CCNA Routing and Switching

Portable Command Guide

Third Edition

All the CCNA Routing and Switching commands in one compact, portable resource

Scott Empson

ciscopress.com

Steps to Configuring a Router

1. Create an IP plan as per your diagram.
    a. Subnetting
    b. VLSM
2. Cable your equipment as per your diagram.
3. Establish a basic router configuration.
    a. Host names
    b. Passwords:
        i. Secret
        ii. Console
        iii. Terminal—vty
        iv. Auxiliary
    c. Turn off DNS so spelling mistakes will not slow you down
    d. Banners: login or MOTD
4. Configure your interfaces.
    a. Addresses and masks: IPv4/IPv6
    b. Clock rates (for serial DCE interfaces)
    c. Descriptions
5. Create IP host name tables for remote access.
6. Configure IPv4 routing.
    a. Static
    b. Default
    c. Dynamic—Pick the routing protocol that best suits your needs:
        i. OSPF
        ii. EIGRP
7. Configure IPv6 routing.
    a. Static
    b. Default
    c. Dynamic—Pick the routing protocol that best suits your needs:
        i. OSPF
        ii. EIGRP
8. Configure access control lists (ACL):
    a. Standard
    b. Extended
    c. Named
9. Change the WAN encapsulation type.
    a. PPP (authentication: CHAP)
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10. Apply advanced IP configuration topics.
    a. NAT/PAT
    b. DHCP
11. Save your configuration.
    a. Locally
    b. Remote

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last page of the book.

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Third Edition

Scott Empson

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Scott Empson is the chair of the Bachelor of Applied Information Systems Technology degree program at the Northern Alberta Institute of Technology in Edmonton, Alberta, Canada, where he teaches Cisco routing, switching, network design, and leadership courses in a variety of different programs (certificate, diploma, and applied degree) at the postsecondary level. Scott is also the program coordinator of the Cisco Networking Academy Program at NAIT, an Area Support Centre for the province of Alberta. He has a Masters of Education degree along with three undergraduate degrees: a Bachelor of Arts, with a major in English; a Bachelor of Education, again with a major in English/Language Arts; and a Bachelor of Applied Information Systems Technology, with a major in Network Management. He currently holds several industry certifications, including CCNP, CCDP, CCAI, C|EH and Network+. Before instructing at NAIT, he was a junior/senior high school English/language arts/computer science teacher at different schools throughout Northern Alberta. Scott lives in Edmonton, Alberta, with his wife, Trina, and two children, Zachariah and Shaelyn.

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Dedications

As always, this book is dedicated to Trina, Zach, and Shae.

Acknowledgments

Anyone who has ever had anything to do with the publishing industry knows that it takes many, many people to create a book. It may be my name on the cover, but there is no way that I can take credit for all that occurred to get this book from idea to publication. Therefore, I must thank:

The team at Cisco Press. Once again, you amaze me with your professionalism and the ability to make me look good. Mary Beth, Chris, Mandie: Thank you for your continued support and belief in my little engineering journal.

To my technical reviewer, Elan: Thanks for keeping me on track and making sure that what I wrote was correct and relevant.

Contents at a Glance

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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:

- **Boldface** indicates commands and keywords that are entered literally, as shown. In actual configuration examples and output (not general command syntax), boldface indicates commands that are manually input by the user (such as a show command).
- *Italics* indicate arguments for which you supply actual values.
- 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.

Introduction

Welcome to CCNA Routing and Switching! This book is the result of a massive redesign by Cisco of their entry-level certification exams to more closely align with industry's need for networking talent as we enter into the era of "the Internet of Everything." The success of the previous two editions of this book prompted Cisco Press to approach me with a request to update the book with the necessary new content to help both students and IT professionals in the field study and prepare for the new CCNA Routing and Switching exam. For someone who originally thought that this book would be less than 100 pages in length and limited to the Cisco Networking Academy program for its complete audience, I am continually amazed that my little engineering journal has caught on with such a wide range of people throughout the IT community.

