00 CCNA Exam_FM.fm Page i Thursday, March 7, 2002 11:43 AM

CCNA Exam 640-607 Certification Guide

Wendell Odom, CCIE #1624

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00 CCNA Exam_FM.fm Page ii Thursday, March 7, 2002 11:43 AM

CCNA Exam 640-607 Certification Guide

Wendell Odom
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00 CCNA Exam_FM.fm Page iii Thursday, March 7, 2002 11:43 AM

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00 CCNA Exam_FM.fm Page iv Thursday, March 7, 2002 11:43 AM

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00 CCNA Exam_FM.fm Page v Thursday, March 7, 2002 11:43 AM

Dedications

To the little boys and girls of our Cisco Press team who missed seeing their daddies for the final month it took to plow through the updates for this edition: I pray a blessing of more time with your daddies the next time we change the book! For my precious Hannah Grace, and for Matthew Christopher Cleveland, I thank you for your sacrifices!

Acknowledgments

I can write a 1000-page book, but I can't find enough words to describe the credit Chris Cleveland deserves for what is good about this book. Michael Jordan, Wayne Gretsky, Chris Cleveland—a list of the absolutely best at what they do! Chris, thanks for putting up with the hand-drawn figures, for meeting my schedule requirements, and for working hard during the holidays. Your ability to edit my style of writing and revising makes my job a breeze. I still refuse to write a book unless you develop it!

Brett Bartow steered the project as executive editor. In his usual unflappable way, he dealt with all the planning and changes with content issues, business issues, and the flow of information to us from Cisco—without ever getting rattled. In the process of hurry up and wait, and then really hurry up, Brett provided calm. Thanks for that, Brett!

For Tammi Ross, who handles a lot of the administrative tasks, thanks for handling things quickly and correctly. It's great to ask for something at a moment's notice, and things happen, no problems!

Behind the scenes at Cisco Press is a vast array of talented people—all of whom are shielded from us authors by the development editor, who was Chris Cleveland again in my case. These are people who take figure changes with scribbled notes and make something meaningful and nice-looking out of them. People who fix my English—I never made an A in an English class in high school or college! People who do the meticulous tasks that make the whole book come together—making sure figures fit on the same page as the text that refers to them, making sure the index is complete and accurate, and the like. I have the easy job in this arrangement. Many thanks to you all for the hard and good work!

The technical editors deserve most of the credit for making the content of this book robust and complete. Even with this third edition of the book, I am constantly amazed at what happens when talented technical editors take the time to really read through the material. Brett lined up the "first team" again, with three editors returning from the last edition—David Barnes, Steve Kalman, and Barb Nolley. Tim Faulk joined us for the first time, bringing his perspective from teaching CCNA classes at a university. All the credit for technical errors in this book lies with me, and all credit for the reduction of technical errors lies with these technical editors. But more importantly, they get credit for their input on improving sections, rewording phrases to clarify information, for finding better ways to describe how the technical pieces fit together, for fixing errors when there was a disconnection between my brain and what I wrote, and yes, even for finding errors in subnetting examples—and so much more. Without you, this book simply wouldn't be nearly as good or as accurate. Many thanks to you for that.

00 CCNA Exam_FM.fm Page vi Thursday, March 7, 2002 11:43 AM

Finally, my boss at Skyline Computer, Mike Zanotto (a.k.a. Mike Z), Managing Director, helped this project by letting me schedule the new CCIE Skylabs remote lab offering to go live the same day I had to have this book's manuscript completed! Seriously, Z always helped by finding a way to give me the time I needed to work on this book and by making sure the job was fun. Thanks, Mike!

Finally, no acknowledgments section could be complete without acknowledging my wife, Kris, who took on all the duties at home with our 7-month-old child during the last month of getting this edition written. She was a trouper, sacrificing without being asked. Thank you so much, my love! Finally, to Jesus Christ, who gives us strength when things are tough, and peace beyond belief—thank you.

00 CCNA Exam_FM.fm Page vii Thursday, March 7, 2002 11:43 AM

Contents at a Glance

Chapter 1 All About the Cisco Certified Network Associate Certification 3

Chapter 2 Cisco IOS Software Fundamentals 27

Chapter 3 OSI Reference Model and Layered Communication 79

Chapter 4 LANs, Bridges, and Switches 145

Chapter 5 Intermediate LANs: Spanning Tree, VLANs, and Trunking 215

Chapter 6 TCP/IP and IP Routing 267

Chapter 7 Routing and Routing Protocols 407

Chapter 8 Understanding Access List Security 489

Chapter 9 WAN Protocols and Design 533

Chapter 10 Frame Relay Concepts and Configuration 605

Chapter 11 Novell IPX 677

Chapter 12 Scenarios for Final Preparation 759

Chapter 13 Hands-on Lab Exercises 823

Appendix A Answers to the "Do I Know This Already?" Quizzes and Q&A Sections 851

Appendix B Decimal to Hexadecimal and Binary Conversion Table 933

Appendix C Subnetting Practice: 25 Subnetting Questions 943

Appendix D Hands-on Lab Exercises: Solutions (included in PDF format on the CD for this book)

Index 991

00 CCNA Exam_FM.fm Page viii Thursday, March 7, 2002 11:43 AM

Table of Contents

Chapter 1 All About the Cisco Certified Network Associate Certification 3

Overview of Cisco Certifications 4
Exams Required for Certification 6
Other Cisco Certifications 7

What's on the CCNA Exam 8

Cross-Reference Between Exam Topics and Book Chapters 16

Cross-Reference Between Chapter and Exam Topics 17

Recommended Training Paths for CCNA 17

How to Use This Book to Pass the Exam 19
I've Taken ICND—Now What? 22
I've Taken the Cisco Networking Academy Courses—Now What? 22
I'm New to Internetworking with Cisco, I Will Not Be Taking the ICND Course, and This Book Is My Only Reference—Now What? 23
I'm New to Internetworking with Cisco, I Will Not Be Taking the ICND Course, and I Bought the Interconnecting Cisco Network Devices Book as Well—Now What? 24
I've Learned a Lot About CCNA Topics Through Experience, but I Will Not Be Taking the ICND Course—Now What? 24

Conclusion 24

Chapter 2 Cisco IOS Software Fundamentals 27

How to Best Use This Chapter 27

"Do I Know This Already?" Quiz 28

The Cisco IOS Software Command-Line Interface 32
Access to the CLI 32
CLI Help Features 35
Syslog and debug 37

Configuring Cisco IOS Software 39
Example Configuration Process 40
Router Memory, Processors, and Interfaces 43
Managing Configuration Files 44

00 CCNA Exam_FM.fm Page ix Thursday, March 7, 2002 11:43 AM

Upgrading Cisco IOS Software and the Cisco IOS Software Boot Process 50
Upgrading an IOS Image into Flash Memory 50
The Cisco IOS Software Boot Sequence 53

Scenario 2-1 70
Questions on Scenario 2-1 71

Scenario 2-2 72
Questions on Scenario 2-2 72

Scenario 2-1 Answers 75

Scenario 2-2 Answers 76

Chapter 3 OSI Reference Model and Layered Communication 79

How to Best Use This Chapter 79

"Do I Know This Already?" Quiz 80

OSI: Concepts, Layers, and Encapsulation 84
OSI Reference Model: Origin and Evolution 84
OSI Layers 85
Layering Concepts and Benefits 89
Interaction Between OSI Layers 90
Data Encapsulation 94
The TCP/IP and NetWare Protocols 97

OSI Transport Layer Functions 98
Connection-Oriented Versus Connectionless Protocols 98
Error Recovery 99
Flow Control 102

OSI Data Link Layer Functions 105
Data Link Function 1: Arbitration 106
Data Link Function 2: Addressing 107
Data Link Function 3: Error Detection 109
Data Link Function 4: Identifying the Encapsulated Data 109
Summary: Data Link Functions 113

OSI Network Layer Functions 114
Routing 114
Network Layer (Layer 3) Addressing 118

Scenario 3-1 136
Task 1 for Scenario 3-1 137
Task 2 for Scenario 3-1 138
Task 3 for Scenario 3-1 138

00 CCNA Exam_FM.fm Page x Thursday, March 7, 2002 11:43 AM

Answers to Task 1 for Scenario 3-1 139

Answers to Task 2 for Scenario 3-1 139

Answers to Task 3 for Scenario 3-1 141

Chapter 4 LANs, Bridges, and Switches 145

How to Best Use This Chapter 145

"Do I Know This Already?" Quiz 146

LAN Overview 150
- 10-Mbps Ethernet 151
- LAN Addressing 157
- LAN Framing 158
- Fast Ethernet and Gigabit Ethernet 161
- LAN Standards 162
- Bridging and Switching 164
- Transparent Bridging 165
- LAN Switching 170
- Comparison of LAN Segmentation Using Bridges, Switches, and Routers 175

LAN Switch Configuration 178
- Basic 1900 Switch Configuration 179

Scenario 4-1: LAN Switch Configuration 203

Scenario 4-2: LAN Switch Concepts 204

Answers to Scenario 4-1: LAN Switch Configuration 206

Answers to Scenario 4-2: LAN Switch Concepts 210

Chapter 5 Intermediate LANs: Spanning Tree, VLANs, and Trunking 215

How to Best Use This Chapter 216

"Do I Know This Already?" Quiz 216

Spanning-Tree Protocol 220
- What Spanning Tree Does 222
- How Spanning Tree Works 223
- Spanning-Tree Protocol Summary 229

Virtual LANs 230
- VLAN Trunking Protocol (VTP) 237

00 CCNA Exam_FM.fm Page xi Thursday, March 7, 2002 11:43 AM

VLAN and Trunking Configuration 240
Basic VLAN Configuration 241

Scenario 5-1: LAN Switch Configuration 257

Answers to Scenario 5-1: LAN Switch Configuration 257

Chapter 6 TCP/IP and IP Routing 267

How to Best Use This Chapter 267

"Do I Know This Already?" Quiz 268

TCP/IP Protocols 272
Overview of a Sample TCP/IP Network 272
Transmission Control Protocol 277
User Datagram Protocol 284
Address Resolution Protocol 286
Internet Control Message Protocol 287
FTP and TFTP 294

IP Addressing and Subnetting 296
IP Addressing and Subnetting 297
Four Steps to Answering IP Addressing Questions 309
CIDR, Private Addressing, and NAT 337

IP Configuration 342
Using Secondary Addresses 355
IP Addressing with Frame Relay Subinterfaces 357
MTU and Fragmentation 360
IP Naming Commands and Telnet 361
Default Routes and the ip classless Command 365
Cisco Discovery Protocol 370

Scenario 6-1: IP Addressing and Subnet Calculation 393

Scenario 6-2: IP Subnet Design with a Class B Network 396

Scenario 6-3: IP Subnet Design with a Class C Network 397

Answers to Scenario 6-1: IP Addressing and Subnet Calculation 398

Answers to Scenario 6-2: IP Subnet Design with a Class B Network 399
Answers to Task 1 for Scenario 6-2 399
Answers to Task 2 for Scenario 6-2 400
Answers to Task 3 for Scenario 6-2 401

00 CCNA Exam_FM.fm Page xii Thursday, March 7, 2002 11:43 AM

Answers to Scenario 6-3: IP Subnet Design with a Class C Network 402
Answers to Task 1 for Scenario 6-3 402
Answers to Task 2 for Scenario 6-3 403
Answers to Task 3 for Scenario 6-3 404

Chapter 7 Routing and Routing Protocols 407

How to Best Use This Chapter 407

"Do I Know This Already?" Quiz 408

Distance Vector Routing Protocols 412
Overview of Routing Protocols 413
Distance Vector Routing Protocol Behavior 416

Configuring RIP and IGRP 429
Basic RIP and IGRP Configuration 430
Advanced RIP and IGRP Configuration 439
Troubleshooting Routing and Routing Protocols 453

Scenario 7-1: IP Configuration 1 471

Scenario 7-2: IP Configuration 2 472

Scenario 7-3: IP Addressing and Subnet Derivation 474

Answers to Scenario 7-1: IP Configuration 1 480
Answers to Task 1 for Scenario 7-1 480
Answers to Task 2 for Scenario 7-1 481
Answers to Task 3 for Scenario 7-1 481
Answers to Task 4 for Scenario 7-1 482
Answers to Task 5 for Scenario 7-1 482

Answers to Scenario 7-2: IP Configuration 2 483
Answers to Task 1 for Scenario 7-2 483
Answers to Task 2 for Scenario 7-2 484
Answers to Task 3 for Scenario 7-2 484
Answers to Task 4 for Scenario 7-2 485

Answers to Scenario 7-3: IP Addressing and Subnet Derivation 485
Answers to Task 1 for Scenario 7-3 485
Answers to Task 2 for Scenario 7-3 486
Answers to Task 3 for Scenario 7-3 486

Chapter 8 Understanding Access List Security 489

How to Best Use This Chapter 489

"Do I Know This Already?" Quiz 490

00 CCNA Exam_FM.fm Page xiii Thursday, March 7, 2002 11:43 AM

Standard IP Access Lists 494
Standard IP Access List Configuration 498

Extended IP Access Lists 503
Extended IP Access Lists: Example 1 506
Extended IP Access Lists: Example 2 508
Extended IP Access Lists: Example 3 508

Named IP Access Lists 512
Controlling vty Access with IP Access Lists 515
IP Access List Summary 516

Scenario 8-1: IP Filtering Sample 1 527

Scenario 8-2: IP Filtering Sample 2 528

Scenario 8-3: IP Filtering Sample 3 528

Answers to Scenario 8-1: IP Filtering Sample 1 529

Answers to Scenario 8-2: IP Filtering Sample 2 529

Answers to Scenario 8-3: IP Filtering Sample 3 530

Exam Topics in This Chapter 532

Chapter 9 WAN Protocols and Design 533

How to Best Use This Chapter 533

"Do I Know This Already?" Quiz 534

Point-to-Point Leased Lines 538
HDLC and PPP Configuration 541
WAN Cabling Standards 546

ISDN Protocols and Design 548
ISDN Channels 548
ISDN Protocols 549
ISDN Function Groups and Reference Points 551

Typical ISDN Configurations 555
PAP and CHAP 557
Multilink PPP 558
Dial-on-Demand Routing 560

Comparison of WAN Options 571

Scenario 9-1: Point-to-Point Verification 591

Scenario 9-2: Point-to-Point Configuration 597

00 CCNA Exam_FM.fm Page xiv Thursday, March 7, 2002 11:43 AM

Answers to Scenario 9-1: Point-to-Point Verification 600

Answers to Scenario 9-2: Point-to-Point Configuration 601

Chapter 10 Frame Relay Concepts and Configuration 605

How to Best Use This Chapter 605

"Do I Know This Already?" Quiz 606

Frame Relay Protocols 609
- Virtual Circuits 612
- LMI and Encapsulation Types 614
- DLCI Addressing Details 616
- Network Layer Concerns with Frame Relay 621

Frame Relay Configuration 627
- Fully-Meshed Network with One IP Subnet/IPX Network 629
- Partially-Meshed Network with One IP Subnet/IPX Network Per VC 637
- Partially-Meshed Network with Some Fully-Meshed Parts 641

Scenario 10-1: Frame Relay Verification 656

Scenario 10-2: Frame Relay Configuration 662

Scenario 10-3: Frame Relay Configuration Dissection 664

Answers to Scenario 10-1: Frame Relay Verification 667

Answers to Scenario 10-2: Frame Relay Configuration 669

Answers to Scenario 10-3: Frame Relay Configuration Dissection 674

Chapter 11 Novell IPX 677

How to Best Use This Chapter 677

"Do I Know This Already?" Quiz 678

Novell IPX Concepts 682
- IPX Addressing 683
- Encapsulation 687
- RIP and SAP 690

IPX Configuration 693

Filtering IPX Traffic and SAPs 707
- IPX Packet Filters (Access Lists) 709
- Standard IPX Access Lists 711
- Extended IPX Access Lists 715

00 CCNA Exam_FM.fm Page xv Thursday, March 7, 2002 11:43 AM

SAP Filters 718
Named IPX Access Lists 721

Scenario 11-1: IPX Examination 741

Scenario 11-2: IPX Configuration 747

Scenario 11-3: IPX Filtering 748

Answers to Scenario 11-1: IPX Examination 751

Answers to Scenario 11-2: IPX Configuration 752
Answers to Task 1 for Scenario 11-2 752
Answers to Task 2 for Scenario 11-2 753

Answers to Scenario 11-4: IPX Filtering 754
Answers to Task 1 for Scenario 11-4 754
Answers to Task 2 for Scenario 11-4 755
Answers to Task 3 for Scenario 11-4 756

Chapter 12 Scenarios for Final Preparation 759

How to Best Use This Chapter 760

Scenario 12-1 761
Scenario 12-1, Part A: Planning 762
Solutions to Scenario 12-1, Part A: Planning 765
Scenario 12-1, Part B: Configuration 766
Solutions to Scenario 12-1, Part B: Configuration 767
Scenario 12-1, Part C: Verification and Questions 768
Solutions to Scenario 12-1, Part C: Verification and Questions 777

Scenario 12-2 779
Scenario 12-2, Part A: Planning 780
Solutions to Scenario 12-2, Part A: Planning 782
Scenario 12-2, Part B: Configuration 783
Solutions to Scenario 12-2, Part B: Configuration 783
Scenario 12-2, Part C: Verification and Questions 785
Solutions to Scenario 12-2, Part C: Verification and Questions 795

Scenario 12-3 797
Scenario 12-3, Part A: Planning 797
Solutions to Scenario 12-3, Part A: Planning 800
Scenario 12-3, Part B: Configuration 802
Solutions to Scenario 12-3, Part B: Configuration 803
Scenario 12-3, Part C: Verification and Questions 806
Solutions to Scenario 12-3, Part C: Verification and Questions 818

00 CCNA Exam_FM.fm Page xvi Thursday, March 7, 2002 11:43 AM

Chapter 13 Hands-on Lab Exercises 823

Options for Gaining Hands-on Skills 824

About the Labs in This Chapter 824

Equipment List 825

List of Labs 826

Lab 1: Router Command-Line Interface Familiarization 827
- Lab 1: Objectives 827
- Lab 1: Step-by-Step Instructions 828
- Lab 1: Hints 830

Lab 2: 1900 Series Switch Command-Line Interface Familiarization 831
- Lab 2: Objectives 831
- Lab 2: Step-by-Step Instructions 832
- Lab 2: Hints 835

Lab 3: 1900 Series Switch VLANs, Trunks, and Spanning Tree 836
- Lab 3: Objectives 836
- Lab 3: Step-by-Step Instructions 837

Lab 4: Basic Router IP Configuration and Management Navigation 838
- Lab 4: Objectives 838
- Lab 4: Step-by-Step Instructions 838

Lab 5: IP Routing Configuration 840
- Lab 5: Objectives 841
- Lab 5: Step-by-Step Instructions 841

Lab 6: IP Access List Configuration 842
- Lab 6: Objectives 843
- Lab 6: Step-by-Step Instructions 843

Lab 7: WAN Configuration 844
- Lab 7: Objectives 844
- Lab 7: Step-by-Step Instructions 845

Lab 8: Novell IPX Configuration 848
- Lab 8: Objectives 848
- Lab 8: Step-by-Step Instructions 848

00 CCNA Exam_FM.fm Page xvii Thursday, March 7, 2002 11:43 AM

Appendix A Answers to the "Do I Know This Already?" Quizzes and Q&A Sections 851

Answers to the Chapter 2 "Do I Know This Already?" Quiz 851

Answers to the Chapter 2 Q&A Section 853

Answers to the Chapter 3 "Do I Know This Already?" Quiz 858

Answers to the Chapter 3 Q&A Section 860

Answers to the Chapter 4 "Do I Know This Already?" Quiz 865

Answers to the Chapter 4 Q&A Section 867

Answers to the Chapter 5 "Do I Know This Already?" Quiz 872

Answers to the Chapter 5 Q&A Section 873

Answers to the Chapter 6 "Do I Know This Already?" Quiz 877

Answers to the Chapter 6 Q&A Section 880

Answers to the Chapter 7 "Do I Know This Already?" Quiz 897

Answers to the Chapter 7 Q&A Section 899

Answers to the Chapter 8 "Do I Know This Already?" Quiz 903

Answers to the Chapter 8 Q&A Section 906

Answers to the Chapter 9 "Do I Know This Already?" Quiz 912

Answers to the Chapter 9 Q&A Section 913

Answers to the Chapter 10 "Do I Know This Already?" Quiz 918

Answers to the Chapter 10 Q&A Section 920

Answers to the Chapter 11 "Do I Know This Already?" Quiz 923

Answers to the Chapter 11 Q&A Section 925

Appendix B Decimal to Hexadecimal and Binary Conversion Table 933

Appendix C Subnetting Practice: 25 Subnetting Questions 943

25 Subnetting Questions 943

Suggestions on How to Attack the Problem 944

Question 1: Answer 946

Question 2: Answer 948

00 CCNA Exam_FM.fm Page xviii Thursday, March 7, 2002 11:43 AM

Question 3: Answer 950
Question 4: Answer 952
Question 5: Answer 954
Question 6: Answer 956
Question 7: Answer 957
Question 8: Answer 959
Question 9: Answer 961
Question 10: Answer 962
Question 11: Answer 964
Question 12: Answer 965
Question 13: Answer 967
Question 14: Answer 969
Question 15: Answer 970
Question 16: Answer 972
Question 17: Answer 973
Question 18: Answer 975
Question 19: Answer 976
Question 20: Answer 978
Question 21: Answer 980
Question 22: Answer 981
Question 23: Answer 983
Question 24: Answer 985
Question 25: Answer 987

Appendix D Hands-on Lab Exercises: Solutions (included in PDF format on the CD for this book)

Lab 1: Router Command Line Interface Familiarization

Lab 2: 1900 Series Switch Command Line Interface Familiarization
Lab 3: 1900 Series Switch VLANs, trunks, and Spanning Tree

Lab 4: Basic Router IP Configuration and Management Navigation
Lab 5: IP Routing Configuration
Lab 6: IP Access List Configuration
Lab 7: WAN Configuration
Lab 8: IPX Configuration

Index 991

00 CCNA Exam_FM.fm Page xix Thursday, March 7, 2002 11:43 AM

Icons Used in This Book

Throughout this book, you will see the following icons used for networking devices:

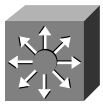
Router

Bridge

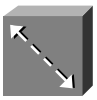
Hub

DSU/CSU

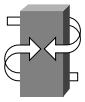
Catalyst Switch

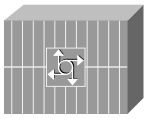

Multilayer Switch

ATM Switch


ISDN/Frame Relay Switch

Communication Server

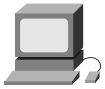

Gateway


Access Server

The following icons are used for peripherals and other devices:

PC

PC with Software

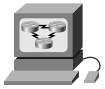

Sun Workstation

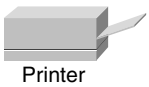
Macintosh

Terminal

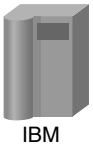
File Server

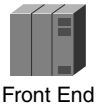
Web Server


Cisco Works Workstation


Printer

Laptop

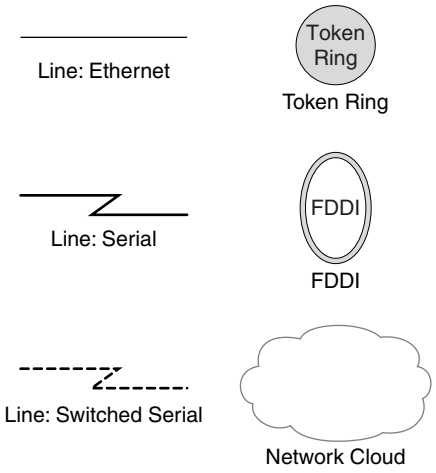

IBM Mainframe


Front End Processor

Cluster Controller

00 CCNA Exam_FM.fm Page xx Thursday, March 7, 2002 11:43 AM

The following icons are used for networks and network connections:



Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in the IOS Command Reference. The Command Reference describes these conventions as follows:

- Vertical bars (|) separate alternative, mutually exclusive elements.
- Square brackets ([ ]) indicate optional elements.
- Braces ({ }) indicate a required choice.
- Braces within brackets ([{ }]) indicate a required choice within an optional element.
- **Boldface** indicates commands and keywords that are entered exactly as shown. In configuration examples and output (not general command syntax), boldface indicates commands that are manually input by the user (such as a **show** command).
- *Italic* indicates arguments for which you supply values.

Introduction: Overview of Certification and How to Succeed

Professional certifications have been an important part of the computing industry for many years and will continue to become more important. Many reasons exist for these certifications, but the most popularly cited reason is that of credibility. All other

00 CCNA Exam_FM.fm Page xxi Thursday, March 7, 2002 11:43 AM

considerations held equal, the certified employee/consultant/job candidate is considered more valuable than one who is not.

Objectives and Methods

The most important and somewhat obvious objective of this book is to help you pass the CCNA exam (640-607). In fact, if the primary objective of this book were different, the book's title would be misleading. However, the methods used in this book to help you pass the CCNA exam are also designed to make you much more knowledgeable about how to do your job. Although this book and the accompanying CD together have more than 500 questions, the method in which they are used is not to simply make you memorize as many questions and answers as you possibly can.

Key methodologies used in this book are to help you discover the exam topics on which you need more review, to help you fully understand and remember those details, and to help you prove to yourself that you have retained your knowledge of those topics. So, this book does not try to help you pass by memorization, but by truly learning and understanding the topics. The CCNA exam is the foundation for many of the Cisco professional certifications, and it would be a disservice to you if this book did not help you truly learn the material. Therefore, this book helps you pass the CCNA exam by using the following methods:

- Helping you discover which test topics you have not mastered
- Providing explanations and information to fill in your knowledge gaps
- Supplying exercises and scenarios that enhance your ability to recall and deduce the answers to test questions
- Providing practice exercises on the topics and the testing process via test questions on the CD

Who Should Read This Book?

This book is not designed to be a general networking topics book, although it can be used for that purpose. This book is intended to tremendously increase your chances of passing the CCNA exam. Although other objectives can be achieved from using this book, it was written with one goal in mind: to help you pass the exam.

So why should you want to pass the CCNA exam? To get a raise. To show your manager you are working hard to increase your skills. To fulfill a requirement from your manager before he or she will spend money on another course. To enhance your resume. To please your reseller-employer, who needs more certified employees for a higher discount from Cisco. To prove that you know the topic, if you learned through on-the-job training (OJT) rather than from taking the prerequisite classes. Or one of many other reasons.

00 CCNA Exam_FM.fm Page xxii Thursday, March 7, 2002 11:43 AM

Others who might want to read this book are those considering skipping Cisco's Interconnecting Cisco Network Devices (ICND) course to take Cisco's Building Scalable Cisco Networks (BSCN) or Building Cisco Multilayer Switched Networks (BCMSN) courses. If you can answer a high percentage of the questions in this book, you should be ready for those courses.

Strategies for Exam Preparation

The strategy you use for CCNA preparation might vary from strategies used by other readers, mainly based on the skills, knowledge, and experience you already have obtained. For instance, if you have attended Cisco's ICND course, you need to take a slightly different approach compared to someone who has gained Cisco knowledge through on-the-job training. Chapter 1, "All About the Cisco Certified Network Associate Certification," includes a strategy that should closely match your background. Regardless of the strategy you use or your background, this book is designed to help you get to the point where you can pass the exam with the least amount of time required. For instance, there is no need for you to practice or read about IP addressing and subnetting if you fully understand it. However, many people like to make sure that they truly know a topic and thus read over material they already know. Several of this book's features help you gain the confidence you need to be convinced that you know some material already. The features also help you know which topics you need to study more.

How This Book Is Organized

This book contains 10 core chapters—Chapters 2 through 11. Each chapter covers a subset of the topics on the exam. Along with these core chapters, three other chapters help you succeed on the CCNA exam. Chapter 1 helps you understand how to use this book to efficiently and effectively study for the CCNA exam. Chapter 12 is full of lab scenarios that force you to think about all the topics in the book, which helps you with final preparation. And, if you can get access to some lab gear, read Chapter 13—it's full of topical lab exercises.

The core chapters cover the following topics:

- **Chapter 2, "Cisco IOS Software Fundamentals"**

  The Cisco IOS™ Software runs on a variety of Cisco products, particularly in routers and in some LAN switches. This chapter covers many of the features and functions of the Cisco IOS Software, as well as its command-line interface (CLI). Also included in this chapter are details about router hardware.

- **Chapter 3, "OSI Reference Model and Layered Communication"**

  The OSI reference model is mainly used today for comparison to other protocol architectures. This chapter discusses the purposes and meanings behind the use of a layered model. The features typically implemented at the various layers are covered,

00 CCNA Exam_FM.fm Page xxiii Thursday, March 7, 2002 11:43 AM

and sample protocols for each layer are given. Much of this information is conceptual and is not necessarily needed in order to implement networks, but it is covered on the exam. Also covered in Chapter 3 are the concepts involved in the typical operation of the OSI network and data link layers. This conceptual discussion is vital to a complete understanding of OSI Layer 2 and Layer 3 operation.

- **Chapter 4, "LANs, Bridges, and Switches"**

  LANs, particularly the various forms of Ethernet, are covered in this chapter. It also covers the concepts behind LAN segmentation using bridges, switches, and routers—a popular set of exam topics, according to the list of exam topics posted on Cisco's Web site. Basic bridge and switch operation is also covered, along with the concepts of collision domains and broadcast domains. The chapter ends with coverage of the Cisco 1900 series LAN switch CLI.

- **Chapter 5, "Intermediate LANs: Spanning Tree, VLANs, and Trunking"**

  Most LANs with multiple interconnected switches have redundant Ethernets between the switches. For such a LAN to be usable, Spanning-Tree Protocol (STP) must be used. The first topic in this chapter describes how STP prevents loops while allowing the redundancy to be used for backup purposes. EtherChannel, a feature that helps optimize STP, is also covered.

  The second section in this chapter covers virtual LANs (VLANs). VLANs allow the engineer to create multiple broadcast domains in a single switch, or spanning multiple interconnected switches. When you use VLANs, interconnected switches need to use VLAN trunking, which is also covered in this chapter. The chapter ends with coverage of configuration details for all these features.

- **Chapter 6, "TCP/IP and IP Routing"**

  This chapter begins by describing TCP and UDP, the two main options for OSI Layer 4 protocols in TCP/IP. After TCP and UDP, a couple other short topics, ARP and ICMP, are covered. The TCP/IP protocols require ARP and ICMP in order to work. You also need solid skills with IP addressing and subnetting to succeed as a network engineer, or on the CCNA exam. The second section of this chapter details IP addressing and subnetting, including some tricks that make the math required to answer test questions a bit easier.

  Finally, you need to be able to configure TCP/IP in a Cisco router. Actually, that part of the chapter is a bit anticlimactic, because configuring IP is pretty easy. Included in that section are some additional features about how to troubleshoot and manage an IP network.

00 CCNA Exam_FM.fm Page xxiv Thursday, March 7, 2002 11:43 AM

- **Chapter 7, "Routing and Routing Protocols"**

  This chapter deals with the concepts and configuration required to fill a router's routing table. Cisco expects CCNAs to demonstrate a comfortable understanding of the logic behind the routing of packets and the different-but-related logic behind a routing protocol. This chapter focuses on *routing protocols*—the protocols used to discover routes.

  The CCNA exam covers the details of distance vector logic, so this topic is covered in the first section of this chapter. This is the logic used by the Routing Information Protocol (RIP) and Interior Gateway Routing Protocol (IGRP), as well as IP RIP. Along the way, alternative routing protocol algorithms (link-state and Diffusing Update Algorithm [DUAL]) are mentioned briefly. Implementation details of RIP (Version 1 and Version 2) and IGRP are covered next. Because EIGRP configuration is similar to IGRP, it is also covered briefly.

- **Chapter 8, "Understanding Access List Security"**

  Cisco expects CCNAs to understand security from the perspective of filtering traffic using access lists. Access lists are important to CCNA candidates because practically every network uses them. If you do more than basic filtering, access lists can become very tricky. Access lists are likely to remain a core competency issue for router support personnel for a long time. Also, several other IOS features call on access list logic to perform packet-matching features.

  This chapter covers standard and extended IP access lists, as well as named IP access lists.

- **Chapter 9, "WAN Protocols and Design"**

  This chapter covers the two popular data link protocols used on point-to-point links—HDLC and PPP. HDLC is pretty simple, but PPP has a few more interesting features. ISDN concepts and configuration are also covered, with a fair number of samples covering dial-on-demand routing, which is one way of causing a dialed ISDN connection to be established between routers.

- **Chapter 10, "Frame Relay Concepts and Configuration"**

  Engineers deploy Frame Relay more than any other WAN protocol today, so it is no surprise that Frame Relay is an important topic for the CCNA exam. This chapter reviews the details of how Frame Relay accomplishes its goal of delivering frames to multiple WAN-connected sites. This chapter covers all the terminology and concepts of Frame Relay that are covered on the exam. This chapter also describes Frame Relay configuration, with its many options.

00 CCNA Exam_FM.fm Page xxv Thursday, March 7, 2002 11:43 AM

- **Chapter 11, "Novell IPX"**

  Routing for IP and IPX is similar, so if you understand IP routing, you probably will find IPX routing easy to grasp. Routing protocols for IP and IPX are also similar. However, unlike TCP/IP, Novell relies on the ability for clients to find their servers, so Novell uses protocols such as Service Advertisement Protocol (SAP) to advertise information about servers. This chapter briefly reviews the concepts that are similar to TCP/IP, details the concepts that are specific to Novell, and helps you refine your retention and recall of the configuration with questions and scenarios. This chapter also describes Novell access lists.

When you are finished with the core chapters, you have several options as to how to finish your exam preparation. Additional scenarios in Chapter 12 provide a method of final preparation with more questions and exercises. If you have access to lab equipment, Chapter 13 provides some lab exercises that can guide you through the hands-on learning experience. You can review the questions at the end of each chapter, and you can use the CD's testing software to practice the exam.

The core chapters have several features that help you make the best use of your time:

- **"Do I Know This Already?" Quiz and Quizlets**—Each chapter begins with a quiz that helps you determine the amount of time you need to spend studying that chapter. The quiz is broken into smaller sections called "quizlets," which correspond to a section of the chapter. If you follow the directions at the beginning of the chapter, the "Do I Know This Already?" quiz directs you to study all or particular parts of the chapter.
- **Foundation Topics**—These are the core sections of each chapter. They explain the protocols, concepts, and configuration for the topics in that chapter.
- **Foundation Summary**—Near the end of each chapter, a summary collects the most important tables and figures from the chapter. The "Foundation Summary" section is designed to help you review the key concepts in the chapter if you scored well on the "Do I Know This Already?" quiz. This section is an excellent tool for last-minute review.
- **Q&A**—Each chapter ends with a Q&A section that forces you to exercise your recall of the facts and processes described inside that chapter. The questions are generally harder than the actual exam, partly because the questions are in "short answer" format, instead of multiple choice. These questions are a great way to increase the accuracy of your recollection of the facts.
- **Extra Credit**—Network engineers need to know more than the CCNA exam covers to build networks. Most chapters contain a few more advanced topics that are not on the CCNA exam, but that are very important when building networks with the technologies described in that chapter. The book denotes these short sections as "extra credit"—ignore them if you are focusing only on the exam, but read them if you are preparing to use this knowledge in your job soon.

00 CCNA Exam_FM.fm Page xxvi Thursday, March 7, 2002 11:43 AM

- **Scenarios**—Located at the end of most chapters, the scenarios allow a much more in-depth examination of a network implementation. Rather than posing a simple question asking for a single fact, the scenarios let you design and build networks (at least on paper) without the clues inherent in a multiple-choice quiz format.
- **CD-based practice exam**—The companion CD contains a large number of questions not included in the book. You can answer these questions by using the simulated exam feature or the topical review feature. This is the best tool for helping you prepare for the test-taking process.

Approach

Retention and recall are the two features of human memory most closely related to performance on tests. This exam preparation guide focuses on increasing both retention and recall of the exam topics. The other human characteristic involved in successfully passing the exam is intelligence, but this book does not address that issue!

Adults' retention is typically less than that of children. For example, it is common for 4-year-olds to pick up basic language skills in a new country faster than their parents. Children retain facts as an end unto itself; adults typically either need a stronger reason to remember a fact or must have a reason to think about that fact several times to retain it in memory. For these reasons, a student who attends a typical Cisco course and retains 50 percent of the material is actually quite an amazing student.

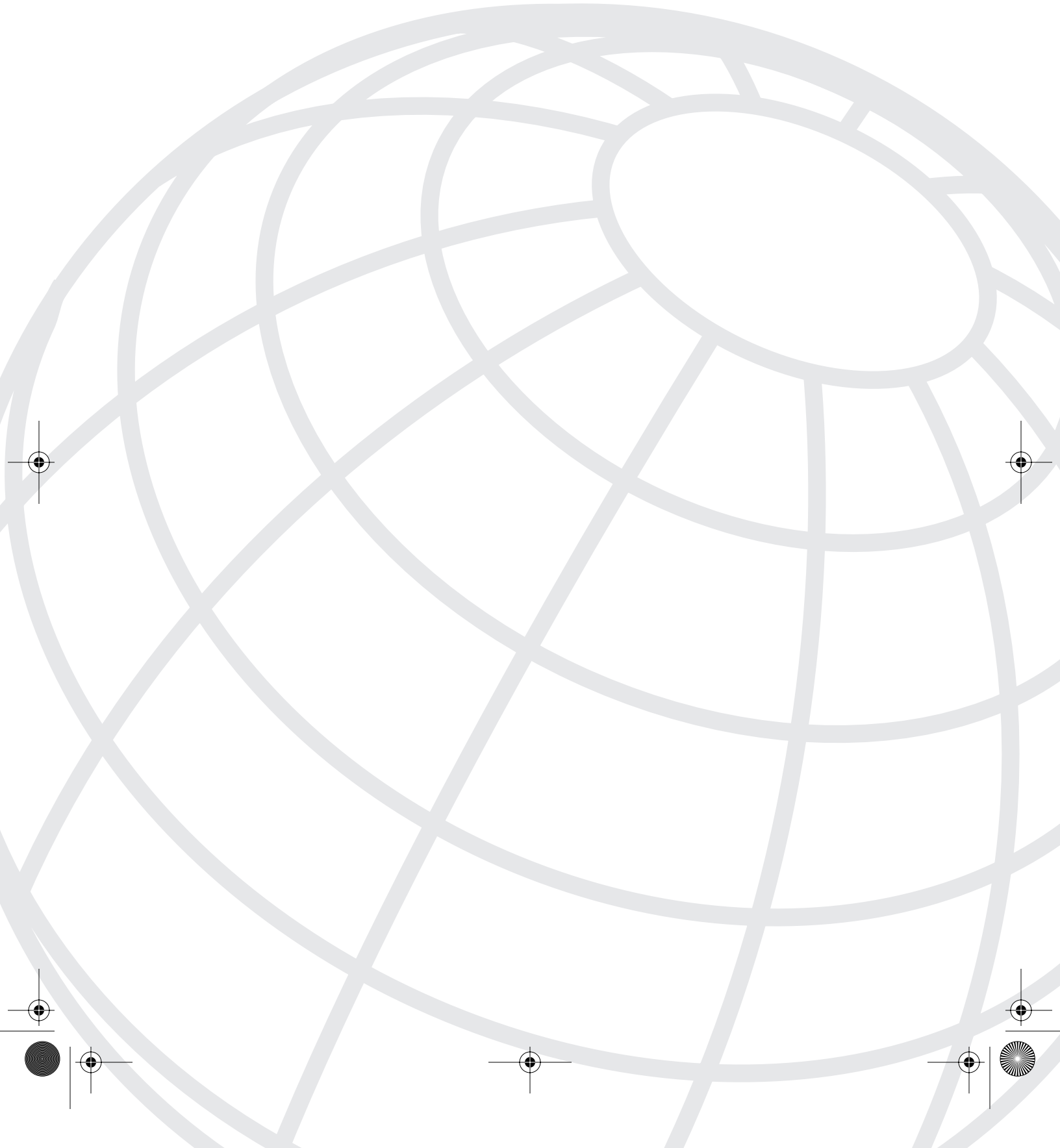
Memory recall is based on connectors to the information that needs to be recalled. The greater the number of connectors to a piece of information, the better the chance and speed of recall. For example, if the exam asks what ARP stands for, you automatically add information to the question. You know the topic is networking because of the nature of the test. You might recall the term "ARP broadcast," which implies that ARP is the name of something that flows in a network. Maybe you do not recall all three words in the acronym, but you recall that it has something to do with addressing. Of course, because the test is multiple-choice, if only one answer begins with "address," you have a pretty good guess. Having read the answer "Address Resolution Protocol," you might even have the infamous "aha" experience, in which you are then sure that your answer is correct (and possibly a brightly lit lightbulb is hovering over your head). All these added facts and assumptions are the connectors that eventually lead your brain to the fact that needs to be recalled. Of course, recall and retention work together. If you do not retain the knowledge, it will be difficult to recall it.

00 CCNA Exam_FM.fm Page xxvii Thursday, March 7, 2002 11:43 AM

This book is designed with features to help you increase retention and recall. It does this in the following ways:

- By providing succinct and complete methods of helping you decide what you recall easily and what you do not recall at all.
- By giving references to the exact passages in the book that review the concepts you did not recall so that you can quickly be reminded of a fact or concept. Repeating information that connects to another concept helps retention, and describing the same concept in several ways throughout a chapter increases the number of connectors to the same piece of information.
- By including exercise questions that supply fewer connectors than multiple-choice questions. This helps you exercise recall and avoids giving you a false sense of confidence, as an exercise with only multiple-choice questions might do. For example, fill-in-the-blank questions require you to have better recall than a multiple-choice question.
- By pulling the entire breadth of subject matter together. Chapter 12 contains scenarios and several related questions that cover every topic on the exam. It gives you a chance to prove that you have mastered the subject matter. This reduces the connectors implied by questions residing in a particular chapter and requires you to exercise other connectors to remember the details.
- Finally, accompanying this book is a CD-ROM that has exam-like multiple-choice questions. These help you practice taking the exam and let you get accustomed to the time restrictions imposed during the exam.

01 CCNA Exam_Ch 01.fm Page 2 Thursday, March 7, 2002 11:43 AM



01 CCNA Exam_Ch 01.fm Page 3 Thursday, March 7, 2002 11:43 AM

CHAPTER 1

All About the Cisco Certified Network Associate Certification

Congratulations! You have taken your first step toward becoming a member of the group of network professionals who are Cisco Career Certified. The credibility you gain by becoming a Cisco Certified Network Associate (CCNA) is the first important key step to opening doors for career advancement in networking.

In case you have already heard some things about the exam, be forewarned—the exam format has changed, as compared with the other Cisco exams, including the old CCNA exam. The latest CCNA exam (test number 640-607) includes the usual types of questions—multiple-choice, single-answer; multiple-choice, multiple-answer; fill-in-the-blank; and drag-and-drop questions. However, for the first time, *Cisco is including router and switch simulations on the exam*. So, your ability to not just remember command syntax but also know what commands to use will be very important. This book is filled with lots of extensive examples as well as complete topical lab scenarios at the end of the chapters designed to help you prepare for the hands-on portions of the exam, even if you do not have lab equipment. If you can get access to some equipment, this book includes a specific lab exercise chapter in addition to more than 20 lab scenarios throughout Chapters 2 through 11. So, you have lots of different scenarios and lab exercises that you can perform on your own gear or using a lab rental service.

You can take the exam either from Vue (www.vue.com) or from Sylvan Prometric (www.2test.com). In the past, Cisco has changed the number of questions and passing score without notice, so, over time, the duration and number of questions per exam will vary. The older version of the test, 640-507, used a point-scoring system in which your score was between 300 and 1000, with a passing score being 849 or better.

Cisco generally succeeds in making the exam truly prove that you know the topic. The exam questions are painstakingly formulated to reduce the number of clues to giving away the correct answer. The test adapts to you—if you answer a question wrong, you will get more questions on that topic. Currently, there are 65 questions and 75 minutes in which to answer them—not a lot of time. And you cannot go back and change earlier answers—when you click on the Next button, you're done with that question!

Be aware that when you register for the exam, you might be notified of a specific length of time; when you actually log in to the testing software at the testing center, you might find that the testing time is 15 minutes shorter. That's because the testing company expects some time to be required for getting settled and taking the tutorial on the testing engine or for taking a survey.

01 CCNA Exam_Ch 01.fm Page 4 Thursday, March 7, 2002 11:43 AM

The "read the book and pass the test" method of certification does not typically work with CCNA. So much of networking relates to how the concepts, protocols, and configurations interact, so it is easy for Cisco to create questions that test your understanding more than just asking for a simple fact. Every vendor, including Cisco, hopes to create certification tests that do not become too easy and, therefore, meaningless. Cisco's philosophy is that, by passing the exam, you fully understand the concepts. More important, Cisco wants to be sure that passing the exam proves that you have the skills to actually implement the features, not just talk about them—that's why simulations are included. From a statistical perspective, those of you who use routers and switches every day have a better chance of passing because more of you will easily remember the commands needed for the simulation questions. But do not despair—CCNA certification can be achieved through study, plus some hands-on experience. In the end, if Cisco succeeds in maintaining the difficulty of the CCNA exam, your CCNA certification will remain valuable.

Overview of Cisco Certifications

Cisco measures the technical readiness of channel partners (resellers) and professional services partners partially by requiring specific numbers of certified employees. For instance, Premier, Silver, and Gold Channel Partners are required to have either two or four CCNAs on staff, along with Cisco professional- and expert-level certified individuals. (see http://www.cisco.com/warp/public/765/partner_programs/certification/requirements.shtml for details). Cisco fulfills only a small portion of its orders through direct sale from Cisco; most often, a Cisco reseller is involved. Also, Cisco has not attempted to become the primary source for consulting and implementation services for network deployment using Cisco products; instead, the company prefers to use partners as much as possible. With that business model, a great need arose to certify the skill levels of the partner companies.

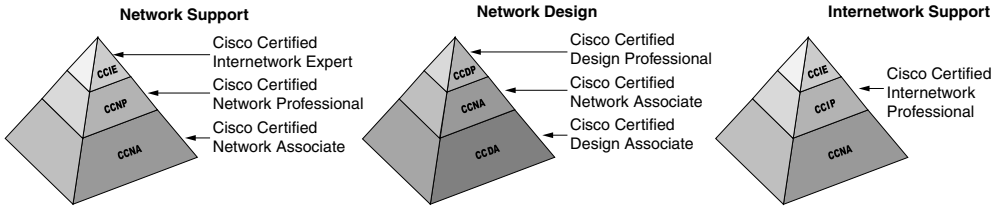
The Cisco Certified Internetworking Expert (CCIE) program was Cisco's first foray into certifications. Introduced in 1994, the CCIE was designed to be one of the most respected, difficult-to-achieve certifications. To certify, a person must pass a written test (also given at Sylvan Prometric centers) and then pass a one-day, hands-on lab test administered by Cisco. Cisco does not publish numbers on pass/fail rates for CCIE or the other certifications, but rumors have it that the failure rate on all lab test takers is more than 50 percent, with failure rate for first-time lab takers at more than 80 percent; a typical CCIE reportedly takes the lab test three times before passing.

Cisco requires a partner to accumulate points, based on the number of employees with certain certifications, to become a Premier, Silver, or Gold Channel Partner. The status, in turn, dictates the discount received by the reseller when buying from Cisco. This practice continues to be a good way for Cisco to judge the commitment of resellers to hire people with proven Cisco skills, which then improves customer satisfaction—and customer satisfaction is tied to every Cisco executive's bonus plan.

01 CCNA Exam_Ch 01.fm Page 5 Thursday, March 7, 2002 11:43 AM

Historically, CCIE was the first and only Cisco certification for about four years (1994 to 1998). As Cisco's base of channel partners grew, The CCIE certification did not provide enough flexibility toward the goal of certifying resellers. For instance, there are around 6,909 CCIEs worldwide (as of January 2002) and about 3,000 resellers—and not all the CCIEs work for resellers, of course. More important, some resellers did not need a CCIE on staff, except to get a better discount. Thus, Cisco needed certifications that were less rigorous than CCIE, which would allow Cisco more granularity in judging the skills of the staff at a partner company. So, Cisco created several additional certifications, with CCNA included. Figure 1-1 shows the CCIE and career certifications for routing and switching.

Figure 1-1 *Cisco Routing and Switching Certifications*



CCNA proves implementation skills for simple networks
CCDA proves design skills for simple networks
CCNP proves implementation skills for intermediate networks
CCDP proves design skills for intermediate networks
CCIE proves implementation skills for complex networks
CCIP proves implementation skills for infrastructure access solutions

Instead of instituting just one level of certification besides CCIE, Cisco created two additional levels: an associate level and a professional level. CCNA is the more basic, and CCNP is the intermediate level between CCNA and CCIE. CCDA, CCDP, and CCIP are a few of the more closely related certifications. You can view these details at Cisco's Web site:

www.cisco.com/warp/public/10/wwtraining/certprog/lan/course.html
www.cisco.com/warp/customer/10/wwtraining/certprog/c_and_s/ccip/
www.cisco.com/warp/customer/10/wwtraining/certprog/lan2/course.html.

Cisco created two categories of certifications: one to certify implementation skills and the other to certify design skills. Resellers working in a presale environment need more design skills, whereas services companies need more implementation skills. So, the CCNA and CCNP certifications provide implementation-oriented certifications, whereas the CCDA and CCDP certifications provide design-oriented certifications.

Several of the certifications require other certifications as a prerequisite. For instance, CCNP certification requires CCNA as a prerequisite. Also, CCDP requires both CCDA and CCNA certification. CCIE, however, does not require any other certification before the written and lab tests, mainly for historical reasons.

01 CCNA Exam_Ch 01.fm Page 6 Thursday, March 7, 2002 11:43 AM

The Cisco Certified Internetworking Professional (CCIP) is a more recent addition to the Cisco series of certifications. Cisco's customers fall into several categories, the largest two being what Cisco terms "enterprise" and "service provider." The CCIP certification is a professional-level certification, like CCNP, that is more oriented toward service provider personnel. Although CCIP does not require CCNA certification first, it is strongly recommended.

Cisco certifications have taken on a much larger role in the networking industry. From a career standpoint, Cisco certification certainly can be used to help you get a new job. Or, you can add certification to your performance-evaluation plan and justify a raise based on passing an exam. If you are looking for a new job, not only might certification help you land the job, but it actually might help you make more money!

Exams Required for Certification

To certify for CCNA, a single exam is required: Cisco exam number 640-607. For CCDA, a single exam is required as well. Multiple exams are required for the professional-level certifications—CCNP, CCIP, and CCDP. The exams generally match the same topics that are covered in one of the official Cisco courses. Table 1-1 outlines the exams and the courses with which they are most closely matched.

Table 1-1 *Exam-to-Course Mappings*

Certification	Exam Number	Name	Course Most Closely Matching Exam Requirements
CCNA	640-607	CCNA Exam	Interconnecting Cisco Network Devices (ICND).
CCDA	640-441	DCN Exam	Designing Cisco Networks.
CCNP	640-503	Routing Exam	Building Scalable Cisco Networks (BSCN).
	640-504	Switching Exam	Building Cisco Multilayer Switched Networks (BCMSN).
	640-505	Remote Access Exam	Building Cisco Remote Access Networks (BCRAN).
	640-509*	Foundation Exam	BSCN, BCMSN, and BCRAN.
	640-506	Support Exam	Cisco Internetwork Troubleshooting (CIT).
CCDP	640-503	Routing Exam	Building Scalable Cisco Networks (BSCN).
	640-504	Switching Exam	Building Cisco Multilayer Switched Networks (BCMSN).
	640-505	Remote Access Exam	Building Cisco Remote Access Networks (BCRAN).

01 CCNA Exam_Ch 01.fm Page 7 Thursday, March 7, 2002 11:43 AM

Table 1-1 *Exam-to-Course Mappings (Continued)*

Certification	Exam Number	Name	Course Most Closely Matching Exam Requirements
	640-509*	Foundation Exam	BSCN, BCMSN, and BCRAN.
	640-025	CID Exam	Cisco Internetwork Design (CID).
CCIP	640-900	BSCI	Building Scalable Cisco Internetworks.
	640-905	Mcast+Qos Exam	Implementing Cisco Multicast.
			Implementing Cisco QoS.
		Various	Elective exam(s). Topics include MPLS, CDN, cable, DSL, metro, packet telephony, and security.

*Exam 640-509 meets the same requirements as passing these three exams: 640-503, 640-504, and 640-505.

Other Cisco Certifications

Cisco has many other certifications as well, as summarized in Table 1-2. Refer to Cisco's Web site at www.cisco.com/warp/public/10/wwtraining/certprog for the latest information.

Table 1-2 *Additional Cisco Certifications*

Certification	Purpose, Prerequisites
CCIE Routing & Switching	The granddaddy of them all! CCIE focused on routing and switching, and is the logical conclusion after getting CCNA and then CCNP.
CCIP	Cisco Certified Internetworking Professional is in concept like CCNP, with a focus on service provider–oriented technologies.
CCIE Communications and Services	CCIE, with a focus on service provider–oriented technologies. Replaces the old CCIE WAN.
CCIE Security	CCIE, requiring IP and IP routing knowledge as well as security.
CCNA WAN	CCNA-level coverage of Cisco WAN switches.
CCNP-WAN	Intermediate certification for Cisco WAN switches. Requires CCNA-WAN.
CCDP-WAN	Design certification for Cisco WAN switches. Requires CCNP-WAN.
Cisco Qualified Specialists	Several specialized certifications are available; these are used as part of the points calculation for channel partners. See http://www.cisco.com/warp/public/10/wwtraining/certprog/ for more details.

