is the design, layout, or channel plan in use. Two common types of channel architectures that pertain to IEEE 802.11 wireless networking are available today: multiple-channel architecture (MCA) and single-channel architecture (SCA). In the 2.4 GHz band, for example, the use of nonoverlapping channels 1, 6, and 11 would be considered MCA.

Multiple-Channel Architecture

Most wireless network deployments today use *multiple-channel architecture* (MCA). This type of installation will use access points set to different RF channels to avoid overlapping channel interference, as shown in Figure 9.21. A channel plan may be used with access points set to specific channels, or in many cases automatic channel selection allows the devices to choose the best channel in which to operate.

FIGURE 9.21 An example of an MCA deployment



Single-Channel Architecture

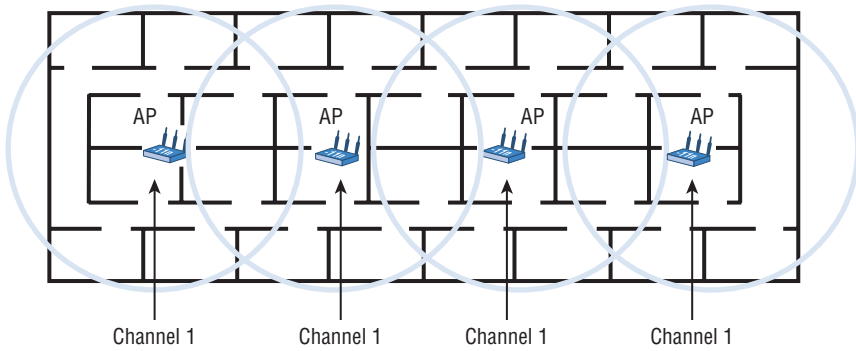
Single-channel architecture (SCA) is a wireless networking technology available from only a couple of manufacturers. SCA allows all access points to communicate on the same RF channel. The controller that the access points are connected to manages these access points and helps to avoid co-channel interference. In SCA deployments, not all access points are transmitting at the same time. The controller will determine which access points can transmit simultaneously based on the wireless devices that are in a specific area. A wireless site survey for SCA equates to providing RF coverage based on the access point placements as the wireless controller manages all the RF.

There are a few terms you should know with respect to SCA: *stacking*, *spanning*, and *blanketing*. They all refer to a means of adding capacity in an SCA network.

For example, let's look at a three-story building. Each floor in the building may be assigned a channel to use; with SCA architecture, this is known as *stacking*. The first floor would be set to channel 1; the second floor would be set to channel 6; and the third floor would be set to channel 11. Since all access points on the same floor are set to the same RF channel, co-channel interference or overlapping channel interference is not a significant issue, because of how the SCA technology works.

Using SCA may help save some time when it comes to the site survey. It is best to follow the manufacturer's recommendations for deployment for this type of system. Figure 9.22 shows an example of an SCA deployment.

FIGURE 9.22 An example of an SCA deployment



Wireless Device Installation Limitations

The installation limitations of any device that will be installed and used on the wireless network need to be evaluated. Sometimes things look great on paper, but when it comes time to actually perform the installation, it may be a little different. Various wireless devices may have the following installation limitations:

Wireless Access Points An installer may run into limitations when it comes to mounting access points or other infrastructure devices. For this reason, the surveyor must pay

close attention to the location where these devices will be mounted. The type of ceiling and mounting hardware needs to be considered. A wireless site survey should include a physical walk-through evaluation of the proposed mounting locations to observe any issues that may affect where access points, bridges, or repeaters can be mounted.

Antennas If antennas other than those designed to be connected directly to an access point are used, special circumstances may need to be taken into account:

- Mounting issues
- Cabling issues
- Aesthetics
- Height restrictions

Ethernet/PoE The maximum distance an Ethernet unshielded twisted-pair cable can run is 328 feet, or 100 meters, per the IEEE 802.3 standard. Part of the wireless site survey process includes verification of the distance infrastructure devices will be mounted from the wiring closet to be certain they do not exceed the maximum. The capabilities of the Ethernet system must also be evaluated to verify the capacity of the wiring system. This will ensure that there is adequate connectivity for the new wireless infrastructure devices.

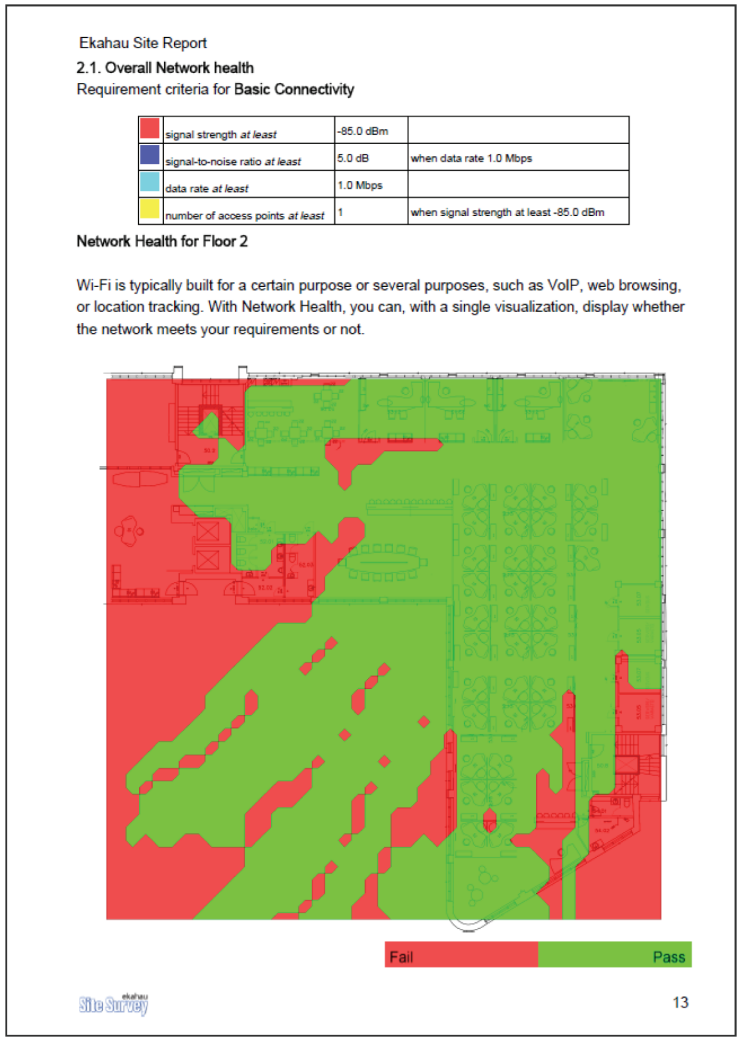
If PoE will be used, it is important to verify that the infrastructure will be able to support the number of devices that require DC power from the PoE infrastructure devices. If the current wired infrastructure is not PoE compliant, the infrastructure may need to be upgraded prior to wireless deployment. If an upgrade is not feasible, an alternate solution, such as single port power injectors or patch panels, may be required.

Local Code Restrictions In some cases, local codes or regulations will not allow devices to be installed in places like elevator shafts and stairwells. This must be identified up front for expectation purposes, especially where VoWLAN is used, so that users are aware of the limitations that may be beyond the surveyor's or installer's control. Also, it is important to be aware of the fact that some fire codes may require plenum-rated (fire-retardant) cable and devices in certain places where wireless networks will be installed.

Site Survey Report

The survey report should be a complete document itemizing all components of the wireless site survey. This includes the business aspects of the wireless site survey as well as the physical aspects. This report should include but not be limited to notes, charts, graphs, photos, test results, and any other pertinent data that will have an effect on the wireless network deployment. Most reports will be customized based on the individual needs and requirements of the customer. Most commercial site survey application programs have built-in reporting features that can be included in the site survey report. Figure 9.23 shows a sample page from a commercial site survey application with report-generation features.

FIGURE 9.23 Ekahau site survey built-in reporting features


Ekahau Site Report

2.1. Overall Network health

Requirement criteria for **Basic Connectivity**

	signal strength *at least*	-85.0 dBm	
	signal-to-noise ratio *at least*	5.0 dB	when data rate 1.0 Mbps
	data rate *at least*	1.0 Mbps	
	number of access points *at least*	1	when signal strength at least -85.0 dBm

Network Health for Floor 2

Wi-Fi is typically built for a certain purpose or several purposes, such as VoIP, web browsing, or location tracking. With Network Health, you can, with a single visualization, display whether the network meets your requirements or not.

Fail Pass

Site Survey 13

The main content of the site survey report should include the following items:

- Customer requirement analysis
- RF interference source analysis
- RF coverage analysis
- Device capacity and application analysis
- Infrastructure device placement and configuration information

The RF dynamics of many environments are constantly changing, as more devices using RF for communications become a part of the wireless network or share the same RF space. It is a wireless network engineer's responsibility to understand that site requirements may also be constantly changing. Therefore, the RF site survey is becoming an ongoing process, and the site survey report can be seen as a living document.

Summary

This chapter discussed the business aspects of wireless network site surveys. The objective of a site survey is to find areas of RF coverage and interference, understand capacity planning, and determine hardware installation locations. We explored some of the factors that determine the complexity of a site survey.

You saw the importance of gathering information as well as the types of information required to successfully perform a wireless site survey and design a wireless network. Anyone designing a wireless network needs to understand completely the expectations of how the network will perform in the environment before deploying the network. These expectations will be met by asking the right questions of the right people—managers and users of the wireless network—because they are the ones who will be using it. Having the appropriate documentation is a key element to a successful deployment. Accurate documentation will also help streamline some of the site survey process and the deployment of wireless networking hardware. Accurate documentation will help with the installation of cabling and access points and minimize questions about the installation.

It is essential to know the location and type of existing networks, both wired and wireless. If existing wireless networks are in place, you must determine what role, if any, they will play in the new deployment or upgrade.

You learned about RF coverage and capacity requirements and the factors to be taken into consideration to ensure proper coverage throughout the location where the wireless network is installed. Client connectivity requirements and other considerations were discussed. The types of wireless client devices that will be used, such as notebook computer, tablet, or bar-code scanner, must be determined. Antenna orientation to ensure correct polarization will need to be considered during the site survey process. We also looked at the type of antennas commonly used in a particular deployment scenario.

The wireless site survey process is one of the most important components of a successful wireless deployment. Many areas need to be considered, including an RF spectrum analysis to determine RF interference sources that may affect the wireless deployment. Although a spectrum analysis can be considered optional, it is advisable to complete one whenever possible. Spectrum analyzers are available in various types, such as instrumentation devices and USB adapters, and now may be part of the wireless access point.

We compared Wi-Fi and non–Wi-Fi sources of interference, both of which can have an effect on the performance of a wireless network installation.

We looked at the various types of wireless site surveys that can be performed, including manual and predictive modeling. We also explored the two types of manual site surveys,

passive and active. You saw some of the items that may be included in a survey toolkit as well as temporary mounting examples for access points and antennas. We looked at the use of a protocol analyzer in a wireless site survey and how one could be used to identify existing wireless networks in the area of concern.

Finally, you learned about both multiple-channel architecture (MCA) and single-channel architecture (SCA) and the differences between them. Best practices for hardware placement were also reviewed, including access points and antennas, as well as some of the limitations that may be encountered during the wireless network site survey process.

Exam Essentials

Understand the business requirements of a wireless network. Be familiar with the business information required for a successful wireless network site survey. These business requirements include bandwidth needs, expected coverage area, and hardware and software applications used (for the devices and the different technologies). Understand that the site survey process will vary based on the business model in which a wireless network is deployed. These will include enterprise, manufacturing, health care, and public access, to name a few.

Understand the interview process. Know whom you should interview and the type of questions to ask during the site survey and design process. This will help ensure a more successful wireless network deployment.

Identify the importance of site-specific documentation. Know the various types of documentation required based on the business model for the wireless network site survey. This includes blueprints and floor plans as well as other important documentation.

Know the importance of identifying existing networks. Understand the details of existing wired and wireless networks and be able to define the characteristics of both, such as wiring closet location and power requirements.

Understand the application requirements for the wireless network. Know that different applications, both software and hardware applications, will have an effect on the wireless network design, and the site survey must take this factor into consideration.

Understand RF coverage and capacity requirements. Know the factors involved with providing adequate RF coverage within a wireless network deployment. Understand that with a wireless site survey, capacity requirements must be met to ensure acceptable performance.

Understand the need for an RF spectrum analysis and how to locate sources of interference. An RF spectrum analysis will allow you to "see" RF in an area proposed for a wireless network. Identify different types of RF interference that can have an effect on a wireless network.

Know the differences between manual and predictive modeling site surveys. A manual site survey typically requires a complete walk-through and testing throughout the proposed area where a wireless network will be deployed. A predictive modeling site survey may require minimal time on site and is a software-based analysis solution.

Identify two different types of manual site surveys. Know that manual site surveys can be passive or active and understand the differences between each.

Know how a protocol analyzer can be used as part of wireless network site survey. Understand how a wireless protocol analyzer can be used to help identify existing wireless networks during a site survey and how the existing wireless networks may have an impact on the wireless network after deployment.

Be familiar with the limitations of placement regarding wireless infrastructure devices Explain some of the limitations regarding placement of wireless network devices, including access points, bridges, and antennas.

Understand the factors regarding proper antenna use. Identify the different uses of antennas based on the customer requirements and characteristics of the environment.

Understand different wireless architectures Two common wireless network architectures exist: multiple-channel architecture (MCA) and single-channel architecture (SCA). Know the differences between them.

Review Questions

1. A main objective of a WLAN site survey is to determine _____ and _____. (Choose the best two options.)
   - **A.** Areas of RF interference
   - **B.** Applications to be used
   - **C.** Access point locations
   - **D.** Wiring closet locations
   - **E.** Security implementations

2. You are a network engineer tasked with performing a site survey for a multiple-channel architecture (MCA) system in a three-story building. Which characteristic must be considered while performing a site survey?
   - **A.** All omnidirectional antennas should be vertically polarized.
   - **B.** Multiple floors require the same channel.
   - **C.** Each floor should be treated as an individual site survey.
   - **D.** The channel plan should take all three floors into consideration.

3. What devices, tools, or programs can be used in a manual site survey? (Choose two.)
   - **A.** Spectrum analyzer
   - **B.** Passive scanning utility
   - **C.** Predictive site analyzer
   - **D.** Association analyzer
   - **E.** Authentication analyzer

4. The manual site survey consists of which possible methods? (Choose two.)
   - **A.** Passive
   - **B.** Scanning
   - **C.** Active
   - **D.** Spectrum
   - **E.** Packet

5. Non–Wi-Fi interference for an 802.11g/n network can be caused by _____ and _____. (Choose two.)
   - **A.** AM radios
   - **B.** Microwave ovens
   - **C.** 802.11b networks
   - **D.** Cordless phones
   - **E.** Radar systems
   - **F.** Digital TV systems

6. You are a network consultant hired to perform a manual site survey for a small office building. The wireless network to be installed will use data and voice. For backward compatibility, the customer needs to support 2.4 GHz equipment. To provide the highest QoS for the voice application, you recommend that the received signal strength be a minimum of _____ for a data rate of 54 mbps.
   - **A.** –20 dBm
   - **B.** –25 dBm
   - **C.** –67 dBm
   - **D.** –76 dBm

7. A type of site survey that is software-based, requires minimum time on site, and takes into consideration the attenuation value of materials such as the type of walls and doors is _____.
   - **A.** Active
   - **B.** Passive
   - **C.** Predictive
   - **D.** Optional

8. You are performing a protocol analysis in order to determine potential interference from other WLANs in the immediate area of the site survey. You discover several WLANs that can potentially cause interference with the proposed installation. Which technology in use would *not* have an impact on the 802.11g/n wireless network you are surveying for?
   - **A.** FHSS
   - **B.** OFDM
   - **C.** DSSS
   - **D.** ERP-OFDM
   - **E.** PBCC

9. You are using a wireless client adapter with a site survey utility and a notebook computer to perform a manual site survey in a very small office building. Which values are important to record to verify proper RF coverage for the location? (Choose two.)
   - **A.** Signal strength
   - **B.** SNR
   - **C.** Packet retries
   - **D.** Signal loss
   - **E.** Propagation loss

10. You have been hired by a company to perform a manual site survey. When explaining the difference between a manual and predictive modeling site survey, you let the customer know the advantages and disadvantages of each. A manual site survey has which advantage?
   - **A.** Speed
   - **B.** No hardware required
   - **C.** Accuracy
   - **D.** Facility access not required

11. A spectrum analyzer can be used to view what?

A. RF

B. Wireless packets

C. Data rates

D. Association frames

12. You have been hired by a company to perform a WLAN site survey in a multitenant building. You discover numerous access points on channels 1, 6, and 11. To optimize the new deployment, what recommendation could you make to the customer? Assume that all new hardware will be purchased and backward compatibility is not required.

A. Configure the access points to automatic channel selection for the 2.4 GHz ISM band.

B. Configure the access points to operate in the 5 GHz band.

C. Perform a spectrum analysis to find space in the 2.4 GHz band.

D. Perform a predictive modeling site survey to determine which channels to use.

13. Which of the following is true of a predictive modeling survey?

A. It takes more time than a passive survey to get accurate results.

B. It takes less time than a passive survey to get accurate results.

C. It finds areas of interference from neighboring WLANs.

D. It helps you choose the manufacturer's equipment to be used for the WLAN.

14. When using a predictive modeling site survey approach, which of the following is true about manual verification?

A. Manual verification never has to be performed.

B. Manual verification is always required.

C. Manual verification should be performed only at the customer's request.

D. Manual verification should be performed, but it is not required.

15. When performing a manual site survey, choose the best way to identify areas that lack RF coverage.

A. Mark them with tape so that they can be located at a later time.

B. Use a camera to take a photograph and document it in the report.

C. Show the site manager the areas that lack coverage.

D. Document the areas on the floor plans or blueprints.

16. When a device associates to an access point during a site survey, it is performing which type of survey?

A. Predictive

B. Active

C. Passive

D. Required

17. When considering the use of antennas for WLAN deployment during a site survey, which antenna could be tested to verify proper coverage for a long hallway or corridor?

A. High-gain omnidirectional

B. Low-gain omnidirectional

C. Parabolic dish

D. Yagi

18. You need to perform a site survey for a small real estate office that currently has no wireless network. Which factors must be considered as part of the site survey?

A. Spectrum analysis

B. Packet analysis

C. Environmental conditions

D. Correct antenna selection

19. Co-channel interference is caused by access points on _____.

A. Channels 1 and 1

B. Channels 1 and 2

C. Channels 1 and 6

D. Channels 1, 6, and 11

20. Which guidelines are recommended when performing a manual site survey? (Choose two.)

A. Walk-through of location

B. Predictive analysis

C. Equipment purchase

D. Client device configuration

E. Spectrum analysis

Chapter

10

Mobile Device Management and BYOD Fundamentals

THE FOLLOWING CWTS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

✓ **6.3 Understand the basic functions and implementation best practices for WLAN security technologies.**

THE FOLLOWING CWS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

✓ **3.7 Determine the best solution for BYOD and guest access**

✓ **4.4 Discover client devices and applications in use**

✓ **4.7 Discover use cases and access types**

✓ **4.8 Match organizational goals to WLAN features and functions**

THE FOLLOWING CWT EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

✓ **2.1 Describe client types and varying capabilities**

Over the past several years we have seen the influx of mobile device technology and the concept of bring your own device (BYOD) within the corporate world. This has created something of an administrative challenge for the information technology professional. While some organizations embrace this concept, others are skeptical of the adoption for various reasons, including network capacity, technical support, and security concerns.

This chapter will explore the basics of mobile device management (MDM) options, including both on-premises and cloud-managed Software as a Service (SaaS) solutions. MDM solutions provide the capability to manage mobile devices of various platform types that connect to the corporate network. This includes access to digital applications (apps) via online stores. You will see that with MDM solutions, you will require special permissions to perform specific tasks on mobile devices. We will explore how mobile apps and other device information can be pushed to devices. You will also see that devices can be grouped based on management requirements and why high availability is an important feature of MDM.

Geo-fencing (building a virtual electronic boundary) and geo-location (the ability to locate a device physically) are two components of the mobile location services you will learn about. A captive portal allows network administrators to restrict access to a network until authentication has occurred or terms and conditions have been accepted. This prevents users from accessing resources or services without proper authorization. Self-service portal solutions enable users to register their devices to the network, allowing for quick access to the network without the need to open a service ticket or contact the help desk for technical support. We will take a look at both the captive portal and self-service portal.

With respect to mobile computing, a policy is documentation that defines rules, restrictions, acceptable use, liability, and more. We will look at some of the basic components of a network security policy. The technology user must have a clear understanding of the policy and how to adhere to it in order to effectively use the network and services it provides. The contents of a policy will vary based on the business model or the organization type; there is really no one-size-fits-all policy.

This chapter provides a basic outline of some of the more common policy components that are part of the framework for most organizations. If a policy is too strict, it may hamper the ability for a user to perform the needed tasks while using the network; therefore, the appropriate balance between security and usability is important. Policies exist for many areas of mobile technology, including passwords/passcodes, remote access, data backup and restoration, and more. You will see an overview of and the importance of a backup and restore policy. Knowing how the mobile device's operating system can affect the adherence to policy is another topic we will explore. Changes to the mobile operating system may also be limited based on the network security policy. We will explore profiles, which allow a

device to connect to a network and follow specific configurations, requirements, or settings for the connected session and how applying grouping concepts will help streamline mobile device administration. Finally, we will look at testing and pilot programs as they pertain to validating technology and changes within an existing network environment.

Mobile Device Management Solutions

The extensive increase in the number of multifunction wireless mobile devices gives users the opportunity to access information of all types from anyplace that provides infrastructure network access via technology such as cellular connections and WLANs (Wi-Fi). This includes the home, public venues, and the workplace. Although convenient and popular, this emerging mobile technology may create something of a challenge for the enterprise and corporate IT services professional and help desk support personnel. This is where MDM solutions stand out. MDM allows network managers, administrators, engineers, and other information technology personnel to manage, control, and secure multiplatform device environments that may be used on the network.

Choosing the correct MDM solution for your networking requirements involves some contemplation. The correct solution must meet the needs of the organization and will require careful consideration to validate it does so. When it comes to MDM, two main options exist. In-house (on-premises) solutions or cloud-managed solutions, which are provided as Software as a Service (SaaS) technology, are widely available. MDM solutions include, but are not limited to, the following features:

- Application distribution (push technology)
- Compliance reporting
- Content management
- Device registration (self-service portal)
- Location-based services
- Multiplatform management and support
- Password control
- Policy enforcement
- Remote lock
- Remote wipe
- Remote unlock
- Secure communications (VPN)
- Telecommunications expense management

Many MDM solutions are available on the market today. If your organization allows employees, contractors, vendors, and others to use their own personal devices or company-owned devices to access your network, you will need to ensure that the platforms are supported in order to lessen support calls and other associated costs.

Most, if not all, MDM providers offer a free trial period or will set up demonstrations over the Internet for you to evaluate their software solutions and packages. We highly recommend you try these products prior to purchasing a specific provider's solution. It is best to know that the solution you choose will meet your specific needs. There is no "one size fits all" when it comes to MDM solutions. Choosing the correct solution will depend on many factors, including business model, number of employees and devices, and company policy requirements.

You will now see an overview of both cloud-managed (SaaS) and on-premises solutions and how each has its own distinct advantages and disadvantages.

The Software as a Service Solution

When it comes to information technology services, the term *cloud* seems to be the newest buzzword. Cloud-managed solutions are commonly known as *Software as a Service* (SaaS) solutions and are not limited to MDM. In many cases, the SaaS MDM solution is a virtual on-premises solution that has many if not all of the same features but without the extra administration overhead and costs that go with the on-premises model. (On-premises MDM are discussed in the next section.) Other SaaS solutions include products that are truly managed services provided from certain software manufacturers.

Some of the advantages and disadvantages of a cloud-managed solution are as follows:

- Advantages
  - Hardware investment is not required.
  - Installation and setup time is minimal compared to an on-premises solution.
  - Less administration overhead and potentially better availability compared to an on-premises solution.
  - Can be administered from any location where an Internet connection is available.
- Disadvantages
  - Recurring monthly subscription fees.
  - Internet connection is required for all management and control.
  - Concerns for unauthorized access of data stored on cloud provider's server if not properly secured.

Depending on the environment where it is deployed, the SaaS MDM solution will be a great fit in many cases. We recommend additional research and reviewing the advantages and disadvantages to determine the best solution.

The On-Premises Solution

Many network managers and administrators have a certain comfort level with the idea of an on-premises MDM solution as with other on-premises technology. This is because these

solutions provide direct access and more control with the installed products. Some of the advantages and disadvantages of an on-premises solution are as follows:

- Advantages
  - Can be maintained within the organization's data center.
  - No recurring monthly subscription fees.
  - Internet connection is not required for management and control.
  - Ownership of the investment including associated hardware and software.
- Disadvantages
  - Initial investment with required hardware and software.
  - Installation requires setup time and may require additional resources.
  - Administration overhead, backup solution, and technical support.
  - May require additional setup resources and administration from outside the organization.

Choosing either a SaaS (cloud-managed) solution or an on-premises solution requires considering many factors, such as corporate policy, security concerns, and cost. It is best to compare all features, advantages, and disadvantages prior to purchasing any one specific solution. Following are some MDM solution providers that offer on-premises solutions, cloud-managed solutions, or both.

MDM Solution	Website	Platform
VMware AirWatch	www.air-watch.com	On-premises and cloud-managed/SaaS
Amtel	www.amtelnet.com	Cloud-managed/SaaS
Apple Profile Manager	www.apple.com/support/osxserver/profilemanager	Cloud-managed/SaaS
Blackberry	www.blackberry.com	On-premises and cloud-managed/SaaS
Centrify	www.centrify.com	On-premises and cloud-managed/SaaS
Citrix – Zenprise	www.citrix.com/products/xenmobile	On-premises and cloud-managed/SaaS
Cloudpath (Ruckus Networks)	cloudpath.net	On-premises and cloud-managed/SaaS
Google G Suite	gsuite.google.com/products/admin/mobile/	Cloud-managed/SaaS

(*continued*)

MDM Solution	Website	Platform
IBM (MaaS360)	www.ibm.com/us/en	On-premises and cloud-managed/SaaS
Ivanti	www.ivanti.com	On-premises and cloud-managed/SaaS
Microsoft Intune	www.microsoft.com/intune	On-premises and cloud-managed/SaaS
MobileIron	www.mobileiron.com	On-premises and cloud-managed/SaaS
Notify Technology	www.notifycorp.com	On-premises and cloud-managed/SaaS
SAP/Sybase	www.sap.com	On-premises and cloud-managed/SaaS
Sencha	www.sencha.com	On-premises and cloud-managed/SaaS
SOTI	www.soti.net	On-premises and cloud-managed/SaaS
Symantec	www.symantec.com	On-premises and cloud-managed/SaaS

Common Mobile Device Operating System Platforms

There have been many mobile device operating systems over the past decade. Some have come and gone, and others have survived. For the corporate or enterprise mobile device user, there are still four main players in the current market: Android, BlackBerry, iOS, and Windows Phone.

Android Android is an operating system based on Linux and designed for smartphones and tablet devices that are mostly touchscreen capable. This operating system was originally developed by Android, Inc., and was acquired by Google in 2005. The Open Handset Alliance (OHA) continues to update the operating system. The OHA (www.openhandsetalliance.com) is a consortium of approximately 84 firms that was created to develop open standards for mobile devices. According to a report published in early 2014 by Good Technology, enterprise Android activations were at about 26 percent compared to 72 percent for Apple iOS during the fourth quarter of 2013. More recent numbers in the fourth quarter of 2016 show Android dominated the market with an 81.7 percent market share.

BlackBerry The first BlackBerry operating system was released in 1999 for the Pager 580. This operating system was designed by BlackBerry Limited and is proprietary to BlackBerry mobile devices. Synchronization of various corporate email services is where the BlackBerry operating system rose in popularity. BlackBerry 10 is the most recent release of the operating system. Although it has had its share of ups and downs, BlackBerry still continues to be a popular operating system in the corporate world for existing adoptions.

iOS In 2007 Apple Inc. introduced the iOS mobile operating system for the iPhone. This operating system is now incorporated into other Apple devices, including iPod Touch, iPad, iPad Mini, and Apple TV devices. According to a report from The Verge (`www.theverge.com/tech`), the 2016 fourth quarter Apple iOS market share was 17.9 percent, up slightly from 17.7 percent in the fourth quarter of 2015.

Windows Phone Microsoft released its proprietary mobile operating system, Windows Phone, also known as WP, in the fourth quarter of 2010. Windows Phone replaced Windows Mobile (last updated in February 2010); however, it is not backward compatible with Windows Mobile. According to The Verge report, the Windows Phone operating system market share was about 0.3 percent over the fourth quarter of 2016, a very small number compared to Android and Apple iOS.

Mobile device multiplatform support must be considered prior to purchasing and implementing an MDM solution. The type of business in which the solution will be deployed and whether employee-owned devices are allowed are factors that must be considered in the selection.

The Mobile Application Store

The *mobile application store*, or more commonly, *app store*, is a digital distribution platform consisting of different websites that allow users to obtain applications (apps) for their mobile devices. These apps may be available at no charge or may be fee-based. App stores fall under two different categories: enterprise app stores and consumer app stores.

The Enterprise Mobile App Store The enterprise app store is a site that allows employees of an organization to visit for company-standard mobile apps. The enterprise mobile app store helps an organization to control and regulate the apps that are used within its environment. The development of an on-premises app store can be involved and expensive, and therefore organizations that may not have the resources or funds for an on-premises solution can create their own store by using an online provider.

The Consumer Mobile App Store The consumer mobile app store is intended for the common user to download or purchase commercial, off-the-shelf mobile apps. The following

list shows some of the available categories within a consumer app store and is only a small sample of what is available:

- Business
- Education
- Games
- Health and fitness
- Medical
- Music
- Productivity
- Sports
- Weather

Although stores are available for a variety of device types, the most popular supported platforms are the Android, BlackBerry, Apple iOS, and Windows Phone. The following list shows popular app stores. These stores may host apps for both the enterprise user and the consumer user.

App Store	Website
Apple App Store	`itunes.apple.com`
BlackBerry World Store	`apps.good.com`
Google Play Store	`play.google.com`
Opera Mobile Store	`store.ovi.com`
Samsung Store	`www.samsung.com`
Windows Phone Store	`www.windowsphone.com`

The use of mobile apps continues to grow at a very fast pace. As people become more dependent on mobile device technology, the need and variety of apps are constantly expanding.

As of March 2017, the Android Google Play Store had officially reached more than 2.8 million apps, compared to 1 million apps in July of 2013.

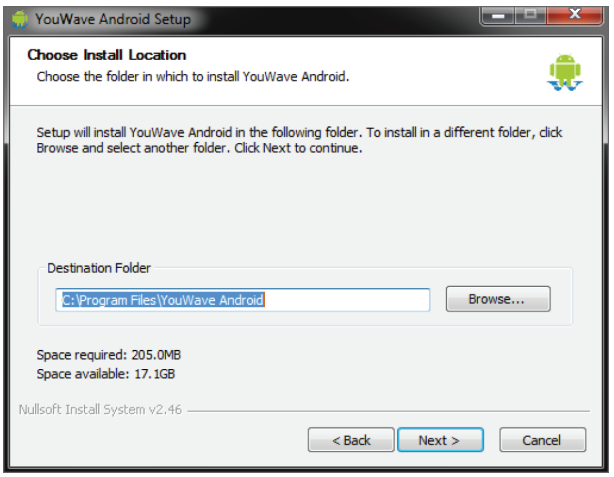
An emulator can be a valuable tool for testing prior to deploying MDM policies, applications, or other content. Exercise 10.1 shows you how to install a free emulator that you can use for a trial period.

EXERCISE 10.1

Installing Android Emulator Software in Microsoft Windows

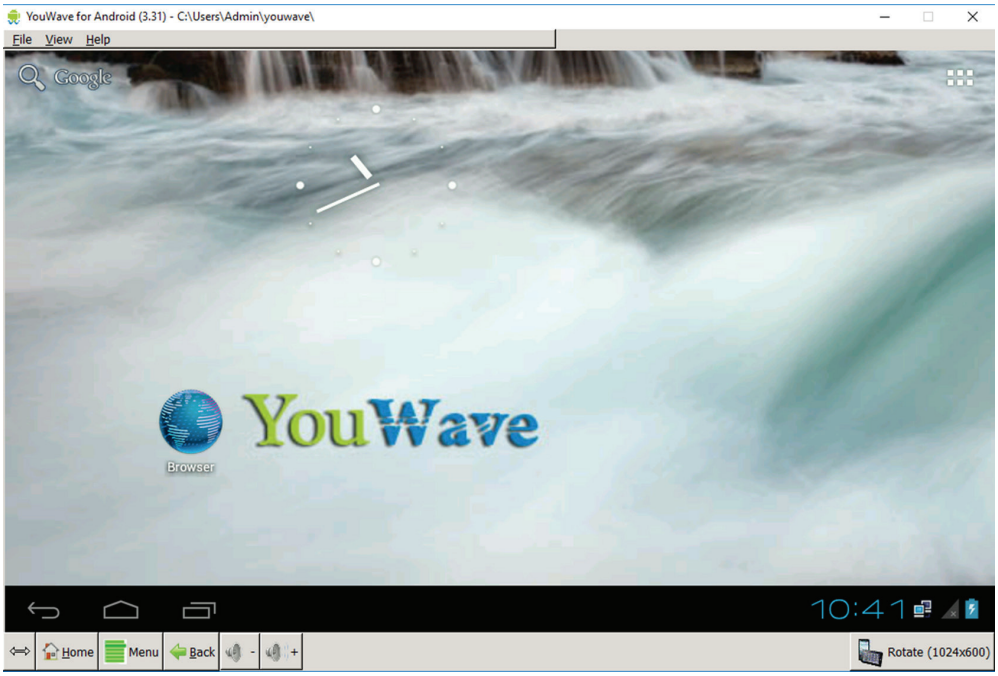
In this exercise, you will install a free version or a 10-day free trial of the premium version of an easy-to-install-and-use Android emulation program on a computer using the Microsoft Windows operating system. To perform this exercise, you will download a Microsoft Windows–based Android emulator program from YouWave (`youwave.com`). For this exercise, the free version of the emulator program was installed on a computer running the Microsoft Windows 10 Professional operating system. The steps will vary based on the operating system used. Note: The premium version requires Windows 64 bit OS and VT-x support in CPU (usually can be enabled in BIOS).

1. Point your Internet browser to `youwave.com`.
2. Navigate to and click the Download button. The Download YouWave For Android landing page will appear. This will allow you to download a free version (Android Version 4.0.4 [ICS]) or a 10-day free trial for a fee-based premium version (5.1.1 [Lollipop]).
3. Select the desired version and click the Download button. In this exercise, the Home 3.31 version was selected.
4. Save the file that contains the program to your download directory. The file is named `YouWave-Android-Free-3-31.exe`.
5. Navigate to the folder on your computer that contains the program you downloaded in step 3 and execute the file. Depending on the version of the operating system you are using, a User Account Control dialog box may appear.
6. Click Yes to continue. The YouWave Android Setup dialog box will appear.
7. Click Next to continue. The license dialog box will appear.
8. Read the agreement and click the I Agree button to continue the installation. The Choose Install Location dialog box will appear.

