This chapter discusses the following advanced IP addressing topics:

- IP Address Planning
- Hierarchical Addressing Using Variable-Length Subnet Masks
- Route Summarization
- Classless Interdomain Routing
- Network Address Translation
- Understanding IP Version 6

CHAPTER 1

# Advanced IP Addressing

Scalable, well-behaved networks are not accidental; they are the result of good network design and effective implementation planning. A key element for effective scalable network implementation is a well-conceived and scalable IP addressing plan. The purpose of a scalable IP addressing plan is to maximize the amount of IP address space available in deployed networks (this address space is shrinking) and to minimize the size of routing tables.

As a network grows, the number of subnets and the volume of network addresses required increase proportionally. Without advanced IP addressing techniques such as summarization and classless interdomain routing (CIDR), the size of the routing tables increases, which causes a variety of problems. For example, networks require more CPU resources to respond to each topology change in the larger routing tables. In addition, larger routing tables can cause delays while the CPU sorts and searches for a match to a destination address. Both of these problems are solved by summarization and CIDR.

To effectively use summarization and CIDR to control the size of routing tables, network administrators employ other advanced IP addressing techniques such as Network Address Translation (NAT) and variable-length subnet masking (VLSM).

NAT allows the use of a private addressing space within an organization while using globally unique addresses for routing across the Internet and between independent divisions of the organization. Different address pools may be used to track groups of users, which makes it easier to manage interconnectivity.

VLSM allows the network administrator to subnet a previously subnetted address to make the best use of the available address space.

Another long-standing problem that network administrators must overcome is the exhaustion of available IP addresses caused by the increase in Internet use. Although the current solution is to use NAT, the long-term solution is to migrate from the IP version 4 (IPv4) 32-bit address space to the IP version 6 (IPv6) 128-bit address space. Gaining insight into IPv6 functionality and deployment will prove valuable for network administrators in the not-too-distant future.

After completing this chapter, you will be able to describe the concepts of network design and explain the benefits and characteristics of an effective scalable IP addressing plan. You will also be able to describe the role of VLSM addressing in a scalable network and calculate VLSM addresses for a network. You will be able to demonstrate the principles of route summarization and CIDR by summarizing a given range of network addresses into larger IP address blocks. You will also be able to configure NAT for multiple address pools using access lists and route maps. Finally, you will be able to describe the features and benefits of using IPv6.

# IP Address Planning

A well-designed large-scale internetwork with an effective IP addressing plan has many benefits. It is scalable, flexible, predictable, and can reduce the routing table size through summarization.

## Scalable Network Design

An understanding of scalable network design concepts is imperative for understanding proper IP address planning.

Corporate organizational structure should affect network design. The structure of a scalable network design reflects a corporation's information flow and is called a *hierarchical network design* .

There are two types of hierarchical network design: functional and geographic.

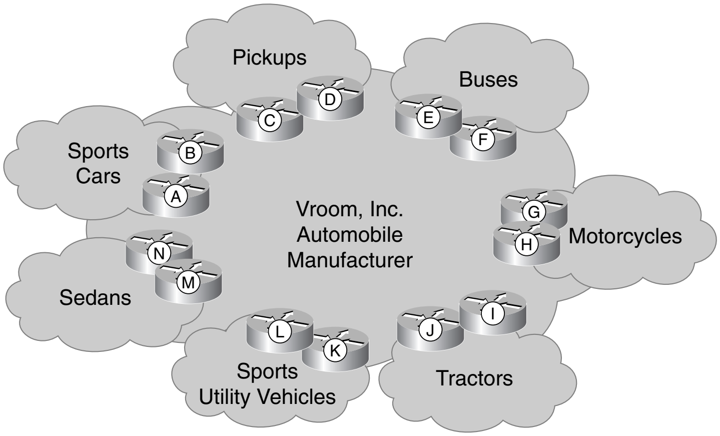
**NOTE** The design concepts discussed in this section are only a very small part of good network design from the perspective of the IP addressing plan. For a full discussion of internetwork design, refer to *CCDA Self-Study: Designing for Cisco Internetwork Solutions (DESGN)* (Cisco Press, 2003).

### Functional Structured Design

Some corporations have independent divisions that are responsible for their own operations, including networking. These divisions interact with one another and share resources; however, each division has an independent chain of command.

This type of corporate structure is reflected in a functional network design, as illustrated in Figure 1-1. In this example, the different divisions of the corporation have their own networks and are connected according to their functional purpose within the corporate structure. The network architecture can follow the corporate organizational chart.

**Figure 1-1** *In a Functional Design, Networks Are Connected According to Their Functional Purpose*

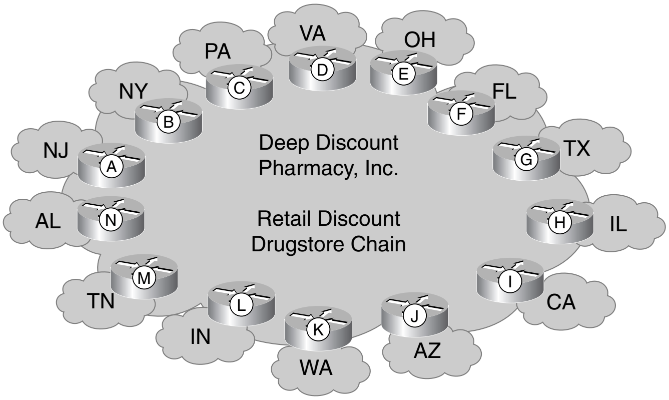


## Geographic Structured Design

Many retail corporations are organized by the geographic location of their stores. Within the corporate structure, each local retail store reports to a district consolidation point. These district consolidation points report to regional consolidation points; the regional consolidation points then report to corporate headquarters. Networks are organized along geographic boundaries, such as countries, states, or provinces.

This type of corporate structure is reflected in a geographic network design, as illustrated in Figure 1-2. In this example, the divisions of the corporation have their own networks and are connected according to their location.

**Figure 1-2** *In a Geographic Design, Networks Are Connected According to Their Location*



**NOTE** From a networking point of view, a geographic network structure is cost-effective because fewer network links require long-haul carriers, often a considerable added expense.

## Hierarchical Layers

Within the functional or geographic networks, the following three primary layer elements are involved in a hierarchical scalable network design:

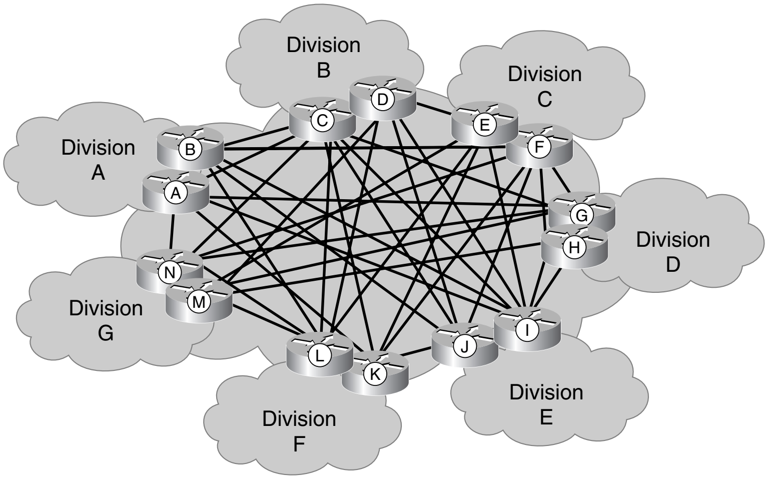
- **Access layer**—Provides local and remote workgroup, end-user, and customer access to the network. Virtual LANs (VLANs), firewalls, and access lists maintain security for this layer.
- **Distribution layer**—Provides policy-based connectivity and is the consolidation point for access layer devices and corporate services. Host services required by multiple access layer devices are assigned to this layer.
- **Core (or backbone) layer**—Provides high-speed transport to satisfy the connectivity and transport needs of the distribution layer devices. The circuits with the fastest bandwidth are in the core layer of the network. Redundancy occurs more frequently at this layer than at the other layers.

There are many different ways of designing these hierarchical layers. Some of the considerations are identified in this section.

### Fully Meshed Core Layer

The core layer is designed to provide quick and efficient access to headquarters and other divisions within a company. Because the core is usually critical to the network, redundancy is often found in this layer. In a fully meshed core layer design, shown in Figure 1-3, each division has redundant routers at the core layer. The core sites are fully meshed, meaning that all routers have direct connections to all other routers. This connectivity allows the network to react quickly when it must route data flow from a downed link to another path.

**Figure 1-3** *In a Fully Meshed Core, All Routers Are Connected to All Other Routers*



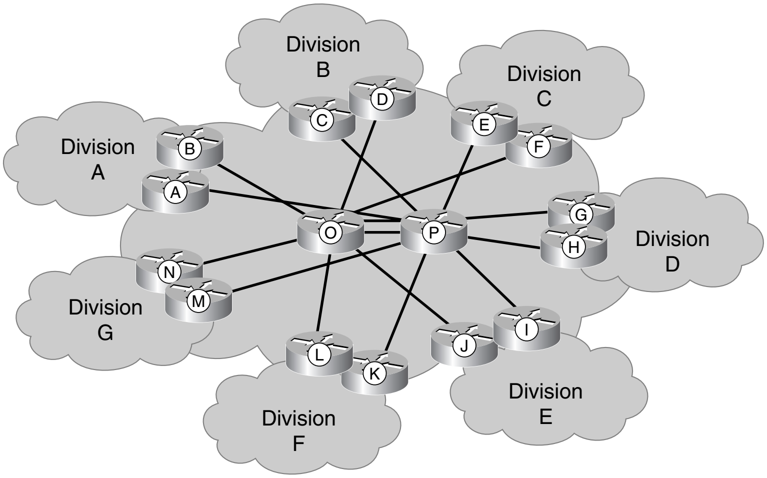
For a small core with a limited number of divisions, this core layer design provides robust connectivity. However, a fully meshed core layer design is very expensive for a corporation with many divisions.

**NOTE** The number of links in a full mesh is $n(n-1)/2$, where $n$ is the number of routers. As the number of routers increases, the cost of full-mesh connectivity might become prohibitive.

## Hub-and-Spoke Core Layer

As a network grows, fully meshing all the core routers can become difficult. At that point, consolidation into geographically separate data centers might be appropriate. For example, in many companies, data travels to a centralized headquarters where the corporate databases and network services reside. To reflect this corporate centralization, the core layer hub-and-spoke configuration establishes a focal point for the data flow at a key site. The hub-and-spoke design, illustrated in Figure 1-4, supports the traffic flow through the corporation.

**Figure 1-4** *In a Hub-and-Spoke Core, Each Division Is Connected Only to the Headquarters*

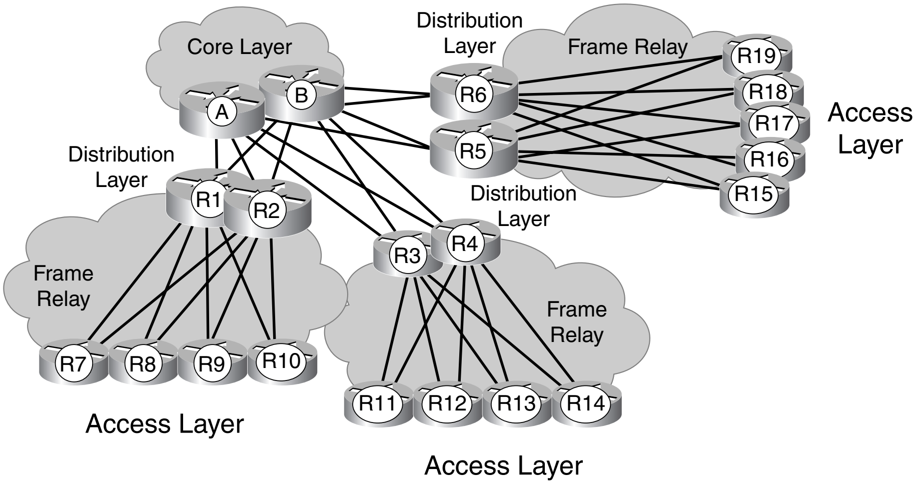


**NOTE** A partial-mesh design is also possible, including some nodes connected in a full mesh and some connected in hub-and-spoke fashion.

## Access and Distribution Layers

Remote sites are points of entry to the network for end users and customers. Within the network, remote sites gain access to network services through the access layer. The distribution layer consolidates the services and devices that the access layer needs to process the activity that is generated by the remote sites. Figure 1-5 illustrates this process.

**Figure 1-5** *The Distribution Layer Consolidates Access Layer Connectivity*



**NOTE** Frame Relay, shown in Figure 1-5, is a WAN access protocol commonly used to interconnect geographically dispersed sites.

Services should be placed in the distribution layer when there is no benefit to having duplicated services at the remote sites. These services may include Dynamic Host Configuration Protocol (DHCP), Domain Name System (DNS), human resources, and accounting servers. One or more distribution layers can connect to each entry point at the core layer.

You can fully mesh connectivity between remote sites at the access layer. However, using a hub-and-spoke configuration by connecting remote sites to at least two distribution layer devices provides redundancy and is relatively easy to administer.

## Benefits of a Good Network Design

An effective network design accommodates unexpected growth and quick changes in the corporate environment. The network design can be adapted to accommodate mergers with other companies, corporate restructuring, and downsizing with minimal impact on the portions of the network that do not change.

The following are characteristics of a good IP addressing plan implemented in a well-designed network:

- **Scalability**—A well-designed network allows for significant increases in the number of supported sites.

- **Predictability**—A well-designed network exhibits predictable behavior and performance.
- **Flexibility**—A well-designed network minimizes the impact of additions, changes, or removals within the network.

These characteristics are described further in the following sections.

## Scalability of a Good Network Design

Private addresses are reserved IPv4 addresses to be used only internally within a company's network. These private addresses are not to be used on the Internet, so they must be mapped to a company's external registered address when you send anything to a recipient on the Internet.

**Key Point: IPv4 Private Addresses**

RFC 1918, *Address Allocation for Private Internets* (available at www.cis.ohio-state.edu/cgi-bin/rfc/rfc1918.html), has set aside the following IPv4 address space for private use:

— **Class A network**—10.0.0.0 to 10.255.255.255

— **Class B network**—172.16.0.0 to 172.31.255.255

— **Class C network**—192.168.0.0 to 192.168.255.255

**NOTE** The examples in this book use only private addressing.

The current proliferation of corporate mergers emphasizes the design issues inherent in private IPv4 addressing. For example, if two companies merge, and both use network 10.0.0.0 addresses, there will likely be some overlapping addressing space.

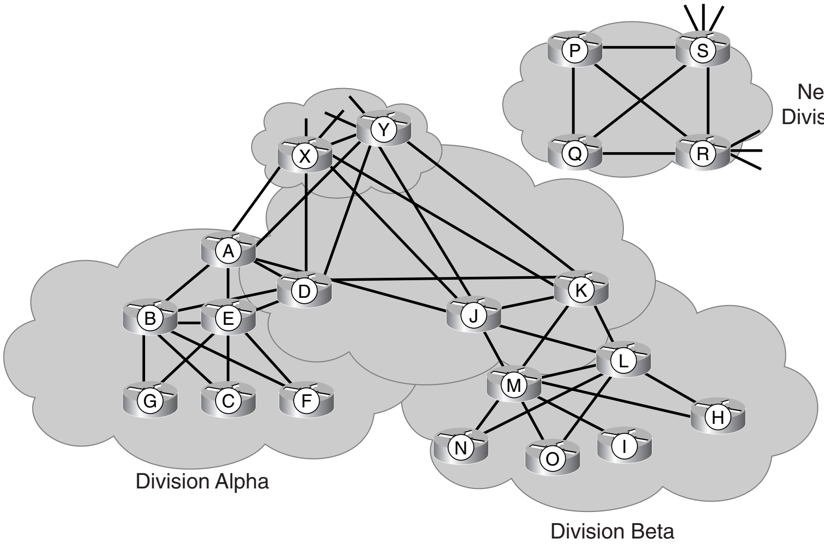
A scalable network that integrates private addressing with a good IP addressing plan minimizes the impact of additions or reorganizations of divisions to a network. A scalable network allows companies that merge to connect at the core layer. Implementing NAT on routers allows the network administrator to translate overlapping network numbers to an unused address space as a temporary solution. Then, the overlapping network numbers can be changed on the devices and/or on the DHCP server in the network.

Good network design also facilitates the process of adding routers to an existing network. For example, in Figure 1-6, two companies have merged. Both companies were using network 10.0.0.0 for addressing. One correct way to merge the two networks would be as follows:

- Attach routers P and Q in the new domain to the other routers in the core layer of the network (routers A, D, J, K, X, and Y).

- Configure NAT on routers P and Q to change the IP address space of the new company from network 10.0.0.0 to network 172.16.0.0.
- Change the DHCP servers to reflect the newly assigned address space in the new network.
- Remove NAT from routers P and Q.

**Figure 1-6** *A Good IP Addressing Design Minimizes the Impact of Merging Networks*



## Predictability of a Good Network Design

The behavior of a scalable network is predictable.

Packets load-balance across the internetwork if equal-cost paths exist between any two routers in the internetwork. When a circuit or router fails, an alternative equal-cost path to the destination that exists in every routing table can be used, without any recalculation. This alternative path reduces convergence times and route recalculation to typically less than 1 second after the failed circuit or router is discovered.

Depending on the routing protocol used, the equal cost is determined based on hop count and/or bandwidth. For example, if the Routing Information Protocol (RIP) is used in the network shown in Figure 1-6, the routing table for router C will have two best paths to X: three hops through B and three hops through E. Routers B and E each have two best paths to the networks behind router X: Both have two hops through either routers A or D. If router D fails, routers B and E do not need to discover alternative routes because the preferred route exists in the routing table. Thus, if router D fails, the routes to X in router C's routing table do not change.

If a routing protocol that uses bandwidth in its calculation is used (for example, Interior Gateway Routing Protocol [IGRP]), the bandwidth should be configured equally on all interfaces within a layer at each site. For example, in Figure 1-6, routers B and E are consolidation points for the access layer routers (G, C, and F in the example). Routers C, B, and E all have the same bandwidth configured on the links that connect them so that load balancing can be used.

The paths between routers B and E and routers A and D need larger-bandwidth pipes to consolidate the traffic between corporate divisions. Because routers A and D consolidate multiple distribution points for a division, the connections for these routers to other divisions in the company need the largest bandwidth.

The result is a predictable traffic pattern. This level of network behavior predictability is a direct benefit of a scalable network design.

### Flexibility of a Good Network Design

A scalable network also needs to be flexible. For example, corporate reorganizations can have minimal impact on the rest of the network when implemented in a scalable network. In the sample network shown in Figure 1-6, assume that Frame Relay is used at the remote sites and that Division Beta is sold and merged with another company, except for remote site H, which becomes part of Division Alpha.

The network administrator in this sample network could accommodate the corporate reorganization with the following process:

- Install two additional virtual circuits from router H to routers B and E.
- Following a successful installation, remove the virtual circuits to routers M and L.
- Perform NAT on the router H interfaces to routers B and E to use the address space of Division Alpha.
- Remove the circuits from routers J and K to the other core routers A, D, X, and Y (and P and Q if they are connected).
- Change the user addresses for router H to the Division Alpha block of addresses.

## Benefits of an Optimized IP Addressing Plan

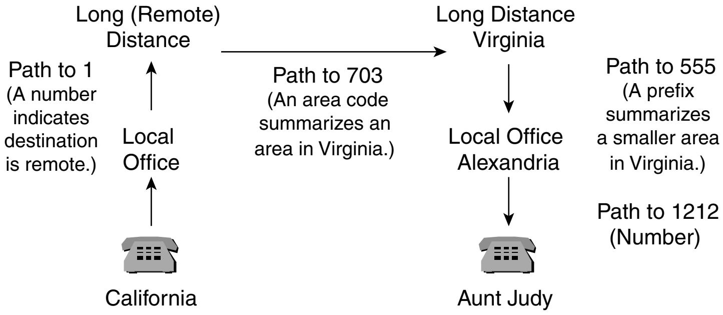
An optimized IP addressing plan uses hierarchical addressing.

Perhaps the best-known addressing hierarchy is the telephone network. The telephone network uses a hierarchical numbering scheme that includes country codes, area codes, and local exchange numbers. For example, if you are in San Jose, California, and you call someone else in San Jose, you dial the San Jose local exchange number, 528, and the person's four digit number. Upon seeing the number 528, the central office recognizes that the destination telephone is within its area, so it looks up the four digit number and transfers the call.

**NOTE** In many places in North America now, the area code must also be dialed for local calls. This is because of changes in the use of specific digits for area codes and local exchange numbers. The telephone network is suffering from *address exhaustion* , just like the IP network. Changes in how telephone numbers are used is one solution being implemented to solve this problem.

In another example (see Figure 1-7), to call Aunt Judy in Alexandria, Virginia, from San Jose, you dial 1, and then the area code 703, and then the Alexandria prefix 555, and then Aunt Judy's local number, 1212. The central office first sees the number 1, indicating a remote call, and then looks up the number 703. The central office immediately routes the call to a central office in Alexandria. The San Jose central office does not know exactly where 555-1212 is in Alexandria, nor does it have to. It needs to know only the area codes, which summarize the local telephone numbers within an area.

**Figure 1-7** *The Telephone Network Uses an Addressing Hierarchy*



**NOTE** As you might have noticed, the telephone number used in this example is the number for international directory assistance; it is used for illustration purposes to ensure that Aunt Judy's personal number is not published.

If there were no hierarchical structure, every central office would need to have every telephone number worldwide in its locator table. Instead, the central offices have summary numbers, such as area codes and country codes. A summary number (address) represents a group of numbers. For example, an area code such as 408 is a summary number for the San Jose area. In other words, if you dial 1-408 from anywhere in the U.S. or Canada, followed by a seven-digit telephone number, the central office routes the call to a San Jose central office. Similarly, a routed network can employ a hierarchical addressing scheme to take advantage of those same benefits.

Here are some of the benefits of hierarchical addressing:

- **Reduced number of routing table entries**—Whether it is with your Internet routers or your internal routers, you should try to keep your routing tables as small as possible by using route summarization. Route summarization is a way of having a single IP address represent a collection of IP addresses; this is most easily accomplished when you employ a hierarchical addressing plan. By summarizing routes, you can keep your routing table entries (on the routers that receive the summarized routes) manageable, which offers the following benefits:
  - More efficient routing
  - A reduced number of CPU cycles when recalculating a routing table or sorting through the routing table entries to find a match
  - Reduced router memory requirements
  - Reduced bandwidth required to send the fewer, smaller routing updates
  - Faster convergence after a change in the network
  - Easier troubleshooting
  - Increased network stability
- **Efficient allocation of addresses**—Hierarchical addressing lets you take advantage of all possible addresses because you group them contiguously. With random address assignment, you might end up wasting groups of addresses because of addressing conflicts. For example, classful routing protocols (discussed in the later section "Implementing VLSM in a Scalable Network") automatically create summary routes at a network boundary. Therefore, these protocols do not support discontiguous addressing (as you will see in Chapter 2, "Routing Principles"), so some addresses would be unusable if not assigned contiguously.

Within the context of hierarchical addressing, the IP addressing plan must include provisions for summarization at key points. Summarization (also called aggregation or information hiding) is not a new concept. When a router announces a route to a given network, the route is a summarization of the addresses in the routing table for all the host devices and individual addresses that reside on that network.

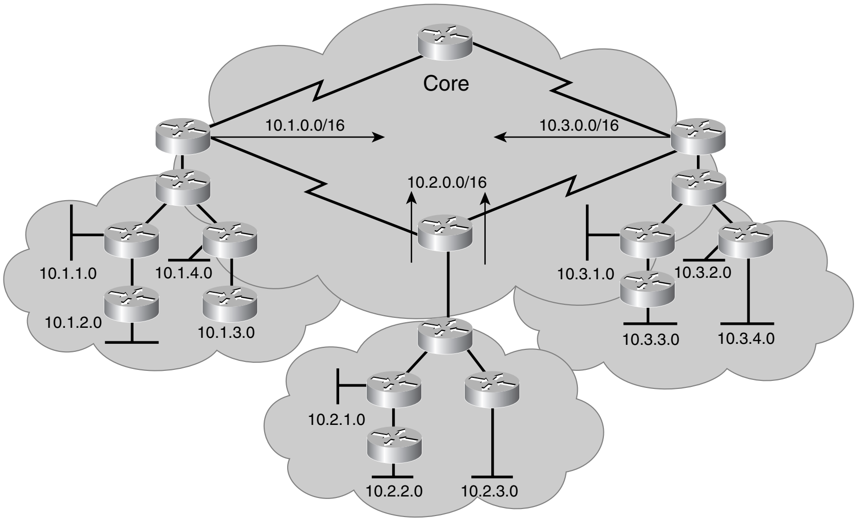
Summarization helps reduce routing-table size and helps localize topology changes. This promotes network stability because a reduced routing-table size means that less bandwidth, memory, and CPU cycles are required to calculate the best path selection. Because summarization limits the propagation of detailed routes, it also reduces the impact to the network when these detailed routes fail.