01 CCNA Exam_Ch 01.fm Page 8 Thursday, March 7, 2002 11:43 AM

What's on the CCNA Exam

Every test taker would like to know exactly what is on the CCNA exam as well as the other Cisco certification exams. Well, to be honest, *exactly* what is on the exam is a very closely guarded secret. Only those who write the questions for Cisco and who have access to the entire question database truly know what is really on the exam.

Cisco makes fairly general CCNA exam content available to the public at the Web site www.cisco.com/warp/public/10/wwtraining/certprog/testing/current_exams/640-507.html.

In fact, this direct quote from the Cisco Web site summarizes the exam:

> CCNA certified professionals can install, configure, and operate LAN, WAN, and dial access services for small networks (100 nodes or fewer), including but not limited to use of these protocols: IP, IGRP, IPX, Serial, AppleTalk, Frame Relay, IP RIP, VLANs, RIP, Ethernet, Access Lists.

Well, a lawyer might have been involved in crafting that message. "Including but not limited to" is a telling phrase—technically, anything is fair game. All of us would like to study and understand exactly the topics that are on the test. I strive to meet that goal, but keep the following perspective in mind—the exam that you take will not include questions on every topic in Cisco's CCNA question database. Someone else may get topics that you will not. Many topics are covered on each exam, but with far fewer than 100 questions, it would be impossible to cover all the topics.

So what did we do to help? Well, in this book, we err on the side of covering everything that is fair game on the exam. So, we operate under the following self-imposed rules:

- If we at Cisco Press believe that a topic is definitely on the exam, it is covered in Chapters 2 through 11. If it's in the exam question database, even though you might not get it on your individual test, it's covered in these chapters!
- If we at Cisco Press believe that a topic is simply not in the Cisco CCNA question database, it is not covered in this book.
- If the topic is in the exam question database, but it has a low likelihood of being on the exam, the book notes the corresponding section with an "extra credit" icon.

Start Extra Credit

Studying these sections might help, but spend time on these topics only after you have mastered the most important topics.

End Extra Credit

01 CCNA Exam_Ch 01.fm Page 9 Thursday, March 7, 2002 11:43 AM

Cisco posts the list of exam topics on its Web site, www.cisco.com/warp/public/10/wwtraining/certprog/testing/current_exams/640-507.html.

These topics provide the greatest insight into what is covered on the exam. The topics are listed in bullet format on the Cisco Web site. To refer to the topics more easily in the book, I have numbered the exam topics. Table 1-3 lists the exam topics, their respective numbers, and an interpretation.

Table 1-3 *CCNA Exam Topics and Comments*

Exam Topic Reference Number	Exam Topic	Comments
1	Name and describe two switching methods.	Cut-through and store-and-forward are the two types referred to, with a third type being FragmentFree. Chapter 4, "LANs, Bridges, and Switches," covers the details.
2	Distinguish between cut-through and store-and-forward LAN switching.	Deal with differences in internal processing by a LAN switch. Details are found in Chapter 4.
3	Describe the operation of the Spanning Tree Protocol and its benefits.	STP prevents frames from looping around LANs when physically redundant links exist. Chapter 5, "Intermediate LANs: Spanning Tree, VLANs, and Trunking," covers the details.
4	Describe the benefits of virtual LANs.	Also in Chapter 5, VLANs allow one switch to create multiple broadcast domains instead of requiring a different switch for each different broadcast domain.
5	Describe data link and network addresses and identify key differences between them.	This topic relates more to the concepts behind addressing, as defined in the OSI reference model. Network addresses are (typically) not correlated to a particular type of physical network, whereas data-link addresses are. Details appear in Chapter 3, "OSI Reference Model & Layered Communication."
6	Define and describe the function of a MAC address.	Media Access Control (MAC) addresses are used to address LAN network interface cards. These addresses include unicast (addressing a single card), broadcast, and multicast.
7	List the key internetworking functions of the OSI Network layer.	Too much to list here—see Chapter 3 for a complete long list and another shorter, easy-to-memorize list.

continues

01 CCNA Exam_Ch 01.fm Page 10 Thursday, March 7, 2002 11:43 AM

Table 1-3 *CCNA Exam Topics and Comments (Continued)*

Exam Topic Reference Number	Exam Topic	Comments
8	Identify at least three reasons why the industry uses a layered model.	Chapter 3 once again covers most of the pure conceptual materials on networking protocols, including layering. Making the software easier to write, making it easier for different vendors to interface with other products, and ensuring that two computers can communicate with each other are just some of the reasons.
9	Describe the two parts of network addressing, then identify the parts in specific protocol address examples.	The first part of several network layer addresses identifies a group, with the second part identifying a single member of the group. For instance, IP has a network or subnet part, followed by the host part of an address. Chapter 3 covers the basics for IP, IPX, and AppleTalk. Chapter 6, "TCP/IP and IP Routing," and Chapter 11, "Novell IPX," cover the details for IP and IPX, respectively.
10	Define and explain the five conversion steps of data encapsulation.	Using the TCP/IP protocol stack as an example, Cisco has described the process of data encapsulation. This explanation has been a part of Cisco's intro courses for many years. The full explanation is in Chapter 3.
11	Describe connection-oriented network service and connectionless network service, and identify their key differences.	Chapter 3 defines and contrasts these two terms. Briefly, *connection-oriented* means that the protocol communicates between the endpoints before any data is passed, and *connectionless* protocols do not.
12	Identify the parts in specific protocol address examples.	IP, IPX, and AppleTalk examples are included in Chapter 3. The formats are actually pretty easy, and IP and IPX are covered in more detail in later chapters, so address formats for IP and IPX will become second nature.
13	Describe the advantages of LAN segmentation.	Segmentation deals with the concept of separating devices that were previously on a single LAN into multiple LANs. Chapter 4 covers the details and benefits.
14	Describe LAN segmentation using bridges.	Segmentation using bridges is the same as segmentation using switches. The main advantage is to split the LANs into different collision domains.

01 CCNA Exam_Ch 01.fm Page 11 Thursday, March 7, 2002 11:43 AM

Table 1-3 *CCNA Exam Topics and Comments (Continued)*

Exam Topic Reference Number	Exam Topic	Comments
15	Describe LAN segmentation using routers.	The main advantage is to split the LANs into different collision and different broadcast domains.
16	Describe LAN segmentation using switches.	Segmentation using switches is the same as segmentation using bridges. The main advantage is to split the LANs into different collision domains.
17	Describe the benefits of network segmentation with bridges.	This exam topic and the next two are really simply reworded versions of the previous three topics. All are covered in Chapter 4.
18	Describe the benefits of network segmentation with routers.	This exam topic, like the one before and after it, is really a simply reworded version of the previous three topics. All are covered in Chapter 4.
19	Describe the benefits of network segmentation with switches.	This exam topic, like the two before it, is really simply a reworded version of the previous three topics. All are covered in Chapter 4.
20	Describe the different classes of IP addresses [and subnetting].	This topic covers all details of IP addressing. If you want to work in networking, you need to know this well. Chapter 6 describes the details.
21	Identify the functions of the TCP/IP network-layer protocols.	There are many parts of the TCP/IP protocol suite, including IP. This topic implies that you need to know the various components and their functions—such as TCP, UDP, ICMP, and ARP. Chapter 6 discusses all these protocols.
22	Identify the functions performed by ICMP.	ICMP has many functions, including the ICMP echo and echo reply messages sent when the **ping** command is used. Chapter 6 covers the details.
23	Configure IP addresses.	Configuration of IP addresses is straightforward when you know the format of IP addresses. Configuration is covered in Chapter 6.
24	Verify IP addresses.	Several **show** commands list information about the configured IP addresses and whether the corresponding interfaces are up and working. Chapter 6 lists the commands.

continues

01 CCNA Exam_Ch 01.fm Page 12 Thursday, March 7, 2002 11:43 AM

Table 1-3 *CCNA Exam Topics and Comments (Continued)*

Exam Topic Reference Number	Exam Topic	Comments
25	List the required IPX address and encapsulation type.	Chapter 11 covers all the details of IPX, including encapsulation types. When a router forwards a packet, it creates a new data-link header. On LANs, there are several alternative types of headers or encapsulation types. Be sure to memorize these types.
26	Define flow control and describe the three basic methods used in networking.	Flow control is normally performed by OSI Layer 4 protocols, but, in some cases, it is performed by protocols from other layers. The basic methods are all covered in Chapter 3.
27	Add the RIP routing protocol to your configuration.	RIP configuration and the concepts behind this distance vector protocol are covered in Chapter 7, "Routing and Routing Protocols." RIP is a routing protocol that fills the IP routing table with routes.
28	Add the IGRP routing protocol to your configuration.	Likewise, IGRP configuration and concepts are covered in Chapter 7. IGRP is an alternative routing protocol.
29	Recognize key Frame Relay terms and features.	Chapter 10, "Frame Relay Concepts and Configuration," is devoted to all Frame Relay concepts and configuration. The terms and features are covered in the first section of the chapter.
30	List commands to configure Frame Relay LMIs, maps, and subinterfaces.	Frame Relay can be configured in several different ways, depending on the network design and the Frame Relay provider. Cisco expects CCNAs to be able to configure all the options.
31	List commands to monitor Frame Relay operation in the router.	The commands are listed, with examples, in Chapter 10. Cisco will test you on these commands with multiple-choice questions as well as with the simulations on the exam.
32	State a relevant use and context for ISDN networking.	Chapter 9, "WAN Protocols and Design," covers the details of ISDN concepts and configuration. ISDN is used as a dial technology, both for occasional access and for dial backup.
33	Identify ISDN protocols, function groups, reference points, and channels.	ISDN includes many options, all defined by a myriad of ITU specifications. Chapter 9 lists the specifications and explains the core concepts.

01 CCNA Exam_Ch 01.fm Page 13 Thursday, March 7, 2002 11:43 AM

Table 1-3 *CCNA Exam Topics and Comments (Continued)*

Exam Topic Reference Number	Exam Topic	Comments
34	Identify PPP operations to encapsulate WAN data on Cisco routers.	Also in Chapter 9, PPP is a serial data-link protocol used on point-to-point serial links.
35	Configure standard access lists to figure IP traffic.	Chapter 8, "Understanding Access List Security," covers the details of all IP access lists. Access lists are used to filter packets as well as filter routing updates and classify traffic for QoS features.
36	Configure extended access lists to filter IP traffic.	Extended IP access lists do the same thing as standard access lists, but with many more options for matching the packets.
37	Monitor and verify selected access list operations on the router.	Regardless of whether standard or extended access lists are used, the same commands, covered in Chapter 8, list the details of what is configured.
38	Describe full- and half-duplex Ethernet operation.	Covered in Chapter 4, Ethernet can operate at full duplex as long as only two devices exist in the same collision domain. This is typical when a single device is cabled to a LAN switch.
39	Describe network congestion problem in Ethernet networks.	Ironically, I first heard of the "Ethernet congestion problem" graphed when researching my senior project in college 18 years ago. Covered in Chapter 4, the problem is that Ethernet collisions and wait times increase as load increases, reducing performance.
40	Describe the features and benefits of Fast Ethernet.	Also covered in Chapter 4, Fast Ethernet is—faster. And it uses the same framing as 10-Mbps Ethernet, which allows for easy migration.
41	Describe the guidelines and distance limitations of Fast Ethernet.	The details are listed in tables in Chapter 4.
42	Examine router elements (RAM, ROM, CDP, **show**).	Cisco IOS Software and configuration files are stored in routers, and you will need to know the commands used to examine them. Also, CDP reveals details about neighboring routers, and you will need to be able to display CDP information as well. Chapter 2, "Cisco IOS Software Fundamentals," covers the router memory, and Chapter 6 covers CDP.

continues

01 CCNA Exam_Ch 01.fm Page 14 Thursday, March 7, 2002 11:43 AM

Table 1-3 *CCNA Exam Topics and Comments (Continued)*

Exam Topic Reference Number	Exam Topic	Comments
43	Manage configuration files from the privileged exec mode.	Managing configuration files includes manipulating the configuration, as well as manipulating and choosing which IOS version to use in the router. Chapter 2 covers the details.
44	Control router passwords, identification, and banner.	Again, in Chapter 2, there are many basic commands that are both useful and covered on the exam. If you see a command in Chapter 2 specifically, you should memorize it—it is surely in the exam question database.
45	Identify the main Cisco IOS software commands for router startup.	All basic commands, router configuration details, and Cisco IOS Software commands are covered in Chapter 2.
46	Log in to a router in both user and privileged modes.	The Cisco IOS Software command-line interface (CLI) allows you to log in using user and privileged modes. Look to Chapter 2 for details.
47	Check an initial configuration using the **setup** command.	If you turn on or reboot your router when there is no configuration stored in NVRAM, the router allows you to enter setup mode. You can also enter setup mode using the **setup** command. Regardless, setup is a way to easily configure the basic information needed for a router configuration, without knowing the syntax of router commands.

01 CCNA Exam_Ch 01.fm Page 15 Thursday, March 7, 2002 11:43 AM

Table 1-3 *CCNA Exam Topics and Comments (Continued)*

Exam Topic Reference Number	Exam Topic	Comments
48	Use the context-sensitive help facility.	You can always get help by simply typing a **?**. There are a few variations on what you get, depending on when you type the **?**. See Chapter 2 for details.
49	Use the command history and editing features.	Chapter 2 lists the picky details, which you should memorize!
50	List the commands to load Cisco IOS software from: flash memory, a TFTP server, or ROM.	These commands are very important to network engineers because the commands let you migrate from one IOS to another.
51	Prepare to backup, upgrade, and load a backup Cisco IOS software image.	The process of upgrading the IOS is as important as the commands used to perform the upgrade, as mentioned in the previous exam topic. The process and the configuration are covered in Chapter 2.
52	List problems that each routing type encounters when dealing with topology changes, and describe techniques to reduce the number of these problems.	Chapter 7 covers IP routing protocols, including the theory and concepts behind routing protocols. Distance vector and link-state routing protocols are the two main categories.
53	Prepare the initial configuration of your router and enable IP.	You should be able to use setup mode, as well as configure the router using configuration mode. Both are covered in detail in Chapter 2.

01 CCNA Exam_Ch 01.fm Page 16 Thursday, March 7, 2002 11:43 AM

Cross-Reference Between Exam Topics and Book Chapters

Table 1-4 lists each exam topic, along with the chapter of the book in which the topic's concepts are covered.

Table 1-4 *CCNA Exam Topics Cross-Reference to Chapters*

Exam Topic	Chapter
1	4
2	4
3	5
4	5
5	3
6	3
7	3
8	3
9	3
10	3
11	3
12	3
13	4
14	4
15	4
16	4
17	4
18	4
19	4
20	6
21	6
22	6
23	6
24	11
25	6
26	3
27	7

Exam Topic	Chapter
28	7
29	10
30	10
31	10
32	9
33	9
34	9
35	8
36	8
37	8
38	4
39	4
40	4
41	4
42	2
43	2
44	2
45	2
46	2
47	2
48	2
49	2
50	2
51	2
52	7
53	2

01 CCNA Exam_Ch 01.fm Page 17 Thursday, March 7, 2002 11:43 AM

Cross-Reference Between Chapter and Exam Topics

Table 1-5 lists each chapter, along with the exam topics covered in that chapter.

Table 1-5 *CCNA Chapters Cross-Reference to Exam Topics*

Chapter	Exam Topics
2	42–51, 53
3	5–12, 26
4	1–2, 13–19, 38–41
5	3–4
6	20–24
7	27–28, 52
8	35–37
9	32–34
10	29–31
11	25

Recommended Training Paths for CCNA

Cisco recommends that you take two courses before you take the CCNA exam. The first, CCNA Basics (CCNAB), is a Web-based introductory course that you can order directly from most any learning partner, my company included. This course covers the basic protocol information needed for CCNA, with an emphasis on the OSI reference model.

The other suggested course is the instructor-led Interconnecting Cisco Network Devices (ICND) course, which is available from almost every Cisco training partner (for a list of training partners, go to www.cisco.com/warp/public/10/wwtraining/listAllTP.html).

So, if you have taken or will take the ICND, that's the best way to prepare for the CCNA exam. But what if you took the Cisco Networking Academy curriculum? Or what if you simply choose not to spend the money on an introductory course? The final section of this chapter suggests a strategy for people from each background.

First, an outline of the ICND course, shown in Table 1-6, should be helpful. Remember, although the CCNA exam is not a test on the ICND course, the ICND is the course that most closely matches the CCNA topics.

01 CCNA Exam_Ch 01.fm Page 18 Thursday, March 7, 2002 11:43 AM

Table 1-6 *ICND Course Summary*

Module Title	Topics in This Module
Interconnecting Cisco Networking Devices Introduction	Typical administrative details.
Internetworking Concepts Overview	OSI model details; common physical and data-link specifications; MAC address definition; description of Ethernet, Token Ring, and FDDI operation; a brief explanation of WAN data links.
Assembling and Cabling Cisco Devices	Basic physical setup and cabling.
Operating and Configuring a Cisco IOS Device	Logging in, initialization, modes of operation, passwords, help, command editing, and various **show** commands.
Managing Your Network Environment	Telnet, CDP, and managing the IOS and config files.
Catalyst 1900 Switch Operations	LAN switching concepts, spanning tree, and 1900 switch configuration.
Extending Switched Networks with Virtual LANs	Virtual LANs, VLAN trunking, and VLAN configuration on 1900 switches.
Interconnecting Networks with TCP/IP	Protocol stack versus OSI; application layer examples; TCP error recovery; TCP and UDP ports; TCP, UDP, and IP headers; and ICMP. For Class A, B, and C networks: IP addresses, mask subnetting, and planning; configuring IP addresses; configuring host names; configuring DNS; and verifying operation with **ping**, **trace**, and **show** commands.
Determining IP Routes	Configuring static routes, configuring default routes, interior versus exterior routing protocols, configuring RIP, debugging RIP, IGRP configuration, and IGRP **debug** and **show** commands.
Basic IP Traffic Management with Access Lists	The purpose of using access lists, logic diagrams, standard and extended access lists, and TCP/IP access lists; wildcard masks; configuring standard IP access lists; configuring extended access lists; monitoring IP access lists.
Configuring Novell IPX	Protocol versus OSI, IPX addresses, Novell encapsulation options, RIP, SAP, GNS, configuring IPX, displaying IPX, debugging IPX, and IPX access lists.
Establishing Serial Point-to-Point Connections	Telephone company service basics, survey of data-link protocols for WANs, SDLC/HDLC/PPP/LAPB framing, PPP functions, PAP and CHAP authentication, and PAP and CHAP configuration.
Completing an ISDN BRI Call	ISDN protocol basics and dial-on-demand routing (DDR).
Establishing a Frame Relay PVC Connection	Terminology, LMI messages, Inverse ARP, addressing, configuration, monitoring, configuration using subinterfaces, NBMA, and full and partial mesh issues.

01 CCNA Exam_Ch 01.fm Page 19 Thursday, March 7, 2002 11:43 AM

How to Use This Book to Pass the Exam

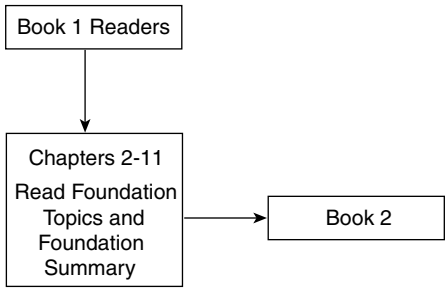
You can choose between two approaches to using this book. In some respects, the *CCNA Exam Certification Guide* is really two books—one book for each of two recommended ways to approach reading the book. "Book 1" guides the reader who is new to CCNA networking topics. If you use this approach, you know that you need to learn about all the topics covered on the exam. "Book 2" guides the reader who has already been to a CCNA-oriented class or who is experienced in these same topics. If you take this approach, you study more quickly, taking advantage of the fact that you already know parts of the knowledge that you need, so you just need to fill in the rest of your knowledge.

So, which method is right for you? Well, I recommend the Book 1 approach if you fall into the following categories:

- You already know that you want to read the book cover to cover.
- You have never been, or you have not recently been, to Cisco's official Interconnecting Cisco Network Devices (ICND) course.
- You have never been, or you have not recently been, to some other CCNA-oriented course or through the Cisco Networking Academy CCNA curriculum.
- You do not have much experience using Cisco routers and switches.

In short, if you need to learn, for the first time, most of the CCNA materials, then Book 1 is where you should start! Figure 1-2 outlines the Book 1 approach.

Figure 1-2 *How to Use This Book: Book 1*

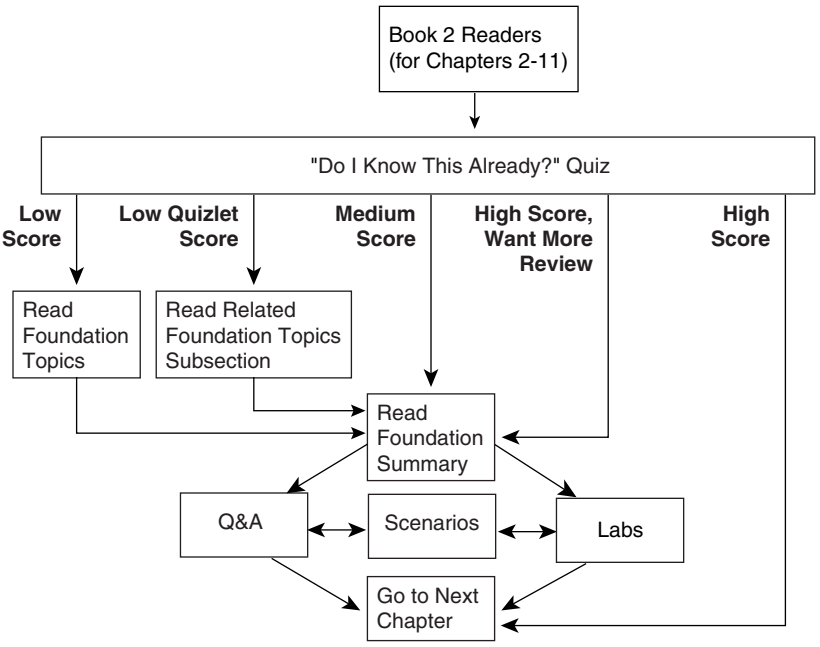


You will notice that you read the core parts of each chapter, ignoring each chapter's quizzes and scenarios. The quizzes and scenarios are most useful to fill in the final gaps in your learning—you will use these sections, but just not yet! You will also notice that, after reading the core parts of all the chapters, it is suggested that you move on to Book 2—the approach that helps you fill in the gaps of your memory.

01 CCNA Exam_Ch 01.fm Page 20 Thursday, March 7, 2002 11:43 AM

Book 2 helps you fill in the gaps in your knowledge and skills. Using the Book 2 approach, you will discover what you know and what you do not know, to focus your study on the topics that you have not mastered. Whether you read Book 1 first, or whether you already knew something about networking when you bought this book, Book 2 will help you with the final steps of preparation. You might not realize which topics you need to study and which topics you really already know, but Book 2 guides you through the process. Figure 1-3 outlines the process that I call Book 2.

Figure 1-3 *How to Use This Book: Book 2*

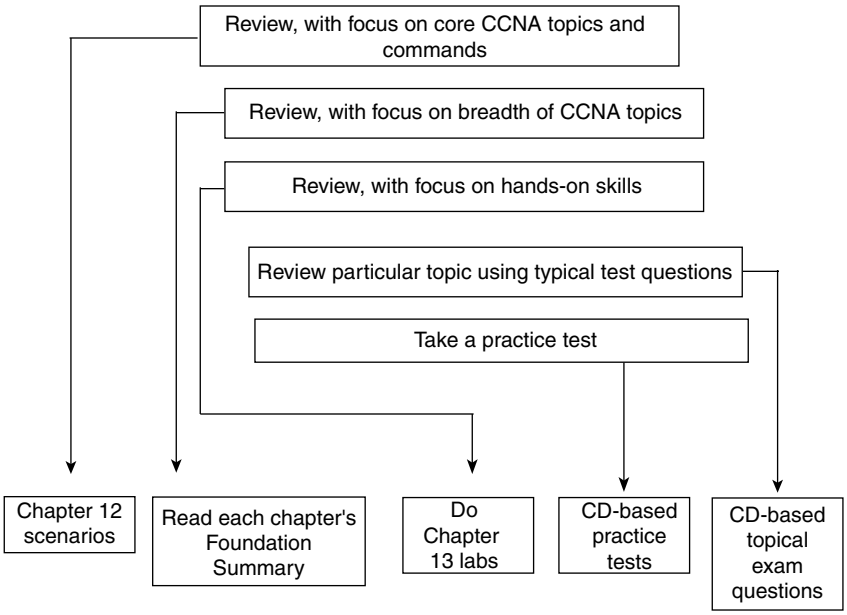


Chapters 2 through 11 begin with a quiz, which is broken into subdivisions called "quizlets." If you get a high score, you might simply review the "Foundation Summary" section at the end of the chapter because you already remember a lot. If you score well on one quizlet but low on another, you are directed to the section of the chapter corresponding to the quizlet on which your score was low. If you score less than 50 percent on the overall quiz, you should read the whole chapter. Of course, these are simply guidelines—if you score well but want more review on that topic, read away!

After completing the core chapters (Chapters 2 through 11), you have several options for your next study activity. Because Chapter 12, "Scenarios for Final Preparation," is the next chapter in succession, it outlines the directions on what to do at the end of your study, right before the test. These same directions are repeated here as well. Figure 1-4 outlines your options for final study for the exam.

01 CCNA Exam_Ch 01.fm Page 21 Thursday, March 7, 2002 11:43 AM

Figure 1-4 *How to Use This Book: Final CCNA Exam Preparation Strategy*



As shown, if you want even more final preparation, you can go over the many practice questions located in each chapter and on the CD. All prechapter quiz and chapter-ending questions, with answers, are in Appendix A, "Answers to the 'Do I Know This Already?' Quizzes and Q&A Sections." You can read and review these conveniently located questions and explanations quickly. The CD includes testing software as well as many additional questions in the format of the CCNA exam. These questions should be a valuable resource when performing final preparations.

You should also strongly consider getting some hands-on experience with real routers and switches. I imagine that most of you will want to do that, and those of you who have access to equipment at work can easily do that. For the rest of you, you might have to buy your own gear, use simulators, or rent lab time from companies such as my company, Skyline Computer. Although this book gives a large number of examples, lab scenarios, and lab exercises, there is no substitute for exercising your memory by actually doing real commands on real devices.

Anyone preparing for the CCNA exam can use the guidelines at the beginning of each chapter as a study aid. However, for some additional guidance, the final parts of this chapter give a few strategies for study, based on how you have prepared before buying this book. So, find the section that most closely matches your background in the next few pages, and read about some additional ideas to help you prepare. There is a section for people who have taken ICND, one for those from the Cisco Networking Academies, one for those who will not be taking any classes and have not had much experience, and a final set of strategies for those who will not be taking any classes but who have some experience.

01 CCNA Exam_Ch 01.fm Page 22 Thursday, March 7, 2002 11:43 AM

I've Taken ICND—Now What?

For starters, you've taken the best path to prepare yourself. But let me temper that with the fact that, if you retain more than 50 percent of what you heard in class, you are an extraordinary person! That said, you need the following two strategies:

Strategy 1: Begin by using the Book 2 approach because you already have learned a lot about the topics on the exam. Each of the core chapters of the book, Chapters 2 through 11, begins with a quiz that helps you assess what you need to study. The chapter then directs you to the appropriate sections in the chapter rather than requiring you to read all of each chapter.

Strategy 2: Use the directions at the beginning of Chapter 12 to direct your final study before the exam. Chapter 12 is designed to review many concepts, and it outlines a good process for study in the days leading up to your exam.

I've Taken the Cisco Networking Academy Courses—Now What?

First of all, congratulations on having the foresight to get into the Cisco Networking Academy program—we need more people who can make this stuff work! (Those of you who didn't take the Cisco Networking Academy track and are wondering what it's all about can check out http://www.cisco.com/warp/public/779/edu/academy/.) Thankfully, the Networking Academy curriculum actually does a great job of preparing you with the skills and knowledge you need to pass the exam. Unfortunately, your study was probably spread over several semesters, and possibly over a couple of years. So, the details that you do not use frequently might have been forgotten. Now, on to the strategies for success on CCNA:

Strategy 1: Pull out your Networking Academy curriculum and notes, and reread them. Most people's memory is exercised better by seeing familiar material—even more so when you wrote it down yourself. If you have ever taken a test and pictured in your mind where the answer was on your page of notes, you can relate.

Strategy 2: Use the Book 2 approach exactly as described here in Chapter 1. Each of the core chapters of the book, Chapters 2 through 11, begins with a quiz that helps you assess what you need to study. It then directs you to the appropriate sections in the chapter rather than requiring you to read all of each chapter.

Strategy 3: Make it a point to read the sections of this book that cover some of the theory behind networking and some of the standards. The biggest reason for that is that the Networking Academy is oriented more toward building practical skills than using theoretical knowledge. The suggested sections are listed here:

- Chapter 5—"Spanning-Tree Protocol"
- Chapter 7—"Distance Vector Routing Protocols"

Strategy 4: Use the directions at the beginning of Chapter 12 to direct your final study before the exam. Chapter 12 is designed to review many concepts, and it outlines a good process for study in the days leading up to your exam.

01 CCNA Exam_Ch 01.fm Page 23 Thursday, March 7, 2002 11:43 AM

This book should help you sift through the topics and choose the right areas for study, and it also should help you to not waste your time. Congratulations on your Networking Academy work—now add the CCNA certification to take away any doubt in the minds of prospective employers that you know Cisco!

I'm New to Internetworking with Cisco, I Will Not Be Taking the ICND Course, and This Book Is My Only Reference—Now What?

You can pass the CCNA exam without taking any courses. Of course, Cisco wants you to take the recommended courses for all the exams. Its motivation is not to make more money because Cisco does not actually deliver the training; the training partners do. Instead, Cisco truly believes that the more people understand its products, ultimately the happier its customers will be and the more products Cisco will sell. Cisco also believes that the official training is the right way to teach people about Cisco products, so you're encouraged to take the classes.

Of course, if you use only one reference and it is this one, thank you! However, no single book or course will provide every reader with everything they need, so a second source is usually very beneficial. If you are looking to save money but can afford one more book, the Cisco Press *Interconnecting Cisco Network Devices* (*ICND*) book is definitely the best companion. The CCNA exam lists ICND as the main prerequisite course before taking the exam. The Cisco Press ICND book contains the actual ICND course materials, which were given to Cisco Press by Cisco and then converted into book format. The same figures used in the presentations by ICND instructors are used as the figures in the ICND book, with explanations matching what a senior instructor might say when teaching the course. So, if you use one other reference, this is the one!

But, under the assumptions that you are new to Cisco and have only this book, here's what you should do:

Strategy 1: Start with the Book 1 approach to this book. Resist the temptation to read the quiz questions—they will actually help you more if you wait until later.
Strategy 2: After reading Book 1, use the Book 2 approach. Each of the core chapters of the book, Chapters 2 through 11, begins with a quiz that helps you assess what you need to study. It then directs you to the appropriate sections in the chapter rather than requiring you to read all of each chapter.
Strategy 3: Use the directions at the beginning of Chapter 12 to direct your final study before the exam. Chapter 12 is designed to review many concepts, and it outlines a good process for study in the days leading up to your exam.
Strategy 4: Find any and every opportunity to get your hands on some Cisco routers and switches. You will learn the user interface and command structures much more easily by doing rather than by reading!

01 CCNA Exam_Ch 01.fm Page 24 Thursday, March 7, 2002 11:43 AM

I'm New to Internetworking with Cisco, I Will Not Be Taking the ICND Course, and I Bought the *Interconnecting Cisco Network Devices* Book as Well—Now What?

If you have no networking experience at all, start with the ICND book. The CCNA exam lists ICND as the main prerequisite course before taking the exam. The Cisco Press ICND book contains the actual ICND course materials, handed over by Cisco to Cisco Press, and then converted into book format. The same figures used in the presentations by instructors are used as the figures in the book, with explanations matching what a senior instructor might say when teaching the course. So, if you use one other reference, this is the one!

Use the Cisco Press book, *Internetworking Technologies Handbook,* 3rd Edition, as a reference—it's got great 4–5 page synopses of what a particular technology is all about. If you want some quick review, and want to get a different perspective on it, use ITH.

After using ICND, you should take the Book 2 approach to using this book.

I've Learned a Lot About CCNA Topics Through Experience, but I Will Not Be Taking the ICND Course—Now What?

If you feel that you know a fair amount about CCNA topics already, but you are worried about the topics you simply just have not worked with, this strategy is for you. This book is designed to help you figure out what CCNA topics you need some help with and then help you learn about them. Here's the simple strategy for you:

Strategy 1: Use the Book 2 approach exactly as described in this chapter. Each of the core chapters of the book, Chapters 2 through 11, begins with a quiz that helps you assess what you need to study. It then directs you to the appropriate sections in the chapter rather than requiring you to read all of each chapter.

Strategy 2: Use the directions at the beginning of Chapter 12 to direct your final study before the exam. Chapter 12 is designed to review many concepts, and it outlines a good process for study in the days leading up to your exam.

You should be able to fill in the gaps in your knowledge this way and not risk being bored in the ICND class when it covers the topics you already know.

Conclusion

The CCNA certification is arguably the most important Cisco certification. It certainly is the most popular, is required for several other certifications, and is the first step in distinguishing yourself as someone who has proven knowledge of Cisco.

The *CCNA Exam 640-607 Certification Guide* is designed to help you attain CCNA certification. This is the CCNA certification book from the only Cisco-authorized publisher. We at Cisco Press believe that this book certainly can help you achieve CCNA certification—but the real work is up to you! I trust that your time will be well spent.

01 CCNA Exam_Ch 01.fm Page 25 Thursday, March 7, 2002 11:43 AM

Exam Topics in This Chapter

42 Examine router elements (RAM, ROM, CDP, **show**).

43 Manage configuration files from the privileged exec mode.

44 Control router passwords, identification, and banner.

45 Identify the main Cisco IOS Software commands for router startup.

46 Log in to a router in both user and privileged modes.

47 Check an initial configuration using the **setup** command.

48 Use the context-sensitive help facility.

49 Use the command history and editing features.

50 List the commands to load Cisco IOS Software from: Flash memory, a TFTP server, or ROM.

51 Prepare to back up, upgrade, and load a backup Cisco IOS Software image.

52 Prepare the initial configuration of your router and enable IP.

CHAPTER 2

Cisco IOS Software Fundamentals

Cisco routers run the Cisco Internetworking Operating System (IOS). So, as you would probably guess, all the questions about implementing something on a router require you to know all about the IOS. Although many topics on the CCNA exam do not relate to the actual implementation on Cisco gear, you probably will not pass the test if you do not know the details of how IOS works.

But do not despair! You need to know about the three main topics of the IOS, and most of this is basic. First, you must know about the IOS command-line interface (CLI)—how to access the interface and how to use it. Next, you need to know how configure the router, even though you might not know what you want to configure yet! Finally, you need to know about upgrading IOS Software; this requires a reboot of the router, so you also need to know what happens during the boot process. By the time you are finished with your CCNA study, the CLI and configuration topics in this chapter will be second nature, for the most part.

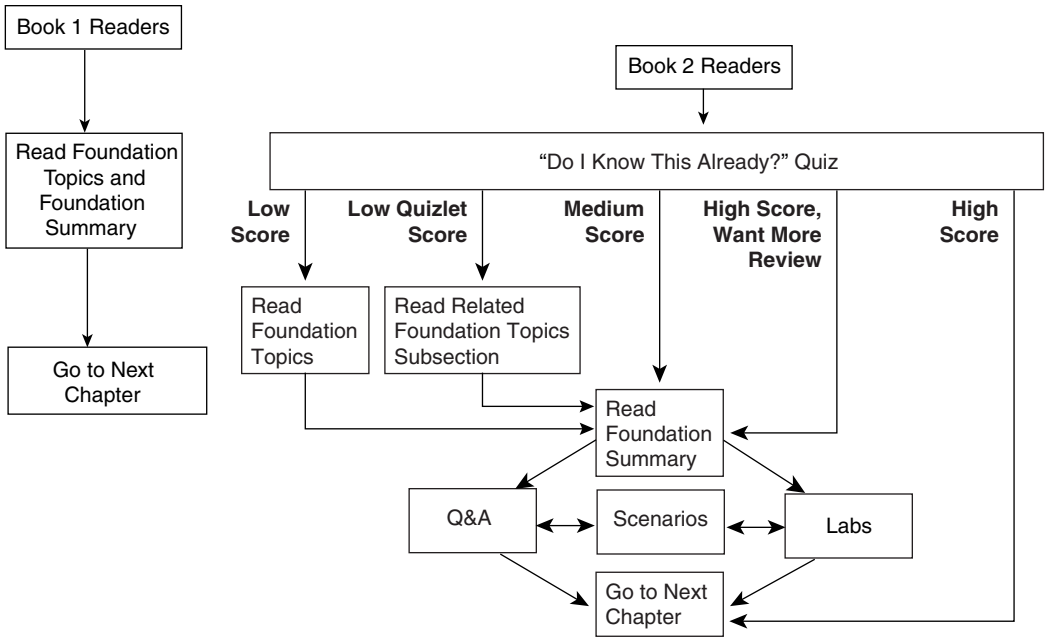
The IOS also runs on some Cisco switch models, and it uses CLI. However, in some cases, the IOS CLI on a switch is slightly different than on a router. In fact, the IOS on the 1900 series switches, on which the exam questions are based, is slightly different than on some other Cisco IOS-based switches. This chapter covers the IOS CLI on a router, and Chapter 4, "LANs, Bridges, and Switches," covers some details of the IOS CLI on LAN switches. Chapter 4 outlines the key differences between the IOS on routers and the IOS on 1900 series switches.

How to Best Use This Chapter

You can choose from two main approaches for using this book, which are described in Chapter 1, "All About the Cisco Certified Network Associate Certification," and are called "Book 1" and "Book 2." Book 1 is for readers who need a through background before their final study time; Book 2 is intended for readers who are reviewing and filling in the missing parts of their CCNA knowledge. Using Figure 2-1 as a guide, you should either read the Foundation sections of this chapter or begin with the "Do I Know This Already?" quiz.

02 CCNA Exam_Ch 02.fm Page 28 Thursday, March 7, 2002 11:44 AM

Figure 2-1 *How to Use This Chapter*



"Do I Know This Already?" Quiz

The purpose of the "Do I Know This Already?" quiz is to help you decide what parts of this chapter to use. If you already intend to read the entire chapter, you do not necessarily need to answer these questions now.

This 12-question quiz helps you determine how to spend your limited study time. The quiz is sectioned into three smaller four-question "quizlets," which correspond to the three major topic headings in the chapter. Figure 2-1 outlines suggestions on how to spend your time in this chapter based on your quiz score. Use Table 2-1 to record your scores.

Table 2-1 *Scoresheet for Quiz and Quizlets*

Quizlet Number	Foundation Topics Section Covering These Questions	Questions	Score
1	Cisco IOS Software and Its User Interface	1 to 4	
2	Configuration Processes and the Configuration File	5 to 8	
3	Managing Cisco IOS Software Images	9 to 12	
All questions		1 to 12	

02 CCNA Exam_Ch 02.fm Page 29 Thursday, March 7, 2002 11:44 AM

1 What are the two different names for the router's mode of operation that, when accessed, enables you to issue commands that could be disruptive to router operations?

2 What command would you use to receive command help if you knew that a **show** command option begins with a *c* but you could not recall the option?

3 After typing **show ip route,** which is the only command that you issued since logging in to the router, you now want to issue the **show ip arp** command. What steps would you take to execute this command by using command-recall keystrokes?

4 What is the name of the user interface mode of operation used when you cannot issue disruptive commands?

5 What configuration command causes the router to require a password from a user at the console? What configuration mode context must you be in? (That is, what command(s) must be typed before this command after entering configuration mode?) List the commands in the order in which they must be typed while in config mode.

6 What does the "NV" stand for in NVRAM?

02 CCNA Exam_Ch 02.fm Page 30 Thursday, March 7, 2002 11:44 AM

7 Name two commands used to view the configuration that is currently used in a router. Which one is a more recent addition to the IOS?

_____

_____

_____

8 Name two commands used to view the configuration to be used at the next reload of the router. Which one is a more recent addition to the IOS?

_____

_____

_____

9 What two methods could a router administrator use to cause a router to load the IOS stored in ROM?

_____

_____

_____

10 What is the process used to update the contents of Flash memory so that a new IOS in a file called c4500-d-mz.120-5.bin, on TFTP server 128.1.1.1, is copied into Flash memory?

_____

_____

_____

11 Two different IOS files are in a router's Flash memory: one called c2500-j-l.111-3.bin and one called c2500-j-l.112-14.bin. Which one does the router use when it boots up? How could you force the other IOS file to be used? Without looking at the router configuration, what command could be used to discover which file was used for the latest boot of the router?

_____

_____

_____

12 What are the primary purposes of Flash memory in a Cisco router?

_____

_____

_____

02 CCNA Exam_Ch 02.fm Page 31 Thursday, March 7, 2002 11:44 AM

The answers to the "Do I Know This Already?" quiz are found in Appendix A, "Answers to the 'Do I Know This Already?' Quizzes and Q&A Sections." The suggested choices for your next step are as follows:

- **6 or less overall score**—Read the entire chapter. This includes the "Foundation Topics" and "Foundation Summary" sections, the Q&A section, and the scenarios at the end of the chapter.
- **2 or less on any quizlet**—Review the subsection(s) of the "Foundation Topics" part of this chapter, based on Table 2-1. Then move on to the "Foundation Summary" section, the Q&A section, and the scenarios at the end of the chapter.
- **7, 8, or 9 overall score**—Begin with the "Foundation Summary" section and then go to the Q&A section and the scenarios at the end of the chapter.
- **10 or more overall score**—If you want more review on these topics, skip to the "Foundation Summary" section and then go to the Q&A section and the scenarios at the end of the chapter. Otherwise, move to the next chapter.

02 CCNA Exam_Ch 02.fm Page 32 Thursday, March 7, 2002 11:44 AM

Foundation Topics

The Cisco IOS Software Command-Line Interface

42 Examine router elements (RAM, ROM, CDP, **show**).

44 Control router passwords, identification, and banner.

45 Identify the main Cisco IOS Software commands for router startup.

46 Log in to a router in both user and privileged modes.

48 Use the context-sensitive help facility.

49 Use the command history and editing features.

The majority of Cisco routers run Cisco IOS Software, with its familiar command-line interface (CLI). Some routing cards in other devices also run Cisco IOS Software. For example, the Multilayer Switch Feature Card (MSFC) daughter card for the Catalyst 6000 series LAN switches performs routing functions and executes IOS. Understanding the Cisco IOS Software CLI is as fundamental to supporting routers as understanding addition is to being able to do math problems!

The exam topics covered in this section will become second nature to you as you work with Cisco routers and switches more often. In fact, because this book purposefully was written for an audience that already has some training and experience with Cisco routers, several of the details in this chapter might already be ingrained in your memory. If you would like more review, or if you are still new to the IOS, read on—the details in this section are important to using Cisco routers and switches. This chapter reviews such topics as the CLI and how to navigate the IOS command set using help and key sequences for command editing and recall.

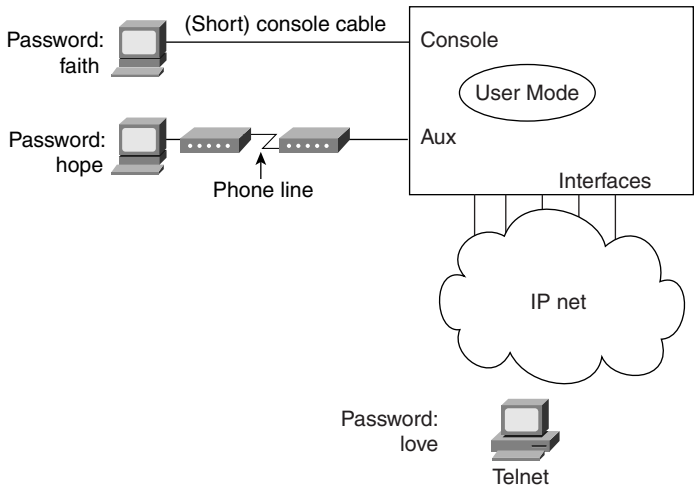
Access to the CLI

Cisco uses the acronym CLI to refer to the terminal user command-line interface to the IOS. The term *CLI* implies that the user is typing commands at a terminal, a terminal emulator, or a Telnet connection. Although you can pass the CCNA exam without ever having used the CLI, actually using the CLI will greatly enhance your chances.

02 CCNA Exam_Ch 02.fm Page 33 Thursday, March 7, 2002 11:44 AM

To access the CLI, use one of three methods, as illustrated in Figure 2-2.

Figure 2-2 *CLI Access*



You access the router through the console, through a dialup device through a modem attached to the auxiliary port, or by using Telnet. In any case, you enter *user exec mode* first. User exec mode, also sometimes called user mode, allows you to look but not break anything. The passwords shown in Figure 2-2 are not defaults—those passwords would be required if the configuration used in Table 2-2 were used. The console, auxiliary, and Telnet passwords are all set separately.

Table 2-2 *CLI Password Configuration*

Access from . . .	Password Type	Configuration
Console	Console password	**line console** *0* **login** **password** *faith*
Auxiliary	Auxiliary password	**line aux** *0* **login** **password** *hope*
Telnet	vty password	**line vty** *0 4* **login** **password** *love*

02 CCNA Exam_Ch 02.fm Page 34 Thursday, March 7, 2002 11:44 AM

Passwords are required for Telnet and auxiliary access as of Cisco IOS Software Release 12.*x*, and the exam is based on Cisco IOS Software Release 12.2. However, there are no preconfigured passwords—therefore, you must configure passwords for Telnet and auxiliary access from the console first.

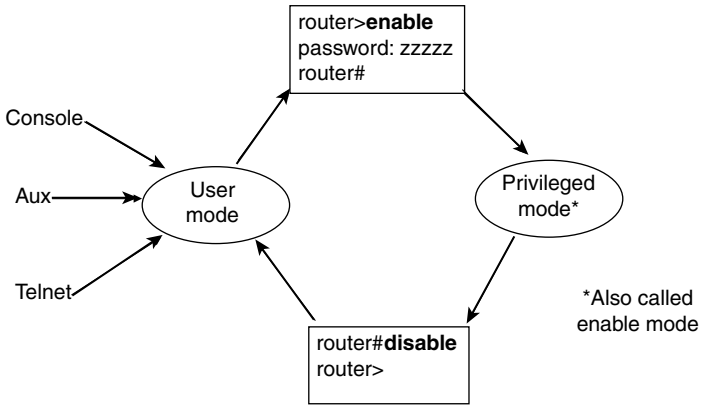
All Cisco routers have a console port, and most have an auxiliary port. The console port is intended for local administrative access from an ASCII terminal or a computer using a terminal emulator. The auxiliary port, which is missing on a few models of Cisco routers, is intended for asynchronous dial access from an ASCII terminal or terminal emulator; the auxiliary port is often used for dial backup.

This chapter focuses on the process of using the CLI. However, if you see a command in this chapter, you probably should remember it. In this case, the first command in each configuration is a context-setting command, as described later in this chapter. But, as you see, the second and third commands would be ambiguous if we did not supply some additional information, such as whether the **password** command was for the console, aux, or Telnet. The **login** command actually tells the router to display a password prompt. The **password** commands specify the text password to be typed by the user to gain access. Typically, all three passwords have the same value because they all let you get into user mode.

Several concurrent Telnet connections to a router are allowed. The **line vty** *0 4* command signifies that this configuration applies to vtys (virtual teletypes/terminals) 0 through 4. Only these five vtys are allowed by the IOS, unless it is an IOS for a dial access server, such as a Cisco AS5300. All five vtys typically have the same password, which is handy because users connecting to the router through Telnet cannot choose which vty they get.

User exec mode is one of two command exec modes in the IOS user interface. *Enable* mode (also known as *privileged* mode or *privileged* exec mode) is the other. Enable mode is so named because the **enable** command is used to reach this mode, as shown in Figure 2-3; privileged mode earns its name because powerful, or privileged, commands can be executed there.

Figure 2-3 *User and Privileged Modes*



02 CCNA Exam_Ch 02.fm Page 35 Thursday, March 7, 2002 11:44 AM

CLI Help Features

If you printed the IOS Command Reference documents, you would end up with a stack of paper several feet tall. No one should expect to memorize all the commands—and no one does in real life, either. Several very easy, convenient tools can be used to help you remember commands and then also save you time typing. As you progress through your Cisco certifications, the exam will cover progressively more commands. However, the only Cisco exam that covers the methods of getting command help is the CCNA exam. So, the following details are important in real life as well as for cramming for the exam.

Table 2-3 summarizes command-recall help options available at the CLI. Note that in the first column, "Command" represents any command. Likewise, "parm" represents a command's parameter. For instance, the third row lists "command ?," which means that commands such as **show ?** and **copy ?** would list help for the **show** and **copy** commands, respectively.

Table 2-3 *Cisco IOS Software Command Help*

What You Type	The Help You Get
?	Help for all commands available in this mode.
Help	Text describing how to get help. No actual command help is given.
Command ?	Text help describing all the first parameter options for the command.
com?	A list of commands that start with "com."
Command parm?	This style of help lists all parameters beginning with "parm." (Notice that no spaces exist between "parm" and the ?.)
command parm<Tab>	If you press the Tab key midword, the CLI will either spell the rest of this parameter at the command line or do nothing. If the CLI does nothing, it means that this string of characters represents more than one possible next parameter, so the CLI does not know which to spell out.
command parm1 ?	If a space is inserted before the question mark, the CLI lists all the next parameters and gives a brief explanation of each.

When you type the **?**, IOS's CLI reacts immediately; that is, you don't need to press the Enter key or any other keys. The router also redisplays what you typed before the **?**, to save you some keystrokes. If you press Enter immediately after the **?**, IOS tries to execute the command with only the parameters that you have typed so far.

"Command" represents any command, not the word *command*. Likewise, "parm" represents a command's parameter, not the word *parameter*.

The information supplied by using help depends on the CLI mode. For example, when **?** is typed in user mode, the commands allowed only in privileged exec mode are not displayed. Also, help is available in configuration mode; only configuration commands are displayed in that mode of operation.

02 CCNA Exam_Ch 02.fm Page 36 Thursday, March 7, 2002 11:44 AM

IOS stores the commands that you type in a history buffer, storing ten commands by default. You can change the history size with the **terminal history size** *x* command, where *x* is the number of commands for the CLI to recall; this can be set to a value between 0 and 256. You can then retrieve commands so that you do not have to retype the commands. Table 2-4 lists the commands used to manipulate previously typed commands.

Table 2-4 *Key Sequences for Command Edit and Recall*

Keyboard Command	What You Get
Up arrow or Ctrl-p	This displays the most recently used command. If it is pressed again, the next most recent command appears until the history buffer is exhausted. (The *p* stands for *previous*.)
Down arrow or Ctrl-n	If you have gone too far back into the history buffer, these keys will go forward, in order, to the more recently typed commands. (The *n* is for *next*.)
Left arrow or Ctrl-b	This moves the cursor backward in the currently displayed command without deleting characters. (The *b* stands for *back*.)
Right arrow or Ctrl-f	This moves the cursor forward in the currently displayed command without deleting characters. (The *f* stands for *forward*.)
Backspace	This moves the cursor backward in the currently displayed command, deleting characters.
Ctrl-a	This moves the cursor directly to the first character of the currently displayed command.
Ctrl-e	This moves the cursor directly to the end of the currently displayed command.
Esc-b	This moves the cursor back one word in the currently displayed command.
Esc-f	This moves the cursor forward one word in the currently displayed command.
Ctrl-r	This creates a new command prompt, followed by all the characters typed since the last command prompt was written. This is particularly useful if system messages confuse the screen and it is unclear what you have typed so far.

02 CCNA Exam_Ch 02.fm Page 37 Thursday, March 7, 2002 11:44 AM

Syslog and debug

Start Extra Credit

IOS creates messages when different events occur and, by default, sends them to the console. These messages are called *syslog* messages. If you have used the console of a router for any length of time, you likely have noticed these messages—and when they are frequent, you probably became a little frustrated.

The router also generates messages that are treated like syslog messages in response to some troubleshooting tasks that you might perform. The **debug** command is one of the key diagnostic tools for troubleshooting difficult problems on a router. **debug** enables monitoring points in the IOS and generates messages that describe what the IOS is doing and seeing. When any **debug** command option is enabled, the router processes the messages with the same logic as other syslog messages. Beware: Some **debug** options create so many messages that the IOS cannot process them all, possibly crashing the IOS.