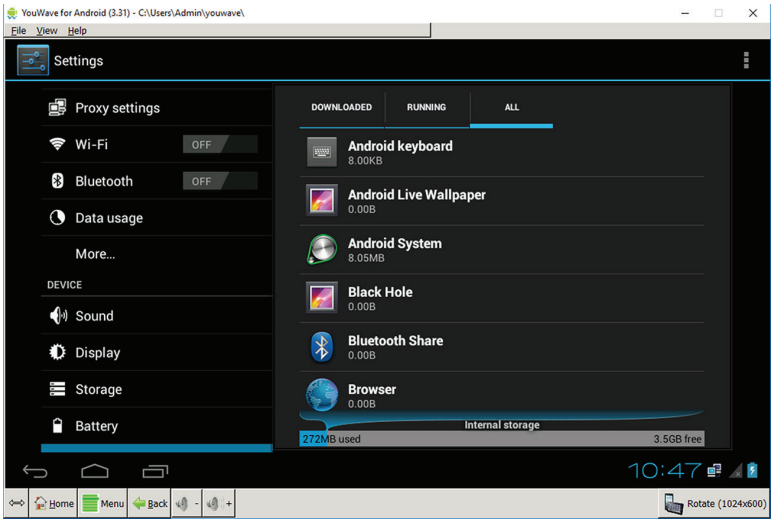


EXERCISE 10.1 *(continued)*

9. Click Next to accept the default installation location. The Choose Start Menu Folder dialog box will appear.
10. Click the Install button to accept the default folder and continue the installation. The Completing The YouWave Android Setup Wizard dialog box will appear.
11. Click the Finish button. A YouWave Android Setup dialog box will appear.
12. Click OK to end the installation.
13. Start the YouWave Android emulator program by choosing Windows Start ➢ YouWave Android ➢ YouWave Android. The trial period dialog box will appear on your screen.
14. Click OK to continue. The YouWave Android emulator will appear on your screen.



15. Explore some of the program features by clicking the green Menu icon and Manage Apps.



You can continue to use the program for the remainder of the 10-day evaluation period. When this trial period expires, you can uninstall the program from your computer or purchase the fee-based premium version from the YouWave website.

Although using actual devices is a great technique for development and testing, emulators of any type can be valuable tools for many aspects of technology. Computer-based Android and other mobile device emulators aid in software development, debugging, pilot test beds, and troubleshooting.

Pushing Content to Mobile Devices

Pushing content to mobile devices is a common requirement in enterprise device deployments. MDM solutions allow for corporate and other applications to be pushed to all specified mobile devices that connect to the corporate network, regardless of whether the device is a company-owned asset or an employee-owned personal device. This lessens the burden of requiring employees to visit the enterprise app store and download a specific app. In addition to apps, the following information can be pushed to mobile devices (among other types of information):

- Operating systems and updates
- Configuration information, such as Wi-Fi profiles and settings
- Security information and updates
- Videos
- Email configurations

Some mobile device operating systems include platform-dependent native push services, such as the Apple Push Notification Service (APNS), which is required for Apple device MDM enrollments.

Mobile Device Management Administrative Permissions

You need to have the proper privileges to manage mobile devices from a corporate network, depending on the action to be performed. This is really no different than common day-to-day network administration tasks that are usually defined with the corporate network policy.

Mobile devices used to access corporate network resources may not be a corporate-owned asset and may be personal property of the employees. You may need special privileges, or *administrative permissions*, to use MDM solutions to perform the following actions:

- Creating and maintaining mobile device policies
- Grouping devices with the correct policy
- Allowing for remote wipe, remote lock, remote unlock, and password control

The privileges will be defined as part of the network policy, and that task may be delegated to the organization responsible for computer network administration. Assigning administrative permissions can be accomplished in different ways, depending on the MDM solution you choose. In the case of BYOD solutions, device owners will need to be familiar with the corporate policies regarding the use and administration of employee-owned devices. The end-user license agreement (EULA) process and how it is accepted will need to be defined for several reasons, including for legal purposes. The EULA and additional pertinent information will be discussed in more detail in the "End-User License Agreement" section later in this chapter.

Understanding Mobile Device Management High Availability and Redundancy

One important component of MDM services is to ensure that access will always be readily available. Consistent or *high availability* for any type of networking service is commonly accomplished by redundancy of some type and is not a new concept. Computer networking services redundancy dates back to the early days of local area networking. At that time, it was important to ensure that various types of data were always readily available and not just accessible from a data backup solution. This was handled in a variety of ways, including hard drive storage failure protection by disk mirroring or using RAID technology. RAID is an acronym that is spelled out a couple of different ways, including Redundant

Array of Inexpensive Disks. In the event of a hard drive or disk storage failure, the file server would be able to continue to operate and provide access to any stored data. Without this type of fault tolerance, the hardware would need to be repaired or replaced and the data restored from a backup, resulting in potentially significant network downtime.

File server redundancy, including grouping, or "clustering," servers together for fault tolerance purposes is another method that would allow for high availability. The cost for this type of redundancy is higher because you would need to have completely redundant servers in the event of a catastrophic hardware failure. The benefit of this type of solution is 100 percent uptime for the network services—hence, a higher cost.

The requirement for information to be always available with no downtime is becoming more common and will be part of a company's best practice policies. MDM solutions are no different from other networking services, such as email and the reliable storage of information. Therefore, redundancy will need to be considered to ensure the availability of appropriate services. This is something that should be considered when evaluating an MDM solution for your organization and is more of a concern with on-premises MDM solutions. With SaaS, or cloud-managed, MDM solutions, the service provider will be responsible for the redundancy by providing redundant data centers, an uninterruptible power source (UPS), and redundant Internet connectivity, in addition to other common redundancy best practices.

Mobile Device Management Device Groups

Creating *device groups* within your MDM solution will help to streamline administration. Creating groups will allow the MDM administrator to identify profiles, applications, and other content that will need to be made available to the device user. This concept is similar to computer network administration. Organizing device groups will simplify management by providing common access to devices based on the requirements of the organization. Different options are available for an administrator to create device groups, which will depend on the specific network operating system and the *directory service* in use. The following directory service implementations are common:

- Microsoft Windows Active Directory
- Red Hat Directory Server
- Novell eDirectory
- Apple's Open Directory

These directory services can be queried using *Lightweight Directory Access Protocol* (LDAP) and will aid in the simplification of the administration process.

Group management with MDM is an important component of the entire practice of MDM. Improper group development and assignments will potentially lead to many technical support incidents and troubleshooting issues. You can also create pilot and test groups that can be used prior to a large-scale deployment for policies, mobile apps, and other configuration information.

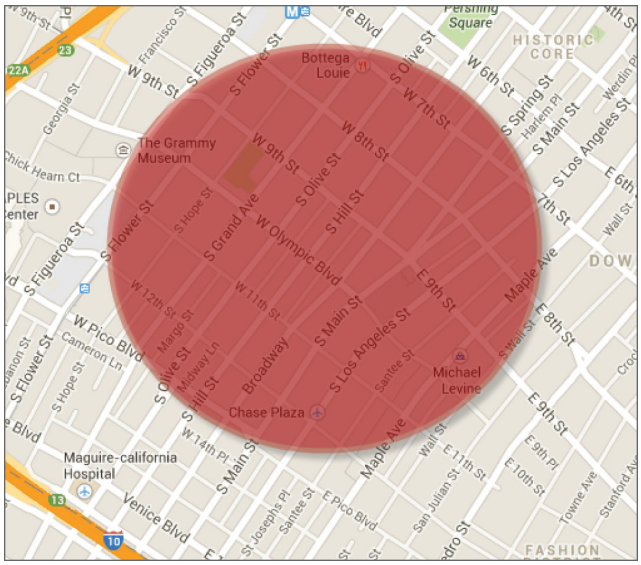
Location-Based Services

Location-based services (LBS) can be used in many ways. One use of LBS allows for various types of assets and devices and even people to be geographically located by different methods of radio frequency (RF) technology. These methods include radio frequency identification (RFID), Global Positioning System (GPS), and WLAN (Wi-Fi) technology. When it comes to mobility and mobile device technology, LBS is widely used with social media and mapping services to help identify the location of a mobile device for various purposes, including personal, work, and entertainment. The following sections provide a brief overview of LBS technology that is used with mobile device technology and a focus on geo-fencing and geo-location. LBS solutions can be software-based, hardware-based, or a combination of both.

Geo-fencing

A fence provides an enclosure at the perimeter of an area. This enclosure is designed to keep items from leaving and entering an area and to know what is contained within an area. Geo-fencing from a mobile computing perspective is taking this concept to an entire new level. This virtual electronic boundary allows network administrators to identify when specific mobile devices enter or leave an area. With the explosion of the number of mobile devices that are now used, keeping private company information within the boundary of the organization is critical. This is just one example of how geo-fencing is used. Figure 10.1 shows how *geo-fencing* is a boundary surrounding a specific geographic area.

FIGURE 10.1 Geo-fencing example



Commonly used with GPS or WLAN technology, geo-fencing–enabled devices can be managed from within the MDM solution. Tasks include managing device features, activating/deactivating devices, restricting access to specific apps such as games and social media, and protecting private company information. Disabling the use of other device features, such as built-in cameras, can also be accomplished with MDM.

From the consumer side, geo-fencing is also popular with social media applications. These applications allow a user to notify their friends or colleagues when they leave a specific location or when they arrive at a new location. The opportunities are endless as to how this can be used, including intentionally informing someone of a location, iOS reminders (which are intended to provide an alert when arriving at or leaving a specific location), and even shopping.

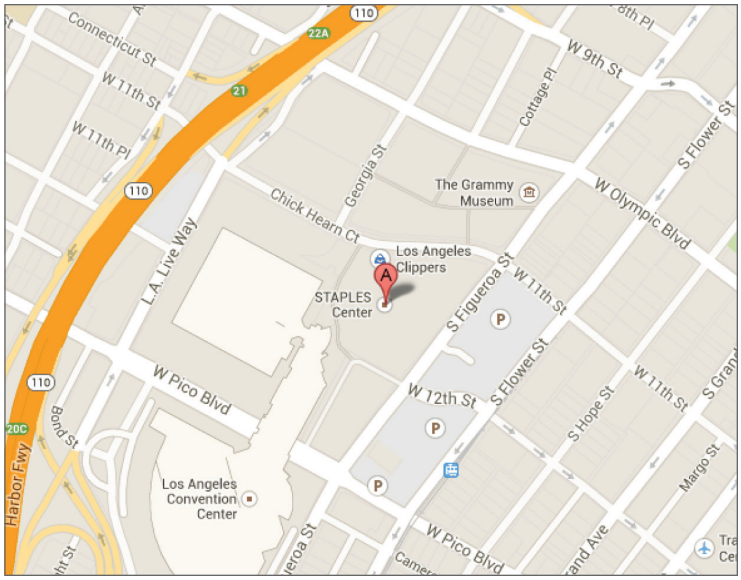
Geo-location

Geo-location technology allows for many different device types to be geographically located. The following devices are among those that can use this technology:

- Smartphones
- Tablets
- Computers

With geo-location, different methods can be used to locate a device. One example is time difference of arrival (TDoA), which is a multilateration technology technique. TDoA will measure the difference in distance between two stations from known locations. This provides an accurate method for locating a device. Another method of identifying the physical location is by using the device's assigned IP address to provide specific information about the physical location of the connected device. Figure 10.2 shows how geo-location can pinpoint a device at a precise location.

FIGURE 10.2 Geo-location can identify the physical location of a device.



The use of geo-location technology covers a wide range of applications. Although with consumer mobile devices, the user has the capability to disable geo-location technology, many opt not to do so. This is because either they are not aware that the technology exists and is enabled or they plan to use it for social media purposes. Geo-location technology can be used for marketing, social media, and enterprise device security.

Mobile Device Telecommunications Expense Management

Managing expenses for mobile device technology can be a daunting task. Many MDM solutions, either on-premises or cloud-managed SaaS, offer *telecommunications expense management* features. One common concern with mobile device technology is that users exceed the amount of data communications available to their device or their data plan. Unlimited data plans are becoming a thing of the past, and data use will need to be strictly managed. This is where telecommunications expense management plays a role. Enabled devices allow MDM systems to handle data plan management and other tasks, including invoicing, identifying excessive roaming, and disabling data capability for lost or underutilized devices. While many carriers are doing away with unlimited data plans, some are increasing the data cap allowed for customers while keeping the price the same. Therefore, the battle to retain or get new customers continues to build amongst the wireless carriers. Some will even pay an early termination fee to try to get subscribers to change to their company. Carriers continue to build out their wireless network infrastructure, providing the ability to handle the increased data usage.

Captive and Self-Service Portals

The following sections compare two different methods that mobile devices can use to access resources on a network, including wireless networks: captive portals and self-service portals.

Captive Portals

A *captive portal*, sometimes called a *walled garden*, is a web page redirection that a wireless device user is presented with after performing an IEEE 802.11 open system authentication and IEEE 802.11 association when connecting to a wireless (Wi-Fi) network. Captive portals are not limited to Wi-Fi networks, but this is one network type where they are often used. In order for the user to access permitted resources or gain wireless network access, a web page will require them to authenticate in some way, which may include the following:

- Entering user credentials (username and password)
- Inputting payment information
- Agreeing to terms and conditions

When one or more of these methods is used, the wireless device will be able to access the network and use whatever resources they have permissions to use. Most public access wireless networks have some type of captive portal enabled. This includes networks at public venues such as hotels, coffeehouses, restaurants, and airports. This will help to protect both the provider (host) and the user of the wireless network. Private corporate networks also use captive portals when a user connects to the guest service set identifier (SSID). Using captive portal authentication with enterprise guest networks will ensure that a user is connecting to an authorized company access point and not a potential rogue access point. Most enterprise-grade wireless access points, including cloud-managed access points and WLAN controllers, have built-in captive portal capabilities that are fairly straightforward and easy to implement.

Keep in mind that a captive portal does not offer security of any data and only provides a way for network infrastructure devices to restrict device and user access to a network until some type of successful authentication has been provided. This "authentication" could be as simple as agreeing to a "Terms and Conditions" web page. After a user connects to a wireless network through a captive portal, additional security measures should be put in place. For public networks, this includes options such as VPN connections or using a secure protocol like HTTPS, at a minimum. With a corporate network, additional authentication may include WPA2 passphrase authentication or IEEE 802.1X/EAP user/certificate-based authentication. Security concepts are discussed in Chapter 8, "Security Fundamentals for Wireless Networking."

Self-Service Portals

MDM platforms often include self-service portal functionality to allow mobile device users to register their devices and connect to a network. With the concept of BYOD continuing to grow and more personal devices being allowed to connect to a corporate network, a self-service portal will help by requiring less administration overhead and therefore providing a cost savings to the organization. The MDM platform that is used will determine which management features the user will have access to.

A *self-service portal* is a method of on-boarding a device and allowing it to comply with the appropriate company/device policy. The way these portals operate will vary based on how each MDM platform incorporates the technology. If a user already has a user logon account such as a Microsoft Windows Active Directory account, it may be as simple as entering their credentials to start the on-boarding process. If they are a guest or new user, they will need to have an account created.

Here is one example of the self-service portal process.

1. Create an account for the device user. This is usually done from an administrative console page.
2. A username, first and last name, email address, and phone number is usually required.
3. An email will be sent to the user with information regarding the device registration.
4. The user will then access the self-service portal web page logon screen, which requires them to accept any terms and conditions or specific device policies.

5. The user will then select their device type (iOS, Android, or other).
6. Depending on the use of device, a guest network or company network will determine the capabilities and policies.
7. A text message will be sent to the device with a password or PIN, which will then allow the user to access to the network.

The preceding steps represent a generic process, and it is important to understand that the steps and processes will vary depending on the MDM platform you are using.

Users may also be able to use their company credentials to log on to a guest network portal. If the company has an agreement with the provider or wireless carrier, the credentials may be transferable. For example, when the user enters an area that charges for Wi-Fi service with which their company has an agreement, instead of paying for access, the user can log on using their company credentials. Many users may not even be aware such agreements exist.

Many benefits are available to the user of the device that is now being managed, including but not limited to the following:

- Locating a device
- Locking a device
- Requesting information from a device
- Remotely wiping a device

One example where these features will prove helpful is when a device is lost or stolen; these features can help protect the integrity of the information contained within the device.

General Technology Network and Security Policy

The definition of the term *policy* will vary based on its specific use. For example, an automobile insurance policy is a contract between an insurance provider and an individual known as the policyholder. The insurance policy identifies details about specific agreements concerning what the policy covers and the responsibility of the provider if a claim is filed by the policyholder. With regards to technology, a security policy defines an agreement between a corporation or the technology provider and the technology user. This agreement defines the specific use as well as the terms and conditions with which the user will comply while using the provider's network and services.

The specific use of the network or services will determine the type of policy and the specifics that are contained within. For example, companies that work within the medical

field will need to understand compliance with the Health Insurance Portability and Accountability Act (HIPAA) in addition to the general policy framework. Another common example is that organizations that process, store, or transmit credit card information must comply with the Payment Card Industry (PCI) standards. You learned about these and other industry regulatory compliance considerations in Chapter 8.

Security Policy Framework

Keep in mind that a network security policy's contents will vary based on the specific type of business or application in which it is applied. For example, the policy for an organization that handles financial information will be different from the policy for a manufacturing company. Most policies, however, are based on a general framework. Using this framework will enable you to build a policy that will meet the needs of the organization.

Typically, a computer network security policy consists of two main parts: general policy components and functional, or technical, components. The general policy components consist of the policy purpose and business justification, management approval, policy definition and documentation processes, training policies, revision processes, violations and response, legal concerns, and potential threat assessment. The functional, or technical, side commonly consists of administrator and user training, monitoring, auditing, response and forensics, defining acceptable use, and security requirements, including authentication, encryption, and passcode and password policies. Keep in mind this is a general framework that can be used as a guide to assist in developing an actual security policy.

The best way to learn the components and features of MDM solutions, including defining profiles to help enforce security policy, is to actually evaluate one and use it. Earlier in this chapter you saw several manufacturers of MDM solutions. Most of these companies provide evaluation or trial periods of their products. Here we will be using examples from Windows Intune, a cloud-managed management solution from Microsoft. You can register for a free trial to evaluate this product at `www.microsoft.com/intune`.

Information Technology and Security Policy Implementation and Adherence

Every company or organization that provides technology resources of any type should already have an information technology and security policy in place for its computer network. If this is not the case, then it should be a very high priority to get one in place as quickly as possible. Given that various wireless technologies are becoming a major part of all networks, it is critical for wireless and mobility technology to be part of this security policy.

If a security policy already exists, adding the wireless technologies that are used will be a fairly straightforward process. Getting the right people involved is essential for the implementation and success of a security policy. This includes the information technology group as well as the management team.

A well-designed policy is critical in order for network security to be successful, balanced, and maintained. Because wireless networks use the RF spectrum for communications, the legal use of unlicensed and licensed RF bands will also need to be understood to ensure compliance with the local governing regulating bodies and the appropriate authorities. The wireless communications/network portion of the security policy should include, at a minimum, sections defining the purpose, scope, policy details, enforcement information, and revisions/maintenance.

Purpose This section should provide an overview of why the policy has been put in place and define the importance of compliance. This ensures that everyone understands that misuse could result in severe interference with the intended use of the network and may put the organization and users at serious security risks.

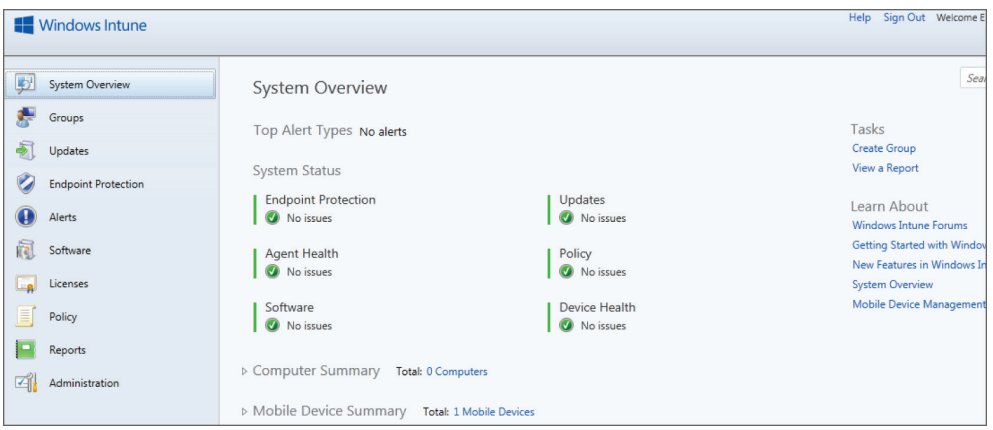
Scope The scope should provide an overview of whom the policy will apply to, the use of the wireless spectrum, the acceptable use policy, and the importance of compliance.

Policy Details This section should contain a basic overview of the wireless technology that will be used, including the allowed RF spectrum and the wireless technology and devices that can or cannot be used. This section should also identify some of the more technical aspects, such as user authentication and data encryption, the tolerance for specific types of network traffic and RF interference, and acceptable applications.

Policy Enforcement This section should define any actions, potentially including potential, that will be taken against those who are not in compliance.

Revisions/Maintenance With the frequent changes in technology, a security policy can be somewhat of a moving target. Revisions and maintenance, including a change record or revision history page, should be documented. Figure 10.3 shows an example of a cloud-managed MDM program that can be used to create device profiles based on policy and provide policy enforcement.

FIGURE 10.3 Windows Intune mobile device management dashboard



Acceptable Use Policy

One of the most basic, common, and important policies for computer networking is an acceptable use policy. This is typically a policy that the user must comply with in order to access and use any computer network resources or services. At a minimum, the acceptable use policy will outline the rules regarding what a user can and cannot do. In most cases this is an abbreviated version of the complete policy that the user will be referred to and have access to if further detail or clarification is needed. Most organizations require all users to sign and agree to this policy. This could be in the form of a physical document or in an electronic format. For the mobile wireless guest user, the acceptable use policy may come in the form of a web-based captive portal and usually includes restrictions and limitations. You learned about captive and self-service portals in Chapter 8 and earlier in this chapter.

Balancing Security and Usability

When it comes to policy, the ability to maintain a good balance between security and usability is a key factor. Some people believe that you can have too much of a good thing. If a policy is too tight, it may limit productivity or a user's ability to utilize their devices correctly and to get their job done. On the other hand, if a policy is too loose, it could potentially compromise the security and integrity of the corporate network. Therefore, an accurate balance between the two must be closely evaluated. A poorly balanced security policy is directly proportional to a policy failure. One example is a passcode or password policy. Most industry best practices agree that the longer and more complex a passcode is, the more secure it will be. However, if it is too long or complex, a user may have difficulty remembering it, or depending on the device, it may be a challenge to type it in. Another example is what exactly the user of the device is allowed to do. Can they install and remove apps? Can they modify the system's or device's settings? All options must be carefully considered in order to maintain a good balance. Much of this will also depend on the type of organization where the device is used. Finding the correct balance will be a challenge and is contingent on understanding what you are trying to protect and what you are trying to prevent.

Backup, Restore, and Recovery Policies

Regardless of whether a device is a company asset or is employee-owned, the importance of backup, restore, and recovery policies cannot be overestimated. A well-written backup policy that can be easily understood and implemented will make what is usually considered an unpleasant or often ignored task much easier to comply with. Mobile devices that are used to store corporate data and intellectual property information such as trade secrets must correctly implement and adhere to the specified policy. Automating this task as much as possible will lessen the reliance on the device's user interaction and allow for a better chance of policy compliance.

Many may think of device backup as only something that is used for recovering data that may be lost because of device failure or unintentionally deleted. With mobile devices, you must also take into consideration that a device can be stolen or lost, which will then put all information that is stored on that device at risk if the device falls into the wrong hands. In such a situation, a network administrator can use an MDM solution to easily locate the device over the Internet using location services and remotely back up the data stored on the device to a corporate file server or cloud-managed storage network. After a backup is complete, the device can be securely locked or even remotely wiped to provide additional security.

Operating System Modifications and Customization

Mobile device operating systems are designed to offer specific features and capabilities. This allows for consistent functionality and operation of the devices that run the operating systems. However, many hardware device manufacturers customize the device to operate with some of their specific features and to include their company branding. In addition, the owner of the device may be able to add their own customizations, which may include:

- Fonts
- Home screens
- Ring tones
- Wallpaper
- Widgets

The fact that some operating systems, such as Android, are open source provides many opportunities for the device manufacturer or the owner to add their own unique flair.

Manufacturers of mobile device technology usually have certain features "locked down," which means they cannot be changed. However, some devices may be "rooted" or "jailbroken" to remove the manufacturer's restrictions. Android rooting and iOS jailbreaking can void the device manufacturer's warranty and cause other issues.

Operating System Vendors

Earlier in this chapter, we explored some of the popular mobile device operating systems, including Android, BlackBerry, Apple iOS, and Windows Phone. Chances are very high that organizations that allow employee-owned devices to access the company network will have a mix of these and other various devices with different operating system vendor platforms. The ability to integrate the various devices and operating systems into the environment may come with certain challenges that limit capabilities among the different

vendors. These capabilities include the remote management of the devices, general support for different operating systems features, and specific technology capabilities, such as passwords and resets.

Because of the diverse number of devices and available operating systems installed, the MDM administrator should be proactive with keeping up to date with any technology changes. Some of the methods an administrator can use to stay current with mobile technology changes include:

- Social media
- Subscribing to available services from the manufacturers
- Rich Site Summary (RSS) services or feeds
- Online webinars and training sessions

The proactive approach will allow the administrator to prevent potential issues or problems from occurring by becoming familiar with various limitations between the mobile device operating systems in use.

Original Equipment Manufacturer

The definition of original equipment manufacturer (OEM) may vary depending on the context in which it is used. In the automobile industry, the term "OEM part" is a replacement part that is manufactured by the same company that made the original part. This gives the buyer confidence that the part will be an exact replacement and will work as designed.

With regards to mobile technology, one definition is when a company purchases the rights to resell a product under its own brand name. One example is the ability for different manufacturers to sell smart phones that run the Android operating system. Integrating directory services into an MDM solution may allow an administrator to use an existing directory database to help streamline user/device authentication and enrollments and can help to gather information from the managed device and the connected user.

Vendor-Default Device Applications

Mobile device operating systems often have default applications that are installed by the manufacturer. These applications may include Internet browsers, email applications, video, audio/music, documents viewers, and others. The type of file that is accessed will determine which application is launched to manage or open that file. Users of Android devices can select which application they want to use to complete a task. Users can use the selected program to "always" open future files that are of that same type, or they can specify to open the file "just once." If users choose the latter option, they will be presented with the option again when a file of the same type is opened. If a user changes their mind and later wants to use a different application, they can easily reset the default application. In Exercise 10.2 you will reset the default application for a device that is running the Android operating system.

EXERCISE 10.2

Resetting the Default Application—Android

This short exercise demonstrates one way to reset the default applications on a device using the Android operating system. Keep in mind these steps may vary based on the operating system and the version that is in use.

1. Select the Android Settings icon.
2. Select Applications.
3. Select the application that is currently set to open the file type you would like to change.
4. Scroll down to launch by default and tap Clear Defaults.
5. You will be prompted to select an application type the next time that file type is launched.

Technology Profiles

Profiles are used in wireless networking to provide configuration or settings information and to help with security policy compliance. Saving this information within a profile helps to lessen the overhead of entering specific information every time you wish to connect to a network or access a network resource. Profiles can be used in a variety of scenarios—for example, with IEEE 802.11 wireless networking client devices or connecting to a VPN from a client to a VPN concentrator. Mobile device profiles using MDM will simplify and streamline access to an infrastructure and device management. You learned about VPN technology in Chapter 8.

Mobile Device Profiles

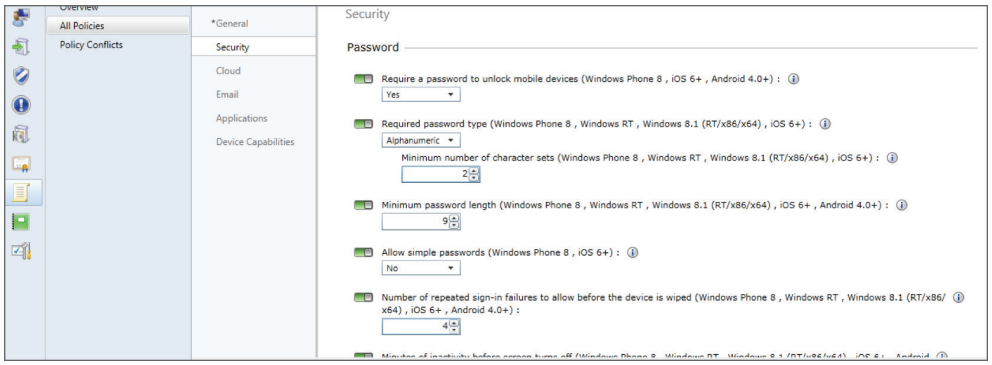
A profile is a set of parameters or instructions that will provide a device the ability to connect to a network and follow specific requirements or settings for the connected session. These profiles will define specific settings and configuration information in addition to restrictions based on the device itself and who is using the device. The profiles can be assigned for operating systems, individuals, and groups. Profiles may contain configuration information for the following:

- Email access
- Internet access
- Network configuration information

- Wi-Fi access
- VPN configuration information

In addition to configuration and settings, a profile will help maintain security policy compliance. Figure 10.4 is an example of a cloud-managed MDM software application that can be used to set password policy enforcement.

FIGURE 10.4 Windows Intune password policy configuration screen



Directory Services Integration

From a computer networking perspective, a directory service is similar to that of a database where information about specific objects can be created, stored, and retrieved. An analogy is a simple address book contained within a smartphone. You could enter specific information about contacts, such as their name, various phone numbers, an email address, and much more. Searching a person by name will provide any additional information that is documented about that contact.

Microsoft Windows Active Directory and Novell eDirectory are examples of computer network directory services. These are X.500-compliant directory services and are used to centrally manage users, groups, devices, and other resources. A network administrator can create user and group objects and allow them access to various network resources, such as a shared folder on a file server or a network printer. Integrating directory services allows a network administrator to assign mobile device applications, user and device profiles, and other data that can be associated with their directory services group membership. Depending on the MDM solution that is used, you can also synchronize any changes that are made to the directory database to the mobile device policy that it is connected to. This will include any changes that are made to the user, device, or group object that the device is associated with. Deleting a user object in the directory services database will allow the MDM software to take the appropriate designated action.

Issuing Digital Certificates

A digital certificate can be used as an access control method for various mobile devices, computers, and other devices and will ensure that only valid authorized users will gain access to the corporate network infrastructure. Certificates are one method of access control used to confirm that a person is who they say they are. This will help to restrict access to a system or resource only to those who are entitled to the access. Digital certificates can use a security concept known as a *public key infrastructure* (PKI). In a full PKI deployment, digital certificates are required on the RADIUS server and the client device. Installing digital certificates can be streamlined using MDM software to issue the certificates automatically without relying on any input from the user of the device.

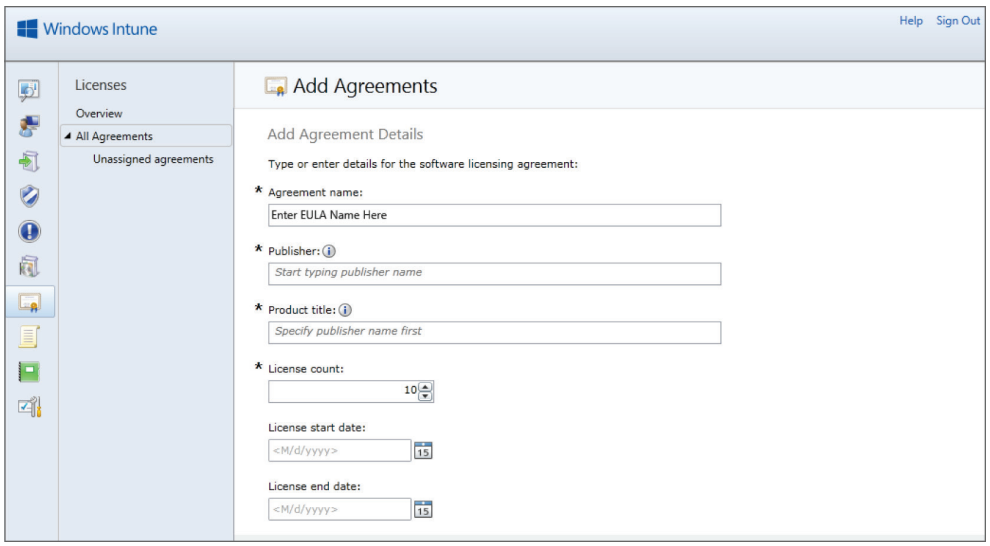
End-User License Agreement

When a user installs proprietary software on a device, they must agree to and comply with the EULA. This is basically an agreement between the creator of the software package and the organization or person who purchased the software. Most software programs used within the mobility environment include a screen that provides specifics regarding the EULA and is usually shown at the beginning of the installation process. This will include some basic information that the user must agree to before continuing.

It is very important that the organization understands the EULA for legal and liability management regarding mobile device technology and employee-owned devices. In most cases these are customized by the legal department to ensure the EULA complies with the company objectives and covers the specific use of the software. Keep in mind that in many cases this is a scaled-down version of a more complete document that defines all the specifics in more detail.

Figure 10.5 shows an example of a cloud-managed MDM administration console used to create a license agreement.

FIGURE 10.5 Windows Intune management console used to create a license agreement



Notice in Figure 10.5 that this program allows an administrator to enter the license name, software publisher, product title, license count, and start and end dates. When a user connects to the portal, they will be able to agree to the license agreement and install the program.

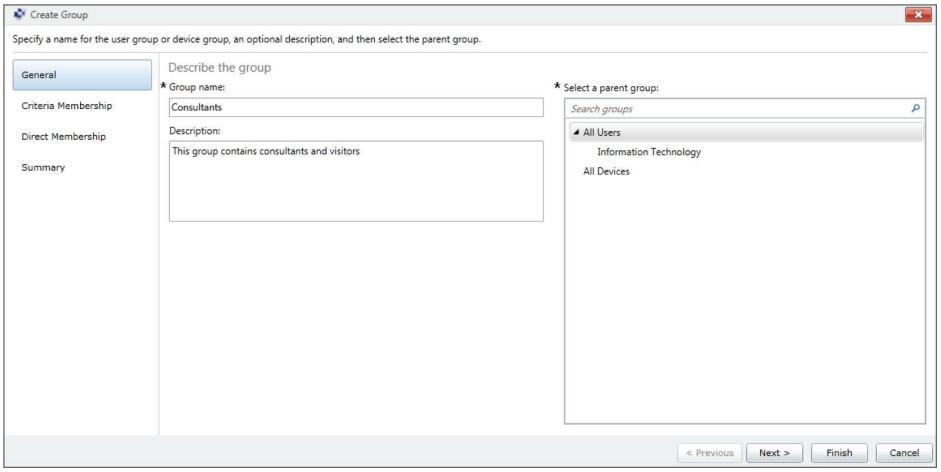
Understanding Group Profiles

For anyone who has performed basic computer network administration tasks, understanding group profiles should be fairly straightforward. Managing a network and access to its resources is much easier and streamlined when using a grouping methodology. See the case study to examine one specific scenario.

Real World Scenario

Assigning Access to Network Resources Using the Group Technique

You are a network administrator and have three departments in the company that each requires access to specific resources located within the computer network. The departments are sales (10 members), engineering (3 members), and consultants (2 members). The sales department requires access to a marketing database; the engineering department must be able to access product technical specifications; and the consultants department requires access to specific company briefings. There are two ways to approach this. One would be to explicitly assign permissions to the resources to the members of each department. The second way would be to create a group object for each department, add the members to each group, and assign the groups access to the resources. If a user no longer requires access to the network service or resource in which they have permissions via the group membership, the administrator can remove them from the group, thereby removing their access. Using groups helps to streamline the administration process of mobile devices by reducing repetitive administrator work in maintaining policy compliance and allowing access to network resources and services.



The first option is an inefficient method of administration because any changes are made on an individual per-user basis and would require potentially extra administration and overhead. The second option is more efficient because any changes are on a per-group basis.

The case study described here is very similar to the concept of creating profiles for devices within an MDM environment. The needs of the individual, whether the device is company-owned, and departments the user of the device belongs to will be factors in determining the capabilities of the device and the user. Some common profiles for specific devices and users with MDM techniques include the following:

- Corporate-owned devices
- Employee-owned devices (BYOD)
- Outside consultants' and visitors' devices

Corporate-Owned Mobile Device Profiles

Issuing corporate-owned mobile devices to employees provides a network administrator with much-needed control over how the device is managed. Unlike with employee-owned mobile device profiles (discussed next), there is less concern about the type of applications or data that is used or stored on the device, because the network administrator can have complete control over ensuring that applications and profiles that are installed on the device comply with corporate security policy. Something to consider is whether personal applications and data will be allowed on a corporate-owned device. The corporate security policy will need to define exactly how this is handled.

