Configuring IP Addressing

This chapter describes how to configure IP addressing. For a complete description of the commands in this chapter, refer to the "IP Addressing Commands" chapter of the *Network Protocols Command Reference, Part 1*. To locate documentation of other commands that appear in this chapter, use the command reference master index or search online.

IP Addressing Task List

A basic and required task for configuring IP is to assign IP addresses to network interfaces. Doing so enables the interfaces and allows communication with hosts on those interfaces using IP. Associated with this task are decisions about subnetting and masking the IP addresses.

To configure various IP addressing features, complete the tasks in the following sections. The first task is required; the remaining are optional.

- Assign IP Addresses to Network Interfaces
- Configure Address Resolution Methods
- Enable IP Routing
- Enable IP Bridging
- Enable Integrated Routing and Bridging
- Configure a Routing Process
- Configure Broadcast Packet Handling
- Configure Network Address Translation (NAT)
- Monitor and Maintain IP Addressing

At the end of this chapter, the examples in the "IP Addressing Examples" section illustrate how you might establish IP addressing in your network.

Assign IP Addresses to Network Interfaces

An IP address identifies a location to which IP datagrams can be sent. Some IP addresses are reserved for special uses and cannot be used for host, subnet, or network addresses. Table 1 lists ranges of IP addresses, and shows which addresses are reserved and which are available for use.

Table 1 Reserved and Available IP Addresses

Class	Address or Range	Status
A	0.0.0.0 1.0.0.0 to 126.0.0.0 127.0.0.0	Reserved Available Reserved
B	128.0.0.0 to 191.254.0.0 191.255.0.0	Available Reserved
C	192.0.0.0 192.0.1.0 to 223.255.254 223.255.255.0	Reserved Available Reserved
D	224.0.0.0 to 239.255.255.255	Multicast group addresses
E	240.0.0.0 to 255.255.255.254 255.255.255.255	Reserved Broadcast

The official description of IP addresses is found in RFC 1166, "Internet Numbers."

To receive an assigned network number, contact your Internet service provider.

An interface can have one primary IP address. To assign a primary IP address and a network mask to a network interface, perform the following task in interface configuration mode:

Task	Command
Set a primary IP address for an interface.	**ip address** *ip-address mask*

A mask identifies the bits that denote the network number in an IP address. When you use the mask to subnet a network, the mask is then referred to as a *subnet mask*.

Note We only support network masks that use contiguous bits that are flush left against the network field.

The tasks required to enable additional, optional, IP addressing features are contained in the following sections:

- Assign Multiple IP Addresses to Network Interfaces
- Enable Use of Subnet Zero
- Enable Classless Routing Behavior
- Enable IP Processing on a Serial Interface

Assign Multiple IP Addresses to Network Interfaces

The software supports multiple IP addresses per interface. You can specify an unlimited number of secondary addresses. Secondary IP addresses can be used in a variety of situations. The following are the most common applications:

- There might not be enough host addresses for a particular network segment. For example, suppose your subnetting allows up to 254 hosts per logical subnet, but on one physical subnet you must have 300 host addresses. Using secondary IP addresses on the routers or access servers allows you to have two logical subnets using one physical subnet.
- Many older networks were built using Level 2 bridges, and were not subnetted. The judicious use of secondary addresses can aid in the transition to a subnetted, router-based network. Routers on an older, bridged segment can easily be made aware that many subnets are on that segment.
- Two subnets of a single network might otherwise be separated by another network. You can create a single network from subnets that are physically separated by another network by using a secondary address. In these instances, the first network is *extended*, or layered on top of the second network. Note that a subnet cannot appear on more than one active interface of the router at a time.

Note If any router on a network segment uses a secondary address, all other routers on that same segment must also use a secondary address from the same network or subnet.

To assign multiple IP addresses to network interfaces, perform the following task in interface configuration mode:

Task	Command
Assign multiple IP addresses to network interfaces.	**ip address** *ip-address mask* **secondary**

Note IP routing protocols sometimes treat secondary addresses differently when sending routing updates. See the description of IP split horizon in the "Configuring IP Enhanced IGRP," "Configuring IGRP," or "Configuring RIP" chapters for details.

See the "Creating a Network from Separated Subnets Example" section at the end of this chapter for an example of creating a network from separated subnets.

Enable Use of Subnet Zero

Subnetting with a subnet address of zero is illegal and strongly discouraged (as stated in RFC 791) because of the confusion that can arise between a network and a subnet that have the same addresses. For example, if network 131.108.0.0 is subnetted as 255.255.255.0, subnet zero would be written as 131.108.0.0—which is identical to the network address.

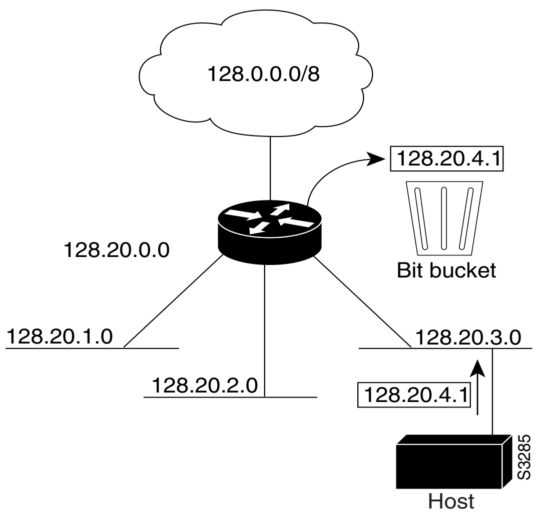
You can use the all zeros and all ones subnet (131.108.255.0), even though it is discouraged. Configuring interfaces for the all ones subnet is explicitly allowed. However, if you need the entire subnet space for your IP address, perform the following task in global configuration mode to enable subnet zero:

Task	Command
Enable the use of subnet zero for interface addresses and routing updates.	**ip subnet-zero**

Enable Classless Routing Behavior

At times, a router might receive packets destined for a subnet of a network that has no network default route. Figure 2 shows a router in network 128.20.0.0 connected to subnets 128.20.1.0, 128.20.2.0, and 128.20.3.0. Suppose the host sends a packet to 128.20.4.1. By default, if the router receives a packet destined for a subnet it does not recognize, the router discards the packet.

Figure 2 No IP Classless Routing



In Figure 3, classless routing is enabled in the router. Therefore, when the host sends a packet to 128.20.4.1, instead of discarding the packet, the router forwards the packet to the best supernet route.

Figure 3 IP Classless Routing

To have the Cisco IOS software forward packets destined for unrecognized subnets to the best supernet route possible, perform the following task in global configuration mode:

Task	Command
Enable classless routing behavior.	**ip classless**

Enable IP Processing on a Serial Interface

You might want to enable IP processing on a serial or tunnel interface without assigning an explicit IP address to the interface. Whenever the unnumbered interface generates a packet (for example, for a routing update), it uses the address of the interface you specified as the source address of the IP packet. It also uses the specified interface address in determining which routing processes are sending updates over the unnumbered interface. Restrictions are as follows:

- Serial interfaces using HDLC, PPP, LAPB, and Frame Relay encapsulations, as well as SLIP and tunnel interfaces, can be unnumbered. Serial interfaces using Frame Relay encapsulation can also be unnumbered, but the interface must be a point-to-point subinterface. It is not possible to use the unnumbered interface feature with X.25 or SMDS encapsulations.
- You cannot use the **ping** EXEC command to determine whether the interface is up, because the interface has no IP address. The Simple Network Management Protocol (SNMP) can be used to remotely monitor interface status.
- You cannot netboot a runnable image over an unnumbered serial interface.
- You cannot support IP security options on an unnumbered interface.

If you are configuring Intermediate System-to-Intermediate System (IS-IS) across a serial line, you should configure the serial interfaces as unnumbered. This allows you to conform with RFC 1195, which states that IP addresses are not required on each interface.