I have long been a fan of what I call the "engineering journal," a small notebook that can be carried around and that contains little nuggets of information—commands that you forget, the IP addressing scheme of some remote part of the network, little reminders about how to do something you only have to do once or twice a year (but is vital to the integrity and maintenance of your network). This journal has been a constant companion by my side for the past 15 years; I only teach some of these concepts every second or third year, so I constantly need to refresh commands and concepts and learn new commands and ideas as they are released by Cisco. My journals are the best way for me to review because they are written in my own words (words that I can understand). At least, I had better understand them, because if I can't, I have only myself to blame.

My first published engineering journal was the *CCNA Quick Command Guide*; it was organized to match to the (then) order of the Cisco Networking Academy program. That book then morphed into the *Portable Command Guide*, the third edition of which you are reading right now. This book is my "industry" edition of the engineering journal. It contains a different logical flow to the topics, one more suited to someone working in the field. Like topics are grouped together: routing protocols, switches, troubleshooting. More-complex examples are given. New topics have been added, such as OSPFv3 and EIGRPv6 for IPv6, multi-area OSPF, PPPoE, GRE tunnels, and Cisco IOS Version 15. The popular "Create Your Own Journal" appendix is still here (blank pages for you to add in your own commands that you need in your specific job). We all recognize the fact that no network administrator's job can be so easily pigeonholed as to just working with CCNA topics; you all have your own specific jobs and duties assigned to you. That is why you will find those blank pages at the end of the book. Make this book your own; personalize it with what you need to make it more effective. That way your journal will not look like mine.

Networking Devices Used in the Preparation of This Book

To verify the commands in this book, I had to try them out on a few different devices. The following is a list of the equipment I used when writing this book:

- C2821 ISR with PVDM2, CMME, a WIC-2T, FXS and FXO VICs, running 12.4(10a) IPBase IOS
- WS-C2960-24TT-L Catalyst switch, running 12.2(25)SE IOS
- WS-C2950-12 Catalyst switch, running Version C2950-C3.0(5.3)WC(1) Enterprise Edition software
- C1941 ISRG2 router with WIC 2T and HWIC-4ESW, running Version 15.1(1)T Cisco IOS with a technology package of IPBaseK9

Those of you familiar with Cisco devices will recognize that a majority of these commands work across the entire range of the Cisco product line. These commands are not limited to the platforms and Cisco IOS Software versions listed. In fact, these devices are in most cases adequate for someone to continue his or her studies into the CCNP level, too.

Private Addressing Used in this Book

This book makes use of RFC 1918 addressing throughout. Because I do not have permission to use public addresses in my examples, I have done everything with private addressing. Private addressing is perfect for use in a lab environment or in a testing situation because it works exactly like public addressing, with the exception that it cannot be routed across a public network. That is why you will see private addresses in my WAN links between two routers using serial connections or in my Frame Relay cloud.

Who Should Read This Book

This book is for those people preparing for the CCNA Routing and Switching exam, whether through self-study, on-the-job training and practice, or through study within the Cisco Networking Academy program. There are also some handy hints and tips along the way to make life a bit easier for you in this endeavor. It is small enough that you will find it easy to carry around with you. Big, heavy textbooks might look impressive on your bookshelf in your office, but can you really carry them all around with you when you are working in some server room or equipment closet somewhere?

Optional Sections

A few sections in this book have been marked as optional. These sections cover topics that are not on the CCNA Routing and Switching certification exam, but they are valuable topics that I believe should be known by someone at a CCNA level. Some of the optional topics might also be concepts that are covered in the Cisco Networking Academy program courses.