## Scalable Network Addressing Example

The network illustrated in Figure 1-8 shows an example of scalable addressing. In this example, a U.S. national drugstore chain plans to have a retail outlet in every city in the country with a population greater than 10,000. Each of the 50 states has up to 100 stores, with two Ethernet LANs in each store:

- One LAN is used to track customer prescriptions and pharmacy inventory and reorder stock.
- The second LAN is used to stock the rest of the store and connect the cash registers to a corporate-wide, instantaneous point-of-sale evaluation tool.

**Figure 1-8** *Scalable Addressing Allows Summarization*



The total number of Ethernet LAN networks is 50 states * 100 stores per state * 2 LANs per store = 10,000. (An equal number of serial links interconnect these stores.)

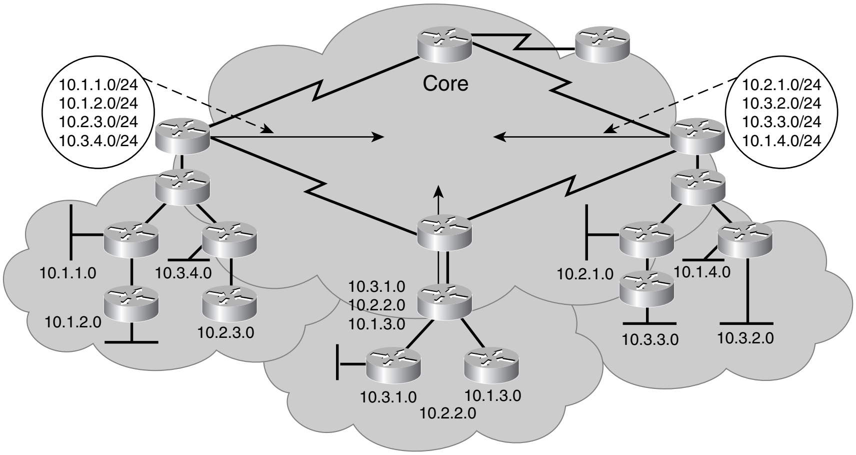
Using a scalable design and creating 51 divisions (one for each state and one for the backbone interconnecting the divisions), the corporation can assign each division a block of IP addresses 10.*x*.0.0 /16. Each LAN is assigned a /24 subnet of network 10.0.0.0, and each division has 200 such subnets (two for each of the 100 stores). The network will have 10,000 subnets; without summarization, each of the 5000 routers will have all these networks in their routing tables.

If each division router summarizes its block of networks 10.*x*.0.0 /16 at the entry point to the core network, any router in a division has only the 200 /24 subnets within that division, plus the 49 10.*x*.0.0 /16 summarizations that represent the other divisions, in its routing table. This results in a total of 249 networks in each IP routing table.

## Nonscalable Network Addressing

In contrast to the previous example, if a hierarchical addressing plan is not used, summarization is not possible, as is the case in Figure 1-9. Problems can occur in this network related to the frequency and size of routing table updates and how topology changes are processed in summarized and unsummarized networks. These problems are described next.

**Figure 1-9** *Nonscalable Addressing Results in Large Routing Tables*



## Update Size

Routing protocols such as RIP and IGRP, which send a periodic update every 30 and 90 seconds, respectively, use valuable bandwidth to maintain a table without summarization. A single RIP update packet is limited to carrying 25 routes; therefore, 10,000 routes means that RIP on every router must create and send 400 packets every 30 seconds. With summarized routes, the 249 routes means that only 10 packets need to be sent every 30 seconds.

## Unsummarized Internetwork Topology Changes

A routing table with 10,000 entries constantly changes. To illustrate this constant change, consider the sample network with a router at each of 5000 different sites. A power outage occurs at site A, a backhoe digs a trench at site B, a newly-hired system administrator begins work at site C, a Cisco IOS software upgrade is in progress at site D, and a newly-added router is being installed at site E.

Every time a route changes, all the routing tables must be updated. For example, when using a routing protocol such as Open Shortest Path First (OSPF), an upgrade or topology change on the internetwork causes a shortest path first (SPF) calculation. The SPF calculations are large because each router needs to calculate all known pathways to each of the 10,000 networks. Each change a router receives requires time and CPU resources to process.

## Summarized Network Topology Changes

In contrast to an unsummarized network, a summarized network responds efficiently to network changes. For example, in the sample drugstore network with 200 routes for each division, the routers within the division see all the subnets for that division. When a change occurs on one of the 200 routes in the division, all other routers in the division recalculate to reflect the topology change of those affected networks. However, the core router of that division passes a summarized /16 route and suppresses the /24 networks from advertisement to the core routers of other divisions. The summarized route is announced as long as any portion of the summarized block can be reached from that core router. The more-specific routes are suppressed so that changes from this division are not propagated to other divisions.

In this scenario, each router has only 200 /24 networks, compared to the 10,000 /24 networks in an unsummarized environment. Obviously, the amount of CPU resources, memory, and bandwidth required for the 200 networks is less than the 10,000 networks. With summarization, each division hides more-specific information from the other divisions and passes only the summarized route that represents that overall division.

# Hierarchical Addressing Using Variable-Length Subnet Masks

VLSM is a crucial component of an effective IP addressing plan for a scalable network. This section introduces VLSM, provides examples, and discusses methods of determining the best subnet mask for a given address requirement.

## Network Mask and Prefix Length

The concept and definition of a network mask and the prefix length field relate to hierarchically addressed network implementation. This section discusses the purpose of the network mask and the prefix length and describes their use within a network.

### IP Addressing and Subnetting

**NOTE** This section is an overview of IP addressing and subnetting. Appendix A, "Job Aids and Supplements," includes a more detailed review of these topics.

A subnet mask is a 32-bit value that identifies which bits in an address represent network bits and which represent host bits. To create a subnet mask for an address, use a 1 for each bit of the address that you want to represent the network or subnet portion of the address, and use a 0 for each bit of the address that you want to represent the node portion of the address. Note that the 1s in the mask are contiguous. The default subnet masks for Classes A, B, and C addresses are as shown in Table 1-1.

**Table 1-1** *IP Address Default Subnet Masks*

| Class | Default Mask in Binary | Default Mask in Decimal |
|---|---|---|
| A | 11111111.00000000.00000000.00000000 | 255.0.0.0 |
| B | 11111111.11111111.00000000.00000000 | 255.255.0.0 |
| C | 11111111.11111111.11111111.00000000 | 255.255.255.0 |

When contiguous 1s are added to the default mask, making the all-1s field in the mask longer, the definition of the network part of an IP address is extended to include subnets. Adding bits to the network part of an address decreases the number of bits in the host part. Thus, creating additional networks (subnets) is done at the expense of the number of host devices that can occupy each network segment.

The number of bits added to a default routing mask creates a counting range for counting subnets. Each subnet is a unique binary pattern.

The number of subnetworks created is calculated by the formula $2^n$, where $n$ is the number of bits by which the default mask was extended. Subnet 0 (where all the subnet bits are 0) must be explicitly allowed using the **ip subnet-zero** global configuration command in Cisco IOS releases before 12.0. In Cisco IOS Release 12.0 and later, subnet 0 is enabled by default.

**NOTE** This book describes the formula for obtaining the number of subnets differently than some previous Cisco courses and books. Previously, the same formula that was used to count hosts, $2^n – 2$, was used to count subnets. Now $2^n$ subnets and $2^n – 2$ hosts are available. The $2^n$ rule for subnets has been adopted because the all-1s subnet has always been a legal subnet according to the RFC, and subnet 0 can be enabled by a configuration command on Cisco routers (and, in fact, it's on by default in Cisco IOS Release 12.0 and later). Note, however, that not all vendor equipment supports the use of subnet 0.

The remaining bits in the routing mask form a counting range for hosts. Host addresses are selected from these remaining bits and must be numerically unique from all other hosts on the subnetwork.

The number of hosts available is calculated by the formula $2^n – 2$, where $n$ is the number of bits in the host portion. In the host counting range, the all-0s bit pattern is reserved as the subnet identifier (sometimes called *the wire*), and the all-1s bit pattern is reserved as a broadcast address, to reach all hosts on that subnet.

Both the IP address and the associated mask contain 32 bits. Routers are similar to computers in that both use the binary numbering scheme to represent addresses. Network administrators, however, typically do not use binary numbers on a daily basis and therefore have adopted other formats to represent 32-bit IP addresses. Some common formats include decimal (base 10) and hexadecimal (base 16) notations.

The generally accepted method of representing IP addresses and masks is to break the 32-bit field into four groups of 8 bits (octets) and to represent those 8-bit fields in a decimal format, separated by decimal points. This is known as 32-bit *dotted-decimal notation* .

**NOTE** Although dotted-decimal notation is commonly accepted, this notation means nothing to routing or computing devices, because devices internally use the 32-bit binary string. All routing decisions are based on the 32-bit binary string.

Subnet masks are used to identify the number of bits in an address that represent the network, subnet, and host portions of the address. Another way of indicating this information is to use a *prefix*. A prefix is a slash (/) followed by a numeric value that is the number of bits in the network and subnet portions of the address—in other words, the number of contiguous 1s that are in the subnet mask. For example, assume you are using a subnet mask of 255.255.255.0. The binary representation of this mask is 11111111.11111111.11111111.00000000, which is 24 1s followed by eight 0s. Thus, the prefix would be /24, for the 24 bits of network and subnet information, the number of 1s in the mask.

## Use of the Network Mask

If a PC has an IP address of 192.168.1.67 with a mask of 255.255.255.240 (or a prefix length of /28), it uses this mask to determine the valid host addresses for devices on its local connection. These devices have the first 28 bits in their IP address in common (the range of these local devices is 192.168.1.65 through 192.168.1.78). If communication with any of these devices is necessary, the PC uses Address Resolution Protocol (ARP) to find the device's corresponding media access control (MAC) address (assuming that it does not already have a destination MAC address for the IP address in its MAC table). If a PC needs to send information to an IP device that is not in the local range, the PC instead forwards the information to its default gateway. (The PC also uses ARP to discover the MAC address of the default gateway.)

A router behaves in a similar manner when it makes a routing decision. A packet arrives on the router and is passed to the routing table. The router compares the packet's destination IP address to the entries in the routing table. These entries have a prefix length associated with them. The router uses the prefix length as the minimum number of destination address bits that must match to use the corresponding outbound interface that is associated with a network entry in the routing table.

## Network Mask Example

Consider a scenario in which an IP packet with a destination address of 192.168.1.67 is sent to a router. The router's IP routing table is shown in Example 1-1.

**Example 1-1** *IP Routing Table for Network Mask Example*

```
192.168.1.0 is subnetted, 4 subnets
O 192.168.1.16/28 [110/1800] via 172.16.1.1, 00:05:17, Serial 0
C 192.168.1.32/28 is directly connected, Ethernet 0
O 192.168.1.64/28 [110/10] via 192.168.1.33, 00:05:17, Ethernet 0
O 192.168.1.80/28 [110/1800] via 172.16.2.1, 00:05:17, Serial 1
```

In this scenario, the router determines where to send a packet that is destined for 192.168.1.67 by looking at the routing table. The routing table has four entries for network 192.168.1.0. The router compares the destination address to each of the four entries for this network.

The destination address of 192.168.1.67 has the first three octets in common with all four entries in the routing table, but it is not clear by looking at the decimal representation which of those entries is the best match to route this packet. A router handles all packets in binary, not dotted-decimal, notation.

Following is the binary representation of the last octet for destination address 192.168.1.67 and the binary representation of the last octet for the four entries in the IP routing table. Because the prefix length is 28 and all four entries match at least the first 24 bits of 192.168.1, the router must find the routing table entry that matches the first 4 bits (bits 25 to 28) of the number 67. It is not important if the last 4 bits match, so the target is 0100*xxxx*. The routing entry 64, which has a value of 0100 in the first 4 bits, is the only one that matches the requirement:

- 67—01000011
- 16—00010000
- 32—00100000
- 64—01000000
- 80—01010000

The router therefore uses the 192.168.1.64 entry in the routing table and forwards this packet to the next router (192.168.1.33) on the Ethernet 0 interface.

## Implementing VLSM in a Scalable Network

**Key Point: Classful Versus Classless Routing**

A major network (also known as a classful network) is a Class A, B, or C network.

With classful routing, routing updates do not carry the subnet mask. Therefore, only one subnet mask must be in use within a major network. This is known as Fixed-Length Subnet Masking (FLSM). Examples of classful routing protocols are RIP version 1 (RIPv1) and IGRP.

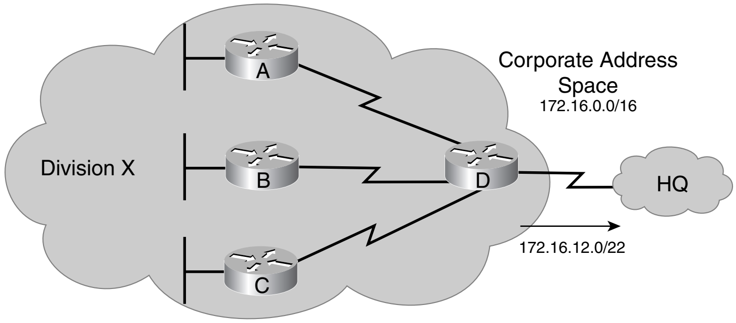
With classless routing, routing updates do carry the subnet mask. Therefore, different masks may be used for different subnets within a major network. This is known as VLSM. Examples of classless routing protocols are RIP version 2 (RIPv2), OSPF, Intermediate System-to-Intermediate System (IS-IS), and Enhanced Interior Gateway Routing Protocol (EIGRP).

**NOTE** Classful and classless routing protocols are discussed further in Chapter 2.

VLSM allows more than one subnet mask within a major network and enables the subnetting of a previously subnetted network address.

The network shown in Figure 1-10 is used to illustrate how VLSM works.

**Figure 1-10** *Network for the VLSM Example*



172.16.12.0/22 has been assigned to Division X.
Range of Addresses: 172.16.12.0 to 171.16.15.255

The following are some characteristics that permit VLSMs to conserve IP addresses:

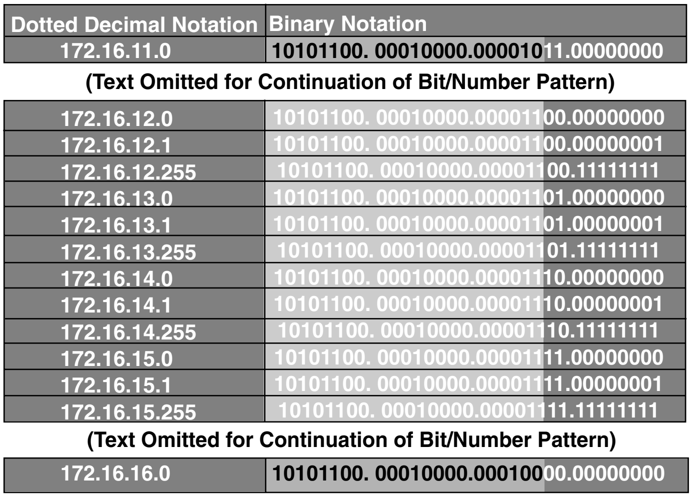
- **Efficient use of IP addresses**—Without the use of VLSMs, companies are locked into implementing a single subnet mask within an entire Class A, B, or C network number.

  For example, suppose a network architect decides to use the 172.16.0.0/16 address space to design a corporate network. The architect determines that 64 blocks of addresses with up to 1022 hosts in each are required. Therefore, 10 host bits ($2^{10} - 2 = 1022$) and 6 subnet bits ($2^6 = 64$) are required for each block. The mask is therefore 255.255.252.0; the prefix is /22.

  The network architect assigns address block 172.16.12.0/22 to Division X, as shown in Figure 1-10. The prefix mask of /22 indicates that all addresses within that range have the first 22 bits in common (when reading from left to right). The prefix mask provides Division X with a range of addresses from 172.16.12.0 through 172.16.15.255. The details of the range of addresses available to Division X are shown in the center block of Figure 1-11. Within Division X, the networks are assigned addresses in this range, with varying subnet masks. Details of these address assignments are provided in the next section.

- **Greater capability to use route summarization**—VLSMs allow for more hierarchical levels within an addressing plan and thus allow better route summarization within routing tables. For example, in Figure 1-10, address 172.16.12.0/22 summarizes all the subnets that are further subnets of 172.16.12.0/22.

**Figure 1-11** *Range of Addresses for VLSM for Division X in Figure 1-10*



| Dotted Decimal Notation | Binary Notation |
|---|---|
| 172.16.11.0 | 10101100. 00010000.00001011.00000000 |

(Text Omitted for Continuation of Bit/Number Pattern)

| | |
|---|---|
| 172.16.12.0 | 10101100. 00010000.00001100.00000000 |
| 172.16.12.1 | 10101100. 00010000.00001100.00000001 |
| 172.16.12.255 | 10101100. 00010000.00001100.11111111 |
| 172.16.13.0 | 10101100. 00010000.00001101.00000000 |
| 172.16.13.1 | 10101100. 00010000.00001101.00000001 |
| 172.16.13.255 | 10101100. 00010000.00001101.11111111 |
| 172.16.14.0 | 10101100. 00010000.00001110.00000000 |
| 172.16.14.1 | 10101100. 00010000.00001110.00000001 |
| 172.16.14.255 | 10101100. 00010000.00001110.11111111 |
| 172.16.15.0 | 10101100. 00010000.00001111.00000000 |
| 172.16.15.1 | 10101100. 00010000.00001111.00000001 |
| 172.16.15.255 | 10101100. 00010000.00001111.11111111 |

(Text Omitted for Continuation of Bit/Number Pattern)

| | |
|---|---|
| 172.16.16.0 | 10101100. 00010000.00010000.00000000 |

- **Reduced number of routing table entries**—In a hierarchical addressing plan, route summarization allows a single IP address to represent a collection of IP addresses. When VLSM is used in a hierarchical network, it allows summarized routes, which keeps routing table entries (on the routers that receive the summarized routes) manageable and provides the following benefits:

  — More-efficient routing

  — Reduction in the number of CPU cycles to sort through the routing table entries to find a match and for routing table recalculation

  — Reduction in router memory requirements

  — Reduced bandwidth required to send the fewer, smaller routing updates

  — Faster convergence after a change in the network

  — Easier troubleshooting

  — Increased network stability

  Because of the reduced router requirements, it also might be possible to use some less-powerful (and therefore less-expensive) routers in the network.

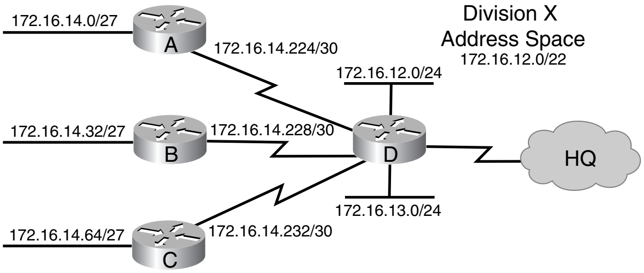
The address 172.16.12.0/22 represents all the addresses that have the same first 22 bits as 172.16.12.0. Figure 1-11 displays the binary representation of networks 172.16.11.0 through 172.16.16.0. Notice that 172.16.12.0 through 172.12.15.255 all have the first 22 bits in common, whereas 172.16.11.0 and 172.16.16.0 do not have the same first 22 bits. Therefore, the address 172.16.12.0/22 represents the range of addresses 172.16.12.0 through 172.16.15.255.

## VLSM Calculation Example

You can best understand the design and implementation of a scalable IP address plan if you study a detailed example of how a VLSM network is laid out.

Figure 1-12 shows a detailed view of the same Division X shown in Figure 1-10.

**Figure 1-12** *Detailed IP Addressing of Division X in Figure 1-10*



In Division X, the following exist:

- One VLAN on each of the two Ethernet ports of Router D, each with 200 users.
- Three remote sites, at Routers A, B, and C, each with a 24-port Cisco 2924 10/100 switch. Corporate management guarantees that the number of users at each remote site does not exceed 20.
- Three serial links to the remote sites. The serial links are point-to-point Frame Relay and require an address on each side.

VLSM allows you to further subnet the 172.16.12.0/22 address space, using variable masks, to accommodate the network requirements. For example, because point-to-point serial lines require only two host addresses, you can use a subnetted address that has only two host addresses and therefore does not waste scarce subnet numbers.

To start the VLSM process, determine the number of subnets necessary for the networks to which you need to assign IP addresses, and determine the number of hosts necessary per subnetwork. You can determine the number of hosts by checking corporate policy to see if a limit is set per segment or VLAN, checking the physical number of ports on a switch, and checking the current size of the network or networks at other sites that fulfill the same role.

**NOTE** The decimal-to-binary conversion chart in Appendix A might be helpful when you are calculating VLSMs.

## LAN Addresses

Because IP addresses are binary, they are used in blocks of powers of 2. A block of addresses contains 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, and so on addresses. Two addresses are lost each time you create a subnet: one for the network (wire) address and the other for the broadcast address.

The lowest address of the range, where the host bits are all 0s, is known as the network number or the wire address. The top of the address range, where the host bits are all 1s, is the broadcast address. The number of addresses in a block that can be assigned to devices is $2^n - 2$, where $n$ is the number of host bits. For example, with 3 host bits, $2^3 - 2 = 8 - 2 = 6$ addresses can be assigned.

To determine the size of the block of addresses needed for a subnet, follow these steps:

**Step 1** Calculate the maximum number of hosts on that subnet.

**Step 2** Add 2 to that number for the broadcast and subnet numbers.

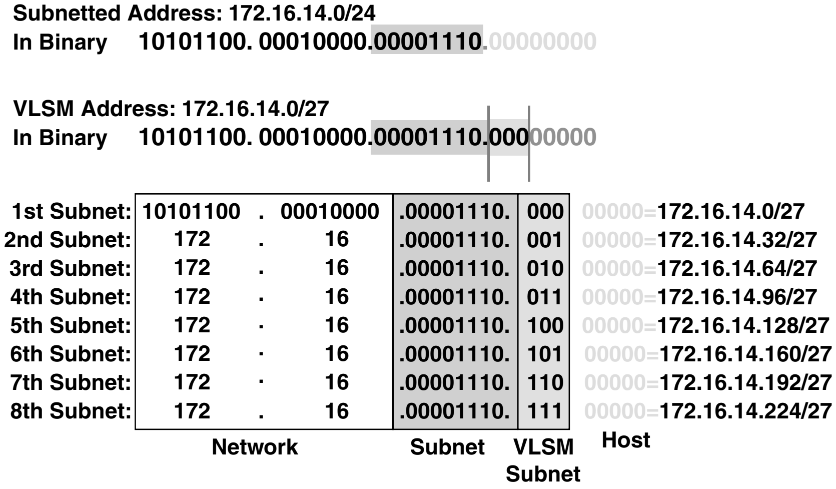
**Step 3** Round up to the next higher power of 2.

In this example, the VLANs each have 200 users; therefore, the number of addresses required is 200 + 2 = 202. Rounding up to the next power of 2 gives you 256. Thus, 8 ($2^8 = 256$) host bits are required for the VLANs; therefore, the prefix is /24 (32 bits – 8 bits for the host = 24 bits). The network administrator subnets the 172.16.12.0/22 into four /24 subnets on router D. 172.16.12.0/24 is assigned to VLAN 1, and 172.16.13.0/24 is assigned to VLAN 2. This leaves two /24 subnets, 172.16.14.0/24 and 172.16.15.0/24, to use for the switches at the three remote sites and the three serial point-to-point links.