Note Using an unnumbered serial line between different major networks requires special care. If, at each end of the link, there are different major networks assigned to the interfaces you specified as unnumbered, any routing protocols running across the serial line should be configured to not advertise subnet information.

To enable IP processing on an unnumbered serial interface, perform the following task in interface configuration mode:

Task	Command
Enable IP processing on a serial or tunnel interface without assigning an explicit IP address to the interface.	**ip unnumbered** *type number*

The interface you specify must be the name of another interface in the router that has an IP address, not another unnumbered interface.

The interface you specify also must be enabled (listed as "up" in the **show interfaces** command display).

See the "Serial Interfaces Configuration Example" section at the end of this chapter for an example of how to configure serial interfaces.

Configure Address Resolution Methods

Our IP implementation allows you to control interface-specific handling of IP addresses by facilitating address resolution, name services, and other functions. The following sections describe how to configure address resolution methods:

- Establish Address Resolution
- Map Host Names to IP Addresses
- Configure HP Probe Proxy Name Requests
- Configure the Next Hop Resolution Protocol

Establish Address Resolution

A device in the IP can have both a local address (which uniquely identifies the device on its local segment or LAN) and a network address (which identifies the network to which the device belongs). The local address is more properly known as a *data link* address because it is contained in the data link layer (Layer 2 of the OSI model) part of the packet header and is read by data link devices (bridges and all device interfaces, for example). The more technically inclined will refer to local addresses as *MAC addresses*, because the Media Access Control (MAC) sublayer within the data link layer processes addresses for the layer.

To communicate with a device on Ethernet, for example, the Cisco IOS software first must determine the 48-bit MAC or local data link address of that device. The process of determining the local data link address from an IP address is called *address resolution.* The process of determining the IP address from a local data link address is called *reverse address resolution.*

The software uses three forms of address resolution: Address Resolution Protocol (ARP), proxy ARP, and Probe (similar to ARP). The software also uses the Reverse Address Resolution Protocol (RARP). ARP, proxy ARP, and RARP are defined in RFCs 826, 1027, and 903, respectively. Probe is a protocol developed by the Hewlett-Packard Company (HP) for use on IEEE-802.3 networks.

ARP is used to associate IP addresses with media or MAC addresses. Taking an IP address as input, ARP determines the associated media address. Once a media or MAC address is determined, the IP address/media address association is stored in an ARP cache for rapid retrieval. Then the IP datagram is encapsulated in a link-layer frame and sent over the network. Encapsulation of IP datagrams and ARP requests and replies on IEEE 802 networks other than Ethernet is specified by the Subnetwork Access Protocol (SNAP).

RARP works the same way as ARP, except that the RARP Request packet requests an IP address instead of a local data link address. Use of RARP requires a RARP server on the same network segment as the router interface. RARP often is used by diskless nodes that do not know their IP addresses when they boot. The Cisco IOS software attempts to use RARP if it does not know the IP address of an interface at startup. Also, our routers are able to act as RARP servers by responding to RARP requests that they are able to answer. See the "Configure Additional File Transfer Functions" chapter in the *Configuration Fundamentals Configuration Guide* to learn how to configure a router as a RARP server.

Perform the following tasks to set address resolution:

- Define a Static ARP Cache
- Set ARP Encapsulations
- Enable Proxy ARP
- Configure Local-Area Mobility

The procedures for performing these tasks are described in the following sections.

Define a Static ARP Cache

ARP and other address resolution protocols provide a dynamic mapping between IP addresses and media addresses. Because most hosts support dynamic address resolution, you generally do not need to specify static ARP cache entries. If you must define them, you can do so globally. Doing this task installs a permanent entry in the ARP cache. The Cisco IOS software uses this entry to translate 32-bit IP addresses into 48-bit hardware addresses.

Optionally, you can specify that the software respond to ARP requests as if it was the owner of the specified IP address. In case you do not want the ARP entries to be permanent, you have the option of specifying an ARP entry timeout period when you define ARP entries.

The following two tables list the tasks to provide static mapping between IP addresses and media address.

Perform either of the following tasks in global configuration mode:

Task	Command
Globally associate an IP address with a media (hardware) address in the ARP cache.	**arp** *ip-address hardware-address type*
Specify that the software respond to ARP requests as if it was the owner of the specified IP address.	**arp** *ip-address hardware-address type* **alias**

Perform the following task in interface configuration mode:

Task	Command
Set the length of time an ARP cache entry will stay in the cache.	**arp timeout** *seconds*

To display the type of ARP being used on a particular interface and also display the ARP timeout value, use the **show interfaces** EXEC command. Use the **show arp** EXEC command to examine the contents of the ARP cache. Use the **show ip arp** EXEC command to show IP entries. To remove all nonstatic entries from the ARP cache, use the privileged EXEC command **clear arp-cache**.

Set ARP Encapsulations

By default, standard Ethernet-style ARP encapsulation (represented by the **arpa** keyword) is enabled on the IP interface. You can change this encapsulation method to SNAP or HP Probe, as required by your network, to control the interface-specific handling of IP address resolution into 48-bit Ethernet hardware addresses.

When you set HP Probe encapsulation, the Cisco IOS software uses the Probe protocol whenever it attempts to resolve an IEEE-802.3 or Ethernet local data link address. The subset of Probe that performs address resolution is called Virtual Address Request and Reply. Using Probe, the router can communicate transparently with Hewlett-Packard IEEE-802.3 hosts that use this type of data encapsulation. You must explicitly configure all interfaces for Probe that will use Probe.

To specify the ARP encapsulation type, perform the following task in interface configuration mode:

Task	Command
Specify one of three ARP encapsulation methods for a specified interface.	**arp** {**arpa** | **probe** | **snap**}

Enable Proxy ARP

The Cisco IOS software uses proxy ARP (as defined in RFC 1027) to help hosts with no knowledge of routing determine the media addresses of hosts on other networks or subnets. For example, if the router receives an ARP request for a host that is not on the same interface as the ARP request sender, and if the router has all of its routes to that host through other interfaces, then it generates a proxy ARP reply packet giving its own local data link address. The host that sent the ARP request then sends its packets to the router, which forwards them to the intended host. Proxy ARP is enabled by default.

To enable proxy ARP if it has been disabled, perform the following task in interface configuration mode (as necessary) for your network:

Task	Command
Enable proxy ARP on the interface.	**ip proxy-arp**

Configure Local-Area Mobility

Local-area mobility provides the ability to relocate IP hosts within a limited area without reassigning host IP addresses and without changes to the host software. Local-area mobility is supported on Ethernet, Token Ring, and FDDI interfaces only.

To create a mobility area with only one router, perform the following tasks:

Task		Command
Step 1	Enable bridging.	**bridge** *group* **protocol** {**dec** | **ieee**}
Step 2	Enter interface configuration mode.	**interface** *type number*
Step 3	Enable local-area mobility.	**ip mobile arp** [**timers** *keepalive hold-time*] [**access-group** *access-list-number* | *name*]
Step 4	Configure bridging on the interface.	**bridge-group** *group*

To create larger mobility areas, you must first redistribute the mobile routes into your IGP. The IGP must support host routes. You can use Enhanced IGRP, OSPF, or IS-IS; you can also use RIP in some cases, but this is not recommended. To redistribute the mobile routes into your existing IGP configuration, perform the following tasks:

Task		Command
Step 1	Enter router configuration mode.	**router** {**eigrp** *autonomous-system* | **isis** [*tag*] | **ospf** *process-id*}
Step 2	Set default metric values.	**default-metric** *number* or **default-metric** *bandwidth delay reliability loading mtu*
Step 3	Redistribute the mobile routes.	**redistribute mobile**

If your IGP supports summarization, you should also restrict the mobile area so that it falls completely inside an IGP summarization area. This lets hosts roam within the mobile area without affecting routing outside the area.