Organization of This Book

This book follows what I think is a logical approach to configuring a small to mid-size network. It is an approach that I give to my students when they invariably ask for some sort of outline to plan and then configure a network. Specifically, this approach is as follows:

Part I: TCP/IP v4

- **Chapter 1, "How to Subnet"**—An overview of how to subnet, examples of subnetting (both a Class B and a Class C address), the use of the binary AND operation, the Enhanced Bob Maneuver to Subnetting
- **Chapter 2, "VLSM"**—An overview of VLSM, an example of using VLSM to make your IP plan more efficient
- **Chapter 3, "Route Summarization"**—Using route summarization to make your routing updates more efficient, an example of how to summarize a network, necessary requirements for summarizing your network

Part II: Introduction to Cisco Devices

- **Chapter 4, "Cables and Connections"**—An overview of how to connect to Cisco devices, which cables to use for which interfaces, and the differences between the TIA/EIA 568A and 568B wiring standards for UTP
- **Chapter 5, "The Command-Line Interface"**—How to navigate through Cisco IOS Software: editing commands, keyboard shortcuts, and help commands

Part III: Configuring a Router

- **Chapter 6, "Configuring a Single Cisco Router"**—Commands needed to configure a single router: names, passwords, configuring interfaces, MOTD and login banners, IP host tables, saving and erasing your configurations

Part IV: Routing

- **Chapter 7, "Static Routing"**—Configuring static routes in your internetwork
- **Chapter 8, "EIGRP"**—Configuring and verifying EIGRP
- **Chapter 9, "Single Area OSPF"**—Configuring and verifying single-area OSPF
- **Chapter 10, "Multi-Area OSPF"**—Configuring and verifying multi-area OSPF

Part V: Switching

- **Chapter 11, "Configuring a Switch"**—Commands to configure Catalyst 2960 switches: names, passwords, IP addresses, default gateways, port speed and duplex; configuring static MAC addresses; managing the MAC address table; port security
- **Chapter 12, "VLANs"**—Configuring static VLANs, troubleshooting VLANs, saving and deleting VLAN information.
- **Chapter 13, "VLAN Trunking Protocol and Inter-VLAN Communication"**—Configuring a VLAN trunk link, configuring VTP, verifying VTP, inter-VLAN communication, router-on-a-stick, subinterfaces, and SVIs.

- **Chapter 14, "Spanning Tree Protocol and EtherChannel"**—Verifying STP, setting switch priorities, and creating and verifying EtherChannel groups between switches

Part VI: Layer 3 Redundancy

- **Chapter 15, "HSRP and GLBP"**— Configuring HSRP, interface tracking, setting priorities, configuring GLBP.

Part VII: IPv6

- **Chapter 16, "IPv6"**— Transitioning to IPv6; format of IPv6 addresses; configuring IPv6 (interfaces, tunneling, static routing)
- **Chapter 17, "OSPFv3"**— Configuring OSPF to work with IPv6,
- **Chapter 18, "EIGRP for IPv6"**— Configuring EIGRP to work with IPv6.

Part VIII: Network Administration and Troubleshooting

- **Chapter 19, "Backing Up and Restoring Cisco IOS Software and Configurations"**—Boot commands for Cisco IOS Software, backing up and restoring Cisco IOS Software using TFTP, Xmodem, and ROMmon environmental variables
- **Chapter 20, "Password-Recovery Procedures and the Configuration Register"**—The configuration register, password recovery procedure for routers and switches
- **Chapter 21, "Cisco Discovery Protocol (CDP)"**—Customizing and verifying CDP
- **Chapter 22, "Remote Connectivity Using Telnet or SSH"**—Commands used for Telnet and SSH to remotely connect to other devices
- **Chapter 23, "Verifying End-to-End Connectivity"**—Commands for both **ping** and extended **ping**; the **traceroute** command
- **Chapter 24, "Configuring Network Management Protocols"**—Configuring SNMP, working with syslog, Severity Levels, Configuring NetFlow
- **Chapter 25, "Basic Troubleshooting"**—Various **show** commands used to view the routing table; interpreting the **show** interface command; verifying your IP settings using different operating systems
- **Chapter 26, "Cisco IOS Licensing"**— Differences between licensing pre- and post-Cisco IOS Version 15, installing permanent and evaluation licenses, backing up and uninstalling licenses