The number of addresses required for the LANs at each remote site is 20 + 2 = 22. Rounding this up to the next power of 2 gives you 32. Thus, 5 host bits ($2^5 = 32$) are required to address the remote users at each site. Therefore, the prefix to use is /27 (32 bits – 5 bits for the host = 27).

You cannot use the 172.16.12.0/24 or 172.16.13.0/24 networks, because they are assigned to VLANs 1 and 2 on router D. The process to further subnet 172.16.14.0/24 into /27 subnets is shown in Figure 1-13. The first three subnets calculated in Figure 1-13 are used on the LANs in Figure 1-12.

**Figure 1-13** *Calculating Subnet Addresses for the LANs in Figure 1-12*



**Subnetted Address: 172.16.14.0/24**
**In Binary** 10101100. 00010000.00001110.00000000

**VLSM Address: 172.16.14.0/27**
**In Binary** 10101100. 00010000.00001110.00000000

| | | | | | | |
|---|---|---|---|---|---|---|
| 1st Subnet: | 10101100 | . | 00010000 | .00001110. | 000 | 00000=172.16.14.0/27 |
| 2nd Subnet: | 172 | . | 16 | .00001110. | 001 | 00000=172.16.14.32/27 |
| 3rd Subnet: | 172 | . | 16 | .00001110. | 010 | 00000=172.16.14.64/27 |
| 4th Subnet: | 172 | . | 16 | .00001110. | 011 | 00000=172.16.14.96/27 |
| 5th Subnet: | 172 | . | 16 | .00001110. | 100 | 00000=172.16.14.128/27 |
| 6th Subnet: | 172 | . | 16 | .00001110. | 101 | 00000=172.16.14.160/27 |
| 7th Subnet: | 172 | . | 16 | .00001110. | 110 | 00000=172.16.14.192/27 |
| 8th Subnet: | 172 | . | 16 | .00001110. | 111 | 00000=172.16.14.224/27 |
| | Network | | | Subnet | VLSM Subnet | Host |

## Serial Line Addresses

After you establish the addresses for the LANs at the remote sites, you must address the serial links between the remote sites and router D. Because the serial links require two addresses, the number of addresses required is 2 + 2 = 4 (the two additional addresses are for the network number and the broadcast address).

In this case, there is no need to round up, because 4 is a power of 2. Therefore, 2 host bits will allow for two hosts per subnet. A network mask of /30 (32 bits – 2 host bits = 30 bits) is used. This prefix allows for only two hosts—just enough hosts for a point-to-point connection between a pair of routers.

To calculate the subnet addresses for the WAN links, further subnet one of the unused /27 subnets. In this example, 172.16.14.224/27 is further subnetted with a prefix of /30. The three additional subnet bits result in $2^3$ = 8 subnets for the WAN links.

**Key Point: Further Subnet Only Unused Subnets**

It is important to remember that only *unused* subnets should be further subnetted. In other words, if you use any addresses from a subnet, that subnet should not be further subnetted. In Figure 1-12, three subnet numbers are used on the LANs. Another, as-yet unused subnet, 172.16.14.224/27, is further subnetted for use on the WANs.

The WAN addresses derived from 172.16.14.224/27 are as follows. The shaded bits are the 3 additional subnet bits:

- 172.16.14.11100000 = 172.16.14.224/30
- 172.16.14.11100100 = 172.16.14.228/30
- 172.16.14.11101000 = 172.16.14.232/30
- 172.16.14.11101100 = 172.16.14.236/30
- 172.16.14.11110000 = 172.16.14.240/30
- 172.16.14.11110100 = 172.16.14.244/30
- 172.16.14.11111000 = 172.16.14.248/30
- 172.16.14.11111100 = 172.16.14.252/30

The first three of these subnets are used on the WANs shown in Figure 1-12.

The address information for the router A to router D link is as follows:

- **Network number**—172.16.14.224
- **Router A serial interface**—172.16.14.225
- **Router D serial interface**—172.16.14.226
- **Broadcast address**—172.16.14.227

The address information for the router B to router D link is as follows:

- **Network number**—172.16.14.228
- **Router B serial interface**—172.16.14.229
- **Router D serial interface**—172.16.14.230
- **Broadcast address**—172.16.14.231

The address information for the router C to router D link is as follows:

- **Network number**—172.16.14.232
- **Router C serial interface**—172.16.14.233
- **Router D serial interface**—172.16.14.234
- **Broadcast address**—172.16.14.235

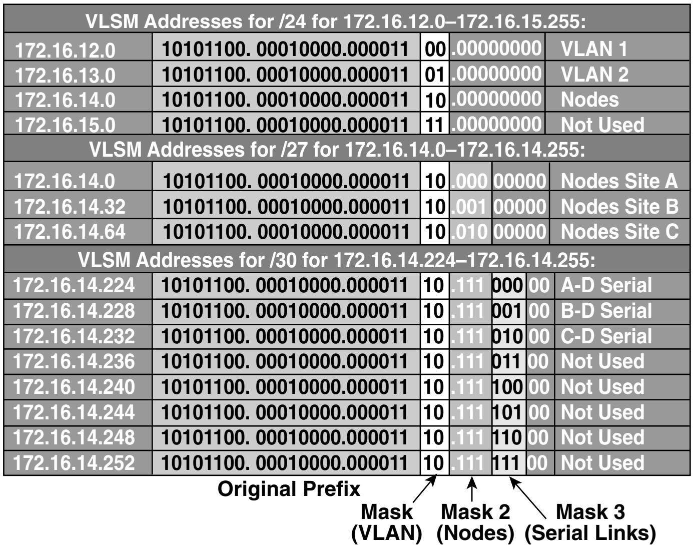
Note that to provide the most flexibility for future growth, the 172.16.14.224/27 subnet was selected for the WANs instead of using the next available subnet, 172.16.14.96/27. For example, if the company purchases more switches, the next IP segment could be assigned the 172.16.14.96/27 subnet, and the new remote site would be connected to router D with the 172.16.14.236/30 serial subnet.

The 172.16.15.0/24 block could have been used for these /30 subnets, but only three subnets are currently needed, so a lot of the address space would be unused. The 172.16.15.0/24 block is now available to use on another LAN in the future.

## Summary of Addresses Used in the VLSM Example

Figure 1-14 summarizes the addresses, in binary, used in this example.

**Figure 1-14** *Binary Representation of the Addresses Used in Figure 1-12*



| | | | | | | |
|---|---|---|---|---|---|---|
| VLSM Addresses for /24 for 172.16.12.0–172.16.15.255: | | | | | | |
| 172.16.12.0 | 10101100. 00010000.000011 | 00 | .00000000 | | | VLAN 1 |
| 172.16.13.0 | 10101100. 00010000.000011 | 01 | .00000000 | | | VLAN 2 |
| 172.16.14.0 | 10101100. 00010000.000011 | 10 | .00000000 | | | Nodes |
| 172.16.15.0 | 10101100. 00010000.000011 | 11 | .00000000 | | | Not Used |
| VLSM Addresses for /27 for 172.16.14.0–172.16.14.255: | | | | | | |
| 172.16.14.0 | 10101100. 00010000.000011 | 10 | .000 | 00000 | | Nodes Site A |
| 172.16.14.32 | 10101100. 00010000.000011 | 10 | .001 | 00000 | | Nodes Site B |
| 172.16.14.64 | 10101100. 00010000.000011 | 10 | .010 | 00000 | | Nodes Site C |
| VLSM Addresses for /30 for 172.16.14.224–172.16.14.255: | | | | | | |
| 172.16.14.224 | 10101100. 00010000.000011 | 10 | .111 | 000 | 00 | A-D Serial |
| 172.16.14.228 | 10101100. 00010000.000011 | 10 | .111 | 001 | 00 | B-D Serial |
| 172.16.14.232 | 10101100. 00010000.000011 | 10 | .111 | 010 | 00 | C-D Serial |
| 172.16.14.236 | 10101100. 00010000.000011 | 10 | .111 | 011 | 00 | Not Used |
| 172.16.14.240 | 10101100. 00010000.000011 | 10 | .111 | 100 | 00 | Not Used |
| 172.16.14.244 | 10101100. 00010000.000011 | 10 | .111 | 101 | 00 | Not Used |
| 172.16.14.248 | 10101100. 00010000.000011 | 10 | .111 | 110 | 00 | Not Used |
| 172.16.14.252 | 10101100. 00010000.000011 | 10 | .111 | 111 | 00 | Not Used |

## Another VLSM Example

This section illustrates another example of calculating VLSM addresses. In this example, you have a subnet address 172.16.32.0/20, and you need to assign addresses to a network that has ten hosts. With this subnet address, however, you have $2^{12} - 2 = 4094$ host addresses, so you would be wasting more than 4000 IP addresses. With VLSM, you can further subnet the address 172.16.32.0/20 to give you more subnetwork addresses and fewer hosts per network, which would work better in this network topology. For example, if you subnet 172.16.32.0/20 to 172.16.32.0/26, you gain 64 ($2^6$) subnets, each of which can support 62 ($2^6 - 2$) hosts.

To further subnet 172.16.32.0/20 to 172.16.32.0/26, do the following, as illustrated in Figure 1-15:

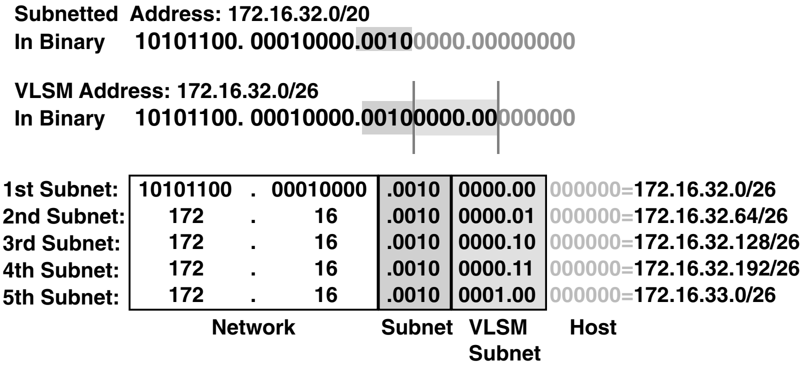
**Step 1** Write 172.16.32.0 in binary.

**Step 2** Draw a vertical line between the 20th and 21st bits, as shown in Figure 1-15.

**Step 3** Draw a vertical line between the 26th and 27th bits, as shown in Figure 1-15.

**Step 4** Calculate the 64 subnet addresses using the bits between the two vertical lines, from lowest to highest. Figure 1-15 shows the first five subnets available.

**Figure 1-15** *Further Subnetting a Subnetted Address*



Subnetted Address: 172.16.32.0/20
In Binary 10101100. 00010000.00100000.00000000

VLSM Address: 172.16.32.0/26
In Binary 10101100. 00010000.00100000.00000000

| | Network | | | Subnet | VLSM Subnet | Host |
|---|---|---|---|---|---|---|
| 1st Subnet: | 10101100 | . | 00010000 | .0010 | 0000.00 | 000000=172.16.32.0/26 |
| 2nd Subnet: | 172 | . | 16 | .0010 | 0000.01 | 000000=172.16.32.64/26 |
| 3rd Subnet: | 172 | . | 16 | .0010 | 0000.10 | 000000=172.16.32.128/26 |
| 4th Subnet: | 172 | . | 16 | .0010 | 0000.11 | 000000=172.16.32.192/26 |
| 5th Subnet: | 172 | . | 16 | .0010 | 0001.00 | 000000=172.16.33.0/26 |

**NOTE** VLSM calculators are available on the web. The following URL contains the one offered by Cisco: www.cisco.com/cgi-bin/Support/IpSubnet/home.pl. (Note that you need to have an account on Cisco's website to use this calculator.)

# Route Summarization

As the result of corporate expansion and mergers, the number of subnets and network addresses in routing tables is increasing rapidly. This growth taxes CPU resources, memory, and bandwidth used to maintain the routing table. Route summarization and CIDR techniques can manage this corporate growth much like Internet growth has been managed. With a thorough understanding of route summarization and CIDR, you can implement a scalable network. This section describes summarization; CIDR is covered in the later section “Classless Interdomain Routing.” The relationship between summarization and VLSM is also examined. With VLSM, you break a block of addresses into smaller subnets; in route summarization, a group of subnets is rolled up into a summarized routing table entry.

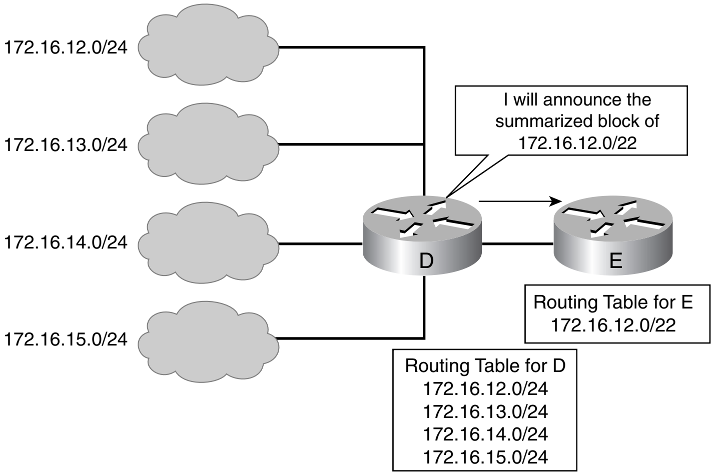
## Route Summarization Overview

In large internetworks, hundreds, or even thousands, of network addresses can exist. It is often problematic for routers to maintain this volume of routes in their routing tables. Route summarization (also called *route aggregation* or *supernetting* ) can reduce the number of routes that a router must maintain, because it is a method of representing a series of network numbers in a single summary address.

For example, in Figure 1-16, router D can either send four routing update entries or summarize the four addresses into a single network number. If router D summarizes the information into a single network number entry, the following things happen:

- Bandwidth is saved on the link between routers D and E.
- Router E needs to maintain only one route and therefore saves memory.
- Router E also saves CPU resources, because it evaluates packets against fewer entries in its routing table.

**Figure 1-16** *Routers Can Summarize to Reduce the Number of Routes*



**Key Point: Summary Routes**

A summary route is announced by the summarizing router as long as at least one specific route in its routing table matches the summary route.

**NOTE** Router D in Figure 1-16 is advertising that it can route to network 172.16.12.0/22, including all subnets of that network. However, if there were other subnets of 172.16.12.0/22 elsewhere in the network (for example, if 172.16.12.0 were discontiguous), summarizing in this way might not be valid.

Another advantage of using route summarization in a large, complex network is that it can isolate topology changes from other routers. For example, in Figure 1-16, if a specific link (such as 172.16.13.0/24) is *flapping* (going up and down rapidly), the summary route (172.16.12.0/22) does not change. Therefore, router E does not need to continually modify its routing table as a result of this flapping activity.

**NOTE** Flapping is a common term used to describe intermittent interface or link failures.

Route summarization is possible only when a proper addressing plan is in place. Route summarization is most effective within a subnetted environment when the network addresses are in contiguous blocks in powers of 2. For example, 4, 16, or 512 addresses can be represented by a single routing entry because summary masks are binary masks—just like subnet masks—so summarization must take place on binary boundaries (powers of 2). If the number of network addresses is not contiguous or not a power of 2, you can divide the addresses into groups and try to summarize the groups separately.

Routing protocols summarize or aggregate routes based on shared network numbers within the network. Classless routing protocols (such as RIPv2, OSPF, IS-IS, and EIGRP) support route summarization based on subnet addresses, including VLSM addressing. Classful routing protocols (RIPv1 and IGRP) automatically summarize routes on the classful network boundary and do not support summarization on any other bit boundaries. Classless routing protocols support summarization on any bit boundary.

**NOTE** Summarization is described in RFC 1518, *An Architecture for IP Address Allocation with CIDR*, available at www.cis.ohio-state.edu/cgi-bin/rfc/rfc1518.html.

As an example of the power of summarization, imagine a company that operates a series of pizza shops, with 200 stores in each of the 50 states in the U.S. Each store has a router with an Ethernet and a Frame Relay link connected to headquarters. Without route summarization, the routing table on any of those routers would have 200 * 50 = 10,000 networks.

Instead, if each state has a central site to connect it with all the other states, and each of these routes is summarized before being announced to other states, every router sees its 200 state subnets and 49 summarized entries representing the other states. This results in less CPU, memory, and bandwidth usage.

## Route Summarization Calculation Example

Router D in Figure 1-16 has the following networks in its routing table:

- 172.16.12.0/24
- 172.16.13.0/24
- 172.16.14.0/24
- 172.16.15.0/24

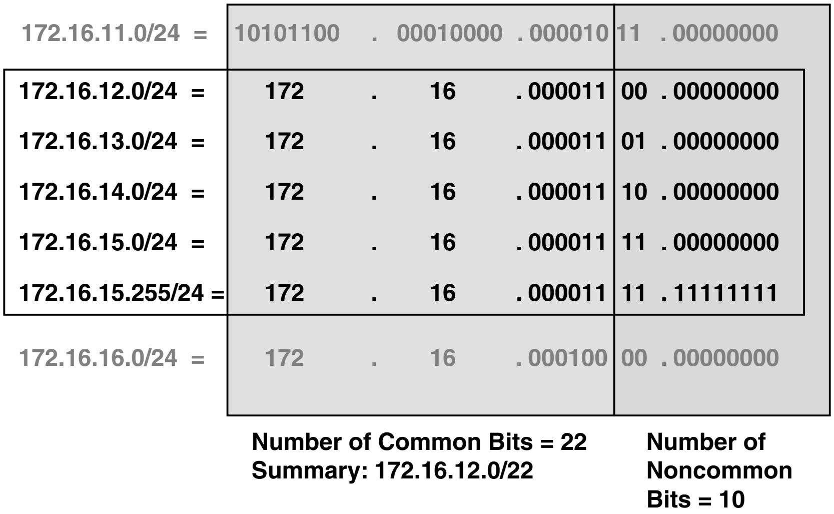
To determine the summary route on router D, determine the number of highest-order (leftmost) bits that match in all the addresses. To calculate the summary route, follow these steps:

**Step 1** Convert the addresses to binary format and align them in a list.

**Step 2** Locate the bit where the common pattern of digits ends. (It might be helpful to draw a vertical line marking the last matching bit in the common pattern.)

**Step 3** Count the number of common bits. The summary route number is represented by the first IP address in the block, followed by a slash, followed by the number of common bits. As Figure 1-17 illustrates, the first 22 bits of the IP addresses from 172.16.12.0 through 172.16.15.255 are the same. Therefore, the best summary route is 172.16.12.0/22.

**Figure 1-17** *Summarizing Within an Octet, for Router D in Figure 1-16*



172.16.11.0/24 = 10101100 . 00010000 . 000010 11 . 00000000

172.16.12.0/24 = 172 . 16 . 000011 00 . 00000000

172.16.13.0/24 = 172 . 16 . 000011 01 . 00000000

172.16.14.0/24 = 172 . 16 . 000011 10 . 00000000

172.16.15.0/24 = 172 . 16 . 000011 11 . 00000000

172.16.15.255/24 = 172 . 16 . 000011 11 . 11111111

172.16.16.0/24 = 172 . 16 . 000100 00 . 00000000

Number of Common Bits = 22
Summary: 172.16.12.0/22

Number of
Noncommon
Bits = 10

**NOTE** In this network, the four subnets are contiguous, and the summary route covers all the addresses in the four subnets and only those addresses. Consider, for example, what would happen if 172.16.13.0/24 were not behind router D, but instead were used elsewhere in the network, and only the other three subnets were behind router D. The summary route 172.16.12.0/22 should no longer be used on router D, because it includes 172.16.13.0/24 and might result in confusing routing tables. (However, this depends on how other routers in the network summarize. If the 172.16.13.0/24 route is propagated to all routers, they choose the route with the most bits that match the destination address and should route properly. This is further described in the section "Route Summarization Operation in Cisco Routers.")

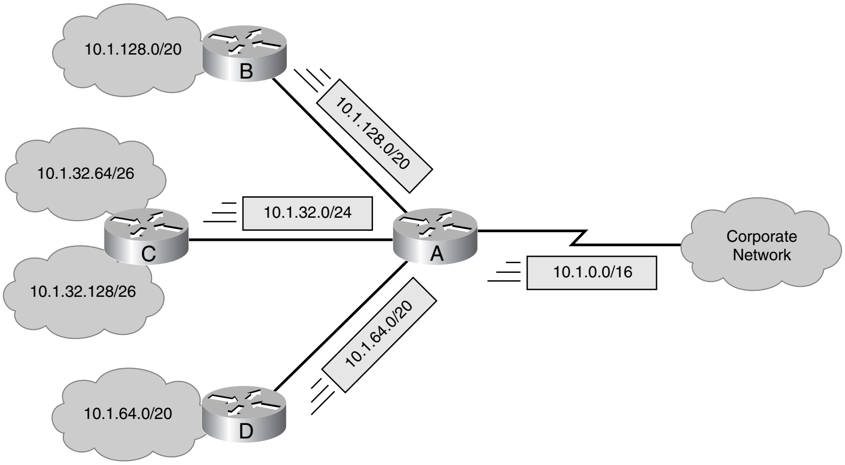
**NOTE** In Figure 1-17, the subnets before and after the subnets to be summarized are also shown. Observe that they do not have the same first 22 bits in common and therefore are not covered by the 172.16.12.0/22 summary route.

## Summarizing Addresses in a VLSM-Designed Network

A VLSM design allows for maximum use of IP addresses as well as more-efficient routing update communication when using hierarchical IP addressing. In Figure 1-18, route summarization occurs at the following two levels:

- Router C summarizes two routing updates from networks 10.1.32.64/26 and 10.1.32.128/26 into a single update: 10.1.32.0/24.
- Router A receives three different routing updates. However, router A summarizes them into a single routing update, 10.1.0.0/16, before propagating it to the corporate network.

**Figure 1-18** *VLSM Addresses Can Be Summarized*



## Route Summarization Implementation

Route summarization reduces memory use on routers and routing protocol network traffic, because it results in fewer entries in the routing table (on the routers that receive the summarized routes). For summarization to work correctly, the following requirements must be met:

- Multiple IP addresses must share the same highest-order bits.
- Routing protocols must base their routing decisions on a 32-bit IP address and a prefix length that can be up to 32 bits.
- Routing updates must carry the prefix length (the subnet mask) along with the 32-bit IP address.

## Route Summarization Operation in Cisco Routers

This section discusses generalities of how Cisco routers handle route summarization. Details about how route summarization operates with a specific protocol are discussed in the corresponding protocol chapter of this book.

Cisco routers manage route summarization in two ways:

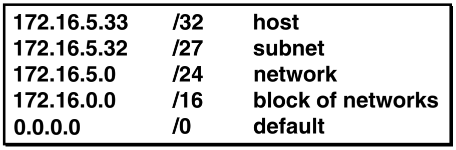
- **Sending route summaries**—Routing information advertised out an interface is automatically summarized at major (classful) network address boundaries by RIP, IGRP, and EIGRP. Specifically, this automatic summarization occurs for routes whose classful network addresses differs from the major network address of the interface to which the advertisement is being sent. For OSPF and IS-IS, you must configure summarization.

  Route summarization is not always a solution. You would not want to use route summarization if you needed to advertise all networks across a boundary, such as when you have discontiguous networks. When using EIGRP and RIPv2, you can disable this automatic summarization.

- **Selecting routes from route summaries**—If more than one entry in the routing table matches a particular destination, the longest prefix match in the routing table is used. Several routes might match one destination, but the longest matching prefix is used.

  For example, if a routing table has the paths shown in Figure 1-19, packets addressed to destination 172.16.5.99 are routed through the 172.16.5.0/24 path, because that address has the longest match with the destination address.

**Figure 1-19** *Routers Use the Longest Match When Selecting a Route*



| | | |
|---|---|---|
| 172.16.5.33 | /32 | host |
| 172.16.5.32 | /27 | subnet |
| 172.16.5.0 | /24 | network |
| 172.16.0.0 | /16 | block of networks |
| 0.0.0.0 | /0 | default |

**NOTE** When running classful protocols (RIPv1 and IGRP), you must enable **ip classless** if you want the router to select a default route when it must route to an unknown subnet of a network for which it knows some subnets. Refer to the section "The **ip classless** Command" in Chapter 2 for more details.