Employee-Owned Mobile Device Profiles

Devices that are employee-owned will require special consideration as to what exactly a user can or cannot do with the device once it is connected to the corporate wireless network. The continued growth of the BYOD concept has raised concerns regarding security and network capacity. However, the benefits of BYOD must also be considered. A company, organization, or school can leverage employee-owned or personal devices to provide a cost savings by allowing these devices to be used on the company network.

In cases such as this, the correct provisioning and policy compliance will need to be closely evaluated. If employee-owned devices are allowed to be used on the corporate network, containerization of applications and data should be considered. This will allow corporate applications and data to be stored, maintained, and managed separate from the employee's own personal data. In the event a device is lost, stolen, or unaccounted for, the MDM software program can take the appropriate action to mitigate any potential security

concerns by performing a device lockdown or remote wipe of the corporate data installed on the device. The owner of the device that is used on the organization's network must be made aware that with certain security threats the appropriate action will be taken in order to secure the device and protect any confidential company data.

MDM providers offer different mechanisms or processes using containerization technology. It is recommended as part of the software evaluation and trial period that you take a close look at how the manufacturer deals with this concept and try to determine whether their way would be a good fit for your organization.

The practice of companies allowing employee-owned devices on the corporate network will continue to grow. Gartner, Inc., estimates that by the end of 2017 more than 50 percent of companies will require that employees supply their own devices for use on the corporate network, helping to justify the use of MDM solutions and technology.

Outside Consultants' and Visitors' Mobile Device Profiles

Depending on the business model or organization type, providing network access to outside consultants and visitors can be considered somewhat of a challenge. In many cases, connecting to the organization's network, wired or wireless, is not allowed under any circumstances. In such situations, it is not uncommon for the organization to provide a third-party service, such as a cable modem or digital subscriber line (DSL) connection from an Internet Service Provider (ISP), to allow outside Internet access for the guest user. A benefit of this scenario is that the outside consultants will in no way be connected to the organization's network infrastructure, which may be a requirement in the network security policy. If this type of service is not provided or allowed, then the only option a consultant will have is to use a cellular data connection, such as 3G, 4G, or LTE, to get outside access.

For various reasons, including security, many organizations allow physical wired access to a network only to its employees but will allow wireless network access via a connection to the guest wireless network. This guest network is typically on a completely separate virtual local area network (VLAN) to ensure it meets the requirements of the network security policy. In this situation, it is important to define how the outside devices will be able to connect and what exactly they will be able to do once they are connected. Defining requirements such as content filtering, the amount of bandwidth, and time restrictions are some examples of the limitations guest networks may be subject to. Most of these restrictions can be achieved through the use of an MDM profile.

Policy and Profile Pilot Testing

Before any new technology, software, or changes are deployed, it is beneficial to perform pilot testing within key areas of the organization in order to validate that the technology will work as specified and designed. This is a concept that is true with various types of

technology, including but not limited to Voice over Wi-Fi (VoWi-Fi) handsets, client device deployments, firmware updates, software patches, fixes and upgrades, and, of course, mobile device policy and profiles. Although some consider this an option rather than a requirement, this process must be carefully considered, as it is best to find any issues that may arise on a smaller scale rather than after a full deployment or upgrade. The pilot program process will vary depending on how and where the technology is used, the scale of the deployment, the type of technology, and who is performing the testing. Some common steps that may be used as part of pilot program testing include the following:

- Selecting the individuals or groups to be part of the test
- Soliciting feedback and monitoring the testing phase
- Making adjustments or changes as needed based on the results
- Getting proper approval from change management
- Implementing full deployment throughout the organization

It is also important to monitor the devices and users after the implementation has occurred and to solicit feedback in order to identify any issues that were not identified during the pilot program testing.

Summary

In this chapter you learned about how the influx of mobile device technology and the concept of BYOD create administrative challenges and how these challenges can be addressed by implementing an MDM solution. We explored the basics of MDM solutions, including both cloud-managed (SaaS) and on-premises solutions. You saw that various platforms can be managed using an MDM solution, and the management options included access to applications (apps) via online stores. As with computer network administration, MDM solutions require special permissions to perform specific tasks on a mobile device.

We also explored the pushing of content to mobile devices. Devices can be grouped based on management requirements. By grouping servers, you can provide a high availability solution to help ensure maximum uptime for the services provided. We looked at how location-based services, including geo-fencing and geo-location, allow a virtual electronic boundary to be built or a device's location to be pinpointed within a specific area. Finally, we explored the concepts of both the captive portal and the self-service portal. You saw that how policies are defined will depend on the organization in which they are used. You learned about the basic components of a network security policy, which include the purpose, scope, details, enforcement, and maintaining changes. We explained the importance of an acceptable use policy and that most organizations require employees and guests to agree to the terms and conditions of this type of policy. You saw the importance of balancing security and usability and looked at some common networking policies, such as device backup, restore, and recovery. In addition to policies, you learned about device technology profiles, which contain configuration or settings information for the device based on the

user and that can also incorporate specific profiles. Finally, you saw the importance of testing technology, mobile device profiles, and policies by using pilot programs and validating any potential implementation issues prior to a full-scale deployment.

Exam Essentials

Be familiar with different MDM solutions. Know the main differences between an on-premises and Software as a Service (SaaS) cloud-managed MDM solutions. Understand the advantages and disadvantages of each type.

Understand the concept of pushing content. Know that mobile applications and device configuration information can be pushed to mobile devices. This will aid in management, troubleshooting, and changes to device configuration.

Know that administrative permissions allow for mobile devices to be managed from a corporate network. MDM solutions may need special privileges in order to perform specific actions on the device.

Be familiar with mobile device grouping. Device groups streamline administration by helping to identify profiles, applications, and other content that will need to be made available to the device user.

Understand the concept of location-based services. Know the difference between geofencing and geo-location and how they are used with mobile device technology. These concepts allow a user to build a virtual electronic boundary and allow networks to identify when mobile devices enter or leave an area. They are also useful for gathering specific information about the location of connected devices.

Know the differences between a captive portal and self-service portal. Understand that a captive portal is a way of restricting access to network resources unless proper authorization has occurred, and that a self-service portal allows users to register their own personal devices. This will give them the capability to use the network resources they have been assigned.

Know the common components of a basic information technology policy. Although policies will vary based on the type of organization, understand the basic components that will be part of the policy. These include the purpose, the scope, the policy details, the policy enforcement, and revision/maintenance.

Review Questions

1. MDM implementations are commonly available in which of the following types of technology? (Choose two.)
   - **A.** Centralized management and control
   - **B.** Software as a Service (SaaS)
   - **C.** On-premises technology
   - **D.** Controller-based technology
2. Different types of mobile app stores are available based on what apps a user will need to download. Which app store would be the best choice to download a custom-built app designed specifically for an organization?
   - **A.** Native mobile app store
   - **B.** Consumer mobile app store
   - **C.** Hybrid mobile app store
   - **D.** Enterprise mobile app store
3. What technology may use a form of multilateration known as time difference of arrival (TDoA) to measure the difference in distance between two stations from known locations?
   - **A.** On-boarding
   - **B.** Geo-location
   - **C.** Off-boarding
   - **D.** Geo-fencing
4. Which of the following is a set of parameters or instructions that will provide a device with the ability to connect to a network and follow specific requirements or settings for the connected session?
   - **A.** Mobile device geo-location
   - **B.** Mobile device certificate
   - **C.** Mobile device profile
   - **D.** Mobile device EULA
5. The help desk for company XYZ received a call from a user who could not locate their company-issued smart phone device. The network administrator that was assigned to the trouble ticket is unable to remotely lock the device through the MDM software that is in use at the organization. Which of the following would most likely cause this issue?
   - **A.** The user installed an app from a consumer store.
   - **B.** The user updated the operating system.
   - **C.** The user disabled the profile on the device.
   - **D.** The user assigned a static IP address.

6. Which of the following would prevent a network administrator from effectively using a geo-fencing technology product on an Android mobile device?
   - **A.** Geo-fencing technology is not allowed with Android devices.
   - **B.** The device is missing the correct API.
   - **C.** Location services are disabled on the device.
   - **D.** The device certificate was revoked.

7. What method defines the process of connecting a device to a wireless network for the first time and allowing a user to register their device in order to gain access to the company and other network resources?
   - **A.** Onboarding
   - **B.** Activation
   - **C.** Tethering
   - **D.** Security policy

8. A well-planned and executed mobile device security strategy will help to ensure that company policy is implemented and enforced as designed and intended with every technology deployment, regardless of the device platform that is used. Which two of the following should be considered with regard to content distribution? (Choose two.)
   - **A.** Secure SSID
   - **B.** Access permissions
   - **C.** Data encryption
   - **D.** Location services
   - **E.** MAC filtering

9. Which of the following is the most secure way of access control that can be used with mobile devices, computers, and other devices and will ensure that only valid, authorized users will gain access to the corporate network infrastructure?
   - **A.** Digital certificates enrollment
   - **B.** Digital rights management
   - **C.** WPA2 passphrase with TKIP
   - **D.** WPA2 enterprise with TKIP

10. Which of the following allows a mobile device such as an iPad or iPhone to receive information even when the destination application is not open or running?
    - **A.** GCM
    - **B.** DHCP
    - **C.** SMTP
    - **D.** APNS

11. Which of the following MDM features allows for corporate and other applications to be distributed to mobile devices that connect to the corporate network?

A. Content update

B. Pushing content

C. Update server

D. Distributed edge

12. Lightweight Directory Access Protocol (LDAP) is used to _____.

A. Create directory service objects

B. Provide replication of directory service databases

C. Query a directory service database

D. Assign permissions to user objects

13. Telecommunications expense management defines which of the following?

A. The corporate budget for departmental expenses

B. The expenses for mobile device technology

C. The limits on the number of devices supported by MDM

D. The return on investment (ROI) for SaaS vs. on-premises MDM solutions

14. Which of the following is another term that describes a captive web portal?

A. EULA

B. PKI

C. Walled garden

D. VPN

15. Which of the following best describes a self-service portal?

A. Enables devices to allow MDM systems to handle data plan management

B. Offers a method of on-boarding a device for corporate policy compliance

C. Provides a multilateration technology technique for device location

D. Allows an administrator to create device groups for ease of access

16. Which of the following describe the two main parts of a computer network security policy? (Choose two.)

A. General policy

B. OEM policy

C. Functional policy

D. Termination policy

17. A digital certificate is commonly used for which of the following?

- **A.** To define specific settings and configuration information
- **B.** To manage users, groups, devices, and other resources
- **C.** As an access control method
- **D.** To locate a device over the Internet

18. Which of the following describe common placements for an MDM solution? (Choose two.)

- **A.** EULA
- **B.** SaaS
- **C.** On-premises
- **D.** Walled garden
- **E.** Self-service portal

19. After the successful installation of an MDM solution, the administrator should ensure that all users of mobile devices agree to rules stated in which of the following documents?

- **A.** EULA policy
- **B.** Acceptable use policy
- **C.** Content-filtering policy
- **D.** Pilot test policy

20. A BYOD device is unable to access a company's intranet website. The user of the device is not experiencing any other network connectivity issues. Which of the following should the administrator perform to troubleshoot this problem? (Choose two.)

- **A.** Verify the EULA installation
- **B.** Verify the PKI installation
- **C.** Verify user group assignment
- **D.** Verify the Wi-Fi settings
- **E.** Verify the MDM policy

Chapter

11

Troubleshooting for Wireless Networking

THE FOLLOWING CWTS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **5.2 Recognize common problems associated with wireless networks and their symptoms, and identify steps to isolate and troubleshoot the problem. Given a problem situation, interpret the symptoms and the most likely cause.**
- ✓ **5.3 Identify procedures to optimize wireless networks**

THE FOLLOWING CWS EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **2.4 Identify factors impacting wireless LAN (WLAN) performance**
- ✓ **3.6 Understand the basic requirements for voice over WLAN (VoWLAN)**

THE FOLLOWING CWT EXAM OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ **1.3 Understand how to detect RF signal factors**
- ✓ **2.5 Configure client devices**
- ✓ **5.1 Troubleshoot connectivity problems**
- ✓ **5.2 Troubleshoot performance problems**
- ✓ **5.3 Troubleshoot security problems**
- ✓ **5.4 Troubleshoot mobility problems**

Troubleshooting and maintenance are important parts of a successful IEEE 802.11 WLAN deployment. Wireless networks, like most areas of technology, do require support and maintenance. The extent of this will depend on the size and complexity of the network. Troubleshooting problems is a key component in the maintenance, reliability, and operation of an IEEE 802.11 wireless network. A WLAN technical support engineer will encounter all the same problems that occur with regular networking as well as additional problems because this technology uses radio frequency (RF) for communication and to exchange information.

In this chapter, you will learn about common problems associated with standards-based IEEE 802.11 wireless networking, how to identify problems based on the symptoms, and how to determine whether they are global (affecting many) or isolated (affecting an individual). These problems range in complexity and magnitude, and many times are associated with the following:

- Wireless connectivity
- RF received signal strength
- WLAN throughput
- Wireless infrastructure and client device upgrades

Troubleshooting is not something that can be learned overnight or from reading a book. Troubleshooting is an acquired skill that requires many hours of hard work and is sometimes learned from the "school of hard knocks." This is true with any type of troubleshooting, not just computer networking. Becoming a good mechanic, for example, takes years of working with automobiles to learn how to diagnose and perform the necessary repairs.

The steps involved in troubleshooting a wireless networking problem will vary, and they depend on the complexity of the network and the environment. In this chapter, you will learn about causes and solutions associated with throughput, connectivity, signal strength, and upgrades. We will also explore procedures used for optimizing a wireless network. Some of these topics may sound familiar because they are also related to site surveys; however, you may have to make changes to accommodate physical environment conditions that have an impact on a WLAN installation. Finally, we will review multipath and the effect it has on an IEEE 802.11 WLAN and look at different types of hidden node problems, which are a very common issue associated with wireless networks.

Identifying Wireless LAN Problems

A first step in troubleshooting WLAN problems is to identify whether an issue is global or isolated. Global issues often include wired and wireless infrastructure devices and components. A global problem usually involves many client devices or groups of

devices. Some of the wireless devices that can be related to a global problem include the following:

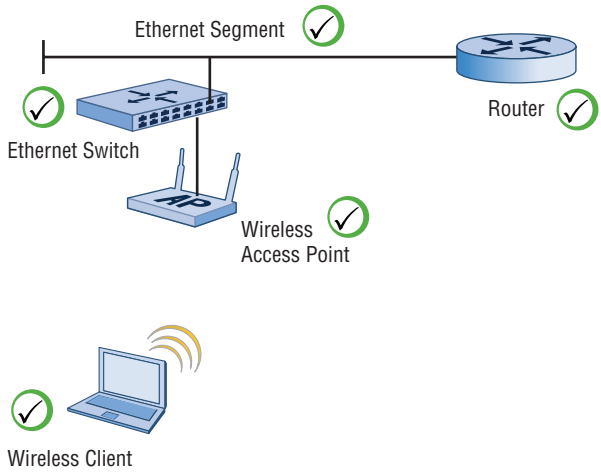
- Wireless access points
- Wireless bridges
- WLAN controllers
- Wired infrastructure devices

In addition to wireless infrastructure devices like access points, wired infrastructure components like Ethernet switches or Layer 3 routers can also be a potential source of global problems. Keep in mind that wireless client devices nearly always require a wired infrastructure in order to pass information between infrastructure devices or outside the wireless network. Devices and components that can contribute to wired infrastructure problems include the following:

- Ethernet cabling
- Ethernet switches
- Layer 3 routers
- Wide area network (WAN) connectivity
- Dynamic Host Configuration Protocol (DHCP) issues

The point is to take into consideration the wired side of a wireless network. As shown in Figure 11.1, many components can be the source of problems associated with wireless networking.

FIGURE 11.1 Many components, whether wired or wireless, can be the source of or contribute to WLAN problems.



Once it has been determined whether the problem is global or isolated, appropriate steps are necessary to determine the solution. Before we look at common problems associated with IEEE 802.11 wireless networking, however, it is important to understand a little more detail about how WLAN technology functions. This includes understanding the components used to send and receive RF information:

- RF transmitters
- RF receivers

Radio Frequency Transmitters and Receivers

IEEE 802.11 wireless networks use RF to send and receive data. This is possible because all wireless devices have transmitter and/or receiver capability. Unlike a television or FM radio you may have in your home, both of which are only receivers, all IEEE 802.11 WLAN devices have the capability to act as either a transmitter or a receiver (also known as a transceiver). The following sections explain transmitter and receiver functionality in order to provide the groundwork necessary to diagnose and resolve IEEE 802.11 wireless networking problems.

Radio Transmitters

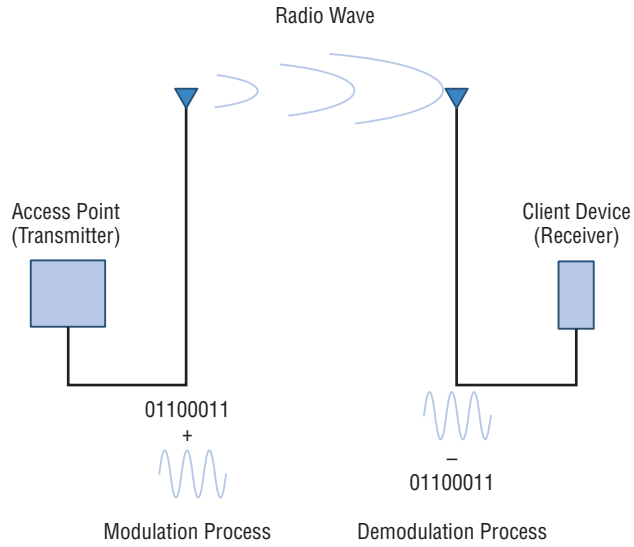
In wireless networking, a *transmitter* combines binary digital computer data (all the 1s and 0s) with high-frequency alternating current (AC) signals to prepare it to be sent across the air. This is known as *modulation*. The connected antenna then transforms this signal into radio waves (electromagnetic energy) and propagates them through the air. The frequency of the signal depends on the technology in use. With IEEE 802.11 standards-based wireless networking, there are a few select frequency ranges.

Radio Receivers

A *receiver* collects the propagated signal from the air using an antenna and reverses the process by transforming the received signal back into an alternating current signal. Through the use of a demodulation process, the digital data is recovered. The modulation/demodulation technology used depends on the wireless standard or amendment with which the device is compliant. For example, an IEEE 802.11g/n WLAN will use 64QAM (quadrature amplitude modulation) when transmitting data at up to 600 Mbps. Figure 11.2 illustrates this entire process. Keep in mind that WLAN devices are transceivers, so they have the capability of performing either task. In this figure, the access point is the transmitter, and the client device is the receiver. The details of modulation technologies are beyond the scope of the exam objectives and are not covered in this book.

Figure 11.2 sums up the entire process of IEEE 802.11 WLAN communications discussed throughout this book and is an introduction to understanding the process of troubleshooting.

FIGURE 11.2 A wireless access point (transmitter) and wireless client device (receiver) with computer data traversing the air using RF



Wireless LAN Connectivity—Coverage and Capacity Problems

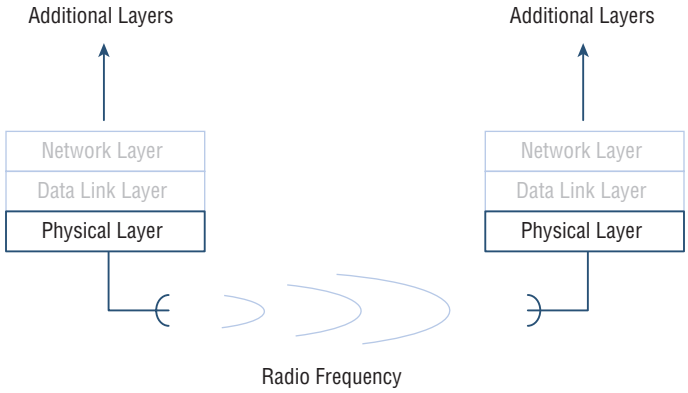
Many factors can cause connectivity problems in IEEE 802.11 WLANs. Wired computer networks use physical cabling to connect devices. This bounded medium is less likely to have connection issues unless the physical medium (cable) is damaged or broken. With wireless communications there is no bounded medium, because the air is used to carry the data using RF.

No Wireless Connectivity

Several components of a network can cause WLAN connectivity issues. Keep in mind that WLANs are not bound by a physical medium such as Ethernet cable; therefore, issues other than wiring may result in either no connectivity or intermittent connection problems.

Let's review some of the OSI model information discussed in Chapter 1, "Computer Networking Fundamentals." The Physical layer provides the medium for connectivity (the air) in a wireless network and is used to carry RF information that contains the computer data. This layer also includes components such as network adapter cards, which provide an interface to the wireless computer or other wireless device. Layer 1 connectivity provides the capability to transfer information that is sent between devices. Figure 11.3 illustrates the Physical layer and wireless connectivity.

FIGURE 11.3 The lower two layers of the OSI model are responsible for the operation of wireless networks. The Physical layer provides a connection between devices.



No Wireless Connectivity on the Client Side

IEEE 802.11 wireless networks require Physical layer connectivity in order to provide successful communications. Several potential connectivity issues are associated with client-side wireless devices. In many cases, no connectivity on the client side is an isolated issue that will not affect a large number of devices or users. Problems that can cause client-side lack of connectivity include the following:

- Disabled radio or wireless network adapter
- Device driver fails to initialize correctly
- Misconfigured wireless client utility
- Microsoft Windows WLAN AutoConfig service not running or not configured correctly
- Protective supplicants (wireless client device side) that can disable the radio in response to specific policy violations

A disabled radio or client adapter in a wireless client device can cause a lack of connectivity. Many devices, such as notebook computers, have physical switches or a combination of keys that can disable a radio. In many cases, a user does not even realize they turned off the physical switch for the WLAN radio. A disabled radio cannot provide RF communication between the client device and the wireless infrastructure, such as an access point. Figure 11.4 shows the icon for a disabled wireless adapter and the window explaining that the Microsoft WLAN AutoConfig service is not started on a notebook computer with Microsoft Windows. Keep in mind that the wireless functionality of certain devices such as laptop computers may have the capability to be enabled and disabled in the Basic Input/Output System (BIOS) or system setup of the device—something that is often overlooked.

With Microsoft Windows operating systems, there are built-in diagnostics and troubleshooting that may help with some WLAN connectivity issues. Figure 11.5 shows the wireless connection dialog box as "Not connected." If you click the Diagnose link, Windows will go through a series of steps to try to resolve the issue. In this case, the Windows wireless service was not running, and Microsoft was able to determine this and identified the

problem. Another frequently occurring problem for wireless client devices regarding the device driver is failure of the driver to initialize properly. Disabling and re-enabling the adapter usually solves this type of problem without having to reboot the device.

FIGURE 11.4 Disabled WLAN adapter and Microsoft Windows 10 WLAN AutoConfig service not running

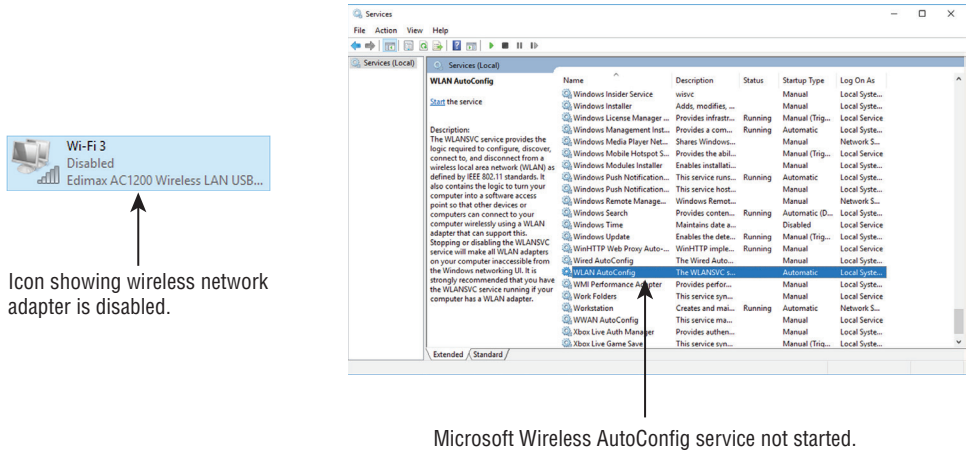
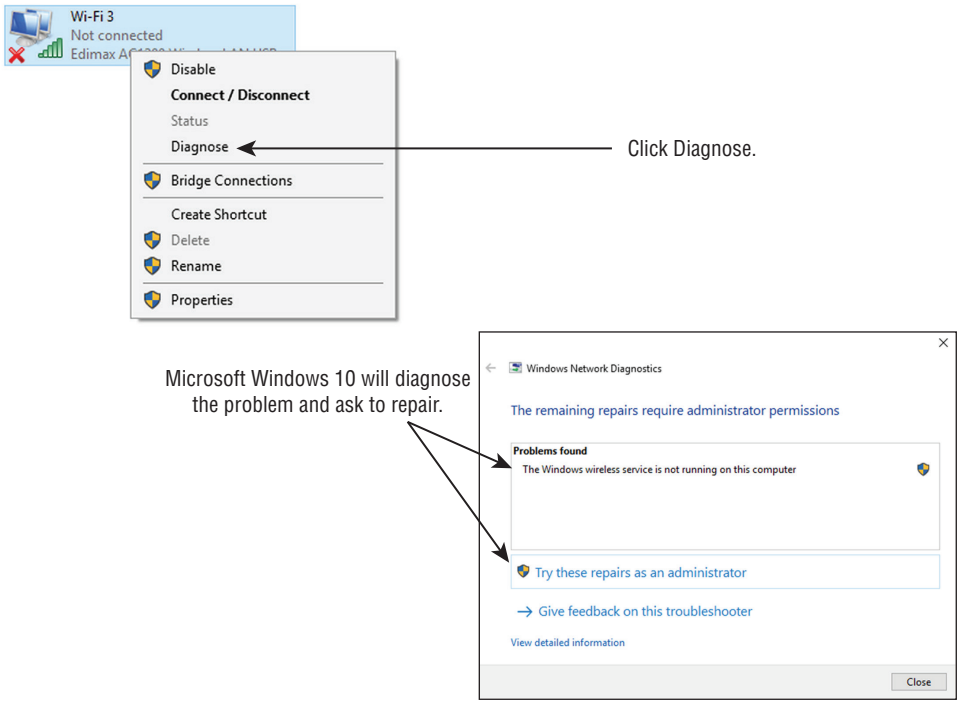


FIGURE 11.5 Microsoft Windows 10 WLAN AutoConfig service not running and resolution using the built-in troubleshooting diagnosis feature

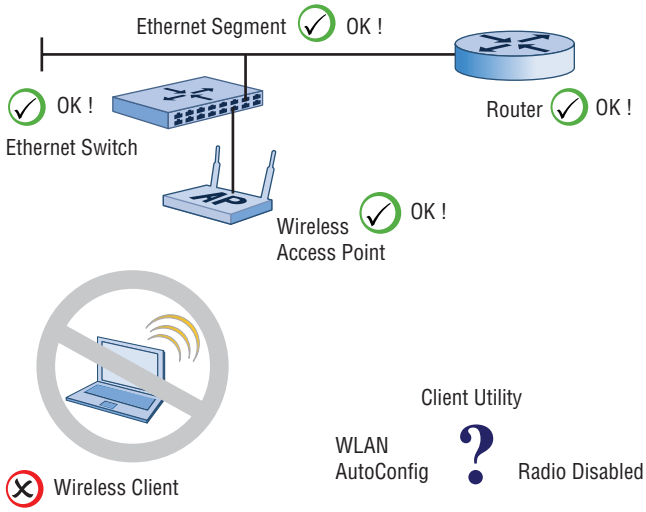


If a client utility is misconfigured—for example, an incorrect service set identifier (SSID) is specified—it would cause a lack of connectivity for the wireless client device. Client utilities have the capability to specify the SSID as a parameter. If the client does not see an access point with the specified SSID, it will not be able to connect to the IEEE 802.11 WLAN. This feature in a client device is often set by a selection to connect to a preferred SSID only by using a specific profile.

Remember that the network name SSID is case-sensitive and has a maximum length of 32 characters or 32 octets as defined in the IEEE 802.11 standard. Incorrect use of case in the SSID can lead to a lack of connectivity, because the SSID will not match. Uppercase and lowercase letters are different ASCII characters. This can also lead to unnecessary help desk calls. Client devices will not connect to the WLAN if they have an incorrect SSID specified in the wireless client utility profile. This could be unintentional (accidental) or in some cases intentional, such as for the purpose of getting around a firewall or other SSID restriction.

The Microsoft Windows built-in wireless client utility is a very popular client utility for connecting to IEEE 802.11 wireless networks. The Microsoft Windows WLAN AutoConfig service runs as a service or background process in the Microsoft Windows operating systems. If this service is not running or if the client device is not configured correctly to use Windows wireless services, the wireless client device will not be able to connect to the wireless network unless a third-party client utility from the adapter manufacturer is used. Figure 11.6 illustrates some of these potential issues from a wireless client device that may cause a lack of connectivity to the wireless network infrastructure.

FIGURE 11.6 Devices and components that make up a WLAN showing potential wireless client-side issues



Other Wireless Connectivity Issues

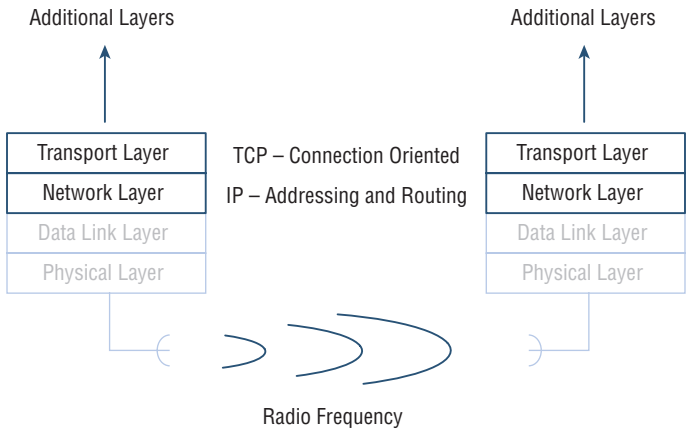
Connectivity issues can also arise if a misconfigured client utility has incorrect WLAN security settings or client IP address issues. Both will prevent a wireless client device from successfully completing the connection process and will prevent the transfer of computer data. Even though the Physical layer (Layer 1) and Data Link layer (Layer 2) connection may have been successful, the Layer 3 process would not be complete, and therefore data would not be transferred.

Before we discuss incorrect security settings further, it is important to have a better understanding of how an IP address (a logical address for a network interface) may have an impact on a successful connection and some of the issues associated with TCP/IP.

IP Address Connectivity Issues

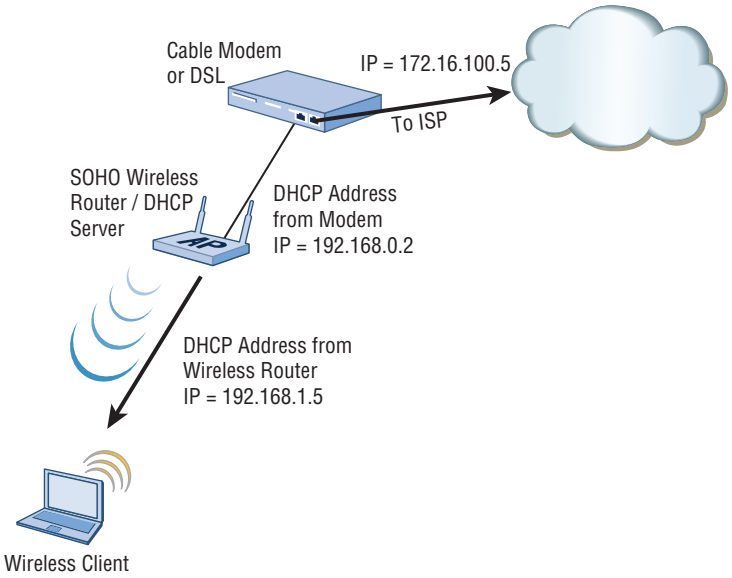
Although wireless networks operate at Layer 1 and Layer 2 of the OSI model, Layer 3 and IP addressing also play a role because TCP/IP is used in most of today's computer networks. (Feel free to refer to the discussion of the seven layers of the OSI model in Chapter 1.) Early computer networks used various proprietary protocols to communicate with one another, such as Novell's IPX/SPX or Microsoft's NetBEUI. (A *protocol* is a set of rules that defines data communication between devices.) Since the growth of local area networks (LANs), expanding to WANs and the World Wide Web (WWW) service becoming available in the mid-1990s, TCP/IP has become the standard protocol used in virtually all computer networks. Remember that Layer 3 and Layer 4 of the OSI model are responsible for addressing and routing both information and the session connection using the TCP/IP protocol. Figure 11.7 illustrates the two layers responsible for the TCP/IP protocol and the function of each.

FIGURE 11.7 Layers 3 and 4 of the OSI model are responsible for the addressing and routing of information as well as the session connection between devices.



Misconfigured IP address information can cause connectivity issues in an IEEE 802.11 WLAN. Most wireless networks, both SOHO and enterprise, have the capability to use *Dynamic Host Configuration Protocol* (DHCP). DHCP is a service that issues IP addresses and other TCP/IP parameters to connected computer network client devices. This service eliminates the need to manually assign logical Layer 3 IP addresses to all devices on the network. In IEEE 802.11 wireless networking, this DHCP service is provided directly from an access point, a wireless router, and a WLAN controller or from a server running DHCP services on the wired LAN. Many client device issues related to Layer 3 or above can cause the failure to obtain a valid IP address. This problem is often blamed on the wireless network, even though a successful IEEE 802.11 authentication and association have occurred. Figure 11.8 shows an example of DHCP services using a wireless residential gateway/router.

FIGURE 11.8 DHCP and IP address information from the ISP to the wireless client device

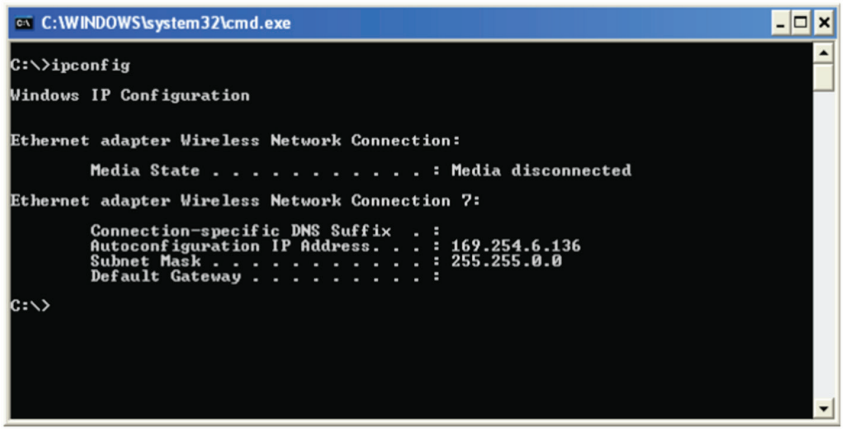


A cable or digital subscriber line (DSL) modem device connected to the ISP service will receive a DHCP address from the ISP. This modem will then issue IP addresses to wireless client devices or intermediary devices such as the IEEE 802.11 wireless router. If DHCP services are not running or are not operating correctly on the wireless router, the connected wireless client devices will not be able to obtain a valid IP address and will not be able to communicate above Layer 2.

The computer operating system in use will determine what action the client device takes if an IP address cannot be obtained from a DHCP server. Windows uses a service that became available starting way back with Windows 98 and is now available in all versions of Windows, called *Automatic Private IP Addressing* (APIPA). APIPA is designed to

provide an IP address automatically to any computer network device requesting one that is connected to a common LAN. APIPA does not require the use of a DHCP server. It also eliminates the need for users to manually set up IP addressing on all the devices. An APIPA address will be in the `169.254.X.X` (`169.254.0.1` through `169.254.255.254`) range, with a default class B subnet mask of `255.255.0.0`. For example, a device such as a notebook computer may have an APIPA such as `169.254.100.20`. If DHCP services are running on the LAN and a device cannot obtain an address from the server or if DHCP services are not available, an APIPA will be issued. Figure 11.9 shows the `ipconfig` command displaying an IP address from Microsoft's APIPA.