The mobile area must consist of a contiguous set of subnets.

Hosts that roam within a mobile area should rely on a configured default router for their routing.

Map Host Names to IP Addresses

Each unique IP address can have a host name associated with it. The Cisco IOS software maintains a cache of host name-to-address mappings for use by the EXEC **connect**, **telnet**, **ping**, and related Telnet support operations. This cache speeds the process of converting names to addresses.

IP defines a naming scheme that allows a device to be identified by its location in the IP. This is a hierarchical naming scheme that provides for *domains*. Domain names are pieced together with periods (.) as the delimiting characters. For example, Cisco Systems is a commercial organization that the IP identifies by a *com* domain name, so its domain name is *cisco.com*. A specific device in this domain, the File Transfer Protocol (FTP) system for example, is identified as *ftp.cisco.com*.

To keep track of domain names, IP has defined the concept of a *name server*, whose job is to hold a cache (or database) of names mapped to IP addresses. To map domain names to IP addresses, you must first identify the host names, then specify a name server, and enable the Domain Naming System (DNS), the Internet's global naming scheme that uniquely identifies network devices. These tasks are described in the following sections:

- Map IP Addresses to Host Names
- Specify the Domain Name
- Specify a Name Server
- Enable the DNS
- Use the DNS to Discover ISO CLNS Addresses

Map IP Addresses to Host Names

The Cisco IOS software maintains a table of host names and their corresponding addresses, also called a *host name-to-address mapping*. Higher-layer protocols such as Telnet use host names to identify network devices (hosts). The router and other network devices must be able to associate host names with IP addresses to communicate with other IP devices. Host names and IP addresses can be associated with one another through static or dynamic means.

Manually assigning host names to addresses is useful when dynamic mapping is not available.

To assign host names to addresses, perform the following task in global configuration mode:

Task	Command
Statically associate host names with IP addresses.	**ip host** *name* [*tcp-port-number*] *address1* [*address2*...*address8*]

Specify the Domain Name

You can specify a default domain name that the Cisco IOS software will use to complete domain name requests. You can specify either a single domain name or a list of domain names. Any IP host name that does not contain a domain name will have the domain name you specify appended to it before being added to the host table.

To specify a domain name or names, perform either of the following tasks in global configuration mode:

Task	Command
Define a default domain name that the Cisco IOS software will use to complete unqualified host names.	**ip domain-name** *name*
Define a list of default domain names to complete unqualified host names.	**ip domain-list** *name*

See the "IP Domains Example" section at the end of this chapter for an example of establishing IP domains.

Specify a Name Server

To specify one or more hosts (up to six) that can function as a name server to supply name information for the DNS, perform the following task in global configuration mode:

Task	Command
Specify one or more hosts that supply name information.	**ip name-server** *server-address1* [[*server-address2*]...*server-address6*]

Enable the DNS

If your network devices require connectivity with devices in networks for which you do not control name assignment, you can assign device names that uniquely identify your devices within the entire internetwork. The Internet's global naming scheme, the DNS, accomplishes this task. This service is enabled by default.

If the DNS has been disabled, you may reenable it by performing the following task in global configuration mode:

Task	Command
Enable DNS-based host name-to-address translation.	**ip domain-lookup**

See the "Dynamic Lookup Example" section at the end of this chapter for an example of enabling the DNS.

Use the DNS to Discover ISO CLNS Addresses

If your router has both IP and International Organization for Standardization Connectionless Network Service (ISO CLNS) enabled and you want to use ISO CLNS Network Service Access Point (NSAP) addresses, you can use the DNS to query these addresses, as documented in RFC 1348. This feature is enabled by default.

To disable DNS queries for ISO CLNS addresses, perform the following task in global configuration mode:

Task	Command
Disable DNS queries for ISO CLNS addresses.	**no ip domain-lookup nsap**

Configure HP Probe Proxy Name Requests

HP Probe Proxy support allows the Cisco IOS software to respond to HP Probe Proxy name requests. These requests are typically used at sites that have Hewlett-Packard equipment and are already using HP Probe Proxy. Tasks associated with HP Probe Proxy are shown in the following two tables.

To configure HP Probe Proxy, perform the following task in interface configuration mode:

Task	Command
Allow the Cisco IOS software to respond to HP Probe Proxy name requests.	**ip probe proxy**

Perform the following task in global configuration mode:

Task	Command
Enter the host name of an HP host (for which the router is acting as a proxy) into the host table.	**ip hp-host** *hostname ip-address*

See the "HP Hosts on a Network Segment Example" section at the end of this chapter for an example of configuring HP hosts on a network segment.

Configure the Next Hop Resolution Protocol

Routers, access servers, and hosts can use Next Hop Resolution Protocol (NHRP) to discover the addresses of other routers and hosts connected to a nonbroadcast, multiaccess (NBMA) network. Partially meshed NBMA networks are typically configured with multiple logical networks to provide full network layer connectivity. In such configurations, packets might make several hops over the NBMA network before arriving at the exit router (the router nearest the destination network). In addition, such NBMA networks (whether partially or fully meshed) typically require tedious static configurations. These static configurations provide the mapping between network layer addresses (such as IP) and NBMA addresses (such as E.164 addresses for Switched Multimegabit Data Service, or SMDS).

NHRP provides an ARP-like solution that alleviates these NBMA network problems. With NHRP, systems attached to an NBMA network dynamically learn the NBMA address of the other systems that are part of that network, allowing these systems to directly communicate without requiring traffic to use an intermediate hop.

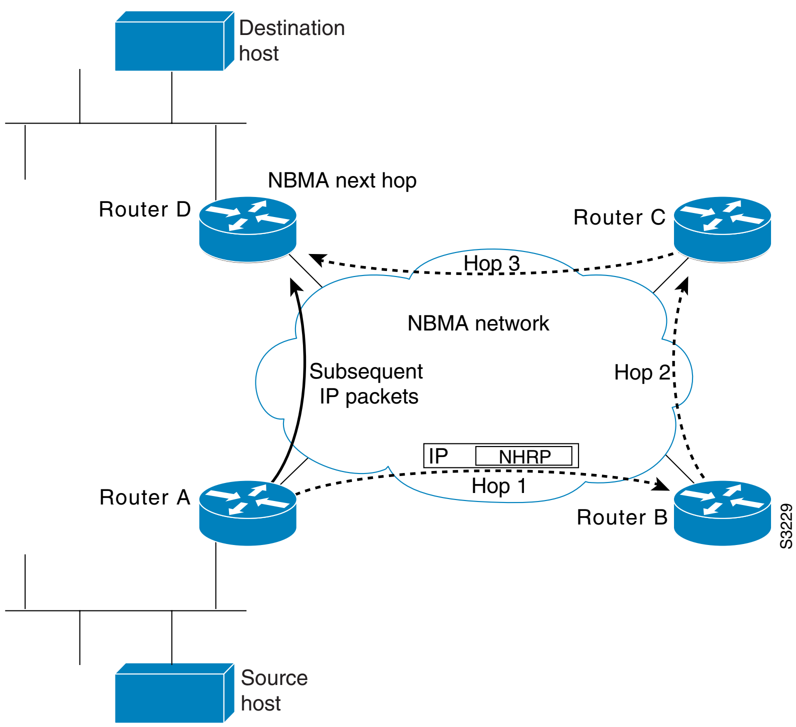
The NBMA network is considered nonbroadcast either because it technically does not support broadcasting (for example, an X.25 network) or because broadcasting is too expensive (for example, an SMDS broadcast group that would otherwise be too large).