Part IX: Managing IP Services

- **Chapter 27, "Network Address Translation"**—Configuring and verifying NAT and PAT
- **Chapter 28, "Dynamic Host Configuration Protocol (DHCP)"**—Configuring and verifying DHCP on a Cisco IOS router

Part X: WANs

- **Chapter 29, "Configuring Serial Encapsulation: HDLC and PPP"**—Configuring PPP, authentication of PPP using CHAP, compression in PPP; multilink in PPP, troubleshooting PPP, returning to HDLC encapsulation
- **Chapter 30, "Establishing WAN Connectivity Using Frame Relay"**—Configuring basic Frame Relay, Frame Relay and subinterfaces, DLCIs, verifying and troubleshooting Frame Relay
- **Chapter 31, "Configuring Generic Routing Encapsulation (GRE) Tunnels"**—Configuring and verifying GRE tunnels
- **Chapter 32, "Configuring Point-to-Point Protocol over Ethernet (PPPoE)"**—Configuring a DSL connection using PPPoE

Part XI: Network Security

- **Chapter 33, "Managing Traffic Using Access Control Lists (ACL)"**—Configuring standard ACLs, wildcard masking, creating extended ACLs, creating named ACLs, using sequence numbers in named ACLs, verifying and troubleshooting ACLs, ACLs and IPv6

Part XII: Appendixes

- **Appendix A, "Binary/Hex/Decimal Conversion Chart"**—A chart showing numbers 0 through 255 in the three numbering systems of binary, hexadecimal, and decimal
- **Appendix B, "Create Your Own Journal Here"**—Some blank pages for you to add in your own specific commands that might not be in this book

Did I Miss Anything?

I am always interested to hear how my students, and now readers of my books, do on both certification exams and future studies. If you would like to contact me and let me know how this book helped you in your certification goals, please do so. Did I miss anything? Let me know. Contact me at ccnaguide@empson.ca or through the Cisco Press website, http://www.ciscopress.com.

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CHAPTER 3

Route Summarization

Route summarization, or supernetting, is needed to reduce the number of routes that a router advertises to its neighbor. Remember that for every route you advertise, the size of your update grows. It has been said that if there were no route summarization, the Internet backbone would have collapsed from the sheer size of its own routing tables back in 1997!

Routing updates, whether done with a distance vector or link-state protocol, grow with the number of routes you need to advertise. In simple terms, a router that needs to advertise ten routes needs ten specific lines in its update packet. The more routes you have to advertise, the bigger the packet. The bigger the packet, the more bandwidth the update takes, reducing the bandwidth available to transfer data. But with route summarization, you can advertise many routes with only one line in an update packet. This reduces the size of the update, allowing you more bandwidth for data transfer.

Also, when a new data flow enters a router, the router must do a lookup in its routing table to determine which interface the traffic must be sent out. The larger the routing tables, the longer this takes, leading to more used router CPU cycles to perform the lookup. Therefore, a second reason for route summarization is that you want to minimize the amount of time and router CPU cycles that are used to route traffic.

NOTE This example is a very simplified explanation of how routers send updates to each other. For a more in-depth description, I highly recommend you go out and read Jeff Doyle's book *Routing TCP/IP*, Volume I, 2nd edition, Cisco Press. This book has been around for many years and is considered by most to be the authority on how the different routing protocols work. If you are considering continuing on in your certification path to try and achieve the CCIE, you need to buy Doyle's book—and memorize it; it's that good.

Example for Understanding Route Summarization

Refer to Figure 3-1 to assist you as you go through the following explanation of an example of route summarization.