FIGURE 11.9 Microsoft Windows APIPA address displayed using the `ipconfig` command



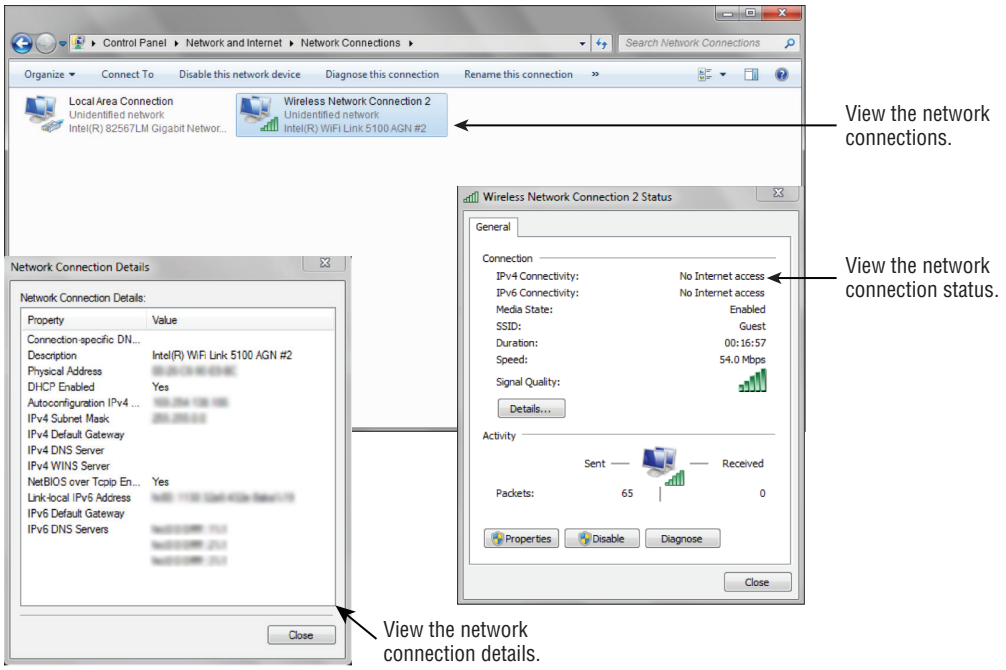
If a wireless access point or wireless router is connected to an IP subnet other than the one that uses automatic addresses, the wireless client device will require a valid IP address from the DHCP service in order to complete a network connection. If a valid IP address cannot be obtained from the DHCP service, the client will not have a valid TCP/IP connection to the access point or wireless router and instead will obtain an IP address from the `169.254.X.X` range. This was much easier to identify in the earlier versions of the Microsoft Windows operating system. If this is the case, the wireless connection icon will show a "Limited or no connectivity" message and exclamation point, as shown in Figure 11.10.

FIGURE 11.10 Limited or no connectivity as the result of an IP address not being obtained from a DHCP server in the Microsoft Windows operating system

No valid IP address received from a DHCP server.

With the newer Microsoft Windows operating systems (basically from Windows 7 onward), you need to look a little further to make the determination, as shown in Figure 11.11.

FIGURE 11.11 Windows 7 on a notebook computer with no IP address



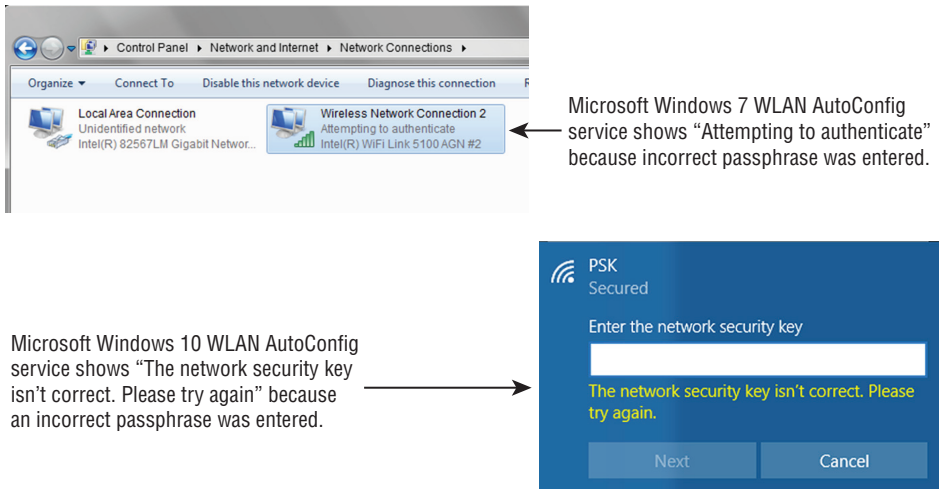
It is always a good idea to simply restart the wireless client network adapter, which will often correct some wireless client device connectivity issues.

Wireless Security Settings

Incorrect security settings can also cause connectivity issues. Although you may get a Layer 2 wireless connection to the access point even with incorrect security settings on a wireless client device, you will not get a valid Layer 3 TCP/IP address from the DHCP server. For example, assume an access point is using WPA 2.0 personal mode, which uses a 256-bit preshared key for security. If a wireless client device has the wrong passphrase or preshared key entered, it will not complete the additional authentication that occurs after the IEEE 802.11 authentication and association process and will not have a valid Layer 3 TCP/IP address. In the Microsoft Windows 7 operating system, the network adapter would show "Attempting to authenticate" in the network adapter status. The error message in Microsoft Windows 10 reads, "The network security key isn't correct. Please try again."

Figure 11.12 shows an example of the errors displayed with the wrong passphrase using the Microsoft Windows 7 and Windows 10 client utilities.

FIGURE 11.12 The Microsoft Windows 7 and Windows 10 wireless adapters show errors when an incorrect WPA2 passphrase is entered.



Intermittent Wireless Connectivity Problems

Intermittent problems of any type are often the most difficult to diagnose and repair. You may have had the experience of an intermittent problem with your car. For example, at a stoplight the car may start to idle roughly and stall. There is not really any rhyme or reason as to when this happens—it could be in the morning; it could be in the afternoon. You take your car to the mechanic for repair and, of course, the problem does not occur. Therefore, the mechanic may have to keep your car for a period of time to try to duplicate the problem.

Intermittent problems with computers and networking are no different; they are difficult to diagnose if they can't be reliably reproduced. In many cases using a protocol analyzer to capture frames is invaluable. Frame traces allow you to see what is happening between the wireless transmitter and the receiver. You learned about protocol analyzers for IEEE 802.11 wireless networks and their use in Chapter 9, "Design for Wireless Networking."

Most intermittent connectivity issues in IEEE 802.11 WLANs are associated with the amount of received signal strength. If nothing else has changed (for example, a security setting or any type of device upgrade) and the wireless client device was working before, there is a good possibility the problem is associated with the amount of received signal.

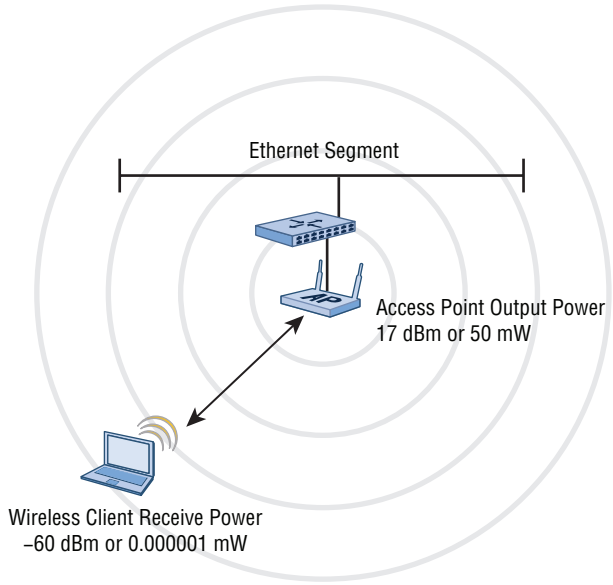
Understanding the Received Signal Strength

One of the main concerns associated with IEEE 802.11 wireless networking is how much of the transmitted signal is identified as usable signal by the wireless client device. This is known as the *received signal strength indicator* (RSSI) value. RSSI is an arbitrary number assigned by the device manufacturer. There is no standard for this value, and it will not

be comparable between devices from different manufacturers. The calculation of the RSSI value is done in a proprietary manner, and a wireless device from one manufacturer may indicate a different received signal strength from that indicated by another, even though they both are receiving the exact same signal and at the same actual signal strength. This value is a key determinant of how well the WLAN device will perform. How the device is used with the network will determine the required levels of signal for optimal connectivity. Two WLAN client devices that are equal distance from the access point may display different RSSI values. Some client software utilities display this information in signal level bars to represent the amount of signal received—the more bars, the better the signal—others may show the value in dBm (decibel-milliwatts). Wireless network engineers and support personnel should be able to know what the bars or numbers reveal and what they do not.

The actual recommended signal strength will vary based on the manufacturer, but some general numbers do exist. In order to get the maximum data rate, and depending on the application (either voice or data), most best practices recommend a range of –65 dBm to –67 dBm of received signal strength. With newer technologies such as IEEE 802.11ac, this value may be even more aggressive in order to demodulate a signal modulated at 256QAM. Keep in mind, the closer the number is to zero, the better the received signal, and –65 dBm is closer to zero than –67 dBm. Figure 11.13 shows an example of an access point with an output power of 50 mW (–60 dBm) and the wireless client receiving a fraction of that amount, or 0.000001 mW (–60 dBm). Although the wireless client device is receiving only a fraction of the transmitted power output, it is still able to move data at the highest data rate. Amazing!

FIGURE 11.13 Wireless client device receiving a fraction of the amount of power output by the access point



Testing the Received Signal Strength

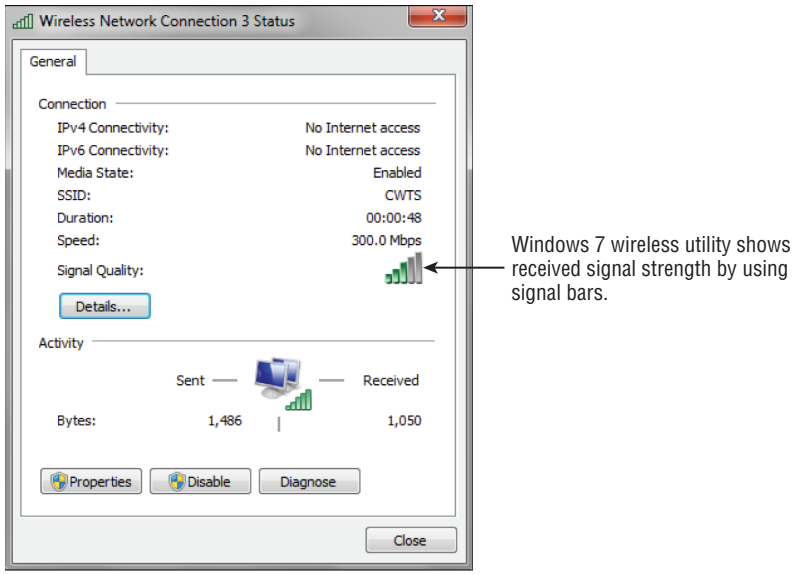
So what does this mean? It means the lower the amount of RF signal that is received by the receiver, the lower the data rate will be. Several tools are available that will allow a technical support specialist to see the received signal strength. These tools include:

- Acrylic WiFi (Microsoft Windows), free for non-commercial use
- AirGrab WiFi Radar (Mac OS X), free
- MetaGeek InSSIDer
- Wireless network adapter client utilities
- Spectrum analyzer utility
- Xirrus Wi-Fi Inspector (Microsoft Windows), free

Any of these tools can be used to check the received signal strength by a wireless client device or at an end user's location to determine how much signal is being received, which will relate to the rate they should be transferring computer data.

Figure 11.14 shows the Microsoft Windows wireless client utility with bars representing the amount of received signal strength and the current data transfer rate.

FIGURE 11.14 Representation of received signal strength (signal quality) and data rate using the Microsoft Windows wireless client utility



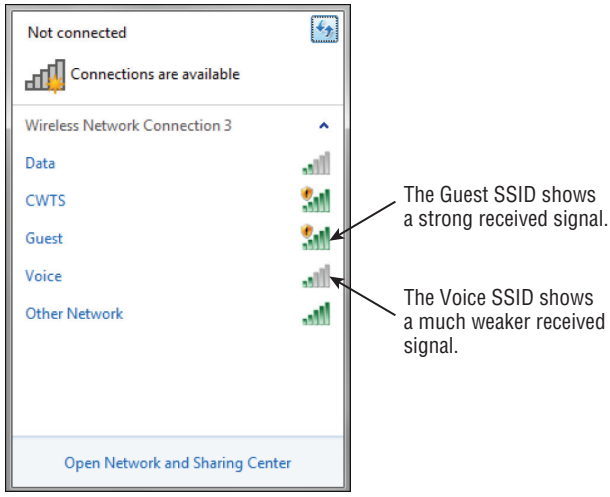
The Microsoft Windows wireless client utility does not contain any specialized features that show signal strength or signal-to-noise ratio values. However, this utility will display bar values representing the received signal strength.

Weak, Low, or No Radio Frequency Signal

Weak, low, or no RF signal is typically an indication that the WLAN client device is too far away from a wireless access point or is experiencing some level of RF interference. This could also be the result of some obstruction either blocking or severely attenuating the RF signal. This is most often the result of a poor or nonexistent WLAN site survey or significant environmental changes. (You learned about performing a WLAN site survey in Chapter 9.) In order for a client device to operate correctly, the signal needs to be strong enough to connect to an access point and maintain the connection. A wireless client device will have a difficult time distinguishing between the RF received signal and the RF noise if the signal level is too close to the noise floor.

To review, the signal-to-noise ratio is the difference between the amount of received signal and the noise floor level in the area where the wireless client device is located. (Chapter 9 discussed the noise floor and signal-to-noise ratio in more detail.) Figure 11.15 shows a Microsoft Windows wireless client utility and several wireless access points in the vicinity. Notice that the client device shows different received signal levels for the access points, as indicated by each one's number of bars. The Guest and CWTS SSIDs show a high received signal, but Data and Voice show only two bars, which represents lower received signal strength.

FIGURE 11.15 Microsoft Windows wireless client utility displays signal strength difference between nearby wireless access points.



Other wireless client utilities may show a more elaborate view of the signal strength and the noise level in an area. These are represented by dBm values rather than bar levels. In addition to client utilities, third-party utilities, such as MetaGeek InSSIDer, will show received signal strength or noise levels, or possibly both.

Wireless LAN Throughput

Papa User says, "Someone's been taking my throughput!" Mama User says, "Someone's been taking my throughput!" Baby User says, "Someone's been taking my throughput and that someone still is!" Sound familiar? Receiving and maintaining enough throughput can be a tough chore in today's world of IEEE 802.11 wireless networking. Users just can't seem to have enough.

It is important to understand the difference between data rate and throughput. *Throughput* is the rate at which data is being transferred. It seems there is never enough to go around. When it comes to throughput, expectations are a key factor. It is important for users to realize that the actual throughput will always be lower than the advertised data rate. For example, in an IEEE 802.11n MIMO network, the maximum data signaling rate is up to 600 Mbps, but the actual throughput will be between 30 and 300 Mbps, much less than half of the advertised data rate. IEEE 802.11ac has a theoretical maximum signaling rate of 6933.3 Mbps aggregate. Keep in mind that these numbers will vary based on many factors, including the environment and the IEEE 802.11n/ac technology features that are enabled such as channel width, the number of spatial streams, and whether the optional short guard interval of 400ns is enabled.

Maximizing throughput is part of overall network design. A well-designed WLAN and site survey will yield excellent results. However, several factors may affect the throughput the users are receiving, including the following:

- The wireless client device distance from an access point
- The RF transmit output power of an access point
- The number of wireless devices associated to the access point

The Wireless Client Device Distance from an Access Point

As the wireless client's distance from an access point increases, the RF received signal strength decreases, thereby providing less average overall throughput. The type of wireless client device in use—computer, VoIP handset, handheld device, tablet, or barcode scanner—will determine the acceptable levels of data throughput. Most wireless client utilities will show that the expected data rate is based on the received signal strength. It is important to remember that the expected data rate is not actual throughput. Figure 11.16 illustrates this point by showing two different throughput sessions, both connected to the same access point. Session 1 is in close proximity, approximately 15–20 feet from the access point. Session 2 shows the throughput at a greater distance, approximately 45 feet from the access point. Since there are many variables that will have an effect on IEEE 802.11n/ac (including channel widths, number of spatial streams, and optional short guard interval), this testing was performed using IEEE 802.11g devices to help illustrate the concept.

FIGURE 11.16 Two FTP sessions showing the difference in throughput based on distance from an access point

The Radio Frequency Transmit Output Power of an Access Point

The amount of RF transmit output power being sent from the wireless access point will also determine RF signal strength for the connected wireless client devices. This is because the higher the RF power, the farther an RF signal will travel or propagate. If a wireless

client device is receiving a low RF signal and adding an additional access point is not an option, increasing the output power of the access point may do the trick. Keep in mind, however, that this needs to be evaluated closely as more RF transmit power is not always the best option.

If a physical wireless RF site survey is performed, we recommend that you have the access points set to less than the full available transmit output power. What the transmit output power level is set to during a site survey will depend on the engineer who performs the survey or the manufacturer recommendations. If an access point is not set to full power, it will be possible to make adjustments to compensate and potentially correct problems such as a wireless client device experiencing low throughput because of a low received signal strength value.

Access Point Loading

Because WLANs use the air as a shared medium, the more wireless client devices that associate to the wireless access point, the less throughput each device will be able to receive. The type of hardware can also affect the throughput based on the number of associated users. For example, if 25 devices are associated to an access point using wireless barcode scanners that typically transfer small amounts of information, they may have better performance than 5 devices using bandwidth-intensive applications such as digital imaging or engineering programs such as CAD/CAM on notebook computers. Load balancing of devices between access points can help limit the number of associated wireless client devices. Co-channel interference can cause the same issue, because wireless devices on the same or a close channel, associated or not, are part of the same contention domain.

Solutions to Low Wireless LAN Throughput

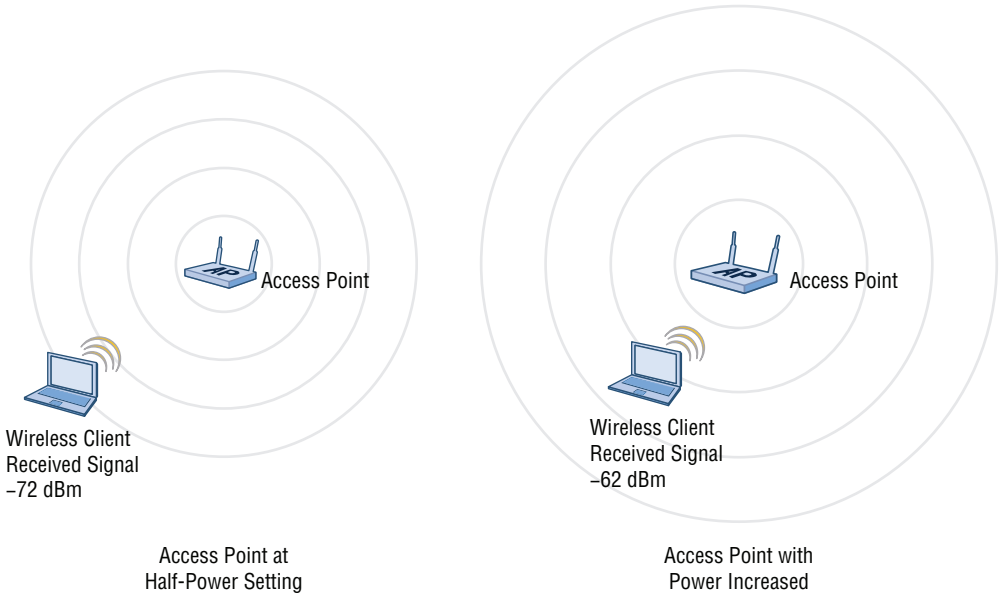
There are several possible solutions to low throughput problems clients may be experiencing. The appropriate solution will depend on the specific situation. If an RF site survey was performed correctly and thoroughly, additional access points should not be needed unless there have been environmental or capacity changes in the area since the original survey was performed. Solutions to low-throughput problems include the following:

- Adding more access points
- Increasing output power of access points (depending on the situation)
- Increasing antenna gain
- Enabling load-balancing solutions on access points

One or more of these solutions may help increase the throughput for users connected to a wireless network. Figure 11.17 shows a before-and-after scenario based on output power of an access point.

Of the solutions just discussed, no particular one is better than the others. Which solution you choose will depend on several factors, including the number of wireless client devices, the number of access points, budget constraints, and potential interference issues.

FIGURE 11.17 Increasing the output power of an access point will provide higher received signal strength for the client, resulting in better overall throughput.



Increasing the output power of an access point will also increase the cell size and potentially allow for more wireless client devices to associate. This will, in turn, increase the load or number of associated devices on the access point and may contribute to interference in other areas. It may also lead to an increase in the hidden node problem (discussed later in this chapter) and cause the overall capacity of a cell to decrease. More power is not always the best choice. If the budget allows, adding more access points as needed to reduce collision domain size (RF cell) is usually a better solution, with the proper design considerations.

Application Performance Problems

As you now know, IEEE 802.11 wireless networks are a major part of every computer network in all industries and homes. Many different types of applications, both software and hardware, want to take advantage of the wireless network capabilities. Therefore, it is important to understand the various types of applications your IEEE 802.11 WLAN may use and how to prevent problems that can arise from the use of these applications. Some of the common applications that are used via WLANs include the following:

- Application servers for user software, such as word processing
- Databases

- Engineering applications, such as computer-aided design
- File servers for storing data
- Barcode scanners
- Printers
- Voice handsets
- Internet of things (IoT)

This is not a complete list, but for the most part every resource or application that is used in the wired network is also a candidate for the wireless network. Many of the problems that are experienced with a wired network will be even more common on a wireless network. We have all the same potential problems as we do in a wired network, but more because it is wireless. Remember that IEEE 802.11 WLANs use an unbounded shared medium (the air) and are contention based, which will create both interference and capacity problems. Using the appropriate tools, such as a wireless packet analyzer and RF spectrum analyzer, will help to identify and resolve these problems. The following sections describe how to identify and resolve these problems.

Wireless Device Software and Hardware Upgrades

Software and hardware upgrades play a role in the maintenance and support of any WLAN deployment. Many problems arise from outdated or corrupt device drivers. Having the latest device drivers or software client utilities will help improve performance and solve problems associated with software-related issues. Firmware also needs to be updated periodically to ensure new features are applied to the devices, such as access points or WLAN controllers.

Client Device Software Upgrades

Upgrading the software related to WLAN technology has many benefits that may help resolve performance or operation issues. Technical support or network engineers should find time to stay up-to-date with the latest software versions available for the hardware in their network. This can be done by looking at the manufacturer's website or subscribing to a service that will announce changes and updates. Software upgrades for wireless networks commonly fall under the following areas:

- Device drivers
- Client device adapter utilities
- Device firmware and BIOS updates

Software upgrades on any of these components will help enhance the performance of the client devices. These upgrades can come as a fix for a problem with the software or potentially provide new features for a client device. In Chapter 3, "Infrastructure and Client Devices Used with Wireless Networking," you learned about some of the software components required in order for a client device to connect to an IEEE 802.11 wireless network. The following sections focus on the process of upgrading the software associated with these devices.

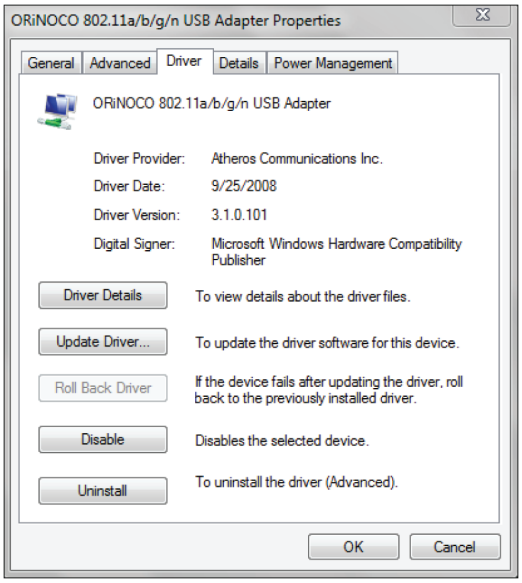
Device Drivers

Device drivers are the software components that allow a hardware device to function with a computer operating system. This is accomplished by the software providing an instruction set for all devices that connect to a computer, tablet, handheld, or any other device that runs with an operating system. The following list is a sampling of the devices that will require a software device driver:

- Hard drive
- Video card
- Keyboard
- Mouse
- USB ports
- Network adapters

With wireless networking, the device driver that is of most concern is the one used for the wireless network adapter. This adapter is what allows a computer or other client device to connect to a wireless network in either infrastructure or ad hoc mode. Figure 11.18 shows an example of viewing the device driver properties for a wireless network adapter in the Microsoft Windows operating system.

FIGURE 11.18 Device driver information in Microsoft Windows for a USB wireless network adapter



In addition to causing intermittent connectivity problems, device drivers may become corrupt and prevent the device from starting up correctly. They can even cause operating system startup problems. With today's sophisticated computer operating systems and

features, such as plug-and-play, having to worry about the physical settings of a device is less common than it was a few years ago. Upgrading or replacing a device driver in Windows operating systems is a fairly straightforward process. Exercise 11.1 steps you through upgrading a device driver for your wireless network adapter.

EXERCISE 11.1

Upgrading a Device Driver

In this exercise, we will look at the process of upgrading a device driver for a wireless network adapter. This process is based on using the Broadcom 802.11g Network Adapter.

Downloading a Driver Package from a Website

1. With the help of a web browser, connect to the appropriate website to search for the latest version of the device driver—in this case, `www.broadcom.com`.
2. In most cases, you will look for either a Support or Downloads link to find the location for software such as drivers. The current link on this site is Support. Click the appropriate link.
3. You may need to create an account that will allow you to log in and search for the correct software. You then should be able to search by model number for the driver you need. Download the correct device driver. This may come in the form of an individual file or possibly an entire software client utility program.
4. In this case, an update for this wireless adapter is not available from the adapter manufacturer, and because the adapter is integrated into a notebook computer, it will be necessary to visit the website for the computer in which this adapter is installed. This is a very common way to get driver updates. It is important to note that for client devices with integrated adapters it is best to visit the website of the manufacturer for the device—in this case, `www.lenovo.com`.
5. This website has links for support and downloads. Click the Support link (`http://support.lenovo.com/en_US/`) and search by product name, serial number, or machine type.
6. Browse for the correct driver based on the installed adapter.
7. In this case, you will have to download an entire package (approximately 78 MB). Run the downloaded program to install the latest device driver file.

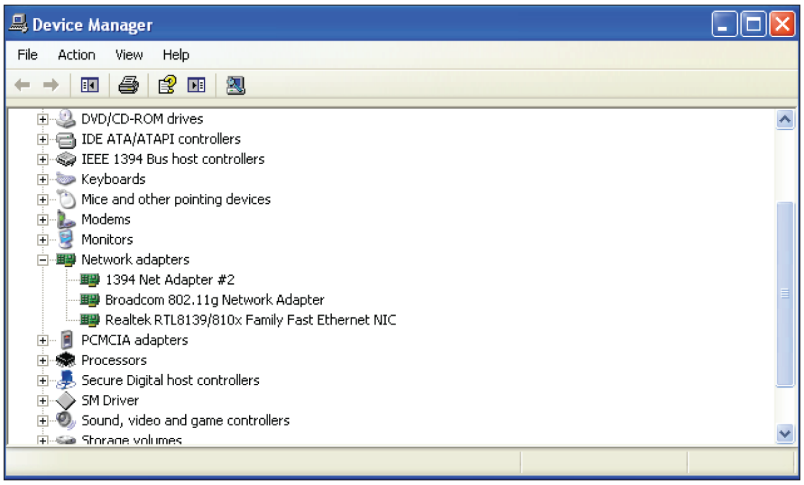
Manually Upgrading a Driver

These next steps show how you would manually upgrade a device driver using an individual file. Keep in mind that the steps will vary based on the operating system and version in use. This example is for the Microsoft Windows 7 operating system.

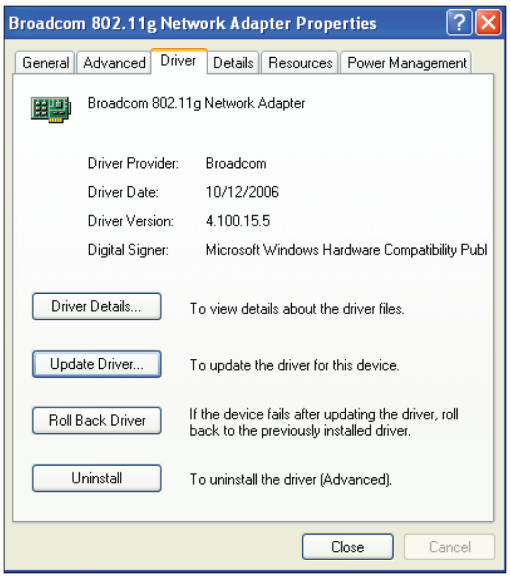
1. Click Start and the Control Panel icon. Double-click the System icon, and the System Properties dialog box appears.

EXERCISE 11.1 *(continued)*

2. Select the Hardware tab and then click the Device Manager button. The Device Manager dialog box appears.

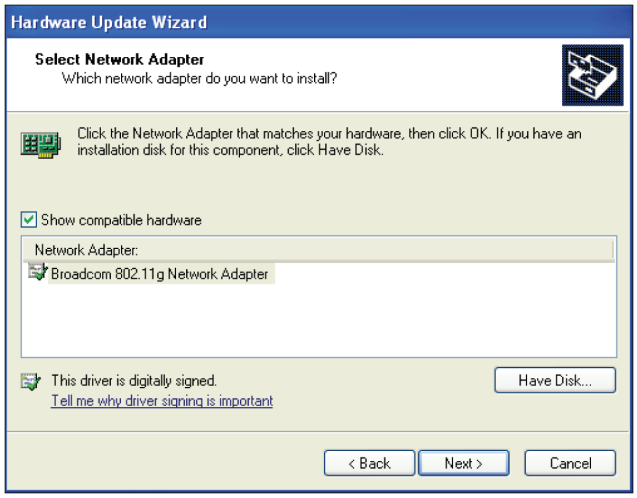


3. Expand the Network Adapters item and double-click the correct network adapter. The Network Adapter Properties dialog box appears.



4. Select the Driver tab and then click the Update Driver button. The Hardware Update Wizard launches. Select the Install From A List Or Specific Location (Advanced) radio button. A new screen (called Please Choose Your Search And Installation Options) appears.

5. Click the Don't Search, I Will Choose The Driver To Install radio button, and then click Next.
6. Click the Have Disk button and browse to the folder where the driver is located. Select the driver and then click Open. At the Install From Disk screen, click OK. The Select Network Adapter screen appears.



7. Click Next to continue. The update will process. Click Finish to complete the device driver upgrade.

Automatically Upgrading a Driver

Some manufacturers are making it easy to upgrade a device driver for your wireless network adapters. They do this by creating an executable program that does everything for you automatically. All you need to do is download a file from the manufacturer's website and execute the program. Everything from that point is automatic.

Client Device Adapter Utilities

Client adapter utilities may need to be upgraded occasionally. By upgrading the client adapter utility, you will usually add new features or settings to enhance the performance and function of the utility.

The Microsoft Windows wireless client utility is usually upgraded either from a service pack or a hotfix available from the Microsoft website.

Device Firmware

Device firmware is the instruction set that allows hardware to operate based on its design. *Firmware* is simply software that remains in memory when the power is removed. Firmware tends to be hardware oriented, but not all firmware involves the control of hardware. Many Layer 7 user interfaces and agents are implemented as firmware burned into read-only memory devices (ROMs).

Conversely, there are many examples of software directly controlling hardware. Most drivers for hardware devices are software (loaded into volatile memory only when power is present) and not firmware (always resident in static memory regardless of power). Firmware upgrades are common support tasks that need to be done periodically, either to fix issues with the way the hardware is operating or to provide new features for the hardware. For example, updating the BIOS of a laptop computer might also solve specific problems such as wireless connectivity. In many cases, the BIOS contains information about the WLAN adapter that is installed or embedded within the wireless device.

All infrastructure devices, either SOHO-grade or enterprise-grade, allow you to upgrade the firmware. In enterprise environments, firmware upgrades can be performed either manually or automatically with the aid of a WLAN management system software or appliance.

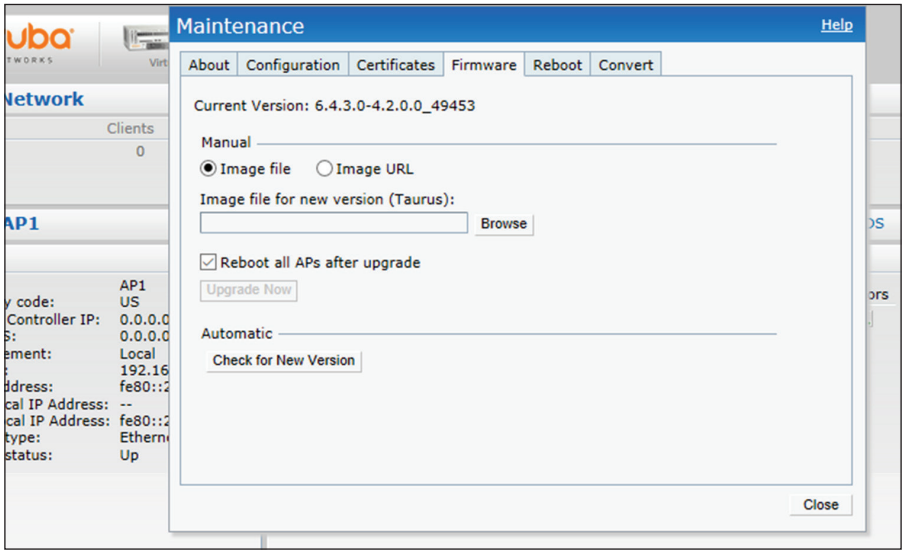
Many manufacturers of enterprise-grade equipment require you to purchase a support contact or service agreement in order to download firmware for wireless infrastructure devices.

Most infrastructure devices have several options for performing upgrades. These upgrade options include

- Hypertext Transfer Protocol (HTTP)
- Trivial File Transfer Protocol (TFTP)
- File Transfer Protocol (FTP)

Figure 11.19 shows an example of a graphical user interface (GUI) screen where a firmware update is being processed.

FIGURE 11.19 Aruba Networks wireless access point firmware update screen



Real World Scenario

Upgrading Firmware Warning

It is imperative to follow the manufacturer's instructions when performing a firmware upgrade. Failure to do so may result in the device becoming unusable or needing to be returned to the manufacturer for repair. Several items are very important when you are performing a firmware upgrade on any device:

- Always verify that you have the correct firmware file for the device to be upgraded prior to performing the upgrade.
- Always read the release notes that come with the firmware.
- Never upgrade firmware on a device that is running on battery power.
- Never power down the device while the firmware upgrade is in process.

The firmware in enterprise-grade access points and wireless controllers can usually be upgraded using the command-line interface instead of the GUI, if desired.

Wireless Infrastructure and Client Device Hardware Upgrades

There may be various reasons to upgrade hardware for both infrastructure and client-side devices. Hardware upgrades are a part of the ongoing maintenance process with all networking devices, including WLANs.

Wireless Infrastructure Devices

Upgrading wireless infrastructure devices can be an expensive and time-consuming task. Justifying these infrastructure device upgrades may require preparing reports that include performance of the WLAN infrastructure and client devices, as well as documentation that shows how an upgrade will enhance the end-user performance and make users more productive in their job functions.