Cisco's Implementation of NHRP

Cisco's implementation of NHRP supports IP Version 4, Internet Packet Exchange (IPX) network layers, and, at the link layer, ATM, Ethernet, SMDS, and multipoint tunnel networks. Although NHRP is available on Ethernet, it is not necessary to implement NHRP over Ethernet media because Ethernet is capable of broadcasting. Ethernet support is unnecessary (and not provided) for IPX.

Figure 4 illustrates four routers connected to an NBMA network. Within the network are ATM or SMDS switches necessary for the routers to communicate with each other. Assume that the switches have virtual circuit connections represented by hops 1, 2, and 3 of the figure. When Router A attempts to forward an IP packet from the source host to the destination host, NHRP is triggered. On behalf of the source host, Router A sends an NHRP request packet encapsulated in an IP packet, which takes three hops across the network to reach Router D, connected to the destination host. After receiving a positive NHRP reply, Router D is determined to be the "NBMA next hop," and Router A sends subsequent IP packets for the destination to Router D in one hop.

Figure 4 Next Hop Resolution Protocol (NHRP)



With NHRP, once the NBMA next hop is determined, the source either starts sending data packets to the destination (in a connectionless NBMA network such as SMDS) or establishes a virtual circuit connection to the destination with the desired bandwidth and quality of service (QOS) characteristics (in a connection-oriented NBMA network such as ATM).

Other address resolution methods can be used while NHRP is deployed. IP hosts that rely upon the LIS (Logical IP Subnet) model might require ARP servers and services over NBMA networks, and deployed hosts might not implement NHRP, but might continue to support ARP variations. NHRP is designed to eliminate the suboptimal routing that results from the LIS model, and can be deployed with existing ARP services without interfering with them.

NHRP is used to facilitate building a virtual private network. In this context, a virtual private network consists of a virtual Layer 3 network that is built on top of an actual Layer 3 network. The topology you use over the virtual private network is largely independent of the underlying network, and the protocols you run over it are completely independent of it.

Connected to the NBMA network are one or more stations that implement NHRP, and are known as *Next Hop Servers*. All routers running Release 10.3 or later are capable of implementing NHRP and, thus, can act as Next Hop Servers.

Each Next Hop Server serves a set of destination hosts, which might or might not be directly connected to the NBMA network. Next Hop Servers cooperatively resolve the NBMA next hop addresses within their NBMA network. In addition to NHRP, Next Hop Servers typically participate in protocols used to disseminate routing information across (and beyond the boundaries of) the NBMA network, and might support ARP service also.

A Next Hop Server maintains a "next-hop resolution" cache, which is a table of network layer address to NBMA address mappings. The table is created from information gleaned from NHRP register packets, extracted from NHRP request or reply packets that traverse the Next Hop Server as they are forwarded, or through other means such as ARP and preconfigured tables.

Protocol Operation

NHRP requests traverse one or more hops within an NBMA subnetwork before reaching the station that is expected to generate a response. Each station (including the source station) chooses a neighboring Next Hop Server to forward the request to. The Next Hop Server selection procedure typically involves performing a routing decision based upon the network layer destination address of the NHRP request. Ignoring error situations, the NHRP request eventually arrives at a station that generates an NHRP reply. This responding station either serves the destination, is the destination itself, or is a client that specified it should receive NHRP requests when it registered with its server. The responding station generates a reply using the source address from within the NHRP packet to determine where the reply should be sent.

NHRP Configuration Task List

To configure NHRP, perform the tasks described in the following sections. The first task is required, the remainder are optional.

- Enable NHRP on an Interface
- Configure a Station's Static IP-to-NBMA Address Mapping
- Statically Configure a Next Hop Server
- Configure NHRP Authentication
- Control NHRP Rate
- Suppress Forward and Reverse Record Options
- Specify the NHRP Responder Address
- Change the Time Period NBMA Addresses Are Advertised as Valid
- Configure a GRE Tunnel for Multipoint Operation

Enable NHRP on an Interface

To enable NHRP for an interface on a router, perform the following task in interface configuration mode. In general, all NHRP stations within a logical NBMA network must be configured with the same network identifier.

Task	Command
Enable NHRP on an interface.	**ip nhrp network-id** *number*

See the "Logical NBMA Example" section and the "NHRP over ATM Example" section at the end of this chapter for examples of enabling NHRP.

Configure a Station's Static IP-to-NBMA Address Mapping

To participate in NHRP, a station connected to an NBMA network should be configured with the IP and NBMA addresses of its Next Hop Server(s). The format of the NBMA address depends on the medium you are using. For example, ATM uses an NSAP address, Ethernet uses a MAC address, and SMDS uses an E.164 address.

These Next Hop Servers may also be the stations's default or peer routers, so their addresses can be obtained from the station's network layer forwarding table.

If the station is attached to several link layer networks (including logical NBMA networks), the station should also be configured to receive routing information from its Next Hop Server(s) and peer routers so that it can determine which IP networks are reachable through which link layer networks.

To configure static IP-to-NBMA address mapping on a station (host or router), perform the following task in interface configuration mode:

Task	Command
Configure static IP-to-NBMA address mapping.	**ip nhrp map** *ip-address nbma-address*

Statically Configure a Next Hop Server

A Next Hop Server normally uses the network layer forwarding table to determine where to forward NHRP packets, and to find the egress point from an NBMA network. A Next Hop Server may alternately be statically configured with a set of IP address prefixes that correspond to the IP addresses of the stations it serves, and their logical NBMA network identifiers.

To statically configure a Next Hop Server, perform the following task in interface configuration mode:

Task	Command
Statically configure a Next Hop Server.	**ip nhrp nhs** *nhs-address* [*net-address* [*netmask*]]

To configure multiple networks that the Next Hop Server serves, repeat the **ip nhrp nhs** command with the same Next Hop Server address, but different IP network addresses. To configure additional Next Hop Servers, repeat the **ip nhrp nhs** command.

Configure NHRP Authentication

Configuring an authentication string ensures that only routers configured with the same string can intercommunicate using NHRP. Therefore, if the authentication scheme is to be used, the same string must be configured in all devices configured for NHRP on a fabric. To specify the authentication string for NHRP on an interface, perform the following task in interface configuration mode:

Task	Command
Specify an authentication string.	**ip nhrp authentication** *string*

Control NHRP Rate

There are three ways to control NHRP:

- Trigger NHRP by IP Packets
- Trigger NHRP on a Per-Destination Basis
- Control the NHRP Packet Rate

These methods are described in this section.

Trigger NHRP by IP Packets

You can specify an IP access list that is used to decide which IP packets can trigger the sending of NHRP requests. By default, all non-NHRP packets trigger NHRP requests. To limit which IP packets trigger NHRP requests, define an access list and then apply it to the interface.

To define an access list, perform one of the following tasks in global configuration mode:

Task	Command
Define a standard IP access list.	**access-list** *access-list-number* {**deny** | **permit**} *source* [*source-wildcard*]
Define an extended IP access list.	**access-list** *access-list-number* {**deny** | **permit**} *protocol source source-wildcard destination destination-wildcard* [**precedence** *precedence*] [**tos** *tos*] [**established**] [**log**]

Then apply the IP access list to the interface by performing the following task in interface configuration mode:

Task	Command
Specify an IP access list that controls NHRP requests.	**ip nhrp interest** *access-list-number*

Trigger NHRP on a Per-Destination Basis

By default, when the software attempts to transmit a data packet to a destination for which it has determined that NHRP can be used, it transmits an NHRP request for that destination. You can configure the system to wait until a specified number of data packets have been sent to a particular destination before NHRP is attempted. To do so, perform the following task in interface configuration mode:

Task	Command
Specify how many data packets are sent to a destination before NHRP is attempted.	**ip nhrp use** *usage-count*

Control the NHRP Packet Rate

By default, the maximum rate at which the software sends NHRP packets is 5 packets per 10 seconds. The software maintains a per interface quota of NHRP packets (whether generated locally or forwarded) that can be transmitted. To change this maximum rate, perform the following task in interface configuration mode:

Task	Command
Change the NHRP packet rate per interface.	**ip nhrp max-send** *pkt-count* **every** *interval*

Suppress Forward and Reverse Record Options

To dynamically detect link-layer filtering in NBMA networks (for example, SMDS address screens), and to provide loop detection and diagnostic capabilities, NHRP incorporates a Route Record in requests and replies. The Route Record options contain the network (and link layer) addresses of all intermediate Next Hop Servers between source and destination (in the forward direction) and between destination and source (in the reverse direction).