End Extra Credit

NOTE The **no debug all** command disables all debugs. Before enabling an unfamiliar **debug** command option, issue a **no debug all** and then issue the **debug** that you want to use; then quickly retrieve the **no debug all** command. If the messages are voluminous, press Enter immediately, executing the **no debug all** command to try to prevent the router from crashing by immediately disabling all debugs**.**

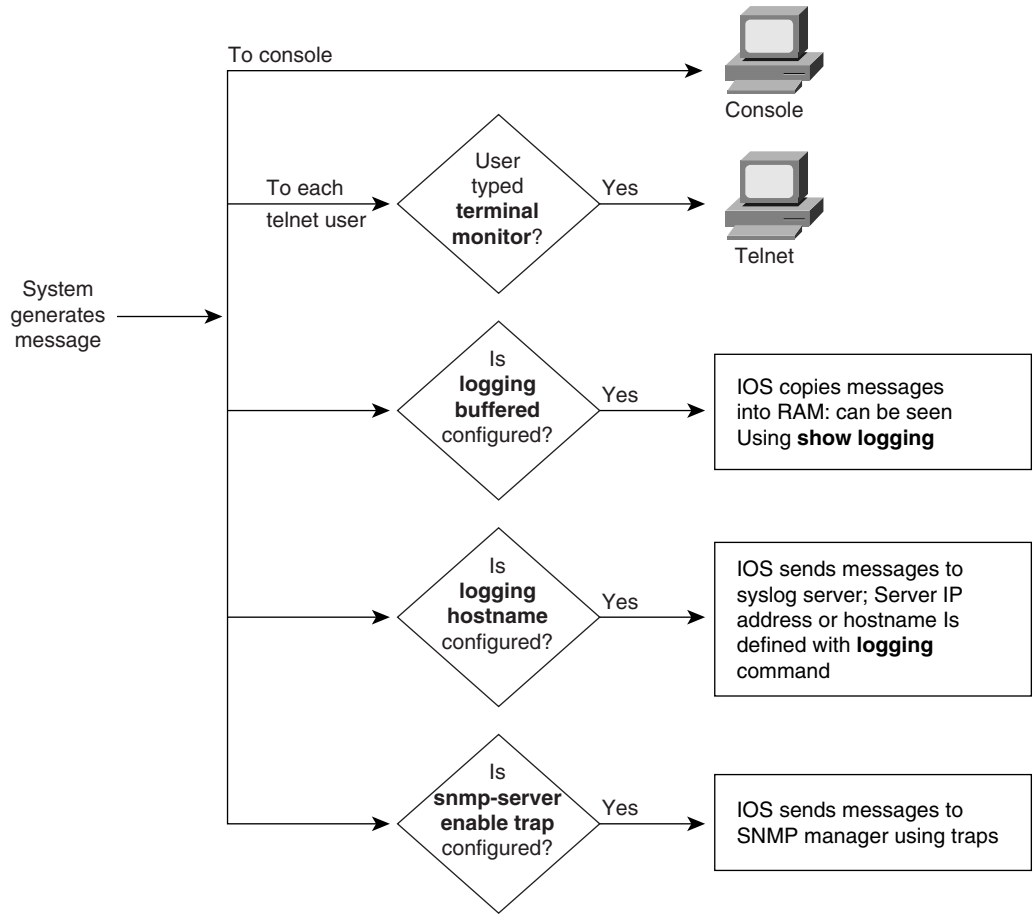
You might or might not be interested in seeing the messages as they occur. The console port always receives syslog messages. When you Telnet to the router, however, no syslog messages are seen unless you issue the **terminal monitor** command. This command simply means that this terminal is monitoring syslog messages. Another alternative for viewing syslog messages is to have the IOS record the syslog messages in a buffer in RAM and then use the **show logging** command to display the messages. For Telnet users, having the messages buffered using the global config command **logging buffered** is particularly useful. Because Telnet users do not get syslog messages by default anyway, these users can wait and look at syslog messages when desired. Finally, the **logging synchronous** line-configuration subcommand can be used for the console and vtys to tell the router to wait until the last command output is displayed before showing any syslog messages onscreen. That provides a little less interruption.

02 CCNA Exam_Ch 02.fm Page 38 Thursday, March 7, 2002 11:44 AM

Syslog messages also can be sent to another device. Two alternatives exist: sending the messages to a syslog server, and sending the messages as SNMP traps to a management station. The **logging** *host* command, where *host* is the IP address or host name of the syslog server, is used to enable sending messages to the external server. After SNMP is configured, the **snmp-server enable traps** tells the IOS to forward traps, including syslog messages.

Figure 2-4 summarizes the flow of syslog messages, including debug messages. For a more detailed view of syslog messages, including restricting messages based on message severity, refer to the Cisco IOS Software documentation CD manual called "Troubleshooting Commands."

Figure 2-4 *Syslog Message Flows*



02 CCNA Exam_Ch 02.fm Page 39 Thursday, March 7, 2002 11:44 AM

Configuring Cisco IOS Software

43 Manage configuration files from the privileged exec mode.

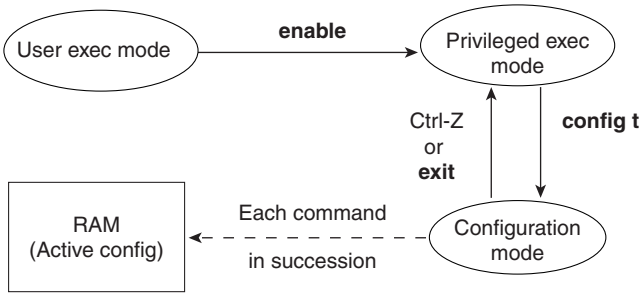
47 Check an initial configuration using the **setup** command.

53 Prepare the initial configuration of your router and enable IP.

You must understand how to configure a Cisco router to succeed on the exam—or to succeed in supporting Cisco routers. This section covers the basic configuration processes, including the concept of a configuration file and the locations in which the configuration files can be stored.

As mentioned in Chapter 1, *configuration mode* is another mode for the Cisco CLI, similar to user mode and privileged mode. User mode allows commands that are not disruptive to be issued, with some information being displayed to the user. Privileged mode supports a superset of commands compared to user mode, including commands that might harm the router. However, none of the commands in user or privileged mode changes the configuration of the router. Configuration mode is another mode in which configuration commands are typed. Figure 2-5 illustrates the relationships among configuration mode, user exec mode, and privileged exec mode.

Figure 2-5 *CLI Configuration Mode versus Exec Modes*



Commands typed in configuration mode update the active configuration file. *These changes to the configuration occur immediately each time you press the Enter key at the end of a command.* Be careful when you type in a configuration command!

Configuration mode itself contains a multitude of *subcommand modes*. Context-setting commands move you from one configuration subcommand mode to another. These context-setting commands tell the router the topic about which you will type the next few configuration commands. More importantly, they tell the router what commands to list when you ask for help.

02 CCNA Exam_Ch 02.fm Page 40 Thursday, March 7, 2002 11:44 AM

After all, the whole reason for these contexts is to make online help more convenient and clear for you. So, if you are confused now, hang on—the next sample will clarify what I mean.

NOTE *Context setting* is not a Cisco term—it's just a term used here to help make sense of configuration mode.

The **interface** command is the most commonly used context-setting configuration command. As an example, the CLI user could enter interface configuration mode after typing the **interface ethernet 0** configuration command. Command help in Ethernet interface configuration mode displays only commands that are useful when configuring Ethernet interfaces. Commands used in this context are called *subcommands*—or, in this specific case, *interface subcommands*. If you have significant experience using the CLI in configuration mode, much of this will be second nature. From a CCNA exam perspective, recalling whether popular commands are global commands or subcommands will be useful, but you should really focus on the particular commands covered here. As a side effect, you will learn whether the commands are global configuration commands or subcommands.

No set rules exist for what commands are global commands or subcommands. Generally, however, when multiple instances of a parameter can be set in a single router, the command used to set the parameter is likely a configuration subcommand. Items that are set once for the entire router are likely global commands. For instance, the **hostname** command is a global command because there is only one host name per router. The **interface ethernet 0** command is a global configuration command because there is only one such interface in this router. Finally, the **ip address** command is an interface subcommand that sets the IP address on the interface; each interface will have a different IP address.

Use Ctrl-z from any part of configuration mode (or use the **exit** command from global configuration mode) to exit configuration mode and return to privileged exec mode. The configuration mode **end** command also exits from any point in the configuration mode back to privileged exec mode. The **exit** commands from submodes or contexts of configuration mode back up one level toward global configuration mode.

Example Configuration Process

Example 2-1 illustrates how the console password is defined; provides banner, host name, prompt, and interface descriptions; and shows the finished configuration. The lines beginning with "!" are comment lines that highlight significant processes or command lines within the example. The **show running-config** command output also includes comment lines with just a "!" to make the output more readable—many comment lines in the examples in this book were added to explain the meaning of the configuration. You should remember the process as well as these particular commands for the CCNA exam.

02 CCNA Exam_Ch 02.fm Page 41 Thursday, March 7, 2002 11:44 AM

Example 2-1 *Configuration Process Example*

```
User Access Verification

Password:
Router>enable
Password:
Router #configure terminal
Router(config)#enable password lu
Router(config)#line console 0
Router(config-line)#login
Router(config-line)#password cisco
Router(config-line)#hostname Critter
Critter(config)#prompt Emma
Emma(config)#interface serial 1
Emma(config-if)#description this is the link to Albuquerque
Emma(config-if)#exit
Emma(config)#exit
Emma#
Emma#show running-config
Building configuration...

Current configuration:
!
version 12.2  934 bytes
! Version of IOS on router, automatic command


service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname Critter
prompt Emma
!
enable password lu
!
ip subnet-zero
no ip domain-lookup
!
interface Serial0
!
interface Serial1
 description this is the link to Albuquerque
!
interface Ethernet0
!
ip classless
no ip http server
line con 0
 password cisco
```

continues

02 CCNA Exam_Ch 02.fm Page 42 Thursday, March 7, 2002 11:44 AM

Example 2-1 *Configuration Process Example (Continued)*

```
 login
!
line aux 0
line vty 0 4
!
end
```

Several differences exist between user and privileged mode, compared to configuration mode. The **configure terminal** command is used to move into configuration mode. The command prompt changes based on the configuration subcommand mode that you are in. Plus, typing a **?** in configuration mode gives you help just on configuration commands.

When you change from one configuration mode to another, the prompt changes. Example 2-2 repeats the same example as in Example 2-1, but with annotations for what is happening.

Example 2-2 *Configuration Process with Annotations*

```
User Access Verification

Password:
Router>enable
!In user mode, then you type the enable command
Password:
Router #configure terminal
!In privileged mode, using the configure terminal command to enter global
Router(config)#enable password lu
!The enable password command is a global command – so the prompt stays as a global
  command prompt
Router(config)#line console 0
!line console changes the context to console line configuration mode
Router(config-line)#login
!login is a console subcommand, so the prompt remains the same
Router(config-line)#password cisco
!password is also a console sub-command
Router(config-line)#hostname Critter
!hostname is a global command, so it is used, and the mode changes back to global
  config mode
Critter(config)#prompt Emma
!prompt is a global command, so the prompt stays as a global command mode prompt
Emma(config)#interface serial 1
!interface changes contexts to interface subcommand mode
Emma(config-if)#description link to Albuquerque
!description is a sub-command in interface config mode, so prompt stays the same
Emma(config-if)#exit
!exit backs up one mode towards global
Emma(config)#exit
!exit in global mode exits back to privileged mode
```

02 CCNA Exam_Ch 02.fm Page 43 Thursday, March 7, 2002 11:44 AM

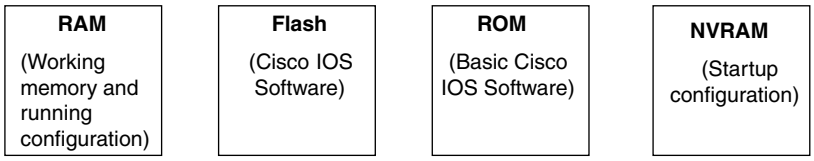
Router Memory, Processors, and Interfaces

The configuration file contains the configuration commands that you have typed, as well as some configuration commands entered by default by the router. The configuration file can be stored in a variety of places, including two inside a router. The router has a couple of other types of memory as well:

- **RAM**—Sometimes called DRAM for dynamic random-access memory, RAM is used by the router just as it is used by any other computer: for working storage. The *running* or *active configuration* file is stored here.
- **ROM**—This type of memory (read-only memory) stores a bootable IOS image, which is not typically used for normal operation. ROM contains the code that is used to boot the router until the router knows where to get the full IOS image, or as a backup bootable image in case there are problems.
- **Flash memory**—Either an EEPROM or a PCMCIA card, Flash memory stores fully functional IOS images and is the default location where the router gets its IOS at boot time. Flash memory also can be used to store configuration files on some Cisco routers.
- **NVRAM**—Nonvolatile RAM stores the initial or *startup* configuration file.

All these types of memory, except RAM, are permanent memory. No hard disk or diskette storage exists on Cisco routers. Figure 2-6 summarizes the use of memory in Cisco routers.

Figure 2-6 *Cisco Router Memory Types*



The processors in the routers vary from model to model. Although knowledge of them is not specifically listed as a requirement for the CCNA exam, some reference to terminology is useful. In most routers, only one processor option is available; thus, you would not order a specific processor type or card. The exception to this is the 7200 and 7500 families of routers. For instance, on the 7500 series, you choose either a Route Switch Processor 1 (RSP-1), RSP-2, or RSP-4 processor. In any case, all 7200 and 7500 routers, as well as most of the other Cisco router families, run IOS. This commonality enables Cisco to formulate exams, such as CCNA, that cover the IOS features without having to cover many hardware details.

The terminology used to describe the physical interfaces used for routing packets and bridging frames varies based on the model of router. Also, the types of interfaces available change over time because of new technology. For example, Packet over SONET and voice interfaces are relatively recent additions to the product line. However, some confusion exists about what to call the actual cards that house the physical interfaces. Table 2-5 summarizes the terminology that might be referred to on the test.

02 CCNA Exam_Ch 02.fm Page 44 Thursday, March 7, 2002 11:44 AM

Table 2-5 *Samples of Router Interface Terminology*

Model Series	What Cisco IOS Software Calls Interfaces	What the Product Catalog Calls the Cards with the Interfaces on Them
2500	Interface	Modules and WAN interface cards
2600/3600	Interface	Network modules and WAN interface cards
4500	Interface	Network processor modules
7200	Interface	Port adapters and service adapters
7500	Interface	Interface processors and versatile interface processors with port adapters

But there is hope! Cisco IOS Software always uses the term *interfaces* rather than any of the other terms, so IOS commands familiar on one platform will be familiar on another. Some nuances are involved in numbering the interfaces, however. In some smaller routers, the interface number is a single number. However, with some other families of routers, the interface is numbered first with the slot in which the card resides, followed by a slash and then the port number on that card. For example, port 3 on the card in slot 2 would be interface 2/3. Numbering starts with 0 for card slots and 0 for ports on any card. In some cases, the interface is defined by three numbers: first the card slot, then the daughter card (typically called a port adapter), and then a number for the physical interface on the port adapter. The 2600 and 3600 families also use a slot/port numbering scheme.

In this book, the single-digit interface numbers are used simply for consistency and readability.

If you want to dig deeper, you might want to read about processors and interfaces in the Cisco Product Catalog (http://www.cisco.com/univercd/cc/td/doc/pcat/).

Managing Configuration Files

The CCNA exam requires that you be able to distinguish between the configuration file used at startup and the active, running configuration file. The startup configuration file is in NVRAM; the other file, which is in RAM, is the one that the router uses during operation. When the router first comes up, the router copies the stored configuration file from NVRAM into RAM, so the running and startup configuration files are identical at that point. Also, exterior to the router, configuration files can be stored as ASCII text files anywhere using TFTP or FTP.

Example 2-3 demonstrates the basic interaction between the two files. In this example, the **show running-config** and **show startup-config** commands are used. These commands display the currently used, active*, running* configuration, and the stored, *startup* configuration used when the router boots, respectively. The full command output is not shown; instead, you can see only a brief excerpt including the **host** command, which will be changed several times. (Notes are included inside the example that would not appear if doing these commands on a real router.)

02 CCNA Exam_Ch 02.fm Page 45 Thursday, March 7, 2002 11:44 AM

Example 2-3 *Configuration Process Example*

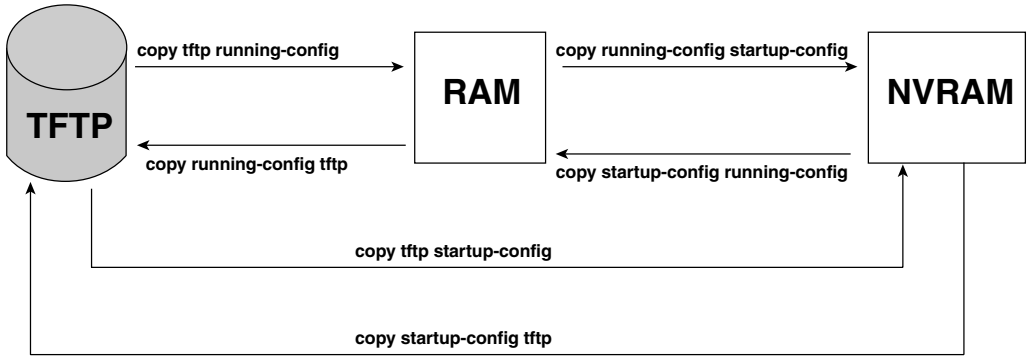
```
hannah#show running-config
… (lines omitted)
hostname hannah
… (rest of lines omitted)

hannah#show startup-config
… (lines omitted)
hostname hannah
… (rest of lines omitted)
hannah#configure terminal
hannah(config)#hostname jessie
jessie(config)#exit
jessie#show running-config
… (lines omitted)
hostname jessie
… (rest of lines omitted – notice that the running configuration reflects the
  changed hostname)
jessie# show startup-config
… (lines omitted)
hostname hannah
… (rest of lines omitted – notice that the changed configuration is not shown
  in the startup config)
```

If you reload the router now, the host name would revert back to hannah. However, if you want to keep the changed host name of jessie, you would use the command **copy running-config startup-config**, which overwrites the current startup-config file with what is currently in the running configuration file.

The **copy** command can be used to copy files in a router, most typically a configuration file, or a new version of the IOS Software. The most basic method for moving configuration files in and out of a router is by using a TFTP server. The **copy** command is used to move configuration files among RAM, NVRAM, and a TFTP server. The files can be copied between any pair, as Figure 2-7 illustrates.

Figure 2-7 *Locations for Copying and Results from Copy Operations*



02 CCNA Exam_Ch 02.fm Page 46 Thursday, March 7, 2002 11:44 AM

The commands can be summarized as follows:

```
copy {tftp | running-config | startup-config} {tftp | running-config | startup-config}
```

The first parameter is the "from" location; the next one is the "to" location. (Of course, choosing the same option for both parameters is not allowed.)

The **copy** command does not always replace the existing file that it is copying. Any **copy** command option moving a file into NVRAM or a TFTP server replaces the existing file—that's the easy, straightforward action. Effectively, any **copy** into RAM works just as if you typed the commands in the "from" configuration file in the order listed in the config file.

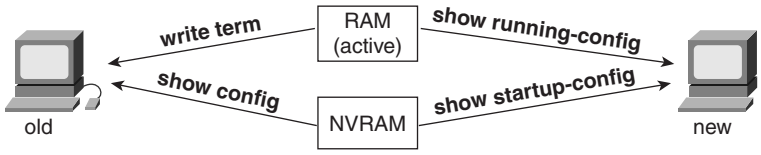
So, who cares? Well, we do. If you change the running config and then decide that you want to revert to what's in the startup-config file, the only way to guarantee that is to issue the **reload** command, which reloads, or reboots, the router.

Two key commands can be used to erase the contents of NVRAM. The **write erase** command is the older command, and the **erase startup-config** command is the newer command. Both simply erase the contents of the NVRAM configuration file. Of course, if the router is reloaded at this point, there will be no initial configuration.

Viewing the Configuration and Old-Style Configuration Commands

Once upon a time, commands that were used to display and move configuration files among RAM, NVRAM, and TFTP did not use easy-to-recall parameters such as **startup-config** and **running-config**. In fact, most people could not remember the commands or got the different ones confused. Figure 2-8 shows both the old and the new commands used to view configurations.

Figure 2-8 *Configuration* **show** *Commands*



Initial Configuration (Setup Mode)

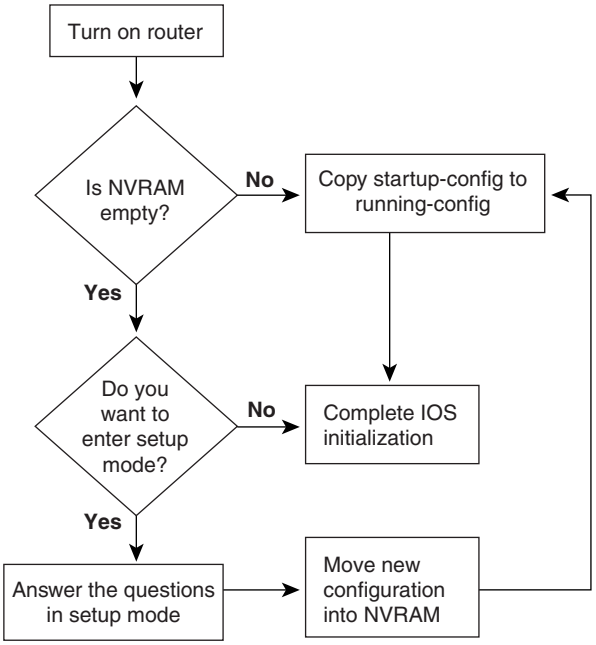
Setup mode leads a router administrator to a basic router configuration by using questions that prompt the administrator for basic configuration parameters. Instead of using setup mode, a Cisco router can be configured using the CLI in configuration mode. In fact, most networking personnel do not use setup at all, but new users sometimes like to use setup mode, particularly until they become more familiar with the CLI configuration mode.

02 CCNA Exam_Ch 02.fm Page 47 Thursday, March 7, 2002 11:44 AM

NOTE If you plan to work with Cisco routers much, you should become accustomed with the CLI configuration mode discussed earlier. Setup mode allows only basic configuration. Both topics are covered on the CCNA exam.

Figure 2-9 and Example 2-4 describe the process used by setup mode. Setup mode is most frequently used when the router boots, and it has no configuration in NVRAM. Setup mode also can be entered by using the **setup** command from privileged mode.

Figure 2-9 *Getting into Setup Mode*



Example 2-4 shows a screen capture of using setup mode after booting a router with no configuration in NVRAM.

Example 2-4 *Router Setup Configuration Mode*

```
         --- System Configuration Dialog ---

Would you like to enter the initial configuration dialog? [yes/no]: yes
At any point you may enter a question mark '?' for help.
Use ctrl-c to abort configuration dialog at any prompt.
Default settings are in square brackets '[]'.Basic management setup configures
  only enough connectivity
```

continues

02 CCNA Exam_Ch 02.fm Page 48 Thursday, March 7, 2002 11:44 AM

Example 2-4 *Router Setup Configuration Mode (Continued)*

```
for management of the system, extended setup will ask you
to configure each interface on the system

Would you like to enter basic management setup? [yes/no]: no
First, would you like to see the current interface summary? [yes]:
Any interface listed with OK? value "NO" does not have a valid configuration

Interface                IP-Address      OK? Method Status                Protocol
Ethernet0                unassigned      NO  unset  up                    down
Serial0                  unassigned      NO  unset  down                  down
Serial1                  unassigned      NO  unset  down                  down

Configuring global parameters:

  Enter host name [Router]: R1  The enable secret is a password used to protect
    access to
  privileged EXEC and configuration modes. This password, after
  entered, becomes encrypted in the configuration.
  Enter enable secret: cisco
The enable password is used when you do not specify an
  enable secret password, with some older software versions, and
  some boot images.
  Enter enable password: fred
The virtual terminal password is used to protect
  access to the router over a network interface.
  Enter virtual terminal password: barney
Configure SNMP Network Management? [yes]: no
Configure bridging? [no]:
Configure DECnet? [no]:
Configure AppleTalk? [no]:
Configure IPX? [no]:
Configure IP? [yes]:
Configure IGRP routing? [yes]:
Your IGRP autonomous system number [1]:
Configuring interface parameters:
Do you want to configure Ethernet0  interface? [yes]:
Configure IP on this interface? [yes]:
IP address for this interface: 172.16.1.1
Subnet mask for this interface [255.255.0.0] : 255.255.255.0
Class B network is 172.16.0.0, 24 subnet bits; mask is /24
Do you want to configure Serial0  interface? [yes]:
  Configure IP on this interface? [yes]:
Configure IP unnumbered on this interface? [no]:
IP address for this interface: 172.16.12.1
Subnet mask for this interface [255.255.0.0] : 255.255.255.0
Class B network is 172.16.0.0, 24 subnet bits; mask is /24
Do you want to configure Serial1  interface? [yes]:
Configure IP on this interface? [yes]:
Configure IP unnumbered on this interface? [no]:
IP address for this interface: 172.16.13.1
Subnet mask for this interface [255.255.0.0] : 255.255.255.0
Class B network is 172.16.0.0, 24 subnet bits; mask is /24
```

02 CCNA Exam_Ch 02.fm Page 49 Thursday, March 7, 2002 11:44 AM

Example 2-4 *Router Setup Configuration Mode (Continued)*

```
The following configuration command script was created:

hostname R1
enable secret 5 $1$VOLh$pkIe0Xjx2sgjgZ/Y6Gt1s.
enable password fred
line vty 0 4
password barney
no snmp-server
!
no bridge 1
no decnet routing
no appletalk routing
no ipx routing
ip routing
!
interface Ethernet0
ip address 172.16.1.1 255.255.255.0
no mop enabled
!
interface Serial0
ip address 172.16.12.1 255.255.255.0
no mop enabled
!
interface Serial1
ip address 172.16.13.1 255.255.255.0
no mop enabled
dialer-list 1 protocol ip permit
dialer-list 1 protocol ipx permit
!
router igrp 1
redistribute connected
network 172.16.0.0
!
end

[0] Go to the IOS command prompt without saving this config.
[1] Return back to the setup without saving this config.
[2] Save this configuration to nvram and exit.

Enter your selection [2]: 2
Building configuration...
[OK]Use the enabled mode 'configure' command to modify this configuration.
Press RETURN to get started!
```

Setup behaves like Example 2-2 illustrates, whether setup was reached by booting with an empty NVRAM or whether the **setup** privileged exec command was used. First, the router asks whether you want to enter the "initial configuration dialog." Answering **y** or **yes** puts you in setup mode.

02 CCNA Exam_Ch 02.fm Page 50 Thursday, March 7, 2002 11:44 AM

When you are finished with setup, you select one of three options for what to do next. Option 2 tells the router to save the configuration to NVRAM and exit; this option is used in Example 2-4. The router places the config in both NVRAM and RAM. This is the only operation in the IOS that changes both configuration files to include the same contents based on a single action by the user. Options 0 and 1 tell the router to ignore the configuration that you just entered and to either exit to the command prompt (option 1) or start over gain with setup (option 1).

Upgrading Cisco IOS Software and the Cisco IOS Software Boot Process

50 List the commands to load Cisco IOS Software from: Flash memory, a TFTP server, or ROM.

51 Prepare to back up, upgrade, and load a backup Cisco IOS Software image.

Engineers need to know how to upgrade the IOS to move to a later release. Typically, a router has one IOS image in Flash memory, and that is the IOS that is used. (The term *IOS image* simply refers to a file containing the IOS.) The upgrade process might include steps such as copying a newer IOS image into Flash memory, configuring the router to tell it which IOS image to use, and deleting the old one when you are confident that the new release works well.

A router decides what IOS image to use when the router boots. Also, to upgrade to a new IOS or back out to an older IOS, you must reload the router. So, it's a convenient time to cover the boot sequence and some of the related issues.

Finally, password recovery is covered in this section. Password recovery is less likely to be on the CCNA exam than some other topics, but, guess what—it requires a reboot of the router, so now is a good time to cover it.

Upgrading an IOS Image into Flash Memory

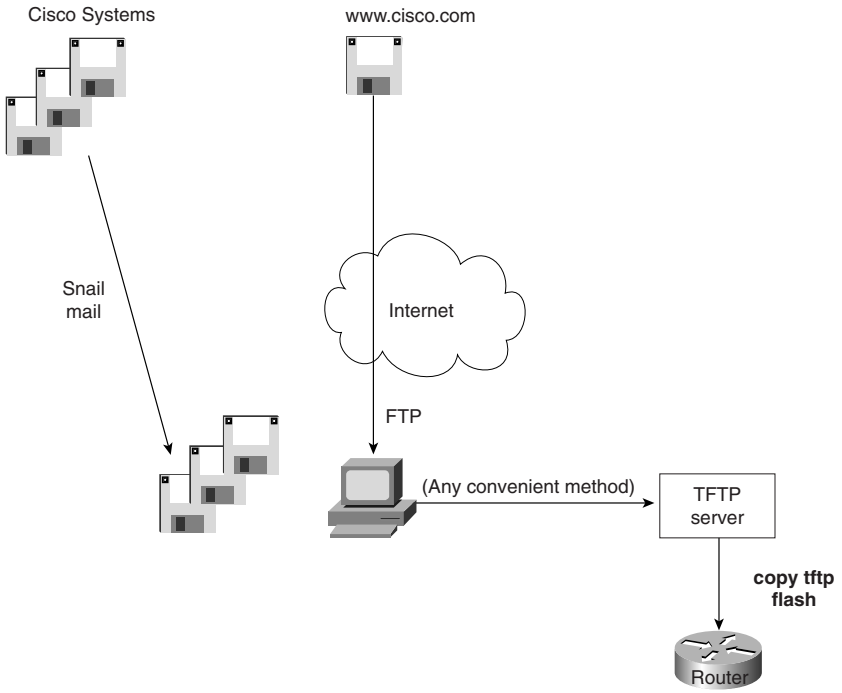
IOS files typically are stored in Flash memory. Flash memory is rewriteable, permanent storage, which is ideal for storing files that need to be retained when the router loses power. Also, because there are no moving parts, there is a smaller chance of failure as compared with disk drives, which provides better availability. As you will read soon, IOS can be placed on an external TFTP server, but using an external server typically is done for testing—in production, practically every Cisco router loads an IOS stored in the only type of large, permanent memory, and that is Flash memory.

02 CCNA Exam_Ch 02.fm Page 51 Thursday, March 7, 2002 11:44 AM

As Figure 2-10 illustrates, to upgrade an IOS image into Flash memory, you first must obtain the IOS image from Cisco. Then you must place the IOS image into the default directory of a TFTP server. Finally, you must issue the **copy** command from the router, copying the file into Flash memory.

NOTE You also can copy the IOS image directly from the FTP server. However, because the TFTP server function has been around a long time, I show it here. There could be plenty of exam questions left in the question database that cover TFTP.

Figure 2-10 *Complete Cisco IOS Software Upgrade Process*



Example 2-5 provides an example of the final step, copying the IOS image into Flash memory.

Example 2-5 **copy tftp flash** *Command Copies the IOS Image to Flash Memory*

```
R1#copy tftp flash

System flash directory:
File  Length   Name/status
  1   7530760   c4500-d-mz.120-2.bin
[7530824 bytes used, 857784 available, 8388608 total]
```

continues

02 CCNA Exam_Ch 02.fm Page 52 Thursday, March 7, 2002 11:44 AM

Example 2-5 **copy tftp flash** *Command Copies the IOS Image to Flash Memory (Continued)*

```
Address or name of remote host [255.255.255.255]? 134.141.3.33
Source file name? c4500-d-mz.120-5.bin
Destination file name [c4500-d-mz.120-5.bin]?
Accessing file c4500-d-mz.120-5.bin ' on 134.141.3.33...
Loading c4500-d-mz.120-5.bin from 134.141.3.33 (via TokenRing0): ! [OK]

Erase flash device before writing? [confirm]
Flash contains files. Are you sure you want to erase? [confirm]

Copy 'c4500-d-mz.120-5.bin ' from server
  as 'c4500-d-mz.120-5.bin ' into Flash WITH erase? [yes/no]y
Erasing device... eeeeeeeeeeeeeeeeeeeeeeeeeeeeeee ...erased
Loading c4500-d-mz.120-5.bin  from 134.141.3.33 (via TokenRing0):
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!! (leaving out
lots of exclamation points…)
[OK - 7530760/8388608 bytes]

Verifying checksum...  OK (0xA93E)
Flash copy took 0:04:26 [hh:mm:ss]
R1#
```

During this process of copying the IOS image into Flash memory, the router will need to discover several important facts:

1. What is the IP address or host name of the TFTP server?
2. What is the name of the file?
3. Is space available for this file in Flash memory?
4. Do you want the router to erase the old files?

The router will prompt you for answers, as necessary. Afterward, the router erases Flash memory as needed, copies the file, and then verifies that the checksum for the file shows that no errors occurred in transmission. The **show flash** command then can be used to verify the contents of Flash memory (see Example 2-6). (The **show flash** output can vary among router families.) Before the new IOS is used, however, the router must be reloaded.

Example 2-6 *Verifying Flash Memory Contents with the* **show flash** *Command*

```
fred#show flash

System flash directory:
File  Length   Name/status
  1   6181132 c4500-d-mz.120-5.bin
[4181196 bytes used, 4207412 available, 8388608 total]
8192K bytes of processor board System flash (Read ONLY)
```

02 CCNA Exam_Ch 02.fm Page 53 Thursday, March 7, 2002 11:44 AM

In some cases, Flash memory could be in read-only mode. That is the case when a router loads only part of the IOS into RAM, to conserve RAM. Other parts of the IOS file are kept in Flash memory (Flash memory access time is much slower than RAM's). In this case, if Flash memory must be erased to make room for a new image, the IOS could not continue to run. So, if the router is running from a portion of IOS in Flash memory, the router first must be booted using IOS in ROM. Then the Flash memory will be in read/write mode and the erase and copy processes can be accomplished. The **copy tftp flash** command in later releases of the IOS actually performs the entire process for you. In earlier releases, you had to boot the router from ROM and then issue the **copy tftp flash** command.

The Cisco IOS Software Boot Sequence

Cisco routers perform the same types of tasks that a typical computer performs when you power it on or reboot (reload) it. Of course, most of us do not think about these details very often. The router performs some somewhat obvious steps, with one of those being tricky—namely, the process of choosing the location of the software to load and use in the router. And that software might not be IOS!

The boot process follows this basic litany:

1. The router performs a power-on self-test (POST) to discover and verify the hardware.
2. The router loads and runs bootstrap code from ROM.
3. The router finds the IOS or other software and loads it.
4. The router finds the configuration file and loads it into running config.

All routers attempt all four steps each time that the router is powered on or reloaded. The POST code and functions cannot be changed by the router administrator. The location of the bootstrap code, the IOS to load, and the configuration file can be changed by the administrator—but you almost always use the default location for the bootstrap code (ROM) and for the initial configuration (NVRAM). So, the location of IOS or other software is the only part that typically is changed.

Three categories of operating systems can be loaded into the router:

- The full-function IOS image that you have been introduced to in this chapter.
- A limited-function IOS that resides in ROM.
- A different non-IOS operating system that is also stored in ROM, and this can be loaded. This operating system, called ROM Monitor, is used for two purposes—for low-level debugging and for password recovery. Unless you are performing password recovery, you would seldom use ROMMON mode.

02 CCNA Exam_Ch 02.fm Page 54 Thursday, March 7, 2002 11:44 AM

Table 2-6 lists the three operating system categories and their main functions.

Table 2-6 *Three OS Categories for Routers*

Operating System	Location Where It Is Stored	Purpose
Full-featured IOS	Typically in Flash memory; can be on TFTP server	Full-featured, normal IOS used in production.
Limited-function IOS	ROM	Basic IP connectivity, used when Flash memory is broken and you need IP connectivity to copy a new IOS into Flash memory. Called RXBOOT mode.
ROMMON	ROM	Low-level debugging, usually by the Cisco TAC and for password recovery. Called ROM Monitor mode.

So, you need to tell the router whether to use ROMMON, the limited-function IOS, or the full-featured IOS. Of course, most of the time you use the full-featured IOS in Flash memory. However, you might want to use IOS that resides on a TFTP server, or there could be multiple IOS images in Flash memory—and all of these options are configurable.

Two configuration tools tell the router what OS to load. First, the configuration register tells the router whether to use a full-featured IOS, ROMMON, or the limited-feature IOS, which is also called RXBOOT mode. The *configuration register* is a 16-bit software register in the router, and its value is set using the **config-register** global configuration command. (Some older routers had a hardware configuration register with jumpers on the processor card, to set bits to a value of 0 or 1.) Figure 2-11 shows an example binary breakdown of the default value for the configuration register, which is hexadecimal 2102.

Figure 2-11 *Binary Version of Configuration Register, Value Hex 2102*

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0

The *boot field* is the name of the low-order 4 bits of the configuration register. This field can be considered a 4-bit value, represented as a single hexadecimal digit. (Cisco represents hexadecimal values by preceding the hex digit(s) with 0x—for example, 0xA would mean a single hex digit *A*.) If the boot field is hex 0, ROMMON is loaded. If the boot field is hex 1, RXBOOT mode is used. For anything else, it loads a full-featured IOS. But which one?

02 CCNA Exam_Ch 02.fm Page 55 Thursday, March 7, 2002 11:44 AM

The second method used to determine where the router tries to obtain an IOS image is through the use of the **boot system** configuration command. If the configuration register calls for a full-featured IOS (boot field 2-F), the router reads the configuration file for boot system commands. If there are no boot system commands, the router takes the default action, which is to load the first file in Flash memory. Table 2-7 summarizes the use of the configuration register and the **boot system** command at initialization time.

Table 2-7 **boot system** *Command*

Value of Boot Field	Boot System Commands	Result
0x0	Ignored if present	ROMMON is loaded.
0x1	Ignored if present	IOS from ROM is loaded, also known as RXBOOT mode.
0x2-0xF	No **boot** command	The first IOS file in Flash memory is loaded; if that fails, the router broadcasts looking for an IOS on a TFTP server. If that fails, IOS from ROM is loaded.
0x2-0xF	**boot system ROM**	IOS from ROM is loaded.
0x2-0xF	**boot system flash**	The first file from Flash memory is loaded.
0x2-0xF	**boot system flash** *filename*	IOS with the name *filename* is loaded from Flash memory.
0x2-0xF	**boot system tftp** *filename* **10.1.1.1**	IOS with the name *filename* is loaded from the TFTP server.
0x2-0xF	Multiple boot system commands, any variety	An attempt occurs to load IOS based on the first boot command in configuration. If that fails, the second boot command is used, and so on, until one is successful.

02 CCNA Exam_Ch 02.fm Page 56 Thursday, March 7, 2002 11:44 AM

Password Recovery

Start Extra Credit

The password-recovery process relies on the fact that the configuration register can be used to make the router ignore the NVRAM configuration when the router is reloaded. The router will be up, but with a default configuration; this allows a console user to log in, enter privileged mode, and change any encrypted passwords or view any unencrypted passwords. However, there is a "chicken and the egg" problem—to cause the router to ignore NVRAM at boot time, the configuration register must be changed. To do that, you must be in privileged mode—and if you were already there, you could reset any encrypted passwords or view any unencrypted ones. It seems to be a vicious circle.

ROMMON will allow you to change the configuration register without knowing any passwords or even booting the IOS. To enter ROMMON mode, press the Break key during the first 60 seconds after power-on of the router. Then you must set bit 6 in the configuration register to binary 1, which is done by setting the entire config register with a four-digit hexadecimal value. For example, hex 2142 is identical to hex 2102, except that bit 6 is binary 1. Knowing how to reset the config register enables you to boot the router (ignoring NVRAM), allowing the console user to see or change the unencrypted or encrypted passwords, respectively.

The process is slightly different for different models of routers, although the concepts are identical. Table 2-8 outlines the process for each type of router. For more information, see http://www.cisco.com/warp/public/474/.

End Extra Credit

Table 2-8 *Password Recovery*

Step	Function	How to Do This for 1600, 2600, 3600, 4500, 7200, 7500	How to Do This for 2000, 2500, 3000, 4000, 7000
1	Turn the router off and then back on again.	Use the power switch.	Same as other routers.
2	Press the Break key within the first 60 seconds.	Find the Break key on your console device's keyboard.	Same as other routers.
3	Change the configuration register so that bit 6 is 1.	Use the ROMMON command **confreg**, and answer the prompts.	Use the ROMMON command **o/r 0x2142**.
4	Cause the router to load IOS.	Use the ROMMON **reload** command or, if unavailable, power off and on.	Use the ROMMON command **initialize**.

02 CCNA Exam_Ch 02.fm Page 57 Thursday, March 7, 2002 11:44 AM

Table 2-8 *Password Recovery (Continued)*

Step	Function	How to Do This for 1600, 2600, 3600, 4500, 7200, 7500	How to Do This for 2000, 2500, 3000, 4000, 7000
5	Avoid using setup mode, which will be prompted for at the console.	Just say no.	Same as other routers.
6	Enter privileged mode at console.	Press Enter and use the **enable** command (no password required).	Same as other routers.
7	Assuming that you still want to use the configuration in NVRAM, copy it to the running config.	**copy startup-config running-config**	**copy startup-config running-config**
8	View startup config to see unencrypted passwords.	Use the exec command **show startup-config**.	Same as other routers.
9	Use the appropriate config commands to reset encrypted commands.	For example, use **enable secret xyz123** command to set the enable secret password.	Same as other routers.
10	Change the config register back to its original value.	Use the config command **config-reg 0x2102**.	Same as other routers.
11	Reload the router after saving the configuration.	Use the **copy running-config startup-config** and **reload** commands.	Same as other routers.

A few nuances need further explanation. First, the **confreg** ROMMON command prompts you with questions that correspond to the functions of the bits in the configuration register. When the prompt asks, "Ignore system config info[y/n]?", it is asking you about bit 6. Entering **yes** sets the bit to 1. The rest of the questions can be defaulted. The last **confreg** question asks, "Change boot characteristics[y/n]?", which asks whether you want to change the boot field of the config register. You don't really need to change it, but the published password-recovery algorithm lists that step, which is the only reason that it is mentioned here. Just changing bit 6 to 1 is enough to get the router booted and you into privileged mode to find or change the passwords.

02 CCNA Exam_Ch 02.fm Page 58 Thursday, March 7, 2002 11:44 AM

Foundation Summary

The "Foundation Summary" is a collection of tables and figures that provide a convenient review of many key concepts in this chapter. For those of you already comfortable with the topics in this chapter, this summary could help you recall a few details. For those of you who just read this chapter, this review should help solidify some key facts. For any of you doing your final preparation before the exam, these tables and figures will be a convenient way to review the day before the exam.

The console, auxiliary, and Telnet passwords are all set separately, as shown in Table 2-9.

Table 2-9 *CLI Password Configuration*

Access from . . .	Password Type	Configuration
Console	Console password	**line console** *0* **login** **password** *faith*
Auxiliary	Auxiliary password	**line aux** *0* **login** **password** *hope*
Telnet	vty password	**line vty** *0 4* **login** **password** *love*

Table 2-10 lists the commands used to manipulate previously typed commands.

Table 2-10 *Key Sequences for Command Edit and Recall*

Keyboard Command	What the User Gets
Up arrow or Ctrl-p	This displays the most recently used command. If it is pressed again, the next most recent command appears until the history buffer is exhausted. (The *p* stands for *previous*.)
Down arrow or Ctrl-n	If you have gone too far back into the history buffer, these keys will go forward, in order, to the more recently typed commands. (The *n* is for *next*.)
Left arrow or Ctrl-b	This moves the cursor backward in the currently displayed command without deleting characters. (The *b* stands for *back*.)
Right arrow or Ctrl-f	This moves the cursor forward in the currently displayed command without deleting characters. (The *f* stands for *forward*.)

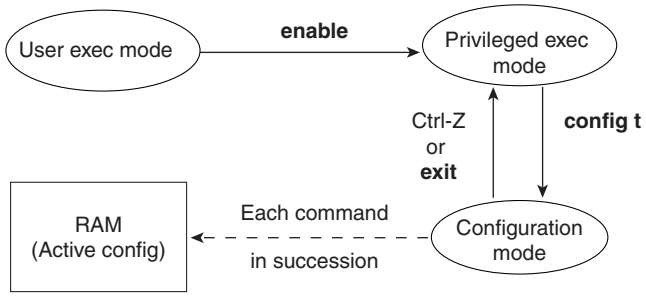
02 CCNA Exam_Ch 02.fm Page 59 Thursday, March 7, 2002 11:44 AM

Table 2-10 *Key Sequences for Command Edit and Recall (Continued)*

Keyboard Command	What the User Gets
Backspace	This moves the cursor backward in the currently displayed command, deleting characters.
Ctrl-a	This moves the cursor directly to the first character of the currently displayed command.
Ctrl-e	This moves the cursor directly to the end of the currently displayed command.
Esc-b	This moves the cursor back one word in the currently displayed command.
Esc-f	This moves the cursor forward one word in the currently displayed command.
Ctrl-r	This creates a new command prompt, followed by all the characters typed since the last command prompt was written. This is particularly useful if system messages confuse the screen and it is unclear what you have typed so far.

Figure 2-12 illustrates the relationships among configuration mode, user exec mode, and privileged exec mode.

Figure 2-12 *CLI Configuration Mode versus Exec Modes*



Routers have four types of memory:

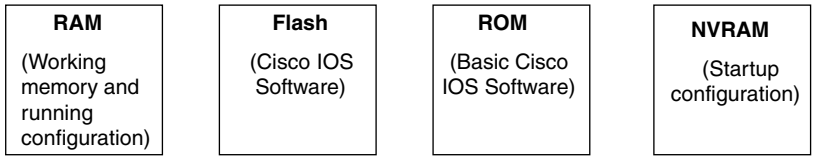
- **RAM**—Sometimes called DRAM for *dynamic* random-access memory, RAM is used by the router just as it is used by any other computer: for working storage. The *running* or *active configuration* file is stored here.
- **ROM**—This type of memory (read-only memory) stores a bootable IOS image, which is not typically used for normal operation. ROM contains the code that is used to boot the router until the router knows where to get the full IOS image, or as a backup bootable image in case there are problems.

02 CCNA Exam_Ch 02.fm Page 60 Thursday, March 7, 2002 11:44 AM

- **Flash memory**—Either an EEPROM or a PCMCIA card, Flash memory stores fully functional IOS images and is the default location where the router gets its IOS at boot time. Flash memory also can be used to store configuration files on some Cisco routers.
- **NVRAM**—Nonvolatile RAM stores the initial or startup configuration file.

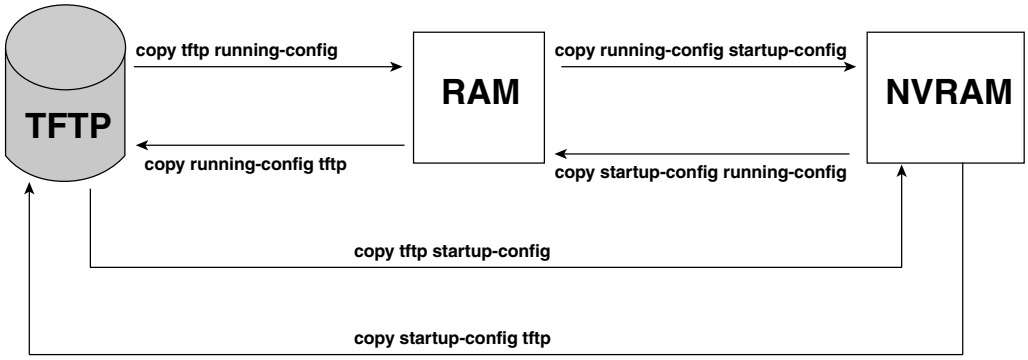
All these types of memory, except RAM, are permanent memory. No hard disk or diskette storage exists on Cisco routers. Figure 2-13 summarizes the use of memory in Cisco routers.

Figure 2-13 *Cisco Router Memory Types*



The **copy** command is used to move configuration files among RAM, NVRAM, and a TFTP server. The files can be copied between any pair, as Figure 2-14 illustrates.

Figure 2-14 *Locations for Copying and Results from Copy Operations*



The commands can be summarized as follows:

```
copy {tftp | running-config | startup-config} {tftp | running-config | startup-config}
```

The first parameter is the "from" location; the next one is the "to" location. (Of course, choosing the same option for both parameters is not allowed.)

Figure 2-15 shows both the old and the new commands used to view configurations.

02 CCNA Exam_Ch 02.fm Page 61 Thursday, March 7, 2002 11:44 AM

Figure 2-15 *Configuration* **show** *Commands*

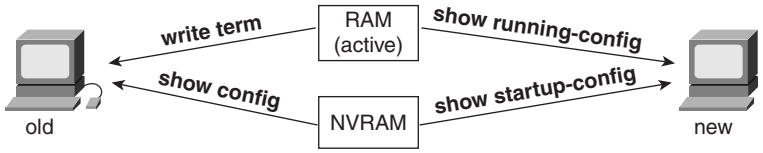
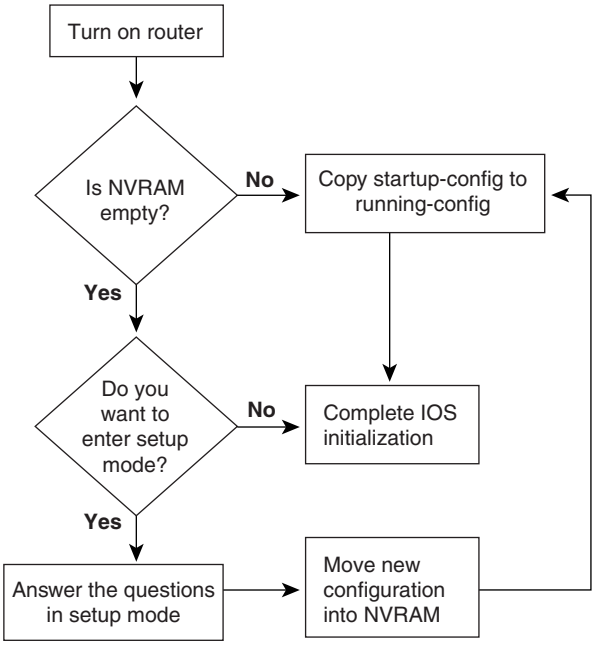


Figure 2-16 illustrates the process of upgrading Cisco IOS Software.

Figure 2-16 *Complete Cisco IOS Software Upgrade Process*



The boot process follows this basic litany:

1. The router performs a power-on self-test (POST) to discover and verify the hardware.
2. The router loads and runs the bootstrap code from ROM.
3. The router finds the IOS or other software and loads it.
4. The router finds the configuration file and loads it into the running config.

Table 2-11 lists the three operating system categories and their main functions.

02 CCNA Exam_Ch 02.fm Page 62 Thursday, March 7, 2002 11:44 AM

Table 2-11 *Three OS Categories for Routers*

Operating System	Location Where It Is Stored	Purpose
Full-featured IOS	Typically in Flash memory, can be on TFTP server	Full-featured, normal IOS used in production
Limited-function IOS	ROM	Basic IP connectivity, used when Flash memory is broken and you need IP connectivity to copy a new IOS into Flash memory. Called RXBOOT mode.
ROMMON	ROM	Low-level debugging, usually by the Cisco TAC and for password recovery. Called ROM Monitor mode.

Figure 2-17 shows an example binary breakdown of the default value for the configuration register, which is hexadecimal 2102.

Figure 2-17 *Binary Version of Configuration Register, Value Hex 2102*

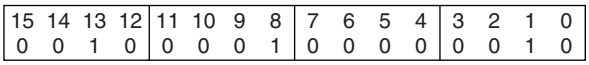


Table 2-12 summarizes the use of the configuration register and the **boot system** command at initialization time.

02 CCNA Exam_Ch 02.fm Page 63 Thursday, March 7, 2002 11:44 AM

Table 2-12 **boot system** *Command*

Value of Boot Field	Boot System Commands	Result
0x0	Ignored if present	ROMMON is loaded.
0x1	Ignored if present	IOS from ROM is loaded, also known as RXBOOT mode.
0x2-0xF	No **boot** command	The first IOS file in Flash memory is loaded; if that fails, the router broadcasts looking for an IOS on a TFTP server. If that fails, IOS from ROM is loaded.
0x2-0xF	**boot system ROM**	IOS from ROM is loaded.
0x2-0xF	**boot system flash**	The first file from Flash memory is loaded.
0x2-0xF	**boot system flash** *filename*	IOS with the name *filename* is loaded from Flash memory.
0x2-0xF	**boot system tftp** *filename* **10.1.1.1**	IOS with the name *filename* is loaded from the TFTP server.
0x2-0xF	Multiple boot system commands, any variety	An attempt occurs to load the IOS based on the first boot command in configuration. If that fails, the second boot command is used, and so on, until one is successful.

02 CCNA Exam_Ch 02.fm Page 64 Thursday, March 7, 2002 11:44 AM

Q&A

As mentioned in Chapter 1, the questions and scenarios in this book are more difficult than what you should experience on the actual exam. The questions do not attempt to cover more breadth or depth than the exam; however, they are designed to make sure that you know the answer. Rather than allowing you to derive the answer from clues hidden inside the question itself, the questions challenge your understanding and recall of the subject. Questions from the "Do I Know This Already?" quiz from the beginning of the chapter are repeated here to ensure that you have mastered the chapter's topic areas. Hopefully, these questions will help limit the number of exam questions on which you narrow your choices to two options and then guess. Make sure to use the CD and take the simulated exams.

The answers to these questions can be found in Appendix A.

1 What are the two names for the router's mode of operation that, when accessed, enables you to issue commands that could be disruptive to router operations?

_____

_____

_____

2 What are three methods of logging on to a router?

_____

_____

_____

3 What is the name of the user interface mode of operation used when you cannot issue disruptive commands?

_____

_____

_____

4 Can the auxiliary port be used for anything besides remote modem user access to a router? If so, what other purpose can it serve?