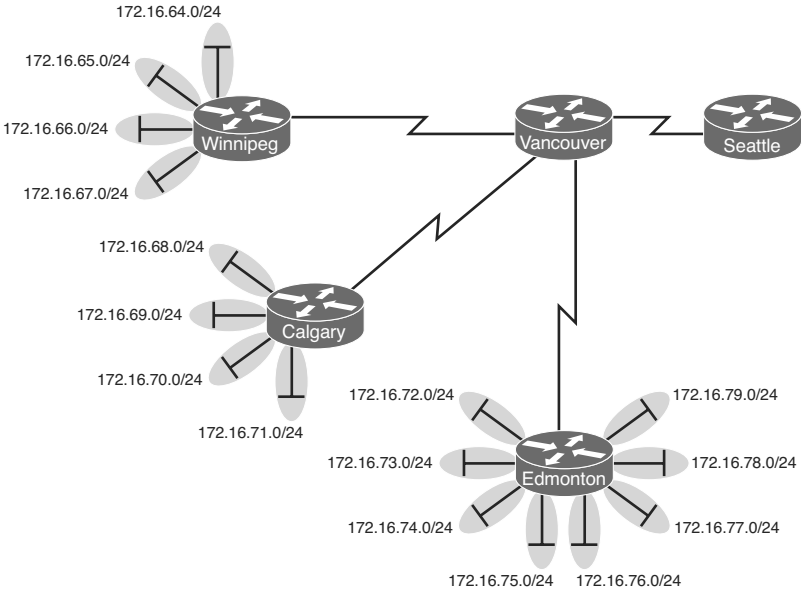


Figure 3-1 Four-City Network Without Route Summarization

As you can see from Figure 3-1, Winnipeg, Calgary, and Edmonton each have to advertise internal networks to the main router located in Vancouver. Without route summarization, Vancouver would have to advertise 16 networks to Seattle. You want to use route summarization to reduce the burden on this upstream router.

Step 1: Summarize Winnipeg's Routes

To do this, you need to look at the routes in binary to see if there are any specific bit patterns that you can use to your advantage. What you are looking for are common bits on the network side of the addresses. Because all of these networks are /24 networks, you want to see which of the first 24 bits are common to all four networks.

172.16.64.0 = *10101100.00010000.01000000*.00000000

172.16.65.0 = *10101100.00010000.01000001*.00000000

172.16.66.0 = *10101100.00010000.01000010*.00000000

172.16.67.0 = *10101100.00010000.01000011*.00000000

Common bits: *10101100.00010000.010000*xx

You see that the first 22 bits of the four networks are common. Therefore, you can summarize the four routes by using a subnet mask that reflects that the first 22 bits are common. This is a /22 mask, or 255.255.252.0. You are left with the summarized address of

172.16.64.0/22

This address, when sent to the upstream Vancouver router, will tell Vancouver: "If you have any packets that are addressed to networks that have the first 22 bits in the pattern of 10101100.00010000.010000xx.xxxxxxxx, then send them to me here in Winnipeg."

By sending one route to Vancouver with this supernetted subnet mask, you have advertised four routes in one line, instead of using four lines. Much more efficient!

Step 2: Summarize Calgary's Routes

For Calgary, you do the same thing that you did for Winnipeg—look for common bit patterns in the routes:

172.16.68.0 = *10101100.00010000.01000*100.00000000

172.16.69.0 = *10101100.00010000.01000*101.00000000

172.16.70.0 = *10101100.00010000.01000*110.00000000

172.16.71.0 = *10101100.00010000.01000*111.00000000

Common bits: *10101100.00010000.010001*xx

Once again, the first 22 bits are common. The summarized route is therefore

172.16.68.0/22

Step 3: Summarize Edmonton's Routes

For Edmonton, you do the same thing that we did for Winnipeg and Calgary—look for common bit patterns in the routes:

172.16.72.0 = *10101100.00010000.01001*000.00000000

172.16.73.0 = *10101100.00010000.01001*001.00000000

172.16.74.0 = *10101100.00010000 01001*010.00000000

172.16.75.0 = *10101100.00010000 01001*011.00000000

172.16.76.0 = *10101100.00010000.01001*100.00000000

172.16.77.0 = *10101100.00010000.01001*101.00000000

172.16.78.0 = *10101100.00010000.01001*110.00000000

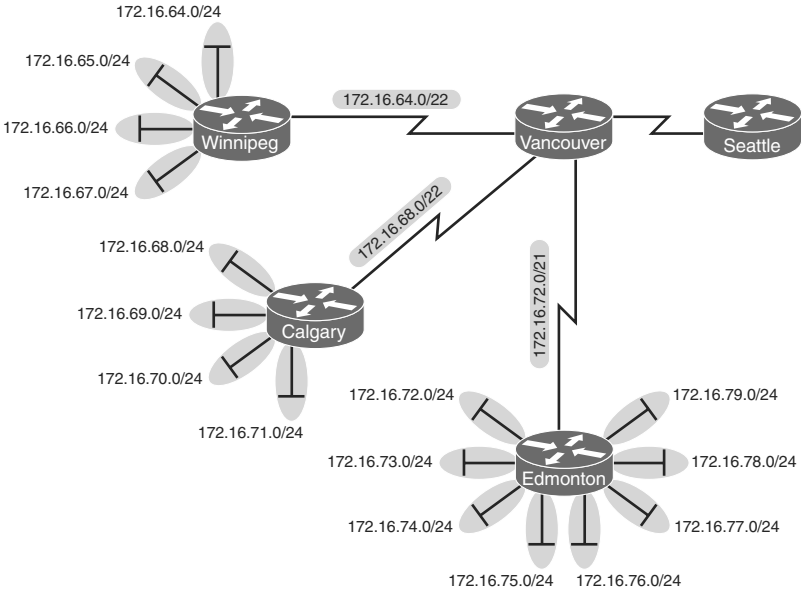
172.16.79.0 = *10101100.00010000.01001*111.00000000

Common bits: *10101100.00010000.01001*xxx

For Edmonton, the first 21 bits are common. The summarized route is therefore

172.16.72.0/21

Figure 3-2 shows what the network looks like, with Winnipeg, Calgary, and Edmonton sending their summarized routes to Vancouver.



/21	/22	/23	/24
172.16.64.0	172.16.64.0	172.16.64.0	172.16.64.0
			172.16.65.0
		172.16.66.0	172.16.66.0
			172.16.67.0
	172.16.68.0	172.16.68.0	172.16.68.0
			172.16.69.0
		172.16.70.0	172.16.70.0
			172.16.71.0
172.16.72.0	172.16.72.0	172.16.72.0	172.16.72.0
			172.16.73.0
		172.16.74.0	172.16.74.0
			172.16.75.0
	172.16.76.0	172.16.76.0	172.16.76.0
			172.16.77.0
		172.16.78.0	172.16.78.0
			172.16.79.0

Figure 3-2 Four-City Network with Edge Cities Summarizing Routes

Step 4: Summarize Vancouver's Routes

Yes, you can summarize Vancouver's routes to Seattle. You continue in the same format as before. Take the routes that Winnipeg, Calgary, and Edmonton sent to Vancouver, and look for common bit patterns:

172.16.64.0 = *10101100.00010000.0100*0000.00000000

172.16.68.0 = *10101100.00010000.0100*0100.00000000

172.16.72.0 = *10101100.00010000.0100*1000.00000000

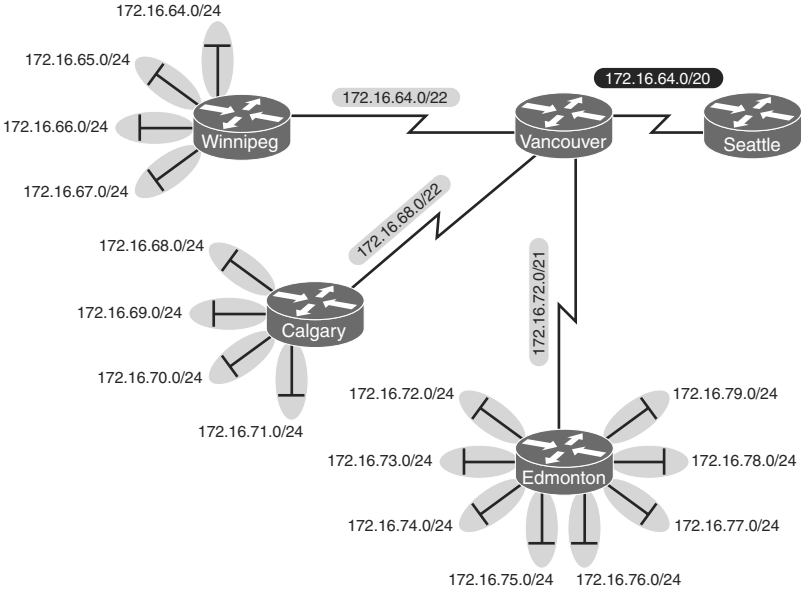
Common bits: *10101100.00010000.0100*xxxx