By default, forward record options and reverse record options are included in NHRP request and reply packets. To suppress the use of these options, perform the following task in interface configuration mode:

Task	Command
Suppress forward and reverse record options.	**no ip nhrp record**

Specify the NHRP Responder Address

If an NHRP requestor wants to know which Next Hop Server generates an NHRP reply packet, it can request that information by including the responder address option in its NHRP request packet. The Next Hop Server that generates the NHRP reply packet then complies by inserting its own IP address in the NHRP reply. The Next Hop Server uses the primary IP address of the specified interface.

To specify which interface the Next Hop Server uses for the NHRP responder IP address, perform the following task in interface configuration mode:

Task	Command
Specify which interface the Next Hop Server uses to determine the NHRP responder address.	**ip nhrp responder** *type number*

If an NHRP reply packet being forwarded by a Next Hop Server contains that Next Hop Server's own IP address, the Next Hop Server generates an Error Indication of type "NHRP Loop Detected" and discards the reply.

Change the Time Period NBMA Addresses Are Advertised as Valid

You can change the length of time that NBMA addresses are advertised as valid in positive and negative NHRP responses. In this context, *advertised* means how long the Cisco IOS software tells other routers to keep the addresses it is providing in NHRP responses. The default length of time for each response is 7,200 seconds (2 hours). To change the length of time, perform the following task in interface configuration mode:

Task	Command
Specify the number of seconds that NBMA addresses are advertised as valid in positive or negative NHRP responses.	**ip nhrp holdtime** *seconds-positive* [*seconds-negative*]

Configure a GRE Tunnel for Multipoint Operation

You can enable a generic routing encapsulation (GRE) tunnel to operate in multipoint fashion. A tunnel network of multipoint tunnel interfaces can be thought of as an NBMA network. To configure the tunnel, perform the following tasks in interface configuration mode:

Task	Command
Enable a GRE tunnel to be used in multipoint fashion.	**tunnel mode gre ip multipoint**
Configure a tunnel identification key.	**tunnel key** *key-number*

The tunnel key should correspond to the NHRP network identifier specified in the **ip nhrp network-id** command. See the "NHRP on a Multipoint Tunnel Example" section at the end of this chapter for an example of NHRP configured on a multipoint tunnel.

Enable IP Routing

IP routing is automatically enabled in the Cisco IOS software. If you choose to set up the router to bridge rather than route IP datagrams, you must disable IP routing. To reenable IP routing if it has been disabled, perform the following task in global configuration mode:

Task	Command
Enable IP routing.	**ip routing**

When IP routing is disabled, the router will act as an IP end host for IP packets destined for or sourced by it, whether or not bridging is enabled for those IP packets not destined for the device. To reenable IP routing, use the **ip routing** command.

Routing Assistance When IP Routing Is Disabled

The Cisco IOS software provides three methods by which the router can learn about routes to other networks when IP routing is disabled and the device is acting as an IP host. These methods are described in the sections that follow:

- Proxy ARP
- Default Gateway (also known as *default router*)
- ICMP Router Discovery Protocol (IRDP)

When IP routing is disabled, the default gateway feature and the router discovery client are enabled, and proxy ARP is disabled. When IP routing is enabled, the default gateway feature is disabled and you can configure proxy ARP and the router discovery servers.

Proxy ARP

The most common method of learning about other routes is by using proxy ARP. Proxy ARP, defined in RFC 1027, enables an Ethernet host with no knowledge of routing to communicate with hosts on other networks or subnets. Such a host assumes that all hosts are on the same local Ethernet, and that it can use ARP to determine their hardware addresses.

Under proxy ARP, if a device receives an ARP Request for a host that is not on the same network as the ARP Request sender, the Cisco IOS software evaluates whether it has the best route to that host. If it does, the device sends an ARP Reply packet giving its own Ethernet hardware address. The host that sent the ARP Request then sends its packets to the device, which forwards them to the intended host. The software treats all networks as if they are local and performs ARP requests for every IP address. This feature is enabled by default. If it has been disabled, see the section "Enable Proxy ARP" earlier in this chapter.

Proxy ARP works as long as other routers support it. Many other routers, especially those loaded with host-based routing software, do not support it.

Default Gateway

Another method for locating routes is to define a default router (or gateway). The Cisco IOS software sends all nonlocal packets to this router, which either routes them appropriately or sends an IP Control Message Protocol (ICMP) redirect message back, telling it of a better route. The ICMP redirect message indicates which local router the host should use. The software caches the redirect messages and routes each packet thereafter as efficiently as possible. The limitations of this method are that there is no means of detecting when the default router has gone down or is unavailable, and there is no method of picking another device if one of these events should occur.

To set up a default gateway for a host, perform the following task in global configuration mode:

Task	Command
Set up a default gateway (router).	**ip default-gateway** *ip-address*

To display the address of the default gateway, use the **show ip redirects** EXEC command.

ICMP Router Discovery Protocol (IRDP)

The Cisco IOS software provides a third method, called *router discovery*, by which the router dynamically learns about routes to other networks using the ICMP Router Discovery Protocol (IRDP). IRDP allows hosts to locate routers. When operating as a client, router discovery packets are generated. When operating as a host, router discovery packets are received. Our IRDP implementation fully conforms to the router discovery protocol outlined in RFC 1256.

The software is also capable of wire-tapping Routing Information Protocol (RIP) and Interior Gateway Routing Protocol (IGRP) routing updates and inferring the location of routers from those updates. The server/client implementation of router discovery does not actually examine or store the full routing tables sent by routing devices, it merely keeps track of which systems are sending such data.

You can configure the four protocols in any combination. When possible, we recommend that you use IRDP because it allows each router to specify *both* a priority and the time after which a device should be assumed down if no further packets are received. Devices discovered using IGRP are assigned an arbitrary priority of 60. Devices discovered through RIP are assigned a priority of 50. For IGRP and RIP, the software attempts to measure the time between updates, and assumes that the device is down if no updates are received for 2.5 times that interval.

Each device discovered becomes a candidate for the default router. The list of candidates is scanned and a new highest-priority router is selected when any of the following events occur:

- When a higher-priority router is discovered (the list of routers is polled at 5-minute intervals).
- When the current default router is declared down.
- When a TCP connection is about to time out because of excessive retransmissions. In this case, the server flushes the ARP cache and the ICMP redirect cache, and picks a new default router in an attempt to find a successful route to the destination.

Enable IRDP Processing

The only required task for configuring IRDP routing on a specified interface is to enable IRDP processing on an interface. Perform the following task in interface configuration mode:

Task	Command
Enable IRDP processing on an interface.	**ip irdp**

Change IRDP Parameters

When you enable IRDP processing, the default parameters will apply. You can optionally change any of these IRDP parameters. Perform the following tasks in interface configuration mode:

Task	Command
Send IRDP advertisements to the all-systems multicast address (224.0.0.1) on a specified interface.	**ip irdp multicast**
Set the IRDP period for which advertisements are valid.	**ip irdp holdtime** *seconds*
Set the IRDP maximum interval between advertisements.	**ip irdp maxadvertinterval** *seconds*
Set the IRDP minimum interval between advertisements.	**ip irdp minadvertinterval** *seconds*
Set a device's IRDP preference level.	**ip irdp preference** *number*

Task	Command
Specify an IRDP address and preference to proxy-advertise.	**ip irdp address** *address* [*number*]

The Cisco IOS software can proxy-advertise other machines that use IRDP; however, this is not recommended because it is possible to advertise nonexistent machines or machines that are down.