_____

_____

_____

02 CCNA Exam_Ch 02.fm Page 65 Thursday, March 7, 2002 11:44 AM

5 How many console ports can be installed on a Cisco 7500 router?

6 What command would you use to receive command help if you knew that a **show** command option *begins with a c but you cannot recall the option?*

7 While you are logged in to a router, you issue the command **copy ?** and get a response of "Unknown command, computer name, or host." Offer an explanation for why this error message appears.

8 Is the number of retrievable commands based on the number of characters in each command, or is it simply a number of commands, regardless of their size?

9 How can you retrieve a previously used command? (Name two ways.)

10 After typing **show ip route,** which is the only command that you typed since logging in to the router, you now want to issue the **show ip arp** command. What steps would you take to execute this command by using command-recall keystrokes?

02 CCNA Exam_Ch 02.fm Page 66 Thursday, March 7, 2002 11:44 AM

11 After typing **show ip route 128.1.1.0,** you now want to issue the command **show ip route 128.1.4.0.** What steps would you take to do so, using command-recall and command-editing keystrokes?

_____

_____

_____

12 What configuration command causes the router to require a password from a user at the console? What configuration mode context must you be in? (That is, what command(s) must be typed before this command after entering configuration mode?) List the commands in the order in which they must be typed while in config mode.

_____

_____

_____

13 What configuration command is used to tell the router the password that is required at the console? What configuration mode context must you be in? (That is, what command(s) must you type before this command after entering configuration mode?) List the commands in the order in which they must be typed while in config mode.

_____

_____

_____

14 What are the primary purposes of Flash memory in a Cisco router?

_____

_____

_____

15 What is the intended purpose of NVRAM memory in a Cisco router?

_____

_____

_____

16 What does the "NV" stand for in NVRAM?

_____

_____

_____

02 CCNA Exam_Ch 02.fm Page 67 Thursday, March 7, 2002 11:44 AM

17 What is the intended purpose of RAM in a Cisco router?

18 What is the main purpose of ROM in a Cisco router?

19 What configuration command would be needed to cause a router to use an IOS image named c2500- j-l.112-14.bin on TFTP server 128.1.1.1 when the router is reloaded? If you forgot the first parameter of this command, what steps must you take to learn the correct parameters and add the command to the configuration? (Assume that you are not logged in to the router when you start.)

20 What command sets the password that would be required after typing the **enable** command? Is that password encrypted by default?

21 To have the correct syntax, what must you add to the following configuration command:

22 Name two commands that affect the text used as the command prompt.

02 CCNA Exam_Ch 02.fm Page 68 Thursday, March 7, 2002 11:44 AM

23 When using setup mode, you are prompted at the end of the process for whether you want to use the configuration parameters that you just typed in. Which type of memory is this configuration stored in if you type **yes**?

_____

_____

_____

24 What two methods could a router administrator use to cause a router to load IOS stored in ROM?

_____

_____

_____

25 What could a router administrator do to cause a router to load file xyz123.bin from TFTP server 128.1.1.1 upon the next reload? Is there more than one way to accomplish this?

_____

_____

_____

26 What is the process used to update the contents of Flash memory so that a new IOS in a file called c4500-d-mz.120-5.bin on TFTP server 128.1.1.1 is copied into Flash memory?

_____

_____

_____

27 Name three possible problems that could prevent the command **boot system tftp c2500-j-l.112- 14.bin 128.1.1.1** from succeeding.

_____

_____

_____

02 CCNA Exam_Ch 02.fm Page 69 Thursday, March 7, 2002 11:44 AM

28 Two different IOS files are in a router's Flash memory: one called c2500-j-l.111-3.bin and one called c2500-j-l.112-14.bin. Which one does the router use when it boots up? How could you force the other IOS file to be used? Without looking at the router configuration, what command could be used to discover which file was used for the latest boot of the router?

29 Is the password required at the console the same one that is required when Telnet is used to access a router?

30 Which IP routing protocols could be enabled using setup?

31 Name two commands used to view the configuration to be used at the next reload of the router. Which one is a more recent addition to the IOS?

32 Name two commands used to view the configuration that is currently used in a router. Which one is a more recent addition to IOS?

33 True or false: The **copy startup-config running-config** command always changes the currently used configuration for this router to exactly match what is in the startup configuration file. Explain.\

02 CCNA Exam_Ch 02.fm Page 70 Thursday, March 7, 2002 11:44 AM

Scenarios

Scenario 2-1

Compare the following output in Example 2-7 and Example 2-8. Example 2-7 was gathered at 11:00 a.m., 30 minutes earlier than in Example 2-8. What can you definitively say happened to this router during the intervening half hour?

Example 2-7 *1:00 a.m.* **show running-config**

```
hostname Gorno
!
enable password cisco
!
interface Serial0
 ip address 134.141.12.1 255.255.255.0
!
interface Serial1
 ip address 134.141.13.1 255.255.255.0
!
interface Ethernet0
 ip address 134.141.1.1 255.255.255.0
!
router rip
 network 134.141.0.0
!
line con 0
 password cisco
 login
line aux 0
line vty 0 4
 password cisco
 login
```

Example 2-8 *11:30 a.m.* **show running-config**

```
hostname SouthernSiberia
prompt Gorno
!
enable secret $8df003j56ske92
enable password cisco
!
interface Serial0
 ip address 134.141.12.1 255.255.255.0
!
interface Serial1
 ip address 134.141.13.1 255.255.255.0
!
interface Ethernet0
 ip address 134.141.1.1 255.255.255.0
```

02 CCNA Exam_Ch 02.fm Page 71 Thursday, March 7, 2002 11:44 AM

Example 2-8 *11:30 a.m.* **show running-config** *(Continued)*

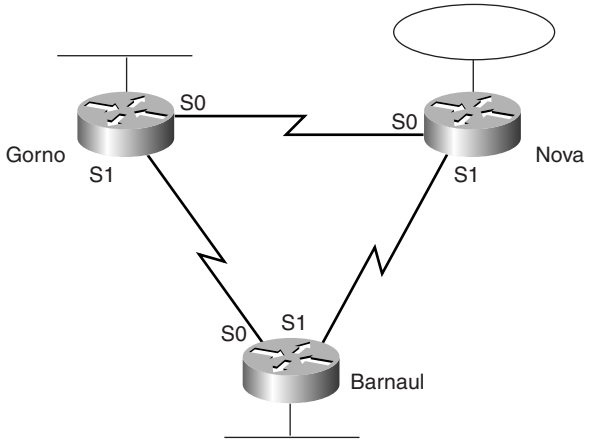
```
 no cdp enable
!
router rip
 network 134.141.0.0
!
line con 0
 password cisco
 login
line aux 0
line vty 0 4
 password cisco
 login
```

Questions on Scenario 2-1

1. During the process of changing the configuration in Scenario 2-1, the command prompt temporarily was **SouthernSiberia(config)#.** What configuration commands, and in what order, could have changed the configuration as shown and allowed the prompt to temporarily be **SouthernSiberia(config)#**?

2. Assuming that Figure 2-18 is complete, what effect does the **no cdp enable** command have?

Figure 2- 18 *Siberian Enterprises' Sample Network*



3. What effect would the **no enable password cisco** command have at this point?

02 CCNA Exam_Ch 02.fm Page 72 Thursday, March 7, 2002 11:44 AM

Scenario 2-2

Example 2-9 shows that the **running-config** command was executed on the Nova router.

Example 2-9 *Configuration of Router Nova*

```
hostname Nova
banner # This is the router in Nova Sibiersk; Dress warmly before entering! #
!
boot system tftp c2500-js-113.bin 134.141.88.3
boot system flash c2500-j-l.111-9.bin
boot system rom
!
enable password cisco
!
interface Serial0
 ip address 134.141.12.2 255.255.255.0
!
interface Serial1
 ip address 134.141.23.2 255.255.255.0
!
interface TokenRing0
 ip address 134.141.2.2 255.255.255.0
!
router rip
 network 134.141.0.0
!
line con 0
 password cisco
 login
line aux 0
line vty 0 4
 password cisco
 login
```

Questions on Scenario 2-2

1. If this is all the information that you have, what IOS do you expect will be loaded when the user reloads Nova?

2. Examine the following command output in Example 2-10, taken immediately before the user is going to type the **reload** command. What IOS do you expect will be loaded?

02 CCNA Exam_Ch 02.fm Page 73 Thursday, March 7, 2002 11:44 AM

Example 2-10 show ip route *Command Output for Nova*

```
Nova#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route


Gateway of last resort is not set

     134.141.0.0/24 is subnetted, 6 subnets
C       134.141.2.0 is directly connected, TokenRing0
R       134.141.3.0 [120/1] via 134.141.23.3, 00:00:15, Serial1
R       134.141.1.0 [120/1] via 134.141.12.1, 00:00:20, Serial0
C       134.141.12.0 is directly connected, Serial0
R       134.141.13.0 [120/1] via 134.141.12.1, 00:00:20, Serial0
                     [120/1] via 134.141.23.3, 00:00:15, Serial1
C       134.141.23.0 is directly connected, Serial1
```

3 Now examine the following **show flash** command in Example 2-11, which was issued immediately after the **show ip route** command in Example 2-10 but before the user issued the **reload** command. What IOS do you think would be loaded in this case?

Example 2-11 show flash *Command Output for Nova*

```
Nova#show flash
4096K bytes of flash memory sized on embedded flash.
File   name/status
 0 c2500-j-l.111-3.bin
[682680/4194304 bytes free/total]
```

4 Now examine the configuration in Example 2-12. Assume that there is now a route to 134.141.88.0 and that the file c2500-j-l.111-9.bin is an IOS image in Flash memory. What IOS do you expect will be loaded now?

02 CCNA Exam_Ch 02.fm Page 74 Thursday, March 7, 2002 11:44 AM

Example 2-12 show running-config *Command Output for Router Nova*

```
hostname Nova
banner # This is the router in Nova Sibiersk; Dress warmly before entering! #
!
boot system tftp c2500-js-113.bin 134.141.88.3
boot system flash c2500-j-l.111-9.bin
!
enable password cisco
!
interface Serial0
 ip address 134.141.12.2 255.255.255.0
!
interface Serial1
 ip address 134.141.23.2 255.255.255.0
!
interface Ethernet0
 ip address 134.141.2.2 255.255.255.0
!
router rip
 network 134.141.0.0
!
line con 0
 password cisco
 login
line aux 0
line vty 0 4
 password cisco
 login
!
config-register 0x2101
```

02 CCNA Exam_Ch 02.fm Page 75 Thursday, March 7, 2002 11:44 AM

Answers to Scenarios

Scenario 2-1 Answers

In Scenario 2-1, the following commands were added to the configuration:

- **enable secret** as a global command.
- **prompt** as a global command.
- **no cdp enable** as an Ethernet0 subcommand.
- The **hostname** command also was changed.

The scenario questions' answers are as follows:

1. If the host name was changed to SouthSiberia first and the **prompt** command was added next, the prompt would have temporarily been SouthSiberia. Configuration commands are added to the RAM configuration file immediately and are used. In this case, when the **prompt** command was added, it caused the router to use Gorno, not the then-current host name SouthernSiberia, as the prompt.
2. No practical effect takes place. Because no other Cisco CDP–enabled devices are on that Ethernet, CDP messages from Gorno are useless. So, the only effect is to lessen the overhead on that Ethernet in a very small way.
3. No effect takes place, other than cleaning up the configuration file. The **enable password** is not used if an **enable secret** is configured.

02 CCNA Exam_Ch 02.fm Page 76 Thursday, March 7, 2002 11:44 AM

Scenario 2-2 Answers

The answers to the questions in Scenario 2-2 are as follows:

1. The first boot system statement would be used: **boot system tftp c2500-js-113.bin 134.141.88.3**.
2. The **boot system flash** command would be used. The TFTP boot presumably would fail because there is not currently a route to the subnet of which the TFTP server is a part. It is reasonable to assume that a route would not be learned 2 minutes later when the router had reloaded. So, the next **boot system** command (**flash**) would be used.
3. The **boot system ROM** command would be used. Because there is no file in Flash memory called c2500-j- l.111-9.bin, the boot from Flash memory would fail as well, leaving only one **boot** command.
4. IOS from ROM would be loaded because of the configuration register. If the configuration register boot field is set to 0x1, **boot system** commands are ignored. So, having a route to the 134.141.88.0/ 24 subnet and having c2500-j-l.111-9.bin in Flash memory does not help.

02 CCNA Exam_Ch 02.fm Page 77 Thursday, March 7, 2002 11:44 AM

Exam Topics in This Chapter

5 Describe data-link and network addresses, and identify key differences between them.

6 Define and describe the function of a MAC address.

7 List the key internetworking functions of the OSI network layer.

8 Identify at least three reasons why the industry uses a layered model.

9 Describe the two parts of network addressing, and then identify the parts in specific protocol address examples.

10 Define and explain the five conversion steps of data encapsulation.

11 Describe connection-oriented network service and connectionless network service, and identify their key differences.

12 Identify the parts in specific protocol address examples.

CHAPTER 3

OSI Reference Model and Layered Communication

In years past, the need to understand the Open System Interconnection (OSI) reference model for networking grew rapidly. The U.S. government passed laws requiring vendors to support OSI software on their systems; if vendors did not offer this support, the government would no longer buy the systems. Several vendors even predicted that the global Internet would evolve toward using the OSI protocols instead of TCP/IP. As the century turns, however, OSI has been implemented on a much smaller scale than predicted. Today, no one even sells a full-complement OSI software suite. However, some components of the OSI model are popularly implemented today. For example, OSI network service access point (NSAP) network layer addresses often are used for signaling in Asynchronous Transfer Mode (ATM) networks. In short, OSI was a great idea that never fully made it to market.

So, why have a whole chapter on OSI? As a CCNA, you'll be expected to learn and interpret new technologies and protocols. The OSI seven-layer reference model is an excellent point of reference for describing the concepts and functions behind these new technologies and protocols. References to Layer 2 switching and Layer 3 switching, which are popular topics today, refer to the comparison between Layers 2 and 3 of the OSI model. Cisco courses make generous use of the OSI model as a reference for comparison with other network protocol implementations. So, this chapter will not actually help you understand OSI fully, but it will discuss OSI functions in comparison with popularly implemented protocols.

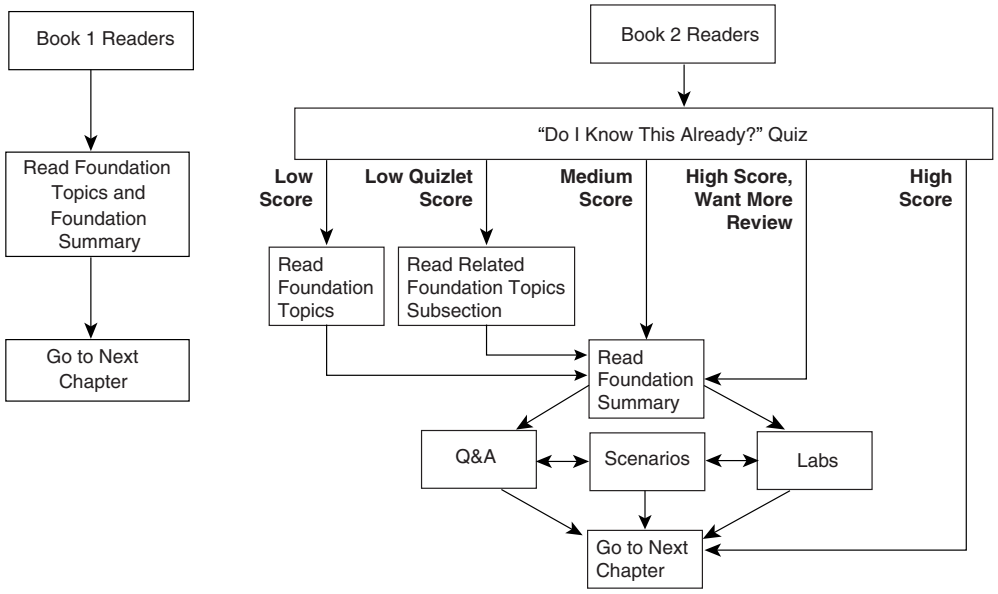
How to Best Use This Chapter

By taking the following steps, you can make better use of your study time:

- Keep your notes and the answers for all your work with this book in one place, for easy reference.
- Take the "Do I Know This Already?" quiz, and write down your answers. Studies show that retention is significantly increased through writing down facts and concepts, even if you never look at the information again.
- Use the diagram in Figure 3-1 to guide you to the next step.

03 CCNA Exam_Ch 03.fm Page 80 Thursday, March 7, 2002 11:46 AM

Figure 3-1 *How to Use This Chapter*



"Do I Know This Already?" Quiz

The purpose of the "Do I Know This Already?" quiz is to help you decide what parts of this chapter to use. If you already intend to read the entire chapter, you do not necessarily need to answer these questions now.

This 16-question quiz helps you determine how to spend your limited study time. The quiz is sectioned into four smaller four-question "quizlets," which correspond to the four major headings in the "Foundation Topics" section of the chapter. Figure 3-1 outlines suggestions on how to spend your time in this chapter. Use Table 3-1 to record your score.

Table 3-1 *Scoresheet for Quiz and Quizlets*

Quizlet Number	Foundation Topics Section Covering These Questions	Questions	Score
1	The OSI, TCP/IP, and NetWare Protocol Architectures	1 to 4	
2	OSI Transport Layer Functions	5 to 8	
3	OSI Data Link Layer Functions	9 to 12	
4	OSI Network Layer Functions	13 to 16	
All questions		1 to 16	

03 CCNA Exam_Ch 03.fm Page 81 Thursday, March 7, 2002 11:46 AM

1 Name the seven layers of the OSI model.

2 What is the main purpose(s) of Layer 3?

3 What is the main purpose(s) of Layer 2?

4 What OSI layer typically encapsulates using both a header and a trailer?

5 Describe the features required for a protocol to be considered connectionless.

6 Describe the features required for a protocol to be considered connection-oriented.

7 In a particular error-recovering (reliable) protocol, the sender sends three frames, labeled 2, 3, and 4. On its next sent frame, the receiver of these frames sets an acknowledgment field to 4. What does this typically imply?

03 CCNA Exam_Ch 03.fm Page 82 Thursday, March 7, 2002 11:46 AM

8 Name three connection-oriented protocols.

_____

_____

_____

9 Name three terms popularly used as synonyms for *MAC address.*

_____

_____

_____

10 What portion of a MAC address encodes an identifier representing the manufacturer of the card?

_____

_____

_____

11 Are DLCI addresses defined by a Layer 2 or a Layer 3 protocol?

_____

_____

_____

12 How many bits are present in a MAC address?

_____

_____

_____

13 How many bits are present in an IPX address?

_____

_____

_____

03 CCNA Exam_Ch 03.fm Page 83 Thursday, March 7, 2002 11:46 AM

14 Name the two main parts of an IP address. Which part identifies the "group" of which this address is a member?

_____

_____

_____

15 Describe the differences between a routed protocol and a routing protocol.

_____

_____

_____

16 Name at least three routed protocols.

_____

_____

_____

The answers to the "Do I Know This Already?" quiz are found in Appendix A, "Answers to the 'Do I Know This Already?' Quizzes and Q&A Sections." The suggested choices for your next step are as follows:

- **8 or less overall score**—Read the entire chapter. This includes the "Foundation Topics" and "Foundation Summary" sections, the Q&A section, and the scenarios at the end of the chapter.
- **2 or less on any quizlet**—Review the subsection(s) of the "Foundation Topics" part of this chapter, based on Table 3-1. Then move into the "Foundation Summary" section, the quiz, and the scenarios at the end of the chapter.
- **9 to 12 overall score**—Begin with the "Foundation Summary" section, and then go to the Q&A section and the scenarios at the end of the chapter.
- **13 or more overall score**—If you want more review on these topics, skip to the "Foundation Summary" section and then go to the Q&A section and the scenarios at the end of the chapter. Otherwise, move to the next chapter.

03 CCNA Exam_Ch 03.fm Page 84 Thursday, March 7, 2002 11:46 AM

Foundation Topics

OSI: Concepts, Layers, and Encapsulation

7 List the key internetworking functions of the OSI network layer.

8 Identify at least three reasons why the industry uses a layered model.

10 Define and explain the five conversion steps of data encapsulation.

Four topics of particular importance for the CCNA exam are covered in this chapter:

- **The OSI reference model**—Expect questions on the functions of each layer and examples at each layer in the CCNA exam.
- **Transport layer protocols**—This section on Layer 4 of the OSI reference model is important to properly understand end-to-end transport.
- **Network layer protocols**—This section on Layer 3 of the OSI reference model is important to properly understand routing.
- **Data link protocols**—This section on Layer 2 of the OSI reference model is important to properly understand LAN switching.

The last three sections all use the terminology discussed in the first section.

OSI Reference Model: Origin and Evolution

To pass the CCNA exam, you must be conversant in a protocol specification with which you are very unlikely to ever have any hands-on experience. The difficulty these days when using the OSI protocol specifications as a point of reference is that almost no one uses those specifications. You cannot typically walk down the hall and see a computer whose main, or even optional, networking protocols are defined by OSI.

OSI is the Open System Interconnection reference model for communications. OSI is a rather well-defined set of protocol specifications with many options for accomplishing similar tasks. Some participants in OSI's creation and development wanted it to become *the* networking protocol used by all applications. The U.S. government went so far as to require OSI support on every computer that it would buy (as of a certain date in the early 1990s) with an edict called the

03 CCNA Exam_Ch 03.fm Page 85 Thursday, March 7, 2002 11:46 AM

Government OSI Profile (GOSIP), which certainly gave vendors some incentive to write OSI code. In fact, in my old IBM days, the company even had charts showing how the TCP/IP–installed base would start declining by 1994, how OSI installations would take off, and how OSI would be *the* protocol from which the 21st century Internet was built. (In IBM's defense, moving the world to OSI might have been yet another case of "You just can't get there from here.")

What is OSI today? Well, the protocols are still in existence and are used around the world, to some degree. The U.S. government reversed its GOSIP directive officially in May 1994, which was probably the final blow to the possibility of pervasive OSI implementations. Cisco routers will route OSI. OSI NSAP addresses are used in Cisco ATM devices for signaling. Digital Equipment's DECnet Phase V uses several portions of OSI, including the network layer (Layer 3) addressing and routing concepts. More often than not, however, the OSI model now is mainly used as a point of reference for discussing other protocol specifications.

OSI Layers

The OSI reference model consists of seven layers, each of which can (and typically does) have several sublayers. Cisco requires that CCNAs demonstrate an understanding of each layer as well as the protocols that correspond to each OSI layer. The names of the OSI reference model layers and their main functions are simply good things to memorize. And frankly, if you want to pursue your Cisco certifications beyond CCNA, these names and functional areas will come up continually. You also will need to know some example protocols and the OSI layers that they most closely match.

The upper layers of the OSI reference model (application, presentation, session, and transport—Layers 7, 6, 5, and 4) define functions focused on the application. The lower three layers (network, data link, and physical—Layers 3, 2, and 1) define functions focused on end-to-end delivery of the data. CCNAs work mostly with issues in the lower layers, in particular with Layer 2, upon which switching is based, and Layer 3, upon which routing is based. Table 3-2 diagrams the seven OSI layers, with a thorough description and a list of example protocols.

Table 3-2 *OSI Reference Model*

Layer Name	Functional Description	Examples
Application (Layer 7)	An application that communicates with other computers is implementing OSI application layer concepts. The application layer refers to communications services to applications. For example, a word processor that lacks communications capabilities would not implement code for communications, and word processor programmers would not be concerned about OSI Layer 7. However, if an option for transferring a file were added, the word processor would need to implement OSI Layer 7 (or the equivalent layer in another protocol specification).	Telnet, HTTP, FTP, WWW browsers, NFS, SMTP gateways (Eudora, CC:mail), SNMP, X.400 mail, FTAM

continues

03 CCNA Exam_Ch 03.fm Page 86 Thursday, March 7, 2002 11:46 AM

Table 3-2 *OSI Reference Model (Continued)*

Layer Name	Functional Description	Examples
Presentation (Layer 6)	This layer's main purpose is defining data formats, such as ASCII text, EBCDIC text, binary, BCD, and JPEG. Encryption also is defined by OSI as a presentation layer service. For example, FTP enables you to choose binary or ASCII transfer. If binary is selected, the sender and receiver do not modify the contents of the file. If ASCII is chosen, the sender translates the text from the sender's character set to a standard ASCII and sends the data. The receiver translates back from the standard ASCII to the character set used on the receiving computer.	JPEG, ASCII, EBCDIC, TIFF, GIF, PICT, encryption, MPEG, MIDI
Session (Layer 5)	The session layer defines how to start, control, and end conversations (called sessions). This includes the control and management of multiple bidirectional messages so that the application can be notified if only some of a series of messages are completed. This allows the presentation layer to have a seamless view of an incoming stream of data. The presentation layer can be presented with data if all flows occur in some cases. For example, an automated teller machine transaction in which you withdraw cash from your checking account should not debit your account and then fail before handing you the cash, recording the transaction even though you did not receive money. The session layer creates ways to imply which flows are part of the same session and which flows must complete before any are considered complete.	RPC, SQL, NFS, NetBios names, AppleTalk ASP, DECnet SCP
Transport (Layer 4)	Layer 4 includes the choice of protocols that either do or do not provide error recovery. Multiplexing of incoming data for different flows to applications on the same host (for example, TCP sockets) is also performed. Reordering of the incoming data stream when packets arrive out of order is included.	TCP, UDP, SPX

03 CCNA Exam_Ch 03.fm Page 87 Thursday, March 7, 2002 11:46 AM

Table 3-2 *OSI Reference Model (Continued)*

Layer Name	Functional Description	Examples
Network (Layer 3)	This layer defines end-to-end delivery of packets. To accomplish this, the network layer defines logical addressing so that any endpoint can be identified. It also defines how routing works and how routes are learned so that the packets can be delivered. The network layer also defines how to fragment a packet into smaller packets to accommodate media with smaller maximum transmission unit sizes. (*Note:* Not all Layer 3 protocols use fragmentation.) The network layer of OSI defines most of the details that a Cisco router considers when routing. For example, IP running in a Cisco router is responsible for examining the destination IP address of a packet, comparing that address to the IP routing table, fragmenting the packet if the outgoing interface requires smaller packets, and queuing the packet to be sent out to the interface.	IP, IPX, AppleTalk DDP, ICMP
Data link (Layer 2)	The data link (Layer 2) specifications are concerned with getting data across one particular link or medium. The data link protocols define delivery across an individual link. These protocols are necessarily concerned with the type of media in question; for example, 802.3 and 802.2 are specifications from the IEEE, which are referenced by OSI as valid data link (Layer 2) protocols. These specifications define how Ethernet works. Other protocols, such as High-Level Data Link Control (HDLC) for a point-to-point WAN link, deal with the different details of a WAN link. As with other protocol specifications, OSI often does not create any original specification for the data link layer but instead relies on other standards bodies such as IEEE to create new standards for the data link layer and the physical layer.	IEEE 802.3/802.2, HDLC, Frame Relay, PPP, FDDI, ATM, IEEE 802.5/802.2

continues

03 CCNA Exam_Ch 03.fm Page 88 Thursday, March 7, 2002 11:46 AM

Table 3-2 *OSI Reference Model (Continued)*

Layer Name	Functional Description	Examples
Physical (Layer 1)	These physical layer (Layer 1) specifications, which are also typically standards from other organizations that are referred to by OSI, deal with the physical characteristics of the transmission medium. Connectors, pins, use of pins, electrical currents, encoding, and light modulation are all part of different physical layer specifications. Multiple specifications are sometimes used to complete all details of the physical layer. For example, RJ-45 defines the shape of the connector and the number of wires or pins in the cable. Ethernet and 802.3 define the use of wires or pins 1, 2, 3, and 6. So, to use a Category 5 cable with an RJ-45 connector for an Ethernet connection, Ethernet and RJ-45 physical layer specifications are used.	EIA/TIA-232, V.35, EIA/TIA-449, V.24, RJ45, Ethernet, 802.3, 802.5, FDDI, NRZI, NRZ, B8ZS

Some protocols define details of multiple layers. For example, because the TCP/IP application layer correlates to OSI Layers 5 through 7, the Network File System (NFS) implements elements matching all three upper OSI layers. Likewise, the 802.3, 802.5, and Ethernet standards define details for the data link and physical layers.

CCNAs deal with many aspects of Layers 1 through 4 on a daily basis, but the upper layers are not as important to CCNAs. In addition, most networking people know about the OSI model, but there is no need to memorize everything about it. Table 3-2 shows plenty of detail and explanation for a more in-depth idea of the OSI model components. If you are daunted by the task of memorizing all the examples in Table 3-2, you can refer to Table 3-3, which offers a more condensed description of the layer characteristics and examples. This table is taken directly from Cisco's ICND course, so if you are just not willing to try to remember all of Table 3-2, the information in Table 3-3 is a good compromise. (ICND is the instructor-led course in the official CCNA training path.)

Table 3-3 *OSI Reference Model (Condensed Information)*

OSI Layer Name	Functional Description	Examples
Application (Layer 7)	Interface between network and application software	Telnet, HTTP
Presentation (Layer 6)	How data is presented Special processing, such as encryption	JPEG, ASCII, EBCDIC
Session (Layer 5)	Keeping data separate from different applications	Operating systems and application access scheduling

03 CCNA Exam_Ch 03.fm Page 89 Thursday, March 7, 2002 11:46 AM

Table 3-3 *OSI Reference Model (Condensed Information) (Continued)*

OSI Layer Name	Functional Description	Examples
Transport (Layer 4)	Reliable or unreliable delivery Multiplexing	TCP, UDP, SPX
Network (Layer 3)	Logical addressing, which routers use for path determination	IP, IPX
Data link (Layer 2)	Combination of bits into bytes, and bytes into frames Access to the media using MAC address Error detection and error recovery	802.3/802.2, HDLC
Physical (Layer 1)	Moving of bits between devices Specification of voltage, wire speed, and cable pinouts	EIA/TIA-232, V.35

Layering Concepts and Benefits

Many benefits can be gained from the process of breaking up the functions or tasks of networking into smaller chunks, called *layers,* and defining standard interfaces between these layers. The layers break a large, complex set of concepts and protocols into smaller pieces, making it easier to talk about, to implement with hardware and software, and to troubleshoot. The following list summarizes the benefits of layered protocol specifications:

- Humans can more easily discuss and learn about the many details of a protocol specification.
- Standardized interfaces among layers facilitate modular engineering. Different products can provide functions of only some layers (such as a router with Layers 1 to 3), or some products could supply parts of the functions of the protocol (such as Microsoft TCP/IP built into Win95, or the Eudora e-mail application providing TCP/IP application layer support).
- A better environment for interoperability is created. One vendor can write software that implements higher layers—for example, a Web browser—and another can write software that implements the lower layers—for example, Microsoft's built-in TCP/IP software in its operating systems.
- Reduced complexity allows easier program changes and faster product evolution.
- One layer uses the services of the layer immediately below it. Therefore, remembering what each layer does is easier. (For example, the network layer needs to deliver data from end to end. To do this, it uses data links to forward data to the next successive device along that end-to-end path.)

03 CCNA Exam_Ch 03.fm Page 90 Thursday, March 7, 2002 11:46 AM

An analogy between the U.S. Postal Service and protocol layers might help. If I write a letter to my boss, Mike Z, at Skyline Computer in Campbell, California, I write the letter on a piece of paper. I then put it in an envelope and write the address on the front. After I put it in the mailbox, I assume that the USPS will deliver it. I don't have to know anything about where my letter goes after the postman picks up the letter. It would be irritating if I had to tell the postman to send my letter to some series of post office sorting centers to deliver the letter. Likewise, layering lets one software package or hardware device perform some of the functions, assuming that other software/hardware will perform the others.

Interaction Between OSI Layers

Imagine a Web browser displaying a Web page that it received from a Web server. Before that happened, the browser somehow interacted with the software implementing other layers of TCP/IP on the client computer, causing a request to flow to the server. Likewise, the broswer application somehow communicated with the Web server application, telling the server what Web page the browser wanted to display. A fancy way to describe these two ideas that is "interaction between OSI layers." The process of how layers interact on the same computer, as well as how the same layer processes on different computers communicate with each other, is all interrelated. The software or hardware products implementing the logic of some of the OSI protocol layers provide two general functions:

- Each layer provides a service to the layer above it in the protocol specification.
- Each layer communicates some information with the same layer's software or hardware on other computers. In some cases, the other computer is connected to the same media; in other cases, the other computer is on the other end of the network.

Interactions Between Adjacent Layers on the Same Computer

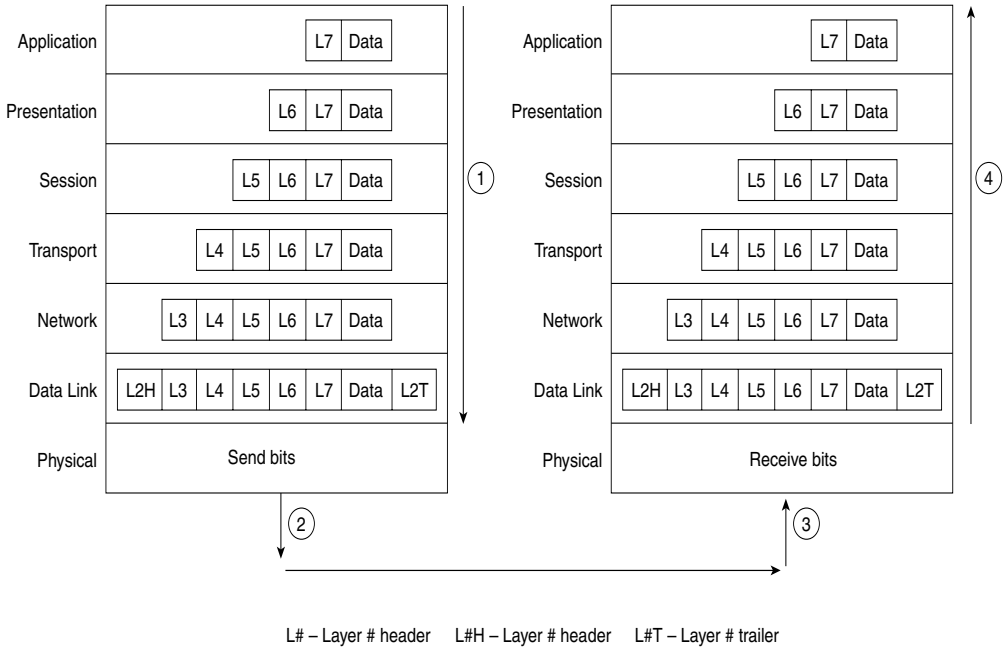
The post office analogy provides an easy comparison to networking and interactions between adjacent layers. The words in my letter to Mike Z are the application data. While still at my office, I put the letter in an envelope because the USPS will not just deliver the paper; it requires me to provide an envelope. On that envelope, I provide an address that meets USPS specifications for addresses. Having done that, and after putting on the correct postage stamp, I expect the USPS to deliver the letter. That's exactly the same concept of the interactions between layers on the same computer. When sending data, the higher layers expect the lower layers to help deliver the data. However, the lower layers expect the higher layers to give them the data in a certain format, with certain header and address information attached. (The header acts like the envelope in the analogy.)

So, to provide services to the next higher layer, the layer must know about the standard interfaces defined between itself and the next higher layer. These interfaces include definitions of what Layer *N*+1 must provide to Layer *N* to get services, as well as what information Layer *N* must provide back to Layer *N*+1 when data has been received. And these details are all part of the protocol specifications.

03 CCNA Exam_Ch 03.fm Page 91 Thursday, March 7, 2002 11:46 AM

Figure 3-2 presents a graphical representation of two computers and provides an excellent backdrop for a discussion of interactions between layers on the same computer.

Figure 3-2 *Example for Discussion of Adjacent-Layer Interactions*



The data is created by some application on Host A. For example, an e-mail message is typed by the user. Each layer creates a header and passes the data down to the next layer. (The arrows in Figure 3-2, Step 1, denote the passing of data between layers.) Just as I had to put an envelope around my letter to Mike, a layer typically has to put some header around its data before giving it to the next lower layer that is providing service. Passing the data down to the next layer implies that the lower layer needs to perform some services for the higher layer; to perform these services, the lower layer adds some information in a header or trailer. For example, the transport layer hands off its data and header; the network layer adds a header with the correct destination network layer address so that the packet can be delivered to the other computer.

From each layer's perspective, the bits after that layer's header are considered to be data. For instance, Layer 4 considers the Layer 5, 6, and 7 headers, along with the original user data, to be one large data field.

After the application creates the data, the software and hardware implementing each layer perform their work, adding the appropriate header and trailer. The physical layer can use the media to send a signal for physical transmission, as shown in Step 2 in Figure 3-2.

Upon receipt (Step 3), Host B begins the adjacent layer interactions on Host B. The right side of Figure 3-2 shows an arrow pointing next to the computer (Step 4), signifying that the

03 CCNA Exam_Ch 03.fm Page 92 Thursday, March 7, 2002 11:46 AM

received data is being processed as it goes up the protocol stack. In fact, thinking about what each layer does in the OSI model can help you decide what information could be in each header.

The following sequence outlines the basics of processing at each layer and shows how each lower layer provides a service to the next higher layer. Consider the *receipt of data* by the host on the right side of Figure 3-2:

Step 1 The physical layer (Layer 1) ensures bit synchronization and places the received binary pattern into a buffer. It notifies the data link layer that a frame has been received after decoding the incoming signal into a bit stream. Therefore, Layer 1 has provided delivery of a stream of bits across the medium.

Step 2 The data link layer examines the frame check sequence (FCS) in the trailer to determine whether errors occurred in transmission (error detection). If an error has occurred, the frame is discarded. (Some data link protocols perform error *recovery*, and some do not.) The data link address(es) are examined so that Host B can decide whether to process the data further. If the data is addressed to host B, the data between the Layer 2 header and trailer is given to the Layer 3 software. The data link has delivered the data across that link.

Step 3 The network layer (Layer 3) destination address is examined. If the address is Host B's address, processing continues (logical addressing) and the data after the Layer 3 header is given to the transport layer (Layer 4) software. Layer 3 has provided the service of end-to-end delivery.

Step 4 If error recovery was an option chosen for the transport layer (Layer 4), the counters identifying this piece of data are encoded in the Layer 4 header along with acknowledgment information (error recovery). After error recovery and reordering of the incoming data, the data is given to the session layer.

Step 5 The session layer (Layer 5) can be used to ensure that a series of messages is completed. For example, this data could be meaningless if the next four exchanges are not completed. The Layer 5 header could include fields signifying that this is a middle flow in a chain, not an ending flow. After the session layer ensures that all flows are completed, it passes the data after the Layer 5 header to the Layer 6 software.

Step 6 The presentation layer (Layer 6) defines and manipulates data formats. For example, if the data is binary instead of character data, the header denotes that fact. The receiver does not attempt to convert the data using the default ASCII character set of Host B. Typically, this type of header is included only

03 CCNA Exam_Ch 03.fm Page 93 Thursday, March 7, 2002 11:46 AM

for initialization flows, not with every message being transmitted (data formats). After the data formats have been converted, the data (after the Layer 6 header) is then passed to the application layer (Layer 7) software.

Step 7 The application layer (Layer 7) processes the final header and then can examine the true end-user data. This header signifies agreement to operating parameters by the applications on Host A and Host B. The headers are used to signal the values for all parameters; therefore, the header typically is sent and received at application initialization time only. For example, for file transfer, the size of the file to be transferred and the file formats used would be communicated (application parameters).

Interactions Between the Same Layers on Different Computers

Layer *N* must interact with Layer *N* on another computer to successfully implement its functions. For example, the transport layer (Layer 4) can send data, but if another computer does not acknowledge that the data was received, the sender will not know when to perform error recovery. Likewise, the sending computer encodes a destination network layer address (Layer 3) in the network layer header. If the intervening routers do not cooperate by performing their network layer tasks, the packet will not be delivered to the true destination.

The post office analogy can help in this case as well. If I write the letter to Mike and put the address but not his name on the envelope, the letter gets to the office because I gave the USPS enough information to deliver the letter. No one knows to whom to give the letter, though. In real life, someone would open the letter and see that it's addressed to Mike—but, of course, the office might have more than one Mike! With real networking, the sending application needs to put some header around the data so that the receiving computer knows what application should receive the data.

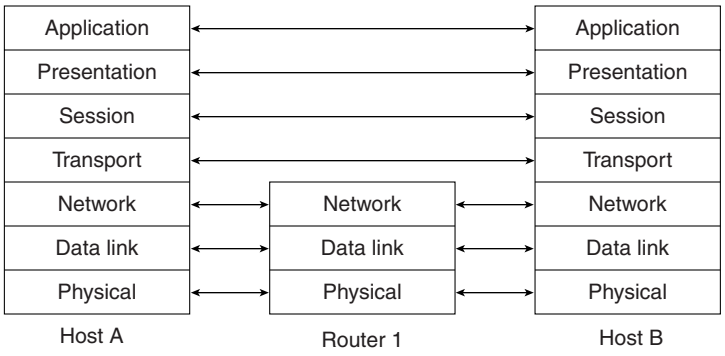
To interact with the same layer on another computer, each layer defines a header and, in some cases, a trailer. Headers and trailers are additional data bits, created by the sending computer's software or hardware, that are placed before or after the data given to Layer *N* by Layer *N+1*. The information needed for this layer to communicate with the same layer process on the other computer is encoded in the header and trailer. The receiving computer's Layer *N* software or hardware interprets the headers and trailers created by the sending computer's Layer *N*, learning how Layer *N*'s processing is being handled, in this case.

Figure 3-3 provides a conceptual perspective on the same-layer interactions. The application layer on Host A communicates with the application layer on Host B. Likewise, the transport, session, and presentation layers on Host A and Host B also communicate. The bottom three layers of the OSI model have to do with delivery of the data; Router 1 is involved in that process.

03 CCNA Exam_Ch 03.fm Page 94 Thursday, March 7, 2002 11:46 AM

Host A's network, physical, and data link layers communicate with Router 1; likewise, Router 1 communicates with Host B's physical, data link, and network layers. Figure 3-3 provides a visual representation of the same-layer interaction concepts.

Figure 3-3 *Same-Layer Interactions on Different Computers*



The post office analogy again helps. I, Wendell, the letter writer, is the equivalent of Host A. I write the letter, put it in the envelope, address and stamp the envelope, and drop it off at the local post office. The post office forwards the letter through many other mail-sorting centers because our home office, where Mike is, is 2,000 miles away. The mailing centers look at only the address—in fact, only at the ZIP code—until the letter makes it to Campbell, California. So I, the sender (Host A), put the address on the letter, which is used by many mailing centers (routers) who deliver the letter to our home office (host B), where the letter is given to the correct individual (correct application).

Data Encapsulation

The term *encapsulation* describes the process of putting headers and trailers around some data. Encapsulation puts the data in the correct, expected format so that another adjacent layer can provide a service or so that the same layer on another computer knows what needs to be done. For example, I put an envelope around my letter to Mike because that was required by the USPS, which provided me a service. I put Mike's name on the envelope so that the people in our home office would know to whom to give the letter—the equivalent of the "same" layer on another computer.

As seen previously in Figure 3-2, when each layer creates its header, it places the data given to it by the next-higher layer behind its own header, thereby encapsulating the higher layer's data. In the case of a data link (Layer 2) protocol, the Layer 3 header and data are placed between the Layer 2 header and the Layer 2 trailer. The physical layer does not use encapsulation because it does not use headers or trailers.

03 CCNA Exam_Ch 03.fm Page 95 Thursday, March 7, 2002 11:46 AM

Again referring to Figure 3-2, Step 1, the following list describes the encapsulation process for sending data by Host A:

Step 1 The application has already created the data. The application layer creates the application header and places the data behind it. This data structure is passed to the presentation layer.

Step 2 The presentation layer creates the presentation header and places the data behind it. This data structure is passed to the session layer.

Step 3 The session layer creates the session header and places the data behind it. This data structure is passed to the transport layer.

Step 4 The transport layer creates the transport header and places the data behind it. This data structure is passed to the network layer.

Step 5 The network layer creates the network header and places the data behind it. This data structure is passed to the data link layer.

Step 6 The data link layer creates the data link header and places the data behind it. The data link trailer is added to the end of the structure. This data structure is passed to the physical layer.

Step 7 The physical layer encodes a signal onto the medium to transmit the frame.

This seven-step process accurately describes what happens for the seven-layer OSI model. However, encapsulation by each layer does not typically happen for each transmission of data by the application. Normally, Layers 5 through 7 use headers during initialization—and occasionally after initialization—but, in most flows, there is no Layer 5, 6, or 7 header. This is because there is no new information to exchange for every flow of data.

An analogy can help in this case. A friend of mine from church spent several summers teaching English in a communist country. When I wrote to her, she assumed that I would write in English, but I could not write about "church" without the sensors tossing the letter. So, we agreed on encryption before she left. Under our code, God was called "Phil," and I could write things such as, "I saw Fred at Phil's house yesterday, and he said hi." I still had to address the letters before I mailed them, just like the lower OSI layers need to exchange some information for every piece of data sent. I didn't need to repeat what "Phil" really meant in each letter, just like the upper layers do not need to repeat encryption rules.

Previous CCNA exams referred to a five-step process for encapsulation. This included the typical encapsulation by the transport, network, and data link layers as steps 2 through 4 in the seven-step process. The first step in the five-step process was the application's creation of the data, and the fifth step was the physical layer's transmission of the bit stream. In case any questions remain in the CCNA question database referring to a five-step encapsulation process, the following list provides the details and explanation.

03 CCNA Exam_Ch 03.fm Page 96 Thursday, March 7, 2002 11:46 AM

NOTE The term *LxPDU*, where *x* represents the number of one of the layers, is used to represent the bits that include the headers and trailers for that layer, as well as the encapsulated data. For instance, an IP packet is an L3PDU, which includes the IP header and any encapsulated data.

Step 1 **Create the data**—This simply means that the application has data to send.

Step 2 **Package the data for transport**—In other words, the transport layer creates the transport header and places the data behind it. The L4PDU is created here.

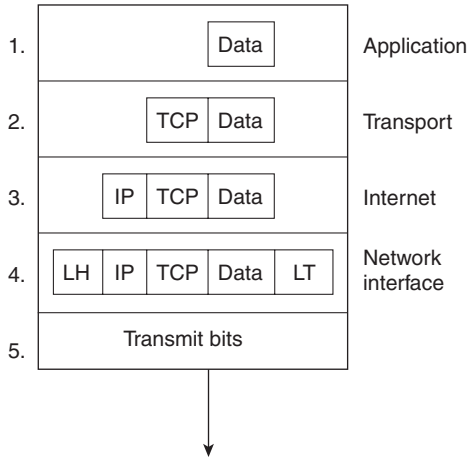
Step 3 **Add the destination network layer address to the data**—The network layer creates the network header, which includes the network layer address, and places the data (L4PDU) behind it. In other words, the L3PDU is created here.

Step 4 **Add the destination data link address to the data**—The data link layer creates the data link header, places the data (L3PDU) behind it, and places the data link trailer at the end. In other words, the L2PDU is created here.

Step 5 **Transmit the bits**—The physical layer encodes a signal onto the medium to transmit the frame.

This five-step process happens to match the TCP/IP network model very well. Figure 3-4 depicts the concept; the numbers shown represent each of the five steps.

Figure 3-4 *Five Steps of Data Encapsulation—TCP/IP*

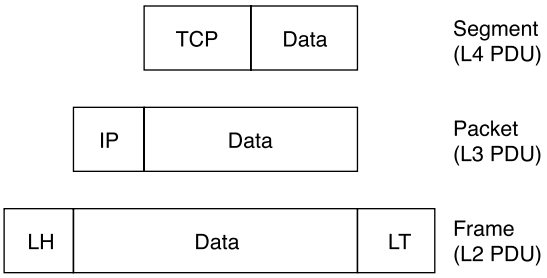


Several very important terms describe details about encapsulation**.** *Layer N PDU* (protocol data unit) is a term used to describe a set of bytes that includes the Layer *N* header and trailer and the user data. From Layer *N*'s perspective, the higher-layer headers and the user data form one large *data* or *information* field. A few other terms describe some of these PDUs. The Layer 2

03 CCNA Exam_Ch 03.fm Page 97 Thursday, March 7, 2002 11:46 AM

PDU (including the data link header and trailer) is called a *frame*. Similarly, the Layer 3 PDU is called a *packet*, or sometimes a *datagram*. Finally, the Layer 4 PDU is called a *segment*. Figure 3-5 illustrates the construction of frames, packets, and segments and the different layers' perspectives on what is considered to be *data*.

Figure 3-5 *Frames, Packets, and Segments*



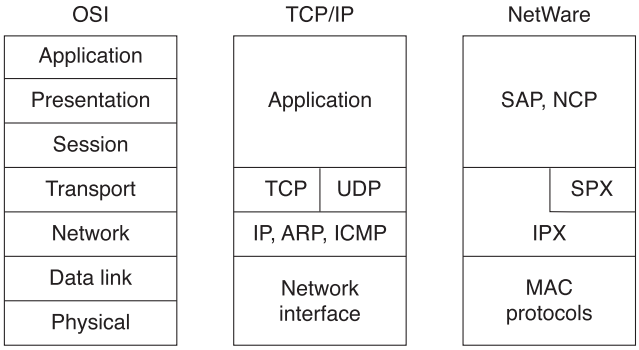
The TCP/IP and NetWare Protocols

Two of the most pervasively deployed protocols are TCP/IP and Novell NetWare; these also are the two key protocol architectures covered on the CCNA exam. TCP/IP and NetWare are covered in much more detail in the upcoming chapters.

This short section compares TCP/IP, Novell, and OSI. The goal is to provide some insight into what some popularly used terminology really means. In particular, routing is defined as a *Layer 3 process*; this section reviews how that term relates to TCP/IP and NetWare.

For perspective, Figure 3-6 shows the layers of these two protocols as compared with OSI.

Figure 3-6 *OSI, TCP/IP, and NetWare Protocols*



As Figure 3-6 illustrates, the IP and IPX protocols most closely match the OSI network layer—Layer 3. Many times, even on the CCNA exam, IP and IPX will be called *Layer 3 protocols*. Clearly, IP is in TCP/IP's Layer 2, but for consistent use of terminology, it is commonly called a

03 CCNA Exam_Ch 03.fm Page 98 Thursday, March 7, 2002 11:46 AM

Layer 3 protocol because its functions most closely match OSI's Layer 3. Both IP and IPX define logical addressing, routing, the learning of routing information, and end-to-end delivery rules.

As with OSI Layers 1 and 2 (physical and data link, respectively), the lower layers of each stack simply refer to other well-known specifications. For example, the lower layers all support the IEEE standards for Ethernet and Token Ring, the ANSI standard for FDDI, the ITU standard for ISDN, and the Frame Relay protocols specified by the Frame Relay Forum, ANSI, and the ITU. The protocol stacks can accommodate other evolving Layer 1 and Layer 2 specifications more easily by referring to emerging international standards rather than trying to evolve these standards themselves.

OSI Transport Layer Functions

1 Describe connection-oriented network service and connectionless network service, and identify their key differences.

The transport layer (Layer 4) defines several functions, the most important of which are error recovery and flow control. Routers discard packets for many reasons, including bit errors, congestion that has caused a lack of buffer space, and instances in which no correct routes are known. The transport layer may provide for retransmission (error recovery) and can help avoid congestion (flow control), or it might not. When you compare similar protocols, you typically want to know whether they perform error recovery or flow control.

Connection-Oriented Versus Connectionless Protocols

The terms *connection-oriented* and *connectionless* have some relatively well-known connotations inside the world of networking protocols. The meaniing of the terms is intertwined with error recovery and flow control, but they are not the same. So, first, some basic definitions are in order:

Connection-oriented protocol—A protocol either that requires an exchange of messages before data transfer begins or that has a required pre-established correlation between two endpoints

Connectionless protocol—A protocol that does not require an exchange of messages and that does not require a pre-established correlation between two endpoints

The definitions are sufficiently general so that all cases can be covered. TCP is connection-oriented because a set of three messages must be completed before data is exchanged. Likewise, SPX is connection-oriented. When using PVCs, Frame Relay does not require any

03 CCNA Exam_Ch 03.fm Page 99 Thursday, March 7, 2002 11:46 AM

messages be sent ahead of time, but it does require predefinition in the Frame Relay switches, establishing a connection between two Frame Relay–attached devices. ATM PVCs are also connection-oriented, for similar reasons.

NOTE Some documentation refers to the terms *connected* or *connection-oriented*. These terms are used synonymously. You will most likely see the use of the term *connection-oriented* in Cisco documentation.

Many people confuse the real meaning of *connection-oriented* with the definition of a reliable, or error-recovering, protocol. A great example that you will learn more about in this book is Frame Relay. Frame Relay requires that some connection be established before any data can flow between two endpoints. However, there is no error receovery. Table 3-4 lists some popular protocols and tells whether they are connected or reliable.