Upgrading wireless infrastructure devices such as access points can enable an organization to enhance the performance of the wireless network by increasing the speed or reliability of the WLAN. The hardware currently in use helps determine the extent of an upgrade. Some upgrades may only require the installation of a new or additional radio. Some access points are modular and provide this capability. One example of a wireless infrastructure upgrade is moving from IEEE 802.11b/g to IEEE 802.11n/ac and MIMO technology.

Antennas

Unless the physical characteristics of the area where the WLAN is deployed have changed since the site survey, chances are that antennas will not need to be upgraded. If characteristics such as additional walls or types of furnishings or other physical attributes have changed, antennas with different propagation patterns or higher gain may be required. Another situation where antennas may need to be upgraded or changed is if the initial site

survey was not performed thoroughly or correctly. In some cases where external antennas are used on an access point, they may have been struck and accidentally moved, changing the polarity. A physical inspection of the deployed infrastructure devices should be part of routine WLAN administration or support to locate and correct such issues.

Wireless Client Device Upgrades

Client device upgrades can be automatic if the technology refresh for devices has taken place. For example, if a company replaces 50 notebook computers with newer models, the new notebooks will probably have WLAN adapters that are capable of IEEE 802.11a/b/g/n/ac. The capabilities of these new notebooks may be more advanced than the wireless infrastructure that is currently deployed.

Another situation where wireless client devices may need upgrading is one in which the infrastructure changes to different hardware or technology. If a company upgrades access points from IEEE 802.11b/g to IEEE 802.11n/ac and the clients only support 802.11b/g, the client devices may need to be upgraded in order to take full advantage of the new IEEE 802.11n/ac wireless infrastructure.

Optimizing Wireless Networks

Making changes to an IEEE 802.11 WLAN installation may be required in order to provide optimal performance for the devices that will be connecting. In some cases, a WLAN site design is considered an ongoing process due to the dynamics of RF and changes in technology. This being the case, an existing WLAN deployment may have to be resurveyed and the design modified to provide optimal performance for the users. Here are some of the factors that you need to consider when *optimizing* a WLAN:

- Wireless infrastructure hardware selection and placement
- RF interference sources
- Client device load balancing
- Access point capacity and utilization
- Minimizing multipath
- Understanding hidden node problems

Wireless Infrastructure Hardware Selection and Placement

Wireless infrastructure hardware selection and placement are typically part of the WLAN site survey and design process. Occasionally, however, you may need to reevaluate after the WLAN has been installed. Although the objective of a site survey is to assist in the design of the network, find locations and sources of interference, and decide on locations

for infrastructure devices, you may have to make some adjustments to allow for optimal performance. These adjustments may include minor relocation of access points as well as RF adjustments, including channel and output power settings. These adjustments would ensure that clients have maximum signal strength, throughput, and roaming capabilities. Applications—both hardware and software—and user requirements could also change, requiring an optimization or resurvey of the wireless network.

Identifying, Locating, and Removing Sources of Wi-Fi and Non-Wi-Fi Interference

Identifying areas of RF coverage and Wi-Fi and non-Wi-Fi interference usually is part of the WLAN site survey process. The best way to identify sources of interference is with an RF spectrum analyzer. This could be in the form of an instrumentation device or a USB–based spectrum analyzer designed specifically for wireless networking.

During this wireless site survey process, interference sources should be identified. However, changes to the environment where the network is installed may introduce new sources of RF interference. Also, keep in mind that a walkthrough spectrum analysis of an area will record only the RF it sees at that instant in time. If a new piece of equipment is introduced into an area, it may cause interference with the wireless network that would not have been present during the RF site survey spectrum analysis process. Businesses or organizations that use WLANs where this could be a factor include

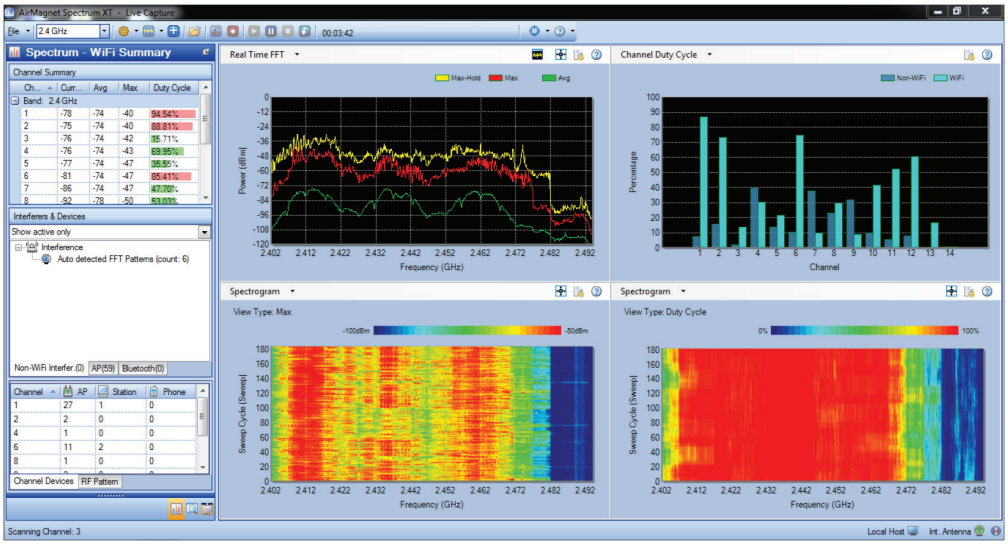
- Healthcare deployments
- Warehouse/retail deployments
- Manufacturing deployments
- Industrial deployments

Therefore, an ongoing spectrum analysis may be required to identify and if possible remove the sources of interference. If these new sources of interference are there to stay, it will be necessary to make appropriate adjustments for the network to operate as designed. The number-one source of interference in a wireless network is other wireless devices.

Enterprise-grade access points contain spectrum analysis capabilities integrated with the access point. This allows an administrator or network engineer to connect to the access point and view the RF in the area without having to visit the location.

Figure 11.20 shows an example of a USB-enabled spectrum analyzer that can be used to perform a spectrum analysis to help locate new sources of RF interference after a WLAN has been deployed.

FIGURE 11.20 NETSCOUT AirMagnet Spectrum XT showing devices that may cause RF interference

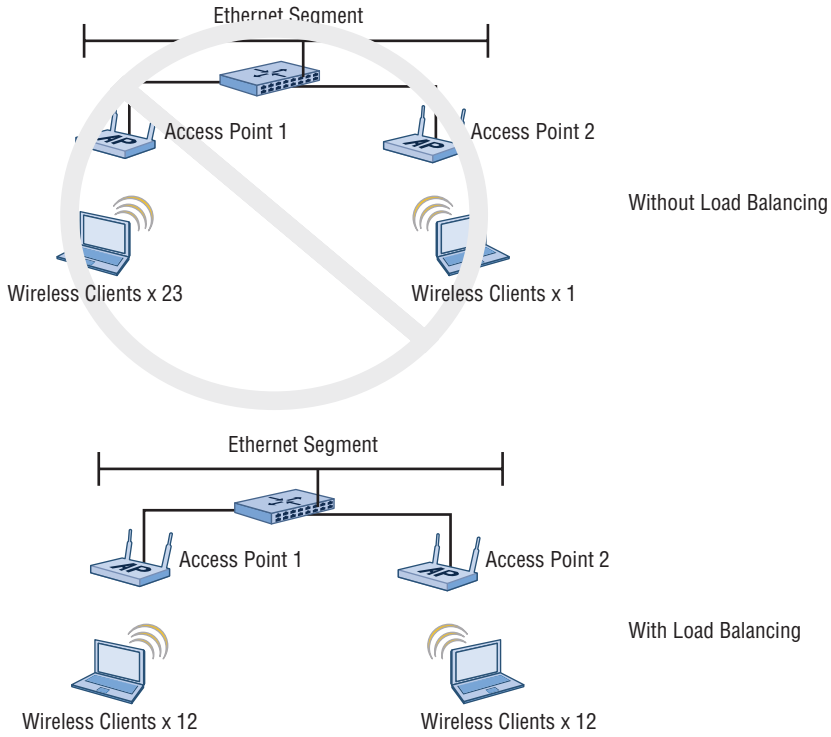


Wireless Client Device Load Balancing and Infrastructure Device Redundancy

Client *load balancing* is a mechanism that prevents wireless client devices from associating to an access point that has already reached the maximum number of client devices for optimal performance. There are a variety of ways this can be accomplished, typically proprietary to the manufacturer. Parameters for load balancing can be set on the access points, WLAN management software, cloud-managed solutions, or hardware WLAN controllers. Load balancing will allow optimal use of all access points in a specific area by preventing too many devices from connecting to a single access point and overloading the access point, which in turn would cause poor performance for all associated devices. Band steering is now implemented by many wireless equipment manufacturers. Band steering will encourage wireless client devices that are 5 GHz capable to use the 5 GHz band rather than the 2.4 GHz band. Figure 11.21 illustrates the load-balancing process for WLAN access points.

The ways in which load balancing is implemented depend on the manufacturer of the WLAN equipment. One solution is a settable parameter in an access point specifying a maximum number of devices allowed to connect at any one time. Once the access point has reached its capacity, a client device wanting to associate will be presented with an error message and will not be allowed to complete the process. Some manufacturers will direct the wireless client device to an access point that will be able to accept the connection rather than deny the connection.

FIGURE 11.21 Load balancing ensures optimal performance for connected wireless client devices.



Wireless Infrastructure Device Redundancy

Designing for WLAN redundancy is an important factor in most enterprise WLAN deployments. In both WLAN controller-based implementations and wireless access points implementations, it is critical to eliminate any potential single point of failure in the WLAN.

Wireless LAN Controller Redundancy If you were to have only a single WLAN controller and that controller failed, the entire wireless network would be down for any controller-based access point. Therefore, a redundant controller should be considered to eliminate the single point of failure. Some manufacturers offer zero license controllers at a decent price that would only be used in the event of a wireless infrastructure controller failure. For example, if you have 24 controller-based access points, that would require 24 access point licenses. You would have two controllers of 24 ports each for a total of 48 ports. However, this would only allow for 24 licensed access points to be used at any one time. The second, which is sometimes referred to as a *zero license controller*, would be for failover purposes only.

Autonomous or Cloud Access Point Redundancy Autonomous and cloud-managed access points do not require a WLAN controller to operate. An autonomous access point operates as a standalone device, requiring each device to be managed individually or with the help of WLAN management software solutions. Cloud access points are cloud based and do not require the use of a WLAN controller, as they have their own management software that does not rely on a dedicated controller. If one of these access points were to fail, only those wireless client devices that were part of that basic service area might lose a connection to the network.

Depending on the design of the WLAN, the surrounding autonomous or cloud-managed access points may be able to increase their RF power to compensate for the failed access point, allowing the wireless client devices that were connected to it to still maintain a connection to the network. This should only be a temporary solution, and the failed access point should be replaced immediately. In a single-access-point installation, if the access point did fail, that would be a single point of failure. For both enterprise and SOHO deployments, we recommend a spare access point be kept on hand in the event of a failure. Another possible solution for this situation using cloud-managed access points is to automatically mesh with another access point, which will continue to allow a connection to the Internet for device access and management capabilities.

Analyzing Wireless Infrastructure Capacity and Utilization

It is important to have a baseline for the performance of your WLAN. This baseline will show the average utilization and capacity of the connected infrastructure devices at various times during the company's business hours. Continuous monitoring of the wireless network is similar to that of a wired network. Performance metrics will be needed to gauge the use of the WLAN and infrastructure devices and show how well the system performs. These metrics will also show areas that are lacking in performance, including bottlenecks or overutilized access points. Using these performance metrics will show which infrastructure devices need attention. This may include moving or adding access points for additional capacity or to allow for higher utilization. Changes to the environment, such as the addition of users, may justify the need for additional access points.

Using IEEE 802.11e or WMM-compliant devices combined with the corresponding QoS settings can improve overall performance for real time applications that are subject to latency, such as wireless devices used for voice and real-time video.

Radio Frequency Performance Problems: Multipath

With IEEE 802.11a/b/g systems, poor throughput can be the result of corrupted data, which may be caused by multipath. *Multipath* is various RF wavefronts of the same signal being received at slightly different times. Multipath is caused by RF reflections based on the

physical attributes where an access point is placed. Antenna diversity will help minimize the problems for IEEE 802.11a/b/g systems caused by multipath.

It is important to understand that although multipath is a hindrance in most IEEE 802.11a/b/g WLAN implementations, it is beneficial for IEEE 802.11n/ac systems. MIMO technology used with 802.11n/ac is designed to take advantage of multipath and increase throughput by using the effects of multipath as an advantage. Unlike IEEE 802.11a/b/g SISO systems, IEEE 802.11n/ac MIMO access points use multiple radios with multiple antennas. The multiple radio chains and some additional intelligence are what give 802.11n/ac MIMO access points the capability to process reflected signals. Because IEEE 802.11n MIMO works with both the 2.4 GHz ISM and 5 GHz UNII bands, a dual-band IEEE 802.11n/ac MIMO access point may have up to eight radio chains—four for 2.4 GHz (802.11n) and four for 5 GHz (802.11n/ac)—and eight antennas (one for each radio) for data rates of up to 600 Mbps for 802.11n and 6933.3 Mbps aggregate for 802.11ac.

If you are experiencing performance problems where multipath may be a potential issue, you will need to evaluate your environment to determine if this is contributing to the issues. Using the proper diversity technology for IEEE 802.11a/b/g systems and upgrading to IEEE 802.11n/ac systems are some of the options. If you are using diversity-capable access points with integrated antennas, spacing between antennas will be correct. If you are using external antennas, keep in mind that the spacing between the antennas should be in multiples of the wavelength for the frequency that is used. Check with the manufacturer of the access points you are using to determine how diversity antennas should be installed.

Radio Frequency Performance Problems: Hidden Node

More IEEE 802.11 WLAN installations experience hidden node problems than you would probably imagine. *Hidden node* is the result of wireless client devices connected to an access point and not able to "hear" each other prior to starting a transmission. This will result in data collisions at the access point and the loss of data. As discussed in Chapter 7, "Modulation Technology for Wireless Networking," the CSMA/CA process is designed to avoid collisions between devices sharing the same medium. This process includes the use of a mechanism called *clear channel assessment* (CCA), which detects RF energy from other IEEE 802.11 wireless client devices in the same RF space and understands that the medium is busy; therefore, that wireless client device will not attempt to complete the transmission process until it detects the medium is clear.

Three causes of the hidden node problem are as follows:

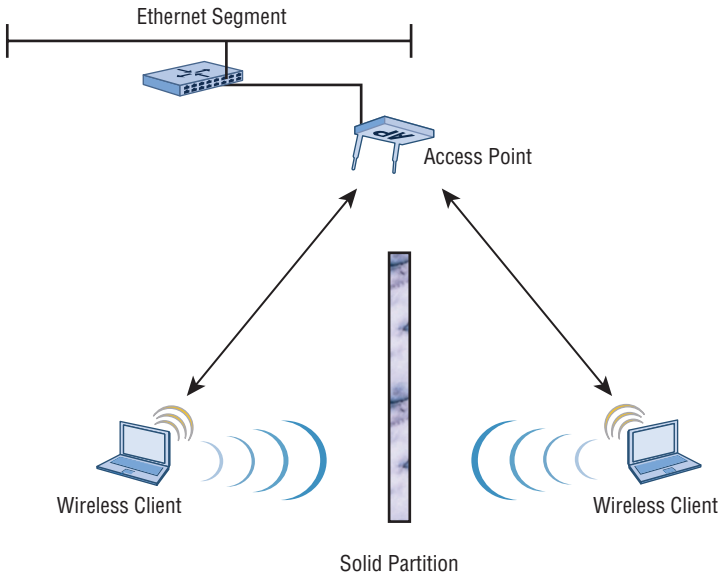
- Hidden node obstacle (obstructions)
- Hidden node distance (signal strength)
- Hidden node technology (signaling methods)

There are both hardware solutions and software solutions to resolving hidden node problems. The following sections describe hidden node problems and solutions in more detail.

Hidden Node Obstruction

Hidden node obstruction is caused by two or more client devices connecting to an access point in which access point–to–client device RF communication is clear, but client device–to–client device RF communication is blocked. Figure 11.22 illustrates an example of hidden node obstruction.

FIGURE 11.22 Hidden node caused by an obstruction



There are several physical solutions to the hidden node obstruction problem. Any of these solutions should allow for the correct RF communication between access points and wireless client devices. Some of the physical solutions to hidden node obstruction include the following:

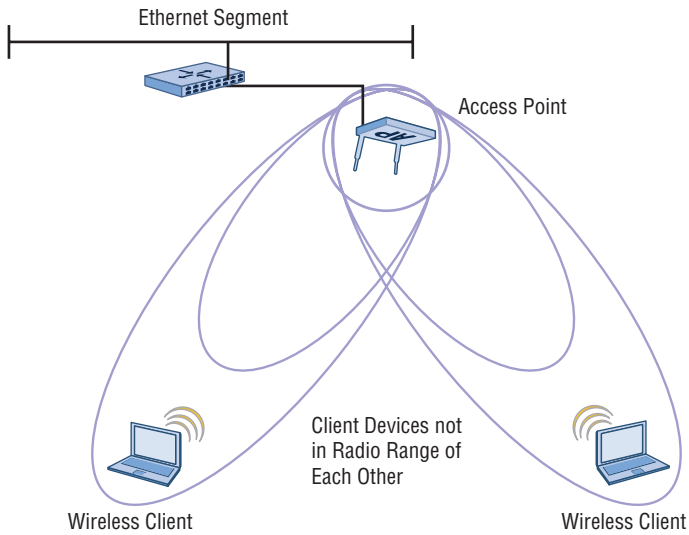
Removing the Obstruction Removing any obstructions that do not allow for clear RF communication between client devices will solve the hidden node problem. In most cases, however, removing obstructions is not feasible. If this type of hidden node problem does exist, a good reason could be poor network design or an inadequate WLAN site survey.

Adding Access Points Adding more access points will help resolve issues caused by hidden node where obstacles are a factor. This will allow for clear RF communication between access points and clients as well as between client devices connected to the same access point. Keep in mind, however, that careful planning must be taken into consideration when adding access points. Too many access points or access points that are too close together can cause other problems, such as co-channel interference. This is where a software-assisted (predictive modeling) WLAN site survey program comes in handy. You can use a program like this to perform a passive RF site survey by walking the area and gathering RF data. You saw various manufacturers of software-assisted WLAN site survey programs and learned about passive site surveys in Chapter 9.

Hidden Node Distance or Signal Strength

With hidden node distance or hidden node signal strength problems, client device–to–client device RF communication cannot occur because the client devices are too far apart and not in radio range of each other. Access point–to–client device RF communication does take place, however, because these devices are within radio range. Figure 11.23 shows an example of hidden node distance/signal strength.

FIGURE 11.23 Hidden node as a result of distance and weak signal strength between wireless client devices



Just as in hidden node obstruction problems, physical solutions exist for the hidden node distance problem. These physical solutions provide adequate RF communication for access point–to–wireless client device and for client device–to–client device. The following are examples of solutions for hidden node distance:

Increasing the Output Power of Client Devices Increasing the RF output power of client devices allows them a larger radio range. This enables wireless client devices to hear each other and therefore know whether the medium is clear prior to starting a transmission.

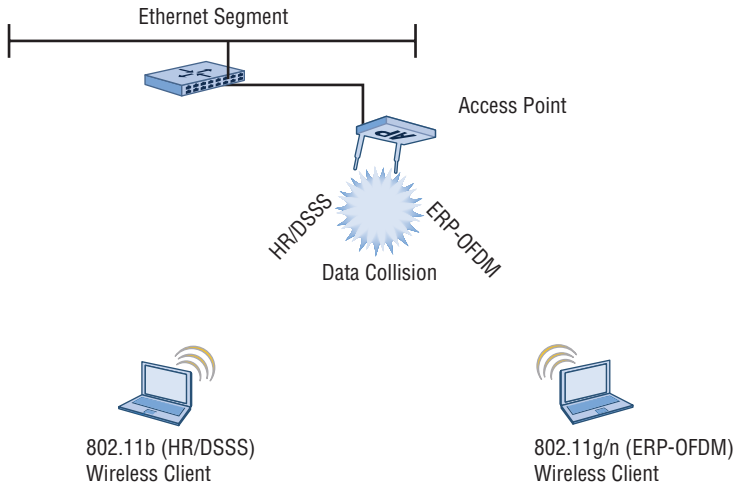
Moving the Client Devices Closer Together Moving the wireless client devices closer together allows the devices to hear the RF communication between each other. In this situation they are able to detect whether the RF medium is clear prior to starting a transmission to the access point. This is a better solution than increasing the transmit power.

Adding More Access Points Another solution is to add more access points. This would allow wireless client devices to detect a clear RF medium. More access points mean a smaller basic service area for each access point on the network. This allows client devices to associate with an access point in close range, and they will not be required to contend for the same access point with other wireless devices at a distance. Adding more access points needs to be carefully considered.

Hidden Node Physical Layer Technology or Signaling Methods

Hidden node technology problems occur when access points experience excessive collisions because of different spread spectrum or Physical layer communication technologies that are sharing the same RF medium. This can happen when, for example, an access point has to share transmissions between 802.11b (HR/DSSS) and 802.11g/n (ERP-OFDM) client devices. Figure 11.24 illustrates the hidden node problem due to different Physical layer technologies in use.

FIGURE 11.24 Hidden node based on technology types such as HR/DSSS and ERP-OFDM



In this example, the only physical solution to the hidden node technology problem is to allow either 802.11b or 802.11g/n devices to communicate with the access point, but not both. In most cases, this is not a realistic solution, because allowing only one of the technologies to communicate with an access point prevents devices using the other technology from using the network. In other words, giving only 802.11g/n (ERP-OFDM) devices the capability to use the network would prevent 802.11b (HR/DSSS) devices from using the network resources, or vice versa.

The IEEE 802.11n, amendment and now part of the IEEE 802.11-2016 standard, consists of four protection modes. The same potential hidden node problems will exist with 802.11n devices but even more so because 802.11n is capable of operating in both the 2.4 GHz ISM and 5 GHz UNII bands. These modes are known as High Throughput (HT) protection modes and are a set of rules client devices and access points will use for backward compatibility. You learned in Chapter 6, "Communication for Wireless Networking," that these modes are constantly changing based on the RF environment and associated wireless client devices.

The Software Solution to Hidden Node Problems

Although not commonly used, there is a software configuration solution for the hidden node problems just described. This software configuration solution is known as a process called *request to send/clear to send*, or RTS/CTS. The RTS/CTS process allows devices to reserve the medium for a specified period of time, enabling a device to complete a frame exchange and avoid collisions. RTS/CTS frames are also used with protection mechanisms to allow different IEEE 802.11a/b/g/n technologies to interoperate. You learned about protection mechanisms and mixed mode in Chapter 6. The RTS/CTS process was discussed briefly in Chapter 6 but is beyond the scope of the exam objectives and therefore is not discussed in detail in this book.

Quality of Service Considerations

Certain types of network traffic require special attention based on how they are used, whereas other types of traffic do not. Consider network printing, for example. When a user sends a file to a network printer, speed is not a major concern. In many cases, there may be one printer for many users of a LAN. The printers are usually in a central location and easily accessible to all the users. After a user sends a document to the printer, they will need to get up from their desk and walk over to the printer to retrieve the print job. In a busy environment, there may be several print jobs queued up that were sent by different users. Depending on the urgency, the user may not retrieve the print job for several minutes or even hours. The point is that this kind of traffic usually has a low priority.

Conversely, other types of network traffic may have a high priority, such as real-time applications like voice, real-time video conferencing, and some streaming content. Using VoIP is becoming more common with enterprise networks, both wired and wireless. The same is true for certain types of video communications. This type of traffic requires special attention and priority in order to provide the user with a good networking experience. As the name implies, quality of service (QoS) will provide a better quality of network communications for traffic such as voice and video. Unlike sending a file to a printer or saving a document to a network file server, using voice and video technology involves human senses such as hearing and sight. If you are having a telephone conversation with another person, you want good, reliable communication. The same goes for attending a live, real-time videoconference. The best way to accomplish this is to incorporate QoS with the network communications.

Both voice and video communications are subject to issues such as latency and jitter.

Latency Voice and video communication are two types of networking applications that are subject to latency. *Latency* is basically a delay in the communications from the source device to a destination device. The latency is measured as the time value for a frame to get to a destination device. Most network engineers try to achieve a total one-way, end-to-end delay for voice communications of less than 150 milliseconds (ms). High latency can result in poor voice or real-time video communications.

Jitter *Jitter* is the variation in the delay or latency of frames received by a destination device. Jitter can be controlled by using something known as a *jitter buffer*. Buffering of information will allow for the data frames to be received as a steady stream of information by the receiving device. Jitter buffers may add 30 to 50 ms to the latency to reduce the effects of jitter. Excessive jitter can cause poor quality VoIP calls and video delays.

Providing end-to-end QoS on a network is not necessarily a simple task, and depending on the device types, number of devices, and network infrastructure, it may be quite complex. QoS is a complex topic, and the technical details are beyond the scope of the exam objectives and this book.

The Wi-Fi Alliance requires support of Wi-Fi Multimedia (WMM) in order for a MIMO device to be Wi-Fi certified. You should not disable WMM on any IEEE 802.11n or 802.11ac access point even if you are not using any QoS features. Disabling WMM on an access point will not use modulation coding scheme (MCS) data rates and will limit you to only 54 Mbps of signaling rate and therefore have a negative effect on your throughput.

Summary

In this chapter, we looked at troubleshooting and maintenance concerns that may involve wireless networking. This included identifying WLAN problems as both global (many) and isolated (individual) and the process for troubleshooting these problems. Global problems may include wireless infrastructure devices, such as:

- Wireless access points
- Wireless bridges
- WLAN controllers

Isolated problems usually include a single WLAN client device or computer that could be experiencing connectivity or data transfer issues. We also looked at basic RF communications using a transmitter and receiver and how these devices operate in a WLAN. We examined connectivity issues, including no connectivity or weak connectivity, and the problems that can be associated with connectivity issues. No connectivity on the client side could be something as simple as a network adapter not enabled or could be related to something more in depth, including:

- Upper layer TCP/IP issues
- Security configurations

In this chapter, you learned about received signal strength and the difference between a strong signal and a weak signal, as well as some of the reasons why a wireless client device may experience weak or no signal. Throughput is another area we explored that involves client-side performance. We discussed some of the factors that could cause low throughput and how to solve these issues.

Upgrading software is another area that needs be taken into consideration with WLANs from the client side, upgrading device drivers or client software utilities, as well as the infrastructure side, which includes upgrading firmware. All of these areas are important parts of WLAN maintenance and support.

Finally, you saw how to optimize wireless networks and some of the areas that should be considered for this optimization, which may include making the necessary adjustments from the original wireless site survey. These adjustments could be a result of changes to the environment, such as walls, doors, windows, or other physical attributes of the location. Other important factors include client load balancing, multipath, hidden node issues, and QoS considerations.

Exam Essentials

Identify the symptoms of common problems associated with wireless networks. Know what may cause poor throughput or connectivity issues with WLAN infrastructure and client devices.

Understand common troubleshooting techniques and procedures to help resolve issues associated with wireless networking. Know how to isolate problems based on symptoms and be able to correct them using a suitable resolution.

Be familiar with the effects radio frequency issues may have on a wireless network. Understand received signal strength and how a weak signal could affect the performance of a wireless client device.

Understand the importance of correct placement of wireless infrastructure devices. Know that load balancing prevents infrastructure devices from becoming overloaded by allowing too many client associations. Understand the hidden node problems, what can cause them, and their solutions. Be familiar with what causes multipath, the solutions for it, and where it can be beneficial.

Review Questions

1. In wireless networking, multipath is the result of what RF behavior?
   - **A.** Refraction
   - **B.** Diffraction
   - **C.** Absorption
   - **D.** Reflection

2. A wireless client device is showing a low receive signal strength value. What option could improve this situation?
   - **A.** Upgrade the client device.
   - **B.** Add another access point.
   - **C.** Upgrade firmware on devices.
   - **D.** Eliminate multipath.

3. You recently installed an IEEE 802.11g/n wireless network in a small office. One of the employees has been complaining of poor performance and mentioned her notebook computer runs very slowly because of the access point it connects to. What could cause this notebook computer to be performing poorly?
   - **A.** The new 5.8 GHz cordless telephone in her office is interfering with the IEEE 802.11g/n WLAN.
   - **B.** The access point is located at the opposite side of the building from the user's office separated by several walls.
   - **C.** A media access control (MAC) filter is enabled on the notebook computer, causing excessive retries.
   - **D.** You recently rolled out a new version of the access point's firmware to enable new features that became available.

4. The RF signal strength seen by a wireless client device from an IEEE 802.11n/ac access point can be improved by _____.
   - **A.** Increasing the output power on the access point
   - **B.** Enabling load balancing
   - **C.** Upgrading the ISP service
   - **D.** Enabling WPA 2.0 on both the access point and the client

5. You are a help desk technician providing support for a wireless network. A user calls and complains that he cannot access the Internet. The user tells you he has good signal strength, but the network connection states "Acquiring network address" and the IP address is all zeros. What could cause this problem?
   - **A.** The client device has a static IP address.
   - **B.** The client has an 802.11a network adapter.
   - **C.** There is an incorrect WPA passphrase on the client device.
   - **D.** A computer virus has infected the client device.

6. You provide consulting services for various companies and receive a call from one of your clients that their notebook computers suddenly started experiencing slow data transfers from the WLAN. This company is located in a multitenant building. What could cause a sudden change in performance for the notebook computers?
   - **A.** A firmware upgrade was recently performed on the access point.
   - **B.** The access point for a new tenant in the building is set to the same RF channel.
   - **C.** The access point shows a low received signal strength.
   - **D.** Someone activated the diversity antennas on the access point.

7. What can solve a hidden node problem caused by an obstruction on an IEEE 802.11n/ac wireless network?
   - **A.** Adding another access point
   - **B.** Setting the access point to mixed mode
   - **C.** Increasing the distance between the access point and the clients
   - **D.** Adjusting the received signal strength on the client

8. Weak signal strength would have an impact on what device?
   - **A.** Infrastructure device
   - **B.** Client device
   - **C.** Multipath device
   - **D.** Transmitter device

9. An incorrect passphrase set on a client device will result in a different preshared key that is generated for a device using WPA 2.0 as a security solution. What will be the result of a mismatched passphrase between the client device and an access point?
   - **A.** Association is established and terminated and no valid IP address
   - **B.** Invalid association and valid IP address
   - **C.** A deauthentication
   - **D.** A disassociation

10. The throughput of a WLAN can be affected by _____ or _____.
    - **A.** Distance from access point, IP address
    - **B.** Distance from access point, MAC address
    - **C.** Distance from access point, output power of access point
    - **D.** Distance from access point, output power of client device

11. The device driver of a wireless network adapter card is _____.
    - **A.** Required
    - **B.** Optional
    - **C.** Used with security
    - **D.** Another name for SSID

12. What is a valid solution to a hidden node problem caused by different technology types?

A. Mixed mode technology

B. Additional access point

C. Increasing output power

D. Removing an obstacle

13. You are a network administrator and receive a call from a user stating that she cannot access the WLAN. The office contains 50 other users, and nobody else is complaining about the network. What could be a potential problem that would keep this user from connecting to the access point?

A. The connection to the Internet has been terminated.

B. The access point needs to be upgraded.

C. Incorrect firmware was installed on the access point.

D. The wireless client device has a corrupt device driver.

14. Lack of RF connectivity on a wireless client could be caused by which layer of the OSI model?

A. Layer 1

B. Layer 3

C. Layer 4

D. Layer 7

15. What address would be considered a Windows Automatic Private IP Address, assigned when no DHCP server is available on the LAN?

A. 192.168.0.1

B. 172.168.0.1

C. 169.254.0.1

D. 10.1.0.1

16. Weak or no signal at a wireless client device can be the result of _____.

A. Distance from an access point

B. Distance from other client devices

C. Distance from the wiring closet

D. Distance from an Ethernet switch

17. What does the signal-to-noise ratio represent?

A. The difference between output power and noise floor

B. The difference between received signal and noise floor

C. The difference between access point output power and received client power

D. The difference between client output power and noise generated by the access point

18. What can IEEE 802.11n/ac MIMO technology use to provide higher throughput to wireless client devices that 802.11b/g cannot?

A. Hidden node

B. Received signal strength

C. DHCP

D. Multipath

19. You can improve the throughput of a WLAN client device by performing which task?

A. Adding access points

B. Upgrading the client software to full-duplex mode

C. Increasing the RF noise

D. Hiding the SSID

20. The received signal strength of a wireless client could be increased by _____.

A. Upgrading the wireless client device

B. Enabling load-balancing features on the access point

C. Increasing the gain of the antenna on the access point

D. Installing the Microsoft Windows WLAN AutoConfig utility

Appendix

Answers to Review Questions

Chapter 1: Computer Networking Fundamentals

1. C, E. Wireless LAN technology operates at Layers 1 and 2 of the OSI model. The Session layer opens, closes, and manages sessions between end-user application processes. The Network layer is responsible for addressing and routing functions of data, and the Application layer is the interface to the user.

2. C. The bus topology is also known as a high-speed linear bus and was commonly used with early IEEE 802.3 networks. The ring topology is rarely used with LANs today but still widely used by Internet Service Providers (ISPs) for high-speed, resilient backhaul connections over fiber-optics link. A mesh topology is where each device in the mesh network has one or more connections to other devices. The star topology consists of multiple devices connected by a central connection device and is the most commonly used method of connecting devices on a LAN today.

3. B. The Physical layer is the lowest layer in the OSI model and consists of bit-level data streams and computer network hardware connecting the devices together. The Data Link layer is responsible for organizing bit-level data for communication between devices on a network, and the network is responsible for addressing and routing functions of data.

4. B. The logical address is an IP address. The Layer 2 address is the hardware address or physical address on the network adapter.

5. D. The Data Link layer is responsible for organizing bit-level data for communication between devices on a network and detecting and correcting Physical layer errors. The Physical layer consists of bit-level data streams and computer network hardware connecting the devices together. The Application layer provides an interface to the user, and the Transport layer is for connection-oriented and connectionless communications.

6. B. The Network layer is responsible for addressing and routing of information. The Physical layer consists of bit-level data streams and computer network hardware connecting the devices together. The Transport layer is for connection-oriented and connectionless communications. The Application layer provides an interface to the user, and the Transport layer is for connection-oriented and connectionless communications.

7. C. Encapsulation allows for Application layer data communication between two stations using lower layers as a support system. Logical addressing is the Layer 3 or IP address, and physical addressing is the hardware or media access control address. Peer communication is the direct communication between devices on a network, and point-to-point communications can be used to connect LANs together.

8. A. The ring topology may use a token-passing access method. The bus topology is also known as a high-speed linear bus and was commonly used with early IEEE 802.3 networks. A mesh topology is where each device in the mesh network has one or more connections to other devices. The star topology consists of multiple devices connected by a central connection device and is the most commonly used method of connecting devices on a LAN today.

9. D. The Application layer provides an interface to the user. The Physical layer consists of bit-level data streams and computer network hardware connecting the devices together. The Data Link layer is responsible for organizing bit-level data for communication between devices on a network. The Presentation layer provides delivery and formatting of information for processing and display, and the Transport layer is for connection-oriented and connectionless communications.

10. A. The media access control (MAC) address is a unique address of the network adapter. The logical address is an IP address as well as the Layer 3 address.

11. D. Encapsulation is adding header and trailer information to a frame. The MAC address is a physical address assigned by the device manufacturer. The IP address is the logical address assigned to a device, and the topology is the physical arrangement of devices in a network.

12. A. Peer communication is direct or the "horizontal" link between devices. The "vertical" link would be equivalent to the encapsulation between layers. The logical link is related to addressing as well as the physical link.

13. B. The physical address of a network device determines the actual hardware address and is used to identify the source and destination of a frame. The routing information is part of the logical addressing process as well as the logical location.

14. B. The Data Link layer of the OSI model is responsible for compiling or packaging bits into frames. The Physical layer allows frames to be sent and received across a medium. The Transport layer is responsible for connection-oriented or connection-less protocols. The Network layer is responsible for addressing and routing of frames, and the Application layer is the "interface to the user."