Enable IP Bridging

To transparently bridge IP on an interface, perform the following tasks beginning in global configuration mode:

Task	Command
Disable IP routing.	**no ip routing**
Specify an interface.	**interface** *type number*
Add the interface to a bridge group.	**bridge-group** *group*

Enable Integrated Routing and Bridging

With integrated routing and bridging (IRB), you can route IP traffic between routed interfaces and bridge groups, or route IP traffic between bridge groups. Specifically, local or unroutable traffic is bridged among the bridged interfaces in the same bridge group, while routable traffic is routed to other routed interfaces or bridge groups. Using IRB, you can

- Switch packets from a bridged interface to a routed interface
- Switch packets from a routed interface to a bridged interface
- Switch packets within the same bridge group

For more information about configuring integrated routing and bridging, refer to the "Configuring Transparent Bridging" chapter in the *Bridging and IBM Networking Configuration Guide*.

Configure a Routing Process

At this point in the configuration process, you can choose to configure one or more of the many routing protocols that are available based on your individual network needs. Routing protocols provide topology information of an internetwork. Refer to subsequent chapters in this document for the tasks involved in configuring IP routing protocols such as BGP, On-Demand Routing (ODR), RIP, IGRP, OSPF, IP Enhanced IGRP, Integrated IS-IS, and IP multicast routing. If you want to continue to perform IP addressing tasks, continue reading the following sections.

Configure Broadcast Packet Handling

A *broadcast* is a data packet destined for all hosts on a particular physical network. Network hosts recognize broadcasts by special addresses. Broadcasts are heavily used by some protocols, including several important Internet protocols. Control of broadcast messages is an essential part of the IP network administrator's job.

The Cisco IOS software supports two kinds of broadcasting: *directed broadcasting* and *flooding*. A directed broadcast is a packet sent to a specific network or series of networks, while a flooded broadcast packet is sent to every network. A directed broadcast address includes the network or subnet fields.

Several early IP implementations do not use the current broadcast address standard. Instead, they use the old standard, which calls for all zeros instead of all ones to indicate broadcast addresses. Many of these implementations do not recognize an all-ones broadcast address and fail to respond to the broadcast correctly. Others forward all-ones broadcasts, which causes a serious network overload known as a *broadcast storm*. Implementations that exhibit these problems include systems based on versions of BSD UNIX prior to Version 4.3.

Routers provide some protection from broadcast storms by limiting their extent to the local cable. Bridges (including intelligent bridges), because they are Layer 2 devices, forward broadcasts to all network segments, thus propagating all broadcast storms.

The best solution to the broadcast storm problem is to use a single broadcast address scheme on a network. Most modern IP implementations allow the network manager to set the address to be used as the broadcast address. Many implementations, including the one in the Cisco IOS software, accept and interpret all possible forms of broadcast addresses.

For detailed discussions of broadcast issues in general, see RFC 919, "Broadcasting Internet Datagrams," and RFC 922, "Broadcasting IP Datagrams in the Presence of Subnets." The support for Internet broadcasts generally complies with RFC 919 and RFC 922; it does not support multisubnet broadcasts as defined in RFC 922.

The current broadcast address standard provides specific addressing schemes for forwarding broadcasts. Perform the tasks in the following sections to enable these schemes:

- Enable Directed Broadcast-to-Physical Broadcast Translation
- Forward UDP Broadcast Packets and Protocols
- Establish an IP Broadcast Address
- Flood IP Broadcasts

See the "Broadcasting Examples" section at the end of this chapter for broadcasting configuration examples.

Enable Directed Broadcast-to-Physical Broadcast Translation

To enable forwarding of directed broadcasts on an interface where the broadcast becomes a physical broadcast, perform one of the tasks that follow. By default, this feature is enabled only for those protocols configured using the **ip forward-protocol** global configuration command. You can specify an access list to control which broadcasts are forwarded. When an access list is specified, only those IP packets permitted by the access list are eligible to be translated from directed broadcasts to physical broadcasts.

Perform either of the following tasks in interface configuration mode as required for your network:

Task	Command
Enable directed broadcast-to-physical broadcast translation on an interface.	**ip directed-broadcast** [*access-list-number*]
Disable directed broadcast-to-physical broadcast translation on an interface.	**no ip directed-broadcast** [*access-list-number*]

Forward UDP Broadcast Packets and Protocols

Network hosts occasionally use UDP broadcasts to determine address, configuration, and name information. If such a host is on a network segment that does not include a server, UDP broadcasts are normally not forwarded. You can remedy this situation by configuring the interface of your router to forward certain classes of broadcasts to a helper address. You can use more than one helper address per interface.

You can specify a UDP destination port to control which UDP services are forwarded. You can specify multiple UDP protocols. You can also specify the Network Disk (ND) protocol, which is used by older diskless Sun workstations, and you can specify the network security protocol SDNS. By default, both UDP and ND forwarding are enabled if a helper address has been defined for an interface. The description for the **ip forward-protocol** command in the *Network Protocols Command Reference, Part 1* lists the ports that are forwarded by default if you do not specify any UDP ports.

If you do not specify any UDP ports when you configure the forwarding of UDP broadcasts, you are configuring the router to act as a BOOTP forwarding agent. BOOTP packets carry Dynamic Host Configuration Protocol (DHCP) information. (DHCP is defined in RFC 1531.) This means that the Cisco IOS software is now compatible with DHCP clients.

To enable forwarding and to specify the destination address, perform the following task in interface configuration mode:

Task	Command
Enable forwarding and specify the destination address for forwarding UDP broadcast packets, including BOOTP.	**ip helper-address** *address*

To specify which protocols will be forwarded, perform the following task in global configuration mode:

Task	Command
Specify which protocols will be forwarded over which ports.	**ip forward-protocol** {**udp** [*port*] | **nd** | **sdns**}

See the "Helper Addresses Example" section at the end of this chapter for an example of how to configure helper addresses.

Establish an IP Broadcast Address

The Cisco IOS software supports IP broadcasts on both LANs and WANs. There are several ways to indicate an IP broadcast address. Currently, the most popular way, and the default, is an address consisting of all ones (255.255.255.255), although the software can be configured to generate any form of IP broadcast address. Our software also receives and understands any form of IP broadcast.

To set the IP broadcast address, perform the following task in interface configuration mode:

Task	Command
Establish a different broadcast address (other than 255.255.255.255).	**ip broadcast-address** [*ip-address*]

If the router does not have nonvolatile memory, and you need to specify the broadcast address to use before the software is configured, you must change the IP broadcast address by setting jumpers in the processor configuration register. Setting bit 10 causes the device to use all zeros. Bit 10 interacts with bit 14, which controls the network and subnet portions of the broadcast address. Setting bit 14 causes the device to include the network and subnet portions of its address in the broadcast address. Table 2 shows the combined effect of setting bits 10 and 14.

Table 2 Configuration Register Settings for Broadcast Address Destination

Bit 14	Bit 10	Address (<net><host>)
Out	Out	<ones><ones>
Out	In	<zeros><zeros>
In	In	<net><zeros>
In	Out	<net><ones>

Some router platforms allow the configuration register to be set through the software; see the "Rebooting the Router" chapter of the *Configuration Fundamentals Configuration Guide* for details. For other router platforms, the configuration register must be changed through hardware; see the appropriate hardware installation and maintenance manual for your system.