Because there are 20 bits that are common, you can create one summary route for Vancouver to send to Seattle:

172.16.64.0/20

Vancouver has now told Seattle that in one line of a routing update, 16 different networks are being advertised. This is much more efficient than sending 16 lines in a routing update to be processed.

Figure 3-3 shows what the routing updates would look like with route summarization taking place.



/20	/21	/22	/23	/24
172.16.64.0	172.16.64.0	172.16.64.0	172.16.64.0	172.16.64.0
				172.16.65.0
			172.16.66.0	172.16.66.0
				172.16.67.0
		172.16.68.0	172.16.68.0	172.16.68.0
				172.16.69.0
			172.16.70.0	172.16.70.0
				172.16.71.0
	172.16.72.0	172.16.72.0	172.16.72.0	172.16.72.0
				172.16.73.0
			172.16.74.0	172.16.74.0
				172.16.75.0
		172.16.76.0	172.16.76.0	172.16.76.0
				172.16.77.0
			172.16.78.0	172.16.78.0
				172.16.79.0

Figure 3-3 Four-City Network with Complete Route Summarization

Route Summarization and Route Flapping

Another positive aspect of route summarization has to do with route flapping. *Route flapping* is when a network, for whatever reason (such as interface hardware failure or misconfiguration), goes up and down on a router, causing that router to constantly advertise changes about that network. Route summarization can help insulate upstream neighbors from these problems.

Consider router Edmonton from Figure 3-1. Suppose that network 172.16.74.0/24 goes down. Without route summarization, Edmonton would advertise Vancouver to remove that network. Vancouver would forward that same message upstream to Calgary, Winnipeg, Seattle, and so on. Now assume the network comes back online a few seconds later. Edmonton would have to send another update informing Vancouver of the change. Each time a change needs to be advertised, the router must use CPU resources. If that route were to flap, the routers would constantly have to update their own tables, as well as advertise changes to their neighbors. In a CPU-intensive protocol such as OSPF, the constant hit on the CPU might make a noticeable change to the speed at which network traffic reaches its destination.

Route summarization enables you to avoid this problem. Even though Edmonton would still have to deal with the route constantly going up and down, no one else would notice. Edmonton advertises a single summarized route, 172.16.72.0/21, to Vancouver. Even though one of the networks is going up and down, this does not invalidate the route to the other networks that were summarized. Edmonton will deal with its own route flap, but Vancouver will be unaware of the problem downstream in Edmonton. Summarization can effectively protect or insulate other routers from route flaps.

Requirements for Route Summarization

To create route summarization, there are some necessary requirements:

- Routers need to be running a classless routing protocol, as they carry subnet mask information with them in routing updates. (Examples are RIP v2, OSPF, EIGRP, IS-IS, and BGP.)
- Addresses need to be assigned in a hierarchical fashion for the summarized address to have the same high-order bits. It does no good if Winnipeg has network 172.16.64.0 and 172.16.67.0 while 172.16.65.0 resides in Calgary and 172.16.66.0 is assigned in Edmonton. No summarization could take place from the edge routers to Vancouver.

TIP Because most networks use NAT and the ten networks internally, it is important when creating your network design that you assign network subnets in a way that they can be easily summarized. A little more planning now can save you a lot of grief later.