Note that by default (and for historical reasons) the routing table on Cisco routers acts in a classful manner, as described in the sidebar "The Routing Table Acts Classfully" in Chapter 2.

## Route Summarization in IP Routing Protocols

Table 1-2 summarizes the route summarization support available in the various IP routing protocols.

**Table 1-2** *Routing Protocol Route Summarization Support*

| Protocol | Automatic Summarization at Classful Network Boundary? | Capability to Turn Off Automatic Summarization? | Capability to Summarize at Other Than a Classful Network Boundary? |
|---|---|---|---|
| RIPv1 | Yes | No | No |
| RIPv2 | Yes | Yes | No |
| IGRP | Yes | No | No |
| EIGRP | Yes | Yes | Yes |
| OSPF | No | — | Yes |
| IS-IS | No | — | Yes |

**NOTE** Cisco IOS 12.0 introduced RIPv2's manual summarization feature with the **ip summary-address rip** command. This command provides limited summarization support; RIPv2 advertises a summarized local IP address pool on the specified interface to dialup clients.

More information on this feature is available in *IP Summary Address for RIPv2* at www.cisco.com /en/US/products/sw/iosswrel/ps1830/products_feature_guide09186a0080087ad1.html.

# Classless Interdomain Routing

CIDR is a mechanism developed to help alleviate the problem of exhaustion of IP addresses and growth of routing tables. The idea behind CIDR is that blocks of multiple addresses (for example, blocks of Class C address) can be combined, or aggregated, to create a larger classless set of IP addresses, with more hosts allowed. Blocks of Class C network numbers are allocated to each network service provider; organizations using the network service provider for Internet connectivity are allocated subsets of the service provider's address space as required. These multiple Class C addresses can then be summarized in routing tables, resulting in fewer route advertisements. (Note that the CIDR mechanism can be applied to blocks of Class A, B, and C addresses; it is not restricted to Class C.)

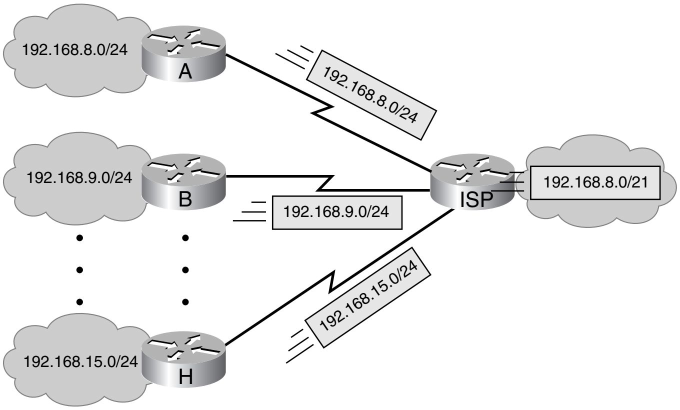
CIDR is described further in RFC 1518, *An Architecture for IP Address Allocation with CIDR,* and RFC 1519, *Classless Inter-Domain Routing (CIDR): An Address Assignment and Aggregation Strategy* , available at www.cis.ohio-state.edu/cgi-bin/rfc/rfc1519.html. RFC 2050, *Internet Registry IP Allocation Guidelines* , specifies guidelines for the allocation of IP addresses. It is available at www.cis.ohio-state.edu/cgi-bin/rfc/rfc2050.html.

Most CIDR debates revolve around summarizing blocks of Class C networks into large blocks of addresses. As a general rule, Internet service providers (ISPs) implement a minimum route advertisement standard of /19 address blocks. A /19 address block equals a block of 32 Class C networks. (In some cases, smaller blocks might be advertised, such as with a /21 mask [eight Class C networks].) Addressing is now so limited that networks such as 12.0.0.0/8 are being divided into blocks of /19 that are assigned to major ISPs, which allows further allocation to customers. CIDR combines blocks of addresses regardless of whether they fall within a single classful boundary or encompass many classful boundaries.

## CIDR Example

Figure 1-20 shows an example of CIDR and route summarization. The Class C network addresses 192.168.8.0/24 through 192.168.15.0/24 are being used and are being advertised to the ISP router. When the ISP router advertises the available networks, it can summarize these into one route instead of separately advertising the eight Class C networks. By advertising 192.168.8.0/21, the ISP router indicates that it can get to all destination addresses whose first 21 bits are the same as the first 21 bits of the address 192.168.8.0.

**Figure 1-20** *CIDR Allows a Router to Summarize Multiple Class C Addresses*



The mechanism used to calculate the summary route to advertise is the same as shown in the "Route Summarization" section. The Class C network addresses 192.168.8.0/24 through 192.168.15.0/24 are being used and are being advertised to the ISP router. To summarize these addresses, find the common bits, as shown here (in bold):

| | |
|---|---|
| 192.168.8.0 | 192.168.**00001**000.00000000 |
| 192.168.9.0 | 192.168.**00001**001.00000000 |
| 192.168.10.0 | 192.168.**00001**010.00000000 |
| . . . | |
| 192.168.14.0 | 192.168.**00001**110.00000000 |
| 192.168.15.0 | 192.168.**00001**111.00000000 |

The route 192.168.00001*xxx.xxxxxxxx*or 192.168.8.0/21 (also written as 192.168.8.0 255.255.248.0) summarizes these eight routes.

In this example, the first octet is 192, which identifies the networks as Class C networks. Combining these Class C networks into a block of addresses with a mask of less than /24 (the default Class C network mask) indicates that CIDR, not route summarization, is being performed.

**Key Point: CIDR Versus Route Summarization**

The difference between CIDR and route summarization is that route summarization is generally done within, or up to, a classful boundary, whereas CIDR combines several classful networks.

In this example, the eight separate 192.168.*x*.0 Class C networks that have the prefix /24 are combined into a single summarized block of 192.168.8.0/21. (At some other point in the network, this summarized block may be further combined into 192.16.0.0/16, and so on.)

Consider another example. A company that uses four Class B networks has the IP addresses 172.16.0.0/16 for Division A, 172.17.0.0/16 for Division B, 172.18.0.0/16 for Division C, and 172.19.0.0/16 for Division D. They can all be summarized as a single block: 172.16.0.0/14. This one entry represents the whole block of four Class B networks. This process is CIDR; the summarization goes beyond the Class B boundaries.

## Network Address Translation

IP address depletion is a key problem facing the Internet. To assist in maximizing the use of registered IP addresses, Cisco IOS Release 11.2 and later implement NAT. This feature, which is Cisco's implementation of RFC 1631, *The IP Network Address Translator* (available at www.cis.ohio-state.edu/cgi-bin/rfc/rfc1631.html), is a solution that provides a way to use the same IP addresses in multiple internal stub networks, thereby reducing the need for registered IP addresses.

NAT is an important function in most scalable networks and is mandatory for the majority of companies that have Internet connections. ISPs have hundreds of users accessing the Internet, yet commonly are assigned only 8 or 16 individual addresses. The ISPs use NAT to map the hundreds of inside addresses to the few globally unique addresses assigned to that company. After introducing NAT terminology and features, this section demonstrates the following:

- How to use basic NAT and a standard access list to assign separate address space to different users.
- How to use an extended access list to check a packet's destination address and assign different source addresses based on it.
- How to use a Cisco IOS software tool called a route map to create a fully extended address translation in an IP NAT table. The IP NAT table tracks the original address and its translation as well as the destination address and the Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) ports for each.

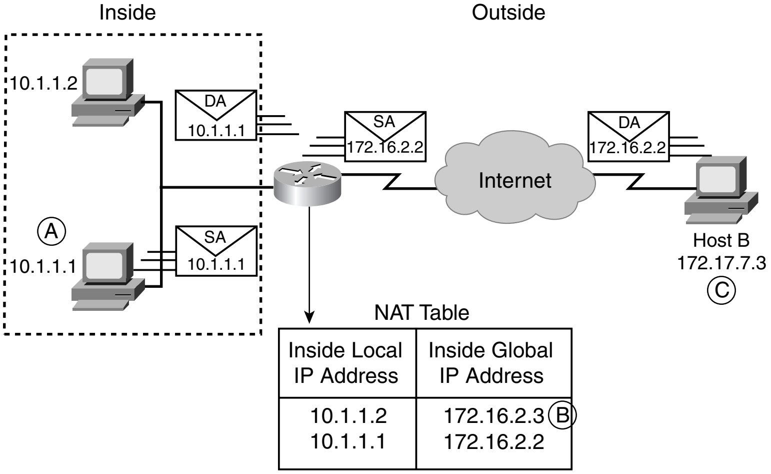
## NAT Terminology and Features

This section first introduces the terminology that is necessary to understand NAT and then explains NAT's various features.

### NAT Terminology

The terms *inside network* and *outside network* are used with NAT, as shown in Figure 1-21. NAT terminology, as used in Figure 1-21, is defined in Table 1-3.

**Figure 1-21** *Network Address Translation Is Used to Translate Addresses Between the Inside and Outside Networks*



| Inside Local IP Address | Inside Global IP Address |
|---|---|
| 10.1.1.2<br>10.1.1.1 | 172.16.2.3<br>172.16.2.2 |

**Table 1-3** *NAT Terminology*

| Term | Definition |
|---|---|
| Inside local IP address (A) | The IP address assigned to a host on the inside network. (The address was either globally unique but obsolete, allocated from RFC 1918, or randomly picked.) |
| Inside global IP address (B) | A legitimate IP address (typically assigned by a service provider) that represents one or more inside local IP addresses to the outside world. (The address was allocated from a globally unique address space, typically provided by the ISP.) |
| Outside global IP address (C) | The IP address that was assigned to a host on the outside network by its owner. (The address was allocated from a globally routable address space.) |
| Outside local IP address (not shown) | The IP address of an outside host as it appears to the inside network. (The address was allocated from address space routable on the inside or possibly was allocated from RFC 1918, for example.) An example of when an outside local IP address is required is given in the "Handling Overlapping Networks" sidebar later in this section. |
| Simple translation entry | A translation entry that maps one IP address to another. This is the type of entry shown in the NAT table in Figure 1-21. |
| Extended translation entry (not shown) | A translation entry that maps one IP address and port pair to another. |

A NAT entry is built in the IP NAT table as the packet goes from an IP NAT inside interface. A NAT entry usually changes the source IP address in the packet from an inside address to an outside address. When a device on the outside responds to the packet, the destination IP address of the returning packet is compared to the entries in the IP NAT table. If a match is found, the destination IP address is translated to the correct inside address and is sent to the routing table to be routed to the correct IP NAT inside interface. If no match is found, the packet is discarded.

NAT is performed when a packet is routed between the following interfaces:

- IP NAT inside interface to an IP NAT outside interface
- IP NAT outside interface to an IP NAT inside interface

A NAT table may contain the following information:

- **Protocol**—IP, TCP, or UDP.
- **Inside local IP address:port**—The IP address and port number used by the inside host before any translations. The inside local IP address is usually the private addressing defined in RFC 1918.
- **Inside global IP address:port**—The IP address and port number used by the inside host as it appears to the outside network; this is the translated IP address and port. Addresses are allocated from a globally unique address space, typically provided by the ISP if the enterprise connects to the global Internet.

- **Outside global IP address:port**—The configured globally unique IP address assigned to a host in the outside network, and the port number used.
- **Outside local IP address:port**—The IP address and port number of an outside host as it appears to the inside network.

**NOTE** Simple NAT entries consist of only the inside local IP address and the inside global IP address.

## Features Supported by NAT

Supported NAT features include the following:

- **Static address translation**—Establishes a one-to-one mapping between inside local and global addresses.
- **Dynamic source address translation**—Establishes a dynamic mapping between the inside local and global addresses. This is accomplished by describing the local addresses to be translated, the pool of addresses from which to allocate global addresses, and associating the two. The router creates translations as needed.
- **Address overloading**—Can conserve addresses in the inside global address pool by allowing source ports in TCP connections or UDP conversations to be translated. When different inside local addresses map to the same inside global address, each inside host's TCP or UDP port numbers are used to distinguish between them.

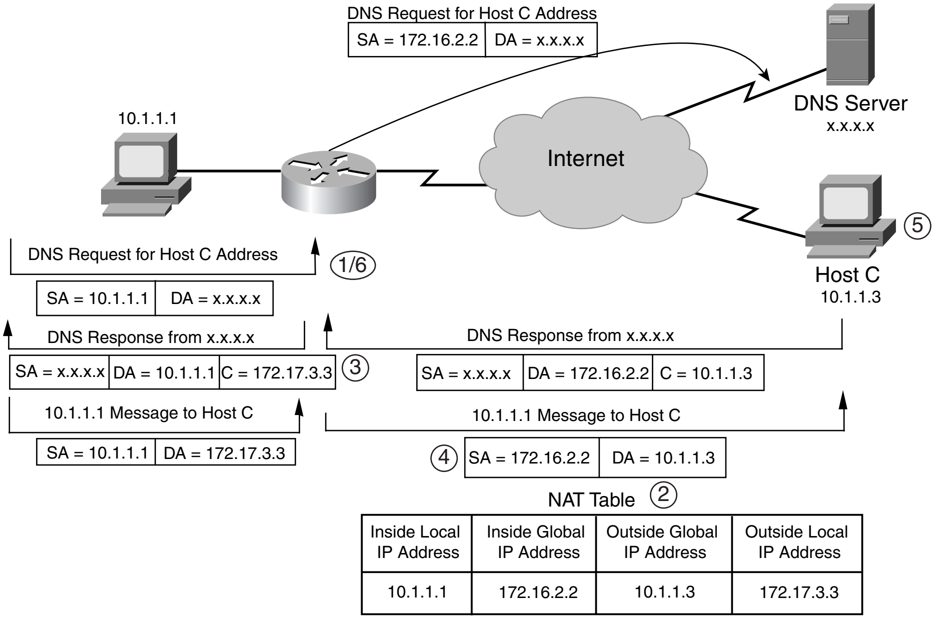
  **NOTE** When the router determines that a packet's path is from an IP NAT inside interface to an IP NAT outside interface, an entry is built to include both the original source IP address and the original TCP for UDP port number. Each of these entries is assigned a unique TCP/UDP source port number to distinguish it from the others. When a packet returns to the IP NAT outside interface, it is compared to the IP NAT table. Although the packet destination address could match thousands of entries, NAT checks the destination TCP/UDP port for the correct entry for the returning packet. After the correct entry is found, the current destination address and port number change to the appropriate IP NAT inside destination address and port number.

- **TCP load distribution**—A dynamic form of destination translation that can be configured for some outside-to-inside traffic. After a mapping is defined, destination addresses matching an access list are replaced with an address from a rotary pool. Allocation is done on a round-robin basis, and only when a new connection is opened from the outside to the inside. All non-TCP traffic is passed untranslated (unless other translations are in effect).

### Handling Overlapping Networks

Figure 1-22 illustrates NAT operation when addresses in the inside network overlap with addresses that are in the outside network; in this case, outside local IP addresses are used.

**Figure 1-22** *Handling Overlapping Networks*



| Inside Local IP Address | Inside Global IP Address | Outside Global IP Address | Outside Local IP Address |
|---|---|---|---|
| 10.1.1.1 | 172.16.2.2 | 10.1.1.3 | 172.17.3.3 |

The following describes this process of handling overlapping addresses:

**Step 1** The user at 10.1.1.1 opens a connection to Host C (10.1.1.3), causing 10.1.1.1 to perform a name-to-address lookup to a DNS server.

**Step 2** If there is an overlap, the router intercepts the DNS reply and translates the returned address. In this case, 10.1.1.3 overlaps with an inside address. To translate the return address of Host C, the router creates a simple translation entry that maps the overlapping address 10.1.1.3 to an address from a separately configured outside local address pool. In this example, the address is 172.17.3.3.

**Step 3** The router forwards the DNS reply to Host 10.1.1.1. The reply has Host C's address as 172.17.3.3. At this point, 10.1.1.1 opens a connection to 172.17.3.3.

**Step 4** When the router receives the packet for Host C (172.17.3.3), it sets up a translation that maps the inside local and global addresses and the outside global and local addresses by replacing the source address of 10.1.1.1 with the inside global address 172.16.2.2 and replacing the destination address of 172.17.3.3 with Host C's outside global address, 10.1.1.3.

**Step 5** Host C receives a packet and continues the conversation.

**Step 6** For each packet sent between Host 10.1.1.1 and Host C, the router performs a lookup, replaces the destination address with the inside local address, and replaces the source address with the outside local address.

## Configuring NAT with Access Lists

This section explains the IP NAT commands to configure IP NAT with access lists. It provides a sample IP NAT configuration and two specific examples of configuring IP NAT with access lists. The first example demonstrates how to use access lists to determine whether an IP address needs translation based on the original source address. The second example demonstrates how to use an access list to assign a NAT source IP address based on the source and destination addresses of the original packet.

The following commands are used to configure IP NAT with access lists:

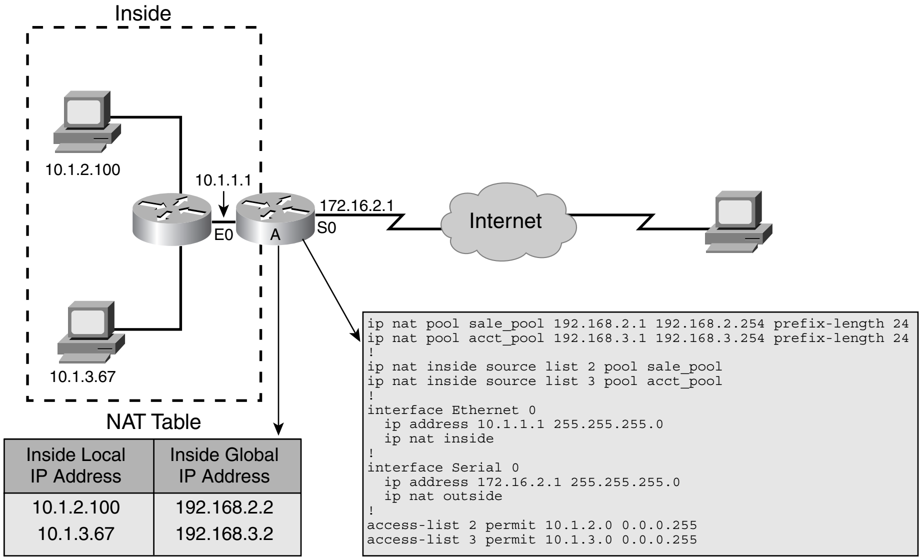
- **ip nat** {**inside** | **outside**}—This interface configuration command marks the IP networks attached to that interface as either internal or external to the controlled network. Only packets arriving on an interface marked as IP NAT inside or outside are subject to translation.
- **ip nat inside source list** {*access-list-number* | *access-list-name* } **pool** *pool-name*—When a packet comes in on an interface marked as IP NAT inside, this global configuration command causes the router to compare the source IP address in the packet to the access list referenced in the command. The access list indicates whether the router should translate that source IP address to the next available address in the *pool-name* listed. NAT translates an address that is permitted in the access list. Addresses that are not permitted by the access list are not translated, and the packet is routed normally.
- **ip nat pool** *pool-name starting-ip-address ending-ip-address* {**prefix-length** *prefix-length* | **netmask** *netmask*}—This global configuration command creates the translation pool referenced by the previous command. This command includes the starting and ending addresses for translation and either the prefix length or network mask associated with this range of addresses.

### Standard Access List Translation Example

In Figure 1-23, when an IP packet comes in on Ethernet 0 of Router A with a source address of 10.1.2.*x,* the router translates it from the NAT pool of addresses defined by the name **sale_pool**. If the packet has a source address of 10.1.3.*x,* the router translates it from the NAT pool of addresses defined by the name **acct_pool**.

In this example, the Information Services (IS) department maps different groups of users to different blocks of NAT addresses. The IS department determines the percentage of users per department who can use the NAT interface and assigns an appropriate number of addresses. The percentage of users can typically be determined using accounting or security software.

**Figure 1-23** *Translating with Standard Access Lists*



| Inside Local IP Address | Inside Global IP Address |
|---|---|
| 10.1.2.100 | 192.168.2.2 |
| 10.1.3.67 | 192.168.3.2 |

```
ip nat pool sale_pool 192.168.2.1 192.168.2.254 prefix-length 24
ip nat pool acct_pool 192.168.3.1 192.168.3.254 prefix-length 24
!
ip nat inside source list 2 pool sale_pool
ip nat inside source list 3 pool acct_pool
!
interface Ethernet 0
  ip address 10.1.1.1 255.255.255.0
  ip nat inside
!
interface Serial 0
  ip address 172.16.2.1 255.255.255.0
  ip nat outside
!
access-list 2 permit 10.1.2.0 0.0.0.255
access-list 3 permit 10.1.3.0 0.0.0.255
```

## Extended Access List Translation Example

The network used in this example is the same as that shown in Figure 1-23. However, in this configuration example, the extended access lists 102 and 103 are used to control NAT decisions. Instead of making the decision based only on the source address, an extended access list makes the decision based on the source and destination addresses of all packets coming in on interface Ethernet 0.

The configuration used on Router A is shown in Example 1-2.

**Example 1-2** *NAT Example Using Extended Access Lists on Router A in Figure 1-23*

```
ip nat pool trusted_pool 192.168.2.1  192.168.2.254 prefix-length 24
ip nat pool untrusted_pool 192.168.3.1 192.168.3.254 prefix-length 24
!
ip nat inside source list 102 pool trusted_pool
ip nat inside source list 103 pool untrusted_pool
!
interface ethernet 0
 ip address 10.1.1.1 255.255.0.0
 ip nat inside
!
interface serial 0
 ip address 172.16.2.1 255.255.255.0
 ip nat outside
!
access-list 102 permit ip  10.1.1.0 0.0.0.255  172.16.1.0 0.0.0.255
access-list 102 permit ip  10.1.1.0 0.0.0.255  192.168.200.0 0.0.0.255
access-list 103 permit ip  10.1.1.0 0.0.0.255  any
```

In this example, if the packet is not from the 10.1.1.0/24 subnet, the packet's source IP address is not translated. If the packet is from the 10.1.1.0/24 subnet and the destination address matches either 172.16.1.0/24 or 192.168.200.0/24, the source IP address is translated to the next available address in the trusted_pool, which is the 192.168.2.0/24 network.

If the packet is from the 10.1.1.0/24 subnet and the destination address does not match either 172.16.1.0/24 or 192.168.200.0/24, the source IP address is translated to the next available address in the untrusted_pool, which is the 192.168.3.0/24 network.

In this example, the outside NAT environment has both trusted and untrustworthy sites. For example, the company might be attached to an industry internetwork where it exchanges information with corporate partners and competitors. 172.16.1.0/24 and 192.168.200.0/24 are addresses of trusted networks on the industry internetwork, but all other destination addresses are considered untrustworthy. (A firewall system may also be added to allow greater control over the trusted sites.)

## Configuring NAT with Route Maps

A route map is a Cisco IOS software function that serves a variety of purposes. This section explains route maps and compares the results of using NAT with a route map to the results of using NAT with only an access list.

**NOTE** Route maps are discussed in more detail in Chapter 7, "Manipulating Routing Updates."

When you use only access lists for NAT, as described in the previous section, the resulting NAT table has only simple translation entries, identifying only which inside local address is being translated to which inside global address. Example 1-3 shows simple translation entries using the **show ip nat translations** command. The simple translation entry contains only local and global IP address entries. It does not include any TCP or UDP port information or the packet's destination address.

**Example 1-3** *Simple IP Address Translation Entries*

```
Router#show ip nat translations
Pro Inside global         Inside local       Outside local        Outside global
--- 192.168.2.1           10.1.2.100               ---                  ---
--- 192.168.3.1           10.1.3.67                ---                  ---
```

The entries in this IP NAT translation table are called simple entries because they track only the original source address (the inside local address) and the address to which it is translated (the inside global address). The other fields in the table are left blank. It is difficult to troubleshoot connectivity using simple address entries, because you do not see the destination address or the application (port) associated with each NAT translation. This might also prevent proper translation among multiple address pools. The first address pool matched creates a simple NAT entry; a second session initiated by the same source to a different host already matches the simple entry, thereby preventing proper translation to the second address pool. (Configuration Exercise 1-2, at the end of this chapter, includes an example of this translation problem.)