Flood IP Broadcasts

You can allow IP broadcasts to be flooded throughout your internetwork in a controlled fashion using the database created by the bridging spanning-tree protocol. Turning on this feature also prevents loops. In order to support this capability, the routing software must include the transparent bridging, and bridging must be configured on each interface that is to participate in the flooding. If bridging is not configured on an interface, it still will be able to receive broadcasts. However, the interface will never forward broadcasts it receives, and the router will never use that interface to send broadcasts received on a different interface.

Packets that are forwarded to a single network address using the IP helper address mechanism can be flooded. Only one copy of the packet is sent on each network segment.

In order to be considered for flooding, packets must meet the following criteria. (Note that these are the same conditions used to consider packets forwarding via IP helper addresses.)

- The packet must be a MAC-level broadcast.
- The packet must be an IP-level broadcast.
- The packet must be a TFTP, DNS, Time, NetBIOS, ND, or BOOTP packet, or a UDP protocol specified by the **ip forward-protocol udp** global configuration command.
- The packet's time-to-live (TTL) value must be at least two.

A flooded UDP datagram is given the destination address you specified with the **ip broadcast-address** command on the output interface. The destination address can be set to any desired address. Thus, the destination address may change as the datagram propagates through the network. The source address is never changed. The TTL value is decremented.

After a decision has been made to send the datagram out on an interface (and the destination address possibly changed), the datagram is handed to the normal IP output routines and is, therefore, subject to access lists, if they are present on the output interface.

To use the bridging spanning-tree database to flood UDP datagrams, perform the following task in global configuration mode:

Task	Command
Use the bridging spanning-tree database to flood UDP datagrams.	**ip forward-protocol spanning-tree**

If no actual bridging is desired, you can configure a type-code bridging filter that will deny all packet types from being bridged. Refer to the "Configuring Transparent Bridging" chapter of the *Bridging and IBM Networking Configuration Guide* for more information about using access lists to filter bridged traffic. The spanning-tree database is still available to the IP forwarding code to use for the flooding.

Speed Up Flooding of UDP Datagrams

You can speed up flooding of UDP datagrams using the spanning-tree algorithm. Used in conjunction with the **ip forward-protocol spanning-tree** command, this feature boosts the performance of spanning tree-based UDP flooding by a factor of about four to five times. The feature, called *turbo flooding*, is supported over Ethernet interfaces configured for ARPA encapsulated, Fiber Distributed Data Interface (FDDI), and HDLC-encapsulated serial interfaces. However, it is not supported on Token Ring interfaces. As long as the Token Rings and the non-HDLC serial interfaces are not part of the bridge group being used for UDP flooding, turbo flooding will behave normally.

To enable turbo flooding, perform the following task in global configuration mode:

Task	Command
Use the bridging spanning-tree database to speed up flooding of UDP datagrams.	**ip forward-protocol turbo-flood**

Configure Network Address Translation (NAT)

Two of the key problems facing the Internet are depletion of IP address space and scaling in routing. Network Address Translation (NAT) is a feature that allows an organization's IP network to appear from the outside to use different IP address space than what it is actually using. Thus, NAT allows an organization with nonglobally routable addresses to connect to the Internet by translating those addresses into globally routable address space. NAT also allows a more graceful renumbering strategy for organizations that are changing service providers or voluntarily renumbering into CIDR blocks. NAT is also described in RFC 1631.

NAT Applications

NAT has several applications. Use it for the following purposes:

- You want to connect to the Internet, but not all your hosts have globally unique IP addresses. NAT enables private IP internetworks that use nonregistered IP addresses to connect to the Internet. NAT is configured on the router at the border of a stub domain (referred to as the *inside network*) and a public network such as the Internet (referred to as the *outside network*). NAT translates the internal local addresses to globally unique IP addresses before sending packets to the outside network.
- You must change your internal addresses. Instead of changing them, which can be a considerable amount of work, you can translate them by using NAT.

- You want to do basic load sharing of TCP traffic. You can map a single global IP address to many local IP addresses by using the TCP load distribution feature.

As a solution to the connectivity problem, NAT is practical only when relatively few hosts in a stub domain communicate outside of the domain at the same time. When this is the case, only a small subset of the IP addresses in the domain must be translated into globally unique IP addresses when outside communication is necessary, and these addresses can be reused when no longer in use.

Benefits of NAT

A significant advantage of NAT is that it can be configured without requiring changes to hosts or routers other than those few routers on which NAT will be configured. As discussed previously, NAT may not be practical if large numbers of hosts in the stub domain communicate outside of the domain. Furthermore, some applications use embedded IP addresses in such a way that it is impractical for a NAT device to translate. These applications may not work transparently or at all through a NAT device. NAT also hides the identity of hosts, which may be an advantage or a disadvantage.

A router configured with NAT will have at least one interface to the inside and one to the outside. In a typical environment, NAT is configured at the exit router between a stub domain and backbone. When a packet is leaving the domain, NAT translates the locally significant source address into a globally unique address. When a packet is entering the domain, NAT translates the globally unique destination address into a local address. If more than one exit point exists, each NAT must have the same translation table. If the software cannot allocate an address because it has run out of addresses, it drops the packet and sends an ICMP Host Unreachable packet.

A router configured with NAT must not advertise the local networks to the outside. However, routing information that NAT receives from the outside can be advertised in the stub domain as usual.

NAT Terminology

As mentioned previously, the term *inside* refers to those networks that are owned by an organization and that must be translated. Inside this domain, hosts will have address in the one address space, while on the outside, they will appear to have addresses in a another address space when NAT is configured. The first address space is referred to as the *local* address space while the second is referred to as the *global* address space.

Similarly, *outside* refers to those networks to which the stub network connects, and which are generally not under the organization's control. As will be described later, hosts in outside networks can be subject to translation also, and can, thus, have local and global addresses.

To summarize, NAT uses the following definitions:

- **Inside local address**—The IP address that is assigned to a host on the inside network. The address is probably not a legitimate IP address assigned by the Network Information Center (NIC) or service provider.
- **Inside global address**—A legitimate IP address (assigned by the NIC or service provider) that represents one or more inside local IP addresses to the outside world.
- **Outside local address**—The IP address of an outside host as it appears to the inside network. Not necessarily a legitimate address, it was allocated from address space routable on the inside.
- **Outside global address—**The IP address assigned to a host on the outside network by the host's owner. The address was allocated from globally routable address or network space.

NAT Configuration Task List

Before configuring any NAT translation, you must know your inside local addresses and inside global addresses. The following sections discuss how you can use NAT to perform optional tasks:

- Translate Inside Source Addresses
- Overload an Inside Global Address
- Translate Overlapping Addresses
- Provide TCP Load Distribution
- Change Translation Timeouts
- Monitor and Maintain NAT