Table 3-4 *Protocol Characteristics: Recovery and Connections*

Connected?	Reliable?	Examples
Connection-oriented	Yes	LLC Type 2 (802.2), TCP (TCP/IP), SPX (NetWare), X.25
Connection-oriented	No	Frame Relay virtual circuits, ATM virtual connections, PPP
Connectionless	Yes	TFTP, NetWare NCP (without Packet Burst)
Connectionless	No	UDP, IP, IPX, AppleTalk DDP, most Layer 3 protocols, 802.3, 802.5

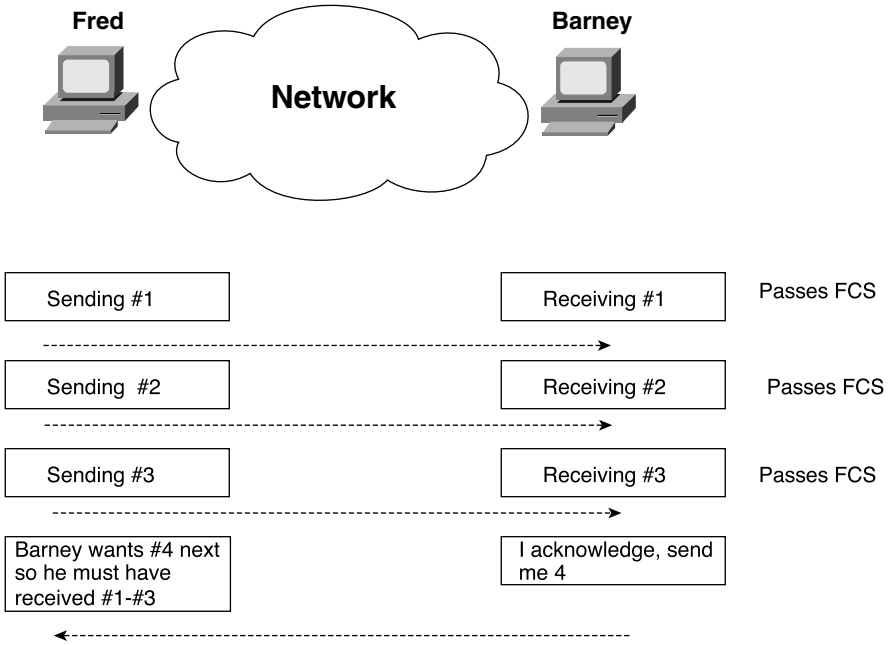
Error Recovery

Cisco expects CCNAs to be able to distinguish between *error detection* and *error recovery*. Any header or trailer with a frame check sequence (FCS) or similar field can be used to detect bit errors in the PDU. The FCS uses some magic math against the contents of the frame, with the result recorded in the FCS field. If the receiving device repeats the same math but gets a different value than what is in the FCS field, there were bit errors in transmission. Error detection uses the FCS to detect the error, which results in discarding the PDU. However, error recovery implies that the protocol reacts to the lost data and somehow causes the data to be retransmitted.

Many protocols offer error recovery, and these protocols accomplish the task in the same general way. Generically, the transmitted data is labeled or numbered. After receipt, the receiver signals back to the sender that the data was received, using the same label or number to identify the data. Figure 3-7 summarizes the operation.

03 CCNA Exam_Ch 03.fm Page 100 Thursday, March 7, 2002 11:46 AM

Figure 3-7 *Forward Acknowledgement*



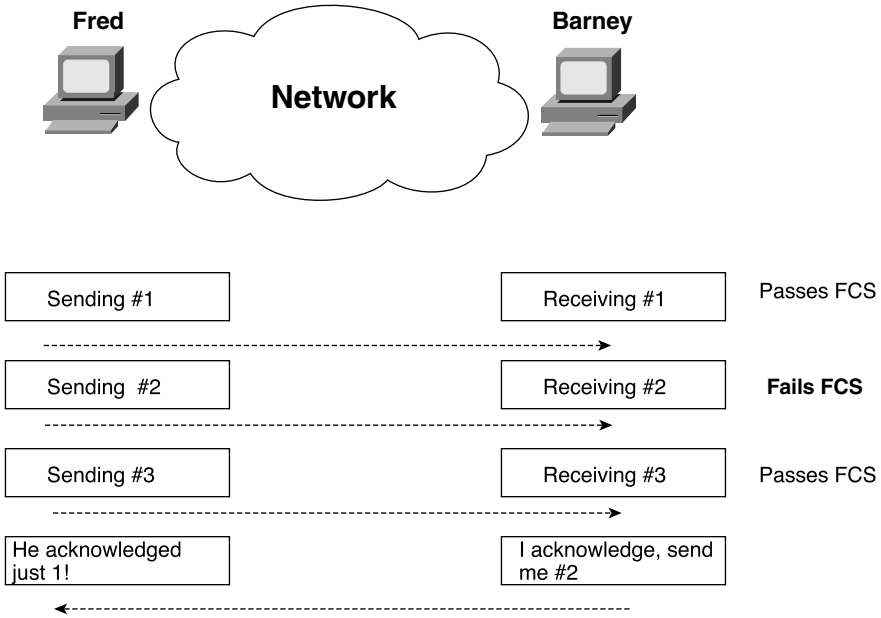
As Figure 3-7 illustrates, the data is numbered, as shown with the numbers 1, 2, and 3. These numbers are placed into the header used by that particular protocol; for example, the TCP header contains similar numbering fields. When Barney sends his next segment to Fred, Barney acknowledges that all three segments were received by setting his acknowledgment field to 4. The number 4 refers to the next data to be received, which is called *forward acknowledgment*. This means that the acknowledgment number in the header identifies the next data that is to be received, not the last one received. (In this case, 4 is next to be received.)

In some protocols, such as LLC2, the numbering always starts with zero. In other protocols, such as TCP, the number is stated during initialization by the sending machine. Also, some protocols count the frame/packet/segment as 1; others count the number of bytes sent. In any case, the basic idea is the same.

Of course, error recovery has not been covered yet. Take the case of Fred and Barney again, but notice Barney's reply in Figure 3-8.

03 CCNA Exam_Ch 03.fm Page 101 Thursday, March 7, 2002 11:46 AM

Figure 3-8 *Recovery Example*



What should Fred do next? Well, Fred certainly should resend number 2. However, should Fred resend number 3? Two choices exist. Fred could send numbers 2 and 3 again, or Fred could send number 2 and wait, hoping that Barney's next acknowledgment will say 4, indicating that Barney just got number 2 and already had number 3 from earlier. What happens in real life is dependant on the praticular protocol.

Finally, error recovery typically uses two sets of counters: one to count data in one direction, and one to count data in the opposite direction. So, the numbers 1, 2, and 3 in the segments sent by Fred would be in the Number Sent field of some header. Barney acknowledges packet number 2 with the Number Acknowledged field in the header. Similarly, segments sent by Barney also have a Number Sent field that identifies the data in Barney's packet, and the Number Acknowledged field in Fred's segments would be used to acknowledge segments sent by Barney.

Table 3-5 summarizes the concepts behind error recovery and lists the behavior of three popular error-recovery protocols.

03 CCNA Exam_Ch 03.fm Page 102 Thursday, March 7, 2002 11:46 AM

Table 3-5 *Examples of Error-Recovery Protocols and Their Features*

Feature	TCP	SPX	LLC2
Acknowledges data in both directions?	Yes	Yes	Yes
Uses forward acknowledgment?	Yes	Yes	Yes
Counts bytes or frame/packets?	Bytes	Packets	Frames
Necessitates resending of all data, or just one part and wait when resending?	One and wait	Resend all	Resend all

Flow Control

Flow control is the process of controlling the rate at which a computer sends data. Depending on the particular protocol, both the sender and the receiver of the data (as well as any intermediate routers, bridges, or switches) might participate in the process of controlling the flow from sender to receiver.

Flow control prevents unnecessary congestion by attempting to send data at a rate that the network can currently accomodate. A sender of data might be sending the data faster than the receiver can receive the data, so the receiver discards the data. Also, the sender might be sending the data faster than the intermediate switching devices (switches and routers) can forward the data, also causing discards. Packets can be lost because of transmission errors as well. This happens in every network, sometimes temporarily and sometimes regularly, depending on the network and the traffic patterns. The receiving computer can have insufficient buffer space to receive the next incoming frame, or possibly the CPU is too busy to process the incoming frame. Intermediate routers might need to discard the packets based on temporary lack of buffers or processing as well.

Flow control attempts to reduce unnecessary discarding of data. Comparing flows when flow control is used and when it is not used is helpful for understanding why flow control can be useful. Without flow control, some PDUs are discarded. If some reliable protocol in use happens to implement error recovery, the data is resent. The sender keeps sending as fast as possible. With flow control, the sender can be slowed enough that the original PDU can be forwarded to the receiving computer, and the receiving computer can process the PDU. Flow-control protocols do not prevent the loss of data as a result of congestion; these protocols simply reduce the amount of lost data, which, in turn, reduces the amount of retransmitted traffic, which hopefully reduces overall congestion. However, with flow control, the sender is artificially slowed or throttled so that it sends data less quickly than it could without flow control.

03 CCNA Exam_Ch 03.fm Page 103 Thursday, March 7, 2002 11:46 AM

The CCNA exam requires that you be familiar with three features, or methods, of implementing flow control:

- Buffering
- Congestion avoidance
- Windowing

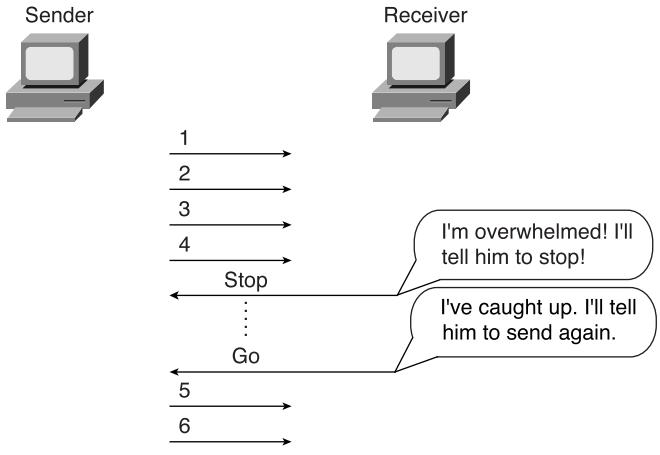
Buffering

Buffering simply means that the computers reserve enough buffer space that bursts of incoming data can be held until processed. No attempt is made to actually slow the transmission rate of the sender of the data. In fact, buffering is such a common method of dealing with changes in the rate of arrival of data that most of us probably would just assume that it is happening. However, some older documentation refers to "three methods of flow control," of which buffering is one of the methods, so be sure to remember it as a separate function.

Congestion Avoidance

Congestion avoidance is the second method of flow control covered here. The computer receiving the data notices that its buffers are filling. This causes either a separate PDU or a field in a header to be sent toward the sender, signaling the sender to stop transmitting. Figure 3-9 shows an example.

Figure 3-9 *Congestion-Avoidance Flow Control*



03 CCNA Exam_Ch 03.fm Page 104 Thursday, March 7, 2002 11:46 AM

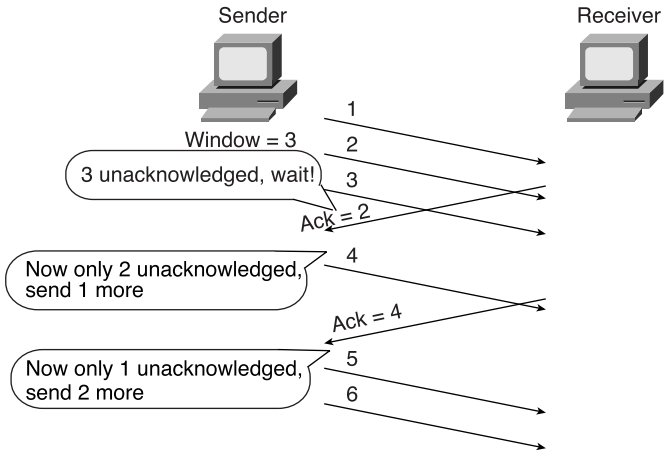
"Hurry up and wait" is a popular expression used to describe the process used in this congestion-avoidance example. This process is used by Synchronous Data Link Control (SDLC) and Link Access Procedure, Balanced (LAPB) serial data-link protocols.

A preferred method might be to get the sender to simply slow down instead of stopping altogether. This method would still be considered congestion avoidance, but instead of signaling the sender to stop, the signal would mean to slow down. One example is the TCP/IP Internet Control Message Protocol (ICMP) source quench message. This message is sent by the receiver or some intermediate router to slow the sender. The sender can slow down gradually until source quench messages are no longer received.

Windowing

The third category of flow-control methods is called *windowing*. A window is the maximum amount of data that the sender can send without getting an acknowledgment. If no acknowledgment is received by the time the window is filled, the sender must wait for acknowledgment. Figure 3-10 shows an example. The slanted lines indicate the time difference between sending a PDU and its receipt.

Figure 3-10 *Windowing Flow Control*



In this example, the sender has a window of three frames. After the receiver acknowledges the receipt of frame 1, frame 4 can be sent. After a time lapse, the acknowledgment for frames 2 and 3 are received, which is signified by the frame sent by the receiver with the Acknowledgment field equal to 4. So, the sender is free to send two more frames—frames 5 and 6—before another acknowledgment is received.

Table 3-6 summarizes the flow-control terms and provides examples of each type. Memorizing these terms should help trigger your memory of flow-control concepts.

03 CCNA Exam_Ch 03.fm Page 105 Thursday, March 7, 2002 11:46 AM

Table 3-6 *Flow-Control Methods—Summary*

Name Used in This Book	Other Names	Example Protocols
Buffering	N/A	N/A
Congestion avoidance	Stop/start, RNR, source quench	SDLC, LAPB, LLC2
Windowing	N/A	TCP, SPX, LLC2

OSI Data Link Layer Functions

5 Describe data-link and network addresses, and identify key differences between them.

6 Define and describe the function of a MAC address.

As a CCNA, you'll need to understand both the abstract concepts about the OSI layers and particular instances of such protocols. This section focuses on more of the abstract concepts. Later chapters provide more details about particular LAN and WAN data-link protocols, as well as their configuration in the IOS.

This section examines four different protocols: Ethernet, Token Ring, HDLC, and Frame Relay. A generalized definition of the function of a data-link protocol will be used to guide you through the comparison of these four data-link protocols. This definition could be used to examine any other data-link protocol. The four components of this definition of the functions of data-link (Layer 2) protocols are as follows:

- **Arbitration**—Determines when it is appropriate to use the physical medium.
- **Addressing**—Ensures that the correct recipient(s) receives and processes the data that is sent.
- **Error detection**—Determines whether the data made the trip across the medium successfully.
- **Identifying the encapsulated data**—Determines the type of header that follows the data-link header. This feature is included in a subset of data-link protocols.

Engineers deploy Ethernet as the chosen type of LAN, but, for the sake of comparison, Token Ring concepts are covered here briefly. These protocols are defined by the IEEE in specifications 802.3 and 802.5, respectively. Because 802.3 and 802.5 define how a station accesses the media, the IEEE calls these protocols *Media Access Control (MAC)* protocols.

03 CCNA Exam_Ch 03.fm Page 106 Thursday, March 7, 2002 11:46 AM

Also, both 802.3 and 802.5 call for the use of another IEEE specification as a separate part of the data link layer—namely, 802.2 Logical Link Control (LLC). 802.2 purposefully is designed to provide functions common to both Ethernet and Token Ring, whereas 802.3 and 802.5 were designed specifically for data-link functions pertinent to either Ethernet or Token Ring topologies, respectively.

The IEEE created 802.3 and 802.2 after the original creation of Ethernet. The original specification is called *DIX Ethernet*, with the letters DIX representing Digital, Intel, and Xerox, giving credit to the creators. DIX Version 2 (the latest and final DIX specification) defines similar functions to both the 802.3 and 802.2 specifications.

HDLC is the default data-link protocol (encapsulation) on Cisco routers' serial interfaces. Frame Relay headers coincidentally are based on the HDLC specification, but Frame Relay was created for multiaccess networks (with more than two devices). The clear differences between Frame Relay and HDLC provide a good backdrop to examine the functions of the data link layer (Layer 2).

Data Link Function 1: Arbitration

Arbitration is needed only when there are instants in time during which it is not appropriate to send data across the media. It's like trying to get through an intersection in your car when all the traffic signals are out—you all want to use the intersection, but you had better use it one at a time! The arbitration methods vary greatly, depending on how conserative you are, how big the other cars are, how new or old your car is, and how much you value your own life! LANs originally were defined as a shared medium on which each device must wait until the appropriate time to send data. The specifications for these data-link protocols define how to arbitrate the use of the physical medium.

Ethernet uses the *carrier sense multiple access collision detect (CSMA/CD*) algorithm for arbitration. The basic algorithm for using an Ethernet when there is data to be sent consists of the following steps:

1. Listen to find out whether a frame is currently being received.
2. If no other frame is on the Ethernet, send.
3. If another frame is on the Ethernet, wait and then listen again.
4. While sending, if a collision occurs, stop, wait, and listen again.

With Token Ring, a totally different mechanism is used. A free-token frame rotates around the ring while no device has data to send. When sending, a device claims the free token, which really means changing bits in the 802.5 header to signify "token busy." The data then is placed onto the ring after the Token Ring header. The basic algorithm for using a Token Ring when there is data to be sent consists of the following steps:

1. Listen for the passing token.
2. If token is *busy*, listen for the next token.

03 CCNA Exam_Ch 03.fm Page 107 Thursday, March 7, 2002 11:46 AM

3 If the token is *free*, mark the token as a *busy* token, append the data, and send the data onto the ring.

4 When the header with the busy token returns to the sender of that frame, after completing a full revolution around the ring, the sender removes the data from the ring.

5 The same device that just sent the frame sends a free token to allow another station to send a frame.

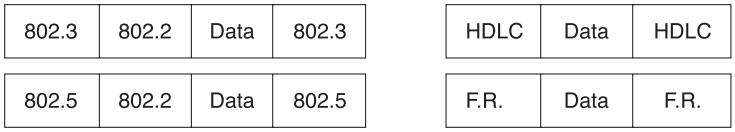
The algorithm for Token Ring does have other rules and variations, but these are beyond the depth of what is needed for the CCNA exam. Network Associates (the "Sniffer" people) have an excellent class covering Token Ring in detail. To find out more about these classes, go to www.nai.com.

With HDLC, arbitration is a nonissue today. HDLC is used on point-to-point links, which are typically full-duplex (four-wire) circuits. In other words, either endpoint can send at any time on a full-duplex link. Full-duplex operation is analogous to driving down a two-lane road—cars pass you going the other direction with no problem because there is a lane for each direction.

From a physical perspective, Frame Relay is comprised of a leased line between a router and the Frame Relay switch. These links are also typically full-duplex links, so no arbitration is needed. The Frame Relay network is shared among many data terminal equipment (DTE) devices, whereas the access link is not shared, so arbitration of the medium is not an issue.

NOTE As used in this book and in the ICND course, the word *frame* refers to particular parts of the data as sent on a link. In particular, *frame* implies that the data-link header and trailer are part of the bits being examined and discussed. Figure 3-11 shows frames for the four data-link protocols.

Figure 3-11 *Popular Frame Formats*



Data Link Function 2: Addressing

Cisco requires that CCNAs master the formats and meanings of data link layer and network layer addresses. LANs need addressing because there can be many possible recipients of data—that is, there could be more than two devices on the link. LANs behave much like people when you have a meeting with three or more people: If you want to say something to someone in particular, you first say that person's name—or at least look at him. Or, if you want to tell everyone in the meeting something, you just say it because they can all hear you. Likewise, LANs are *broadcast media*—a term signifying that all devices on the media receive the same data.

03 CCNA Exam_Ch 03.fm Page 108 Thursday, March 7, 2002 11:46 AM

With Ethernet and Token Ring, the addresses are very similar. Each uses Media Access Control (MAC) addresses, which are 6 bytes long and are represented as a 12-digit hexadecimal number. Table 3-7 summarizes most of the details about MAC addresses.

Table 3-7 *LAN MAC Address Terminology and Features*

LAN Addressing Terms and Features	Description
MAC	Media Access Control. 802.3 (Ethernet) and 802.5 (Token Ring) are the MAC sublayers of these two LAN data-link protocols.
Ethernet address, NIC address, LAN address, Token Ring address, card address	Other names often used instead of MAC address. These terms describe the 6-byte address of the LAN interface card.
Burned-in address	The 6-byte address assigned by the vendor making the card. It usually is burned into a ROM or EEPROM on the LAN card and begins with a 3-byte organizationally unique identifier (OUI) assigned by the IEEE.
Locally administered address	Through configuration, an address that is used instead of the burned-in address.
Unicast address	Fancy term for a MAC that represents a single LAN interface.
Broadcast address	An address that means "all devices that reside on this LAN right now."
Multicast address	Not valid on Token Ring. On Ethernet, a multicast address implies some subset of all devices currently on the LAN.
Functional address	Not valid on Ethernet. On Token Ring, these addresses are reserved to represent the device(s) on the ring performing a particular function. For example, all source-route bridges supply the ring number to other devices; to do so, they each listen for the Ring Parameter Server (RPS) functional address.

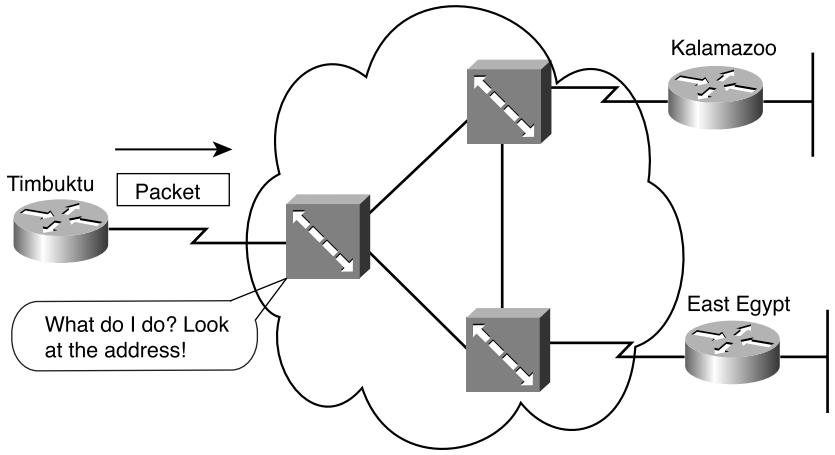
HDLC includes a meaningless address field because it is used only on point-to-point serial links. The recipient is implied; if one device sent a frame, the other device is the only possible intended recipient. In the earlier analogy of three or more people in a meeting, point-to-point links are more like a meeting with two people—you do not have to say someone's name before you speak because the other person is the only one you can talk to!

Frame Relay acts more like a LAN than a point-to-point link, regarding the need for addressing. With Frame Relay, there is one physical link that has many logical circuits called *virtual circuits*

03 CCNA Exam_Ch 03.fm Page 109 Thursday, March 7, 2002 11:46 AM

(VCs). (See Chapter 10, "Frame Relay Concepts and Configuration," for more background on Frame Relay.) The address field in Frame Relay defines a data-link connection identifier (DLCI), which identifies each VC. For example, in Figure 3-12, the Frame Relay switch to which router Timbuktu is connected receives frames; the switch forwards the frame to either Kalamazoo or East Egypt based on the DLCI, which identifies each VC. So, Timbuktu has one physical connection but multiple logical connections.

Figure 3-12 *Frame Relay Network*



Data Link Function 3: Error Detection

Error detection discovers whether bit errors occurred during the transmission of the frame. To do this, most data links include a *frame check sequence (FCS)* or *cyclical redundancy check (CRC)* field in the data link trailer. This field contains a value that is the result of a mathematical formula applied to the data in the frame. The FCS value calculated and sent by the sender should match the value calculated by the receiver. All four data links discussed in this section contain an FCS field in the frame trailer.

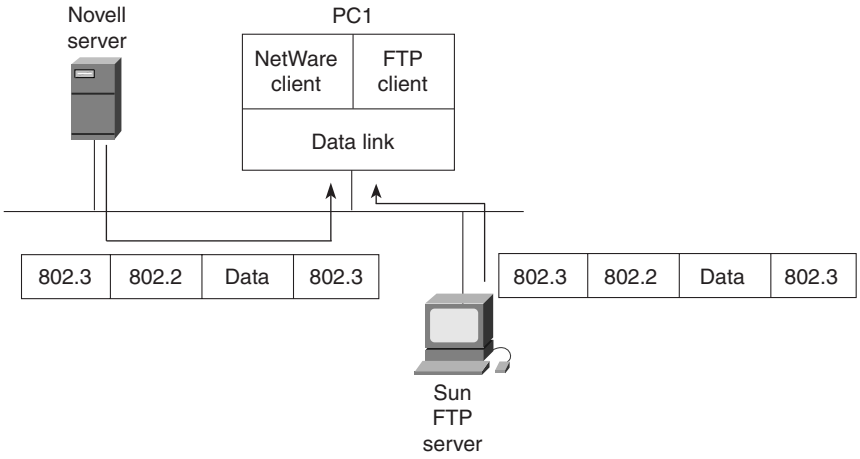
Error detection does not imply recovery; most data links, including 802.5 Token Ring and 802.3 Ethernet, do not provide error recovery. In these two cases, however, an option in the 802.2 protocol, called LLC Type 2, does perform error recovery. (SNA and NetBIOS are the typical higher-layer protocols in use that request the services of LLC2.) Neither HDLC or Frame Relay does error recovery.

Data Link Function 4: Identifying the Encapsulated Data

Finally, the fourth part of a data link identifies the contents of the data field in the frame. Figure 3-13 helps make the usefulness of this feature apparent.

03 CCNA Exam_Ch 03.fm Page 110 Thursday, March 7, 2002 11:46 AM

Figure 3-13 *Multiplexing Using Data Link Type and Protocol Fields*



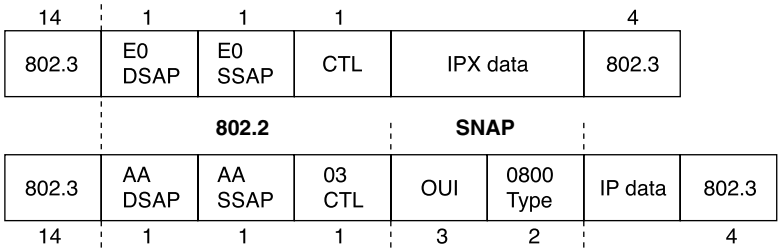
When PC1 receives data, does it give the data to the TCP/IP software or the NetWare client software? Of course, that depends on what is inside the data field. If the data came from the Novell server, PC1 hands the data off to the NetWare client code. If the data comes from the Sun FTP server, PC1 hands it off to the TCP/IP code. But what does PC1 look at to make this decision? Well, Ethernet and Token Ring 802.2 LLC use a field in its header to identify the type of data in the data field, and that is the field that PC1 examines to decide whether the packet is an IP packet or an IPX packet.

Each data-link header has a field with a code that means IP, IPX, or some other designation defining the type of protocol header that follows. For example, in the first frame in Figure 3-14, the destination service access point (DSAP) field has a value of E0, which means that the next header is a Novell IPX header. Why is that? Well, when the IEEE created 802.2, they saw the need for a protocol type field. They called it DSAP, and anyone could register favorite protocols to use a reserved value in the DSAP field; Novell registered IPX and was assigned hex E0 by the IEEE.

However, the IEEE did not plan for a large number of protocols—in fact, the 1-byte-long DSAP field is not big enough to number them all. In the second frame of Figure 3-14, the DSAP field is AA, which implies that a *subnetwork access protocol (SNAP)* header follows. The SNAP header uses a 2-byte protocol type field, which has a value of 0800 in this case, signifying that the next header is an IP header. RFC 1700, the "Assigned Numbers" RFC (http://www.isi.edu/in-notes/rfc1700.txt), lists the SAP and SNAP Type field values and the protocol types that they imply.

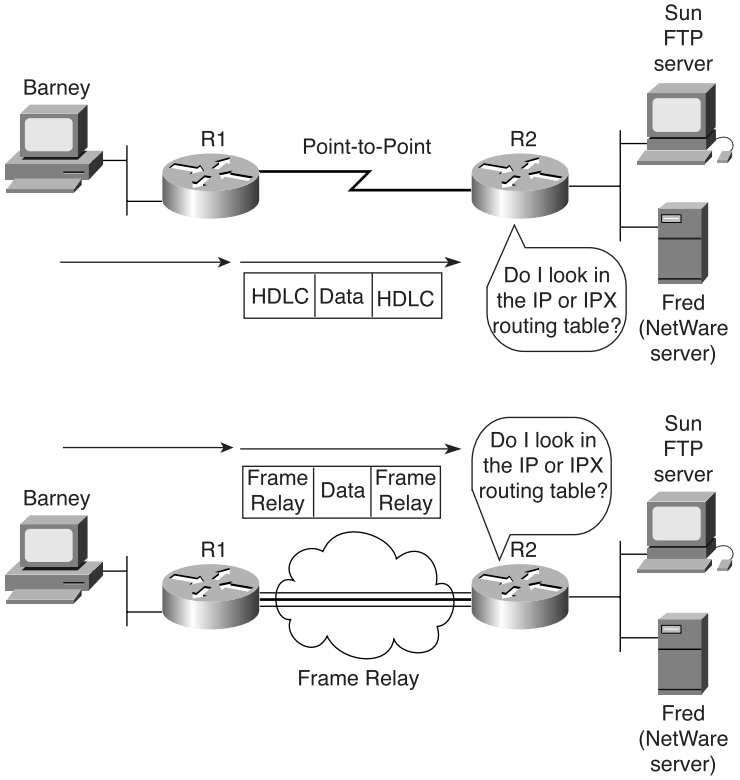
03 CCNA Exam_Ch 03.fm Page 111 Thursday, March 7, 2002 11:46 AM

Figure 3-14 *802.2 SAP and SNAP Type Fields*



Similarly, HDLC and Frame Relay need to identify the contents of the data field. Of course, it is atypical to have end-user devices attached to either of these types of data links. In this case, routers provide an example more typically found in most WAN environments, as shown in Figure 3-15.

Figure 3-15 *Identifying Protocols over HDLC and Frame Relay*



03 CCNA Exam_Ch 03.fm Page 112 Thursday, March 7, 2002 11:46 AM

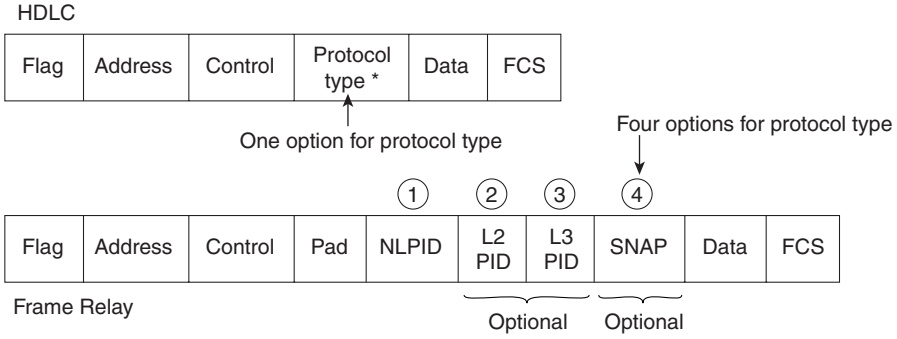
Referring to the top part of Figure 3-15, if Barney is using FTP to transfer files to the Sun system and also is connected to the NetWare server (Fred) using IPX, Barney will generate both TCP/IP and NetWare IPX traffic. As this traffic passes over the HDLC-controlled link, R2 will need to know whether an IP or IPX packet follows the HDLC header. Mainly, this is so that the router can find the Layer 3 destination address, assume its length (32 bits or 80 bits), perform table lookup in the correct routing table (IP or IPX), and make the correct routing decision.

HDLC does not provide a mechanism to identify the type of packet in the data field. IOS adds a proprietary 2-byte field immediately after the HDLC header that identifies the contents of the data. Likewise, with Frame Relay, the receiving router (R2) needs to know whether an IP or IPX packet follows the Frame Relay header. Frame Relay headers originally did not address this issue, either, because the headers were based on HDLC. However, the IETF created a specification called RFC 1490 that defined additional headers that followed the standard Frame Relay header. These headers include several fields that can be used to identify the data so that the receiving device knows what type is hidden inside.

The ITU and ANSI picked up the specifications of RFC 1490 and added it to their official Frame Relay standards: ITU T1.617 Annex F and ANSI Q.933 Annex E, respectively.

Figure 3-16 shows the fields that identify the type of protocol found in the data field.

Figure 3-16 *Identifying Protocols over HDLC and Frame Relay*



* Cisco proprietary

As Figure 3-16 shows, a Protocol Type field comes after the HDLC Control field. In the Frame Relay example, four different options exist for identifying the type of data inside the frame. RFC 2427, which obsoletes RFC 1490, provides a complete reference and is useful reading for those of you moving on to CCNP certification (see www.isi.edu/in-notes/rfc2427.txt). ("Obsoletes" in the RFC world implies that a newer document has superceded it but does not necessarily mean that all or most of the original RFC has been changed.)

Table 3-8 summarizes the different choices for encoding protocol types for each of the four data-link protocols. Notice that the length of some of these fields is only 1 byte, which historically has led to the addition of other headers that have a 2-byte Protocol Type field

03 CCNA Exam_Ch 03.fm Page 113 Thursday, March 7, 2002 11:46 AM

because 1 byte is just not enough to number all the different protocols. For example, the SNAP header contains a 2-byte type field because a 1-byte DSAP field is not big enough to number all the available options for what type of protocol is inside the data.

Table 3-8 *Different Choices for Encoding Protocol Types for Each of the Four Example Data-Link Protocols*

Data-Link Protocol	Field	Header in Which It Is Found	Size
802.3 Ethernet and 802.5 Token Ring	DSAP	802.2 header	1 byte
802.3 Ethernet and 802.5 Token Ring	SSAP	802.2 header	1 byte
802.3 Ethernet and 802.5 Token Ring	Protocol Type	SNAP header	2 bytes
Ethernet (DIX)	Ethertype	Ethernet header	2 bytes
HDLC	Cisco-proprietary Protocol ID field	Extra Cisco header	2 bytes
Frame Relay RFC 2427	NLPID	RFC 1490	1 byte
Frame Relay RFC 2427	L2 or L3 Protocol ID	Q.933	2 bytes each
Frame Relay RFC 2427	SNAP Protocol Type	SNAP Header	2 bytes

Summary: Data Link Functions

Table 3-9 summarizes the basic functions of data-link protocols.

Table 3-9 *Data-Link Protocol Functions*

Function	Ethernet	Token Ring	HDLC	Frame Relay
Arbitration	CSMA/CD algorithm (part of MAC)	Token passing (part of MAC)	N/A	N/A
Addressing	Source and destination MAC addresses	Source and destination MAC addresses	Single 1-byte address; unimportant on point-to-point links	DLCI used to identify virtual circuits
Error detection	FCS in trailer	FCS in trailer	FCS in trailer	FCS in trailer

continues

03 CCNA Exam_Ch 03.fm Page 114 Thursday, March 7, 2002 11:46 AM

Table 3-9 *Data-Link Protocol Functions (Continued)*

Function	Ethernet	Token Ring	HDLC	Frame Relay
Identifying contents of data	802.2 DSAP, SNAP header, or Ethertype, as needed	802.2 DSAP or SNAP header, as needed	Proprietary Type field	RFC 1490/2427 headers, with NLPID, L2 and L3 protocol IDs, or SNAP header

OSI Network Layer Functions

9 Identify the parts in specific protocol address examples.

12 Describe the two parts of network addressing, and then identify the parts in specific protocol address examples.

OSI Layer 3 equivalent protocols use *routing* and *addressing* to accomplish their goals**.** The choices made by the people who made up addressing greatly affect how routing works, so the two topics are best described together.

Network layer (Layer 3) addressing will be covered in enough depth to describe IP, IPX, and AppleTalk addresses. Also, now that data link layer and network layer addresses have been covered in this chapter, this section undertakes a comparison between the two.

Routing

Routing can be thought of as a three-step process, as seen in Figure 3-17. Thinking about routing in these three separate steps helps make some of the details more obvious. However, most people will not think of routing as a three-step process when going about their normal jobs—this is just a tool to make a few points more clearly.

As illustrated in Figure 3-17, the three steps of routing include the following:

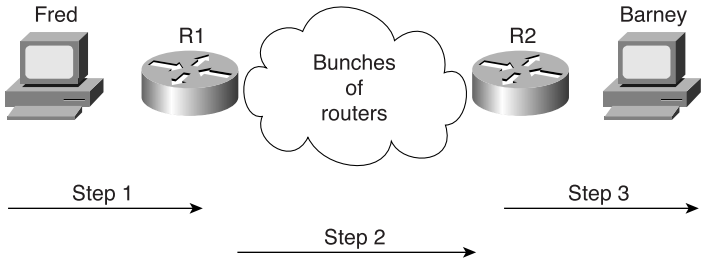
Step 1 Sending the data from the source computer to some nearby router

Step 2 Delivering the data from the router near the source to a router near the destination

Step 3 Delivering the data from the router near the destination to the end destination computer

03 CCNA Exam_Ch 03.fm Page 115 Thursday, March 7, 2002 11:46 AM

Figure 3-17 *Three Steps of Routing*



Sending Data to a Nearby Router

The creator of the data, who is also the sender of the data, decides to send data to a device in another group. A mechanism must be in place so that the sender knows of some router on a *common data link with the sender* to ensure that data can be sent to that router. The sender sends a data-link frame across the medium to the nearby router; this frame includes the packet in the data portion of the frame. That frame uses data link layer (Layer 2) addressing in the data-link header to ensure that the nearby router receives the frame. The main point here is that the originator of the data does not know much about the network—just how to get the data to some nearby router. In the post office analogy, I know how to get to the local post office, but that's all I need to know to send that letter to Mike in Califonia.

Routing Data Across the Network

The routing table for that particular network layer protocol contains a list of network layer address *groupings*. Instead of a single entry in the routing table per destination address, there is one entry per group. The router compares the destination network layer address in the packet to the entries in the routing table in memory, and a match is made. This matching entry in the routing table tells this router where to forward the packet next.

The concept of network layer address grouping is identical to the U.S. ZIP code system. Everyone living in the same vicinity is in the same ZIP code, and the postal sorters just look for the ZIP codes, ignoring the rest of the address.

Any intervening routers repeat the same process. The destination network layer (Layer 3) address in the packet identifies the group in which the destination resides. The routing table is searched for a matching entry, which tells this router where to forward the packet next. Eventually, the packet is delivered to the router connected to the network or subnet of the destination host, as previously shown in Figure 3-17.

03 CCNA Exam_Ch 03.fm Page 116 Thursday, March 7, 2002 11:46 AM

Delivering Data to the End Destination

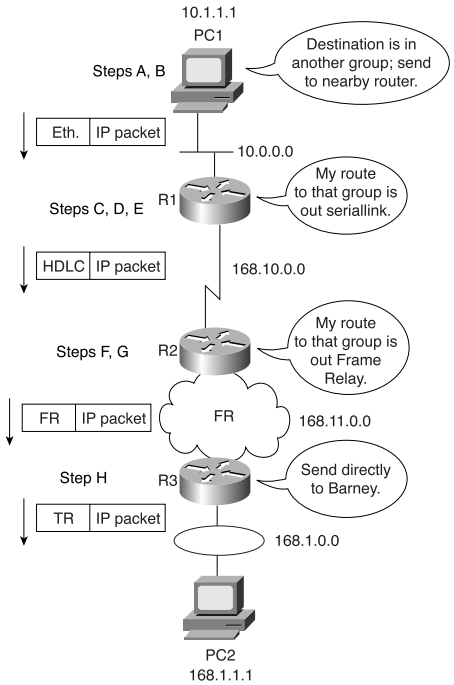
The final router in the path also needs a list of all the address groupings, but because the destination is on the same LAN as the router, this final router needs to look at the entire address. When the packet arrives at a router sharing a data link with the true destination, the router and the destination of the packet are in the same L3 grouping. That final router can forward the data directly to the destination. As usual, a new data-link header and trailer are created before a frame (which contains the packet that made the trip across the entire network) can be sent on to the media. This matches the final step (Step 3), as previously shown in Figure 3-17.

A Comment About Data Links

Because the routers build new data-link headers and trailers, and because the new headers contain data-link addresses, the routers must have some way to decide what data-link addresses to use. An example of how the router determines which data-link address to use is the IP Address Resolution Protocol (ARP) protocol. *ARP is used to dynamically learn the data-link address of some IP host*.

An example specific to TCP/IP will be useful to solidify the concepts behind routing. Imagine that PC1 is sending packets to PC2. (If you do not understand the basics of IP addressing already, you might want to bookmark this page and refer to it after you have reviewed Chapter 5, which covers IP addressing.) Figure 3-18 provides an example network so that you can review the routing process.

Figure 3-18 *Routing Logic and Encapsulation—PC1 Sending to PC2*



03 CCNA Exam_Ch 03.fm Page 117 Thursday, March 7, 2002 11:46 AM

The logic behind the earlier three-step routing process is described in the following more detailed steps:

Step A PC1 needs to know its nearby router. PC1 first knows of R1's IP address by having either a *default router* or a *default gateway* configured. The default router defined on some host is the router to which that host forwards packets that are destined for subnets other than the directly attached subnet. Assume that a default router of 10.1.1.100 is configured on PC1 and that it is R1's Ethernet IP address.

Step B PC1 needs to know R1's Ethernet MAC address before PC1 can finish building the Ethernet header (see Figure 3-18). In the case of TCP/IP, the ARP process is used to dynamically learn R1's MAC address. (See Chapter 5 for a discussion of ARP.) When R1's MAC address is known, PC1 completes the Ethernet header with the destination MAC address being R1's MAC address and sends the packet to R1.

Step C At Step 2 of the routing process, the router has many items to consider. First, the incoming frame (Ethernet interface) is processed only if the Ethernet FCS is passed and the router's MAC address is in the destination address field. Then the appropriate Protocol Type field is examined so that R1 knows what type of packet is in the data portion of the frame. At this point, R1 discards the Ethernet header and trailer.

Step D The next part of Step 2 involves finding an entry in the routing table for network 168.1.0.0, the network of which PC2 is a member. In this case, the route in R1 references 168.1.0.0 and lists R1's serial interface as the interface by which to forward the packet.

Step E To complete Step 2, R1 builds an HDLC header and trailer to place around the IP packet. Because the HDLC data link uses the same address field every time, no process such as ARP is needed to allow R1 to build the HDLC header.

Step F Routing Step 2 is repeated by R2 when it receives the HDLC frame. The HDLC FCS is checked; the type field is examined to learn that the packet inside the frame is an IP packet, and then the HDLC header and trailer are discarded. The IP routing table in R2 is examined for network 168.1.0.0, and a match is made. The entry directs R2 to forward the packet to its Frame Relay serial interface. The routing entry also identifies the next router's IP address—namely, R3's IP address on the other end of the Frame Relay VC.

03 CCNA Exam_Ch 03.fm Page 118 Thursday, March 7, 2002 11:46 AM

Step G Before R2 can complete its Step 2 of this end-to-end routing algorithm, R2 must build a Frame Relay header and trailer. Before it can complete the task, the correct DLCI for the VC to R3 must be decided. In most cases today, the dynamic Inverse ARP process will have associated R3's IP address with the DLCI that R2 uses to send frames to R3. (See Chapter 8 for more details on Inverse ARP and Frame Relay mapping.) With that mapping information, R2 can complete the Frame Relay header and send the frame to R3.

Step H Step 3 of the original algorithm is performed by R3. Like R1 and R2 before it, R3 checks the FCS in the data link trailer, looks at the type field to decide whether the packet inside the frame is an IP packet, and then discards the Frame Relay header and trailer. The routing table entry for 168.1.0.0 shows that the outgoing interface is R3's Token Ring interface. However, there is no next-router IP address because there is no need to forward the packet to another router. R3 simply needs to build a Token Ring header and trailer and forward the frame that contains the original packet to PC2. Before R3 can finish building the Token Ring header, an IP ARP must be used to find PC2's MAC address (assuming that R3 doesn't already have that information in its IP ARP cache).

Network Layer (Layer 3) Addressing

Cisco requires that CCNAs master the details of Layer 3 addressing, both the concepts and the particulars of IP and IPX. One key feature of network layer addresses is that they were designed to allow logical grouping of addresses. In other words, something about the numeric value of an address implies a group or set of addresses, all of which are considered to be in the same grouping. In TCP/IP, this group is called a *network* or a *subnet*. In IPX, it is called a *network*. In AppleTalk, the grouping is called a *cable range*. These groupings work just like USPS ZIP codes, allowing the routers (mail sorters) to speedily route (sort) lots of packets (letters).

Just like street addresses, network layer addresses are grouped based on physical location in a network. The rules differ for some network layer protocols, but the grouping concept is identical for IP, IPX, and AppleTalk. In each of these network layer protocols, all devices with addresses in the same group cannot be separated from each other by a router that is configured to route that protocol, respectively. Stated differently, all devices in the same group (IP subnet/IPX network/AppleTalk cable range) must be connected to the same data link; for example, all devices must be connected to the same Ethernet to be in the same group.

03 CCNA Exam_Ch 03.fm Page 119 Thursday, March 7, 2002 11:46 AM

Routing relies on the fact that Layer 3 addresses are grouped together. The routing tables for each network layer protocol can have one entry for the group, not one entry for each individual address. Imagine an Ethernet with 100 Novell clients. A router needing to forward packets to any of those clients needs only one entry in its IPX routing table. If those clients in the same IPX network were not required to be attached to the same data link, and if there was no way to encode the IPX network number as part of the IPX address of the client, routing would not be capable of using just one entry in the table. This basic fact is one of the key reasons that routers can scale to allow tens and hundreds of thousands of devices. It's very similar to the USPS ZIP code system—it would be ridiculous to have people in the same ZIP code as me live somewhere far away. Likewise, devices in the same IP subnet, IPX network, or AppleTalk cable range are physically close, relatively speaking.

With that in mind, most network layer (Layer 3) addressing schemes were created with the following goals:

- The address space should be large enough to accommodate the largest network for which the designers imagined the protocol would be used.
- The addresses should allow for unique assignment so that little or no chance of address duplication exists.
- The address structure should have some grouping implied so that many addresses are considered to be in the same group.
- Dynamic address assignment for clients is desired.

A great analogy for this concept of network addressing is the addressing scheme used by the U.S. Postal Service. Instead of getting involved with every small community's plans for what to name new streets, the post office simply has a nearby office with a ZIP code. The rest of the post offices in the country are already prepared to send mail to new businesses and residences on the new streets because they care only about the ZIP code, which they already know. It is the local postmaster's job to assign a mail carrier to deliver and pick up mail on those new streets. There might be hundreds of Main streets in different ZIP codes, but as long as there is just one per ZIP code, the address is unique—and with an amazing percentage of success, the U.S. Postal Service delivers the mail to the correct address.

Example Layer 3 Address Structures

Each Layer 3 address structure contains at least two parts. One (or more) part at the beginning of the address works like the ZIP code and essentially identifies the grouping. All instances of addresses with the same value in these first bits of the address are considered to be in the same group—for example, the same IP subnet or IPX network or AppleTalk cable range. The last part of the address acts as a local address, uniquely identifying that device in that particular group. Table 3-10 outlines several Layer 3 address structures.

03 CCNA Exam_Ch 03.fm Page 120 Thursday, March 7, 2002 11:46 AM

Table 3-10 *Layer 3 Address Structures*

Protocol	Size of Address (Bits)	Name and Size of Grouping Field	Name and Size of Local Address Field
IP	32	Network or subnet (variable, between 8 and 30 bits)	Host (variable, between 2 and 24 bits)
IPX	80	Network (32)	Node (48)
AppleTalk	24	Network (16) (Consecutively numbered values in this field can be combined into one group, called a cable range.)	Node (8)
OSI	Variable	Many formats, many sizes	Domain Specific Part (DSP) (typically 56, including NSAP)

Routing Protocols

Conveniently, the routing tables in the example based on Figure 3-18 had the correct routing information already in their routing tables. In most cases, these entries are built dynamically by use of a *routing protocol*. Routing protocols define message formats and procedures, just like any other protocol. With routing protocols, however, the goal is not to help with end-user data delivery—the end goal is to fill the routing table with all known destination groups and with the best route to reach each group.

A technical description of the logic behind two underlying routing protocol algorithms, *distance vector* and *link-state*, is found in Chapter 7, "Routing and Routing Protocols."

Nonroutable Protocols

Start Extra Credit

In the early and mid-1990s, one of the reasons that Cisco sold a lot of routers is that the IOS could route more Layer 3 protocols than most—if not all—competitors. However, some protocols are not routable. To support those, Cisco supported and evolved variations of bridging to support nonroutable protocols.

What makes a protocol nonroutable? Basically, a protocol stack that does not define an OSI Layer 3 equivalent, including a logical Layer 3 address structure, cannot be routed. To be fair,

03 CCNA Exam_Ch 03.fm Page 121 Thursday, March 7, 2002 11:46 AM

because the answer to the question "Is a protocol routable?" for any particular protocol is more of a geek-party discussion, no hard-and-fast rules govern what has to be true for a protocol to be considered routable. As this chapter shows, however, forwarding packets (L3PDUs) based on a destination Layer 3—equivalent address involves routing; a protocol stack with no Layer 3 is considered nonroutable.

If a protocol is not routable, bridging must be enabled to support those protocols. (Bridging concepts are covered in Chapter 4, "LANs, Bridges, and Switches.") To support nonroutable protocols over WAN links, some other protocol must be used, such as encapsulated transparent bridging and data-link switching (a form of remote bridging for SNA and NetBIOS).

The details of how to support nonroutable protocols is beyond the scope of CCNA. What is reasonably expected to be in the scope of CCNA is to know the most popular nonroutable protocols. Consider Table 3-11, which lists protocols that some people consider to be nonroutable.

Table 3-11 *Purported Nonroutable Protocols*

Protocol	Do Protocol Specifications Allow Routing?	Does IOS Support Routing This Protocol?
DEC Local Area Transport (LAT)	No	No
NetBIOS	No	No
SNA (Traditional Subarea SNA)	Yes; routed by IBM products running VTAM and NCP	No
SNA (APPN)	Yes	Yes

DEC LAT and NetBIOS (sometimes referred to as NetBEUI, for NetBIOS End User Interface) are definitely nonroutable. IBM's SNA has two general categories: Subarea SNA is the traditional Mainframe DataCenter SNA and advanced peer-to-peer networking (APPN) is a newer, more easily routable variation. Both are routable, have Layer 3 addressing, and can be routed by products that you can purchase today. However, be careful—Cisco folklore has it that SNA is not routable because Cisco IOS Software did not route SNA. If CCNA exam questions touch on this topic, focus on the context and be sure to remember that LAT and NetBIOS are truly nonroutable.

End Extra Credit

The section that follows, however, presents an anecdote that might help you remember the difference among the terms *routing*, *routed protocols*, and *routing protocols*.

03 CCNA Exam_Ch 03.fm Page 122 Thursday, March 7, 2002 11:46 AM

The Story of Ted and Ting

NOTE This somewhat silly story is the result of the Cisco World Wide Training division's proctors for the instructor certification process, who emphasize that the instructors should be creative in the use of tools to help students remember important details. After I tried this story during certification, it was propagated by other instructors. I am curious—if you have heard this story or a variation, please let me know when you heard it and from whom (wendell@lacidar.com).

Ted and Ting both work for the same company at a facility in Snellville, Georgia. They work in the same department; their job is to make lots of widgets. (Widgets are imaginary products; the term *widget* is used in the United States often to represent a product when the actual product is not the topic of discussion.)

Ted worked quickly and was a hard worker. In fact, because he was a very intense person, Ted tended to make more widgets than anyone else in Snellville, including Ting. Ted also liked to have everything he needed instantly available when and where he wanted it so that he could make the widgets more quickly.

Ting, on the other hand, also worked very hard but was much more of a planner. He tended to think first and then act. Ting planned very well and had all supplies well stocked, including all the instructions needed to make the different kinds of widgets. In fact, all the information about how to build each type of widget was on a table by his door. He had a problem with the table getting "reallocated" (that is, stolen), so he applied a nonremovable label with the words "Ting's Table" to the surface so that he could find the table in case someone stole it.

It turns out that Ted's productivity was partly a result of sitting next to Ting. In fact, Ted often was ready to make the next widget but needed something, such as the instruction sheet for a particular unique widget. By swinging into Ting's office, Ted could be back at it in just a few seconds. In fact, part of the reason Ting kept the instruction sheets on Ting's Table by the door was that he was tired of Ted always interrupting him looking for something.

Well, Ted got lots of bonuses for being the most productive worker, and Ting did not. Being fair, though, Ted realized that he would not be as successful without Ting, so Ted shared his bonuses with Ting. (Hey, it's an imaginary story!)

Then one day the president decided to franchise the company because it was the best widget-making company in the world. The president, Dr. Rou (pronounced like the word "ouch"), decided to create a manual to be used by all the franchisees to build their business. So, Dr. Rou went to the most productive widget maker, Ted, and asked him what he did every day. Along the way, Dr. Rou noticed that Ted went next door a lot. So, being the bright guy that he was, Dr. Rou visited Ting next and asked him what he did.

03 CCNA Exam_Ch 03.fm Page 123 Thursday, March 7, 2002 11:46 AM

The next day Dr. Rou emerged with the franchise manual. Being an ex–computer networking professional, he had called the manual "Protocols for Making Widgets." One part of the protocol defined how Ted made widgets very quickly. Another part described how Ting kept everything needed by Ted at arm's length, including all the instructions that Ted needed. It even mentioned Ting's Table as the place to store the instruction sheets. To give credit where credit was due—but not too much credit—the names of these protocols were as follows:

- **The "Rou-Ted Protocol"**—How to make widgets really quickly
- **The "Rou-Ting Protocol"**—How to plan and collect information so that the other guy can make widgets fast
- **The "Rou-Ting Table"**—The place to store your widget-making instruction sheets

Similarly, with networking, the *routed protocol* is the one being routed, such as IP, IPX, OSI, DECnet, and so forth. The *routing protocol* is the one preparing the information needed to perform the routing process quickly, such as RIP, IGRP, OSPF, NLSP, and so forth. The *routing table* is where the information needed to perform routing is held, as built by the routing protocol and used by the routing process to forward the packets of the routed protocol.