To get an extended translation entry in the NAT table, you must either configure NAT for overloading (using the **overload** keyword on the **ip inside source** command) or use a Cisco IOS software tool called a route map. Example 1-4 shows an example of an extended translation entry. The extended translation entry identifies the source and destination addresses with their appropriate translations, the transport layer protocol used, and the port (or application) used for the session.

**Example 1-4** *IP Address Translation with Route Maps*

```
Router#show ip nat translations
Pro Inside global        Inside local       Outside local      Outside global
udp 192.168.2.1:1024     10.1.2.100:1024    172.16.1.20:69     172.16.1.20:69
tcp 192.168.2.1:4097     10.1.2.100:4097    172.16.1.20:21     172.16.1.20:21
tcp 192.168.2.1:1084     10.1.2.100:1084    172.16.1.20:20     172.16.1.20:20
tcp 192.168.3.1:1024     10.1.3.67:1024     172.16.1.20:23     172.16.1.20:23
tcp 192.168.3.1:5553     10.1.3.67:5553     172.16.1.20:80     172.16.1.20:80
```

## Understanding Route Maps

Route maps are complex access lists that allow some conditions to be tested against the packet or route in question using **match** commands. If the conditions match, some actions can be taken to modify attributes of the packet or route. These actions are specified by **set** commands.

A collection of route map statements that have the same route map name are considered one route map. Within a route map, each route map statement is numbered and therefore can be edited individually.

The statements in a route map correspond to the lines of an access list. Specifying the match conditions in a route map is similar to specifying the source and destination addresses and masks in an access list.

**Key Point: Route Maps Versus Access Lists**

One big difference between route maps and access lists is that route maps can modify the route by using **set** commands.

The **route-map** *map-tag* [**permit | deny**] [*sequence-number*] global configuration command can be used to define the conditions for NAT. This command is explained in detail in Table 1-4.

**Table 1-4** **route-map** *Command*

| Command | Description |
|---|---|
| *map-tag* | Name of the route map |
| **permit** \| **deny** | Optional parameter that specifies the action to be taken if the route map match conditions are met |
| *sequence-number* | Optional sequence number that indicates the position that a new route map statement will have in the list of route map statements already configured with the same name |

The default for the **route-map** command is **permit**, with a *sequence-number* of 10.

**Route Map Sequence Numbering**

If you leave out the sequence number when configuring all statements for the same route map name, the router will assume that you are editing and adding to the first statement, sequence number 10. Route map sequence numbers do not automatically increment!

A route map may be made up of multiple route map statements. The statements are processed top-down, similar to an access list. The first match found for a route is applied. The sequence number is used for inserting or deleting specific route map statements in a specific place in the route map.

The **match** *condition* route map configuration commands are used to define the conditions to be checked. The **set** *condition* route map configuration commands are used to define the actions to be followed if there is a match and the action to be taken is permit. (The consequences of a deny action depend on how the route map is being used.)

A single match statement may contain multiple conditions. At least one condition in the match statement must be true for that match statement to be considered a match. A route map statement may contain multiple match statements. All match statements in the route map statement must be considered true for the route map statement to be considered matched.

**Key Point: Route Map Match Conditions**

Only one match condition listed on the same line must match for the entire line to be considered a match.

For example, IP standard or extended access lists can be used to establish match criteria using the **match ip address** {*access-list-number* | *name*} [...*access-list-number* | *name*] route map configuration command. (If multiple access lists are specified, matching any one results in a match.) A standard IP access list can be used to specify match criteria for a packet's source address; extended access lists can be used to specify match criteria based on source and destination addresses, application, protocol type, type of service (ToS), and precedence.

The sequence number specifies the order in which conditions are checked. For example, if two statements in a route map are named MYMAP, one with sequence 10 and the other with sequence 20, sequence 10 is checked first. If the match conditions in sequence 10 are not met, sequence 20 is checked.

Like an access list, an implicit deny any appears at the end of a route map. The consequences of this deny depend on how the route map is being used.

Another way to explain how a route map works is to use a simple example and see how a router would interpret it. Example 1-5 shows a sample route map configuration. (Note that on a router, all the conditions and actions shown would be replaced with specific conditions and actions, depending on the exact **match** and **set** commands used.)

**Example 1-5** **route-map** *Command*

```
route-map demo permit 10
  match x y z
  match a
  set b
  set c
route-map demo permit 20
  match q
  set r
route-map demo permit 30
```

The route map named **demo** in Example 1-5 is interpreted as follows:

```
If {(x or y or z) and (a) match} then {set b and c}
Else
    If q matches then set r
    Else
        Set nothing
```

## NAT with Route Maps Example

The **ip nat inside source route-map** *route-map-name* **pool** *pool-name* global configuration command causes the router to compare the source IP address in the packet to the route map referenced in the command. The route map indicates whether the router should translate that source IP address to the next available address in the *pool-name* listed. NAT translates an address that is matched in the route map.

Example 1-6 provides an alternative configuration for Router A in Figure 1-23. Two route maps have been added to the configuration shown in Figure 1-23. In this example, the what_is_sales_doing route map is linked to the sales_pool using the **ip nat inside source route-map what_is_sales_doing pool sales_pool** command.

**Example 1-6** *Alternative Configuration for Router A in Figure 1-23*

```
ip nat pool sales_pool 192.168.2.1 192.168.2.254 prefix-length 24
ip nat pool acct_pool 192.168.3.1 192.168.3.254 prefix-length 24
!
ip nat inside source route-map what_is_sales_doing pool sales_pool
ip nat inside source route-map what_is_acct_doing pool acct_pool
!
interface ethernet 0
  ip address 10.1.1.1 255.255.0.0
  ip nat inside
!
interface serial 0
  ip address 172.16.2.1 255.255.255.0
  ip nat outside
!
route-map what_is_sales_doing permit 10
  match ip address 2
!
route-map what_is_acct_doing permit 10
  match ip address 3
access-list 2 permit 10.1.2.0 0.0.0.255
access-list 3 permit 10.1.3.0 0.0.0.255
```

Following the path of a packet through this configuration is the best way to understand it. An IP packet with a source address of 10.1.2.100 arrives on interface Ethernet 0, which is an IP NAT inside interface. The **ip nat inside source route-map what_is_sales_doing pool sales_pool** command causes the router to send the packet to the what_is_sales_doing route map. Sequence 10 of this route map matches the packet's source IP address, 10.1.2.100, against access list 2, which permits the packet and therefore matches the route map. The router then queries the NAT pool sales_pool and obtains the next address to which to translate the 10.1.2.100 packet.

The what_is_acct_doing route map together with the **ip nat inside source route-map what_is_acct_doing pool acct_pool** command causes the router to look for source IP addresses in the 10.1.3.0/24 range and change them to source IP addresses in the 192.168.3.0/24 range.

As discussed, to examine the IP NAT translation table, use the **show ip nat translations** command. When using just an access list (as in the configuration shown in Figure 1-23), the router creates only a simple translation entry, one entry per application, without the TCP and UDP ports; Example 1-3 shows a simple translation entry. However, when using a route map, the router creates a fully extended translation entry in the IP NAT translation table, which includes the source and destination TCP or UDP port numbers. The extended translation entry shown in Example 1-4 results from the configuration in Example 1-6.

Notice in Example 1-4 that each session has individual entries; the IP address of each user and the applications in use can be determined from these entries. The local device with IP address 10.1.2.100 has three sessions with an outside device that has IP address 172.16.1.20. Example 1-4 shows that 10.1.2.100 has a TFTP session (UDP port 69) and an FTP session (TCP ports 20 and 21) with 172.16.1.20. Local device 10.1.3.67 has two sessions with the same remote device (172.16.1.20). Its two sessions are Telnet (TCP port 23) and HTTP (TCP port 80).

# Understanding IP Version 6

The ability to scale networks for future demands requires a new generation of IP addresses. IPv6 combines expanded addressing with a more efficient and feature-rich header to meet the demands for scalable networks in the future. This section describes the functionality and benefits of IPv6.

## Benefits of IPv6

IPv6 is a powerful enhancement to IPv4. Its primary features are as follows:

- The larger address space provides new global reachability, flexibility, aggregation, multihoming, autoconfiguration, plug and play, and renumbering. IPv6 increases the IP address size from 32 bits to 128 bits, allowing more support for addressing hierarchical levels, a much greater number of addressable nodes, and simpler autoconfiguration of addresses.
- The simpler, fixed-size header enables better routing efficiency, performance, and forwarding rate scalability.
- The numerous possibilities to transition from IPv4 to IPv6 allow existing IPv4 capabilities to exist with the added features of IPv6. Various mechanisms are defined for transitioning to IPv6, including dual stack, tunneling, and translation.
- Mobility and security ensures compliance with Mobile IP and IP Security (IPSec) standards.

Mobility is an important feature in networks. Mobile IP is an Internet Engineering Task Force (IETF) standard available for both IPv4 and IPv6. This standard lets mobile devices move without breaks in current connections. In IPv6, mobility is built in, which means that any IPv6 node can use it when necessary. However, mobility is not provided in IPv4; you must add it. IPv6's routing headers make mobile IPv6 much more efficient for end nodes than mobile IPv4.

IPSec is the IETF standard for IP network security. It enables integrity, authentication, and confidentiality. IPSec is available for both IPv4 and IPv6. Although the functionality is essentially identical in both environments, IPSec is mandatory in IPv6.

IPSec is enabled on every IPv6 node and is available for use, resulting in the IPv6 Internet being more secure. IPSec also requires keys for each party, which implies global key deployment and distribution.

**NOTE** RFC 2460, *Internet Protocol, Version 6 (IPv6) Specification* (available at www.cis.ohio-state.edu /cgi-bin/rfc/rfc2460.html), defines the IPv6 standard.

You can find information on IPv6 features supported in specific Cisco IOS releases by following the links on the *Cisco IOS IPv6* page, at www.cisco.com/warp/public/732/Tech/ipv6/.

## IPv6 Addressing

IPv6 increases the number of address bits by a factor of 4, from 32 to 128. During the IPv6 design specification, factoring to 64, 128, and 160 bits was considered. Ultimately, the design team selected 128 bits as the most appropriate factoring choice, resulting in a very large number of addressable nodes. (However, as in any addressing scheme, not all the addresses are used.)

**Key Point: IPv6 Addresses Are 128 Bits**

The 128 bits of an IPv6 address provide a much larger address space than IPv4.

IPv6 can provide approximately 3.4 * $10^{38}$ addresses (340,282,366,920,938,463,374,607,432,768,211,456), or approximately 5 * $10^{28}$ addresses for every person on the planet!

Increasing the number of bits for the address also increases the header size. Because each IP header contains a source and a destination address, the sizes of the header fields that contain the addresses are 64 bits for IPv4 and 256 bits for IPv6.

IPv6 allows hosts to have multiple IPv6 addresses and networks to have multiple IPv6 prefixes, thereby facilitating connection to multiple ISPs, for example.

### IPv6 Address Format

IPv6 addresses are represented as a series of 16-bit hexadecimal fields separated by colons (:), in the format *x:x:x:x:x:x:x:x*. Techniques are available to shorten written IPv6 addresses:

- The leading 0s within a field are optional.
- IPv6 addresses often contain successive hexadecimal fields of 0s. To shorten IPv6 addresses, two colons (::) may be used to compress and represent successive hexadecimal fields of 0s. This can be done at the beginning, middle, or end of an IPv6 address, but it is allowed only once in an address. To determine the number of missing 0s in an IPv6 address, write the two parts of the address separately, and fill in between with 0s until you have 128 bits.

**NOTE** An address parser identifies the number of missing 0s by separating the two parts and entering 0 until the 128 bits are complete. If two :: notations are placed in the address, there is no way to identify the size of each block of 0s.

For example, the IPv6 address 2031:**0000**:130F:**0000**:**0000**:**0**9C0:876A:130B can be written as 2031:**0**:130F**::**9C0:876A:130B. An *incorrect* way to write this address is 2031::130F::9C0:876A:130B; two colons are allowed only once in an address.

The address 0:0:0:0:0:0:0:0 can be written as :: because it contains all 0s.

**NOTE** The IPv6 addressing architecture is described in RFC 2373, *IP Version 6 Addressing Architecture,* available at www.cis.ohio-state.edu/cgi-bin/rfc/rfc2373.html.

Like the IPv4 prefix, the IPv6 prefix represents the *network* part of the address. The IPv6 prefix is written in *prefix*/*prefix-length* format; the *prefix-length* is a decimal value indicating the number of higher-order bits in the address that are included in the prefix. For example, 1080:5E40::/32 indicates that the higher-order 32 bits represent the network part of the address.

## IPv6 Address Types

**Key Point: IPv6 Address Types**

IPv6 addresses can be *unicast* (one-to-one), *anycast* (one-to-nearest), or *multicast* (one-to-many); IPv6 has no concept of a broadcast address.

**NOTE** Broadcasting in IPv4 results in a number of problems, including interrupting every computer on the network and, in some cases, completely hanging up an entire network (this is called a *broadcast storm*).

IPv6 *unicast* addresses are the same as IPv4 unicast: A single source sends data to a single destination. A packet sent to a unicast IPv6 address is delivered to the interface identified by that address.

An IPv6 *multicast* address is the same as in IPv4 multicast: an address for a set of interfaces (in a given scope) that typically belong to different nodes. A packet sent to a multicast address is delivered to all the interfaces identified by the multicast address (in a given scope). (IPv6 uses a 4-bit scope ID to specify address ranges reserved for multicast addresses for each scope.) Multicast addresses enable efficient network operation by using a number of functionally specific multicast groups to send requests to a limited number of computers on the network. The multicast groups prevent the majority of problems related to broadcast storms in IPv4. The range of multicast addresses in IPv6 is larger than in IPv4. For the foreseeable future, allocation of multicast groups is not being limited.

IPv6 defines a new type of address called an *anycast* address. It identifies a list of interfaces that typically belong to different nodes. A packet sent to an anycast address is delivered to the *closest* interface, as defined by the routing protocols in use, identified by the anycast address. In other words, devices that share the same characteristics are assigned the same anycast address. A sender interested in contacting a device (a receiver) with those characteristics sends a packet to the anycast address, and the routers deliver the packet to the receiver nearest to the sender. Anycast can be used for service location. For example, an anycast address could be assigned to a set of replicated FTP servers. A user in China who wants to retrieve a file would be directed to the Chinese server, and a user in Europe would be directed to the European server.

Anycast addresses are allocated from the unicast address space and must not be used as the source address of an IPv6 packet. To devices that are not configured for anycast, these addresses appear as unicast addresses. When a unicast address is assigned to more than one interface, thus turning it into an anycast address, the nodes to which the anycast address is assigned must be explicitly configured to know that it is an anycast address.

An example of anycast use in a Border Gateway Protocol (BGP) multihomed network is when a customer has multiple connections to multiple ISPs. The customer uses a different anycast address for each ISP; each router for that ISP has the same configured anycast address. The source device can choose which ISP to send the packet to. However, the routers along the path determine the closest router to reach that ISP using the anycast address.

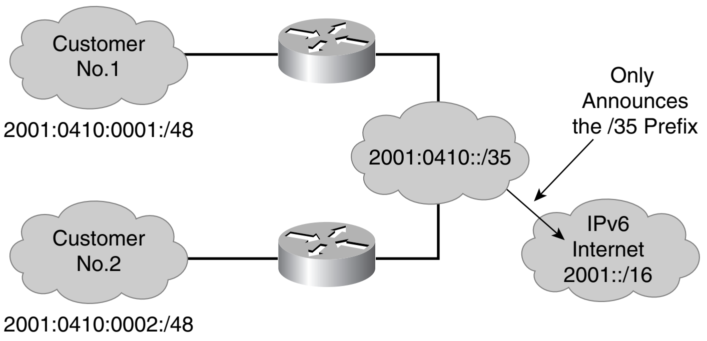
Another use for an anycast address is when a LAN is attached to multiple routers, and the routers are all configured with the same anycast address. Distant devices need to specify only the anycast address, and then intermediate devices can choose the best path to reach the closest entry point to that LAN.

## IPv6 Address Aggregation

A larger address space means that larger address allocations can be made to ISPs and organizations. As for IPv4, IPv6 summarization (or aggregation) reduces the routing table size and results in an efficient and scalable routing table. Scalable routing is necessary to connect to various devices and networks on the Internet in the future.

An ISP aggregates all its customers' prefixes into a single prefix and announces that single prefix to the IPv6 Internet, as shown in Figure 1-24.

**Figure 1-24** *IPv6 Address Summarization*



## IPv6 Autoconfiguration

A much larger address space allows IPv6 engineers to design a better way to enable autoconfiguration of the addresses and maintain their global uniqueness. The *stateless autoconfiguration* method is one way to do this. With stateless autoconfiguration, a router on the local link sends network-type information, such as the prefix of the local link and the default route, to all its nodes. An IPv6-enabled host uses the prefix advertised by the router as the top 64 bits of the address; the remaining 64 bits contain the 48-bit MAC address in an extended universal identifier 64-bit (EUI-64) format. This autoconfiguration produces a full 128-bit address that can be used on the local link and that guarantees global uniqueness.

**NOTE** IPv6 detects duplicate addresses in special circumstances to avoid address collision.

**The EUI-64 Format**

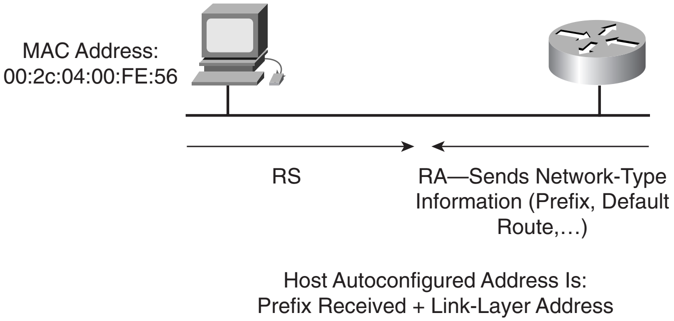
The EUI-64 format interface ID is derived from the 48-bit link-layer MAC address by inserting the hex number FFFE between the upper 3 bytes (the Organizational Unique Identifier [OUI] field) and the lower 3 bytes (the serial number) of the link-layer address. To make sure that the chosen address is from a unique MAC address, the seventh bit in the high-order byte is set to 1 (equivalent to the IEEE G/L bit) to indicate the uniqueness of the 48-bit address.

The information in this sidebar is derived from Cisco's "The ABCs of IP Version 6," available at www.cisco.com/warp/public/732/abc/docs/abcipv6.pdf.

Autoconfiguration enables a plug-and-play feature, which connects devices (such as DHCP servers) to the network without configuration. Plug and play is a key feature to deploy new devices on the Internet, including cell phones, wireless devices, home appliances, and networks.

Stateless autoconfiguration is accomplished via a handshake between the host and the router. As illustrated in Figure 1-25, the host sends a router solicitation (RS) at boot time to ask the router to send an immediate router advertisement (RA) on the local link. The router sends an RA immediately after the host sends an RS. The host therefore receives the autoconfiguration information without waiting for the next scheduled RA.

**Figure 1-25** *Stateless Autoconfiguration Means That IPv6 Can Be Plug and Play*


MAC Address:
00:2c:04:00:FE:56
RS
RA—Sends Network-Type Information (Prefix, Default Route,…)
Host Autoconfigured Address Is:
Prefix Received + Link-Layer Address

Routers also send RAs periodically, upon request, on all their configured interfaces. The router sends an RA to the *all-nodes* multicast address. Information contained in the RA message includes the following:

- One or more prefixes to use on the link
- A prefix's lifetime
- Flags that indicate the kind of autoconfiguration that hosts perform
- Default router information, including existence and lifetime
- Other types of host information

RA timing and other parameters can be configured on the routers.

## IPv6 Renumbering

RAs may announce the pending retirement of an old node prefix with a short lifetime and the use of a new node prefix. Decreasing the lifetime of the old prefix tells the nodes to begin using the new prefix and, at the same time, to continue maintaining connections opened with the old prefix for a period. During that period, nodes have two unicast addresses that they can use. When the old node prefix is retired (its lifetime decreases to 0), the RA announces only the new node prefix.

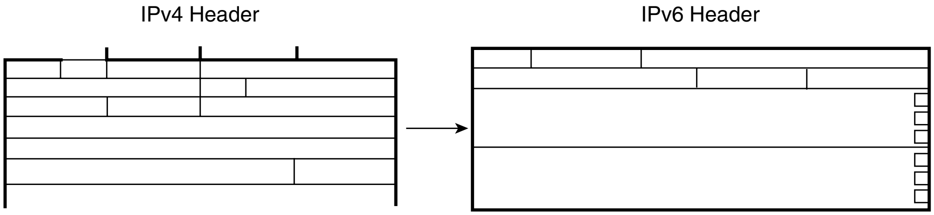
If you are renumbering an entire site, you must also renumber the routers. A router renumbering protocol is currently under review by the IETF. Renumbering an entire site also requires changes to the DNS entries; the introduction of new DNS records for IPv6 facilitates this process.

# IPv6 Packet Format

As illustrated in Figure 1-26, the new IPv6 header is less complicated than the IPv4 header in the following ways:

- It contains half of the previous IPv4 header fields. Fewer fields means easier packet processing, enhanced performance, and routing efficiency.
- It enables direct routing data storage and faster routing data retrieval with 64-bit aligned fields.

**Figure 1-26** *The IPv6 Header Is Simpler and More Efficient Than the IPv4 Header*

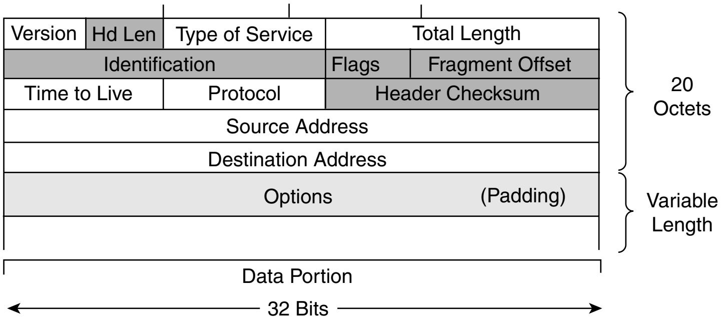


IPv6 header enhancements enable hardware-based processing that provides forwarding rate scalability for the next generation of high-speed lines. In the long term, it is clear that IPv6 improves routing efficiency. In the short term, however, the impact of the larger, 128-bit addressing remains unclear.

## IPv4 Header Format

As illustrated in Figure 1-27, the IPv4 header contains 12 basic header fields, followed by an Options field and a data portion (usually the transport layer segment). The basic IPv4 header has a fixed size of 20 octets. The variable-length Options field increases the size of the total IP header.

**Figure 1-27** *IPv4 Header Format*



IPv6 contains fields similar to seven of the 12 IPv4 basic header fields. The IPv6 header does not require the other fields for the following reasons:

- Routers handle fragmentation in IPv4, which causes a variety of processing issues. IPv6 routers no longer perform fragmentation. Instead, a discovery process is used to determine the most optimum maximum transmission unit (MTU) to use during a given session, as follows:

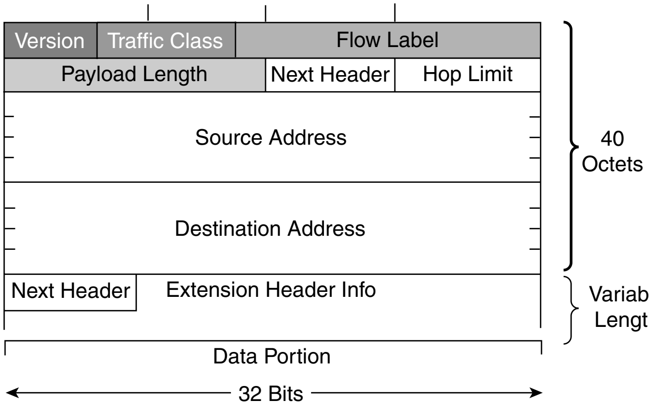
- In the discovery process, the source IPv6 device attempts to send a packet at the size specified by the upper IP layers—for example, the transport and application layers. If the device receives an "ICMP packet too big" message, it tells the upper layer to discard the packet and to use the new MTU. The "ICMP packet too big" message contains the proper MTU size for the pathway. Each source device needs to track the MTU size for each session. Generally, the tracking is done by creating a cache based on the destination address; however, it also can be built using the flow label. If source-based routing is performed, the tracking of the MTU size can be built using the source address.
- The discovery process is beneficial because as routing paths change, a new MTU can be more appropriate. When a device receives an "ICMP packet too big" message, it decreases its MTU size if the ICMP message contains a recommended MTU less than the device's current MTU. A device can perform MTU discovery every 5 minutes to see if the MTU has increased along the path.
- Applications and transport layers for IPv6 accept MTU reduction notifications from the IPv6 layer. If they do not, IPv6 has a mechanism to fragment packets that are too large. However, upper layers are encouraged to avoid sending messages that require fragmentation.