15. D. TCP is a connection-oriented protocol that uses acknowledgments. UDP is a connection-less protocol and does not guarantee delivery. IP is used for addressing and routing. ARP is used to resolve physical addresses to logical addresses, and HTTP is an Application layer protocol.

16. A. Internet Protocol (IP) is used for addressing and routing functions and operates at Layer 3 of the OSI model. TCP is a connection-oriented delivery protocol. UDP is a connection-less protocol, and ARP is used to resolve addresses.

17. D. The Network layer is responsible for translating physical (MAC) addresses into logical (IP) addresses. The Application layer is where the user sends data to the OSI model. The Session layer opens, closes, and manages sessions, and the Transport layer is for session delivery.

18. B. The Data Link layer consists of two sublayers, the LLC and the MAC. The PLCP and PMD are at the Physical layer. TCP and UDP are Transport layer protocols, and HTTP and FTP are Application layer protocols.

19. A. The Physical layer of the OSI model is used to deliver data to a destination. The Data Link layer is responsible for organizing bit-level data for communication between devices on a network. The Network layer is responsible for addressing and routing functions of data, and the Transport layer is responsible for connections.

20. B. 192.168.200.1 is a valid logical IP address. 255.255.0.0 is an example of a subnet mask. Both AB.CD.EF12.34.56 and 12.34.56.AB.CD.EF would represent physical (MAC) addresses.

Chapter 2: Wireless Local Area Networking, Standards, and Certifications

1. A, C. Semidirectional and highly directional antennas are used for point-to-point links. Omnidirectional antennas are for point-to-multipoint links. Long-range omnidirectional antennas do not exist.

2. B. Point-to-multipoint links typically have three or more connections.

3. A. MIMO can use reflections due to the multiple radio chain technology. Reflections will hurt throughput in a single-input single-output (SISO) technology. Antenna diversity is used with SISO to lessen the effects of reflections.

4. D. The FCC is the local regulatory authority responsible for frequency regulation in the United States. ETSI is a European standards organization responsible for producing standards for information and communications technologies. The Wi-Fi Alliance is an interoperability testing organization. The IEEE creates standards, and WPA is a pre-802.11 certification by the Wi-Fi Alliance.

5. D. 802.11g LANs operate in the 2.4-2.5 GHz ISM band. 900 MHz is not used with 802.11 WLANs, and 5 GHz is for 802.11a.

6. E. The Wi-Fi Alliance performs interoperability testing. The FCC is the local regulatory authority responsible for frequency regulation in the United States. ETSI is a European standards organization responsible for producing standards for information and communications technologies. The IEEE creates standards, and WPA2 is a post-802.11 certification by the Wi-Fi Alliance.

7. C. 802.11a uses OFDM; ERP-OFDM is used in 802.11g. HR/DSSS is used with 802.11b and 802.11g. FHSS is specified in the original IEEE 802.11 standard and is obsolete with respect to modern Wi-Fi technology.

8. A, C, D. 802.11b can use 1, 2, 5.5, and 11 Mbps. 6 and 12 Mbps are OFDM data rates and used in 802.11a and 802.11g networks.

9. A, D. 802.11g is backward compatible with DSSS and HR/DSSS. 802.11a OFDM operates in the 5 GHz band. ERP-OFDM is not used in 802.11a technology, and 802.3af is for Power over Ethernet (PoE).

10. A. The UNII-3 band can be used indoors or outdoors but was at one time mainly used outdoors only.

11. C. 802.11i addresses security. 802.11e addresses QoS. DSSS is a PHY technology defined in the IEEE 802.11 standard, and MIMO is used with IEEE 802.11n technology.

12. B. Wi-Fi Alliance performs interoperability testing for IEEE 802.11 WLAN standards-based equipment. The IEEE creates standards. The FCC is the local regulatory authority responsible for frequency regulation in the United States, and ETSI is a European standards organization responsible for producing standards for information and communications technologies.

13. D. WMM is a proactive Wi-Fi Alliance certification for QoS. WPA and WPA are certifications that address wireless security. IEEE 802.11w is for protection of management frames, and IEEE 802.11r is for Fast Transition (FT); neither currently has an associated Wi-Fi Alliance certification.

14. A. Wi-Fi Protected Setup was designed with SOHO users in mind. Enterprise organizations use IEEE 802.11i, WPA, and WPA2 certifications. The FCC is the local regulatory authority responsible for frequency regulation in the United States.

15. C, D. 802.11g can use ERP-OFDM and DSSS. The 802.11 standard specifies FHSS for 1 and 2 Mbps. OFDM is used with 802.11a devices, and MIMO is used with 802.11n technology.

16. D. WPA was designed as a pre-802.11i solution for wireless security and intended as an interim certification. 802.11a, 802.11n, and 802.11g are communication amendments, and the 802.11e amendment specifies QoS.

17. D. 802.11e is a specific function amendment addressing QoS. 802.11e can operate in either the 5 GHz frequency range or the 2.4 GHz frequency range. 802.11i addresses wireless security, and 802.11e can work with all data rates, not only 1, 2, 5.5, and 11 Mbps.

18. D. The IEEE requires 6, 12, and 24 Mbps for 802.11a. The data rates of 1, 2, 5.5, and 11 Mbps are for the 2.4 GHz band and 802.11b/g.

19. B, C. WPA 2.0 Personal and WPS are both designed with the small business in mind. Wired Equivalent Privacy (WEP) is legacy and not secure. Wi-Fi Multimedia (WMM) addresses QoS, and WPA 2.0 enterprise is designed for larger organizations.

20. A, D. WPA 2.0 consists of personal mode using passphrase and enterprise mode using 802.1X/EAP.

Chapter 3: Infrastructure and Client Devices Used with Wireless Networking

1. D. In computer terminology, half-duplex is two-way communication but only one way at a time. Full-duplex is two-way communication in both directions simultaneously.

2. C. An autonomous access point is an intelligent, self-contained network infrastructure device. Controller-managed access points (also called *thin access points*) work with a WLAN controller.

3. B, C. Bridges must be on the same RF channel and have the same SSID in order to communicate.

4. B, E. Wireless repeaters do extend the cell size and will potentially allow more users to connect. However, using a wireless repeater will decrease throughput.

5. A. A midspan device will inject power into an Ethernet cable. Endpoint power is delivered directly from a switch or controller.

6. A, B. Depending on the specific function, access points operate at Layers 1 and 2. Repeaters function only at Layer 1.

7. A, B, D. Enterprise access points have adjustable output power. Power sourcing equipment is used in PoE to deliver power and data.

8. A. A controller-managed access point connected to a port on the switch is considered to have direct connectivity.

9. C. Root access point is the default mode in most cases. An access point in root access point mode allows users to connect to the network.

10. A, B, D. WLAN controllers may contain many advanced features, including centralized administration, captive portal, and built-in RADIUS services. Network Address Translation (NAT) and IP routing are common in wireless residential gateway devices.

11. D. Wireless USB adapters connect through a USB port in the notebook computer. Virtually all notebook computers have USB ports. PCI adapters are for desktop computers and are installed in an available PCI slot on the motherboard. Wireless Full Mini-PCIe is internal to the device and would require an available interface.

12. A. A device driver is a required component for the USB adapter to function with the operating system. Installation of client utility software may not be required when using a device that has the wireless client software built into the operating system, such as Windows AutoConfig service. Profiles are typically a function of the client utility software.

13. B. A USB 3.0 adapter can be connected to a port on the outside of the computer. Mini-PCI and Half Mini-PCIe are typically used in notebook computers and other portable devices and require some level of disassembly. PCMCIA cards can be used in desktop computers only if an internal PCI adapter is used, which will require disassembly of the computer case.

14. A. Serial communication transmits one bit at a time. Parallel transmits several bits at a time.

15. B. Most manufacturers recommend installing a wireless USB adapter at a specific point. This is usually after the device driver has been copied to the computer during the setup process. In order for the device drivers to load, the device must be powered on. USB and other adapters are capable of being inserted or removed while a device is powered on. Technical support should be called when the user has exhausted other troubleshooting steps.

16. D. Enterprise client utilities have more advanced features such as a site survey utility. PCI configuration includes physical settings prior to installation. A spectrum analyzer is a separate product used to analyze RF. A setup wizard can be part of a SOHO-grade adapter as well as an enterprise-grade adapter.

17. B. A wireless workgroup bridge acting as a client device will connect an Ethernet segment to an access point, eliminating the need to install wireless adapters in all of the Ethernet computers. Two wireless NICs connected together are said to be in ad hoc mode. Connecting two client bridges together is not common practice.

18. B. USB devices connect to an interface external to the computer, and no disassembly is required. PCI, PCIe, and Mini-PCI adapters all require some type of disassembly of the computer device.

19. A. Wireless network cards require device drivers in order for the card to work with the computer operating system. The operating system uses the device driver to control the wireless network adapter or other device that is installed.

20. B. Device drivers are required. A third-party client utility is optional because manufacturers usually include a utility with the device.

Chapter 4: Radio Frequency Fundamentals for Wireless Networking

1. B. Frequency is the number of times in one second a signal will oscillate. Phase is a shift, amplitude is height, and wavelength is a distance of one cycle.

2. B. There are three nonoverlapping channels in the 2.4 GHz ISM band. Fourteen channels are available in this band. The locale will determine which channels can be used.

3. A, D. The capacity of an access point is dependent upon the number of devices and software applications in use. Too many users or too many bandwidth-intensive applications will affect the performance of an access point.

4. A. Refraction occurs when a signal changes speed and bends when passing between mediums of different densities. Reflection bounces off a smooth surface, diffraction will pass around, and scattering bounces off an uneven surface.

5. A, E. RF communications require a transmitter and receiver. A transistor is an electronic component. A reactor does not exist in RF.

6. B, D. dB and dBi are relative measures of RF power. mW, dBm, and watt are absolute measures of RF power.

7. C. 25 MHz is required for channels to be considered nonoverlapping. 22 MHz is the width of a DSSS channel in the 2.4 GHz band.

8. A, C. Amplitude and phase are two characteristics of RF signals. Reflection, refraction, and diffraction are behaviors of RF.

9. B. UNII-1 band has four channels available for WLAN use. Eleven channels are available in UNII-2e.

10. A, C. Watt and mW are absolute measures of RF power. dB, dBi, and dBd are relative measures.

11. A. Channels 1 and 6 are nonoverlapping. There must be a separation of five channels (with the exception of channel 14) to be considered nonoverlapping in the 2.4 GHz band.

12. D. There are 14 channels available in the unlicensed 2.4 GHz ISM band. The channels used are determined by the locale.

13. B. The wavelength is the measurement of one complete cycle of an RF signal. The higher the frequency, the shorter the wavelength—therefore, the shorter the range. Frequency is the number of times an RF signal cycles in one second, amplitude is the height from a 2D perspective, and phase is a shift.

14. B. Obstacles affect the RF line of sight. Phase and amplitude are characteristics of radio frequency, and interference affects the throughput.

15. C. There are now 12 channels available for WLAN use in the unlicensed UNII-2e band as a result of the 802.11ac addition to the standard. Channel 144 is now available for use. Two of the other three 5 GHz bands have only 4 channels each, and depending on where it is used, the UNII-3 band now allows for up to 5 channels with the reclassification of channel 165 to the UNII band.

16. A. The amplitude is the height of an RF signal. The length of one cycle is the wavelength, the shift is phase, and width is not a valid factor.

17. B. A 2.4 GHz 802.11b signal is 22 MHz wide. 25 MHz is the distance required to be considered nonoverlapping.

18. B. An RF signal that bounces off a smooth surface is reflection. Refraction passes through, diffraction bends around, and scattering bounces off a non-smooth surface.

19. C. The gain of an antenna is measured in dBi. This is a relative measure of power.

20. D. Diffraction passes or bends around an obstacle. Reflection bounces off a smooth surface, refraction passes through, and scattering bounces off an uneven surface.

Chapter 5: Antenna Technology for Wireless Networking

1. D. Omnidirectional antennas have a horizontal beamwidth of 360°. The vertical beamwidth will vary depending on the design and the gain of the antenna.

2. B. Antennas provide an increase in RF coverage by means of passive gain. Passive gain occurs when isotropic RF energy is focused into a specific radiation pattern. Active gain requires the use of an external power source.

3. A. Horizontal beamwidth is parallel to the earth's surface. This is based on how the E-field propagates away from the antenna element. Vertical beamwidth is perpendicular to the earth's surface.

4. B. An IEEE 802.11a or IEEE 802.11b/g access point will require two antennas for diversity. Although there are two antennas, a single input/single output access point will have only one radio. The access point provides additional intelligence to determine which antenna to use. Other WLAN technologies, such as IEEE 802.11ac MIMO, may use multiple antennas.

5. B. A lightning arrestor is used to protect a WLAN system from an indirect lightning strike. A lightning arrestor will direct transient or induced electrical current to earth ground as a result of a lightning strike.

6. A. Active gain requires an external power source to provide an increase in signal strength. An amplifier is an example of a device that uses active gain. Antennas provide an increase in strength by using passive gain.

7. C. Highly directional antennas are typically used for long-range point-to-point connectivity, such as bridge links. Omnidirectional antennas are used as part of an access point system or to provide point-to-multipoint links.

8. A. Changing the orientation of a device or antenna will change the polarization and affect the received signal strength. The signal strength may either increase or decrease depending on how the polarization is changed from the original position. Wavelength, frequency, and phase are characteristics of RF.

9. A, C. Point-to-point and point-to-multipoint both require RF line of sight to be able to effectively communicate. Scattering, reflection, and refraction are all behaviors of RF.

10. C, D. Cables and connectors can both result in a loss of signal strength. Antennas and amplifiers will add gain or increase signal strength. A transmitter outputs an absolute amount of power.

11. A. 802.11g access points require only one antenna to function. Systems that support antenna diversity will require two antennas to correctly operate.

12. B. 802.11a access points can use antenna diversity. Gain and polarization are considered RF concepts.

13. A. The image is an example of an omnidirectional antenna. This type of antenna provides a horizontal radiation pattern of 360°.

14. C. Of the answers listed, wind would have the biggest impact on a WLAN system. Rain, snow, and hail do not affect wireless transmission unless the weather is severe. In this case, the collection of the elements may have an impact on the WLAN signal transmitted or received.

15. C. WLAN cables and devices are rated at 50 ohms impedance. Cable and satellite television is rated at 75 ohms.

16. B. The curvature of the earth or earth bulge will have an impact on a WLAN signal after seven miles. If the signal needs to travel farther than seven miles, the antenna will have to be installed in a higher location.

17. A. A patch antenna provides semidirectional coverage. The amount of coverage depends on the design and gain of the antenna. Parabolic dishes are highly directional.

18. B. The horizontal RF radiation pattern of an antenna is displayed using an azimuth chart. The vertical radiation pattern is displayed using an elevation chart.

19. D. It is recommended that at least 60 percent of the Fresnel zone be free of obstruction in order to have acceptable RF line of sight. Up to 40 percent of the zone can be blocked by obstructions without affecting the signal.

20. D. The image shows a patch antenna. This is an example of a semidirectional antenna.

Chapter 6: Communication for Wireless Networking

1. B. When a wireless client device listens for beacons, it is performing passive scanning. Active scanning is sending a probe request. Authentication occurs after the probe phase. Power save puts the device into a low power state.

2. C. Dynamic rate switching (also called dynamic rate selection) allows a WLAN device to adjust data rates based on received signal. Dynamic frequency selection allows an access point to pick the best frequency to operate on based on the environment. Transmit power control automatically adjusts output power. Transmit save mode does not exist.

3. A. An IBSS uses no access points and is also known as peer-to-peer or ad hoc networking. A BSS uses one access point.

4. C. If a device is part of a peer-to-peer network, it will connect to other like devices. An access point and a wireless switch are both infrastructure networking devices and will be part of either a BSS or ESS.

5. A. The data rate decreases as a WLAN device moves away from an access point. The data rates increase as a WLAN device moves closer to one access point. The output power does not change based on the location of the wireless device in the radio range of the access point.

6. C. An SSID can be a maximum of 32 characters or octets and is also case-sensitive.

7. B. If access points on the same DS are set with different SSIDs, the client will lose the connection while roaming unless all SSIDs are set in the client utility. The channel is set by the access point, and the BSSID is the MAC address of the AP radio.

8. C. Beacons are management frames and are used in the passive scanning process. Data frames carry data payload. Control frames reserve the medium and acknowledgment frames. Detail frames do not exist.

9. B. The client must authenticate to an access point before it can associate. After both authentication and association have been completed, the client is considered to be part of the BSS.

10. B. Moving throughout a location will cause a wireless client to roam from one access point to another. As part of the roaming process a client sometimes, but not always, needs to reauthenticate.

11. A, C. To successfully set up an ad hoc network, a user must know two parameters: the SSID and the RF channel it will be operating on. The BSSID is automatically generated in an ad hoc network. The BSSID is the MAC address of an AP radio; APs are not used in ad hoc networks. Protection mode does not apply to the situation.

12. B. Open system authentication uses two frames. The first frame is from the client to the access point, and the second frame is from the access point back to the client. Shared-key authentication uses four frames.

13. C. In 802.11b/g/n and mixed mode environments, throughput will be affected because of ERP protection mechanisms. Association and authentication are normal frames exchanged and do not affect throughput. HT protection mode is for 802.11n.

14. A, C. An SSID has a maximum of 32 characters or octets. SSIDs are case sensitive.

15. A. The BSSID is the unique identifying MAC address of the access point's radio network adapter. This abbreviation is sometimes confused with SSID, which is a network name. The other MAC addresses are used in networking but are not representative of the BSSID.

16. B. A network consisting only of wireless client stations is an independent basic service set (IBSS). Other terms for this type of network are ad hoc and peer-to-peer. Infrastructure mode is a term used with a basic service set that consists of a single access point. Active and passive are scanning modes in which wireless devices connect to a wireless network.

17. C. Because the computer is almost always plugged into an AC power source, it is unnecessary to have the device perform power save functions. Therefore, active mode (sometimes referred to as continuous aware mode) is the best solution. Power save mode would work well for a device that is on battery power and will help extend the battery life. Association and passive mode do not pertain to power save.

18. A. An ESS, as stated in the IEEE 802.11 standard, is one or more interconnected basic service sets.

19. A. In order for a wireless client to become part of a basic service set, it must first authenticate and then associate. The distribution system is the network in which the access point is physically connected. Deauthentication and reauthentication occur when a client either logs off the wireless network or roams from one access point to another.

20. B. A BSS consists of only one access point. An IBSS has zero access points. A network with more than one access point would be considered an ESS.

Chapter 7: Modulation Technology for Wireless Networking

1. C. IEEE WLAN devices use half-duplex communication. Half-duplex is defined as two-way communication only one way at a time. Wired LANs can use full-duplex communication, which is two-way communication transmitting in both directions simultaneously. An example of duplex is to combine signals from two different frequencies into a single transmitter/receiver.

2. A. DSSS devices operate in the 2.4 to 2.5 GHz ISM band. OFDM devices operate in the 5 GHz UNII bands.

3. B. IEEE 802.11g/n operates in the 2.4 GHz ISM band. A total of three access points can be co-located before interference becomes an issue.

4. D, E. The IEEE 802.11n and 802.11ac amendment devices use MIMO, multiple radio chains, and antennas to operate. IEEE 802.11a/b/g devices use one radio and may use multiple antennas for diversity.

5. C. Spread-spectrum technology sends data over many subcarrier frequencies. Narrowband technology is not used in IEEE-based WLANs but is used in other technology, such as radio and TV. Wireless broadband provides high-speed wireless data communications and wireless Internet over a WAN. Wideband uses a wide range of frequencies, and spectral mask refers to the signal levels of the RF.

6. B, C, D. 802.11b channels need to be separated by at least five channels or 25 MHz to be considered non-overlapping. Channels 3 and 9 are separated by six channels; channels 6 and 11 are separated by five channels; and channels 2 and 8 are separated by six channels. All of these scenarios are nonoverlapping channels.

7. A. CSMA/CA uses collision avoidance. CSMA/CD uses collision detection. CSMA/CR and CSMA/DSSS do not exist.

8. A. DSSS uses Barker code at 1 Mbps. CCK is for 5.5 Mbps. DBPSK and DQPSK are modulation technologies, not spreading codes.

9. A. FM radio stations use narrowband communication, which is high power and narrow frequency. WLANs use spread-spectrum technology, which is low power and wide frequency.

10. D. HR/DSSS channels are 22 MHz wide. FHSS uses 1 MHz subcarrier frequencies. OFDM, ERP-OFDM, and HT-OFDM use 20 MHz–wide channels, and HT-OFDM can also use 40 MHz–wide channels.

11. D. Bluetooth operates in the 2.4 GHz band and can cause interference with WLAN devices that operate in the 2.4 GHz band, including FHSS, DSSS, and OFDM.

12. D. OFDM can be used in 802.11a or ERP-OFDM used in 802.11g and supports a maximum data rate of 54 Mbps. 802.11b supports a maximum data rate of 11 Mbps. OFDM is also used with 802.11n devices, but the maximum data rate is 600 Mbps.

13. C. HT-OFDM used in IEEE 802.11n can support data rates as high as 600 Mbps, OFDM used in 802.11a supports a maximum of 54 Mbps, and DSSS supports a maximum of 11 Mbps. Ethernet is not a WLAN technology.

14. C, D. IEEE 802.11a WLANs operate in the 5 GHz UNII bands. 802.11b/g WLANs operate in the 2.4 GHz ISM band.

15. D. IEEE 802.11b and 802.11g amendments are interoperable. 802.11a networks operate in the 5 GHz UNII bands and therefore are incompatible with 802.11b/g.

16. D. 802.11b/g/n operates in the 2.4 GHz ISM band and will allow for 14 channels. The channels that can be used will depend on where the WLAN is located.

17. B. OFDM uses a 20–MHz wide channel to transfer data. 22 MHz–wide, 40 MHz–wide, and 80 MHz–wide channels are used with other technologies.

18. B. The IEEE 802.11b amendment specifies data rates of 5.5 and 11 Mbps. OFDM allows for data rates up to 54 Mbps and is used in IEEE 802.11a and IEEE 802.11g amendments.

19. C. VHT-OFDM, defined in the IEEE 802.11ac amendment to the standard, allows for 20 MHz–, 40 MHz–, 80 MHz–, and 160 MHz–wide channels for transmitting and receiving data. DSSS uses a 22 MHz–wide channel, and OFDM and ERP-OFDM use only 20 MHz–wide channels to transmit and receive data.

20. D. Current MIMO technology allows for up to 600 Mbps in the 2.4 GHz ISM band. One way this is accomplished is by using multipath as a benefit rather than a hindrance.

Chapter 8: Security Fundamentals for Wireless Networking

1. A, B, E. WPA Enterprise, WEP, and MAC filtering can all be used to secure 802.11a/b/g access points. PPTP is a Layer 3 security solution that consists of both tunneling and encryption. IPSec is a Layer 3 VPN encryption mechanism. RBAC stands for role-based access control and is a way of restricting access to only authorized users.

2. A, D. Both WPA2 Personal and WEP support shared key security. The WPA2 Personal algorithm creates a 256-bit preshared key. WEP can be used with either a 64-bit or 128-bit key. WPA Enterprise, 802.1X/EAP, and WPA2 Enterprise all use the 802.1X process to create a key.

3. B. Passphrases are available for use with WPA Personal or WPA2 Personal and are capable of providing strong security for the home user or small office. SSID hiding should not be used for security because the SSID can be found in frames other than beacons. MAC filters are considered legacy solutions and can be easily spoofed using software downloadable from the Internet. 128-bit WEP can be cracked very quickly using software tools and is therefore not a secure solution.

4. C. In order to provide a secure connection between your laptop and the office network, a Layer 3 VPN solution would be the best choice. Passphrase security and WEP require the access point to be configured, and this typically is not the case in public hotspots. 802.1X/EAP is enterprise security and usually does not apply to public hotspots.

5. E. A MAC filter is used to allow or deny WLAN devices access to a wireless access point. WEP is a shared key security mechanism. IPSec encryption is used in Layer 3 VPNs. SSIDs are used as a network name and for segmentation. RF is radio frequency and cannot be filtered.

6. B. The IEEE 802.11i amendment to the standard requires CCMP. WEP is an optional authentication/encryption method defined in the original 802.11 standard. TKIP is an enhancement to WEP that usually was accomplished as a firmware upgrade for older equipment. PPTP and VPN are both Layer 3 solutions and not defined in any IEEE wireless amendment.

7. A. A VPN is a Layer 3 security solution that provides secure data transmissions over a public network infrastructure such as the Internet. WEP, WPA, 802.1X/EAP, and WPA 2.0 are examples of Layer 2 security solutions.

8. A. RBAC is a method used to restrict access only to authorized users. RBAC assigns permissions or access to roles to which users can be added.

9. D. If the SSID of the wireless network is hidden, the user will need knowledge of the SSID in order to connect to the wireless network. The SSID broadcast is only enabled on an access point or WLAN controller/switch. Getting a new password from the help desk will not provide the SSID of the wireless network. Entering a username and password is user-based authentication.

10. C. RADIUS is a centralized authentication method that is used to authenticate users on a wireless network. Accessing a corporate network using a modem is a function of remote access services. Making a call to the help desk and requesting a username and password is not a function of RADIUS; however, the help desk may be able to assist with username and password issues. Requesting remote assistance to help solve a software problem is more related to troubleshooting and not a function of RADIUS.

11. B. In 802.1X networking, the access point is also known as the authenticator. The supplicant is another term for the client device, and the authentication server can be a RADIUS or AAA authentication source.

12. D. The original IEEE 802.11 standard identifies WEP as an optional authentication/encryption method. AES and CCMP are addressed in the 802.11i amendment to the standard. TKIP is an enhancement to WEP and not identified in the original standard. EAP provides an authentication process and is used with 802.1X networks.

13. A, C. Higher levels of RF activity reported by an intrusion prevention system could mean an RF DoS attack is underway or could be misrepresented as interference from a neighboring access point. A deauthentication storm or encryption attack would be identified differently in a wireless intrusion prevention system. A misconfigured client workstation would not cause this type of alert.

14. C. WEP is typically 64-bit or 128-bit encryption. The numbers 5, 10, 13, and 26 are related to the number of characters the WEP key can be in either ASCII or hexadecimal.

15. B. PIN-based security is mandatory for both access points and client devices in order to be considered Wi-Fi Protected Setup certified. PBC or push-button configuration is optional for client devices in this certification. WPA is a pre-802.11i certification that addresses TKIP and is used in either SOHO or enterprise-based wireless networks. Wi-Fi Protected Setup is not intended for enterprise WLAN deployments.

16. B. A WIPS will automatically monitor the network for signatures that match potential intrusion techniques. An intrusion prevention system has the capability to automatically shut down a rogue access point. An intrusion detection system requires a manual shutdown. A WIPS will not notify a network administrator of a recent firmware upgrade.

17. B. If WEP must be used on a wireless network, the devices that use WEP should be separated using VLANs. This will protect the rest of the network from being compromised. Voice transmissions can be seen with the correct tools. CCMP/AES is available in newer devices that support the latest wireless security methods but is not available in older devices.

18. B. An intruder can spoof a MAC address in order to circumvent the MAC filter and gain access to the wireless network. Encryption cracking is a different form of intrusion that also could possibly allow an intruder to steal a user's authentication credentials. An RF DoS attack is caused by transmitting high-energy RF to prevent access to the wireless network.

19. C. PIN-based security is usually used with SOHO brand wireless devices that support WPS certification. The devices are typically used in SOHO installations or by home-based users. WPA 2.0 solutions can use either passphrase or 802.1X/EAP.

20. A. L2TP commonly uses IPSec for encryption. PPTP is another VPN method that uses MPPE 128-bit encryption. AES and WEP are used with Layer 2 802.11-based wireless networks.

Chapter 9: Design for Wireless Networking

1. A, C. The main objectives of a wireless site survey are to determine areas of RF interference and RF coverage as well as locations of access points and other infrastructure devices. The applications used have more to do with capacity planning. Wiring closet locations and security implantations are factors that need to be taken into account but are not the main objectives.

2. D. Because of RF propagation, site surveys are really three-dimensional. Therefore, in a three-story building all floors need to be taken into consideration. Omnidirectional antennas may be polarized either vertically or horizontally. Single-channel architectures use the same channel for multiple floors.

3. A, B. A spectrum analyzer and a tool that passively scans for wireless networks, such as NetStumbler, can be used for a manual site survey. The other options' association and authentication can be viewed using a protocol analyzer and are not "standalone" tools.

4. A, C. Manual site surveys can be either passive or active. Scanning is a method of locating WLANs. A spectrum analyzer will allow you to see the RF. A packet is information that carries computer data from one device to another.

5. B, D. Non–Wi-Fi interference is interference by anything other than WLANs that operates in the same frequency range. AM radios and digital TV systems do not operate in the license-free bands. 802.11b interference is WLAN interference. Radar systems operate in the 5 GHz U-NII band.

6. C. Recommended received signal strength for voice applications in the 2.4 GHz ISM band at a data rate of 54 Mbps is about –67 dBm. A recommended SNR is more than 20 to 25 dB.

7. C. A predictive modeling site survey is software-based and takes the attenuation values of the building and other materials into consideration. Active and passive are forms of manual site surveys and record actual information about the site.

8. B. OFDM networks operate in the 5 GHz U-NII band and would not affect an 802.11g/n network that operates in the 2.4 GHz ISM band. FHSS, DSSS, and ERP-OFDM all operate in the 2.4 GHz ISM band and could cause interference with an 802.11g network.

9. A, B. The signal strength and SNR are two important values to record during the manual site survey process. Signal loss and propagation loss have different effects, and packet retries are more of an issue with dynamic rate selection.

10. C. Manual site surveys can be very accurate because actual readings are taken at the site using test access points and a wireless client. This can take quite some time to complete depending on the size of the location. Wireless hardware is required to perform the site survey, and access to the whole facility is required.

11. A. A spectrum analyzer can be used to view RF. Wireless packets, data rates, and association frames can be viewed with a protocol analyzer.

12. B. Since new hardware will be purchased and backward compatibility is not required, you could recommend using wireless network hardware that works in the 5 GHz band. This will eliminate interference from the other tenants that are using the 2.4 GHz ISM band. Automatic channel selection, spectrum analysis, and predictive modeling site survey will not help, because surrounding access points already use the entire band.

13. B. A predictive modeling site survey will take less time than a passive survey, because a passive survey requires a manual analysis. Onsite protocol analysis or scanning utility will determine areas of RF interference from WLANs. The predictive modeling survey does not help you choose manufacturers' equipment to be used in a deployment.

14. D. A verification of the predictive survey should be performed to verify that the survey meets the customer's requirements. Although not required, it should be considered.

15. D. Dead spots (areas that lack RF coverage) should be identified on floor plans or blueprints. This is part of standard documentation practices. Marking them with tape, taking a photograph, and showing the site manager in person are not the best ways to document dead spots.

16. B. An active site survey requires the survey device to associate to an access point. A passive site survey monitors all access points in the area. A predictive modeling site survey does not involve associating to an access point. Associating to an access point is not a required part of manual testing.

17. D. A semidirectional antenna such as a Yagi is a good choice for an application requiring coverage down a long hallway or corridor. Low- or high-gain omnidirectional antennas will provide 360-degree horizontal coverage. Parabolic dish antennas are typically used for outdoor, long-range bridging.

18. D. In this situation, correct antenna selection is important to provide optimal coverage as well as proper aesthetics. In this example, a spectrum analysis or protocol analysis could be performed but is not required. Environmental conditions are typically not an issue in a small office deployment.

19. A. Co-channel interference is caused by two access points operating on the same RF channel. Access points operating on channels 1 and 2 may cause adjacent channel interference. Channels 1, 6, and 11 are nonoverlapping channels and will not interfere with one another.

20. A, E. A walk-through of the location and spectrum analysis are both recommended guidelines when performing a manual site survey. Equipment purchase and client device configuration are additional factors to consider but are not part of the manual site survey. A predictive analysis is a software-based site survey solution that does not require manual testing.

Chapter 10: Mobile Device Management and BYOD Fundamentals

1. B, C. Software as a Service (SaaS) is a type of MDM solution that is cloud-managed and does not require a hardware investment for the organization. This type of solution can be can be used anywhere there is an active Internet connection. On-premises technology is an MDM solution that requires the organization supply all hardware and software components and may require a significant investment. Centralized management and control is a method used with managing networks. Controller-based technology is used by some WLAN manufacturers to provide centralized management and control of the wireless network infrastructure.

2. D. The enterprise app store helps an organization control and regulate the apps that are used within its environment, including custom- or purpose-built apps. The consumer mobile app store is intended for the common user to download or purchase commercial, off-the-shelf (COTS) mobile apps. Native and hybrid apps can actually be accessed from either a consumer or enterprise app store.

3. B. Geo-location can use different methods to locate a device. One example is time difference of arrival (TDoA), which is a multilateration technology technique. TDoA measures the difference in distance between two stations from known locations. Geo-fencing, from a mobile computing perspective, is a virtual electronic boundary that allows network administrators to identify when specific mobile devices enter or leave an area. On-boarding is the process of connecting a device to a wireless network for the first time and allowing a user to register it in order to gain access to the company and other network resources. Off-boarding or de-provisioning is the opposite; a device is removed from the network.

4. C. A profile is a set of parameters or instructions that will provide a device with the ability to connect to a network and follow specific requirements or settings for the connected session. The EULA is an agreement between the creator of the software package and the organization or person that purchased the software. Geo-location technology allows for many different device types to be geographically located using different techniques. A mobile device digital certificate can be used as an access control method and will ensure that only valid, authorized users can gain access to the corporate network infrastructure.

5. C. A profile is a set of parameters or instructions that will provide a device with the ability to connect to a network and follow specific requirements or settings for the connected session. Disabling or changing a profile can cause a variety of technical issues. Typically, an app installation or operating system update would not cause this type of problem. Assigning a static IP address should not be a problem as long as the address is on the correct IP subnet.

6. C. Location services will need to be enabled on the physical device in order to physically locate it and to benefit from geo-location and geo-fencing. Geo-fencing technology can work on a variety of mobile devices, including Android devices. An application programming interface (API) is a set of programming instructions and standards used within software development. A revoked certificate would prevent a device from authenticating to the network.

7. A. On-boarding is the process of connecting a device to a wireless network for the first time and allowing a user to register it to gain access to the company and other network resources. Devices that contain cellular capabilities will require some type of activation process in order to be used on the wireless carrier network. Tethering a smartphone using a USB cable or Bluetooth technology will allow a device to have wireless broadband capabilities, usually for an additional fee. With regard to technology, a security policy defines an agreement between a corporation or the technology provider and the technology user.

8. B, C. Both access permissions and data encryption will limit the access of information to authorized users. Data encryption methods will ensure that the information is secure in transit. Secure SSID is another term for SSID hiding and is not a recommended security practice. Location services will allow for geo-fencing and geo-location services to track devices. MAC address filtering will allow or deny device access to a wireless access point based on its MAC address.

9. A. A digital certificate can be used as an access control method and will ensure that only valid, authorized users can gain access to the corporate network infrastructure. Digital rights management is a method of controlling access to copyrighted material for many different electronic digital formats. Both WPA and WPA2 are methods used to control access; however, the encryption of TKIP is weak compared to CCMP.

10. D. The Apple Push Notification Service (APNS) uses a native push notification technology and allows an iOS device to receive information even when the destination app is not open or running. GCM (Google Cloud Messaging) is a push notification service that allows for data to be sent from a server to Android-based devices. Dynamic Host Configuration Protocol (DHCP) is a networking protocol/service that provides the dynamic mapping and assignments of logical Layer 3 IP addresses of a network device to the physical Layer 2 MAC addresses of a network device. Simple Mail Transfer Protocol (SMTP) is the Internet standard that electronic mail services use to send and receive email messages.

11. B. Pushing content is a method to allow operating systems and updates, configuration settings, and more to be sent to mobile devices. This is a common requirement in enterprise device deployments. MDM solutions allow for information to be pushed out to all specified mobile devices that connect to the corporate network. Content update is a process in which information is changed on servers that will be accessed via an Internet browser or used to provide updates to devices. An update server is a machine used to provide the content for devices, and distributed edge is a technology that provides intelligent devices such as wireless access points the ability to handle specific functions without the aid of a centralized control point.