That's all just to distinguish among the terms *routed protocol*, *routing protocol*, and *routing table*.

03 CCNA Exam_Ch 03.fm Page 124 Thursday, March 7, 2002 11:46 AM

Foundation Summary

The "Foundation Summary" is a collection of tables and figures that provide a convenient review of many key concepts in this chapter. For those of you already comfortable with the topics in this chapter, this summary could help you recall a few details. For those of you who just read this chapter, this review should help solidify some key facts. For any of you doing your final prep before the exam, these tables and figures will be a convenient way to review the day before the exam.

Table 3-12 offers a more condensed description of the layer characteristics and examples. This table is taken directly from Cisco's ICND course.

Table 3-12 *OSI Reference Model (Condensed Information)*

OSI Layer Name	Functional Description	Examples
Application (Layer 7)	Interface between network and application software	Telnet, HTTP
Presentation (Layer 6)	How data is presented Special processing, such as encryption	JPEG, ASCII, EBCDIC
Session (Layer 5)	Keeping data separate from different applications	Operating systems and application access scheduling
Transport (Layer 4)	Reliable or unreliable delivery Multiplexing	TCP, UDP, SPX
Network (Layer 3)	Logical addressing, which routers use for path determination	IP, IPX
Data link (Layer 2)	Combination of bits into bytes, and bytes into frames Access to the media using MAC address Error detection and error recovery	802.3/802.2, HDLC
Physical (Layer 1)	Moving of bits between devices Specification of voltage, wire speed, and cable pinouts	EIA/TIA-232, V.35

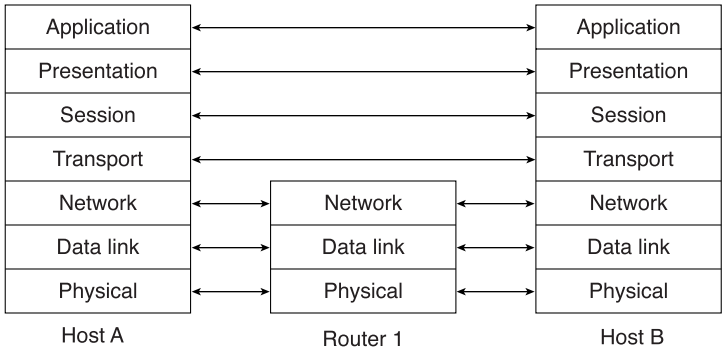
03 CCNA Exam_Ch 03.fm Page 125 Thursday, March 7, 2002 11:46 AM

The following list summarizes the benefits of layered protocol specifications:

- Humans can more easily discuss and learn about the many details of a protocol specification.
- Standardized interfaces among layers facilitate modular engineering. Different products can provide functions of only some layers (such as a router with Layers 1 to 3), or some products could supply parts of the functions of the protocol (such as Microsoft TCP/IP built into Win95, or the Eudora e-mail application providing TCP/IP application layer support).
- A better environment for interoperability is created. One vendor can write software that implements higher layers—for example, a Web browser—and another can write software that implements the lower layers—for example, Microsoft's built-in TCP/IP software in its operating systems.
- Reduced complexity allows easier program changes and faster product evolution.
- One layer uses the services of the layer immediately below it. Therefore, remembering what each layer does is easier. (For example, the network layer needs to deliver data from end to end. To do this, it uses data links to forward data to the next successive device along that end-to-end path.)

Figure 3-19 provides a visual representation of the same-layer interaction concepts.

Figure 3-19 *Same-Layer Interactions on Different Computers*



This five-step process happens to match the TCP/IP network model very well. Figure 3-20 depicts the concept; the numbers shown represent each of the five steps.

03 CCNA Exam_Ch 03.fm Page 126 Thursday, March 7, 2002 11:46 AM

Figure 3-20 *Five Steps of Data Encapsulation—TCP/IP*

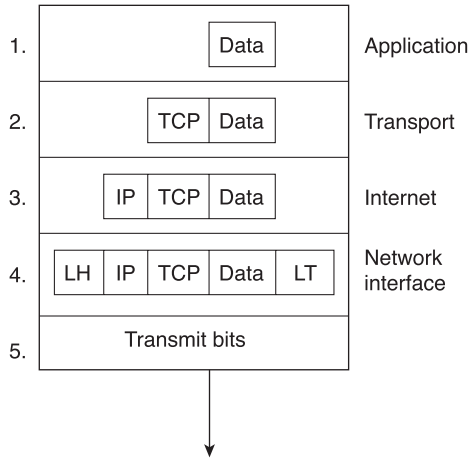
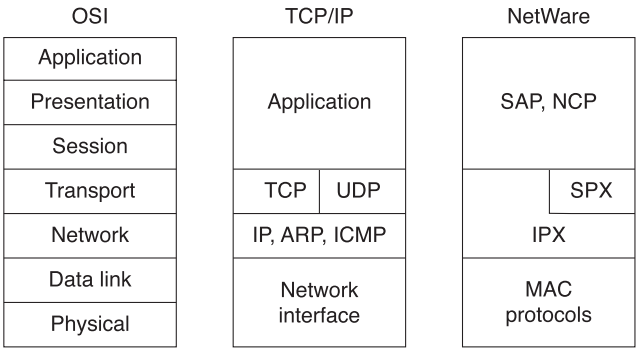


Figure 3-21 shows the layers of TCP/IP and NetWare, as compared with OSI.

Figure 3-21 *OSI, TCP/IP, and NetWare Protocols*



The terms *connection-oriented* and *connectionless* have some relatively well-known connotations inside the world of networking protocols. The meaniing of the terms is intertwined with error recovery and flow control, but they are not the same. So, first, some basic definitions are in order:

Connection-oriented protocol—A protocol either that requires an exchange of messages before data transfer begins or that has a required pre-established correlation between two endpoints

Connectionless protocol—A protocol that does not require an exchange of messages and that does not require a pre-established correlation between two endpoints

03 CCNA Exam_Ch 03.fm Page 127 Thursday, March 7, 2002 11:46 AM

Table 3-13 summarizes the concepts behind error recovery and lists the behavior of three popular error-recovery protocols.

Table 3-13 *Examples of Error-Recovery Protocols and Their Features*

Feature	TCP	SPX	LLC2
Acknowledges data in both directions?	Yes	Yes	Yes
Uses forward acknowledgment?	Yes	Yes	Yes
Counts bytes or frame/packets?	Bytes	Packets	Frames
Necessitates resending of all data, or just one part and wait when resending?	One and wait	Resend all	Resend all

Figure 3-22 shows frames for the four data-link protocols.

Figure 3-22 *Popular Frame Formats*

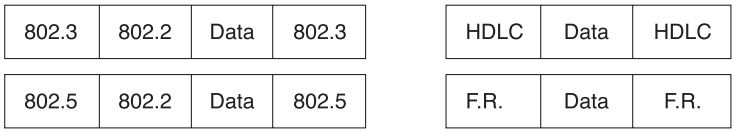


Table 3-14 summarizes most of the details about MAC addresses.

Table 3-14 *LAN MAC Address Terminology and Features*

LAN Addressing Terms and Features	Description
MAC	Media Access Control. 802.3 (Ethernet) and 802.5 (Token Ring) are the MAC sublayers of these two LAN data-link protocols.
Ethernet address, NIC address, LAN address, Token Ring address, card address	Other names often used instead of MAC address. These terms describe the 6-byte address of the LAN interface card.
Burned-in address	The 6-byte address assigned by the vendor making the card. It is usually burned in to a ROM or EEPROM on the LAN card and begins with a 3-byte organizationally unique identifier (OUI) assigned by the IEEE.
Locally administered address	Through configuration, an address that is used instead of the burned-in address.
Unicast address	Fancy term for a MAC that represents a single LAN interface.

continues

03 CCNA Exam_Ch 03.fm Page 128 Thursday, March 7, 2002 11:46 AM

Table 3-14 *LAN MAC Address Terminology and Features (Continued)*

LAN Addressing Terms and Features	Description
Broadcast address	An address that means "all devices that reside on this LAN right now."
Multicast address	Not valid on Token Ring. On Ethernet, a multicast address implies some subset of all devices currently on the LAN.
Functional address	Not valid on Ethernet. On Token Ring, these addresses are reserved to represent the device(s) on the ring performing a particular function. For example, all source-route bridges supply the ring number to other devices; to do so, they each listen for the Ring Parameter Server (RPS) functional address.

Table 3-15 summarizes the basic functions of data-link protocols.

Table 3-15 *Data-Link Protocol Functions*

Function	Ethernet	Token Ring	HDLC	Frame Relay
Arbitration	CSMA/CD algorithm (part of MAC)	Token passing (part of MAC)	N/A	N/A
Addressing	Source and destination MAC addresses	Source and destination MAC addresses	Single 1-byte address; unimportant on point-to-point links	DLCI used to identify virtual circuits
Error detection	FCS in trailer	FCS in trailer	FCS in trailer	FCS in trailer
Identifying contents of data	802.2 DSAP, SNAP header, or Ethertype, as needed	802.2 DSAP or SNAP header, as needed	Proprietary Type field	RFC 1490/2427 headers, with NLPID, L2 and L3 protocol IDs, or SNAP header

03 CCNA Exam_Ch 03.fm Page 129 Thursday, March 7, 2002 11:46 AM

Table 3-16 outlines several Layer 3 address structures.

Table 3-16 *Layer 3 Address Structures*

Protocol	Size of Address (Bits)	Name and Size of Grouping Field	Name and Size of Local Address Field
IP	32	Network or subnet (variable, between 8 and 30 bits)	Host (variable, between 2 and 24 bits)
IPX	80	Network (32)	Node (48)
AppleTalk	24	Network (16) (Consecutively numbered values in this field can be combined into one group, called a cable range.)	Node (8)
OSI	Variable	Many formats, many sizes	Domain Specific Part (DSP) (typically 56, including NSAP)

03 CCNA Exam_Ch 03.fm Page 130 Thursday, March 7, 2002 11:46 AM

Q&A

As mentioned in Chapter 1, "All About the Cisco Certified Network Associate Certification," the questions and scenarios in this book are more difficult than what you should experience on the actual exam. The questions do not attempt to cover more breadth or depth than the exam; however, they are designed to make sure that you know the answer. Rather than allowing you to derive the answer from clues hidden inside the question itself, the questions challenge your understanding and recall of the subject. Questions from the "Do I Know This Already?" quiz from the beginning of the chapter are repeated here to ensure that you have mastered the chapter's topic areas. Hopefully, these questions will help limit the number of exam questions on which you narrow your choices to two options and then guess.

The answers to these questions can be found in Appendix A.

1 Name the seven layers of the OSI model.

_____

_____

_____

2 What is the main purpose(s) of Layer 7?

_____

_____

_____

3 What is the main purpose(s) of Layer 6?

_____

_____

_____

4 What is the main purpose(s) of Layer 5?

_____

_____

_____

5 What is the main purpose(s) of Layer 4?

_____

_____

_____

03 CCNA Exam_Ch 03.fm Page 131 Thursday, March 7, 2002 11:46 AM

6 What is the main purpose(s) of Layer 3?

7 What is the main purpose(s) of Layer 2?

8 What is the main purpose(s) of Layer 1?

9 Describe the process of data encapsulation as data is processed from creation until it exits a physical interface to a network. Use the OSI model as an example.

10 Describe the features required for a protocol to be considered connectionless.

11 Name at least three connectionless protocols.

12 Describe the features required for a protocol to be considered connection-oriented.

03 CCNA Exam_Ch 03.fm Page 132 Thursday, March 7, 2002 11:46 AM

13 In a particular error-recovering protocol, the sender sends three frames, labeled 2, 3, and 4. On its next sent frame, the receiver of these frames sets an acknowledgment field to 4. What does this typically imply?

_____

_____

_____

14 Name three connection-oriented protocols.

_____

_____

_____

15 What does MAC stand for?

_____

_____

_____

16 Name three terms popularly used as a synonym for *MAC address.*

_____

_____

_____

17 Are IP addresses defined by a Layer 2 or Layer 3 protocol?

_____

_____

_____

18 Are IPX addresses defined by a Layer 2 or Layer 3 protocol?

_____

_____

_____

19 Are OSI NSAP addresses defined by a Layer 2 or Layer 3 protocol?

_____

_____

_____

03 CCNA Exam_Ch 03.fm Page 133 Thursday, March 7, 2002 11:46 AM

20 What portion of a MAC address encodes an identifier representing the manufacturer of the card?

21 Are MAC addresses defined by a Layer 2 or a Layer 3 protocol?

22 Are DLCI addresses defined by a Layer 2 or a Layer 3 protocol?

23 Name two differences between Layer 3 addresses and Layer 2 addresses.

24 How many bits are present in an IP address?

25 How many bits are present in an IPX address?

26 How many bits are present in a MAC address?

03 CCNA Exam_Ch 03.fm Page 134 Thursday, March 7, 2002 11:46 AM

27 Name the two main parts of an IPX address. Which part identifies which "group" this address is a member of?

_____

_____

_____

28 Name the two main parts of an IP address. Which part identifies which "group" this address is a member of?

_____

_____

_____

29 Name the two main parts of a MAC address. Which part identifies which "group" this address is a member of?

_____

_____

_____

30 Name three benefits to layering networking protocol specifications.

_____

_____

_____

31 What header and/or trailer does a router discard as a side effect of routing?

_____

_____

_____

32 Describe the differences between a routed protocol and a routing protocol.

_____

_____

_____

03 CCNA Exam_Ch 03.fm Page 135 Thursday, March 7, 2002 11:46 AM

33 Name at least three routed protocols.

34 Name at least three routing protocols.

35 How does an IP host know what router to send a packet to? In which cases does an IP host choose to send a packet to this router instead of directly to the destination host?

36 How does an IPX host know which router to send a packet to? In which case does an IPX host choose to send a packet to this router instead of directly to the destination host?

37 Name three items in an entry in any routing table.

38 What OSI layer typically encapsulates using both a header and a trailer?

03 CCNA Exam_Ch 03.fm Page 136 Thursday, March 7, 2002 11:46 AM

Scenarios

Scenario 3-1

Given the network in Figure 3-23 and the address table in Table 3-17, perform the tasks that follow. This scenario uses an imaginary Layer 3 addressing structure as a method to review concepts. When in doubt, concentrate on the concepts. Also, the imaginary Layer 3 used in this example is here only to allow you to concentrate on the concepts instead of a particular protocol; there is no need to memorize this scheme or expect questions like this on the exam.

Figure 3-23 *Musketeer Network for Scenario*

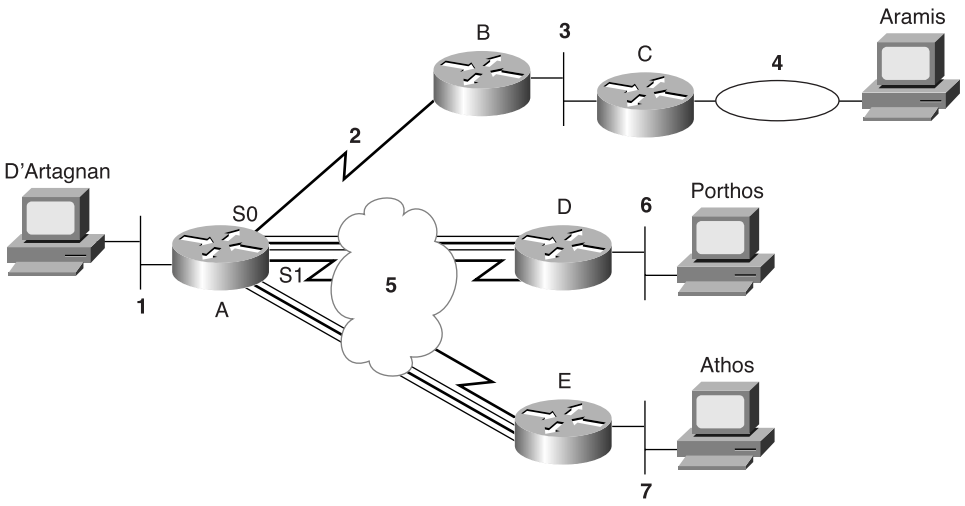


Table 3-17 provides the routing table for the network setup in Figure 3-23.

Table 3-17 *Layer 3 Address Table for Network in Figure 3-23*

Router	Interface	Address
A	E0	group-1.local-A
A	S0	group-2.local-A
A	S1	group-5.local-A
B	S0	group-2.local-B

03 CCNA Exam_Ch 03.fm Page 137 Thursday, March 7, 2002 11:46 AM

Table 3-17 *Layer 3 Address Table for Network in Figure 3-23 (Continued)*

Router	Interface	Address
B	E0	group-3.local-B
C	E0	group-3.local-C
C	T0	group-4.local-C
D	S0	group-5.local-D
D	E0	group-6.local-D
E	S0	group-5.local-E
E	E0	group-7.local-E
D'Artagnan		group-1.local-M
Aramis		group-4.local-M
Porthos		group-6.local-M
Athos		group-7.local-M

Task 1 for Scenario 3-1

Create the routing table in Router A; assume that all parts of the network are up and working properly. Table 3-18 provides an empty routing table to record your answers.

Table 3-18 *Scenario 3-1 Task 1 Routing Table Answer Form*

Group	Outgoing Interface	Next Router

03 CCNA Exam_Ch 03.fm Page 138 Thursday, March 7, 2002 11:46 AM

Task 2 for Scenario 3-1

D'Artagnan sends a packet to Aramis (source group-1.local-M, destination group-4.local-M). D'Artagnan sends this packet inside an Ethernet frame to Router A. Given this information, determine the following:

1. List the routing table entries in each router that are necessary for the packet to be delivered to Aramis.
2. What type of data-link header or trailer is discarded by each router in that route?
3. What destination data-link addresses are placed into the new data-link headers by each router?
4. What routes must be in which routers to ensure that Aramis can send a return packet to D'Artagnan?

Task 3 for Scenario 3-1

D'Artagnan sends a packet to Porthos (source group-1.local-M, destination group-6.local-M). D'Artagnan sends this packet inside an Ethernet frame to Router A. Given this information, determine the following:

1. List the routing table entries in each router that are necessary for the packet to be delivered to Porthos.
2. What type of data-link header or trailer is discarded by each router in that route?
3. What destination data-link addresses are placed into the new data-link headers by each router?
4. What routes must be in which routers to ensure that Porthos can send a return packet to D'Artagnan?

03 CCNA Exam_Ch 03.fm Page 139 Thursday, March 7, 2002 11:46 AM

Scenario Answers

Answers to Task 1 for Scenario 3-1

Based on the network design illustrated in Figure 3-23, Task 1 for Scenario 3-1 asks you to create the routing table in Router A; assume that all parts of the network are up and working properly. The routing table for Router A is as follows:

Group	Outgoing Interface	Next Router
group-1	Ethernet 0	N/A
group-2	serial 0	N/A
group-3	serial 0	group-2.local-B
group-4	serial 0	group-2.local-B
group-5	serial 1	N/A
group-6	serial 1	group-5.local-D
group-7	serial 1	group-5.local-E

Answers to Task 2 for Scenario 3-1

Based on the network design illustrated in Figure 3-23, Task 2 for Scenario 3-1 states that D'Artagnan sends a packet to Aramis (source group-1.local-M, destination group-4.local-M). D'Artagnan sends this packet inside an Ethernet frame to Router A. The following are the solutions to exercises 1 through 4 for Task 2.

1 The routing tables are as follows:

In Router A:

Group	Outgoing Interface	Next Router
group-2	serial 0	N/A
group-4	serial 0	group-2.local-B

03 CCNA Exam_Ch 03.fm Page 140 Thursday, March 7, 2002 11:46 AM

In Router B:

Group	Outgoing Interface	Next Router
group-3	Ethernet 0	N/A
group-4	Ethernet 0	group-3.local-C

In Router C:

Group	Outgoing Interface	Next Router
group-4	Token Ring 0	N/A

2. Router A discards the Ethernet header and adds an HDLC header. Router B discards the HDLC header and adds an Ethernet header. Router C discards the Ethernet header and adds a Token Ring header.
3. Router A places the never-changing HDLC address (Hex 03) into the header. Router B places Router C's Ethernet MAC address into the destination address field. Router C places Aramis's Token Ring MAC address into the destination address field.
4. This is all noise if Aramis cannot get a packet back to D'Artagnan. The following routing tables show the routes needed for both directions; the routes with asterisks signify routes required for the routes back to D'Artagnan.

In Router A:

Group	Outgoing Interface	Next Router
group-1*	Ethernet 0	N/A
group-2	serial 0	N/A
group-4	serial 0	group-2.local-B

In Router B:

Group	Outgoing Interface	Next Router
group-1*	serial 0	group-2.local-A
group-2*	serial 0	N/A
group-3	Ethernet 0	N/A
group-4	Ethernet 0	group-3.local-C

03 CCNA Exam_Ch 03.fm Page 141 Thursday, March 7, 2002 11:46 AM

In Router C:

Group	Outgoing Interface	Next Router
group-1*	Ethernet 0	group-3.local-B
group-3*	Ethernet 0	N/A
group-4	Token ring 0	N/A

Answers to Task 3 for Scenario 3-1

Based on the network design illustrated in Figure 3-23, Task 3 for Scenario 3-1 states that D'Artagnan sends a packet to Porthos (source group-1.local-M, destination group-6.local-M). D'Artagnan sends this packet inside an Ethernet frame to Router A. The following are the solutions to exercises 1 through 4 for Task 3.

1 The routing tables are as follows:

In Router A:

Group	Outgoing Interface	Next Router
group-5	serial 1	N/A
group-6	serial 1	group-5.local-D

In Router D:

Group	Outgoing Interface	Next Router
group-6	Ethernet 0	N/A

2 Router A discards the Ethernet header and adds a Frame Relay header. Router D discards the Frame Relay header and adds an Ethernet header.

3 Router A places the Frame Relay DLCI for the VC connecting it to Router D into the address field in the header. Router D places Porthos's Ethernet MAC address into the destination address field.

4 This is all noise if Porthos cannot get a packet back to D'Artagnan. The following routing tables show the routes needed for both directions; the routes with asterisks signify routes required for the routes back to D'Artagnan.

03 CCNA Exam_Ch 03.fm Page 142 Thursday, March 7, 2002 11:46 AM

In Router A:

Group	Outgoing Interface	Next Router
group-1*	Ethernet 0	N/A
group-5	serial 1	N/A
group-6	serial 1	group-5.local-D

In Router D:

Group	Outgoing Interface	Next Router
group-1*	serial 0	group-5.local-A
group-5*	serial 0	N/A
group-6	Ethernet 0	N/A

03 CCNA Exam_Ch 03.fm Page 143 Thursday, March 7, 2002 11:46 AM

Exam Topics in This Chapter

1 Name and describe two switching methods.

2 Distinguish between cut-through and store-and-forward LAN switching.

13 Describe the advantages of LAN segmentation.

14 Describe LAN segmentation using bridges.

15 Describe LAN segmentation using routers.

16 Describe LAN segmentation using switches.

17 Describe the benefits of network segmentation with bridges.

18 Describe the benefits of network segmentation with routers.

19 Describe the benefits of network segmentation with switches.

38 Describe full- and half-duplex Ethernet operation.

39 Describe network congestion problems in Ethernet networks.

40 Describe the features and benefits of Fast Ethernet.

41 Describe the guidelines and distance limitations of Fast Ethernet.

04 CCNA Exam_Ch 04.fm.1 Page 145 Thursday, March 7, 2002 11:47 AM

CHAPTER 4

LANs, Bridges, and Switches

Cisco's LAN switch revenue surpassed router revenues about the time that the CCNA exam was first announced, back in 1998. There is little doubt about the importance of LAN switch revenue to Cisco. However, router concepts and configuration consume a much larger share of the CCNA exam's questions—a seemingly odd fact. So, if switches drive more revenue for Cisco, why is most of the popular Cisco certification about routers and routing issues?

Simply put, LAN switches are simpler than routers. LAN switches operate at OSI Layer 2, and Layer 2 issues are generally less complicated than Layer 3 issues. But before you take exception with me, that in no way means that LAN issues are not complicated! There are simply fewer concepts and issues to consider. Furthermore, because Layer 3–aware devices, such as routers, make extensive use of Layer 2 features to forward packets, the routing-centric topics can never totally ignore LAN and WAN Layer 2 concepts. However, when discussing LAN concepts, Layer 3 issues can be ignored, making the discussion of LANs and LAN switches much briefer and to the point. So, this book includes two LAN-specific chapters in addition to the more lengthy coverage of routing.

This chapter describes the core basic concepts of Ethernet LANs, bridging, and LAN switches. Along the way, Cisco LAN switch configuration also will be covered. Some historical perspectives about Ethernet are important in this chapter because Cisco definitely expects you to understand why installing a switch for ten users is better than using a hub, a router, or a bridge, or simply using a single coax cable, as the older Ethernet specifications called for.

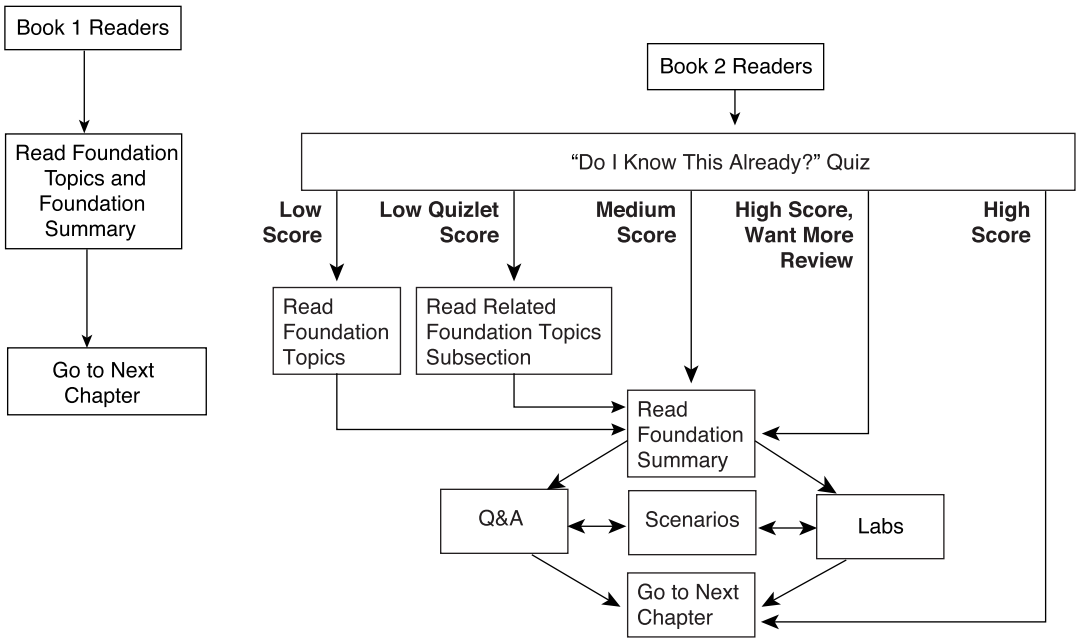
How to Best Use This Chapter

By taking the following steps, you can make better use of your study time:

- Keep your notes and the answers for all your work with this book in one place, for easy reference.
- Take the "Do I Know This Already?" quiz, and write down your answers. Studies show that retention is significantly increased through writing down facts and concepts, even if you never look at the information again.
- Use the diagram in Figure 4-1 to guide you to the next step.

04 CCNA Exam_Ch 04.fm.1 Page 146 Thursday, March 7, 2002 11:47 AM

Figure 4-1 *How to Use This Chapter*



"Do I Know This Already?" Quiz

The purpose of the "Do I Know This Already?" quiz is to help you decide what parts of this chapter to use. If you already intend to read the entire chapter, you do not necessarily need to answer these questions now.

This 12-question quiz helps you determine how to spend your limited study time. The quiz is sectioned into four smaller four-question "quizlets" that correspond to the three major headings in the chapter. Suggestions on how to spend your time in this chapter, based on your quiz scores, are outlined in Figure 4-1. Use Table 4-1 to record your score.

Table 4-1 *Scoresheet for Quiz and Quizlets*

Quizlet Number	Foundation Topics Section Covering These Questions	Questions	Score
1	LAN Overview	1 to 4	
2	Bridging and Switching	5 to 8	
3	LAN Switch Configuration	9 to 12	
All questions		1 to 12	

04 CCNA Exam_Ch 04.fm.1 Page 147 Thursday, March 7, 2002 11:47 AM

1 What do the letters *MAC* stand for? What other terms have you heard to describe the same or similar concept?

2 If a Fast Ethernet NIC currently is receiving a frame, can it begin sending a frame?

3 What are the two key differences between a 10-Mbps NIC and a 10/100 NIC?

4 What is the distance limitation of a single cable for 10BaseT? 100BaseTX?

5 What routing protocol does a transparent bridge use to learn about Layer 3 addressing groupings?

6 Name two of the methods of internal switching on typical switches today. Which provides less latency for an individual frame?

04 CCNA Exam_Ch 04.fm.1 Page 148 Thursday, March 7, 2002 11:47 AM

7 Describe how a transparent bridge decides whether it should forward a frame, and tell how it chooses the interface out which to forward the frame.

_____

_____

_____

8 Define the term *collision domain*.

_____

_____

_____

9 How many IP addresses must be configured for network management on a Cisco Catalyst 1900 switch if eight ports are to be used with three VLANs?

_____

_____

_____

10 How do exec and configuration commands refer to the two Fast Ethernet ports on a Catalyst 1912 switch?

_____

_____

_____

11 Configuration is added to the running configuration in RAM when commands are typed in Catalyst 1900 configuration mode. What causes these commands to be saved into NVRAM?

_____

_____

_____

12 What command erases the startup config in a Catalyst 1900 switch?

_____

_____

_____

04 CCNA Exam_Ch 04.fm.1 Page 149 Thursday, March 7, 2002 11:47 AM

The answers to the quiz are found in Appendix A, 'Answers to the 'Do I Know This Already?' Quizzes and Q&A Sections." The uggested choices for your next step are as follows:

- **8 or less overall score**—Read the entire chapter. This includes the "Foundation Topics" and "Foundation Summary" sections and the Q&A section at the end of the chapter.
- **2 or less on any quizlet**—Review the subsection(s) of the "Foundation Topics" part of this chapter, based on Table 4-1. Then move into the "Foundation Summary" section and the Q&A section at the end of the chapter.
- **9 to 10 overall score**—Begin with the "Foundation Summary" section, and then go to the Q&A section and the scenarios at the end of the chapter.
- **11 or more overall score**—If you want more review on these topics, skip to the "Foundation Summary" section and then go to the Q&A section at the end of the chapter. Otherwise, move to the next chapter.

04 CCNA Exam_Ch 04.fm.1 Page 150 Thursday, March 7, 2002 11:47 AM

Foundation Topics

LAN Overview

38 Describe full- and half-duplex Ethernet operation.

39 Describe network-congestion problems in Ethernet networks.

40 Describe the features and benefits of Fast Ethernet.

41 Describe the guidelines and distance limitations of Fast Ethernet.

Network engineers install Ethernet variants more than any other type of LAN today. Not surprisingly, the CCNA exam covers Ethernet. But most everyone would guess that Ethernet is relatively important on the exam—the trick is to make sure that you know what details about Ethernet LANs are on the exam. This chapter and Chapter 5, "Intermediate LANs: Spanning Tree, VLANs, and Trunking" describe those details.

The CCNA exam covers the functions and protocol specifications for the more popular types of Ethernet. 10BaseT, Fast Ethernet, and Gigabit Ethernet are all on the exam. But to appreciate how some of the features of Ethernet work, a historical knowledge of 10Base2 and 10Base5 Ethernet is helpful. Similarly, LAN switching concepts and configuration will definitely be covered on the exam. Developing an understanding of how transparent bridges work gives you a historical perspective that lets you appreciate how LAN switches work and why they work that way. All these topics help your understanding, but expect more questions about Fast Ethernet than 10Base2, and more questions about LAN switching than transparent bridging.

Engineers make important design decisions when implementing LANs, and the CCNA exam attempts to test your knowledge of these decisions by comparing several options. In particular, a comparison of a single LAN segment with multiple segments with a transparent bridge between them and with multiple segments with a hub, or a switch, or a router among them—all these comparisons get at the heart of the reasons behind how you design a LAN today. CCNA does not test your ability to design a LAN site with 30 switches, but it does test your ability to think through all the building-block concepts that you would need to make good choices in building that network.

04 CCNA Exam_Ch 04.fm.1 Page 151 Thursday, March 7, 2002 11:47 AM

This chapter details all the basics of Ethernet LANs that are on the CCNA exam. First, a historical view of 10-Mbps Ethernet provides the basis for understanding some of the reasons behind why switches act as they do. LAN addressing and LAN framing define somewhat mundane but important parts of the networking puzzle and are found in the next section. Fast Ethernet and Gigabit Ethernet follow.

The second "Foundation Topics" section details bridging and switching. In this section, comparisons of using a single segment and segmenting into multiple segments using either a hub, a bridge, a switch, or a router are made. Finally, in the third section, configuration details on Cisco IOS-based switches is covered.

By the end of the "Foundation Topics" section of this chapter, you should be able to describe everything that happens in a typical LAN today that uses a single switch. In the next chapter, the details of what happens in a network with multiple switches are described fully.

10-Mbps Ethernet

Ethernet is best understood by first considering the early *10Base5* and *10Base2* specifications. These two Ethernet specifications defined the details of the physical layer of early Ethernet networks. With these two specifications, the engineer installs a series of coaxial cables to each device on the Ethernet network—there is no hub, switch, or wiring panel. The series of cables creates an electrical bus that is shared among all devices on the Ethernet. Because it is a single bus, only one electrical signal can flow at a single time. If two or more signals were sent, the two would overlap, making both signals unintelligible.

Not surprisingly, Ethernet also defined a specification for how to ensure that only one device sends traffic on the Ethernet at one time—otherwise, the Ethernet would have been unusable. The algorithm, known as the carrier sense multiple access collision detect (CSMA/CD) algorithm, defines how the bus is accessed. In human terms, CSMA/CD is similar to what happens in a meeting room with many attendees. Some people talk much of the time. Some do not talk, but they listen. Others talk occasionally. Being humans, it's hard to understand what two people are saying at the same time, so generally, one person is talking and the rest are listening. Imagine that Bob and Larry both want to reply to the current speaker's comments. As soon as the speaker takes a breath, Bob and Larry might both try to speak. If Larry hears Bob's voice before Larry actually makes a noise, Larry might stop and let Bob speak. Or, maybe they both start at almost the same time, so they talk over each other, and many others in the room can't hear what was said. Then there's the proverbial "Excuse me, you talk next . . . " and eventually Larry or Bob talks. Or, in some cases, another person jumps in and talks while Larry and Bob are both backing off. These "rules" are based on your culture; CSMA/CD is based on Ethernet protocol specifications and achieves the same type of goal.

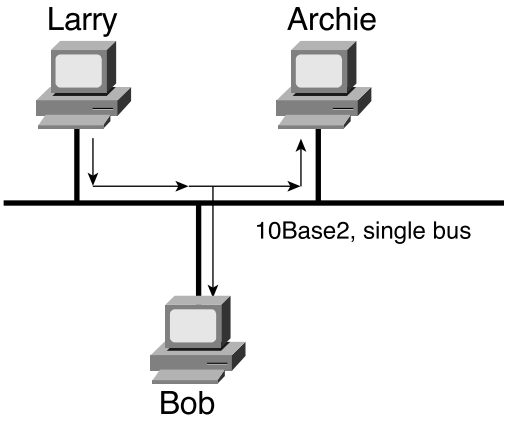
04 CCNA Exam_Ch 04.fm.1 Page 152 Thursday, March 7, 2002 11:47 AM

Figure 4-2 shows the basic logic of an old Ethernet 10Base2 network, which literally uses a single electrical bus, created with coaxial cable.

The CSMA/CD algorithm works like this:

1. A device with a frame to send listens until the Ethernet is not busy.
2. When the Ethernet is not busy, the sender begins sending the frame.
3. The sender listens to make sure that no collision occurred.
4. If there was a collision, the sender randomizes a timer and waits that long.
5. When the timer expires, the process starts over with Step 1.

Figure 4-2 *Small Ethernet 10Base2 Network*



10Base2 and 10Base5 Ethernet would not work without some method to arbitrate use of the bus. However, because of the CSMA/CD algorithm, Ethernet becomes more inefficient under higher loads. In fact, two particular negative features of the CSMA/CD algorithm are as follows:

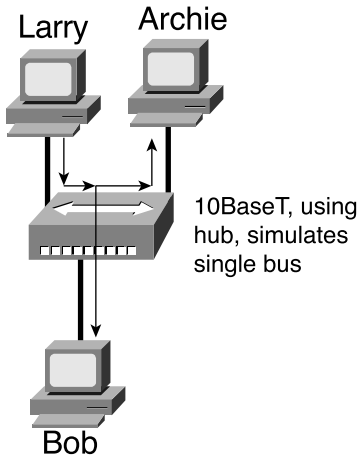
- All collided frames become corrupted, so each sending station must resend the frames. This wastes time on the bus and increases the latency for delivering the collided frames.
- Latency increases for stations waiting for the Ethernet to be silent before sending their frames. Because there are more frames per second, each sender has a longer wait time before sending. This increases latency while waiting for the incoming frame to complete.

10BaseT solved several problems with the early Ethernet specifications. 10BaseT allowed the use of telephone cabling that was already installed, or simply allowed the use of cheaper, easier-to-install cabling when new cabling was required. The use of 10BaseT *hubs* gave Ethernet much higher availability because a single cable problem does not affect the other users. These hubs are essentially multiport repeaters; they extend the bus concept of 10Base2 and 10Base5 by regenerating the same electrical signal sent by the original sender of a frame out every other port. Therefore, collisions can still occur, so CSMA/CD access rules continue

04 CCNA Exam_Ch 04.fm.1 Page 153 Thursday, March 7, 2002 11:47 AM

to be used. Figure 4-3 shows the same network as Figure 4-2, after migration to using hubs and twisted-pair cabling instead of co-ax cabling.

Figure 4-3 *Small Ethernet 10BaseT Network*



The concept of cabling each device to a central hub, with that hub creating the same electrical bus as in the older types of Ethernet, was a core fact of 10BaseT Ethernet. Because hubs continued the concept and physical reality of a single electrical path that is shared by all devices, today we call this *shared Ethernet*: All devices are sharing a single 10-Mbps bus.

So, hubs solved some cabling and availability problems. However, the degrading performance of CSMA/CD when the Ethernet utilization increased was still not addressed. The next step was to make the hub smart enough to ensure that collisions simply did not happen—which means that CSMA/CD would no longer be needed. First, you need a deeper knowledge of 10BaseT hubs before the solution to the congestion problem becomes obvious. Figure 4-4 outlines the operation of half-duplex 10BaseT with hubs.

Figure 4-4 outlines how a 10BaseT hub behaves to create an electrical bus. The chronological steps illustrated in Figure 4-4 are as follows:

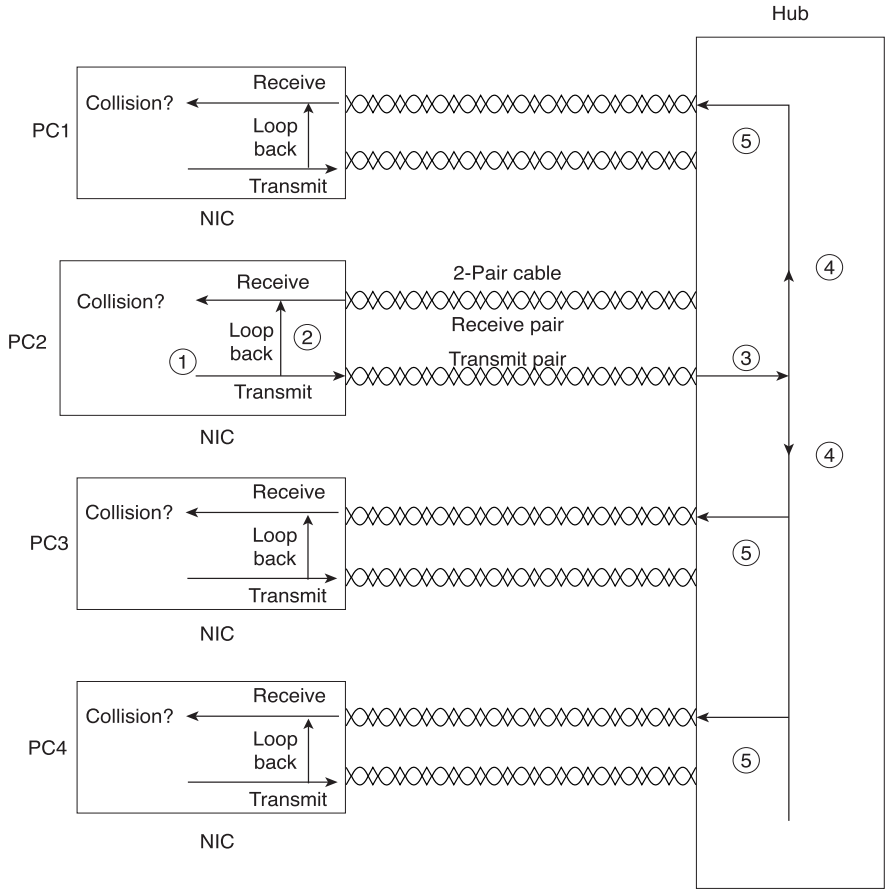
1. The network interface card (NIC) sends a frame.
2. The NIC loops the sent frame onto its receive pair.
3. The hub receives the frame.
4. The hub sends the frame across an internal bus so that all other NICs can receive the electrical signal. It does not forward the electrical signal back out to the device that sent the original signal.
5. The hub repeats the signal to each receive pair to all other devices. In other words, the hub sends so that the attached stations receive on their receive pair. (Similarly, the hub listens on the transmit pair because that is the pair used by each station for transmissions.)

04 CCNA Exam_Ch 04.fm.1 Page 154 Thursday, March 7, 2002 11:47 AM

The figure details how the hub works, with one device sending and no collision. If PC1 and PC2 sent a frame at the same time, a collision would occur. At Step 4, the hub would forward both electrical signals, which would cause the overlapping signals to be sent to all the NICs. CSMA/CD logic is still needed to have PC1 and PC2 wait and try again.

The term *collision domain* defines the set of devices for which their frames could collide. All devices on a 10Base2, 10Base5, or 10BaseT network using a hub risk collisions between the frames that they send, so all devices on one of these types of Ethernet networks are in the same collision domain.

Figure 4-4 *10BaseT Half-Duplex Operation*



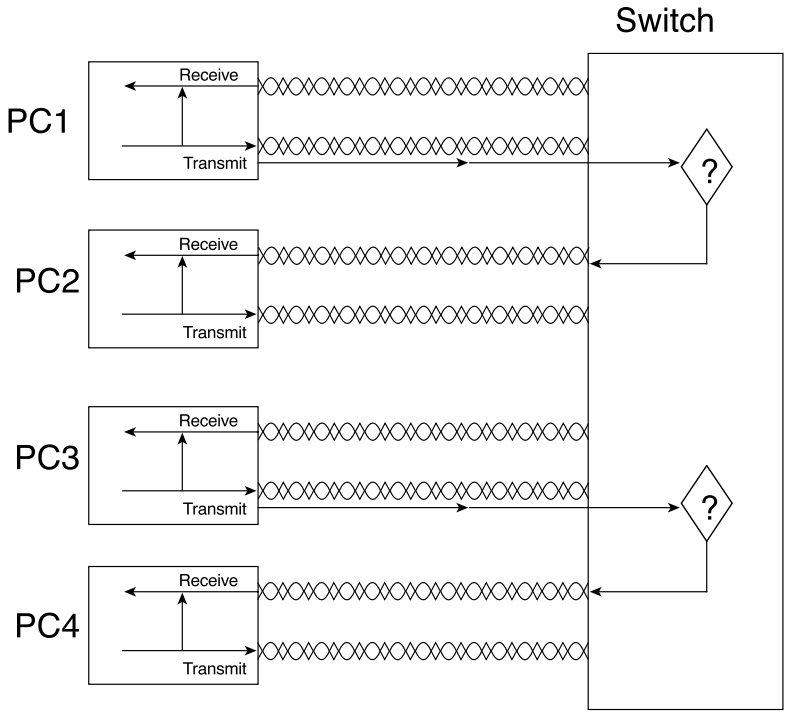
04 CCNA Exam_Ch 04.fm.1 Page 155 Thursday, March 7, 2002 11:47 AM

NOTE PC2 would sense a collision because of its loopback circuitry on the NIC. The hub does not forward the signal that PC2 sent back to PC2—if the hub did that, PC2 would think that there was a collision on every frame. So, each NIC loops the frame that it sends back to its own receive pair on the NIC, as shown in Step 2 of the figure. The signal sent by PC1 is sent to PC2 on PC2's receive pair, so the incoming signal from the hub, plus the looped signal on PC2's NIC, let it notice that there is a collision. Who cares? Well, to appreciate full-duplex LAN operation, you need to know about the NIC's loopback feature.

The original Ethernet specifications implied half-duplex behavior. Just like having a single speaker in a meeting room, there is a single sender on an Ethernet (so far). Essentially, if the topology allows collisions, CSMA/CD is used to react to the collisions. With a shared 10BaseT hub—or with 10Base2 or 10Base5, for that matter—if a station is receiving a frame, it would not choose to also start sending another frame because sending a frame would cause a collision.

LAN switches overcome the problems created by collisions and the CSMA/CD algorithm. Switches do not create a single shared bus, but rather they treat each individual physical port as a separate bus. Switches use memory buffers to hold incoming frames as well. So, as seen in Figure 4-5, collisions can be avoided.

Figure 4-5 *Basic Switch Operation*



04 CCNA Exam_Ch 04.fm.1 Page 156 Thursday, March 7, 2002 11:47 AM

In Figure 4-5, both PC1 and PC3 are sending at the same time. The switch looks at the destination Ethernet address, and sends only the frame from PC1 to PC2 and the frame sent by PC3 to PC4. The big difference between the hub and the switch is that the switch interpreted the electrical signal as an Ethernet frame and processed the frame to make a decision. (The details of Ethernet addressing and framing are coming up in the next two sections.) A hub simply repeats the electrical signal and makes no attempt to interpret the electrical signal (Layer 1) as a LAN frame (Layer 2).

Buffering also helps prevent collisions. Imagine that PC1 had sent a broadcast, which needs to be sent out all ports in Figure 4-3. PC3 is sending another frame to PC4. The switch, knowing that forwarding both frames to PC4 would cause a collision, buffers one frame until the first one has been completely sent to PC4.

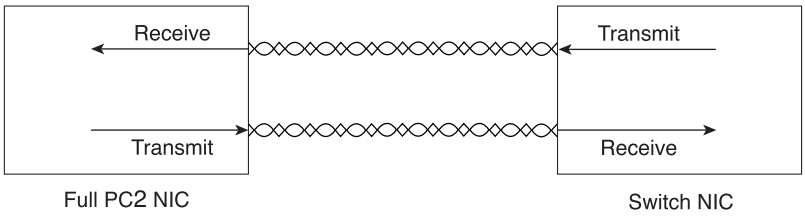
So, back to the historical picture. 10BaseT switches added forwarding logic based on the address of the frame, which avoids collisions. Switches also added buffering so that additional collisions were avoided. In short:

> If only one device is cabled to each port of a switch, no collisions occur.

The final concept in this section requires the assumption that no collision can occur. If no collision can occur, CSMA/CD is not needed—at least, not the collision detection and recovery part. If CSMA/CD is not needed, the implied half-duplex operation no longer is needed. In short, LAN switches with only one device cabled to the switch allow the use of *full-duplex* operation.

Full-duplex means that an Ethernet card can send and receive concurrently. Consider Figure 4-6, which shows the full-duplex circuitry used with a single PC cabled to a LAN switch.

Figure 4-6 *10BaseT Full-Duplex Operation*



04 CCNA Exam_Ch 04.fm.1 Page 157 Thursday, March 7, 2002 11:47 AM

Because no collisions are possible, the NIC disabled its loopback circuitry. Both ends can send and receive simultaneously. This reduces Ethernet congestion and provides the following advantages, as compared to half-duplex 10BaseT operation:

- Collisions do not occur; therefore, time is not wasted retransmitting frames.
- There is no latency waiting for others to send their frames.
- There are 10 Mbps in each direction, doubling the available capacity (bandwidth).

So far in this chapter, you have seen 12 years of Ethernet evolution. Table 4-2 summarizes some of the key points as they relate to what is covered in this initial section of the chapter. More of the specification details are listed later in this chapter.

Table 4-2 *Summary of Some Basic Ethernet Features*

10Base2, 10Base5	Single bus cabled serially between devices using coaxial cable.
10BaseT with a Hub	One electrical bus shared among all devices creating a single collision domain, cabled in a star topology using twisted-pair cabling.
10BaseT with a Switch	One electrical bus per switch port creating multiple collision domains, cabled in a star topology using twisted-pair cabling.
Half Duplex	Logic that requires a card to only send or receive at a single point in time. Used to avoid collisions.
Full Duplex	Logic that enables concurrent sending and receiving, allowed when one device is attached to a switch port, ensuring that no collisions can occur.

LAN Addressing

LAN addressing identifies either individual devices or groups of devices on a LAN. On the CCNA exam, you are expected to confidently understand and interpret LAN addresses.

Unicast addresses identify a single LAN card. Frames between a pair of LAN stations use a source and destination address field to identify each other. These addresses are called unicast addresses, or *individual addresses*, because they identify an individual LAN interface card. (The term *unicast* was chosen mainly for contrast with the terms *broadcast*, *multicast*, and *group addresses*.) It's a fancy term but a simple concept.

The IEEE defines the format and assignment of LAN addresses. The IEEE requires globally unique unicast Media Access Control (MAC, another term for LAN address) addresses on all LAN interface cards. The manufacturers encode the MAC address onto the LAN card, usually in

04 CCNA Exam_Ch 04.fm.1 Page 158 Thursday, March 7, 2002 11:47 AM

a ROM chip. The first half of the address identifies the manufacturer of the card. This code, which is assigned to each manufacturer by the IEEE, is called the *organizationally unique identifier (OUI)*. The manufacturer assigns a MAC address with its own OUI as the first half of the address, with the second half of the address being assigned a number that this manufacturer has never used on another card. These addresses are called *burned-in addresses (BIAs)* because they are burned into ROM chips. They also are sometimes called *universally administered addresses (UAA)* because the IEEE universally (well, at least worldwide) administers address assignment.

Group addresses identify more than one LAN interface card. The IEEE defines three general categories of group addresses:

- **Broadcast addresses**—The most often used of IEEE group MAC address, the broadcast address, has a value of FFFF.FFFF.FFFF (hexadecimal notation). The broadcast address implies that all devices on the LAN should process the frame.
- **Multicast addresses**—Used by Ethernet and FDDI, multicast addresses fulfill the requirement to address a subset of all the devices on a LAN. Multicast addresses are not burned into the card, but they are added by the software on the NIC in the direction of the software in the computer. If the software on the computer wants to listen for frames sent to a particular multicast address, the software configures the NIC to listen for that address. An example of multicast addresses is a range of addresses—0100.5exx.xxxx—with different values assigned in the last 3 bytes; these MAC addresses are used in conjunction with the Internet Group Multicast Protocol (IGMP) and IP multicast. IP hosts on an Ethernet that want to receive IP packets to a particular IP multicast address all use the same Ethernet MAC address, which begins with 0100.5E.
- **Functional addresses**—Valid only on Token Ring, functional addresses identify one or more interfaces that provide a particular function. For example, c000.0000.0001 is used by the device on a Token Ring that is currently implementing the Active Monitor function.