- Most currently implemented link-layer technologies already do checksum and error control. Because link-layer technologies are relatively reliable, an IP header checksum is considered redundant. Without the IP header checksum, the upper-layer optional checksums, such as UDP, are now mandatory.

## IPv6 Header Format

The IPv6 header is illustrated in Figure 1-28.

**Figure 1-28** *IPv6 Header Format*



**Key Point: IPv6 Header**

The IPv6 header has 40 octets in contrast to the 20 octets in IPv4. IPv6 has a smaller number of fields, and the header is 64-bit aligned to enable fast processing by current processors. The IPv6 address fields are four times larger than in IPv4.

The IPv6 header contains these fields:

- **Version**—A 4-bit field, the same as in IPv4, that indicates the IP version. It contains the number 6 for IPv6 instead of the number 4 for IPv4.
- **Traffic Class**—An 8-bit field similar to the ToS field in IPv4. It tags the packet with a traffic class that it uses in differentiated services. These functions are the same for IPv6 and IPv4.
- **Flow Label**—A new 20-bit field. It tags a flow for IP packets. It can be used for multilayer switching techniques and faster packet-switching performance.
- **Payload Length**—A 16-bit field similar to the Total Length field in IPv4. This field indicates the total length of the packet's data portion.
- **Next Header**—An 8-bit field similar to the Protocol field in IPv4. The value of this field determines the type of information following the basic IPv6 header. It can be a transport layer segment, such as TCP or UDP, or it can be an extension header.
- **Hop Limit**—This 8-bit field specifies the maximum number of hops that the IP packet can traverse. It is similar to the Time To Live (TTL) field in IPv4. Each hop or router decreases this field by 1. Because the IPv6 header has no checksum, the router can decrease the field without recomputing the checksum. (On IPv4 routers, the recomputation costs processing time.)
- **Source Address**—This field has 16 octets or 128 bits and contains the packet's source address.
- **Destination Address**—This field has 16 octets or 128 bits and contains the packet's destination address.

The extension headers, if any, and the packet's data portion follow the eight fields. The number of extension headers is not fixed, so the total length of the extension header chain is variable.

## Stream Control Transmission Protocol

IPv6 also uses Stream Control Transmission Protocol (SCTP) at the transport layer. SCTP is a reliable transport service like TCP and supports sequence and acknowledgment functions. SCTP was built to overcome TCP's limitations—for example, the TCP requirement for a strict order of transmission that can cause head-of-line blocking.

The main difference between the two protocols lies in SCTP's purpose. SCTP is used for multihomed nodes and to combine several streams within a single data connection. TCP sends a stream of bytes, and SCTP sends a stream of messages. In TCP, the application has to know how to divide the stream of bytes into usable segments. SCTP is designed to provide a general-purpose transport protocol for message-oriented applications, such as signaling used in the public telephone network. If multiple streams are integrated into one connection and one of these streams has reliability problems, all the streams in TCP have difficulty. SCTP is aware of the messages in the connection, and functionality is provided with SCTP to selectively acknowledge SCTP packets.

In multihoming, clients and servers can have multiple network interface cards (NICs), and each can be reached through a variety of physical pathways. During SCTP setup, the client informs the server of all its IP addresses. The client needs to know only a single address for the server, because when the server responds to the client, it has in its acknowledgment a list of addresses to use to reach it. SCTP monitors all paths between the devices with a heartbeat function and identifies one path as the primary. Secondary paths can be used for retransmissions or in case the primary path fails.

SCTP has greater security than TCP, because SCTP uses a cookie function for each session and is immune to a TCP SYN attack. For example, if Device A wants to set up an SCTP session with Device B, the following steps occur:

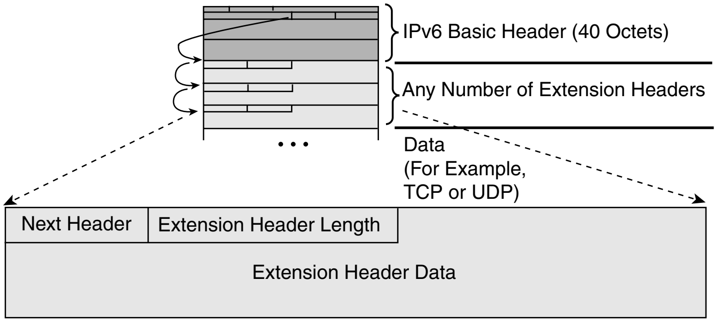
- Device A creates an initialization request and sends it to Device B. Device A then waits for a message from Device B.
- Device B receives the request, generates an encrypted key and a message authentication code (indicating who created the message), and puts these into a cookie message. It sends the cookie to Device A.
- Device A receives the cookie and sends it back to Device B in a cookie echo message. Device A again waits for a message from Device B.
- Device B receives the cookie echo message and examines it to ensure that the message authentication code indicates that it was indeed Device B that created the cookie. It sends a cookie acknowledgment to Device A. Only then does Device B initiate the SCTP session; it is now in a state in which it can accept and send data.
- Device A receives the cookie acknowledgment and enters a state in which it can accept and send data.

**NOTE** RFC 2960, *Stream Control Transmission Protocol* , available at www.cis.ohio-state.edu/cgi-bin/rfc/rfc2960.html, further describes SCTP.

## IPv6 Extension Headers

There are many types of extension headers. Each extension header is 64-bit aligned. The extension headers form a chained list of headers; the Next Header field of the previous header identifies each header, as shown in Figure 1-29.

**Figure 1-29** *IPv6 Extension Headers Form a Chained List of Headers*



When multiple extension headers are used in the same packet, their order is as follows:

1. IPv6 header
2. Hop-by-Hop Options header
3. Destination Options header (when using the Routing header)
4. Routing header
5. Fragment header
6. Authentication header
7. Encapsulating Security Payload header
8. Destination Options header
9. Upper-layer header

## IPv6 to IPv4 Interoperability

The transition from IPv4 to IPv6 will be a slow process, but fortunately it does not require upgrades on all nodes at the same time. Meanwhile, IPv4 and IPv6 must coexist.

Many transition mechanisms enable smooth integration of IPv4 and IPv6. Other mechanisms that allow IPv4 nodes to communicate with IPv6 nodes are available.

**Key Point: IPv6 Transition Techniques**

The two most common techniques to transition from IPv4 to IPv6 are as follows:

— **Dual stack**—IPv4 and IPv6 stacks run on a system. The system can communicate with both IPv4 and IPv6 devices.

— **Tunneling**—The most common type of tunneling used is IPv6 to IPv4 (6to4) tunneling to encapsulate IPv6 packets in IPv4 packets.

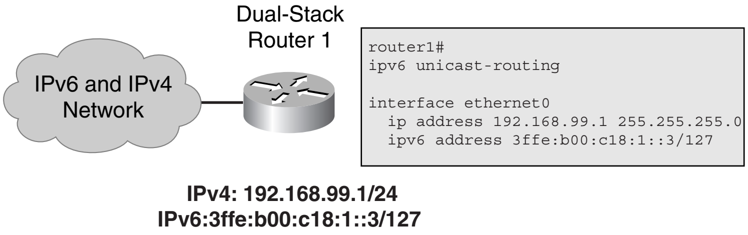
A third method uses an extension of IP NAT to translate an IPv4 address to an IPv6 address and an IPv6 address to an IPv4 address.

## Dual-Stack Transition

A dual stack enables both the IPv4 and IPv6 protocols. Cisco IOS software is IPv6-ready. As soon as IPv4 and IPv6 basic configurations are complete on an interface, the interface is dual stacked, and it forwards IPv4 and IPv6 traffic.

As shown in Figure 1-30, using IPv6 on a Cisco IOS software router requires the global configuration command **ipv6 unicast-routing**. This command enables the forwarding of IPv6 datagrams. All interfaces that forward IPv6 traffic must have an IPv6 address, assigned with the interface configuration command **ipv6 address** *IPv6-address* [*/prefix length*]. This command specifies the IPv6 address to be assigned to the interface and enables IPv6 processing on the interface.

**Figure 1-30** *Assigning IPv4 and IPv6 Addresses Creates a Dual-Stack Interface*



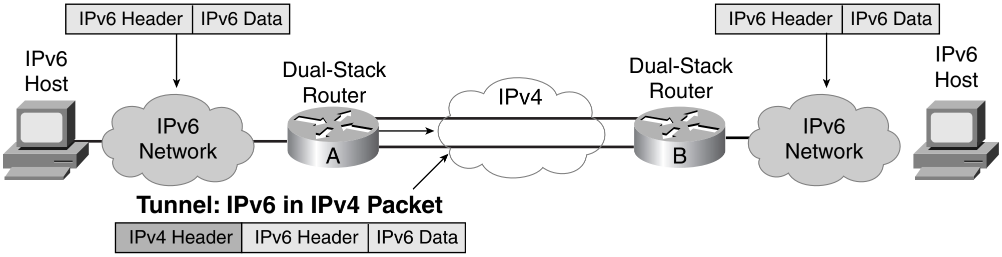
```
router1#
ipv6 unicast-routing

interface ethernet0
  ip address 192.168.99.1 255.255.255.0
  ipv6 address 3ffe:b00:c18:1::3/127
```

## Overlay Tunnels

Tunnels are often used to overlay an incompatible protocol on an existing network. Tunneling IPv6 traffic over an IPv4 network requires one edge router to encapsulate the IPv6 packet inside an IPv4 packet and another router to decapsulate the packet. This process lets you interconnect IPv6 islands without converting the entire network to IPv6, as illustrated in Figure 1-31.

**Figure 1-31** *Tunneling Encapsulates an IPv6 Packet in an IPv4 Packet*



When you tunnel, remember the following:

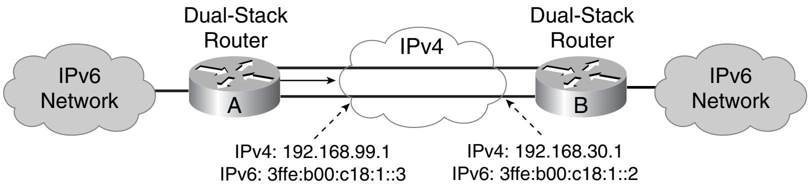
- If the IPv4 header does not contain an optional field, the MTU effectively decreases by 20 octets.
- A tunneled network is often difficult to troubleshoot. Tunneling is a *transition* technique that should be used only where it is appropriate; do not consider it a final architecture. Using native IPv6 throughout the network is still the final goal.

Tunnels can be either manually or automatically configured.

### Manually Configured Tunnel

In a manually configured tunnel, you configure both the IPv4 and IPv6 addresses statically on the routers at each end of the tunnel, as illustrated in Figure 1-32. These end routers must be dual-stacked, and the configuration does not change dynamically as network and routing needs change. Routing must be set up properly to forward a packet between the two IPv6 networks.

**Figure 1-32** *A Manually Configured Tunnel Has Static Addresses*

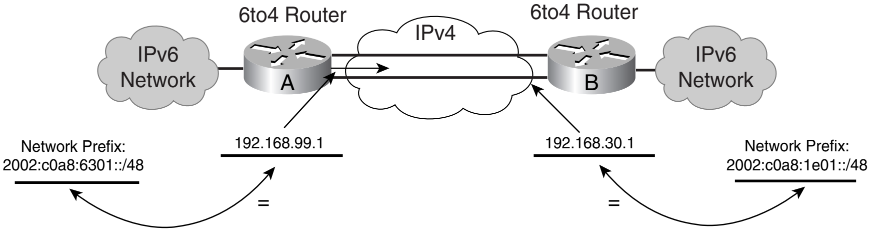


**NOTE** Tunnel endpoints can be unnumbered, but unnumbered endpoints make troubleshooting difficult. The IPv4 practice of saving addresses by using unnumbered tunnel endpoints is no longer an issue.

### 6to4 Tunneling

The 6to4 tunneling method automatically establishes and enables the connection of IPv6 islands through an IPv4 network, as illustrated in Figure 1-33. The 6to4 tunneling method assigns a valid IPv6 prefix to each IPv6 island, which enables the fast deployment of IPv6 in a corporate network without obtaining addresses from the ISPs or registries.

**Figure 1-33** *6to4 Tunneling Automatically Establishes Connections*



The 6to4 tunneling method requires configuration of the edge routers, but the IPv6 hosts and routers inside the 6to4 site do not require new features to support 6to4.

**Key Point: 6to4 Tunnel Addresses**

The 6to4 tunnel treats the IPv4 network as a virtual link. Each 6to4 edge router has an IPv6 address with a /48 prefix, which is the concatenation of 2002::/16 and the edge router's IPv4 address (in hexadecimal); 2002::/16 is a specially assigned address range for the purpose of 6to4. The edge routers automatically build the tunnel using the IPv4 addresses imbedded in the IPv6 addresses.

For example, if the edge router's IPv4 address is 192.168.99.1, the prefix of its IPv6 network is 2002:c0a8:6301::/48, because c0a86301 is the hexadecimal representation of 192.168.99.1.

When the edge router receives an IPv6 packet with a destination address in the range of 2002::/16, it determines from its routing table that the packet must go through the tunnel. The router extracts the IPv4 address embedded as the third to sixth octets inclusive in the IPv6 next-hop address; this is the IPv4 address of the 6to4 router at the other end of the tunnel. The router encapsulates the IPv6 packet in an IPv4 packet with the extracted IPv4 address of the destination edge router. The packet then goes through the IPv4 network. The destination edge router decapsulates the IPv6 packet from the received IPv4 packet and forwards the IPv6 packet to its final destination. (To be able to reach a native IPv6 Internet, a 6to4 relay router, which offers traffic forwarding to the IPv6 Internet, is needed.)

## IPv6 Routing Protocols

This section introduces IPv6 routing protocols and compares them to their IPv4 counterparts.

The routing protocols available in IPv6 include interior gateway protocols (IGPs), for within an autonomous system, and exterior gateway protocols (EGPs), for between autonomous systems. The following routing protocols or draft proposals are available:

- IGPs:
  - RIP new generation (RIPng)
  - OSPF version 3 (OSPFv3)
  - Integrated IS-IS version 6 (IS-ISv6)
- EGP—BGP4+

**NOTE** Routing protocols for IPv4 are discussed in detail in other chapters.

## RIPng

RIPng is a distance-vector protocol with a limit of 15 hops that uses split horizon and poison reverse to prevent routing loops. IPv6 features include the following:

- RIPng is based on the IPv4 RIPv2 and is similar to RIPv2.
- RIPng uses an IPv6 prefix and next-hop IPv6 address.
- A multicast group, FF02::9, is the all-RIP-routers multicast group and is used as the destination address for RIP updates.
- RIPng uses IPv6 for transport.

**NOTE** RIPng is defined in RFC 2080, *RIPng for IPv6*, available at www.cis.ohio-state.edu/cgi-bin/rfc/rfc2080.html.

## OSPFv3

OSPFv3 is a new protocol implementation for IPv6. It has the following features:

- OSPFv3 is similar to the IPv4 version of OSPF.
- OSPFv3 carries IPv6 addresses.
- OSPFv3 uses IPv6 link-local unicast addresses as source addresses. (A link-local unicast address can serve as a method of connecting devices on the same local network without the need for either site-local or globally unique addresses.)
- OSPFv3 uses IPv6 for transport.

**NOTE** OSPFv3 is defined in RFC 2740, *OSPF for IPv6*, available at www.cis.ohio-state.edu/cgi-bin/rfc/rfc2740.html.

## Integrated IS-ISv6

The large address support in Integrated IS-ISv6 facilitates the IPv6 address family. IS-ISv6 is the same as IS-IS for IPv4, with the following extensions added for IPv6:

- Two new types, lengths, values (TLVs):
  - IPv6 reachability
  - IPv6 interface address
- A new protocol identifier

### BGP4+

Multiprotocol extensions for BGP4 let other protocols besides IPv4 be routed, including IPv6. Other IPv6-specific extensions also are included in BGP4+, including the definition of a new identifier for the IPv6 address family.

**NOTE** Multiprotocol extensions to BGP are defined in RFC 2858, *Multiprotocol Extensions for BGP-4* , available at www.cis.ohio-state.edu/cgi-bin/rfc/rfc2858.html. BGP4+ for IPv6 is defined in RFC 2545, *Use of BGP-4 Multiprotocol Extensions for IPv6 Inter-Domain Routing*, available at www.cis.ohio-state.edu/cgi-bin/rfc/rfc2545.html.

**NOTE** Cisco routers support the RIPng, IS-ISv6, and BGP4+ routing protocols. OSPFv3 is also supported on some platforms. You can find information on IPv6 features supported in specific Cisco IOS releases and platforms by following the links on the *Cisco IOS IPv6* page, at www.cisco.com/warp/public/732/Tech/ipv6/.

In the Cisco 12000 Internet Router Series, IPv6 routing is supported in the Cisco IOS 12.0(22)S configuration and later. In all other platforms, the IPv6 routing protocols are supported in IOS 12.2(2)T and later. Redistribution is not supported between IPv4 routing protocols and IPv6 routing protocols.

The largest use of IPv6 is across the Internet using BGP extensions for IPv6.

## Summary

In this chapter, you learned that networks must be designed to support the benefits of advanced IP routing protocols. Well-designed networks allow corporations to react quickly to changes in their networking requirements, including mergers, reorganizations, and downsizing.

There are two types of hierarchical network design: functional and geographic. In a functional network design, the different divisions of a corporation have their own networks and are connected according to their functional purpose within the corporate structure. In a geographic network design, the divisions of a corporation have their own networks and are connected according to their location.

The access, distribution, and core layers comprise a hierarchical scalable network design.

In a fully meshed core layer design, all routers in the core have direct connections to all other routers in the core. A core layer hub-and-spoke configuration establishes a focal point for the data flow at a key site.

A good IP addressing plan implemented in a well-designed network provides scalability, predictability, and flexibility.

RFC 1918 has set aside the following IPv4 address space for private use:

- **Class A network**—10.0.0.0 to 10.255.255.255
- **Class B network**—172.16.0.0 to 172.31.255.255
- **Class C network**—192.168.0.0 to 192.168.255.255

The benefits of hierarchical addressing include a reduced number of routing table entries and efficient allocation of addresses.

A subnet mask is a 32-bit value that identifies which bits in an address represent network bits and which represent host bits. To create a subnet mask for an address, use a 1 for each bit of the address that you want to represent the network or subnet portion of the address, and use a 0 for each bit of the address that you want to represent the node portion of the address. The number of subnetworks created by adding *n* bits to the default mask is calculated by the formula $2^n$. The number of hosts available is calculated by the formula $2^n - 2$, where *n* is the number of bits in the host portion.

A prefix is a slash (/) followed by a numeric value that is the number of bits in the network and subnet portions of the address—in other words, the number of contiguous 1s that would be in the subnet mask.

A major network is a Class A, B, or C network. With classful routing, routing updates do not carry the subnet mask. Therefore, only one subnet mask must be in use within a major network; this is known as FLSM. With classless routing, routing updates do carry the subnet mask. Therefore, different masks may be used for different subnets within a major network; this is known as VLSM.

With VLSM, it is important to remember that only *unused* subnets should be further subnetted. In other words, if you use any addresses from a subnet, that subnet should not be further subnetted.

Route summarization (also called *route aggregation* or *supernetting* ) can reduce the number of routes that a router must maintain, because it is a method of representing a series of network numbers in a single summary address. Route summarization is most effective within a subnetted environment when the network addresses are in contiguous blocks in powers of 2.

Routing information advertised out an interface is automatically summarized at major (classful) network address boundaries by RIP, IGRP, and EIGRP. When using EIGRP and RIPv2, you can disable this automatic summarization. For OSPF and IS-IS, you must configure summarization.

CIDR is a mechanism developed to help alleviate the problem of exhaustion of IP addresses and growth of routing tables. The idea behind CIDR is that blocks of multiple addresses (for example, blocks of Class C address) can be combined, or aggregated, to create a larger classless set of IP addresses, with more hosts allowed.

The difference between CIDR and route summarization is that route summarization is generally done within, or up to, a classful boundary, whereas CIDR combines several classful networks.

NAT terminology includes the following:

- **Inside local IP address**—The IP address used by the inside host before any translations.
- **Inside global IP address**—The IP address used by the inside host as it appears to the outside network; this is the translated IP address.
- **Outside global IP address**—The configured globally unique IP address assigned to a host in the outside network.
- **Outside local IP address**—The IP address of an outside host as it appears to the inside network.

When you use only access lists for NAT, the resulting NAT table has only simple translation entries, identifying only which inside local address is being translated to which inside global address. To get an extended translation entry in the NAT table, you must either configure NAT for overloading or use route maps.

Route maps are complex access lists that allow some conditions to be tested against a packet or route in question using **match** commands. If the conditions match, some actions can be taken to modify attributes of the packet or route. These actions are specified by **set** commands.

IPv6 addresses have 128 bits. The IPv6 header has 40 octets in contrast to the 20 octets in IPv4. IPv6 has a smaller number of fields, and the header is 64-bit aligned to enable fast processing by current processors. The IPv6 address fields are four times larger than in IPv4.

IPv6 addresses are represented as a series of 16-bit hexadecimal fields separated by colons (:), in the format *x:x:x:x:x:x:x:x*. The leading 0s within a field are optional. Two colons (::) may be used to compress successive hexadecimal fields of 0s. This can be done at the beginning, middle, or end of an IPv6 address, but it is allowed only once in an address.

IPv6 addresses can be *unicast* (one-to-one), *anycast* (one-to-nearest), or *multicast* (one-to-many); IPv6 has no concept of a broadcast address.

With IPv6 *stateless autoconfiguration,* a router on the local link sends network-type information to all its nodes. An IPv6-enabled host uses the prefix advertised by the router as the top 64 bits of the address; the remaining 64 bits contain the 48-bit MAC address in an extended universal identifier 64-bit (EUI-64) format. This autoconfiguration produces a full 128-bit address that can be used on the local link and that guarantees global uniqueness.

The two most common techniques to transition from IPv4 to IPv6 are as follows:

- **Dual stack**—IPv4 and IPv6 stacks run on a system. The system can communicate with both IPv4 devices and IPv6 devices.
- **Tunneling**—The most common type of tunneling used is IPv6 to IPv4 (6to4) tunneling, to encapsulate IPv6 packets in IPv4 packets. Each 6to4 edge router has an IPv6 address with a /48 prefix, which is the concatenation of 2002::/16 and the edge router's IPv4 address (in hexadecimal). The edge routers automatically build the tunnel using the IPv4 addresses imbedded in the IPv6 addresses.

The following routing protocols or draft proposals are available for IPv6: RIPng, OSPFv3, IS-ISv6, and BGP4+.

## References

For additional information, refer to these resources:

- Cisco IP Version 6 Solutions, www.cisco.com/univercd/cc/td/doc/cisintwk/intsolns/ipv6_sol/index.htm.
- Cisco IOS IPv6, www.cisco.com/warp/public/732/Tech/ipv6.
- "The ABCs of IP Version 6," www.cisco.com/warp/public/732/abc/docs/abcipv6.pdf.

## Configuration Exercise 1-1: Basic Connectivity

In this exercise, you give the routers in your pod a basic configuration.

**Introduction to the Configuration Exercises**

This book uses Configuration Exercises to help you practice configuring routers with the commands and topics presented. If you have access to real hardware, you can try these exercises on your routers. See Appendix H, "Configuration Exercise Equipment Requirements and Initial Configurations," for a list of recommended equipment and initial configuration commands for the routers. However, even if you don't have access to any routers, you can go through the exercises and keep a log of your own running configurations or just read through the solution. Commands used and solutions to the Configuration Exercises are provided after the exercises.

In the Configuration Exercises, the network is assumed to consist of two pods, each with four routers. The pods are interconnected to a backbone. You configure pod 1. No interaction between the two pods is required, but you might see some routes from the other pod in your routing tables in some exercises if you have it configured (the Configuration Exercise answers show the routes from the other pod). In most of the exercises, the backbone has only one router; in some cases, another router is added to the backbone. Each Configuration Exercise assumes that you have completed the previous chapters' Configuration Exercises on your pod.