12. C. Lightweight Directory Access Protocol (LDAP) is used to query an X.500 directory service database, which will authenticate users or devices based on their credentials. Directory services objects are users and group objects that are created in a database to allow access to network resources. Directory service database replication is a method of duplicating a network database to provide redundancy and fault tolerance. Assigning permissions to user objects allows the user to gain access to any resource it is granted access to.

13. B. Telecommunications expense management defines managing expenses for mobile device technology, such as managing the amount of data communications available to a device or data plan. Defining the corporate budget for departmental expenses is unrelated to the actual expense management and falls under those responsible for budgetary tasks. Limits for the number of devices supported by MDM are based on the number of licenses purchased for the MDM solution. The ROI for SaaS vs. on-premises MDM solutions is performed prior to any purchasing or implementation of on MDM solution.

14. C. A walled garden is another term used to describe a captive web portal, which is a web page redirection. The EULA is an agreement between the creator of the software package and the organization or person that purchased the software. PKI is an enterprise security solution that requires a certificate-based implementation for user and device authentication. A VPN will create private secure communications over a public network infrastructure, such as the Internet.

15. B. A self-service portal is a method of onboarding a device for corporate policy compliance, which gives users the ability to register their devices to the network, enabling quick access to the network without the need to open a service ticket or contact the help desk for technical support. Enabling devices to allow MDM systems to handle a data plan management falls under telecommunications expense management. Multilateration technology is a technique for device location utilizing time difference of arrival (TDoA) with geo-location. Creating device groups for ease of access is part of a directory service administration task.

16. A, C. General policy and functional policy are two of the main parts of a corporate security policy. The general policy components consist of the policy purpose and business justification, management approval, policy definition and documentation processes, training policies, revision processes, violations and response, legal concerns, and potential threat assessment. The functional, or technical, side commonly consists of administrator and user training, monitoring, auditing, response and forensics, defining acceptable use, and security requirements, including authentication, encryption, and passcode and password policies. OEM is the definition for original equipment manufacturer and with regards to mobile technology defines when a company purchases the rights to resell a product under its own brand name. A termination policy is used to disconnect devices from a network based on a specific policy violation.

17. C. The digital certificate is commonly used as an access control method by validating a user or device identity based on the criteria on which a certificate was issued. A policy is used to define specific settings and configuration information based on the user or device type connecting to a network. A directory service database—such as Microsoft Active Directory, Novell eDirectory, or Red Hat Directory Server—is used to manage users, groups, devices, and other resources. LBS is a method used for locating devices over the Internet.

18. B, C. Software as a Service (SaaS) and on-premises are two common placements for an MDM solution. The EULA is an agreement between the creator of the software package and the organization or person that purchased the software. A walled garden is another term used to describe a captive web portal, which is a web page redirection. A self-service portal is a method of on-boarding a device for corporate policy compliance.

19. B. An acceptable use policy a technology method to ensure a user will comply with corporate policy in order to access and use any computer network resources or services. EULA is an agreement between the creator of the software package and the organization or person that purchased the software. A content-filtering policy is used to identify how content may be accessed based on the device or user that connects to a network. A pilot program enables a network administrator to validate that technology will work as specified and designed prior to a full deployment.

20. C, E. User group assignments and an MDM policy are two items that could make a device unable to access a company's intranet website. The EULA is used an agreement between the creator of the software package and the organization or person who purchased the software. A PKI installation is an enterprise security method that uses digital certificates to validate a user's identity. The correct Wi-Fi settings will enable a device to connect to a network; incorrect settings would not allow any type of connectivity.

Chapter 11: Troubleshooting for Wireless Networking

1. D. Multipath is caused by reflected signals arriving at the receiver at slightly different times (delay spread). Refraction is an RF behavior caused by passing through an object of different density, resulting in a change of the signal strength. Absorption is the result of a signal not reflecting or bending or passing around an obstacle.

2. B. A wireless client device showing a low received signal strength value could be too far away from an access point. Of the answers listed, an additional access point would be the best solution. Upgrading the client device or the firmware would not help the situation. Multipath is caused by reflections and cannot be eliminated.

3. B. A user experiencing a slow connection could be too far away from an access point to get a strong enough signal to move data at the highest rate. A 5.8 GHz phone is operating at a different frequency and would not cause interference with an 802.11g/n 2.4 GHz WLAN. A MAC filter is set on an access point and will either allow or disallow a client connection. If a firmware upgrade were causing a problem for an access point, it would affect all users.

4. A. Increasing the output power of the access point will result in a higher received signal at the wireless client device. Enabling load balancing will not improve signal strength but will limit the number of devices that associate with an access point and may improve throughput. Upgrading the ISP service to faster data rates will not improve signal strength for the wireless client. Enabling security such as WPA 2.0 will not increase the signal strength seen by the client but is recommended to secure the transmission.

5. C. Incorrect security parameters such as a WPA passphrase will prevent a wireless client device from completing a Layer 2 connection and obtaining an IP address from a DHCP service. If the client device is different technology like 802.11a, the device would not have been able to connect. If a static IP address is used, it will not display all zeros. Although a computer virus can create problems for the client device, it would not prevent the device from obtaining an IP address after connecting to the wireless network.

6. B. A sudden change in performance might occur if an access point for a new tenant is set to the same RF channel as your client's access point. This could cause interference, which would degrade performance. A firmware upgrade on the access point usually fixes problems or provides enhancements. Received signal strength is typically an issue based on distance from an access point. Diversity antennas would help minimize the problems associated with multipath and in most cases would improve performance rather than degrade it.

7. A. A hidden node problem caused by obstructions could be resolved by adding another access point so that wireless client devices would not be subject to clear channel assessment issues. Setting an access point to mixed mode will allow both 802.11b and 802.11g/n client devices to connect to the network. Increasing the distance between the access point and the clients will not improve the situation but will actually make it worse. Adjusting the received signal strength on the client would improve performance for that client but would not necessarily solve the hidden node problem.

8. B. The WLAN client device would be mostly affected by weak signal strength. An infrastructure device such as an access point generates the signal received by the client. Multipath is a phenomenon that is a result of several wavefronts of the same signal reaching a receiver at different times. A transmitter device is responsible for sending an RF signal.

9. A. A passphrase or preshared key will be validated after an 802.11 authentication and association. In order for the client device to get a valid IP address, a successful authentication, association, and passphrase would have to occur. A deauthentication will end the authentication state, and a disassociation will no longer allow a device to pass traffic across the access point.

10. C. Two factors that may have an impact on throughput in a WLAN are distance from the access point or the output power level of an access point. The IP address and MAC address identify the device on the network and would not affect throughput. The output power of the client device has more to do with its transmitting capabilities than the receiver's capabilities.

11. A. The device driver is a required component that allows the wireless network adapter card to interface with the operating system. A device driver neither provides security nor identifies the network.

12. A. Hidden node caused by different technology types is the result of the access point not being able to differentiate between spread-spectrum technologies. An access point set to mixed mode will understand both HR/DSSS and ERP-OFDM, which will solve the problem. Adding another access point or increasing output power would not solve the problem, although such actions could be solutions for other hidden node scenarios. Removing an obstacle is a valid solution for a different hidden node problem.

13. D. A corrupt device driver may cause the network adapter card in a wireless client device to operate incorrectly or to malfunction. A terminated Internet connection would be a global problem and would affect all users. An upgrade or incorrect firmware would not cause the problem for only a single user.

14. A. Layer 1 provides the physical connectivity between devices, which use the air as the medium to carry the RF. Layers 3 and 4 are responsible for TCP/IP. Layer 7 is the interface to the user, also known as the Application layer.

15. C. Windows 98 and later are designed to use the Automatic Private IP Address service. This service will provide an IP address to client devices in the range of 169.254.*x*.*x*. This will allow local connectivity for any devices that are connected to a common LAN.

16. A. The distance from an access point could affect the received signal strength for a wireless client device. The distance from other clients has no impact on devices that are connected to an access point. The distance from an Ethernet switch or from the wiring closet has no impact on a wireless client.

17. B. The signal-to-noise ratio represents the difference between the received signal strength and the level of the noise floor. A good signal-to-noise ratio will enable a client to distinguish between signal and noise and allow it to recover data that was transmitted.

18. D. 802.11n/ac takes advantage of multipath, which is typically a problem for other WLAN technologies. By using multipath, 802.11n/ac devices will have better throughput than 802.11b/g devices. Received signal strength means the same thing across technologies. DHCP is a service that provides IP addresses automatically. Hidden node is a problem that may degrade throughput for connected devices.

19. A. Adding access points can help increase the throughput for a WLAN client device. This is possible because additional access points would allow for load-balancing features and therefore provide less contention at that access point. Upgrading the client software to full-duplex mode is not an option, and if the RF noise were increased, throughput would be less. Hiding the SSID has no impact on throughput.

20. C. Increasing the gain of an antenna will provide a larger RF coverage cell, thereby providing more received signal at the same distance for a wireless client device. Upgrading the wireless client will not improve the received signal strength. Load balancing will help with throughput, and Microsoft Windows WLAN AutoConfig service is an example of a built-in client utility.

Index

Note to the Reader: Throughout this index **boldfaced** page numbers indicate primary discussions of a topic. *Italicized* page numbers indicate illustrations.

A

AAA (Authentication, Authorization, and Accounting) protocol, **312–313**
absolute measurements of RF power, **158–159**
absorption of RF signals, **157**, *158*
AC (alternating current) signals, 134
acceptable use policies, **445**
access methods
  CSMA/CA, **264–265**
  CSMA/CD, **263–264**, *264*
  DCF, **265–266**, *266*
  narrowband vs. spread-spectrum, **267–269**, *268*
  overview, 262
access points (APs). *See* wireless access points (WAPs)
accounting in AAA, **312–313**
Acrylic WiFi utility, 179–180, 475
active antenna gain, **178**
active mode (AM), 249
active scanning, **230–231**, *230–231*
active site surveys, **392**
ad hoc networks
  connections, **12**, *12*
  description, 217
  SSIDs, 219–220, *219*
adapters
  troubleshooting, 466–467, *467*
  utilities, **485**
adaptive access points, 94
adaptive frequency hopping (AFH), 286
Address Resolution Protocol (ARP), 21
addresses
  device, **21–27**, *25–27*
  IP. *See* Internet Protocol (IP) addresses
  logical, **23–25**, *23–25*
  MAC. *See* Media Access Control (MAC) addresses
  Network Address Translation, **25–27**, *27*
  physical, **22**, *22*
adjacent-channel interference
  description, 385
  overview, **152–154**, *153–154*
  planning for, **284–286**, *285*
  RF, 149
adjustable output transmit power, **89**
administration in IBSSs, 221
administrative permissions, **436**
Advanced Encryption Standard (AES) algorithm, 316
Aerohive Wi-Fi Planner program, 402
aesthetics in antenna selection, 412
AFH (adaptive frequency hopping), 286
AFP (Apple Filing Protocol), 18
AIDs (association IDs), 250
AirCheck G2WirelessTester spectrum analyzer, 338
AirDefense spectrum analyzer, 377
AirGrab WiFi Radar, 475
AirMagnet analyzer
  site surveys, 389, *389*, 393, *393*
  working with, 377, *377*
AirWave network management, 336
alternating current (AC) signals, 134
AM (active mode), 249
amplitude, RF, **138**, *138*
Amtel product, 429
Android operating system
  emulator software, **433–435**, *433–435*
  mobile devices, **430**
antennas
  azimuth and elevation, **174–175**, *175*
  beamwidth, **173–174**, *174*
  clear communications, **206–208**, *208*
  enterprise-grade access points, **89**
  exam essentials, **209–210**
  gain, **176–178**, *176–177*
  grounding rods, **203**
  installation, **199–200**, **203**
  integrated and external, **204**
  limitations, 415
  manual site surveys, **399**
  mounting, **203–206**, *205–206*
  multipath, **200–201**, *200*
  overview, **172–173**
  placement, **199–200**
  polarization, **178–180**, *179*
  review questions, **211–214**
  RF cables, **195–197**, *196–197*
  RF connectors, **198**, *198*
  RF lobes, **173–174**, *173*

safety, **203**
selecting, **412–413**
SOHO-grade access points, **85**
summary, **208–209**
testing, **411–413**, *411*
types, **180**
highly directional, **193–195**, *193*, *195*
omnidirectional, **180–183**, *181*, *183*
semidirectional, **184–193**, *184–188*, *190–192*
upgrades, **487–488**
use considerations, **370–374**, *371*
wind and lightning effects, **201–203**, *202*
APIPA (Automatic Private IP Addressing), 470–471, *471*
app store, **431–435**, *433–435*
Apple App Store, 432
Apple Filing Protocol (AFP), 18
Apple Profile Manager, 429
Application layer in OSI model, **18**
applications
business requirements, *356*
design considerations, 361
requirements, **368–369**
APs (access points). *See* wireless access points (WAPs)
APSD (automatic power save delivery), **251**
ARP (Address Resolution Protocol), 21
association, IEEE, **235–236**, *235*
association IDs (AIDs), 250
audits, 373
authentication
AAA, **312–313**
defined, 297
and encryption, **302–304**
IEEE, **231–235**, *232–235*
MS-CHAP, 320
open system, **298**
RADIUS, **309–312**, *311–312*
shared-key, **298**
Authentication, Authorization, and Accounting (AAA) protocol, **312–313**
authentication servers, 309
authenticators for client devices, 309
authorization in AAA, **312–313**
AutoConfig service, 123, 467–468, *467*
automatic power save delivery (APSD), **251**
Automatic Private IP Addressing (APIPA), 470–471, *471*
autonomous access points, 80–81
cloud-managed, **93–94**, *94*
consumer-grade, **82–83**, *83*
controller-managed, **91–93**, *92*
enterprise-grade, **87–91**, *88*, *90*
overview, **82**
SOHO-grade, **83–87**, *83–84*, *87*
troubleshooting, **492**
wireless branch router, **94**
azimuth
omnidirectional antennas, 183, *183*
parabolic dish antennas, 195, *195*
patch/panel antennas, 187, *187*
RF coverage, **174–175**, *174–175*
sector antennas, 188, *190*
Yagi antennas, 192, *192*

B

backup policies, **445–446**
bandwidth
business requirements, *356*
design, *359*
basic service areas (BSAs)
basic service sets, 222
description, 225
SOHO-grade access points, 85
basic service set identifiers (BSSIDs), **226**
basic service sets (BSSs), 54, **222–224**, *223–224*
battery packs, **399**
Bayonet Neill-Concelman (BNC) connectors, 8
beacon frames, 229, *229*
beamwidth, antenna, **173–174**, *174*
Berkeley Varitronics Systems (BV Systems) Swarm, 402
BlackBerry operating system, **431**
Blackberry product, 429
BlackBerry World Store, 432
blanketing in SCA networks, 414
blockage, RF, 152
blueprints
design, *359*
gathering, **362–363**, *363*
manual site surveys, **388**
Bluetooth wireless technology
PANs, 7, *7*
WPANs, 37
BNC (Bayonet Neill-Concelman) connectors, 8
bridge mode
enterprise-grade access points, **90**
SOHO-grade access points, **86**
bridges
overview, **96**, *96*
translational, 237
workgroup. *See* wireless workgroup bridges (WWBs)
bring your own device (BYOD)
device density, 148
issues, 426

policies, **452–453**
site survey considerations, **354**, *355*
trends, 108
broadband routers, 82
BSAs (basic service areas)
basic service sets, 222
description, 225
SOHO-grade access points, 85
BSSIDs (basic service set identifiers), **226**
BSSs (basic service sets), 54, **222–224**, *223–224*
buffers, jitter, 498
building age issues in site surveys, **355**
building materials and RF signals, **146**
burned-in addresses (BIAs), 302
bus topology, **8–9**, *8*
business requirements, **356–357**, *357*
BYOD. *See* bring your own device (BYOD)

C

cables, **195–197**, *196–197*
CAM (continuous aware mode), 249
cameras for manual site surveys, **400**
campus area networks (CANs), **5–6**, *6*
Canada, RF regulations in, 139
capacity, RF. *See* radio frequency (RF)
captive portals
description, 63
mobile device management, **440–441**
security, **334**
WLAN controllers, **100–101**
carpeted deployments, **64**, *65*
Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA), **264–265**
Carrier Sense Multiple Access/Collision Detection (CSMA/CD), **263–264**, *264*
carts for manual site surveys, **400**
CCA (clear channel assessment), 265, 493
CCMP (Counter Mode with Cipher Block Chaining Message Authentication Code Protocol), **316–317**, *316*
ceiling mounts for antennas, **206**, *206*
cells, RF, 144
centralized administration for WLAN controllers, **99**
centralized data forwarding, **103**
Centrify product, 429
CEPT (Conference of Postal and Telecommunications Administrations), 42
certificates for mobile device management, **450**
Chanalyzer spectrum analyzer, 376, *376*
Physical layer monitoring, 337–338, *337*
working with, **379–383**, *379–383*
channels
adjacent channel and co-channel interference, **152–154**, *153–154*, **284–285**, *285*
DSSS, **270–273**, *272–273*
IEEE 802.11ac amendment, 51
MCA, **413**, *413*
OFDM, **276–278**, *276*
reuse, **149–150**, *149–150*
RF, **141–143**, **220**, *220*
China, RF regulations in, 139
Cisco Prime NMS, 336
Cisco Spectrum Expert spectrum analyzer, 338
Citrix - Zenprise product, 429
classes for IP addresses, 23–24, *24*
classification signatures in PoE, **106–107**
classrooms, **64–66**, *66*
clear channel assessment (CCA), 265, 493
Clear to Send (CTS) to Self option, 252–253
Clearwire Inc., 38
CLI (command-line interface) for enterprise-grade access points, **91**
client devices, **79**
adapter utilities, **485**
business requirements, 356
capabilities, **352–353**
connectivity requirements, **369–370**
drivers, **121**, *121*
exam essentials, **125**
firmware, **485–487**, *486*
hardware upgrades, **487–488**
load balancing, **490**, *491*
manual site surveys, **399**
Mini-PCI, **115–118**, *115*, *117*
output power, 495
PCI, **112–115**, *112–114*
PoE, **104–107**, *104*, *107*
radio hardware, **108**
review questions, **126–129**
software upgrades, **481–487**, *482*, *484–486*
summary, **124**
USB, **108–111**, *109–111*
utility software, **121–123**, *122–123*
wireless bridges, **96**, *96*, **118–120**, *119–120*
wireless repeaters, **97–98**, *97*
WLAN hardware controllers, **98–103**, *103*
client side connectivity, troubleshooting, **466–468**, *467–468*
closed networks, 219
cloud-managed access points, 80–81, **93–94**, *94*, **492**
cloud-managed architectures, **98–103**, *103*
cloud-managed solutions, **428**
Cloudpath product, 429
clustering servers, 437

co-channel interference
description, 385
overview, **152–154**, *153–154*
planning for, **284–286**, *285*
co-location in OFDM, **282–283**, *284*
coexistence, WLAN/WPAN, **285–286**
collisions
CSMA/CA, **264–265**
CSMA/CD, **263–264**, *264*
command-line interface (CLI) for enterprise-grade access points, **91**
communications
association, **235–236**, *235*
authentication, **231–235**, *232–235*
basic service areas, **225**
basic service sets, **222–224**, *223–224*
data rates, **238–239**, *239*
deauthentication and disassociation, **236–237**, *236*
distribution systems, **237–238**, *238*
dynamic rate switching, **246–247**, *247*
exam essentials, **256**
extended service sets, **224–225**, *225*
frame types, **227–228**
IBSSs, **217–222**, *217–220*
overview, **216–217**
power save operations, **249–251**, *250*
protection mechanisms, **251–254**
review questions, **257–260**
RF channels, **220**, *220*
summary, **254–256**
throughput, **240–246**, *240*, *242–246*
transitioning/roaming, **247–249**, *248–249*
wireless network discovery, **228–231**, *229–231*
CommView for WiFi protocol analyzer, 338, 403, **405–409**, *406–409*
compliance
design considerations, 362
industry regulatory, **339–340**
WIPSs for, 330
conference deployments, **70**
Conference of Postal and Telecommunications Administrations (CEPT), 42
configuration and settings options
enterprise-grade access points, **91**
SOHO-grade access points, **86–87**, *87*
connections, speed, 367
connectivity
client devices, **369–370**
troubleshooting, **465–472**, *466–472*
wireless access points, **102–103**, *103*
WLANs, **38–39**, *39*
connectors, RF, **198**, *198*
construction materials issues in site surveys, **355**
consultants in mobile device management, **453**
consumer-grade access points, **82–83**, *83*
consumer mobile app store, 431–432
continuous aware mode (CAM), 249
control frames in IEEE, **227–228**
controller-managed access points, 80–81, **91–93**, *92*
cooperative control architecture, 80
corporate-owned mobile devices profiles, **452**
corporate policies in design, 362
cost of RF cables, **197**
Counter Mode with Cipher Block Chaining Message Authentication Code Protocol (CCMP), **316–317**, *316*
coverage area, RF. *See* radio frequency (RF)
CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance), **264–265**
CSMA/CD (Carrier Sense Multiple Access/Collision Detection), **263–264**, *264*
CTS (Clear to Send) to Self option, 252–253
current in power formula, 159
customer requirements in antenna selection, 412

D

data buses in PCI, 112
data encapsulation, **20**, *20*
data forwarding, **103**
data frames in IEEE, **228**
Data Link layer
monitoring, **338–339**
OSI model, **16**, *16*
data rates
communications, **238–239**, *239*
IEEE 802.11ac amendment, 51
data transmissions, DCF, **265–266**, *266*
dB (decibels), **160**, *160*
dBd (decibels dipole), **161–162**
dBi (decibels isotropic), **160–162**, 176
dBm for RF power, **159**
DCF (distributed coordination function), **265–266**, *266*
dead spots, 377
deauthentication, **236–237**, *236*
decibel relative to a milliwatt, **159**
decibels (dB), **160**, *160*
decibels dipole (dBd), **161–162**
decibels isotropic (dBi), **160–162**, 176
delay spread, 139
deployment guides, 362

design
antennas
testing, **411–413**, *411*
use considerations, **370–374**, *371*
application requirements, **368–369**
business requirements, **356–357**, *357*
channel architectures, **413–414**, *413–414*
client connectivity requirements, **369–370**
device installation limitations, **414–415**
documentation, **362–366**, *363*, *365*
exam essentials, **418–419**
infrastructure connectivity and power requirements, **366–368**
infrastructure hardware selection and placement, **410**
interference sources, **378**, *378*, **384**
overview, **349**
protocol analysis, **403–409**, *404*, *406–409*
received signal strength, **385–386**, *386*
review questions, **420–423**
RF coverage and capacity requirements, **369**
RF coverage planning, **410**
site surveys. *See* site surveys
spectrum analysis, **375–377**, *376–377*, **379–383**, *379–383*
stakeholder interviews, **358–362**, *358*, *360*
summary, **417–418**
device addressing, **21–27**, *21–25*
device co-location, **149–150**, *149–150*
device drivers
client devices, **121**, *121*
upgrades, **482–485**, *482*, *484–485*
device groups, **437**
Device Manager utility, 121, *121*
DHCP (Dynamic Host Configuration Protocol)
IP address connectivity issues, 470–471, *470*
OSI model, 17
SOHO-grade access points, **86**
dictionary attacks, 320
diffraction, **156–157**, *156*
diffusion, **158**
digital cameras for manual site surveys, **400**
digital certificates for mobile device management, **450**
direct access point connectivity, **102**
direct link RF line of sight, **151–152**
direct-sequence spread spectrum (DSSS), **270–271**, *271*
directory services in mobile device management, 437, **449**
disassociation, **236–237**, *236*
discovery
SSIDs, 218
wireless network, **228–231**, *229–231*
dish antennas, **193–195**, *193*, *195*
distance issues
access points, **477**, *478*
hidden nodes, **495**, *495*
distributed access point connectivity, **102**
distributed coordination function (DCF), **265–266**, *266*
distributed data forwarding, **103**
distribution systems (DSs)
basic service sets, 222–223, *223*
communications, **237–238**, *238*
extended service sets, 225, *225*
wireless access points, 80
diversity
antenna, 201
SISO, 278–279
documentation
electrical specifications, **364**
existing network characteristics, **364–366**, *365*
floor plans and blueprints, **362–363**, *363*
furnishings, **363–364**
dollies, **400**
dotted-decimal addresses, 23
drivers
client devices, **121**, *121*
upgrades, **482–485**, *482*, *484–485*
DRS (dynamic rate switching) process, 144, **246–247**, *247*
DSs. *See* distribution systems (DSs)
DSSS (direct-sequence spread spectrum), **270–271**, *271*
Dynamic Host Configuration Protocol (DHCP)
IP address connectivity issues, 470–471, *470*
OSI model, 17
SOHO-grade access points, **86**
dynamic rate switching (DRS) process, 144, **246–247**, *247*

E

EAP (Extensible Authentication Protocol), **308–312**, *311–312*
earth curvature effects, **199**
education environments
antenna use considerations, **372**
deployments, **64–66**, *66*
Ekahau HeatMapper program, 387, *387*, **393–398**, *395–397*
Ekahau Site Survey tool, 402
electrical power requirements, **367**
electrical specifications, **364**

elevation
omnidirectional antennas, 183, *183*
parabolic dish antennas, 195, *195*
patch/panel antennas, 187, *187*
RF coverage, **174–175**, *174–175*
sector antennas, 188, *190*
Yagi antennas, 192, *192*
email, **18**
employee-owned mobile devices profiles, **452–453**
encapsulation, **20**, *20*, 319
encryption
and authentication, **302–304**
CCMP, **316–317**, *316*
overview, **313**
TKIP, **315–316**, *315*
WEP, **314**
end-user license agreement (EULA) processes, **436**, **450–451**, *450*
endpoint injectors in PoE, **106**
endpoints in VPNs, 320–321
enforcement of information technology policies, 444
enterprise app store, 431
enterprise-grade access points, **87–91**, *88*, *90*
enterprise networks
antenna use considerations, 371
business requirements, **357**, *357*
client utilities, 122
deployments, **61–62**, *62*
security, **304–308**, *305–306*
environment issues
antenna selection, 412
interference, **155–158**, *155–158*
site surveys, **353**
equipment preferences in design, 359
ERP (Extended Rate Physical), **252–253**, **273–274**, *274*
ESSs (extended service sets)
overview, **224–225**, *225*
vs. SSIDs and BSSIDs, **226**
Ethernet limitations, **415**
EULA (end-user license agreement) processes, **436**, **450–451**, *450*
Europe, RF regulations in, 140
European Telecommunications Standards Institute (ETSI), **42**
exclusive OR (XOR) process in DSSS, 270
existing networks
characteristics, **364–366**, *365*
extensions, **62**
manual site surveys, **388**, *389*
expandable antennas, **89**
expectations, performance, **353**
expense management in mobile device management, **440**
Extended Rate Physical (ERP), **252–253**, **273–274**, *274*
extended service sets (ESSs)
overview, **224–225**, *225*
vs. SSIDs and BSSIDs, **226**
Extensible Authentication Protocol (EAP), **308–312**, *311–312*
extension cords, **399**
external antennas, **204**
Extreme AirDefense Services Platform (ADSP), 336
Eye P.A. protocol analyzer, 338, 403

F

fast transition (FT) technology, 54
Federal Communications Commission (FCC)
overview, **41**
unlicensed frequency bands, **140–141**
FHSS (frequency-hopping spread spectrum), **269**
IEEE 802.11 standard, 44
WPANs, 37
file server redundancy, 437
File Transfer Protocol (FTP), **18**
filtering MAC addresses, **301–302**, *301*
firewalls, **101**
firmware
client devices, **485–487**, *486*
upgrading, 317
Flexmaster NMS, 336
floor plans
design, 359
gathering, **362–363**, *363*
manual site surveys, **388**
forensics, WIPSs for, 330
Fortinet Wireless LAN Manager, 336
frames
active scanning, 230
IEEE, **227–228**
roaming, 248
shared-key authentication, **234**, *235*
free space path loss (FSPL), 158
frequency, RF, **137–138**, *137*
frequency bands, **139–140**
RF channels, **141–143**
RF range, **143**
unlicensed frequency bands, **140–141**
frequency-hopping spread spectrum (FHSS), **269**
IEEE 802.11 standard, 44
WPANs, 37

Fresnel zones
antennas, **207–208**, *208*
description, 151, *152*
FSPL (free space path loss), 158
FT (fast transition) technology, 54
FTP (File Transfer Protocol), **18**
full-duplex, 80
Full Mini-PCIe cards, 117
functional components in mobile device management security, 443
furnishings, **363–364**

G

gain
antenna, **176–178**, *176–177*
RF, 138
general offices
antenna use considerations, 371
business requirements, **357**, *357*
general policy components, 443
geo-fencing, 426, **438–439**, *438*
geo-location, **439–440**, *439*
Global Positioning System (GPS), 438
Google G Suite, 429
Google Play Store, 432
government environments, **372**
GPS (Global Positioning System), 438
Graphical User Interface (GUI) configuration for enterprise-grade access points, **91**
Greenfield mode, **253**, *275*
grounding rods, **203**
group policies, **451–453**, *451*
guest access, 359

H

half-duplex communication
throughput effects, 266–267, *267*
wireless access points, 80, *81*
Half Mini-PCIe cards, 116
half-power point in RF lobes, 174
half-split troubleshooting method, 8
Handheld spectrum analyzer, 377
hard-coded addresses, 302
hardware
client device upgrades, **487–488**
RF signals, **146**
selection and placement, **410**, **488–489**
hardware addresses
BSSIDs, 226
devices, *16*
hardware controllers, **98–103**, *103*
hardware sensors in WIPSs, 330
HCF (hybrid coordination function), 53, 266
Health Insurance Portability and Accountability Act of 1996 (HIPAA), 69, **340**
healthcare deployments
antenna use considerations, **372**
overview, **67–69**, *69*
HeatMapper program, 387, *387*, **393–398**, *395–397*
hidden nodes
distance and signal strength, **495**, *495*
obstruction, **494**, *494*
overview, **493**
Physical layer technology and signaling methods, **496**, *496*
software solution, **497**
hiding SSIDs, **53–54**, 219, **299–300**, *300*
high availability in mobile device management, **436–437**
high-density deployments, **70**
high rate/direct-sequence spread spectrum (HR/DSSS)
channels, **271–273**, *272–273*
co-location, **282–283**
IEEE 802.11b amendment, 45
high-speed linear bus, 8
high throughput (HT)
overview, **275**
protection mechanisms, **253–254**
highly directional antennas
overview, **193–195**, *193*, *195*
placement, **200**
HIPAA (Health Insurance Portability and Accountability Act of 1996), 69, **340**
HiveManager NMS, 336
horizontal polarized antennas, 178, *179*
hospital deployments, **67–69**, *69*
hospitality sites
antenna use considerations, **372**
deployments, **62–63**, *63*
hotspot environments, **372**
HR/DSSS (high rate/direct-sequence spread spectrum)
channels, **271–273**, *272–273*
co-location, **282–283**
IEEE 802.11b amendment, 45
HT (high throughput)
overview, **275**
protection mechanisms, **253–254**
hybrid coordination function (HCF), 53, 266
Hypertext Transfer Protocol (HTTP)
logical addresses, 23
OSI model, **18**

I

IBSSs. *See* independent basic service sets (IBSSs)
ID badges, 361–362
IEEE
  association, **235–236**, *235*
  authentication, **231–235**, *232–235*
  data rates, **238–239**, *239*
  deauthentication and disassociation, **236–237**, *236*
  enterprise-grade access point support, **88**
  ERP, **273–274**, *274*
  frame types, **227–228**
  high throughput, **275**
  IEEE 802.1X security, **308–312**, *309*, *311–312*
  IEEE 802.3 standard, 104–105
  IEEE 802.11 standard, **41–44**
  IEEE 802.11a amendment, **44–45**, *45*, **275–278**, **282–283**
  IEEE 802.11ac amendment, **50–52**, **275–282**
  IEEE 802.11ah amendment, 137
  IEEE 802.11b amendment, **45–46**, **271**, **282–283**
  IEEE 802.11b/g/n mixed mode, **252–253**
  IEEE 802.11b-only mode, **252**
  IEEE 802.11e amendment, **53**
  IEEE 802.11g amendment, **46–48**, *47*, **273–278**, *274*, **282–283**
  IEEE 802.11g-only mode, **252**
  IEEE 802.11i amendment, **53–54**
  IEEE 802.11k amendment, **54–55**
  IEEE 802.11n amendment, **49–50**, *49*, **275–282**
  IEEE 802.11n high-throughput protection mechanisms, **253–254**
  IEEE 802.11r amendment, **54**
  IEEE 802.11s amendment, **55**
  IEEE 802.11w amendment, **55**
  licensed RF bands, **41–42**
  MIMO, **278–282**, *280–281*
  OFDM, **275–278**, *276*, **282–283**, *284*
  overview, **42–43**, **216**
  protection mechanisms, **251–254**
  SOHO-grade access point support, **84**
  summary, **52–53**
  transitioning, **247–249**, *248–249*
  wireless mesh, 95
impedance in RF cables, **197**
independent basic service sets (IBSSs)
  advantages and disadvantages, **221–222**
  overview, **217**, *217*
  RF channels, **220**, *220*
  security, **221–222**
  SSIDs, **218–220**, *218–219*
  terminology, **221**
industrial deployments, **67**, *68*
Industrial, Scientific, and Medical (ISM), 37, **140–142**
industry regulatory compliance, **339–340**
Industry Standard Architecture (ISA) bus, 112
information technology policies, **443–444**, *444*
infrastructure, **79**
  capacity and utilization, **492**
  device redundancy, **102**, **491–492**
  exam essentials, **125**
  hardware selection and placement, **410**, **488–489**
  hardware upgrades, **487**
  identifying connectivity, **366–368**
  review questions, **126–129**
  summary, **124**
  wireless access points. *See* wireless access points (WAPs)
infrastructure devices for site surveys, **355–356**
infrastructure mode for wireless access points, 80
initialization vectors (IVs) in WEP, 314
insertion loss, 198
installing
  antennas, **199–200**, **203**
  protocol analyzers, **405–409**, *406–409*
  USB devices, **110–111**, *110–111*
  wireless workgroup bridges, **120**, *120*
integrated antennas, **204**
integrated technology, WIPSs for, 330, **332–333**
intelligent access points, 81
interface cards for PCI, **112–115**, *112–114*
interference
  adjacent-channel and co-channel, **152–154**, *153–154*, **284–286**, *285*
  definitions, **384–385**
  design considerations, 360, **378**, *378*, **384**
  eliminating, **489**, *490*
  environment issues, **155–158**, *155–158*
  hospital deployments, 68
  IBSSs, 221
  overview, **152**
  WLAN/WPAN, **154**
interframe spacing, 265
intermittent wireless connectivity problems, **473–476**, *474–476*
International Organization for Standardization (ISO), 14
International Telecommunication Union-Radiocommunication Sector (ITU-R), 40, *40*
Internet-based predictive modeling site survey, **402**
Internet Protocol (IP) addresses, **22–23**, *24*
  connectivity issues, **469–472**, *469–472*
  Network Address Translation, **25–27**, *27*
  OSI model, 17, *17*

interoperability certifications
overview, **55–56**
Wi-Fi Alliance, **56**, *56*
Wi-Fi Multimedia certification, **58**
Wi-Fi Multimedia Power Save certification, **58**
Wi-Fi Protected Access certification, **56–57**
Wi-Fi Protected Access 2 certification, **57**
Wi-Fi Protected Setup certification, **58–59**
interviewing stakeholders, **358–362**, *358*, *360*
Intune product, 430
iOS operating system, **431**
IP addresses. *See* Internet Protocol (IP) addresses
IP frames in VPNs, 319
ipconfig command, 22, *22*, 24–25, *24–25*
IPv4 addresses, 24, 26
IPv6 addresses, 24, 26
ISA (Industry Standard Architecture) bus, 112
ISM (Industrial, Scientific, and Medical), 37, **140–142**
ISO (International Organization for Standardization), 14
isotropic energy, 176, *176*
isotropic radiators, **160–161**
Israel, RF regulations in, 140
ITU-R (International Telecommunication Union-Radiocommunication Sector), 40, *40*
Ivanti product, 430
IVs (initialization vectors) in WEP, 314