The following list summarizes many of the key features of MAC addresses:

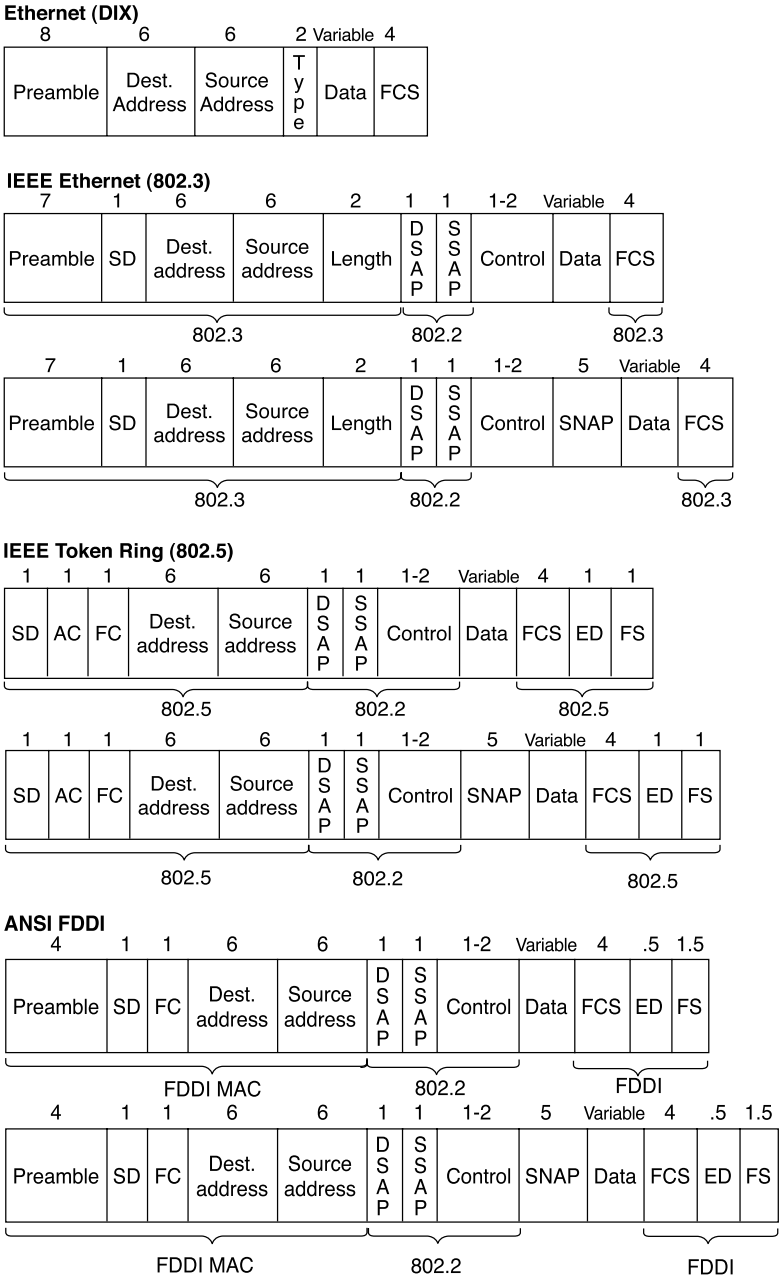
- Unicast MAC addresses address an individual LAN interface card.
- Broadcast MAC addresses address all devices on a LAN.
- Multicast MAC addresses address a subset of the devices on an Ethernet or FDDI LAN.
- Functional MAC addresses identify devices performing a specific IEEE-defined function on Token Ring only.

LAN Framing

Framing defines how a string of binary numbers is interpreted. For example, Ethernet defines how the first several bytes of a received electrical signal are interpreted after that signal is received and converted into a binary string. Figure 4-7 shows the details of several type LAN frames.

04 CCNA Exam_Ch 04.fm.1 Page 159 Thursday, March 7, 2002 11:47 AM

Figure 4-7 *LAN Header Formats*



04 CCNA Exam_Ch 04.fm.1 Page 160 Thursday, March 7, 2002 11:47 AM

Don't be alarmed—it is unlikely that you would get CCNA exam questions asking about all these LAN framing fields! You should remember some details about the contents of the headers and trailers for each LAN type, though. In particular, the addresses and their location in the headers are important. Also, the name of the field that identifies the type of header that follows the LAN headers—namely, the Type, DSAP, and SNAP fields—is important. Finally, the fact that a frame check sequence (FCS) exists in the trailer is also vital. Figure 4-7 summarizes the various header formats.

The 802.3 specification limits the data portion of the 802.3 frame to a maximum of 1500 bytes. The data was designed to hold Layer 3 packets; the term *maximum transmission unit (MTU)* defines the maximum Layer 3 packet that can be sent over a medium. Because the Layer 3 packet rests inside the data portion of an Ethernet frame, 1,500 is the largest MTU allowed over an Ethernet.

The function of identifying the header that follows the LAN header (what's in the data in Figure 4-7) is covered rather extensively in Chapter 3, "OSI Reference Model and Layered Communication." Any computer receiving a LAN frame needs to know what is in the data portion of the frame. Table 4-3 summarizes the fields that are used for identifying the types of data contained in a frame.

Table 4-3 *Protocol Type Fields in LAN Headers*

Field Name	Length	LAN Type	Comments
Ethernet Type	2 bytes	Ethernet	RFC 1700 ("Assigned Numbers" RFC) lists the values. Xerox owns the assignment process.
802.2 DSAP and SSAP	1 byte each	IEEE Ethernet, IEEE Token Ring, ANSI FDDI	The IEEE Registration Authority controls the assignment of valid values. The source SAP (SSAP) and destination SAP (DSAP) do not have to be equal, so 802.2 calls for the sender's protocol type (SSAP) and the destination's type (DSAP).
SNAP Protocol	2 bytes	IEEE Ethernet, IEEE Token Ring, ANSI FDDI	This field uses Ethernet Type values and is used only when DSAP is hex AA. It is needed because the DSAP and SSAP fields are only 1 byte in length.

Some examples of values in the Ethernet Type and SNAP Protocol fields are 0800 for IP and 8137 for NetWare. Examples of IEEE SAP values are E0 for NetWare, 04 for SNA, and AA for SNAP.

04 CCNA Exam_Ch 04.fm.1 Page 161 Thursday, March 7, 2002 11:47 AM

Fast Ethernet and Gigabit Ethernet

Fast Ethernet and Gigabit Ethernet provide faster Ethernet options. Both have gained widespread acceptance in networks today, with Fast Ethernet most likely being used to the desktop and Gigabit Ethernet being used between networking devices or to servers.

Fast Ethernet retains many familiar features of 10-Mbps Ethernet variants. The age-old CSMA/CD logic still exists, but it can be disabled for full-duplex point-to-point topologies in which no collisions can occur. A variety of cabling options is allowed—unshielded and shielded copper cabling as well as multimode and single-mode fiber. Both Fast Ethernet shared hubs and switches can be deployed. However, because Fast Ethernet gained market acceptance around the same time that LAN switching became popular, most Fast Ethernet cards either are connected to a switch or are directly cabled to another device.

The two key additional features of Fast Ethernet, as compared to 10-Mbps Ethernet, are higher bandwidth and autonegotiation.

Fast Ethernet operates at 100 Mbps—enough said. The other key difference, autonegotiation, allows an Ethernet card or switch to operate at 10 or 100 Mbps. Also, support for half-duplex or full-duplex operation is negotiated. If the other device, such as a 10BaseT NIC, does not support autonegotiation, autonegotiation settles for half-duplex operation at 10 Mbps.

The autonegotiation process has been known to fail. Cisco recommends that, for devices that seldom move, you should configure the LAN switch and the device to use the identical desired setting rather than depend on autonegotiation. Generally, for ports that are used for end-user devices, autonegotiation is enabled because these devices are moved frequently relative to servers or other network devices, such as routers.

Gigabit Ethernet also retains many familiar features of slower Ethernet variants. CSMA/CD is still used and can be disabled for full-duplex support. Although gigabit hubs are allowed, it is more likely that Gigabit Ethernet switch ports will be the most popular use for Gigabit Ethernet, along with use as a trunk between high-throughput switches and routers.

Gigabit Ethernet is similar to its slower cousins in several ways. The most important similarity is that the same Ethernet headers and trailers are used, no matter whether it's 10 Mbps, 100 Mbps, or 1000 Mbps. If you understand how Ethernet works for 10 and 100 Mbps, then you know most of what you need to know about Gigabit Ethernet.

Gigabit Ethernet differs from the slow specifications in how it encodes the signals onto the cable. Gigabit Ethernet is obviously faster, at 1000 Mbps, or 1 Gbps. The physical layer differences are truly beyond the scope of the CCNA exam.

Both Fast Ethernet (FE) and Gigabit Ethernet (GE) relieve congestion in some fairly obvious ways. Collisions and wait time are decreased when compared to 10-Mbps Ethernet simply because it takes 90 percent (FE) or 99 percent (GE) less time to transmit the same frame on the

04 CCNA Exam_Ch 04.fm.1 Page 162 Thursday, March 7, 2002 11:47 AM

faster LANs. Capacity is greatly increased as well: If all frames were 1250 bytes long, a theoretical maximum of 10,000 frames per second could be reached on Fast Ethernet, and a theoretical maximum of 100,000 frames per second could be reached on Gigabit Ethernet. (Of course, this little math problem ignores such details as interframe gaps and the unlikely case of identical length frames; it's just an example to give you perspective.)

LAN Standards

The IEEE defines most of the standards for Ethernet and Token Ring, with ANSI defining standards for FDDI. These specifications match OSI Layer 2 and typically are divided into two parts: the Media Access Control (MAC) and Logical Link Control (LLC) sublayers. The MAC sublayer is very specific to that particular type of LAN, whereas the LLC sublayer performs functions that are relevant to several types of LANs. For instance, all LANs need some form of protocol type field; the LLC specification, rather than the MAC, defines the use of the DSAP field for that purpose. Table 4-4 lists the various protocol specifications.

Table 4-4 *MAC and LLC Details for Three Types of LANs*

Name	MAC Sublayer Spec	LLC Sublayer Spec	Other Comments
Ethernet Version 2 (DIX Ethernet)	Ethernet	N/A	This spec is owned by Digital, Intel, and Xerox.
IEEE Ethernet	IEEE 802.3	IEEE 802.2	This is also popularly called 802.3 Ethernet. It is built upon details of DIX Ethernet.
IEEE Token Ring	IEEE 802.5	IEEE 802.2	IBM helped with development before the IEEE took over.
ANSI FDDI	ANSI X3T9.5	IEEE 802.2	ANSI liked 802.2, so it just refers to the IEEE spec.

Start Extra Credit

With the advent of Fast Ethernet and Gigabit Ethernet, the variety of Ethernet standards has increased to the point that most networking personnel do not memorize all the standards. The CCNA exam probably will not require you to be that familiar with Ethernet standards—or, at least, not the full list. Table 4-5 lists the key Ethernet specifications and several related details about the operation of each.

04 CCNA Exam_Ch 04.fm.1 Page 163 Thursday, March 7, 2002 11:47 AM

Table 4-5 *Ethernet Standards*

Standard	MAC Sublayer Specification	Maximum Cable Length	Cable Type	Pairs Required
10Base5	802.3	500 m[1]	50-ohm thick coaxial cable	
10Base2	802.3	185 m[1]	50-ohm thin coaxial cable	
10BaseT	802.3	100 m[1]	Category 3, 4, or 5 UTP	2
10BaseFL	802.3	2000 m[2]	Fiber	1
100BaseTx	802.3u	100 m[2]	Category 5 UTP	2
100BaseT4	802.3u	100 m[2]	Category 3 UTP	4
100BaseT2	802.3u	100 m[2]	Category 3, 4, or 5 UTP	2
100BaseFx	802.3u	400/2,000 m[3]	Multimode fiber	1
100BaseFx	802.3u	10,000 m	Single-mode fiber	1
1000BaseSx	802.3z	220-550 m	Multimode fiber	1
1000BaseLx	802.3z	3000 m	Single-mode or multimode fiber	1
1000BaseCx	802.3z	25 m	Shielded copper	2
1000BaseT	802.3ab	100 m	Category 5 UTP	2

[1]For entire bus, without using a repeater
[2]From device to hub/switch
[3]Numbers shown are for half- or full-duplex operation

For more information on Fast Ethernet and information on Gigabit Ethernet, try the following Web pages:

- www.host.ots.utexas.edu/ethernet/ethernet-home.html
- www.ots.utexas.edu/ethernet/descript-100quickref.html
- www.iol.unh.edu/training
- www.cisco.com/warp/customer/cc/so/neso/lnso/lnmnso/feth_tc.htm
- www.cisco.com/warp/customer/cc/techno/media/lan/gig/tech/index.shtml
- www.10gea.org

NOTE A Cisco.com login is required for the preceding Cisco URLs.

End Extra Credit

04 CCNA Exam_Ch 04.fm.1 Page 164 Thursday, March 7, 2002 11:47 AM

Bridging and Switching

1 Name and describe two switching methods.

2 Distinguish between cut-through and store-and-forward LAN switching.

13 Describe the advantages of LAN segmentation.

14 Describe LAN segmentation using bridges.

15 Describe LAN segmentation using routers.

16 Describe LAN segmentation using switches.

17 Describe the benefits of network segmentation with bridges.

18 Describe the benefits of network segmentation with routers.

19 Describe the benefits of network segmentation with switches.

So far in this chapter, you have learned the fundamental components of Ethernet. The varied Ethernet specifications define different characteristics, but more similarities exist among the various types of Ethernet. You have seen that the early Ethernet specifications used a single shared bus, whether it was truly a long Ethernet cable or a bus created inside a shared-media Ethernet hub. You have seen that a switch creates multiple buses, which reduces or eliminates collisions and greatly improves performance. In spite of these differences, the various Ethernet specifications use the same framing and MAC addresses, which makes your job as a network engineer much easier when you migrate to a different physical specification for Ethernet.

04 CCNA Exam_Ch 04.fm.1 Page 165 Thursday, March 7, 2002 11:47 AM

Like the first major section of this chapter, a historical perspective gives you a chance to see why Ethernet has evolved to where it is today. You would not likely deploy a device called a transparent bridge today, and there is only a small chance that you might enable transparent bridging features in a Cisco router. So why bother to talk about bridging? Well, to understand bridging is to understand LAN switching. And you might infer that bridging concepts might well be on a test soon as well.

An old adage best describes LAN switching: Switches are bridges on steroids. The underlying logic between the two is similar, so both are described in this section. Also, a comparison of what happens when a single Ethernet is migrated to a pair of Ethernets—separated by a bridge in one case, a switch in another case, and a router in the third case—serves as a good review of the concepts behind all three types of campus forwarding devices. The trade-offs when using bridges, switches, and routers are important for two reasons. First, the concepts are still at the core of your decisions when designing a campus LAN today; second, the comparisons are a great tool for Cisco to test your knowledge about how the various devices work.

Transparent Bridging

Transparent bridges connect two or more LAN segments. The term *segment* defines a LAN in terms of older Ethernet terminology. For example, a 10Base2 network was a series of coaxial cables with taps for each device, so the whole series of cables was one segment. As a LAN segment grew, eventually it became too crowded with collisions or exceeded cabling length restrictions. So, the one segment was separated into two segments, and a bridge was placed between the two segments. As you will soon see, this separated the world into two collision domains, meaning that frames sent by devices on one side of the bridge could not collide with frames sent by devices on the other side of the bridge. Because the bridge does not forward all traffic, traffic to each node was reduced. In short, transparent bridges were created to alleviate congestion problems on a single Ethernet segment and to extend allowed cabling distances because the segments on each side of the bridge conformed to the same distance limitation as a single segment.

Transparent bridging is called “transparent” because the endpoint devices do not need to know that the bridge(s) exist(s). In other words, the computers attached to the LAN do not behave any differently in the presence or absence of transparent bridges.

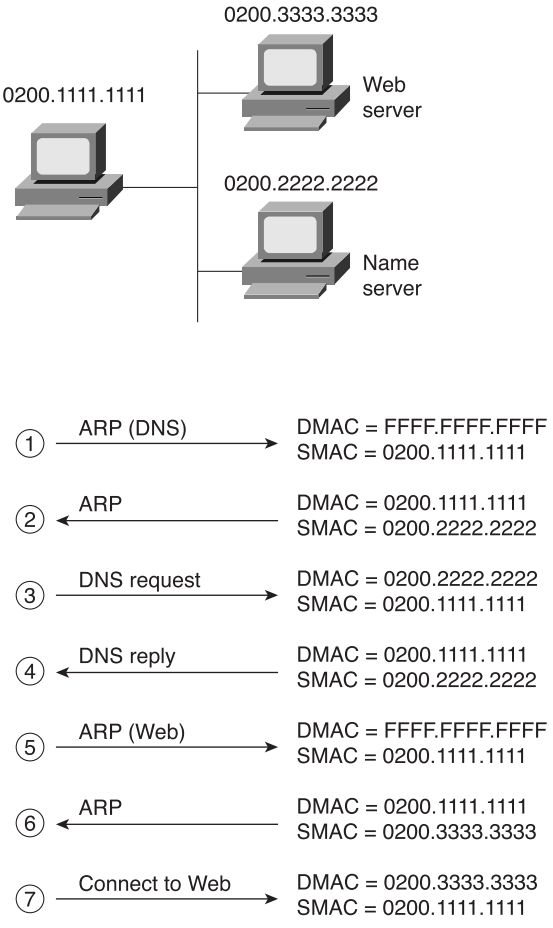
Transparent bridges forward frames when necessary and do not forward when there is no need to do so, thus reducing overhead. To accomplish this, transparent bridges perform three actions:

- Learning MAC addresses by examining the source MAC address of each frame received by the bridge
- Deciding when to forward a frame or when to filter (not forward) a frame, based on the destination MAC address
- Creating a loop-free environment with other bridges by using the Spanning Tree Protocol

04 CCNA Exam_Ch 04.fm.1 Page 166 Thursday, March 7, 2002 11:47 AM

To fully understand transparent bridging logic, consider Figure 4-8. A client first asks for DNS name resolution and then connects to a Web server. All three devices are on the same LAN segment. The LAN segment is drawn as if it is a 10Base2 or 10Base5 network, but it could be 10BaseT using a shared hub. Regardless, focus on the Ethernet addresses and the bridges actions in the figure.

Figure 4-8 *Example Protocol Flows—Single Ethernet Segment*



04 CCNA Exam_Ch 04.fm.1 Page 167 Thursday, March 7, 2002 11:47 AM

In this example, the devices send messages just like they would if the user, the Web server, and the DNS were on the same segment. The destination and source MAC addresses are listed in the figure. The following list provides some additional text relating the steps shown in Figure 4-8:

1. The PC is preconfigured with the IP address of the DNS; it must use ARP to find the DNS's MAC address.
2. The DNS replies to the ARP request with its MAC address, 0200.2222.2222.
3. The PC requests name resolution by the DNS for the Web server's name.
4. The DNS returns the IP address of the Web server to the PC.
5. The PC does not know the Web server's MAC address, but it does know its IP address, so the PC sends an ARP broadcast to learn the MAC address of the Web server.
6. The Web server replies to the ARP, stating that its MAC address is 0200.3333.3333.
7. The PC now can send frames directly to the Web server.

One somewhat obvious point must be made: All frames are received by all devices. In this case, the single LAN segment is a bus, or a 10BaseT hub, which creates a single bus. Ethernet is considered a *broadcast medium* because when one device sends, all the rest receive the electrical signal. Each device then must decide whether to process the frame.

Why bother to point out that everyone gets each frame? Well, a transparent bridge would not always forward a copy of each frame on each segment. Now consider the same protocol flow, but with the DNS on a separate segment and a transparent bridge separating the segments, as shown in Figure 4-9. The computers act no differently, sending the same frames and packets. (Remember, "transparent" bridges are transparent to the end user devices.) The transparent bridge forwards all broadcasts, all unicast destination frames not in its bridge table, and multicasts.

04 CCNA Exam_Ch 04.fm.1 Page 168 Thursday, March 7, 2002 11:47 AM

Figure 4-9 *Example Protocol Flows—Using a Transparent Bridge*

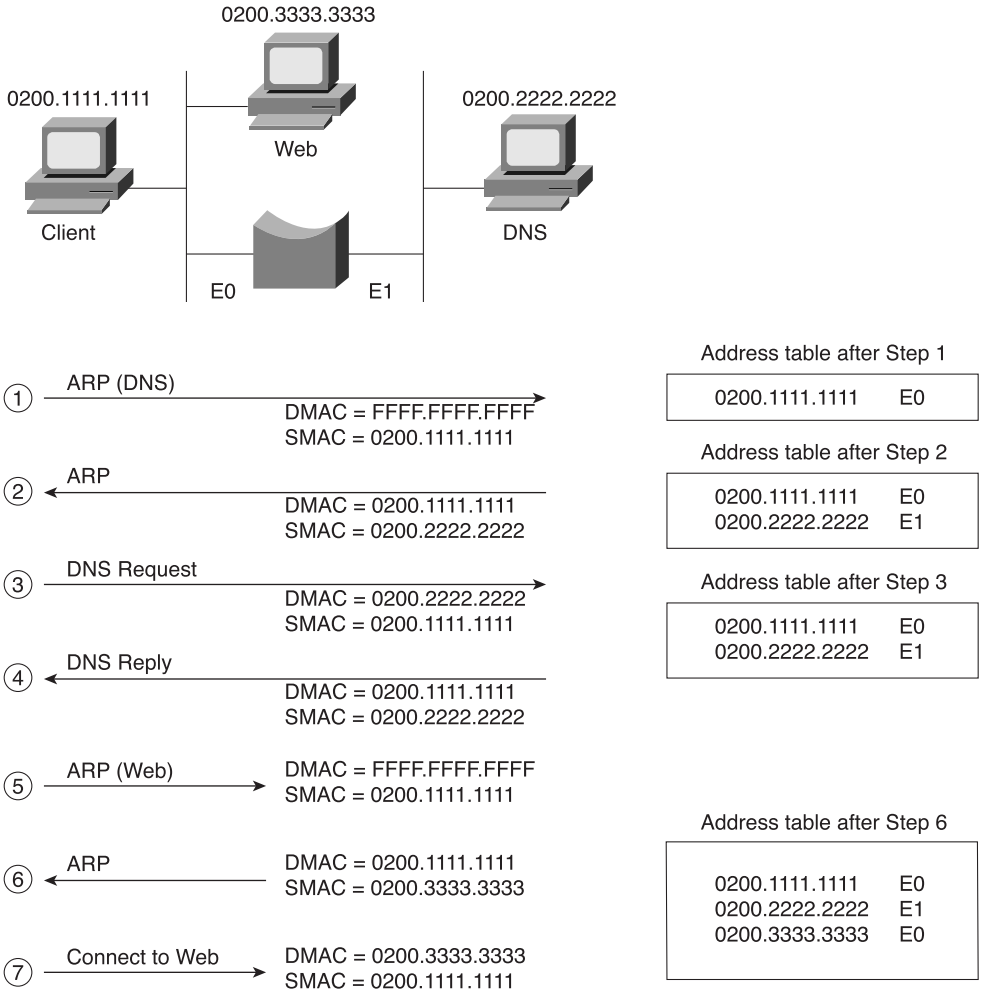


Figure 4-9 illustrates several important ideas related to segmentation. To see the real end goal of the bridge, consider Step 7 and the state of the address table after Step 6. Because the bridge knows the unicast MAC addresses of all three devices, when the client sends the frame to the Web server (Step 7), the bridge simply asks itself, "Should I forward this frame?" Because the frame came in the bridge's E0 port and the Web server (0200.3333.3333) is also out its E0 port, there is no need to forward the frame.

04 CCNA Exam_Ch 04.fm.1 Page 169 Thursday, March 7, 2002 11:47 AM

The following list outlines the logic used at each step in the process of Figure 4-9:

1. The first frame is a broadcast, so the bridge forwards the frame. The source MAC address, 0200.1111.1111, is added to the address table.
2. The ARP reply is a unicast destined to 0200.1111.1111, so the bridge knows to forward it out its E0 port, according to the address table. The source MAC of the frame, 0200.2222.2222, is added to the address table.
3. The DNS request is a unicast frame, and the bridge knows where the destination, 0200.2222.222, is. The bridge forwards the frame. The bridge checks the source address (0200.1111.1111) and notices that it is already in the table.
4. The DNS reply is a unicast, with a known destination (0200.1111.1111) and a known source (0200.2222.2222). The bridge forwards the frame.
5. The ARP broadcast is destined to MAC address FFFF.FFFF.FFFF, so it is forwarded by the bridge, in spite of the fact that the ARP broadcast will reach the Web server without the bridge forwarding the frame.
6. The ARP reply from the Web server is a unicast to 0200.1111.1111, and the bridge has that MAC in its address table. The bridge does not forward the frame because it came in its E0 interface and it is destined out that same interface. The source MAC address, 0200.3333.3333, is added to the address table.
7. The last frame is a unicast whose destination MAC (0200.3333.3333) is in the address table, and the bridge should not forward it.

Networks using bridges have the following general characteristics:

- Broadcasts and multicast frames are forwarded by a bridge.
- Transparent bridges perform switching of frames using Layer 2 headers and Layer 2 logic and are Layer 3 protocol-independent. This means that installation is simple because no Layer 3 address group planning or address changes are necessary. For example, because the bridge retains a single broadcast domain, all devices on all segments attached to the bridge can look like a single subnet.
- Store-and-forward operation is typical in transparent bridging devices. Because an entire frame is received before being forwarded, additional latency is introduced (as compared to a single LAN segment).
- The transparent bridge must perform processing on the frame, which also can increase latency (as compared to a single LAN segment).

04 CCNA Exam_Ch 04.fm.1 Page 170 Thursday, March 7, 2002 11:47 AM

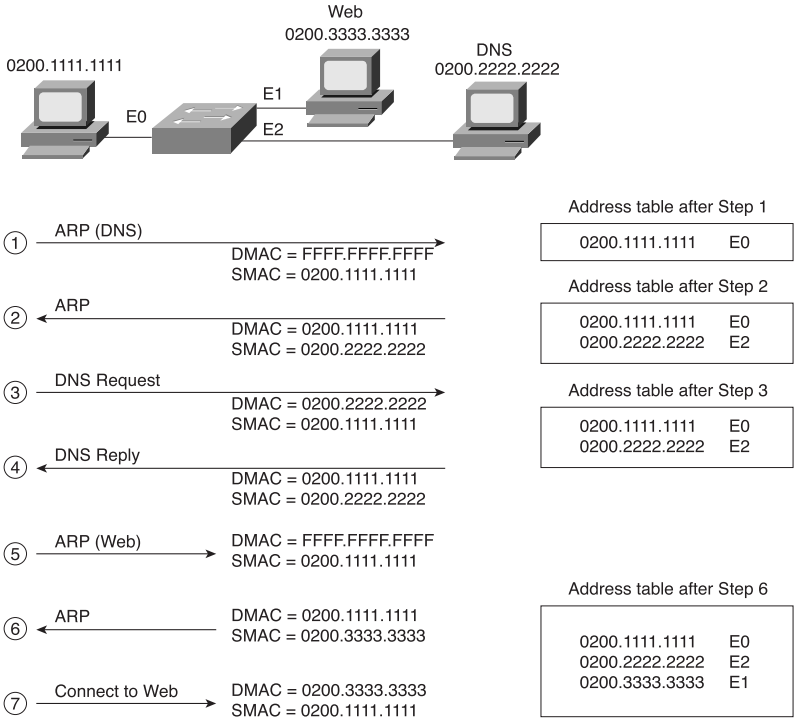
LAN Switching

An Ethernet switch uses the same logic as a transparent bridge. However, switches perform more functions, have more features, and have more physical ports. Switches use hardware to learn addresses and to make forwarding and filtering decisions. Bridges use software running on general-purpose processors, so they tend to run much more slowly than switches. The reason behind this difference is simply the time frame in which each technology was developed: Switches came later and took advantage of newer hardware capabilities, such as application-specific integrated circuits (ASICs). But if you look at the basic forward/filter logic, just as with a transparent bridge, the basic logic of a LAN switch is as follows:

1. A frame is received.
2. If the destination is a broadcast or multicast, forward on all ports.
3. If the destination is a unicast and the address is not in the address table, forward on all ports.
4. If the destination is a unicast and the address is in the address table, and if the associated interface is not the interface in which the frame arrived, forward the frame.

Consider Figure 4-10, which separates LANs with a switch.

Figure 4-10 *Example Protocol Flows—Using a Switch*



04 CCNA Exam_Ch 04.fm.1 Page 171 Thursday, March 7, 2002 11:47 AM

It appears that exactly the same thing happened in Figure 4-10 with a switch as it did in Figure 4-9 using a bridge. The basic logic is similar, but there are some differences. The key physical difference is that each device is attached to a separate port on the switch, whereas, in Figure 4-9, the client and the Web server share the same port on the bridge.

The following list provides some additional insights relating to the steps shown in Figure 4-10, including where this figure describes a slightly different action than in Figure 4-9:

1. The PC is preconfigured with the IP address of the DNS. The PC notices that the DNS IP address is in the same subnet as its own IP address; therefore, the PC sends an ARP broadcast hoping to learn the DNS's MAC address. *This frame is forwarded out all other ports by the switch*, just like the transparent bridge did in Figure 4-9.
2. The DNS replies to the ARP request with its MAC address, 0200.2222.2222. The destination MAC is 0200.1111.1111, which is already in the address table, *so the switch forwards this frame only out port E0*.
3. The PC requests name resolution for the Web server by sending a packet with the destination IP address of the DNS. The destination MAC is 0200.2222.2222, which is already in the address table, *so the switch forwards this frame only out port E2*.
4. The DNS returns the IP address of the Web server to the PC in the DNS reply. The destination MAC is 0200.1111.1111, which is already in the address table, *so the switch forwards this frame only out port E0*.
5. The PC does not know the Web server's MAC address, so it sends an ARP broadcast to learn the MAC address. Because it is a MAC broadcast, *the switch forwards the frame on all ports*.
6. The Web server replies to the ARP, stating that its MAC address is 0200.3333.3333. This frame has a destination MAC of 0200.1111.1111, which is already in the address table, *so the switch forwards this frame only out port E0*.
7. The PC now can connect to the Web server. This frame has a destination MAC of 0200.3333.3333, which is already in the address table, *so the switch forwards this frame only out port E1*.

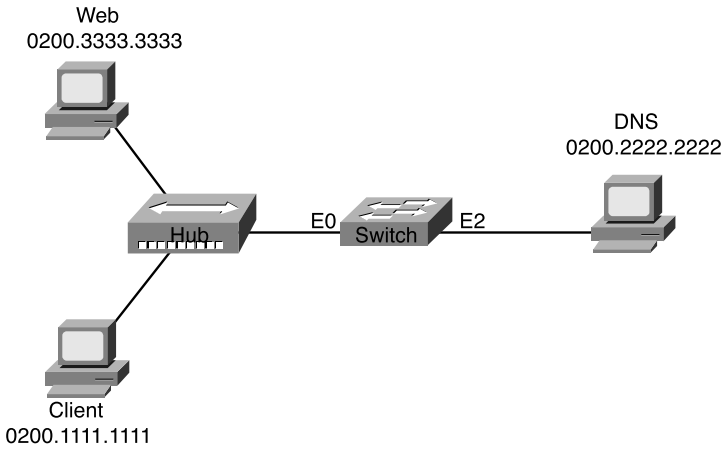
The switch behaves exactly like a transparent bridge would if the bridge used three ports instead of two. The switch learned the MAC addresses by examining the source MAC addresses and made forwarding decisions based on the contents of the address table.

The switch reduces the possibility of collisions. For example, imagine a fourth device, on port E3. If that new device sent a frame to the DNS's address of 0200.2222.2222 at the same time that the client sent a frame to the Web server (0200.3333.3333), the switch's basic logic would prevent a collision. For different reasons, the switch prevents a broadcast sent by this new device from colliding with the frame that the client sent to the server. The switch buffers one of the frames until the first frame has been sent and then forwards the second frame.

04 CCNA Exam_Ch 04.fm.1 Page 172 Thursday, March 7, 2002 11:47 AM

Collisions can occur on segments attached to switches. Consider Figure 4-11, which shows the same switch but with a shared hub connected to E0.

Figure 4-11 *Switch Connected to a Hub*



The switch connects to a shared hub, to which the client and the Web server are attached. As you might recall, the shared-media hub does not perform any Layer 2 logic—it just forwards all incoming electrical signals out all other ports. So, if the switch forwarded a frame out E0 to the client, and if the client is sending a frame to the Web server, a collision could occur. However, a frame sent by the client should never collide with frames sent by the DNS because they are on different switch ports. So, a more general statement should be made about switches and collisions:

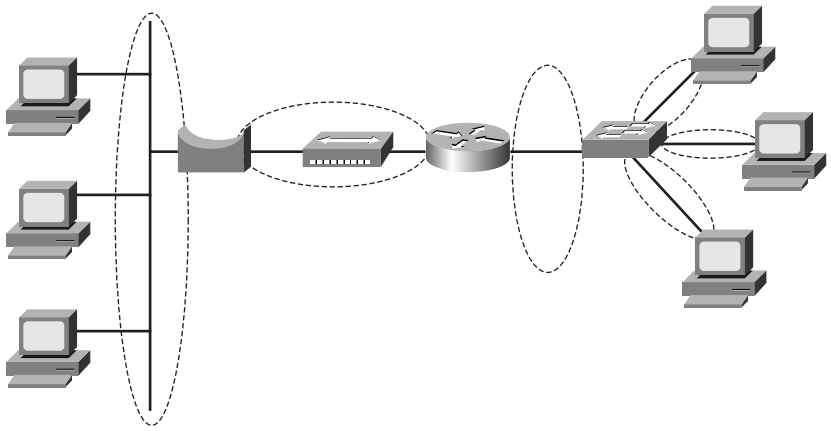
> Switches prevent collisions for ports with only one device connected to the port. If a hub is attached to the switch port with multiple devices attached to the hub, collisions can occur between frames sent by those devices. These frames would not collide with frames sent from devices on other switch ports.

To better discuss LANs, bridging, and switching, a term is needed to describe the set of devices whose frames could collide. *Collision domain* is the set of LAN interfaces whose frames could collide with each other but not with any other devices in the network. The switch network in Figure 4-10 has created three separate Ethernet segments, and each is a separate collision domain. For example, frames sent by the client in Figure 4-10 would not collide with frames sent by the DNS and the Web server. However, the switch could forward a frame out E0 toward the client at the same instant that the client sends a frame and would create a collision—unless the switch and the client are using full-duplex operation, as covered in the earlier section of this chapter. Regardless, transparent bridges, switches, and routers all create separate collision domains, one per interface.

Figure 4-12 shows a typical example of the definition of collision domains.

04 CCNA Exam_Ch 04.fm.1 Page 173 Thursday, March 7, 2002 11:47 AM

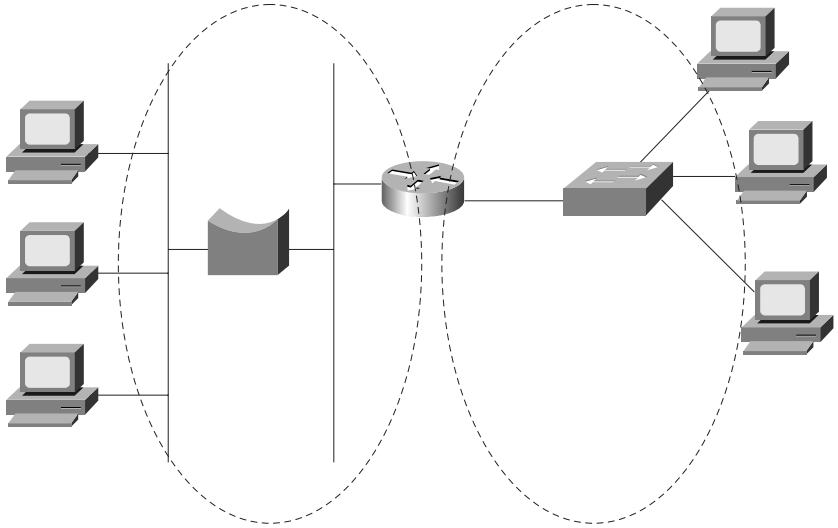
Figure 4-12 *Collision Domains*



Bridges and switches forward broadcasts and multicasts on all ports. (Actually, the forwarding of multicasts can be optimized using several switch features, such as the Cisco Group Management Protocol (CGMP), but these are beyond the scope of CCNA.) Because broadcast frames are sent out all ports, a bridge or switch creates only a single *broadcast domain*. A broadcast domain is the set of devices for which, when one of the devices sends a broadcast, all the other devices receive a copy of the broadcast.

The broadcast domain concept is similar to the concept of collision domains; however, only routers stop the flow of broadcasts. Figure 4-13 provides the broadcast domains for the same network depicted in Figure 4-12.

Figure 4-13 *Broadcast Domains*



04 CCNA Exam_Ch 04.fm.1 Page 174 Thursday, March 7, 2002 11:47 AM

Broadcasts sent by a device in one broadcast domain are not forwarded to devices in another broadcast domain. In this example, there are two broadcast domains. For instance, an ARP sent by a PC on the left is not forwarded by the router. In the old days, the term *broadcast firewall* described the fact that routers did not forward LAN broadcasts.

General definitions for a collision domain and a broadcast domain are as follows:

A *collision domain* is a set of network interface cards (NICs) for which a frame sent by one NIC could result in a collision with a frame sent by any other NIC in the same collision domain.

A *broadcast domain* is a set of NICs for which a broadcast frame sent by one NIC will be received by all other NICs in the broadcast domain.

Engineers design networks keeping broadcast domains in mind because, in most cases, all the devices in a single broadcast domain are also in the same IP subnet. For example, if only bridges and switches had existed in the network in Figure 4-13, and if the router was later added, some IP addresses would have had to be changed. To use the terminology in Chapter 3, two separate address groupings (for example, IP subnets) would be used for IP in Figure 4-13—one for the devices to the left of the router and another for devices to the right of the router. A definition of Layer 3 address groupings on LANs will help you understand VLANs better:

NOTE All devices in the same broadcast domain (Layer 2) typically will be in the same Layer 3 address grouping—in other words, the same IP subnet or same IPX network.

Internal Switching Paths

The internal processing on a switch can decrease latency for frames. Transparent bridges use store-and-forward processing, which means that the entire frame is received before the first bit of the frame is forwarded. Switches can use store-and-forward processing as well as *cut-through* processing logic. With cut-through processing, the first bits of the frame are sent out the outbound port before the last bit of the incoming frame is received instead of waiting for the entire frame to be received. In other words, as soon as the incoming switch port receives enough of the frame to see the destination MAC address, the frame is transmitted out the appropriate outgoing port to the destination device.

04 CCNA Exam_Ch 04.fm.1 Page 175 Thursday, March 7, 2002 11:47 AM

Cut-through processing can help, and it can hurt. Because the frame check sequence (FCS) is in the Ethernet trailer, a cut-through forwarded frame might have bit errors that the switch will not notice before sending most of the frame. And, of course, if the outbound port is busy, the switch stores the frame until the output port is available, gaining no advantage of store-and-forward switching.

The internal processing algorithms used by switches vary among models and vendors; regardless, the internal processing can be categorized as one of the methods listed in Table 4-6.

Table 4-6 *Switch Internal Processing*

Switching Method	Description
Store-and-forward	The switch fully receives all bits in the frame (store) before forwarding the frame (forward). This allows the switch to check the FCS before forwarding the frame. (FCS is in the Ethernet trailer.)
Cut-through	The switch performs the address table lookup as soon as the destination address field in the header is received. The first bits in the frame can be sent out the outbound port before the final bits in the incoming frame are received. This does not allow the switch to discard frames that fail the FCS check. (FCS is in the Ethernet trailer.)
FragmentFree	This performs like cut-through switching, but the switch waits for 64 bytes to be received before forwarding the first bytes of the outgoing frame. According to Ethernet specifications, collisions should be detected during the first 64 bytes of the frame; frames in error because of a collision will not be forwarded. The FCS still cannot be checked.

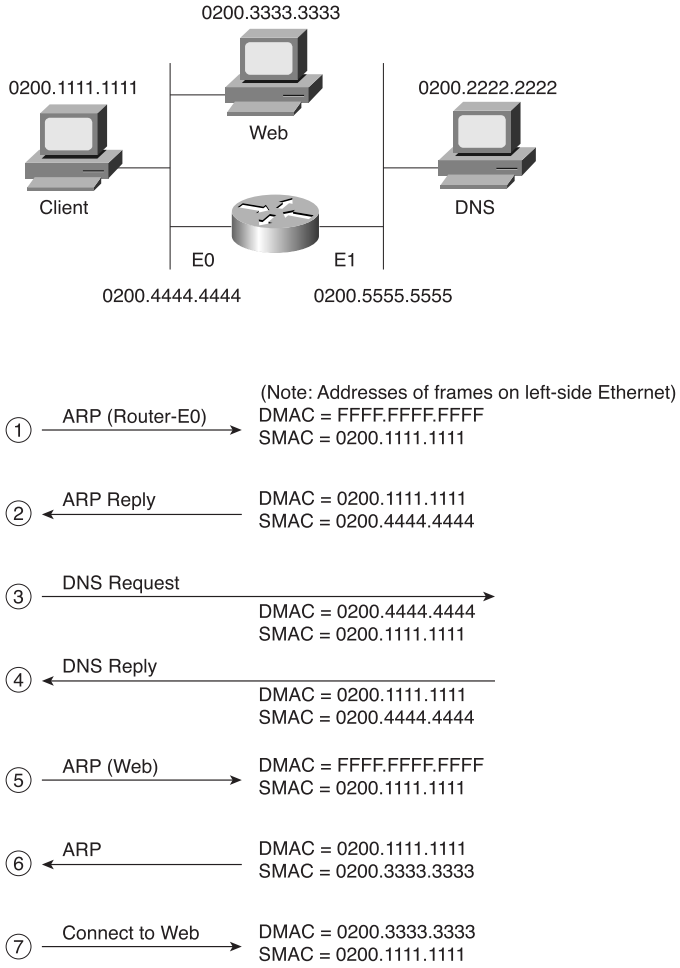
Comparison of LAN Segmentation Using Bridges, Switches, and Routers

The CCNA exam tests your ability to compare networks that use bridges, switches, and routers to separate LAN segments. The basic workings of a bridge and a switch have already been covered in this chapter. To compare these three options, first routing logic is covered. Afterward, comparisons will be made among the three options.

Routing is covered more fully in other chapters. For comparison, a router separates two segments in Figure 4-14. The client initiates the same example flow that was used in the earlier examples. Figure 4-14 illustrates a couple of key features of routing.

04 CCNA Exam_Ch 04.fm.1 Page 176 Thursday, March 7, 2002 11:47 AM

Figure 4-14 *Example Protocol Flows—Using a Router*



The flows in Figure 4-14 match the numbers in this list, which explains the meaning and implications of the flows in the figure:

1. The PC is preconfigured with the IP address of the DNS. The PC notices that the IP address of the DNS is on a different subnet, so the PC wants to forward the packet to its default router. However, the PC does not know its default router's MAC address yet, so *it must use ARP to find that router's MAC address. The ARP broadcast is not forwarded by the router.*
2. The router replies to the ARP request with its MAC address, 0200.4444.4444.

04 CCNA Exam_Ch 04.fm.1 Page 177 Thursday, March 7, 2002 11:47 AM

3. The PC requests name resolution for the Web server by sending a packet with the destination IP address of the DNS. The destination MAC address in the frame sent by the PC is the router's E0 MAC address. The router receives the frame, extracts the packet, and forwards it.
4. The DNS returns the IP address of the Web server to the PC in the DNS reply.
5. The PC does not know the Web server's MAC address, so it sends an ARP broadcast to learn the MAC address. The router has no need to forward the ARP broadcast.
6. The Web server replies to the ARP, stating that its MAC address is 0200.3333.3333.
7. The PC can now connect to the Web server.

The router does not forward ARP broadcasts. In fact, the logic in Step 1 begins with an ARP looking for the MAC address of the client's default router—namely, the router's E0 MAC address. This broadcast was not forwarded by the router, a fact that causes a router to be called a *broadcast firewall*. Comparing this to a transparent bridge or a LAN switch, this difference in broadcast treatment is the biggest advantage of routers.

Table 4-7 lists several features relating to segmenting LANs with bridges, switches, and routers. Essentially, this chart summarizes features that might differ among the three devices. Table 4-8 lists features that describe how each device performs when separating two Ethernet segments, compared to using a single Ethernet segment with no bridge, switch, or router. The two tables together provide the necessary details when comparing the three types of devices.

Table 4-7 *Comparison of Segmentation Options*

Feature	Single Segment	Bridging	Switching	Routing
Number of broadcast domains	1	1	1	1 per router interface
Number of collision domains	1	1 per bridge port	1 per switch port	1 per router interface
Forwards LAN broadcasts?	N/A	Yes	Yes	No
Forwards LAN multicasts?	N/A	Yes	Yes; can be optimized for less forwarding	No[1]
OSI layer used when making forwarding decision	N/A	Layer 2	Layer 2	Layer 3
Internal processing variants	N/A	Store-and-forward	Store-and-forward, cut-through, FragmentFree	Store-and-forward

continues

04 CCNA Exam_Ch 04.fm.1 Page 178 Thursday, March 7, 2002 11:47 AM

Table 4-7 *Comparison of Segmentation Options (Continued)*

Feature	Single Segment	Bridging	Switching	Routing
Frame/packet fragmentation allowed?	N/A	No	No	Yes
Multiple concurrent equal-cost paths to same destination allowed?	N/A	No	No	Yes

[1]Routers can forward IP multicast packets, if configured to do so. However, this does not mean that the LAN multicast frame is forwarded.

Table 4-8 lists features that should be interpreted within the following context: If I migrated from a single Ethernet segment to a network with two segments separated by a bridge/switch/router, and if traffic loads and destinations stayed constant, the result would be _____.

Table 4-8 *Benefits when Moving from One Ethernet Segment to Multiple Segments Using Bridges, Switches, and Routers*

Feature	Bridging	Switching	Routing
Greater cabling distances allowed	Yes	Yes	Yes
Decrease in collisions, assuming equal traffic loads	Yes	Yes	Yes
Decreased adverse impact of broadcasts	No	No	Yes
Decreased adverse impact of multicasts	No	No, unless mcast optimizations enabled	Yes
Increase in bandwidth	Yes	Yes	Yes
Filtering on Layer 2 header allowed	Yes	Yes	No
Filtering on Layer 3 header allowed	No	No	Yes

Certainly, the most important distinction among the three segmentation methods is their treatment of broadcasts and multicasts. Remembering the concepts of collision domains, broadcast domains, and how each device separates LANs into different domains is one key to understanding campus LAN design and troubleshooting.

LAN Switch Configuration

Cisco expects CCNAs to master the concepts behind LAN switching and VLANs. This mastery includes the ability to configure IOS-based LAN switches using the IOS CLI. This section outlines the similarities of the switch IOS CLI to the router IOS CLI, and contrasts the commands, syntax, and required configuration elements unique to switches.

04 CCNA Exam_Ch 04.fm.1 Page 179 Thursday, March 7, 2002 11:47 AM

Not all Cisco LAN switches provide an IOS CLI interface to the network engineer. Cisco wants its certifications to prove that the candidate knows the technology and can implement it; that proof would be onerous if all switch families' user interfaces were required on the CCNA exam. This book covers some implementation details and examples on the 1900 series switch, which is the same (and only) switch user interface covered by the ICND course.

The similarities between the 1900 series switch CLI and the router IOS CLI far outnumber the differences. In fact, most of the differences relate to the commands needed on a switch, which are simply not needed on a router. The up arrow retrieves the previous command. The ? key requests help. The Tab key completes a parameter after you have typed in a unique set of beginning characters. The **configure terminal** command takes you from privileged exec mode to configuration mode. The **show running-config** command lists the currently used configuration. In fact, when in doubt, assume that the switch and router IOS CLIs are identical. The important differences are mentioned as appropriate in this section.

Basic 1900 Switch Configuration

On the Catalyst 1900 switch, three different configuration methods exist:

- Menu-driven interface from the console port
- Web-based Visual Switch Manager (VSM)
- IOS command-line interface (CLI)

As mentioned earlier, this book focuses on using the CLI to configure the switch. Table 4-9 lists the switch commands referred to in this section.

Table 4-9 *Commands for Catalyst 1900 Switch Configuration*

Command	Description
ip address *address subnet-mask*	Sets the IP address for in-band management of the switch
ip default-gateway	Sets the default gateway so that the management interface can be reached from a remote network
show ip	Displays IP address configuration
show interfaces	Displays interface information
mac-address-table permanent *mac-address type module/port*	Sets a permanent MAC address
mac-address-table restricted static *mac-address type module/port src-if-list*	Sets a restricted static MAC address

continues

04 CCNA Exam_Ch 04.fm.1 Page 180 Thursday, March 7, 2002 11:47 AM

Table 4-9 *Commands for Catalyst 1900 Switch Configuration (Continued)*

Command	Description
port secure [**max-mac-count** *count*]	Sets port security
show mac-address-table {**security**}	Displays the MAC address table; the **security** option displays information about the restricted or static settings
address-violation {**suspend** | **disable** | **ignore**}	Sets the action to be taken by the switch if there is a security address violation
show version	Displays version information
copy tftp://*host/src_file* {**opcode** [*type module*] | **nvram**}	Copies a configuration file from the TFTP server into NVRAM
copy nvram tftp://*host/dst_file*	Saves a configuration file to the TFTP server
delete nvram [*type module*]	Removes all configuration parameters and returns the switch to factory default settings

Default 1900 Configuration

The default values vary depending on the features of the switch. The following list provides some of the default settings for the Catalyst 1900 switch. (Not all the defaults are shown in this example.)

- IP address: 0.0.0.0
- CDP: Enabled
- Switching mode: FragmentFree
- 100BaseT port: Autonegotiate duplex mode
- 10BaseT port: Half duplex
- Spanning Tree: Enabled
- Console password: None

Numbering Ports (Interfaces)

The terms *interface* and *port* both are used to describe the physical connectors on the switch hardware. For instance, the **show running-config** command uses the term *interface*; the **show spantree** command uses the term *port*. The numbering of the interfaces is relatively straightforward; the interface numbering convention for the 1912 and 1924 switches is shown in Table 4-10. Example 4-1 shows three exec commands and highlights the use of the terms *interface* and *port*.

04 CCNA Exam_Ch 04.fm.1 Page 181 Thursday, March 7, 2002 11:47 AM

Table 4-10 *Catalyst 1912 and 1924 Interface/Port Numbering*

	Catalyst 1912	Catalyst 1924
10BaseT ports	12 total (e0/1 to e0/12)	24 total (e0/1 to e0/24)
AUI port	e0/25	e0/25
100BaseT uplink ports	fa0/26 (port A)	fa0/26 (port A)
	fa0/27 (port B)	fa0/27 (port B)

Example 4-1 **show run** *Output Refers to Port e0/1 as Interface Ethernet 0/1*

```
wg_sw_d#show running-config

Building configuration...
Current configuration:
!
!
interface Ethernet 0/1
!
interface Ethernet 0/2
! Portions omitted for brevity...

wg_sw_d#show spantree

Port Ethernet 0/1 of VLAN1 is Forwarding
   Port path cost 100, Port priority 128
   Designated root has priority 32768, address 0090.8673.3340
   Designated bridge has priority 32768, address 0090.8673.3340
   Designated port is Ethernet 0/1, path cost 0
   Timers: message age 20, forward delay 15, hold 1
! Portions omitted for brevity...
wg_sw_a#show vlan-membership

Port  VLAN    Membership Type     Port  VLAN    Membership Type
-------------------------------------------------------------------
1        5          Static         13       1           Static
2        1          Static         14       1           Static
3        1          Static         15       1           Static
```

Basic IP and Port Duplex Configuration

Two features commonly configured during switch installation are TCP/IP support and the setting of duplex on key switch ports. Switches support IP, but in a different way than a router. The switch acts more like a normal IP host, with a single address/mask for the switch and a default router. Each port/interface does not need an IP address because the switch is not performing Layer 3 routing. In fact, if there were no need to manage the switch, IP would not be needed on the switch at all.

04 CCNA Exam_Ch 04.fm.1 Page 182 Thursday, March 7, 2002 11:47 AM

The second feature typically configured at installation time is to preconfigure some ports to always use half- or full-duplex operation rather than allow negotiation. At times, autonegotiation can produce unpredictable results. For example, if a device attached to the switch does not support autonegotiation, the Catalyst switch sets the corresponding switch port to half-duplex mode by default. If the attached device is configured for full-duplex operation, a duplex mismatch occurs. To avoid this situation, manually set the duplex parameters of the switch to match the attached device.

Similar to the router IOS, the Catalyst 1900 switch has various configuration modes. Example 4-2 shows the initial configuration of IP and duplex, with the actual prompts showing the familiar exec and configuration modes.

Example 4-2 *Configuration Modes for Configuring IP and Duplex*

```
wg_sw_a# configure terminal
wg_sw_a(config)#ip address 10.5.5.11 255.255.255.0
wg_sw_a(config)#ip default-gateway 10.5.5.3
wg_sw_a(config)# interface e0/1
wg_sw_a(config-if)#duplex  half
wg_sw_a(config-if)#end
wg_sw_a
```

In the example, the duplex could have been set to one of the following modes:

- **auto**—Sets autonegotiation of duplex mode. This is the default option for 100-Mbps TX ports.
- **full**—Sets full-duplex mode.
- **full-flow-control**—Sets full-duplex mode with flow control.
- **half**—Sets half-duplex mode. This is the default option for 10-Mbps TX ports.

To verify the IP configuration and duplex settings on a given interface, use the **show ip** and **show interface** commands, as shown in Example 4-3.

Example 4-3 **show ip** *and* **show interfaces** *Output*

```
wg_sw_a#show ip
IP address: 10.5.5.11
Subnet mask: 255.255.255.0
Default gateway: 10.5.5.3
Management VLAN:  1
Domain name:
Name server 1: 0.0.0.0
Name server 2: 0.0.0.0
HTTP server: Enabled
HTTP port:  80
RIP: Enabled

wg_sw_a#show interfaces
```

04 CCNA Exam_Ch 04.fm.1 Page 183 Thursday, March 7, 2002 11:47 AM

Example 4-3 show ip *and* **show interfaces** *Output (Continued)*

```
Ethernet 0/1 is Enabled
Hardware is Built-in 10Base-T
Address is 0090.8673.3341
MTU 1500 bytes, BW 10000 Kbits
802.1d STP State:  Forwarding     Forward Transitions:  1
Port monitoring: Disabled
Unknown unicast flooding: Enabled
Unregistered multicast flooding:  Enabled
Description:
Duplex setting: Half duplex
Back pressure: Disabled

    Receive Statistics                      Transmit Statistics
-------------------------------------   -------------------------------------
Total good frames               44841   Total frames                   404502
Total octets                  4944550   Total octets                 29591574
Broadcast/multicast frames      31011   Broadcast/multicast frames     390913
Broadcast/multicast octets    3865029   Broadcast/multicast octets   28478154
Good frames forwarded           44832   Deferrals                           0
Frames filtered                     9   Single collisions                   0
Runt frames                         0   Multiple collisions                 0
No buffer discards                  0   Excessive collisions                0
                                        Queue full discards                 0
Errors:                                 Errors:
  FCS errors                        0     Late collisions                   0
  Alignment errors                  0     Excessive deferrals               0
  Giant frames                      0     Jabber errors                     0
  Address violations                0     Other transmit errors             0
```

No IP address is in the **show interface** output because the IP address is associated with the entire switch, not just a single interface. The spanning-tree state of the interface is shown, as is the duplex setting. If duplex was mismatched with the device on the other end, the late collisions counter most likely would increment rapidly.