**NOTE** Throughout this exercise, the pod number is referred to as *x*, and the router number is referred to as *y*. Substitute the appropriate numbers as needed.

### Objectives

Given that the routers in your pod are properly cabled, your task is to do the following:

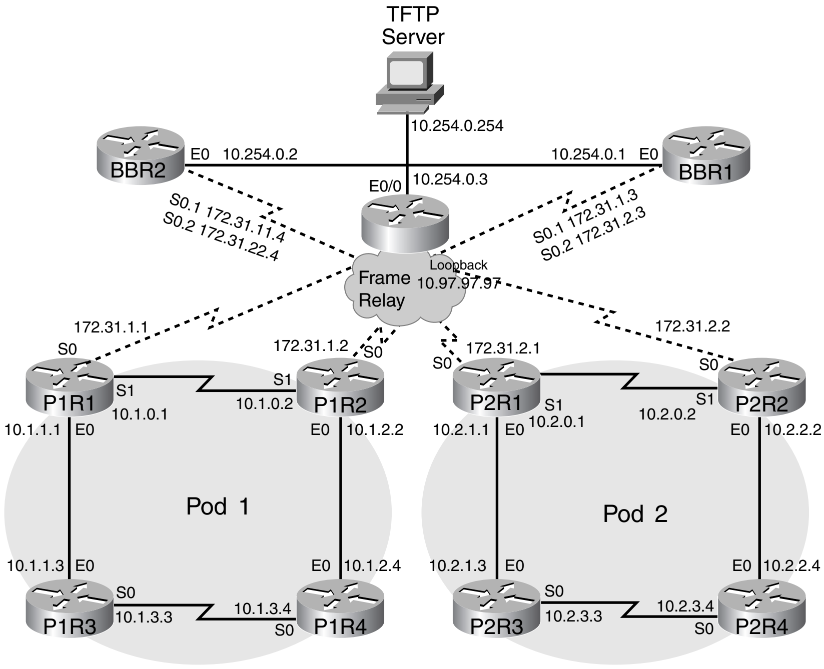
- Provide an initial configuration on your edge routers, P*x*R1 and P*x*R2, so that you can connect to the TFTP server in the core.

- Connect to the TFTP server in the core from the P*x*R1 and P*x*R2 routers.
- Download a configuration file and complete the setup of your edge routers.

## Visual Objective

Figure 1-34 illustrates the topology used in this exercise. You will configure only the P*x*R1 and P*x*R2 routers in this exercise.

**Figure 1-34** *Basic Configuration Exercise Topology*



**NOTE** Backbone Router 2 (BBR2), shown in Figure 1-34, is not used until a later Configuration Exercise.

## Command List

In this exercise, you use the commands in Table 1-5, listed in logical order. Refer to this list if you need configuration command assistance during the exercise.

**CAUTION** Although the command syntax is shown in this table, the addresses shown are typically for the P*x*R1 and P*x*R3 routers. Be careful when addressing your routers! Refer to the exercise instructions and the appropriate visual objective diagram for addressing details.

**Table 1-5** *Basic Configuration Exercise Commands*

| Command | Description |
|---|---|
| (config-if)#**encapsulation frame-relay** | Enables Frame Relay encapsulation. |
| (config-if)#**ip address 172.31.*x*.*y* 255.255.255.0** | Assigns an IP address. |
| (config-if)#**frame-relay map ip 172.31.*x*.3 1*xy* broadcast** | Maps a next-hop IP address to a permanent virtual circuit (PVC). |
| (config-if)#**no shutdown** | Brings up an interface. |
| (config)#**ip route 10.0.0.0 255.0.0.0 172.31.*x*.3** | Creates a static route. |
| #**copy tftp run** | Copies the configuration file into the running configuration from a TFTP server. |
| #**copy run start** | Copies the running configuration file (in RAM) into the startup configuration file (in NVRAM). |

**NOTE** Refer to Appendix C, "Summary of ICND Router and Switch Commands," for a listing of the Cisco IOS router commands covered in the Cisco Press *Interconnecting Cisco Network Devices* book, which this book assumes that you are familiar with.

## Task: Setting Up the Edge Routers

In this task, you will use a terminal utility to establish a console connection to the equipment. You will establish connectivity between the edge routers in your pod (P*x*R1 and P*x*R2) and the BBR1 router. Then you will download configurations to these routers from the TFTP server in the core. Complete the following steps:

**Step 1** Connect to each of your pod routers; they should not have configurations on them. If a router does have a configuration, delete the configuration using the **erase start** command, and then use the **reload** command to reboot.

**NOTE** In this exercise, you will apply some minimal addressing and routing information so that your routers can reach the TFTP server.

**Step 2** Connect to each of your pod edge routers (P*x*R1 and P*x*R2). Configure the serial s0 interface of these routers for Frame Relay by turning on Frame Relay encapsulation.

**Step 3** Assign an IP address to your serial 0 interface. Your IP address is 172.31.*x*.*y*/24 (where *x* is your pod number and *y* is your router number).

**Step 4** Inverse ARP has been turned off in the core Frame Relay network. Manually map a data-link connection identifier (DLCI) to BBR1 (172.31.*x*.3). The DLCI number will be in the form 1*xy*, where *x* is your pod number and *y* is your router number. For instance, P2R1 will use DLCI 121.

**NOTE** Remember to specify the **broadcast** keyword so that the Frame Relay mapping supports broadcasts and multicasts, such as routing protocol traffic.

**Step 5** Use the **no shutdown** command on the interface, and exit configuration mode.

**Step 6** Verify successful connectivity from your P*x*R1 and P*x*R2 router to the core BBR1 router (172.31.*x*.3) using the **ping** command.

**Step 7** The goal of this exercise is to download a file from the TFTP server (at 10.254.0.254), which is connected to BBR1. Look at your P*x*R1 and P*x*R2 routing tables. Is there a route to the network that the TFTP server is located on? Why not?

**Step 8** Add a static route to 10.0.0.0/8 on your edge routers, through BBR1 (172.31.*x*.3), to provide a path to the TFTP server. Verify that the edge routers can see this route.

**Step 9** Verify successful connectivity to the TFTP server (10.254.0.254) from your P*x*R1 and P*x*R2 router using the **ping** command.

**Step 10** Retrieve the configuration file for your router from the TFTP server. The file should be named P*x*R*y*.txt. (For example, Pod 1 Router 2 will download P1R2.txt.)

**NOTE** Filenames are not case-sensitive.

**NOTE** The configuration files include the **no ip classless** command to force your router to behave classfully (although this command is on by default in IOS 12.0 and later). These files also include all required IP addresses and enable all required interfaces. Remember that files copied to running-config are merged, so this configuration complements what is already in your running-config.

**NOTE** The initial configuration files for the routers are provided in Appendix H.

**Step 11** Save your configuration before proceeding.

## Exercise Verification

You have successfully completed this exercise if you can ping the core BBR1 router and the TFTP server from your edge routers (P*x*R1 and P*x*R2) and if you have downloaded the configuration files for your edge routers from the TFTP server.

# Configuration Exercise 1-2: NAT Using Access Lists and Route Maps

In this exercise, you will use NAT to allow your internal routers (P*x*R3 and P*x*R4) to download a configuration file from the TFTP server.

**NOTE** Throughout this exercise, the pod number is referred to as *x*, and the router number is referred to as *y*. Substitute the appropriate numbers as needed.

## Objectives

After completing this exercise, you will be able to

- Demonstrate the uses and limits of access control list (ACL)-based NAT
- Demonstrate the usefulness of NAT with route maps by implementing separate concurrent translations
- Connect the internal router to the TFTP server or the opposite edge router using appropriate translation
- Download a configuration file for the internal routers

## Visual Objective

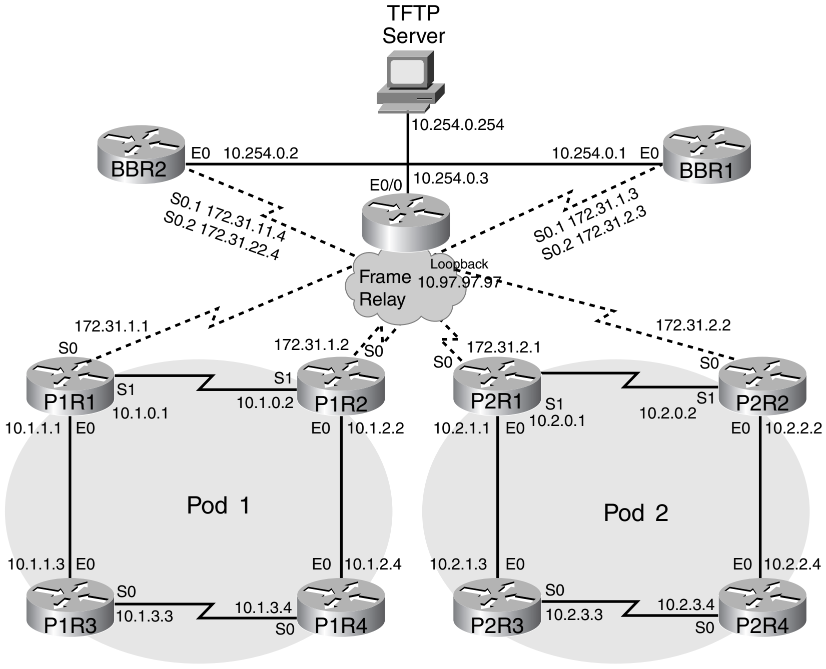
Figure 1-35 illustrates the topology used in this exercise.

**NOTE** Backbone Router 2 (BBR2), shown in Figure 1-35, is not used until a later Configuration Exercise.

## Command List

In this exercise, you will use the commands in Table 1-6, listed in logical order. Refer to this list if you need configuration command assistance during the exercise.

**Figure 1-35** *NAT Configuration Exercise Topology*



**CAUTION** Although the command syntax is shown in this table, the addresses shown are typically for the P*x*R1 and P*x*R3 routers. Be careful when addressing your routers! Refer to the exercise instructions and the appropriate visual objective diagram for addressing details.

**Table 1-6** *NAT Configuration Exercise Commands*

| Command | Description |
|---|---|
| (config)#**access-list 100 permit ip 10.1.*x*.0 0.0.0.255 10.254.0.0 0.0.0.255** | Creates an access list that specifies the traffic that should be translated. |
| (config)#**ip nat pool BBR 192.168.*x*.1 192.168.*x*.254 netmask 255.255.255.0**<br>or<br>(config)#**ip nat pool BBR 192.168.*x*.1 192.168.*x*.254 prefix-length 24** | Creates a named pool of addresses for use by NAT. |
| (config)#**ip nat inside source list 100 pool BBR** | Translates inside addresses that match the access list into this pool. |

*continues*

**Table 1-6** *NAT Configuration Exercise Commands (Continued)*

| Command | Description |
|---|---|
| (config-if)#**ip nat inside** | Identifies an inside NAT address. |
| (config-if)#**ip nat outside** | Identifies an external NAT address. |
| (config)#**ip route 0.0.0.0 0.0.0.0 e0** | Creates a default route pointing out interface E0. |
| #**show ip nat translations** | Views the translation table. |
| #**debug ip icmp** | Starts the console display of ICMP events. |
| #**debug ip packet** | Starts the console display of IP packet events. |
| (config)#**route-map TO_BBR permit 10**<br>(config-route-map)#**match ip address 100** | Creates a route map to match the source address with addresses permitted by the access list. |
| #**clear ip nat translation *** | Removes all address translations from the NAT table. |
| (config)#**ip nat inside source route-map TO_POD pool POD** | Specifies a route map to be used for NAT. |
| #**debug ip nat detailed** | Starts the console display of translation entries being created. |

## Task 1: Connecting the Internal Router to the Edge Router

In this task, you will connect the internal routers in your pod, P*x*R3 and P*x*R4, to the edge routers, P*x*R1 and P*x*R2. Complete the following steps:

**Step 1** The internal routers (P*x*R3 and P*x*R4) should not have a configuration. If a configuration is present, use the **erase start** and **reload** commands to clear the configuration and reload the router.

**Step 2** Connect to your internal routers. Supply an IP address to the Ethernet interface, and enable the interface. The Ethernet address of P*x*R3 should be 10.*x*.1.3/24, and the Ethernet address of P*x*R4 should be 10.*x*.2.4/24.

**Step 3** P*x*R1 has an Ethernet address of 10.*x*.1.1, and P*x*R2 has an Ethernet address of 10.*x*.2.2. Verify connectivity to the Ethernet-attached edge router from each internal router.

## Task 2: Setting Up ACL-Based NAT

In this task, you will configure one-to-one NAT using an access list on the edge routers (P*x*R1 or P*x*R2). The access list translates the internal router Ethernet address using either 192.168.*x*.0/24 or 192.168.*xx*.0/24.

**NOTE** BBR1 has static routes for 192.168.*x*.0/24 and 192.168.*xx*.0/24. It does not have any remote routes for the pod 10.*x*.0.0 addresses, only its local TFTP server network 10.254.0.0.

Complete the following steps:

**Step 1** On the P*x*R1 and P*x*R2 routers, configure the sources to be translated using extended access list 100. Access list 100 should match traffic sourced from the network on your edge router's Ethernet interface, destined for the network that the TFTP server is located on. For example, P*x*R1 should match traffic sourced from 10.*x*.1.0/24, and P*x*R2 should match traffic sourced from 10.*x*.2.0/24. The access list must match only packets with a destination of 10.254.0.0/24.

**Step 2** On the P*x*R1 and P*x*R2 routers, create a pool of addresses called **BBR** for use by NAT, using the **ip nat pool** command. P*x*R1 should use the address range of 192.168.*x*.0/24, and P*x*R2 should use 192.168.*xx*.0/24. For example, P2R1 would use 192.168.2.1 through 192.168.2.254, and P2R2 would use 192.168.22.1 through 192.168.22.254.

**Step 3** On the P*x*R1 and P*x*R2 routers, use the **ip nat inside source list** command to specify that packets that match access list 100 should have their source addresses translated into the BBR pool.

**Step 4** On the P*x*R1 and P*x*R2 routers, define which interfaces are inside or outside for NAT translation purposes.

**Step 5** On the P*x*R3 and P*x*R4 routers, configure a default route pointing to the attached edge router e0 interface. This configuration allows the internal router to reach the core network.

**Step 6** From the P*x*R3 and P*x*R4 routers, verify connectivity to the TFTP server (10.254.0.254) using the **ping** command.

**CAUTION** You will not be able to reach the TFTP server if the NAT translation is not done correctly.

**Step 7** View the NAT translation table on the edge router (P*x*R1 and P*x*R2).

## Task 3: Translating to the Other Edge Router

In this task, you will translate traffic from the odd half of the pod (P*x*R1 and P*x*R3) to the even half of the pod (P*x*R2 and P*x*R4) and vice versa. Because you are not running a routing protocol, you will translate the internal addresses to addresses that would be appropriate on the serial link between P*x*R1 and P*x*R2. Complete the following steps:

**Step 1** On the P*x*R1 and P*x*R2 routers, configure the source addresses to be translated using extended access list 101. Access list 101 should match traffic sourced from the network on your edge router's Ethernet interface, bound for any destination. For instance, P*x*R1 should match traffic from 10.*x*.1.0/24, and P*x*R2 should match traffic from 10.*x*.2.0/24. The access list must match packets with a destination to any network.

**Step 2** On the P*x*R1 and P*x*R2 routers, create a pool of addresses named **POD** for use by NAT. P*x*R1 should use the address range 10.*x*.0.64 to 10.*x*.0.95, and P*x*R2 should use the address range 10.*x*.0.96 to 10.*x*.0.127.

**Step 3** On the P*x*R1 and P*x*R2 routers, specify that packets that match access list 101 should have their source addresses translated into the POD pool.

**Step 4** At the P*x*R1 and P*x*R2 routers, define the S1 interface of each router as the NAT outside interface by using the **ip nat outside** command so that traffic from the respective internal routers is translated.

**Step 5** From one internal router, ping the Serial 1 interface of the nonconnected edge router. (For example, from P*x*R3, ping the Serial 1 address of P*x*R2.) Is the ping successful?

**Step 6** Look at the IP translation table on the edge routers to help explain the result of the previous ping.

**Step 7** From the nonconnected edge router, use the **debug ip icmp** and **debug ip packet** commands while the pings are still active. Observe the output to help explain the results of the previous ping. Turn off all debugging when you are finished.

**Step 8** Look at the routing table on the nonconnected edge router. Is there a route back to the destination address of the ping echo reply message?

**Step 9** What does a router do when it does not find an appropriate address?

## Task 4: Using a Route Map with NAT to Translate Internal Addresses

In this task, you will configure NAT using a route map to match traffic. You saw in Task 3 that when NAT uses an access list without overloading addresses, the translation entry contains only local and global inside IP addresses. When a route map is used with NAT, the translation entry contains both the inside and outside (local and global) address entries and any TCP or UDP port information. This translation entry lets the router recognize different conversations.

In this exercise, traffic needs to be translated based on destination. Traffic to the TFTP server and the core should still be translated to 192.168.*x*.0/24 or 192.168.*xx*.0/24, but traffic to the other edge router should be translated to an IP address in the 10.*x*.0.0 subnet. This address will appear to be local to the serial 1 interface of the other edge and will have a path entered in the routing table (connected routes are automatically in the routing table). To prevent confusion, P*x*R1 uses the address range of 10.*x*.0.64/24 through 10.*x*.0.95/24, and P*x*R2 uses the address range of 10.*x*.0.96/24 through 10.*x*.0.127/24.

Complete the following steps:

**Step 1** Create a route map that will be used to conditionally translate traffic based on the packet's destination.

**Step 2** Replace the translation commands from Task 3 with route map-based commands to perform the required translation.

**NOTE** If the router reports "%Dynamic mapping in use, cannot remove," simply go to privileged mode and enter the **clear ip nat translation *** command to remove all mappings. You then can configure the router.

**Step 3** Ping from one internal router to the opposite edge router and to the TFTP server to verify that the previous step was successful. Turn on **debug ip nat detailed** debugging on the edge routers to see the translation.

**Step 4** Use the **show ip nat translations** command on each edge router to see the resulting NAT translation table.

## Task 5: Downloading a Configuration File

Now that NAT is properly configured and working, you will download a configuration for the internal routers (P*x*R3 and P*x*R4).

On the internal routers, use TFTP to download the configuration file called P*x*R*y*.txt from the TFTP server to the running-config.

**NOTE** The configurations for P*x*R3 and P*x*R4 include the command **no ip classless** in preparation for the next Configuration Exercise at the end of the next chapter. If you try to communicate with the TFTP server now, it will not work. The reasoning behind this behavior is examined in the next Configuration Exercise.

## Exercise Verification

You have successfully completed this exercise when you achieve the following results:

- Your internal router can ping the TFTP server using a translation to 192.168.*x*.0/24.
- Your internal router can ping the opposite edge router using a translation to 10.*x*.0.0/24.
- You have demonstrated the limitations of access list-based NAT and have overcome those limitations by configuring NAT using a route map.
- You have connected to the TFTP server through NAT and have downloaded a configuration file for your internal routers.

# Solution to Configuration Exercise 1-1: Basic Connectivity

This section provides the answers to the questions in the Configuration Exercise.

**NOTE** Some answers provided cover multiple steps; the answers are given after the last step for which that answer applies.

## Solution to Task: Setting Up the Edge Routers

**Step 1** Connect to each of your pod routers; they should not have configurations on them. If a router does have a configuration, delete the configuration using the **erase start** command, and then use the **reload** command to reboot.

**NOTE** In this exercise, you will apply some minimal addressing and routing information so that your routers can reach the TFTP server.

**Step 2** Connect to each of your pod edge routers (P*x*R1 and P*x*R2). Configure the serial s0 interface of these routers for Frame Relay by turning on Frame Relay encapsulation.

**Step 3** Assign an IP address to your serial 0 interface. Your IP address is 172.31.*x.y*/24, where *x* is your pod number and *y* is your router number.

**Step 4** Inverse ARP has been turned off in the core Frame Relay network. Manually map a DLCI to BBR1 (172.31.*x*.3). The DLCI number will be in the form 1*xy*, where *x* is your pod number and *y* is your router number. For instance, P2R1 will use DLCI 121.

**NOTE** Remember to specify the **broadcast** keyword so that the Frame Relay mapping supports broadcasts and multicasts, such as routing protocol traffic.

**Step 5** Use the **no shutdown** command on the interface and exit configuration mode.

**Solution:**

The following shows how to perform the required steps on the P1R1 router:

```
Router>en
Router#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#int s0
Router(config-if)#encapsulation frame-relay
Router(config-if)#ip address 172.31.1.1 255.255.255.0
Router(config-if)#frame-relay map ip 172.31.1.3 111 broadcast
Router(config-if)#no shutdown
```

**Step 6** Verify successful connectivity from your P*x*R1 and P*x*R2 router to the core BBR1 router (172.31.*x*.3) using the **ping** command.

**Solution:**

The following shows the ping from the P1R1 router:

```
Router#ping 172.31.1.3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.31.1.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 36/36/36 ms
Router#
```

**Step 7** The goal of this exercise is to download a file from the TFTP server (at 10.254.0.254), which is connected to BBR1. Look at your P*x*R1 and P*x*R2 routing tables. Is there a route to the network that the TFTP server is located on? Why not?

**Solution:**

The following shows the routing table on P1R1. There is no route to the 10.254.0.0 network. P1R1 only has a route to its connected S0 interface; it does not have any other interfaces configured, and it has not learned any other routes from other routers.

```
Router#show ip route
<output omitted>
     172.31.0.0/24 is subnetted, 1 subnets
C       172.31.1.0 is directly connected, Serial0
Router#
```

**Step 8** Add a static route to 10.0.0.0/8 on your edge routers, through BBR1 (172.31.*x*.3), to provide a path to the TFTP server. Verify that the edge routers can see this route.

**Solution:**

The following configuration and output are on the P1R1 router. P1R1 now has a route to the 10.0.0.0 network.

```
Router#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#ip route 10.0.0.0 255.0.0.0 172.31.1.3
Router(config)#exit

Router#show ip route
<output omitted>
     172.31.0.0/24 is subnetted, 1 subnets
C       172.31.1.0 is directly connected, Serial0
S    10.0.0.0/8 [1/0] via 172.31.1.3
Router#
```

**Step 9** Verify successful connectivity to the TFTP server (10.254.0.254) from your P*x*R1 and P*x*R2 router using the **ping** command.

**Solution:**

The following ping is from the P1R1 router; the ping is successful:

```
Router#ping 10.254.0.254
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.254.0.254, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 32/35/40 ms
Router#
```

The following ping is from the P1R2 router; the ping is successful:

```
Router#ping 10.254.0.254
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.254.0.254, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/44/96 ms
Router
```

**Step 10** Retrieve the configuration file for your router from the TFTP server. The file should be named P*x*R*y*.txt. (For example, Pod 1 Router 2 will download P1R2.txt.)

**NOTE** Filenames are not case-sensitive.

**NOTE** The configuration files include the **no ip classless** command to force your router to behave classfully (although this command is on by default in IOS 12.0 and later). These files also include all required IP addresses and enable all required interfaces. Remember that files copied to running-config are merged, so this configuration complements what is already in your running-config.

**Solution:**

The following output is from the P1R1 router. The download was successful.

```
Router#copy tftp run
Address or name of remote host []? 10.254.0.254
Source filename []? P1R1.txt
Destination filename [running-config]?
Accessing tftp://10.254.0.254/P1R1.txt...
Loading P1R1.txt from 10.254.0.254 (via Serial0): !
[OK - 1334/2048 bytes]
1334 bytes copied in 25.184 secs (53 bytes/sec)
P1R1#
```

**NOTE** The initial configuration files for the routers are provided in Appendix H.

**Step 11** Save your configuration before proceeding.

**Solution:**

The following output is from the P1R1 router. The configuration was saved successfully.

```
P1R1#copy run start
Destination filename [startup-config]?
Building configuration...
[OK]
P1R1#
```

## Exercise Verification

You have successfully completed this exercise if you can ping the core BBR1 router and the TFTP server from your edge routers (P*x*R1 and P*x*R2) and you have downloaded the configuration files for your edge routers from the TFTP server.