J

Japan, RF regulations in, 140
jitter, **498**
JPerf software program, **241–246**, *242–246*

L

L2TP (Layer 2 Tunneling Protocol), **320**
ladders for manual site surveys, 400
LANs (local area networks)
controller redundancy, **491**
overview, **3**, *3*
virtual, **99–100**
wireless. *See* wireless local area networks (WLANs)
last-mile data delivery, **69–70**, *70*
latency, **497**
law enforcement networks, **71**
Layer 2 Tunneling Protocol (L2TP), **320**
LBS (location-based services), **438–440**, *438–439*
LDAP (Lightweight Directory Access Protocol), 437
legislative compliances, 339
length of RF cables, **196–197**, *197*
licensed RF bands, **41–42**
lifts for manual site surveys, **400**
lightning arrestors, **202**, *202*
lightning effects, **201–203**, *202*
Lightweight Directory Access Protocol (LDAP), 437
line of sight (LoS)
antennas, **207**
radio frequency, **150–152**, *151*
LLC (Logical Link Control) layer, 16, *16*
load balancing client devices, **490**, *491*
loading access points, **479**
lobes, RF, **173–174**, *173*
local area networks (LANs)
controller redundancy, **491**
overview, **3**, *3*
virtual, **99–100**
wireless. *See* wireless local area networks (WLANs)
local codes
antenna selection, 413
device limitations, **415**
local MAC architecture and autonomous access points, 92
local regulatory authorities, **40–42**, *40*
location-based services (LBS), **438–440**, *438–439*
location size considerations, **351**
logical addresses, **21**, **23–25**, *23–25*
Logical Link Control (LLC) layer, 16, *16*
LoS (line of sight)
antennas, **207**
RF, **150–152**, *151*
loss, RF, 138
low RF signals, **476**, *476*

M

MaaS360 product, 430
MAC addresses. *See* Media Access Control (MAC) addresses
MAC (Media Access Control) layer, 16, *16*
maintenance in information technology policies, 444
management frames, **227**
management systems for security, **334–339**, *335–337*
MANs (metropolitan area networks)
overview, **4–5**, *5*
wireless, **37–38**
manual site surveys
access point placement, **390–391**, *390*
advantages and disadvantages, **391**
existing wireless networks, **388**, *389*

floor plans and blueprints, **388**
overview, **387–388**, *387*
results analysis, **391**
software-assisted, **392**, *393*
toolkit, **398–400**
manufacturer guidelines
antenna selection, 412
design, 362
manufacturer-specific client utilities, **122**, *122–123*
manufacturing environments, antenna use considerations in, 371
markers for manual site surveys, 400
maximal ratio combining (MRC), 50, 279
MCA (multiple-channel architecture), **413**, *413*
MCS (modulation and coding scheme), 51, 283
MDM. *See* mobile device management (MDM)
measurement units for RF
overview, **158**
power, **158–162**, *160*
signal, **162–165**, *163–164*, *166*
measuring devices for manual site surveys, 399
Media Access Control (MAC) addresses
BSSIDs, 226
filtering, **53–54**, **301–302**, *301*
overview, **21–22**, *21–22*
security issues, **300–302**, *301*
spoofing, **302**
Media Access Control (MAC) layer, 16, *16*
medical deployments, **372**
Meraki WiFi Mapper program, 402
mesh mode for enterprise-grade access points, **91**
mesh networking in IEEE 802.11s amendment, 55
mesh topology, **10–12**, *11*
MetaGeek InSSIDer, 475
metropolitan area networks (MANs)
overview, **4–5**, *5*
wireless, **37–38**
Microsoft Point-to-Point Encryption (MPPE-128) Protocol, 320
Microsoft Windows Active Directory, 437
midspan injectors in PoE, **105**
military environments, **372**
milliwatts, **159**
MIMO (multiple-input, multiple-output) technology
IEEE 802.11n amendment, 50
overview, **278–282**, *280–281*
RF diversity, 201
Mini-PCI standard
card installation and configuration, **117–118**
features, **116–117**, *117*
overview, **115–116**, *115*
mobile application store, **431–435**, *433–435*
mobile device management (MDM)
administrative permissions, **436**
captive portals, **440–441**
device groups, **437**
digital certificates, **450**
end-user license agreements, **450–451**
exam essentials, **455**
group policies, **451–453**, *451*
high availability and redundancy, **436–437**
location-based services, **438–440**, *438–439*
mobile application store, **431–435**, *433–435*
on-premises solutions, **428–430**
operating system modifications and customization, **446–448**
operating system platforms, **430–431**
overview, **426–428**
policies. *See* policies in mobile device management
pushing content, **435–436**
review questions, **456–459**
SaaS solutions, **428**
self-service portals, **441–442**
summary, **454–455**
technology profiles, **448–451**, *449*
telecommunications expense management, **440**
mobile device transition for WLAN controllers, **100**
MobileIron product, 430
Mode 0-no protection mode, **253**
Mode 1-HT nonmember protection mode, **253–254**
Mode 2-HT 20 MHz protection mode, **254**
Mode 3-Non-HT mixed mode, **254**
modular classrooms, 66
modulation and coding scheme (MCS), 51, 283
modulation technology
access methods, **262–269**, *264*, *266–268*
adjacent-channel and co-channel interference, **284–286**, *285*
ERP, **273–274**, *274*
exam essentials, **287–288**
high throughput, **275**
MIMO, **278–282**, *280–281*
OFDM, **275–278**, *276*, **282–283**, *284*
overview, **262–263**
review questions, **289–292**
spread-spectrum technology, **269–273**, *271–273*
summary, **287**
WLAN/WPAN coexistence, **285–286**
monitoring
Data Link layer, **338–339**
Physical layer, **337–338**, *337*
security, **334–339**, *335–337*
WIPSs for, 330

mounting antennas, **203–206**, *205–206*
mounting hardware for manual site surveys, **399**
movable carts for manual site surveys, **400**
MPPE-128 (Microsoft Point-to-Point Encryption) Protocol, 320
MRC (maximal ratio combining), *50*, *279*
MS-CHAP, 320
multi-user MIMO (MU-MIMO), *51*, *279*
multipath
  minimizing, **200–201**, *200*
  overview, **492–493**
  RF, 139
  SISO, *50*
multiple-channel architecture (MCA), **413**, *413*
multiple-input, multiple-output (MIMO) technology
  IEEE 802.11n amendment, *50*
  overview, **278–282**, *280–281*
  RF diversity, 201
multiport injectors in PoE, *105*
municipal networks, **71**

N

names for SSIDs, 218
narrowband vs. spread-spectrum, **267–269**, *268*
near field communication (NFC) tokens, 306
Network Address Translation (NAT), **25–27**, *27*
Network Allocation Vector (NAV), *265*
Network File System (NFS), 18
Network layer in OSI model, **17**, *17*
network topologies, **7–8**
  ad hoc, **12**, *12*
  bus, **8–9**, *8*
  mesh, **10–12**, *11*
  point-to-multipoint connections, **13–14**, *14*
  point-to-point connections, **13**, *13*
  ring, **9**, *10*
  star, **10**, *11*
network types, **2–3**
  campus area networks, **5–6**, *6*
  local area networks, **3**, *3*
  metropolitan area networks, **4–5**, *5*
  personal area networks, **6–7**, *7*
  wide area networks, **3–4**, *4*
  wireless. *See* wireless local area networks (WLANs)
networking fundamentals
  device addressing, **21–27**, *21–25*, *27*
  exam essentials, **28–29**
  network topologies, **7–14**, *8*, *10–14*
  network types, **2–7**, *3–7*
  OSI model, **14–20**, *15–18*, *20*
  review questions, **30–33**
  summary, **27–28**
NFC (near field communication) tokens, 306
NFS (Network File System), 18
no protection mode, **253**
noise, RF, **163–165**, *164*
nonmember protection mode, **253–254**
Notify Technology product, 430
Novell eDirectory, 437
null frames, 228, *249*
null SSIDs, 230, *299*

O

obstacles, RF, **146**
obstruction, hidden node, **494**, *494*
OEMs (original equipment manufacturers) for operating systems, **447**
OFDM (orthogonal frequency-division multiplexing)
  co-location, **282–283**, *284*
  IEEE 802.11a amendment, 44
  overview, **275–278**, *276*
office deployments, **64**, *65*
OHA (Open Handset Alliance), 430
omnidirectional antennas
  overview, **180–183**, *181*, *183*
  placement, **199**
OmniPeek protocol analyzer, 338, 403, *404*
one-to-many NAT, 26–27
one-to-one NAT, 26
Open Directory, 437
Open Handset Alliance (OHA), 430
open system authentication, **231–232**, *232–233*, **298**
Open Systems Interconnection (OSI) model, **14**, *15*
  Application layer, **18**
  data encapsulation, **20**, *20*
  Data Link layer, **16**, *16*
  layer interaction, **18–19**
  memorization tips, **19**
  Network layer, **17**, *17*
  peer-layer communication, **19**, *20*
  Physical layer, **15**, *16*
  Presentation layer, **18**
  Session layer, **18**
  Transport layer, **17**, *18*
Opera Mobile Store, 432
operating system platforms
  mobile devices, **430–431**
  modifications and customization, **446–448**
operation modes for enterprise-grade access points, **90–91**

optimizing performance
client device load balancing, **490**, *491*
infrastructure capacity and utilization, **492**
infrastructure device redundancy, **491–492**
infrastructure hardware selection and placement, **488–489**
interference, **489**, *490*
overview, **488**
quality of service considerations, **497–498**
RF, **492–497**, *494–495*
organizationally unique identifiers (OUIs), 22
original equipment manufacturers (OEMs) for operating systems, **447**
orthogonal frequency-division multiplexing (OFDM)
co-location, **282–283**, *284*
IEEE 802.11a amendment, 44
overview, **275–278**, *276*
OSI model. *See* Open Systems Interconnection (OSI) model
OUIs (organizationally unique identifiers), 22
output power
access points, **478–479**
client devices, 495
RF signals, **146**
SOHO-grade access points, **85**
overlapping interference, 153–154, *153*
overlay technology in WIPSs, **331–333**

P

panel antennas, **184–187**, *184–187*
PANs (personal area networks)
overview, **6–7**, *7*
wireless, **36–37**
paper for manual site surveys, 400
parabolic dish antennas, **193–195**, *193*, *195*
parallel communication, 108
passive antenna gain, **176–178**, *177*
passive scanning, **228–229**, *229*
passive site surveys, **392**
passphrase-based security, **307–308**, *308*
PAT (Port Address Translation), 27, *27*
patch/panel antennas, **184–187**, *184–187*
Payment Card Industry (PCI), **339**
PBC (push-button configuration) security, 59, **306–307**, *306*
PCF (point coordination function) mode, 53, 266
PCI (Peripheral Component Interconnect standard), **112**, *112*
card installation and configuration, **113–115**, *113–114*
features, **112**
PDs (powered devices), 104, **106–107**, *107*
peer-layer communication, **19**, *20*
peer-to-peer networks, **12**, *12*, 217
pencils for manual site surveys, 400
pens for manual site surveys, 400
performance
RF, **148**
site survey considerations, **353**
troubleshooting
application, **480–488**, *482*, *484–486*
optimizing, **488–498**, *490–491*, *494–496*
Peripheral Component Interconnect standard (PCI), **112**, *112*
card installation and configuration, **113–115**, *113–114*
features, **112**
permissions for mobile devices, **436**
personal area networks (PANs)
overview, **6–7**, *7*
wireless, **36–37**
phase and phase difference, RF, **138–139**, *139*
physical addresses, 16, **21–22**, *21–22*
Physical layer
hidden nodes, **496**, *496*
monitoring, **337–338**, *337*
OSI model, **15**, *16*
Physical Layer Convergence Protocol (PLCP), 15, *16*
physical location
antenna selection, 413
size considerations, **351**
Physical Medium Dependent (PMD) layer, 15, *16*
pigtail adapter cables, 197, *197*
PIN-based configuration, *59*
PIN-based security, **304–305**, *305*
PKI (public key infrastructure), 450
planning site surveys, 373
PLCP (Physical Layer Convergence Protocol), 15, *16*
Plug and Play (PnP) feature, 113
PMD (Physical Medium Dependent) layer, 15, *16*
PoE. *See* power over Ethernet (PoE)
point coordination function (PCF) mode, 53, 266
point-of-sale (PoS) antenna installations, **371–372**
point-to-multipoint connections
overview, **13–14**, *14*
wireless, **39**, *39*
point-to-point connections
overview, **13**, *13*
wireless, **38–39**, *39*
Point-to-Point Tunneling Protocol (PPTP), **320**
polarization of antennas, **178–180**, *179*, 412
pole/mast antenna mounts, **205**, *205*

policies in mobile device management
acceptable use, **445**
backup, restore, and recovery, **445–446**
consultants, **453**
corporate-owned mobile devices, **452**
employee-owned mobile device, **452–453**
general, **442–443**
group, **451–453**, *451*
information technology, **443–444**, *444*
testing, **453–454**
usability issues, **445**
POP3 (Post Office Protocol v3), **18**
Port Address Translation (PAT), 27, *27*
portable battery packs, **399**
portals
captive, *63*, **100–101**, **334**, **440–441**
self-service, **441–442**
PoS (point-of-sale) antenna installations, **371–372**
post-deployment site surveys, **403**
Post Office Protocol v3 (POP3), **18**
power
budgets, 107
requirements, **366–368**
RF, **158–162**, *160*
power over Ethernet (PoE)
benefits, **107**
design considerations, 361
limitations, **415**
overview, **104–105**, *104*
power sourcing equipment, **105–106**
powered devices and classification signatures, **106–107**, *107*
WLAN controllers, **99**
power save operations, **249–251**, *250*
power save (PS) mode, **250–251**, *250*
power sourcing equipment (PSE), **104–106**
powered devices (PDs), 104, **106–107**, *107*
PPTP (Point-to-Point Tunneling Protocol), **320**
predictive modeling site surveys
process, **400–402**
tools, **101**
Presentation layer in OSI model, **18**
private IP addresses, 23, 26
probe requests, 230, *231*
problems. *See* troubleshooting
profiles
corporate-owned mobile devices, **452**
employee-owned mobile devices, **452–453**
technology, **448–451**, *449*
testing, **453–454**
WLAN, **100**
propagation of RF signals, **146**
proprietary connectors, 198
protection mechanisms, **251–254**
protocol analyzers
common, **338–339**
installing, **405–409**, *406–409*
overview, **403–405**, *404*
protocols, defined, 469
PS-Poll frames, 250
PS (power save) mode, **250–251**, *250*
PSE (power sourcing equipment), **104–106**
public access environments, antenna use considerations in, **372**
public IP addresses, 23, 26
public key infrastructure (PKI), 450
public wireless hotspots (public Wi-Fi) and hospitality deployments, **62–63**, *63*
purpose of information technology policies, 444
push-button configuration (PBC) security, 59, **306–307**, *306*
pushing content to mobile devices, **435–436**

Q

QAM (Quadrature Amplitude Modulation), 51
QoS null frames, 228
quality of service (QoS)
design considerations, 361
IEEE 802.11e amendment, 53
optimization considerations, **497–498**
WLAN controllers, **102**

R

radio frequency (RF)
amplitude, **138**, *138*
cables, **195–197**, *196–197*
channels, **141–143**, **220**, *220*
coverage and capacity
antenna planning, 412
application types, **145–146**
business requirements, 356
capacity overview, **146–147**
channel reuse and device co-location, **149–150**, *149–150*
coverage overview, **144–145**
design, 359
device and user effects, **148–149**
hardware and output power, **146**
overview, **143–144**, *145*
physical size of area, **145**
planning, **410**
requirements, **369**
site surveys, 373–374
software and hardware applications, **147–148**
throughput, **148**

device troubleshooting, **464**, *465*
exam essentials, **167**
frequency, **137–138**, *137*
frequency bands, **139–143**
hidden nodes, **493–497**, *494–497*
interference
adjacent channel and co-channel, **152–154**, *153–154*
environment issues, **155–158**, *155–158*
overview, **152**
WLAN/WPAN, **154**
line of sight, **150–152**, **207**
lobes, **173–174**, *173*
measurement units
overview, **158**
power, **158–162**, *160*
signal, **162–165**, *163–164*, *166*
multipath, **492–493**
noise, **163**, *164*
overview, **133–134**, *134–135*
phase, **138–139**, *139*
range and speed, **143**, **150–152**, *151*
review questions, **168–170**
SOHO-grade access point cells, 85
spectrum analysis, **375–377**, *376–377*
spectrum management, **101**
summary, **166–167**
wavelength, **136–137**, *136*
weak signals, **476**, *476*
radio frequency identification (RFID), 438
radio hardware, **108**
RADIUS (Remote Authentication Dial-In User Service) authentication
enterprise-grade access points, 89
overview, **309–312**, *309*, *311–312*
WLAN controllers, **101**
radome covers, 187, 193
RAID (Redundant Array of Inexpensive Disks), **436–437**
range, RF, **150–152**, *151*
range extenders, **97–98**, *97*
RBAC (role-based access control), **317–318**
reassociation of frames, 248
received signal strength as design consideration, **385–386**, *386*
received signal strength indicator (RSSI)
description, 386
overview, **165**, **473–474**, *474*
testing, **475**, *475*
receivers
radio transmissions, 134, *135*
sensitivity measurements, **162–163**, *163*
troubleshooting, **464**, *465*
recovery policies, **445–446**
Red Hat Directory Server, 437
redundancy
infrastructure devices, **102**, **491–492**
mobile device management, **436–437**
Redundant Array of Inexpensive Disks (RAID), **436–437**
reflection
multipath, **200–201**, *200*
RF signals, **155**, *155*
refraction of RF signals, **156**, *156*
regulatory authorities, **40–42**, *40*
regulatory compliance
antenna selection, 413
industry, **339–340**
WIPSs for, 330
relative measurements of RF power, **160–162**, *160*
remote access points, **94**
Remote Authentication Dial-In User Service (RADIUS) authentication
enterprise-grade access points, 89
overview, **309–312**, *309*, *311–312*
WLAN controllers, **101**
remote-MAC architecture, 81, 92–93
Remote Procedure Call Protocol (RPC), 18
removable antennas
enterprise-grade access points, **89**
SOHO-grade access points, **85**
repeaters
enterprise-grade access points, **90–91**
SOHO-grade access points, **86**
wireless, **97–98**, *97*
reports
site surveys, **415–417**, *416*
WIPSs for, 330
Request to Send/Clear to Send (RTS/CTS) process, 252–253, 497
restore policies, **445–446**
retail installations, antenna use considerations in, **371–372**
revisions of information technology policies, 444
RF. *See* radio frequency (RF)
RFID (radio frequency identification), 438
ring topology, **9**, *10*
ripple effect, 283
roaming
design considerations, 361
overview, **247–249**, *248–249*
WLAN controllers, **100**
robust security networks (RSNs), 232, 304
role-based access control (RBAC), **317–318**
root access point mode, 90
routers, wireless branch, **94**
RPC (Remote Procedure Call Protocol), 18
RSNs (robust security networks), 232, 304

RSSI (received signal strength indicator)
description, 386
overview, **165**, **473–474**, *474*
testing, **475**, *475*
RTS/CTS (Request to Send/Clear to Send) process, 252–253, 497
rubber duck antennas, 181, *181*, 183, *183*

S

S1G (Sub 1 GHz) band, 137
SaaS (Software as a Service) solutions, **428**
safety in antenna installation, **203**
Samsung Store, 432
SANs (storage area networks), 2
SAP/Sybase product, 430
SCA (single-channel architecture), **414**, *414*
scalability of IBSSs, 222
scattering RF signals, **157**, *157*
school deployments, **64–66**, *66*
scope of information technology policies, 444
sector antennas, 188–190, *188*, *190*
security
AAA, **312–313**
authentication and encryption, **302–304**
captive portals, **334**
connectivity issues from, 469, **472–473**, *473*
design considerations, 361
EAP, **310–312**, *311–312*
early methods, **298–300**, *300–301*
encryption, **314–317**, *315–316*
enterprise-grade access points, **89**
exam essentials, **341–342**
IBSSs, **221–222**
industry regulatory compliance, **339–340**
MAC addresses, **300–302**, *301*
management and monitoring systems, **334–339**, *335–337*
mobile device management, **442–443**
overview, **294–295**
RADIUS, **309–312**, *311–312*
RBAC, **317–318**
review questions, **343–346**
SOHO and enterprise, **304–307**, *305–306*
SOHO-grade access points, **86**
standard, **297–298**
summary, **340–341**
threats and intrusion, **295–297**, *296*
VPNs, **318–328**, *318–319*, *321–328*
WIPSs, **328–333**, *329*, *331–333*
wireless hotspots, 63
WLAN controllers, **100–101**
WPA and WPA2, **307–308**, *308*
self-service portals, **441–442**
semidirectional antennas, **184**
patch/panel, **184–187**, *184–187*
placement, **199–200**
sector, 188–190, *188*, *190*
uses, 185–186, *185–186*
Yagi, **190–193**, *192*
Sencha product, 430
sensors in WIPSs, **332–333**, *333*
serial communication, 108
service set identifiers (SSIDs)
captive portals, 441
client side connectivity, 468
vs. ESSIDs and BSSIDs, **226**
extended service sets, 225
hiding, **53–54**, 219, **299–300**, *300*
IBSSs, **218–220**, *218–219*
wireless access points, 80
wireless network discovery, 230
Session layer in OSI model, **18**
shared-key authentication, **233–235**, *234–235*, **298**
shared media, 148
signal measurements and strength
hidden nodes, **495**, *495*
RF, **162–165**, *163–164*, *166*
transitioning, 248
signal-to-noise ratio (SNR), **165**, 386
signaling methods in hidden nodes, **496**, *496*
sine waves, 134, *135*
Singapore, RF regulations in, 140
single-channel architecture (SCA), **414**, *414*
single-input, single-output (SISO) technology
description, 278–279
IEEE 802.11n amendment, 50
RF diversity, 201
single-port injectors in PoE, 105
site surveys
building age and construction materials, **355**
BYOD acceptance, **354**, *355*
device capabilities, **352–353**
environment, **353**
hybrid approach, **402**
infrastructure devices, **355–356**
intended use considerations, **351–352**
location size, **351**
manual. *See* manual site surveys
number of devices, **352**
overview, **349–351**
performance expectations, **353**
post-deployment, **403**
predictive modeling, **101**, **400–402**
process, **374–375**
reports, **415–417**, *416*
steps, **372–374**

size of physical location, **351**
SM (spatial multiplexing), 50, 276, 279
small office/home office (SOHO) deployments
  overview, **60**, *61*
  security, **304–307**, *305–306*
Sniffer protocol analyzer, 403
SNR (signal-to-noise ratio), **165**, 386
Software as a Service (SaaS) solutions, **428**
software-assisted manual site surveys, **392**, *393*
software upgrades for client devices, **481–487**, *482*, *484–486*
SOHO-grade access points, **83–87**, *83–84*, *87*
SOHO (small office/home office) deployments
  overview, **60**, *61*
  security, **304–307**, *305–306*
SOTI product, 430
space-time block coding (STBC), 50
spanning in SCA networks, 414
spatial multiplexing (SM), 50, 276, 279
spatial streams, 51
spectrum analysis and analyzers
  design, **375–377**, *376–377*
  interference, **489**, *490*
  manual site surveys, 398
  Physical layer monitoring, 337, *337*
  process, **379–383**, *379–383*
  site surveys, 373
Spectrum XT spectrum analyzer, 338
speed
  connections, 367
  RF, **150–152**, *151*
split-MAC architecture, 81, 92
spoofing MAC addresses, **302**
spread-spectrum technology
  DSSS, **270–271**, *271*
  FHSS, **269**
  HR/DSSS, **271–273**, *272–273*, **282–283**
  vs. narrowband, **267–269**, *268*
spreading code technology, 270
SSIDs. *See* service set identifiers (SSIDs)
STA (stations)
  extended service sets, 224
  wireless access points, 80
stacking in SCA networks, 414
stakeholders, interviewing, **358–362**, *358*, *360*
star topology, **10**, *11*
static output transmit power, **85**
stations (STA)
  extended service sets, 224
  wireless access points, 80
STBC (space-time block coding), 50
storage area networks (SANs), 2
Sub 1 GHz (S1G) band, 137
subcarriers in DSSS, 270
SuperSpeed USB, 109
supplicants for client devices, 122, 309
Symantec MDM product, 430
Systems Manager NMS, 336

T

Taiwan, RF regulations in, 140
TamoGraph Site Survey tool, 402
target beacon transmission time (TBTT), 230
TCP (Transmission Control Protocol)
  logical addresses, 23
  OSI model, 17
TDoA (time difference of arrival), 439
technical components in mobile device management security, 443
technology profiles in mobile device management, **448–451**, *449*
telecommunications expense management, **440**
television channels, 141
Temporal Key Integrity Protocol (TKIP), **315–316**, *315*
temporary classrooms, 66
10s and 3s Rule, **160**
testing
  access point placement, **390–391**, *390*
  antennas, **411–413**, *411*
  mobile device management policies, **453–454**
  RSSI, **475**, *475*
thin access points, 81
third-party client utilities, **123**, *123*
threats and intrusion
  overview, **295–297**, *296*
  WIPSs for, 330
3s and 10s Rule, **160**
throughput
  high throughput, **275**
  IEEE 802.11g/n networks, **48**
  measuring, **241–246**, *242–246*
  overview, **240–241**, *240*
  RF, **148**
  troubleshooting, **477–480**, *478*, *480*
  wireless repeaters, 98
time difference of arrival (TDoA), 439
timelines for site surveys, 373
TKIP (Temporal Key Integrity Protocol), **315–316**, *315*
Token Ring technology, 9
toolkits for manual site surveys, **398–400**

topologies. *See* network topologies
torus pattern in omnidirectional antennas, 180, *181*
transceivers, 134, *135*
transitioning
  overview, **247–249**, *248–249*
  WLAN controllers, **100**
translational bridges, 237
Transmission Control Protocol (TCP)
  logical addresses, 23
  OSI model, 17
transmit beamforming (TxBF), 50, 279
transmit power
  enterprise-grade access points, **89**
  SOHO-grade access points, **85**
transmitters
  radio transmissions, 134, *135*
  troubleshooting, **464**, *465*
Transport layer in OSI model, **17**, *18*
transportation networks, **71**
troubleshooting
  bus topology, **9**
  connectivity, **465**
    client-side, **466–468**, *466–468*
    intermittent, **473–476**, *474–476*
    IP addresses, **469–472**, *469–472*
    security issues, **472–473**, *473*
  exam essentials, **499**
  overview, **462**
  performance
    application, **480–488**, *482*, *484–486*
    optimizing, **488–498**, *490–491*, *494–496*
  problem identification, **462–464**, *463*
  review questions, **500–503**
  summary, **498–499**
  throughput, **477–480**, *478*, *480*
  transmitters and receivers, **464**, *465*
tunneling
  L2TP, **320**
  PPTP, **320**
256-QAM, 51
TxBF (transmit beamforming), 50, 279

U

UDP (User Datagram Protocol)
  logical addresses, 23
  OSI model, 17
Ultra High Security Password Generator, 307
UNII band. *See* Unlicensed National Information Infrastructure (UNII) band
United States
  RF regulations, 140
  unlicensed frequency bands, **140–141**
Universal Serial Bus (USB) devices
  features, **109**
  installation and configuration, **110–111**, *110–111*
  overview, **108–109**, *109*
unlicensed frequency bands, **140–141**
Unlicensed National Information Infrastructure (UNII) band
  frequency bands, **140–141**
  IEEE 802.11a amendment, **44–45**
  IEEE 802.11n amendment, 50
  OFDM, **276–278**
  RF channels, **143**
  WLANs, 37
upfade, 139
upgrades of client devices, *482*
  hardware, **487–488**
  software, **481–487**, *484–486*
USB (Universal Serial Bus) devices
  features, **109**
  installation and configuration, **110–111**, *110–111*
  overview, **108–109**, *109*
USB-IF (USB Implementers Forum), 109
USB Implementers Forum (USB-IF), 109
user-based security, 308
User Datagram Protocol (UDP)
  logical addresses, 23
  OSI model, 17

V

VDC (volts of direct current) in PoE, 104
vendor-default device applications, **447–448**
vendors, operating systems from, **446–447**
vertical polarized antennas, 178, *179*
Very High Throughput (VHT), 51
video communications, design considerations for, 361
virtual local area networks, **99–100**
virtual private networks (VPNs)
  components, **320–322**, *321*
  L2TP, **320**
  overview, **318–319**, *318–319*
  PPTP, **320**
  setting up, **322–328**, *322–328*
  wireless hotspots, 63
visitors in mobile device management, **453**
VisiWave - AZO Technologies tool, 402
visual line of sight (LoS)
  antennas, **207**
  radio frequency, **150–152**
VMware AirWatch product, 429

voice over IP (VoIP) technology, 54
Voice over Wireless LAN (VoWLAN) technology, 148
voltage in in power formula, 159
voltage standing wave ratio (VSWR), **196–197**
volts of direct current (VDC) in PoE, 104
VPNs. *See* virtual private networks (VPNs)
VSWR (voltage standing wave ratio), **196–197**

W

wall mounts for antennas, **206**
walled gardens, **440–441**
WANs (wide area networks)
  overview, **3–4**, *4*
  wireless, **38**
WAPs. *See* wireless access points (WAPs)
warehousing environments, 371
watts
  absolute measurements of RF power, **158–159**
  relative measurements of RF power, **160–162**, *160*
wavelength, **136–137**, *136*
WDS (wireless distribution system)
  enterprise-grade access points, 91
  IEEE 802.11s amendment, *55*
weak RF signals, **476**, *476*
web browsing, **18**
WECA (Wireless Ethernet Compatibility Alliance), *56*
WEP. *See* Wired Equivalent Privacy (WEP)
Wi-Fi Alliance
  enterprise-grade access interoperability certifications, **89**
  overview, **56**, *56*
  SOHO-grade access interoperability certifications, **85**
Wi-Fi HaLOW, 137
Wi-Fi Multimedia (WMM)
  certification, **58**
  IEEE 802.11e amendment, *53*
  jitter, 498
Wi-Fi Multimedia Power Save (WMM-PS) certification, **58**
Wi-Fi Protected Access (WPA), **56–57**, **307–308**, *308*
Wi-Fi Protected Access (WPA) 2, **57**, **307–308**, *308*
Wi-Fi Protected Setup (WPS) certification, **58–59**, *305*
Wi-Spy spectrum analyzer, *377*
wide area networks (WANs)
  overview, **3–4**, *4*
  wireless, **38**
WiFi Analyzer, 338, 403
wildcard SSIDs, 230, 299
wind effects, **201–203**, *202*
Windows Phone operating system, **431**
Windows Phone Store, 432
Windows Registry for MAC addresses, 302
Wired Equivalent Privacy (WEP)
  authentication, **233–234**
  encryption, **314**
  IEEE 802.11i amendment, **53–54**
  security issues, 100, **303–304**
wireless access points (WAPs)
  antenna selection, 412–413
  autonomous, **82–87**, *83–84*, *87*
  capacity, **146–148**
  connectivity, **102–103**, *103*
  distance issues, **477**, *478*
  hidden nodes, **494–495**
  limitations, 414–415
  loading, **479**
  manual site surveys, 398
  mesh topology, 12
  overview, **80–81**, *81*
  placement, **390–391**, *390*
  redundancy, **492**
  RF output power, **478–479**
  wireless mesh, **95–96**, *95*
wireless branch routers, **94**
wireless bridges, **96**, *96*
wireless distribution system (WDS)
  enterprise-grade access points, 91
  IEEE 802.11s amendment, *55*
Wireless Ethernet Compatibility Alliance (WECA), *56*
wireless hotspots, **62–63**, *63*
wireless Internet service providers (WISPs), 62, **69–70**, *70*
wireless intrusion prevention systems (WIPSs)
  configuration and maintenance, **330–331**, *331*
  enterprise-grade access points, 89
  overlay and integrated technology, **331–333**, *332–333*
  overview, **328–330**, *329*
  WLAN controllers, 102
wireless local area networks (WLANs), **36–38**
  communications. *See* communications
  connectivity, **38–39**, *39*

deployment scenarios, **59–60**
educational institutions, **64–66**, *66*
enterprise, **61–62**, *62*
healthcare, **67–69**, *69*
high-density, **70**
industrial, **67**, *68*
last-mile data delivery, **69–70**, *70*
municipal, law enforcement, and transportation networks, **71**
office, **64**, *65*
public wireless hotspots and hospitality, **62–63**, *63*
small office/home office, **60**, *61*
exam essentials, **72**
existing network extensions, **62**
hardware controllers, **98–103**, *103*
IEEE. *See* IEEE
interference, **154**
interoperability certifications, **55–59**, *56*
regulatory authorities, **40–42**, *40*
review questions, **73–76**
RF. *See* radio frequency (RF)
summary, **71–72**
WPAN coexistence, **285–286**
wireless mesh distribution systems, 238, *238*
wireless mesh networks, **95–96**, *95*
wireless metropolitan area networks (WMANs), **37–38**
wireless network discovery, **228–231**, *229–231*
wireless network management system (WNMS), **334–337**, *336*
wireless personal area networks (WPANs)
interference, **154**
overview, **36–37**
WLAN coexistence, **285–286**
wireless point-to-multipoint connections, **39**, *39*
wireless point-to-point connections, **38–39**, *39*
wireless repeaters, **97–98**, *97*
wireless wide area networks (WWANs), **38**
wireless workgroup bridges (WWBs)
features, **119**
installation and configuration, **120**, *120*
overview, **118–119**, *119*
wiring closets, **366–367**
WISPs (wireless Internet service providers), 62, **69–70**, *70*
WLAN AutoConfig utility, 123
WLAN Coverage Estimator program, 402
WLANs. *See* wireless local area networks (WLANs)
WMANs (wireless metropolitan area networks), **37–38**
WMM-PS (Wi-Fi Multimedia Power Save) certification, **58**
WMM (Wi-Fi Multimedia)
certification, **58**
IEEE 802.11e amendment, 53
jitter, 498
WNMS (wireless network management system), **334–337**, *336*
World Wide Web (WWW) service logical addresses, 23
Worldwide Interoperability for Microwave Access (WiMAX), **37–38**
WPA (Wi-Fi Protected Access), **56–57**, **307–308**, *308*
WPA (Wi-Fi Protected Access) 2, **57**, **307–308**, *308*
WPANs (wireless personal area networks)
interference, **154**
overview, **36–37**
WLAN coexistence, **285–286**
WPS (Wi-Fi Protected Setup) certification, **58–59**, 305
WWANs (wireless wide area networks), **38**
WWBs (wireless workgroup bridges)
features, **119**
installation and configuration, **120**, *120*
overview, **118–119**, *119*

X

Xirrus Management System - Cloud (XMS-Cloud), 336
Xirrus Wi-Fi Inspector, 475
XOR (exclusive OR) process in DSSS, 270

Y

Yagi antennas, **190–193**, *192*
Yellowjacket-BAND Wi-Fi Analyzer, 403

Z

zero license controllers, 491

Comprehensive Online Learning Environment

Register to gain access to the online interactive learning environment and test bank to help you study for your CWTS certification - included with your purchase of this book!

The online tool includes:

- **Assessment Test** to help you focus your study to specific objectives
- **Chapter Tests** to reinforce what you learned
- **Practice Exams** to test your knowledge of the material
- **Electronic Flashcards** to reinforce your learning and provide last-minute test prep before the exam
- **Searchable Glossary** gives you instant access to the key terms you'll need to know for the exam

Register and Access the Online Test Bank

To register your book and get access, you will need to follow these steps:

1. Go to `bit.ly/SybexTest`.
2. Select your book from the list
3. Complete the required information including answering the security verification proving book ownership
4. You will be emailed a pin code. Go to `http://www.wiley.com/go/sybextestprep` and find your book on that page and click the "Register or Login" link under your book.
5. If you already have an account at `testbanks.wiley.com`, login and then click the "Redeem Access Code" button to add your new book with the pin code you received. If you don't have an account already, create a new account and use the PIN code you received.

SYBEX®
A Wiley Brand

WILEY END USER LICENSE AGREEMENT

Go to www.wiley.com/go/eula to access Wiley’s ebook EULA.