Viewing and Configuring Entries in the MAC Address Table

The switching/bridging table concept discussed earlier in this chapter is called the *MAC address table* on the 1900 family of switches. The MAC address table contains dynamic entries, which are learned when the switch receives frames and examines the source MAC address. Two other variations of entries in the MAC address table are important to switch configuration and are outlined along with dynamic entries in the following list:

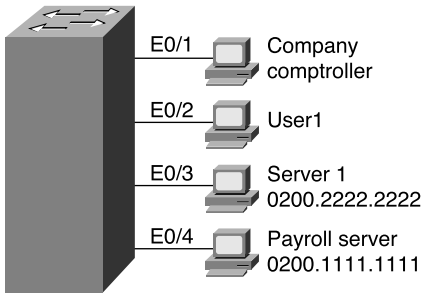
- **Dynamic addresses**—MAC addresses are added to the MAC address table through normal bridge/switch processing. In other words, when a frame is received, the source MAC of the frame is associated with the incoming port/interface. These entries in the table time out with disuse (default 300 seconds on a 1900 series switch) and are cleared whenever the entire table is cleared.

04 CCNA Exam_Ch 04.fm.1 Page 184 Thursday, March 7, 2002 11:47 AM

- **Permanent MAC addresses**—Through configuration, a MAC address is associated with a port, just as it would have been associated as a dynamic address. However, permanent entries in the table never time out.
- **Restricted-static entries**—Through configuration, a MAC address is configured to be associated only with a particular port, with an additional restriction: Frames destined to that MAC address must have entered through a particular set of incoming ports.

Figure 4-15 provides a simple example to show the use of permanent and restricted-static addresses. A popular server (Server 1) is on port E0/3, and there is never a case when its MAC address should not be in the table. The payroll server is also on this switch, and only the company comptroller is allowed access. The configuration and resulting MAC address table are shown in Example 4-4, which follows the figure.

Figure 4-15 *MAC Address Table Manipulation—Sample Network*



Example 4-4 *The MAC Address Table, with Dynamic, Permanent, and Restricted Static Entries*

```
wg_sw_a(config)#mac-address-table permanent 0200.2222.2222 ethernet 0/3
wg_sw_a(config)#mac-address-table restricted static 0200.1111.1111 e0/4 e0/1
wg_sw_a(config)#End
wg_sw_a#
wg_sw_a#show mac-address-table
Number of permanent addresses : 1
Number of restricted static addresses : 1
Number of dynamic addresses : 5

Address           Dest Interface     Type         Source Interface List
-------------------------------------------------------------------------
0200.4444.4444    Ethernet 0/1       Dynamic      All
00E0.1E5D.AE2F    Ethernet 0/2       Dynamic      All
0200.2222.2222    Ethernet 0/3       Permanent    All
0200.1111.1111    Ethernet 0/4       Static       Et0/1
00D0.588F.B604    FastEthernet 0/26  Dynamic      All
00E0.1E5D.AE2B    FastEthernet 0/26  Dynamic      All
00D0.5892.38C4    FastEthernet 0/27  Dynamic      All
```

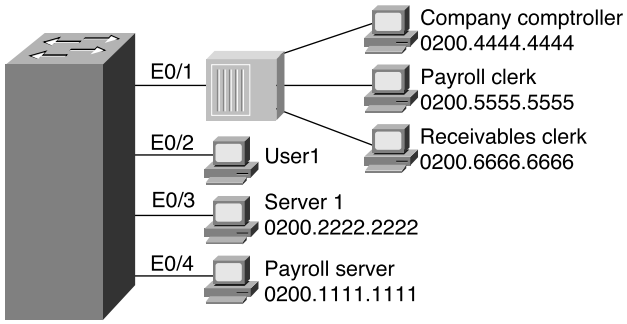
04 CCNA Exam_Ch 04.fm.1 Page 185 Thursday, March 7, 2002 11:47 AM

In the example, Server 1 is always in the address table as the permanent entry. The payroll server is always in the table off port 0/4, and only devices on port 0/1 are allowed to send frames to it.

Another feature affecting the MAC address table is called *port security*. Port security is a feature that, when enabled, limits the number of MAC addresses associated with a port in the MAC address table. In other words, there is a preset limit to the number of sources that can forward frames into that switch port.

An example is particularly useful for understanding this concept; the configuration is straightforward. Consider Figure 4-16, which shows a similar configuration to Figure 4-15, except that the finance department has increased to three employees. These three employees are on the same shared hub, which then is cabled to switch port 0/1.

Figure 4-16 *Sample Network with Port Security*



Port security can be used to restrict port 0/1 so that only three MAC addresses can source frames that enter port 0/1; this is because only the finance department is expected to use the shared hub. Any permanent or restricted-static MAC addresses count against this total of three. Example 4-5 shows a sample configuration, with **show** commands.

Example 4-5 *Port Security Example*

```
wg_sw_a(config)#mac-address-table permanent 0200.2222.2222 ethernet 0/3
wg_sw_a(config)#mac-address-table permanent 0200.4444.4444 ethernet 0/1
wg_sw_a(config)#mac-address-table restricted static 0200.1111.1111 e0/4 e0/1
wg_sw_a(config)#interface ethernet 0/1
wg_sw_a(config-if)#port secure max-mac-count 3
wg_sw_a(config-if)#End
wg_sw_a#
wg_sw_a#show mac-address-table
Number of permanent addresses : 2
Number of restricted static addresses : 1
Number of dynamic addresses : 6
```

continues

04 CCNA Exam_Ch 04.fm.1 Page 186 Thursday, March 7, 2002 11:47 AM

Example 4-5 *Port Security Example (Continued)*

```
Address           Dest Interface     Type         Source Interface List
-------------------------------------------------------------------
0200.4444.4444    Ethernet 0/1       Permanent    All
0200.5555.5555    Ethernet 0/1       Dynamic      All
0200.6666.6666    Ethernet 0/1       Dynamic      All
00E0.1E5D.AE2F    Ethernet 0/2       Dynamic      All
0200.2222.2222    Ethernet 0/3       Permanent    All
0200.1111.1111    Ethernet 0/4       Static       Et0/1
00D0.588F.B604    FastEthernet 0/26  Dynamic      All
00E0.1E5D.AE2B    FastEthernet 0/26  Dynamic      All
00D0.5892.38C4    FastEthernet 0/27  Dynamic      All
wg_sw_a#show mac-address-table security
Action upon address violation : Suspend

Interface         Addressing Security       Address Table Size
-------------------------------------------------------------
Ethernet 0/1       Enabled                    3
Ethernet 0/2       Disabled                   N/A
Ethernet 0/3       Disabled                   N/A
Ethernet 0/4       Disabled                   N/A
Ethernet 0/5       Disabled                   N/A
Ethernet 0/6       Disabled                   N/A
Ethernet 0/7       Disabled                   N/A
Ethernet 0/8       Disabled                   N/A
Ethernet 0/9       Disabled                   N/A
Ethernet 0/10      Disabled                   N/A
Ethernet 0/11      Disabled                   N/A
Ethernet 0/12      Disabled                   N/A
```

In this example, the permanently defined MAC address of 0200.4444.444, the comptroller's MAC address, is always associated with port e0/1. Notice that the two new employees' MAC addresses are also in the MAC address table. The **port secure max-mac-count 3** command means that a total of three addresses can be learned on this port.

What should the switch do when a fourth MAC address sources a frame that enters E0/1? An address violation occurs when a secured port receives a frame from a new source address that, if added to the MAC table, would cause the switch to exceed its address table size limit for that port. When a port security address violation occurs, the options for action to be taken on a port include suspending, ignoring, or disabling the port. When a port is suspended, it is re-enabled when a frame containing a valid address is received. When a port is disabled, it must be manually re-enabled. If the action is ignored, the switch ignores the security violation and keeps the port enabled.

Use the **address-violation** global configuration command to specify the action for a port address violation. The syntax for this command is as follows:

```
address-violation {suspend | disable | ignore}
```

Use the **no address-violation** command to set the switch to its default value, which is **suspend**.

04 CCNA Exam_Ch 04.fm.1 Page 187 Thursday, March 7, 2002 11:47 AM

Managing Configuration and System Files

Commands that are used to manage and control the configuration and system software files are slightly different on the 1900 switch family than on IOS-based routers. One of the reasons for the difference is that the switch does not actually run IOS—it has many features similar to IOS, including the IOS CLI, but there are and probably always will be some differences. For example, in Example 4-6, the familiar **show version** command is used to display uptime and software levels, but it does not show the IOS level because IOS is not running.

Example 4-6 **show version** *Output Displays Switch Hardware and Cisco IOS Software Information*

```
wg_sw_a#show version
Cisco Catalyst 1900/2820 Enterprise Edition Software
Version V9.00.00(12) written from 171.071.114.222
Copyright  Cisco Systems, Inc.  1993-1999
DS2820-1 uptime is 2day(s) 19hour(s) 34minute(s) 41second(s)
cisco Catalyst 2820 (486sxl) processor with 2048K/1024K bytes of memory
Hardware board revision is 1
Upgrade Status: No upgrade currently in progress.
Config File Status: No configuration upload/download is in progress
25 Fixed Ethernet/IEEE 802.3 interface(s)
SLOT A:
 FDDI (Fiber DAS Model), Version 00
  v1.14 written from 172.031.004.151: valid
SLOT B:
 100Base-TX(1 Port UTP Model), Version 0
Base Ethernet Address: 00-E0-1E-87-21-40
```

Another difference is that when the configuration is changed, the running config is modified but the startup config file in NVRAM is automatically updated. In other words, there is no need for a **copy running-config startup-config** command on the 1900 family of switches, as there would be on a router. Configuration files can be copied to an external TFTP server, but instead of using the keyword **startup-config** (used by routers), **NVRAM** is used.

The syntax of the **copy** command is slightly different than what was covered in Chapter 2, "Cisco IOS Software Fundamentals," relating to the router IOS **copy** command. The syntax of the command used to copy the NVRAM configuration file to host 10.1.1.1 into file mybackup.cfg is **copy nvram tftp://10.1.1.1/mybackup.cfg**. Unlike the router IOS, the switch IOS CLI will not prompt for the server name or IP address or the name of the file. Instead, the address or server host name and the filename are entered at the command line. The fact that the command does not prompt you is certainly different than with the router IOS. However, the same general syntax is available on the router IOS as of Cisco IOS Software release 12.0. For example, a similar, valid router IOS command would be **copy startup-config tftp://10.1.1.1/myrouter.cfg**.

Table 4-11 summarizes some of the key differences between the router IOS CLI and the 1900 IOS CLI.

04 CCNA Exam_Ch 04.fm.1 Page 188 Thursday, March 7, 2002 11:47 AM

Table 4-11 *IOS CLI Differences: Router Versus 1900 Switch*

Function	Router Command, Features	Switch Command, Features
Finding software version	**show version** command; shows IOS version.	**show version** command; shows switch software version.
Copying configuration files to TFTP server	**copy startup-config tftp** command; router IOS prompts for TFTP parameters.	**copy nvram tftp://server/file** command; switch IOS CLI does not prompt for TFTP parameters. "Server" can be IP address or host name.
Updating the config file used at reload time	**copy running-config startup-config** command.	Changes made to running configuration using config mode automatically are reflected in NVRAM config file.
Erasing the config file used at reload time	**write erase** or **erase startup-config** command.	**delete nvram** command.

04 CCNA Exam_Ch 04.fm.1 Page 189 Thursday, March 7, 2002 11:47 AM

Foundation Summary

The "Foundation Summary" is a collection of tables and figures that provide a convenient review of many key concepts in this chapter. For those of you already comfortable with the topics in this chapter, this summary could help you recall a few details. For those of you who just read this chapter, this review should help solidify some key facts. For any of you doing your final prep before the exam, these tables and figures will be a convenient way to review the day before the exam.

Table 4-12 summarizes the basic features of Ethernet.

Table 4-12 *Summary of Some Basic Ethernet Features*

10Base2, 10Base5	Single bus cabled serially between devices using coaxial cable.
10BaseT with a hub	One electrical bus shared among all devices creating a single collision domain cabled in a star topology, using twisted-pair cabling.
10BaseT with a switch	One electrical bus per switch port, creating multiple collision domains, cabled in a star topology using twisted-pair cabling.
Half duplex	Logic that requires a card to only send or receive at a single point in time. Used to avoid collisions.
Full duplex	Logic that enables concurrent sending and receiving, allowed when one device is attached to a switch port, ensuring that no collisions can occur.

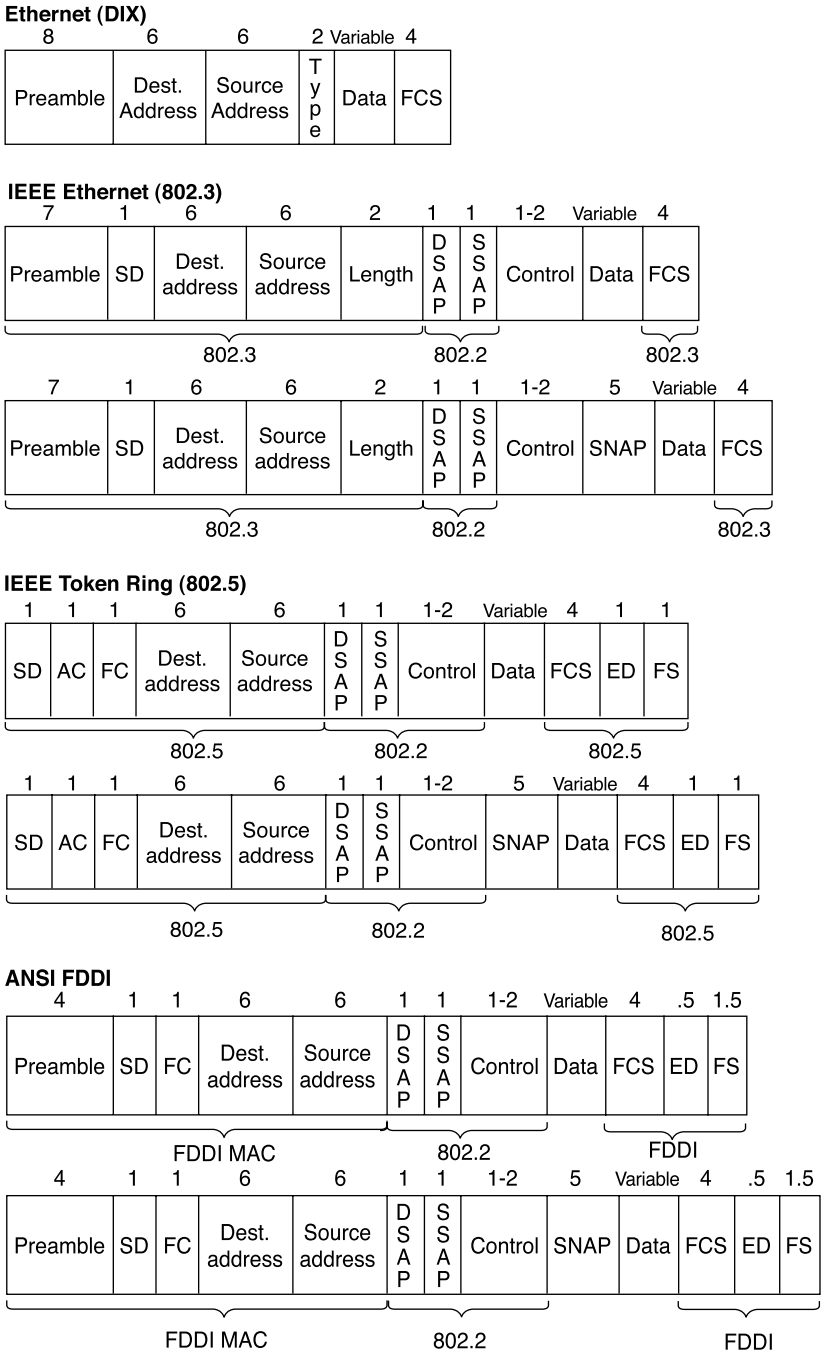
The following list summarizes many of the key features of MAC addresses:

- Unicast MAC addresses address an individual LAN interface card.
- Broadcast MAC addresses address all devices on a LAN.
- Multicast MAC addresses address a subset of the devices on an Ethernet or FDDI LAN.
- Functional MAC addresses identify devices performing a specific IEEE-defined function on Token Ring only.

Figure 4-17 outlines the various LAN framing fields. Focus on the addressing fields, the location of the FCS, and the different "type" fields.

04 CCNA Exam_Ch 04.fm.1 Page 190 Thursday, March 7, 2002 11:47 AM

Figure 4-17 *LAN Header Formats*



04 CCNA Exam_Ch 04.fm.1 Page 191 Thursday, March 7, 2002 11:47 AM

Table 4-13 summarizes the fields used for identifying the types of data contained in a frame.

Table 4-13 *Protocol Type Fields in LAN Headers*

Field Name	Length	LAN Type	Comments
Ethernet Type	2 bytes	Ethernet	RFC 1700 ("Assigned Numbers" RFC) lists the values. Xerox owns the assignment process.
802.2 DSAP and SSAP	1 byte each	IEEE Ethernet, IEEE Token Ring, ANSI FDDI	The IEEE Registration Authority controls the assignment of valid values. The source SAP (SSAP) and destination SAP (DSAP) do not have to be equal, so 802.2 calls for the sender's protocol type (SSAP) and the destination's type (DSAP).
SNAP Protocol	2 bytes	IEEE Ethernet, IEEE Token Ring, ANSI FDDI	Uses Ethernet Type values and is used only when DSAP is hex AA. It is needed because the DSAP and SSAP fields are only 1 byte in length.

Table 4-14 lists the specification that defines the Media Access Control (MAC) and Logical Link Control (LLC) sublayers of the three LAN types, for comparison.

Table 4-14 *MAC and LLC Details for Three Types of LANs*

Name	MAC Sublayer Spec	LLC Sublayer Spec	Other Comments
Ethernet Version 2 (DIX Ethernet)	Ethernet	N/A	This spec is owned by Digital, Intel, and Xerox.
IEEE Ethernet	IEEE 802.3	IEEE 802.2	This is also popularly called 802.3 Ethernet. It is built upon details of DIX Ethernet.
IEEE Token Ring	IEEE 802.5	IEEE 802.2	IBM helped with development before the IEEE took over.
ANSI FDDI	ANSI X3T9.5	IEEE 802.2	ANSI liked 802.2, so it just refers to the IEEE spec.

Transparent bridges forward frames when necessary and do not forward when there is no need to do so, thus reducing overhead. To accomplish this, transparent bridges perform three actions:

- Learning MAC addresses by examining the source MAC address of each frame received by the bridge

04 CCNA Exam_Ch 04.fm.1 Page 192 Thursday, March 7, 2002 11:47 AM

- Deciding when to forward a frame or when to filter (not forward) a frame, based on the destination MAC address
- Creating a loop-free environment with other bridges by using the Spanning Tree Protocol

Figures 4-18 and 4-19 detail the concepts of a collision domain and a broadcast domain.

Figure 4-18 *Collision Domains*

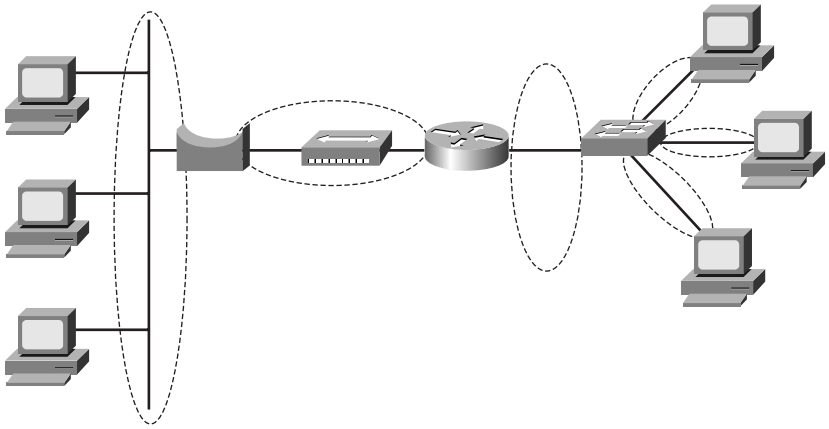
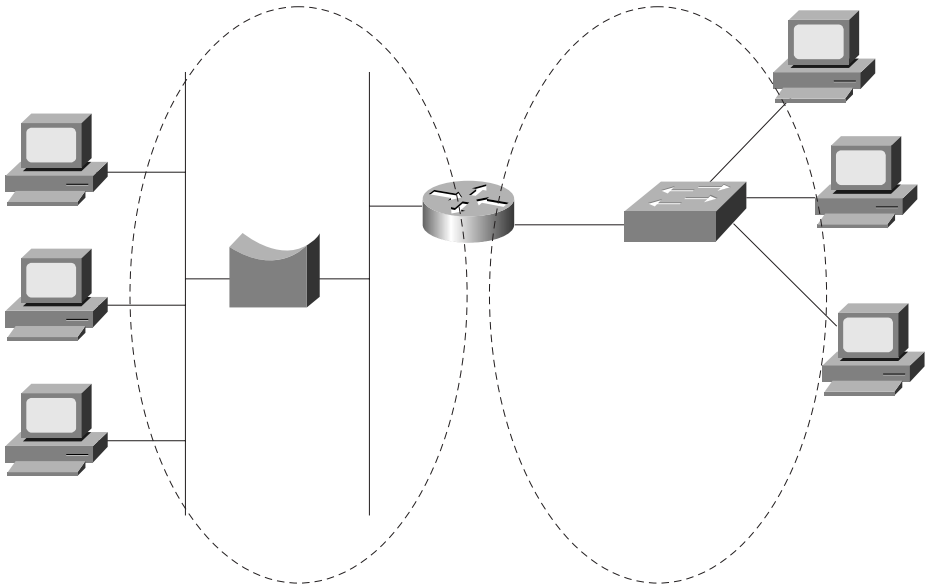


Figure 4-19 *Broadcast Domains*



04 CCNA Exam_Ch 04.fm.1 Page 193 Thursday, March 7, 2002 11:47 AM

General definitions for *collision domain* and *broadcast domain* are as follows:

A *collision domain* is a set of network interface cards (NICs) for which a frame sent by one NIC could result in a collision with a frame sent by any other NIC in the same collision domain.

A *broadcast domain* is a set of NICs for which a broadcast frame sent by one NIC will be received by all other NICs in the broadcast domain.

Table 4-15 lists the internal processing methods of LAN switches.

Table 4-15 *Switch Internal Processing*

Switching Method	Description
Store-and-forward	The switch fully receives all bits in the frame (store) before forwarding the frame (forward). This allows the switch to check the FCS before forwarding the frame. (FCS is in the Ethernet trailer.)
Cut-through	The switch performs the address table lookup as soon as the destination address field in the header is received. The first bits in the frame can be sent out the outbound port before the final bits in the incoming frame are received. This does not allow the switch to discard frames that fail the FCS check. (FCS is in the Ethernet trailer.)
FragmentFree	This performs like cut-through switching, but the switch waits for 64 bytes to be received before forwarding the first bytes of the outgoing frame. According to Ethernet specifications, collisions should be detected during the first 64 bytes of the frame; frames in error because of a collision will not be forwarded. The FCS still cannot be checked.

Table 4-16 lists several features relating to segmenting LANs with bridges, switches, and routers.

Table 4-16 *Comparison of Segmentation Options*

Feature	Single Segment	Bridging	Switching	Routing
Number of broadcast domains	1	1	1	1 per router interface
Number of collision domains	1	1 per bridge port	1 per switch port	1 per router interface
Forwards LAN broadcasts?	N/A	Yes	Yes	No
Forwards LAN multicasts?	N/A	Yes	Yes; can be optimized for less forwarding	No[1]
OSI layer used when making forwarding decision	N/A	Layer 2	Layer 2	Layer 3

continues

04 CCNA Exam_Ch 04.fm.1 Page 194 Thursday, March 7, 2002 11:47 AM

Table 4-16 *Comparison of Segmentation Options (Continued)*

Feature	Single Segment	Bridging	Switching	Routing
Internal processing variants	N/A	Store-and-forward	Store-and-forward, cut-through, FragmentFree	Store-and-forward
Frame/packet fragmentation allowed?	N/A	No	No	Yes
Multiple concurrent equal-cost paths to same destination allowed?	N/A	No	No	Yes

[1]Routers can forward IP multicast packets, if configured to do so. However, this does not mean that the LAN multicast frame is forwarded.

Table 4-17 lists features that must be interpreted within the following context: If I migrated from a single Ethernet segment to a network with two segments separated by a bridge/switch/router, and if traffic loads and destinations stayed constant, the result would be _____.

Table 4-17 *Benefits when Moving from One Ethernet Segment to Multiple Segments Using Bridges, Switches, and Routers*

Feature	Bridging	Switching	Routing
Greater cabling distances allowed	Yes	Yes	Yes
Decrease in collisions, assuming equal traffic loads	Yes	Yes	Yes
Decreased adverse impact of broadcasts	No	No	Yes
Decreased adverse impact of multicasts	No	No, unless mcast optimizations enabled	Yes
Increase in bandwidth	Yes	Yes	Yes
Filtering on Layer 2 header allowed	Yes	Yes	No
Filtering on Layer 3 header allowed	No	No	Yes

Table 4-18 lists the 1900 switch commands used to perform basic switch configuration.

04 CCNA Exam_Ch 04.fm.1 Page 195 Thursday, March 7, 2002 11:47 AM

Table 4-18 *Commands for Catalyst 1900 Switch Configuration*

Command	Description
ip address *address subnet-mask*	Sets the IP address for in-band management of the switch
ip default-gateway	Sets the default gateway so that the management interface can be reached from a remote network
show ip	Displays IP address configuration
show interfaces	Displays interface information
mac-address-table permanent *mac-address type module/port*	Sets a permanent MAC address
mac-address-table restricted static *mac-address type module/port src-if-list*	Sets a restricted static MAC address
port secure [**max-mac-count** *count*]	Sets port security
show mac-address-table {**security**}	Displays the MAC address table; the **security** option displays information about the restricted or static settings
address-violation {**suspend** | **disable** | **ignore**}	Sets the action to be taken by the switch if there is a security address violation
show version	Displays version information
copy tftp://*host/src_file* {**opcode** [*type module*] | **nvram**}	Copies a configuration file from the TFTP server into NVRAM
copy nvram tftp://*host/dst_file*	Saves a configuration file to the TFTP server
delete nvram [*type module*]	Removes all configuration parameters and returns the switch to factory default settings

Table 4-19 lists the port-numbering conventions for the 1912 and 1924 series switches.

04 CCNA Exam_Ch 04.fm.1 Page 196 Thursday, March 7, 2002 11:47 AM

Table 4-19 *Catalyst 1912 and 1924 Interface/Port Numbering*

	Catalyst 1912	Catalyst 1924
10BaseT ports	12 total (e0/1 to e0/12)	24 total (e0/1 to e0/24)
AUI port	e0/25	e0/25
100BaseT uplink ports	fa0/26 (port A)	fa0/26 (port A)
	fa0/27 (port B)	fa0/27 (port B)

Table 4-20 lists the key differences between the switch CLI and the router CLI.

Table 4-20 *IOS CLI Differences: Router Versus 1900 Switch*

Function	Router Command, Features	Switch Command, Features
Finding software version	**show version** command; shows IOS version	**show version** command; shows switch software version.
Copying configuration files to TFTP server	**copy startup-config tftp** command; router IOS prompts for TFTP parameters	**copy nvram tftp://server/file** command; switch IOS CLI does not prompt for TFTP parameters. "Server" can be IP address or host name.
Updating the config file used at reload time	**copy running-config startup-config** command	Changes made to running configuration using config mode automatically are reflected in NVRAM config file.
Erasing the config file used at reload time	**write erase** or **erase startup-config** command	**delete nvram** command.

04 CCNA Exam_Ch 04.fm.1 Page 197 Thursday, March 7, 2002 11:47 AM

Q&A

As mentioned in Chapter 1, "All About the Cisco Certified Network Associate Certification," the questions and scenarios in this book are more difficult than what you should experience on the actual exam. The questions do not attempt to cover more breadth or depth than the exam; however, they are designed to make sure that you know the answer. Rather than allowing you to derive the answer from clues hidden inside the question itself, the questions challenge your understanding and recall of the subject. Questions from the "Do I Know This Already?" quiz from the beginning of the chapter are repeated here to ensure that you have mastered the chapter's topic areas. Hopefully, these questions will help limit the number of exam questions on which you narrow your choices to two options and then guess.

The answers to these questions can be found in Appendix A.

1 What do the letters *MAC* stand for? What other terms have you heard to describe the same or similar concept?

_____

_____

_____

2 Name two benefits of LAN segmentation using transparent bridges.

_____

_____

_____

3 What routing protocol does a transparent bridge use to learn about Layer 3 addressing groupings?

_____

_____

_____

4 If a Fast Ethernet NIC is currently receiving a frame, can it begin sending a frame?

_____

_____

_____

04 CCNA Exam_Ch 04.fm.1 Page 198 Thursday, March 7, 2002 11:47 AM

5 Why did Ethernet networks' performance improve with the advent of bridges?

_____

_____

_____

6 Why did Ethernet networks' performance improve with the advent of switches?

_____

_____

_____

7 What are two key differences between a 10-Mbps NIC and a 10/100 NIC?

_____

_____

_____

8 Assume that a building has 100 devices attached to the same Ethernet. These users then are migrated onto two separate shared Ethernet segments, each with 50 devices, with a transparent bridge between them. List two benefits that would be derived for a typical user.

_____

_____

_____

9 What standards body owns the process of ensuring unique MAC addresses worldwide?

_____

_____

_____

10 Assume that a building has 100 devices attached to the same Ethernet. These devices are migrated to two different shared Ethernet segments, each with 50 devices. The two segments are connected to a Cisco LAN switch to allow communication between the two sets of users. List two benefits that would be derived for a typical user.

_____

_____

_____

04 CCNA Exam_Ch 04.fm.1 Page 199 Thursday, March 7, 2002 11:47 AM

11 Name two of the methods of internal switching on typical switches today. Which provides less latency for an individual frame?

12 What is the distance limitation of a single cable for 10BaseT? 100BaseTX?

13 Describe how a transparent bridge decides whether it should forward a frame, and tell how it chooses the interface out which to forward the frame.

14 How fast is Fast Ethernet?

15 How does a transparent bridge build its address table?

16 How many bytes long is a MAC address?

04 CCNA Exam_Ch 04.fm.1 Page 200 Thursday, March 7, 2002 11:47 AM

17 Assume that a building has 100 devices attached to the same Ethernet. These users then are migrated onto two separate Ethernet segments, each with 50 devices and separated by a router. List two benefits that would be derived for a typical user.

_____

_____

_____

18 Does a bridge/switch examine just the incoming frame's source MAC, the destination MAC, or both? Why does it examine the one(s) that it examines?

_____

_____

_____

19 Define the term *collision domain.*

_____

_____

_____

20 Define the difference between broadcast and multicast MAC addresses.

_____

_____

_____

21 Excluding the preamble and starting delimiter fields, but including all other Ethernet headers and trailers, what is the maximum number of bytes in an Ethernet frame?

_____

_____

_____

22 Define the term *broadcast domain.*

_____

_____

_____

04 CCNA Exam_Ch 04.fm.1 Page 201 Thursday, March 7, 2002 11:47 AM

23 Describe the benefits of creating 3 VLANs of 25 ports each, versus a single VLAN of 75 ports, in each case using a single switch. Assume that all ports are switched ports (each port is a different collision domain).

24 Explain the function of the loopback and collision-detection features of an Ethernet NIC in relation to half-duplex and full-duplex operations.

25 How many IP addresses must be configured for network management on a Cisco Catalyst 1900 switch if eight ports are to be used and with three VLANs?

26 What command on a 1900 series switch would cause the switch to block frames destined to 0200.7777.7777 entering interface 0/5 from going out port 0/6?

27 What Catalyst 1900 switch command displays the version of IOS running in the switch?

28 What does the Catalyst 1900 switch command **address violation disable** do?

04 CCNA Exam_Ch 04.fm.1 Page 202 Thursday, March 7, 2002 11:47 AM

29 What command erases the startup config in a Catalyst 1900 switch?

_____

_____

_____

30 Configuration is added to the running configuration in RAM when commands are typed in Catalyst 1900 configuration mode. What causes these commands to be saved into NVRAM?

_____

_____

_____

31 How do exec and configuration commands refer to the two Fast Ethernet ports on a Catalyst 1912 switch?

_____

_____

_____

32 What Catalyst 1900 switch command displays the switching table?

_____

_____

_____

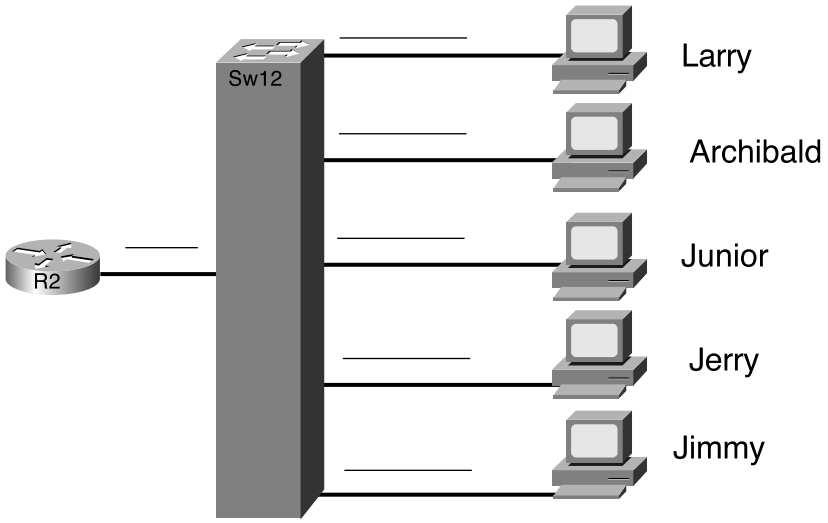
04 CCNA Exam_Ch 04.fm.1 Page 203 Thursday, March 7, 2002 11:47 AM

Scenarios

Scenario 4-1: LAN Switch Configuration

Your job is to deploy a new LAN switch at a remote site. Figure 4-20 depicts the network. Perform the activities in the list that follows the diagram.

Figure 4-20 *Scenario 4-1: Basic LAN Switch Configuration*



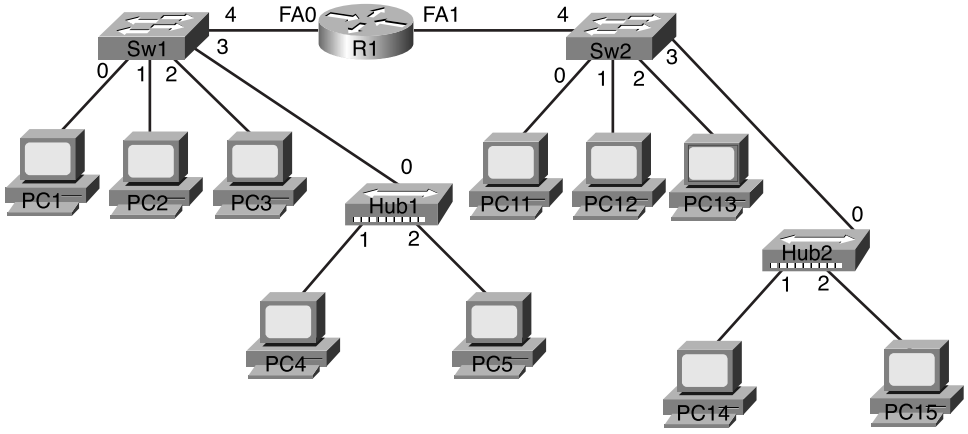
04 CCNA Exam_Ch 04.fm.1 Page 204 Thursday, March 7, 2002 11:47 AM

1. Clear the saved configuration before starting.
2. Assign IP address 172.16.2.254, mask 255.255.255.0, to SW12. Assign it an appropriate default gateway, and configure SW12 to use a DNS, which is at 172.16.1.250.
3. Assign a host name of SW12.
4. Choose port numbers to be used for each device, as if you were planning the physical installation. Write down these numbers on the diagram.
5. Configure so that the router uses 100-Mbps full-duplex operation.
6. Configure Archibald's MAC address so that it never leaves the address table.
7. Configure Junior so it gets frames only from Jimmy and Jerry.
8. List the commands that you would use to verify all of these features.
9. Identify the command that you would use to examine the running configuration, saved configuration, and IOS level.
10. Describe the contents of the address table after all devices have sent at least one frame.

Scenario 4-2: LAN Switch Concepts

In this scenario, you will answer some questions about a simple network diagram. Figure 4-21 depicts the network. Answer the questions that follow the diagram.

Figure 4-21 *Scenario 4-2: Basic LAN Switch Concepts*



04 CCNA Exam_Ch 04.fm.1 Page 205 Thursday, March 7, 2002 11:47 AM

1. How many collision domains exist in this network?
2. How many broadcast domains exist in this network?
3. Assuming that all cards, switches, and router interfaces are 10/100 cards, how many ports total on each switch could run full duplex?
4. Assuming that all cards, switches, and router interfaces are 10/100 cards, how many ports total on each switch could run 100 Mbps?
5. The first frames to flow in this network are the following: PC5 sends an IP ARP, encapsulated in an Ethernet frame, to its default gateway, which is R1's FA0 interface's IP address. The Ethernet frame containing the ARP reply is the second frame. Describe what ports each frame is sent out. Use Table 4-21 to list where the frame flowed, or is draw on the diagram. If you use the table, write "received" if the frame was received in that port, or write "sent" if the frame was sent out that port.

Table 4-21 *List of Hub/Switch/Router Ports for Figure 4-21*

Port	Was Frame 1 Either Received in or Sent out This Port?	Was Frame 2 Either Received in or Sent out This Port?
Hub1—port 0		
Hub1—port 1		
Hub1—port 2		
SW1—port 0		
SW1—port 1		
SW1—port 2		
SW1—port 3		
SW1—port 4		
Hub2—port 0		
Hub2—port 1		
Hub2—port 2		
SW2—port 0		
SW2—port 1		
SW2—port 2		
SW2—port 3		
SW2—port 4		
R1—FA0		
R1—FA1		

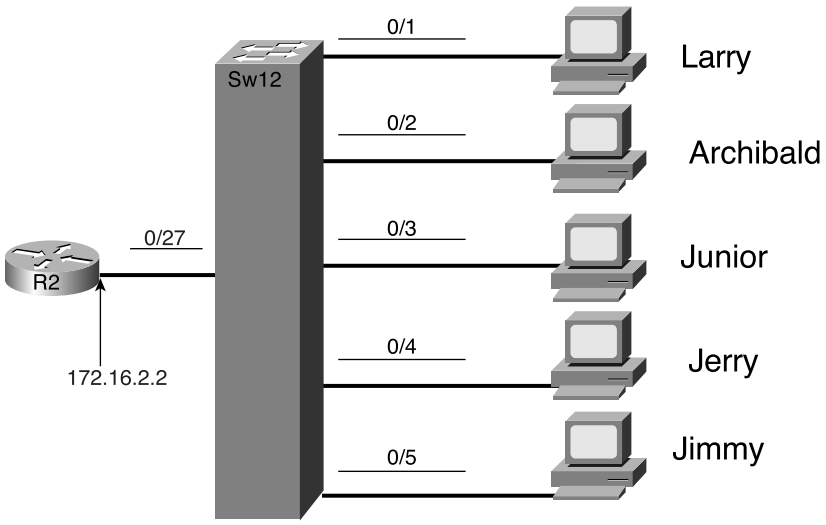
04 CCNA Exam_Ch 04.fm.1 Page 206 Thursday, March 7, 2002 11:47 AM

Scenario Answers

Answers to Scenario 4-1: LAN Switch Configuration

This scenario should have forced you to perform basic LAN configuration. Figure 4-22 lists the port numbers and MAC addresses used for the solution. Example 4-7 lists the output from actually performing these steps sequentially on a 1900 series switch. An explanation of the steps follows the example.

Figure 4-22 *MAC Address Format*



Example 4-7 *Scenario 4-1 Configuration and* **show** *Commands*

```
#delete nvram
This command resets the switch with factory defaults.  All system
parameters will revert to their default factory settings.  All static
and dynamic addresses will be removed.

Reset system with factory defaults, [Y]es or [N]o?  Yes

(some time passes…)
Catalyst 1900 Management Console
Copyright (c) Cisco Systems, Inc.  1993-1999
All rights reserved.
Enterprise Edition Software
Ethernet Address:      00-10-29-DE-7B-C0

PCA Number:            73-2241-04
PCA Serial Number:     SAD02030649
```

04 CCNA Exam_Ch 04.fm.1 Page 207 Thursday, March 7, 2002 11:47 AM

Example 4-7 *Scenario 4-1 Configuration and* **show** *Commands (Continued)*

```
Model Number:          WS-C1924C-EN
System Serial Number:  FAA0208T0BH
-------------------------------------------------

1 user(s) now active on Management Console.

        User Interface Menu

     [M] Menus
     [K] Command Line
     [I] IP Configuration
     [P] Console Password

Enter Selection:  K


      CLI session with the switch is open.
      To end the CLI session, enter [Exit].

>enable

#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z
(config)#ip address 172.16.2.254 255.255.255.0
(config)#ip default-gateway 172.16.2.2
(config)#hostname SW12
SW12(config)#interface fastethernet 0/27
SW12(config-if)#duplex ?
  auto               Enable auto duplex configuration
  full               Force full duplex operation
  full-flow-control  Force full duplex with flow control
  half               Force half duplex operation
SW12(config-if)#duplex full
SW12(config-if)#interface e 0/1
SW12(config-if)#duplex auto
Error: Invalid configuration for this interface
SW12(config)#mac-address-table permanent 0000.0c3E.5183 e 0/2
SW12(config)#mac-address-table restricted static 0100.3333.3333 e0/3 e0/4 e0/5
12(config)#exit
SW12#show mac-address-table
Number of permanent addresses : 1
Number of restricted static addresses : 1
Number of dynamic addresses : 2

Address           Dest Interface    Type         Source Interface List
-------------------------------------------------------------------------
0000.0C3E.5183    Ethernet 0/2      Permanent    All
0100.3333.3333    Ethernet 0/3      Static       Et0/4,Et0/5
0000.0C4A.8BCA    Ethernet 0/1      Dynamic      All
0004.5A0A.EBBE    Ethernet 0/6      Dynamic      All
SW12#show version
Cisco Catalyst 1900/2820 Enterprise Edition Software
Version V9.00.04
```

continues

04 CCNA Exam_Ch 04.fm.1 Page 208 Thursday, March 7, 2002 11:47 AM

Example 4-7 *Scenario 4-1 Configuration and* **show** *Commands (Continued)*

```
Copyright (c) Cisco Systems, Inc.  1993-1999
SW12 uptime is 0day(s) 00hour(s) 05minute(s) 45second(s)
cisco Catalyst 1900 (486sxl) processor with 2048K/1024K bytes of memory
Hardware board revision is 1
Upgrade Status: No upgrade currently in progress.
Config File Status: No configuration upload/download is in progress
27 Fixed Ethernet/IEEE 802.3 interface(s)
Base Ethernet Address: 00-10-29-DE-7B-C0

SW12#show running-config
Building configuration...
Current configuration:
!
mac-address-table permanent 0000.0C3E.5183 Ethernet 0/2
mac-address-table restricted static 0100.3333.3333 Ethernet 0/3 Ethernet 0/4
Ethernet 0/5
!
hostname "SW12"
!
ip address 172.16.2.254 255.255.255.0
ip default-gateway 172.16.2.2
ip domain-name  "atl.mediaone.net"
ip name-server 24.88.1.66
ip name-server 24.88.1.67
!
interface Ethernet 0/1

!
interface Ethernet 0/2

!
interface Ethernet 0/3
!
interface Ethernet 0/4
!
interface Ethernet 0/5
!
interface Ethernet 0/6
!
interface Ethernet 0/7
!
interface Ethernet 0/8
!
interface Ethernet 0/9
!
interface Ethernet 0/10
!
interface Ethernet 0/11
!
interface Ethernet 0/12
!
```

04 CCNA Exam_Ch 04.fm.1 Page 209 Thursday, March 7, 2002 11:47 AM

Example 4-7 *Scenario 4-1 Configuration and* **show** *Commands (Continued)*

```
interface Ethernet 0/13
!
interface Ethernet 0/14
!
interface Ethernet 0/15
!
interface Ethernet 0/16
!
interface Ethernet 0/17
!
interface Ethernet 0/18
!
interface Ethernet 0/19
!
interface Ethernet 0/20
!
interface Ethernet 0/21
!
interface Ethernet 0/22
!
interface Ethernet 0/23
!
interface Ethernet 0/24
!
interface Ethernet 0/25
!
interface FastEthernet 0/26
!
interface FastEthernet 0/27
  duplex full
!
line console
end
SW12#show startup
           ^
% Invalid input detected at '^' marker.
SW12#show config
            ^
% Invalid input detected at '^' marker.
SW12#
```

Example 4-7 begins with the startup config being deleted using the **delete nvram** configuration. Because only one configuration file exists, the command also clears the running config. As shown in the example, some time passes (about 10 seconds) and then the console is presented with the usual option for the menu system or the command line. In this case, the command line is chosen. The **delete nvram** command does clear the MAC table and put everything in VLAN 1 (the default), so it interrupts typical switch operation. The global commands for setting the IP address, default gateway, and host name are straightforward.

04 CCNA Exam_Ch 04.fm.1 Page 210 Thursday, March 7, 2002 11:47 AM

You need to know some information about 1900 switch architecture to get the configuration completely correct. For example, the 1900 has only 10-Mbps or 100-Mbps ports, but no autosensing 10/100 ports. Also, full-duplex operation is supported only on 100-Mbps ports. So, the only ports that can do any negotiation are the two uplink ports, namely 0/26 and 0/27. (To prove the point, in Example 4-7, the **duplex auto** command failed on interface E 0/1.) In this case, 0/27 is used to connect to R2, and it is set to full-duplex mode.

The static entry in the MAC table and the restricted port pose the most challenging part of the configuration. Although the entry is indeed static, the term used for Cisco IOS switches for statically configured entries in the MAC table is *permanent*. So, the **mac-address-table permanent 0000.0c3E.5183 e 0/2** command permanently places the MAC address in the MAC table, off port e 0/2. The command that restricts traffic to Junior so that only Jimmy and Jerry can reach him is **mac-address-table restricted static 0100.3333.3333 e0/3 e0/4 e0/5.** The **show mac-address-table** command lists the results of these two commands—one permanent entry and one MAC address with restrictions so that it is accessible only from ports 0/4 and 0/5.

Finally, you view the configuration file with the **show running-config** command. Because there is only one config file, there is no need for a **show startup-config** command or a **show config** command. Notice that both commands are rejected at the end of Example 4-7.

Answers to Scenario 4-2: LAN Switch Concepts

This scenario tests your recollection of a few of the core concepts for LAN switching. The answers are listed in succession:

1. Ten collision domains exist in the network for this scenario. Routers and switches separate LANs into separate collision domains, but shared hubs do not. In this diagram, each switch port and the device(s) connected to it form the individual collision domains.
2. Two broadcast domains exist in this network. Switches and hubs do not separate the LAN segments into different broadcast domains, but routers do. The two broadcast domains consist of the devices to the left of R1 and the devices to the right of R1.
3. Eight total switch ports could run full-duplex operation. Port 3 on each switch could not because there is a shared hub attached to this port, so collisions could happen. When collisions could happen, FDX is not allowed.
4. All ten switch ports could run 100 Mbps Fast Ethernet. Router FastEthernet interfaces support 100 Mbps, and the assumption was made that all the PCs support 100 Mbps. Shared hubs also can support 100 Mbps. So, all switch ports could run at 100 Mbps, but port 3 on each switch could not use full-duplex operation.
5. Figures 4-23 and 4-24 depict the flows of frame 1 and frame 2. Frame 1 has a source of PC5 and a broadcast destination. Frame 2 has a source of R1's FA0 MAC address and a destination of PC5's MAC address. Table 4-22 also describes the ports that the frames came in and out on their journeys, respectively.

04 CCNA Exam_Ch 04.fm.1 Page 211 Thursday, March 7, 2002 11:47 AM

Figure 4-23 *Scenario 4-2: Path of First Frame in Question Number 5*

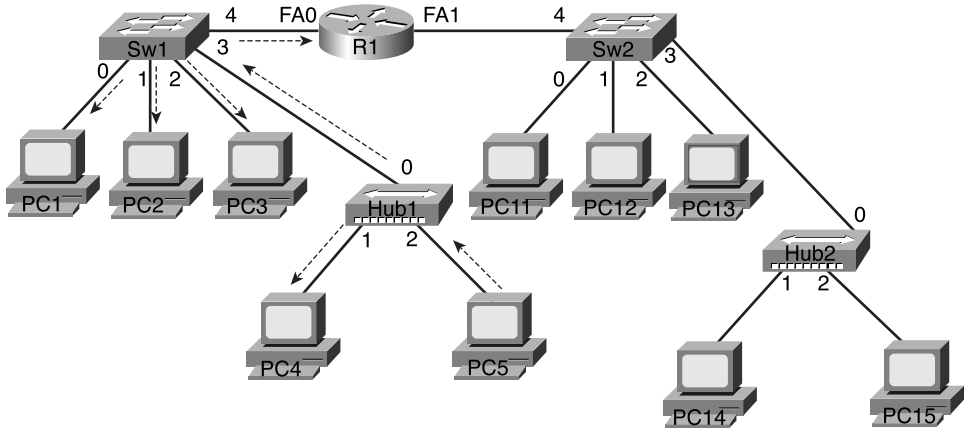


Figure 4-24 *Scenario 4-2: Path of Second Frame in Question Number 5*

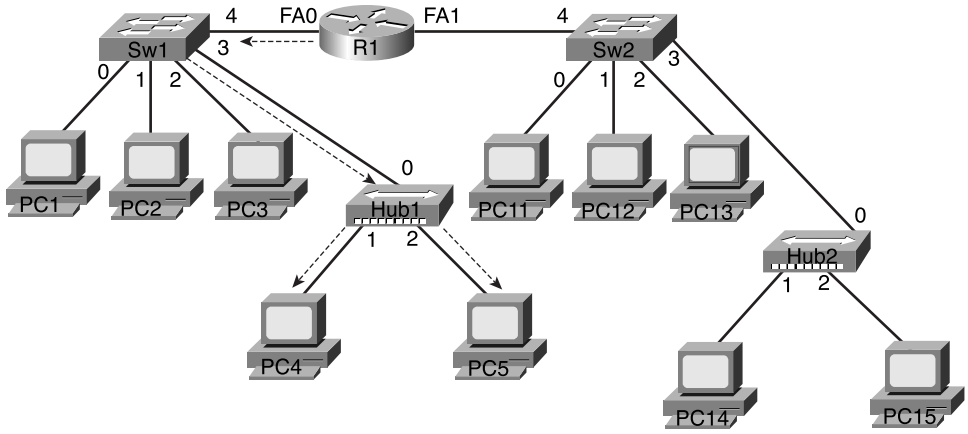


Table 4-22 *Table of Incoming and Outgoing Ports for Frames in Scenario 4-2, Question 5*

Port	Was Frame 1 Either Received in or Sent out This Port?	Was Frame 2 Either Received in or Sent out This Port?
Hub1—port 0	Sent	Received
Hub1—port 1	Sent	Sent
Hub1—port 2	Received	Sent
SW1—port 0	Sent	

continues

04 CCNA Exam_Ch 04.fm.1 Page 212 Thursday, March 7, 2002 11:47 AM

Table 4-22 *Table of Incoming and Outgoing Ports for Frames in Scenario 4-2, Question 5 (Continued)*

Port	Was Frame 1 Either Received in or Sent out This Port?	Was Frame 2 Either Received in or Sent out This Port?
SW1—port 1	Sent	
SW1—port 2	Sent	
SW1—port 3	Received	Sent
SW1—port 4	Sent	Received
Hub2—port 0		
Hub2—port 1		
Hub2—port 2		
SW2—port 0		
SW2—port 1		
SW2—port 2		
SW2—port 3		
SW2—port 4		
R1—FA0	Received	Sent
R1—FA1		

Frame 1 is a broadcast, so it must flow throughout the broadcast domain. So, Hub1 and Switch1 forward out all ports. R1, however, is the boundary of the broadcast domain, so R1 does not forward the broadcast. R1 replies to the ARP and encapsulates it in an Ethernet frame. This second frame has a destination of PC5's MAC address. SW1 learned that PC5's MAC is out its port 3. The hub did not learn anything because it does not keep an address table. So, R1 sends the second frame to PC5. SW1 forwards only out port 3, according to its address table. The hub still forwards out all ports.

04 CCNA Exam_Ch 04.fm.1 Page 213 Thursday, March 7, 2002 11:47 AM