# Solution to Configuration Exercise 1-2: NAT Using Access Lists and Route Maps

This section provides the answers to the questions in the Configuration Exercise.

**NOTE** Some answers provided cover multiple steps; the answers are given after the last step for which that answer applies.

## Solution to Task 1: Connecting the Internal Router to the Edge Router

**Step 1** The internal routers (P*x*R3 and P*x*R4) should not have a configuration. If a configuration is present, use the **erase start** and **reload** commands to clear the configuration and reload the router.

**Step 2** Connect to your internal routers. Supply an IP address to the Ethernet interface, and enable the interface. The Ethernet address of P*x*R3 should be 10.*x*.1.3/24, and the Ethernet address of P*x*R4 should be 10.*x*.2.4/24.

**Solution:**

The following example shows the configuration of P1R3:

```
Router(config)#int e0
Router(config-if)#no shutdown
Router(config-if)#ip address 10.1.1.3 255.255.255.0
```

The following example shows the configuration of P1R4:

```
Router(config)#int e0
Router(config-if)#no shutdown
Router(config-if)#ip address 10.1.2.4 255.255.255.0
```

**Step 3** P*x*R1 has an Ethernet address of 10.*x*.1.1, and P*x*R2 has an Ethernet address of 10.*x*.2.2. Verify connectivity to the Ethernet-attached edge router from each internal router.

**Solution:**

To verify connectivity, the edge routers are pinged from the appropriate internal router.

The following output is from the P1R3 router. The ping was successful.

```
Router#ping 10.1.1.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.1.1.1, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 4/4/4 ms
Router#
```

The following output is from the P1R4 router. The ping was successful.

```
Router#ping 10.1.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.1.2.2, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 4/5/8 ms
Router#
```

## Solution to Task 2: Setting Up ACL-Based NAT

**NOTE** BBR1 has static routes for 192.168.*x*.0/24 and 192.168.*xx*.0/24. It does not have any remote routes for the pod 10.*x*.0.0 addresses, only its local TFTP server network 10.254.0.0.

**Step 1** On the P*x*R1 and P*x*R2 routers, configure the sources to be translated using extended access list 100. Access list 100 should match traffic sourced from the network on your edge router's Ethernet interface, destined for the network that the TFTP server is located on. For example, P*x*R1 should match traffic sourced from 10.*x*.1.0/24, and P*x*R2 should match traffic sourced from 10.*x*.2.0/24. The access list must match only packets with a destination of 10.254.0.0/24.

**Step 2** On the P*x*R1 and P*x*R2 routers, create a pool of addresses called **BBR** for use by NAT, using the **ip nat pool** command. P*x*R1 should use the address range of 192.168.*x*.0/24, and P*x*R2 should use 192.168.*xx*.0/24. For example, P2R1 would use 192.168.2.1 through 192.168.2.254, and P2R2 would use 192.168.22.1 through 192.168.22.254.

**Step 3** On the P*x*R1 and P*x*R2 routers, use the **ip nat inside source list** command to specify that packets that match access list 100 should have their source addresses translated into the BBR pool.

**Step 4** On the P*x*R1 and P*x*R2 routers, define which interfaces are inside or outside for NAT translation purposes.

**Solution:**

Because the traffic to be translated will come from the Ethernet interface, that will be the inside NAT interface. Translated traffic will leave via the Serial0 interface, so S0 will be the outside interface for NAT purposes. The following example shows the configuration on the P1R1 router:

```
P1R1(config)#access-list 100 permit ip 10.1.1.0 0.0.0.255 10.254.0.0 0.0.0.255
P1R1(config)#ip nat pool BBR 192.168.1.1 192.168.1.254 netmask 255.255.255.0
P1R1(config)#ip nat inside source list 100 pool BBR
P1R1(config)#int e0
P1R1(config-if)#ip nat inside
P1R1(config-if)#exit
P1R1(config)#int s0
P1R1(config-if)#ip nat outside
```

**Step 5** On the P*x*R3 and P*x*R4 routers, configure a default route pointing to the attached edge router e0 interface. This configuration allows the internal router to reach the core network.

**Solution:**

The following example shows the configuration on the P1R3 router:

```
Router(config)#ip route 0.0.0.0 0.0.0.0 e0
```

**Step 6** From the P*x*R3 and P*x*R4 routers, verify connectivity to the TFTP server (10.254.0.254) using the **ping** command.

**Solution:**

The following output shows the result of the **ping** command on the P1R3 router; the ping is successful.

```
Router#ping 10.254.0.254
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.254.0.254, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 36/36/36 ms
Router#
```

**CAUTION** You will not be able to reach the TFTP server if the NAT translation is not done correctly.

**Step 7** View the NAT translation table on the edge router (P*x*R1 and P*x*R2).

**Solution:**

The following output shows the NAT translation table on the P1R1 router. From this output, you can see that one address has been translated.

```
P1R1>show ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
--- 192.168.1.1        10.1.1.3           ---                ---
P1R1>
```

## Solution to Task 3: Translating to the Other Edge Router

**Step 1** On the P*x*R1 and P*x*R2 routers, configure the source addresses to be translated using extended access list 101. Access list 101 should match traffic sourced from the network on your edge router's Ethernet interface, bound for any destination. For instance, P*x*R1 should match traffic from 10.*x*.1.0/24, and P*x*R2 should match traffic from 10.*x*.2.0/24. The access list must match packets with a destination to any network.

**Step 2** On the P*x*R1 and P*x*R2 routers, create a pool of addresses named **POD** for use by NAT. P*x*R1 should use the address range 10.*x*.0.64 to 10.*x*.0.95, and P*x*R2 should use the address range 10.*x*.0.96 to 10.*x*.0.127.

**Step 3** On the P*x*R1 and P*x*R2 routers, specify that packets that match access list 101 should have their source addresses translated into the POD pool.

**Step 4** At the P*x*R1 and P*x*R2 routers, define the S1 interface of each router as the NAT outside interface by using the **ip nat outside** command so that traffic from the respective internal routers is translated.

**Solution:**

The following example shows the configuration of the P1R1 and P1R2 routers:

```
P1R1(config)#access-list 101 permit ip 10.1.1.0 0.0.0.255 any
P1R1(config)#ip nat pool POD 10.1.0.64 10.1.0.95 netmask 255.255.255.0
P1R1(config)#ip nat inside source list 101 pool POD
P1R1(config)#int s1
P1R1(config-if)#ip nat outside

P1R2(config)#access-list 101 permit ip 10.1.2.0 0.0.0.255 any
P1R2(config)#ip nat pool POD 10.1.0.96 10.1.0.127 netmask 255.255.255.0
P1R2(config)#ip nat inside source list 101 pool POD
P1R2(config)#int s1
P1R2(config-if)#ip nat outside
```

**Step 5** From one internal router, ping the Serial 1 interface of the nonconnected edge router. (For example, from P*x*R3, ping the Serial 1 address of P*x*R2.) Is the ping successful?

**Solution:**

The following example is a ping from the P1R3 router to the P1R2 router's Serial 1 address:

```
Router>ping 10.1.0.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.1.0.2, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)
```

The ping is unsuccessful.

**Step 6** Look at the IP translation table on the edge routers to help explain the result of the previous ping.

**Solution:**

The following output is from the P1R1 router:

```
P1R1#show ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
--- 192.168.1.1        10.1.1.3           ---                ---
P1R1#
```

As you can see in the translation table, the P1R1 router has already translated the 10.1.1.3 source address, in Task 2, to 192.168.1.1. The router doesn't recognize that ping is a separate conversation, to a different destination, so it doesn't translate the traffic again for the new destination. You need a way to distinguish between different conversations.

**Step 7** From the nonconnected edge router, use the **debug ip icmp** and **debug ip packet** commands while the pings are still active. Observe the output to help explain the results of the previous ping. Turn off all debugging when you are finished.

**Solution:**

The following output is from the P1R2 router while the pings from P1R3 to the P1R2 Serial 1 address are ongoing:

```
P1R2#debug ip icmp
ICMP packet debugging is on
P1R2#debug ip packet
IP packet debugging is on
P1R2#
Feb 28 21:44:55 EST: IP: s=192.168.1.1 (Serial1), d=10.1.0.2 (Serial1),
    len 100, rcvd 3
Feb 28 21:44:55 EST: ICMP: echo reply sent, src 10.1.0.2, dst 192.168.1.1
Feb 28 21:44:55 EST: IP: s=10.1.0.2 (local), d=192.168.1.1, len 100, unroutable
```

P1R2 receives a packet with source address 192.168.1.1 and tries to reply to this packet. However, P1R2 reports that 192.168.1.1 is unroutable.

**Step 8** Look at the routing table on the nonconnected edge router. Is there a route back to the destination address of the ping echo reply message?

**Solution:**

The following output is from the P1R2 router:

```
P1R2#sh ip route
<output omitted>
     172.31.0.0/24 is subnetted, 1 subnets
C       172.31.1.0 is directly connected, Serial0
     10.0.0.0/8 is variably subnetted, 3 subnets, 2 masks
C       10.1.0.0/24 is directly connected, Serial1
C       10.1.2.0/24 is directly connected, Ethernet0
S       10.0.0.0/8 [1/0] via 172.31.1.3
```

There is no route in P1R2's routing table to 192.168.1.1; this is why P1R2 cannot reply to the ping.

**Step 9** What does a router do when it does not find an appropriate address?

**Solution:**

The router drops the packet.

## Solution to Task 4: Using a Route Map with NAT to Translate Internal Addresses

**Step 1** Create a route map that will be used to conditionally translate traffic based on the packet's destination.

**Solution:**

The following example shows the configuration on P1R1:

```
P1R1(config)#route-map TO_BBR permit 10
P1R1(config-route-map)#match ip address 100
P1R1(config-route-map)#exit
P1R1(config)#route-map TO_POD permit 10
P1R1(config-route-map)#match ip address 101
```

**Step 2** Replace the translation commands from Task 3 with route map-based commands to perform the required translation.

**NOTE** If the router reports "%Dynamic mapping in use, cannot remove," simply go to privileged mode and enter the **clear ip nat translation *** command to remove all mappings. You then can configure the router.

**Solution:**

The following configuration is from the P1R1 router:

```
P1R1#clear ip nat translation *
P1R1#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
P1R1(config)#no ip nat inside source list 100 pool BBR
P1R1(config)#no ip nat inside source list 101 pool POD
P1R1(config)#ip nat inside source route-map TO_BBR pool BBR
P1R1(config)#ip nat inside source route-map TO_POD pool POD
```

**Step 3** Ping from one internal router to the opposite edge router and to the TFTP server to verify that the previous step was successful. Turn on **debug ip nat detailed** debugging on the edge routers to see the translation.

**Solution:**

The following ping output is from the P1R3 internal router to the TFTP server. (The P1R4 internal router produced the same result.)

```
Router#ping 10.254.0.254
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.254.0.254, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 36/38/48 ms
```

The following debug output is from the P1R1 router while the preceding ping from P1R3 to the TFTP server was ongoing. This output shows the translation using the BBR pool:

```
P1R1#debug ip nat detailed
IP NAT detailed debugging is on
P1R1#
Feb 28 21:59:37 EST: NAT: map match TO_BBR
Feb 28 21:59:37 EST: NAT: map match TO_BBR
Feb 28 21:59:37 EST: NAT: i: icmp (10.1.1.3, 2567) -> (10.254.0.254, 2567) [65]
Feb 28 21:59:37 EST: NAT: s=10.1.1.3->192.168.1.1, d=10.254.0.254 [65]
Feb 28 21:59:37 EST: NAT*: o: icmp (10.254.0.254, 2567) -> (192.168.1.1, 2567) [189]
Feb 28 21:59:37 EST: NAT*: s=10.254.0.254, d=192.168.1.1->10.1.1.3 [189]
```

The following ping output is from the P1R3 internal router to the P1R2 router's Serial 1 interface. (The same results were obtained when P1R4 pinged the P1R1 router Serial 1 interface.)

```
Router#ping 10.1.0.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.1.0.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 52/54/60 ms
```

The following debug output is from the P1R1 router while the preceding ping from P1R3 to P1R2 was ongoing. This output shows the translation using the POD pool:

```
P1R1#debug ip nat detailed
IP NAT detailed debugging is on
P1R1#
Feb 28 22:03:45 EST: NAT: map match TO_POD
Feb 28 22:03:45 EST: NAT: map match TO_POD
Feb 28 22:03:45 EST: NAT: i: icmp (10.1.1.3, 330) -> (10.1.0.2, 330) [85]
Feb 28 22:03:45 EST: NAT: s=10.1.1.3->10.1.0.64, d=10.1.0.2 [85]
Feb 28 22:03:45 EST: NAT*: o: icmp (10.1.0.2, 330) -> (10.1.0.64, 330) [85]
Feb 28 22:03:45 EST: NAT*: s=10.1.0.2, d=10.1.0.64->10.1.1.3 [85]
```

**Step 4** Use the **show ip nat translations** command on each edge router to see the resulting NAT translation table.

**Solution:**

The following output is from the P1R1 and P1R2 routers:

```
P1R1#show ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
icmp 10.1.0.64:1652    10.1.1.3:1652      10.1.2.2:1652      10.1.2.2:1652
icmp 10.1.0.64:1653    10.1.1.3:1653      10.1.2.2:1653      10.1.2.2:1653
icmp 10.1.0.64:1654    10.1.1.3:1654      10.1.2.2:1654      10.1.2.2:1654
icmp 10.1.0.64:1655    10.1.1.3:1655      10.1.2.2:1655      10.1.2.2:1655
icmp 10.1.0.64:9208    10.1.1.3:9208      10.1.0.2:9208      10.1.0.2:9208
icmp 10.1.0.64:9209    10.1.1.3:9209      10.1.0.2:9209      10.1.0.2:9209
icmp 10.1.0.64:9210    10.1.1.3:9210      10.1.0.2:9210      10.1.0.2:9210
icmp 10.1.0.64:9211    10.1.1.3:9211      10.1.0.2:9211      10.1.0.2:9211
icmp 10.1.0.64:9212    10.1.1.3:9212      10.1.0.2:9212      10.1.0.2:9212
icmp 192.168.1.1:133   10.1.1.3:133       10.254.0.254:133   10.254.0.254:133
icmp 192.168.1.1:134   10.1.1.3:134       10.254.0.254:134   10.254.0.254:134
icmp 192.168.1.1:135   10.1.1.3:135       10.254.0.254:135   10.254.0.254:135
icmp 192.168.1.1:136   10.1.1.3:136       10.254.0.254:136   10.254.0.254:136
icmp 192.168.1.1:137   10.1.1.3:137       10.254.0.254:137   10.254.0.254:137
P1R2#show ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
icmp 192.168.11.1:5005 10.1.2.4:5005      10.254.0.254:5005  10.254.0.254:5005
icmp 192.168.11.1:5006 10.1.2.4:5006      10.254.0.254:5006  10.254.0.254:5006
icmp 192.168.11.1:5007 10.1.2.4:5007      10.254.0.254:5007  10.254.0.254:5007
icmp 192.168.11.1:5008 10.1.2.4:5008      10.254.0.254:5008  10.254.0.254:5008
icmp 192.168.11.1:5009 10.1.2.4:5009      10.254.0.254:5009  10.254.0.254:5009
icmp 10.1.0.96:1481    10.1.2.4:1481      10.1.0.1:1481      10.1.0.1:1481
icmp 10.1.0.96:1482    10.1.2.4:1482      10.1.0.1:1482      10.1.0.1:1482
icmp 10.1.0.96:1483    10.1.2.4:1483      10.1.0.1:1483      10.1.0.1:1483
icmp 10.1.0.96:1484    10.1.2.4:1484      10.1.0.1:1484      10.1.0.1:1484
icmp 10.1.0.96:1485    10.1.2.4:1485      10.1.0.1:1485      10.1.0.1:1485
```

Notice that the NAT translation table is completely developed. The inside and outside local and global addresses are included in the table, along with the TCP and UDP port numbers. Much more troubleshooting information is available within this table than with the table shown in Task 3.

## Solution to Task 5: Downloading a Configuration File

On the internal routers, use TFTP to download the configuration file called P*x*R*y*.txt from the TFTP server to the running-config.

**Solution:**

The following configuration and output are from the P1R3 router. Notice that the router's name, P1R3, is configured after the configuration is downloaded:

```
Router#copy tftp run
Address or name of remote host []? 10.254.0.254
Source filename []? p1r3.txt
Destination filename [running-config]?
Accessing tftp://10.254.0.254/p1r3.txt...
Loading p1r3.txt .from 10.254.0.254 (via Ethernet0): !
[OK - 1085/2048 bytes]
1085 bytes copied in 31.956 secs (35 bytes/sec)
P1R3#
```

The following configuration and output are from the P1R4 router. Again, notice that the router's name changes after the configuration is loaded:

```
Router#copy tftp run
Address or name of remote host []? 10.254.0.254
Source filename []? p1r4.txt
Destination filename [running-config]?
Accessing tftp://10.254.0.254/p1r4.txt...
Loading p1r4.txt .from 10.254.0.254 (via Ethernet0): !
[OK - 1085/2048 bytes]
1085 bytes copied in 31.992 secs (35 bytes/sec)
P1R4#
```

**NOTE** The configurations for P*x*R3 and P*x*R4 include the command **no ip classless** in preparation for the Configuration Exercise in the next chapter. If you try to communicate with the TFTP server now, it will not work. The reasoning behind this behavior is examined in the next Configuration Exercise.

## Exercise Verification

You have successfully completed this exercise when you achieve the following results:

- Your internal router can ping the TFTP server using a translation to 192.168.*x*.0/24.
- Your internal router can ping the opposite edge router using a translation to 10.*x*.0.0/24.
- You have demonstrated the limitations of access list-based NAT and have overcome those limitations by configuring NAT using a route map.
- You have connected to the TFTP server through NAT and have downloaded a configuration file for your internal routers.

## Review Questions

Answer the following questions, and then refer to Appendix G, "Answers to Review Questions," for the answers.

1 When networks are connected based on their location, is this a functional or geographic network design?

2 Describe the role of each layer in the hierarchical network model.

3 Name an advantage and a disadvantage of a fully meshed core layer.

4 At what layer are DHCP and DNS servers typically found?

5 What are three benefits of a good IP address design?

6 What are private IP addresses, and what are they used for?

7 How does route summarization benefit a network?

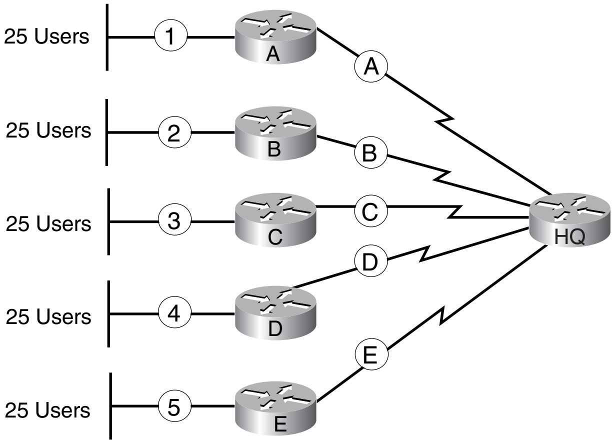
8 Given a host address 10.1.17.61/28, what is the range of addresses on the subnet that this host is on?

9 How does VLSM allow a more efficient use of IP addresses?

10 What range of addresses is represented by the summary route 172.16.16.0/21?

11 You are in charge of the network shown in Figure 1-36. It consists of five LANs with 25 users on each LAN and five serial links. You have been assigned the IP address 192.168.49.0/24 to allocate addressing for all links.

**Figure 1-36** *Network for Address Assignment*

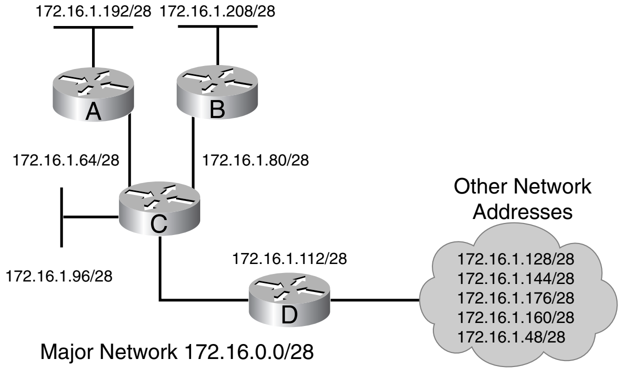


Write down the addresses you would assign to each of the LANs and serial links

| | |
|---|---|
| LAN 1 | |
| LAN 2 | |
| LAN 3 | |
| LAN 4 | |
| LAN 5 | |
| WAN A | |
| WAN B | |
| WAN C | |
| WAN D | |
| WAN E | |

**12** Figure 1-37 shows a network with subnets of the 172.16.0.0 network configured. Indicate in the following table where route summarization can occur in this network and what the summarized addresses would be.

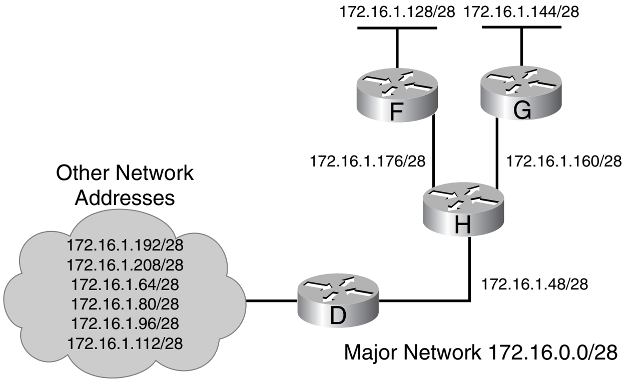
**Figure 1-37** *Network for Route Summarization*



| Router C Routing Table Entries | Summarized Routes That Can Be Advertised to Router D from Router C |
|---|---|
| | |
| | |
| | |
| | |
| | |
| | |

**13** Figure 1-38 shows a network with subnets of the 172.16.0.0 network configured. Indicate in the following table where route summarization can occur in this network and what the summarized address would be.

**Figure 1-38** *Network for Route Summarization*



| Router H Routing Table Entries | Summarized Routes That Can Be Advertised to Router D from Router H |
|---|---|
| | |
| | |
| | |
| | |
| | |

**14** When selecting a route, which prefix match is used?

**15** What is the difference between route summarization and CIDR?

**16** The following networks are in Router A's routing table:

192.168.12.0/24

192.168.13.0/24

192.168.14.0/24

192.168.15.0/24

Using CIDR, what route could Router A advertise to its neighbor?

**17** What is the difference between a NAT inside local IP address and an inside global IP address?

**18** Which command indicates that NAT translation is to be done for packets arriving on an interface?

**19** In the following configuration example, what does the first line do? What does the fourth line do?

```
ip nat pool our_pool 192.168.4.1  192.168.4.254 prefix-length 24
ip nat pool their_pool 192.168.5.1 192.168.5.254 prefix-length 24
!
ip nat inside source list 104 pool our_pool
ip nat inside source list 105 pool their_pool
!
interface ethernet 0
 ip address 10.1.1.1 255.255.0.0
 ip nat inside
!
interface serial 0
 ip address 172.16.2.1 255.255.255.0
 ip nat outside
!
access-list 104 permit ip  10.1.1.0 0.0.0.255  172.16.1.0 0.0.0.255
access-list 104 permit ip  10.1.1.0 0.0.0.255  192.168.200.0 0.0.0.255
access-list 105 permit ip  10.1.1.0 0.0.0.255  any
```

**20** Describe how a route map works.

**21** What are some differences between IPv4 and IPv6?

**22** What is the difference between the IPv4 header and the IPv6 header?

**23** What features does the larger address space of IPv6 provide?

**24** Write the shortest legal format for the following IPv6 address:

2210:0000:0011:ABCD:0000:0000:0000:0101

**25** Write out the following IPv6 address completely:

2214::15:ABCD

**26** Describe how IPv6 stateless autoconfiguration works.

**27** Name two IPv4 packet header fields that are no longer defined in the IPv6 packet header.

**28** Describe how 6to4 transition works.

**29** What does dual stack mean?

**30** What is the difference between an IPv6 anycast address and an IPv6 multicast address?

**31** What is the IPv6 broadcast address?

**32** What does the 2001::/16 summary route mean?

**33** The IPv6 header is aligned on what bit boundary?