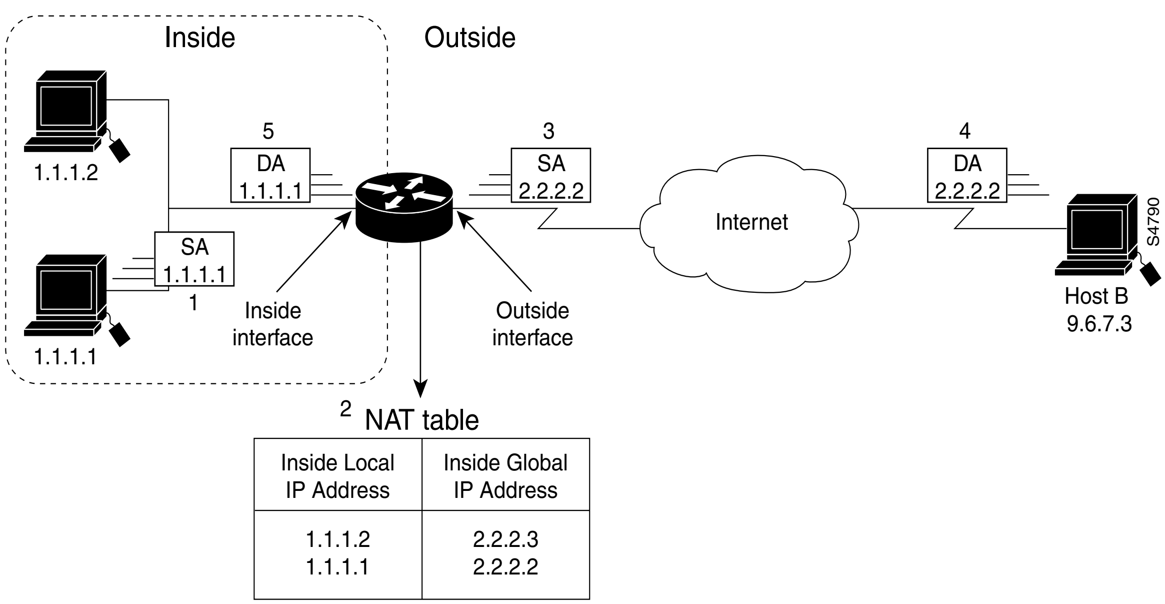
Translate Inside Source Addresses

Use this feature to translate your own IP addresses into globally unique IP addresses when communicating outside of your network. You can configure static or dynamic inside source translation as follows:

- *Static translation* establishes a one-to-one mapping between your inside local address and an inside global address. Static translation is useful when a host on the inside must be accessible by a fixed address from the outside.
- *Dynamic translation* establishes a mapping between an inside local address and a pool of global addresses.

Figure 5 illustrates a router that is translating a source address inside a network to a source address outside the network.

Figure 5 NAT Inside Source Translation



The following process describes inside source address translation, as shown in Figure 5:

1 The user at Host 1.1.1.1 opens a connection to Host B.

2 The first packet that the router receives from Host 1.1.1.1 causes the router to check its NAT table.

- If a static translation entry was configured, the router goes to Step 3.
- If no translation entry exists, the router determines that source address (SA) 1.1.1.1 must be translated dynamically, selects a legal, global address from the dynamic address pool, and creates a translation entry. This type of entry is called a *simple entry*.

3 The router replaces the inside local source address of Host 1.1.1.1 with the translation entry's global address, and forwards the packet.

4 Host B receives the packet and responds to Host 1.1.1.1 by using the inside global IP destination address (DA) 2.2.2.2.

5 When the router receives the packet with the inside global IP address, it performs a NAT table lookup by using the inside global address as a key. It then translates the address to the inside local address of Host 1.1.1.1 and forwards the packet to Host 1.1.1.1.

6 Host 1.1.1.1 receives the packet and continues the conversation. The router performs Steps 2 through 5 for each packet.

Configure Static Translation

To configure static inside source address translation, perform the following tasks beginning in global configuration mode:

Task	Command
Establish static translation between an inside local address and an inside global address.	**ip nat inside source static** *local-ip global-ip*
Specify the inside interface.	**interface** *type number*
Mark the interface as connected to the inside.	**ip nat inside**
Specify the outside interface.	**interface** *type number*
Mark the interface as connected to the outside.	**ip nat outside**

The previous steps are the minimum you must configure. You could configure multiple inside and outside interfaces.

Configure Dynamic Translation

To configure dynamic inside source address translation, perform the following tasks beginning in global configuration mode:

Task	Command
Define a pool of global addresses to be allocated as needed.	**ip nat pool** *name start-ip end-ip* {**netmask** *netmask* | **prefix-length** *prefix-length*}
Define a standard access list permitting those addresses that are to be translated.	**access-list** *access-list-number* **permit** *source* [*source-wildcard*]
Establish dynamic source translation, specifying the access list defined in the prior step.	**ip nat inside source list** *access-list-number* **pool** *name*
Specify the inside interface.	**interface** *type number*

Task	Command
Mark the interface as connected to the inside.	**ip nat inside**
Specify the outside interface.	**interface** *type number*
Mark the interface as connected to the outside.	**ip nat outside**

Note The access list must permit only those addresses that are to be translated. (Remember that there is an implicit "deny all" at the end of each access-list.) An access list that is too permissive can lead to unpredictable results.

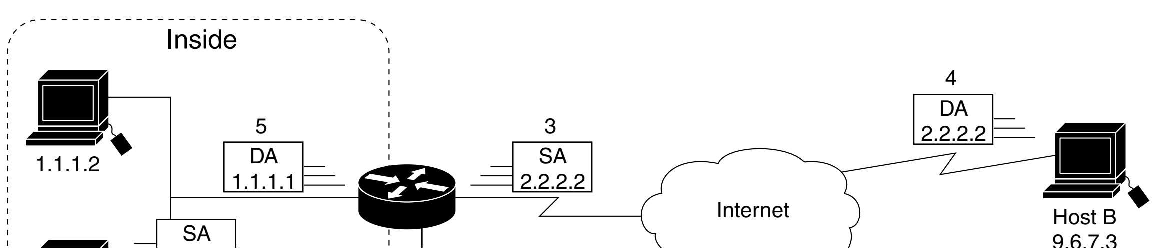
See the "Dynamic Inside Source Translation Example" section at the end of this chapter for an example of dynamic inside source translation.

Overload an Inside Global Address

You can conserve addresses in the inside global address pool by allowing the router to use one global address for many local addresses. When this overloading is configured, the router maintains enough information from higher-level protocols (for example, TCP or UDP port numbers) to translate the global address back to the correct local address. When multiple local addresses map to one global address, each the TCP or UDP port numbers of each inside host distinguish between the local addresses.

Figure 6 illustrates NAT operation when one inside global address represents multiple inside local addresses. The TCP port numbers act as differentiators.

Figure 6 NAT Overloading Inside Global Addresses



The router performs the following process in overloading inside global addresses, as shown in Figure 6. Both Host B and Host C think they are talking to a single host at address 2.2.2.2. They are actually talking to different hosts; the port number is the differentiator. In fact, many inside hosts could share the inside global IP address by using many port numbers.

1. The user at Host 1.1.1.1 opens a connection to Host B.
2. The first packet that the router receives from Host 1.1.1.1 causes the router to check its NAT table.

   If no translation entry exists, the router determines that address 1.1.1.1 must be translated, and sets up a translation of inside local address 1.1.1.1 to a legal global address. If overloading is enabled, and another translation is active, the router reuses the global address from that translation and saves enough information to be able to translate back. This type of entry is called an *extended entry*.
3. The router replaces the inside local source address 1.1.1.1 with the selected global address and forwards the packet.
4. Host B receives the packet and responds to Host 1.1.1.1 by using the inside global IP address 2.2.2.2.
5. When the router receives the packet with the inside global IP address, it performs a NAT table lookup, using the protocol, inside global address and port, and outside address and port as a key, translates the address to inside local address 1.1.1.1, and forwards the packet to Host 1.1.1.1.
6. Host 1.1.1.1 receives the packet and continues the conversation. The router performs Steps 2 through 5 for each packet.

To configure overloading of inside global addresses, perform the following tasks beginning in global configuration mode:

Task	Command
Define a pool of global addresses to be allocated as needed.	**ip nat pool** *name start-ip end-ip* {**netmask** *netmask* | **prefix-length** *prefix-length*}
Define a standard access list.	**access-list** *access-list-number* **permit** *source* [*source-wildcard*]
Establish dynamic source translation, identifying the access list defined in the prior step.	**ip nat inside source list** *access-list-number* **pool** *name* **overload**
Specify the inside interface.	**interface** *type number*
Mark the interface as connected to the inside.	**ip nat inside**
Specify the outside interface.	**interface** *type number*
Mark the interface as connected to the outside.	**ip nat outside**

Note The access list must permit only those addresses that are to be translated. (Remember that there is an implicit "deny all" at the end of each access list.) An access list that is too permissive can lead to unpredictable results.

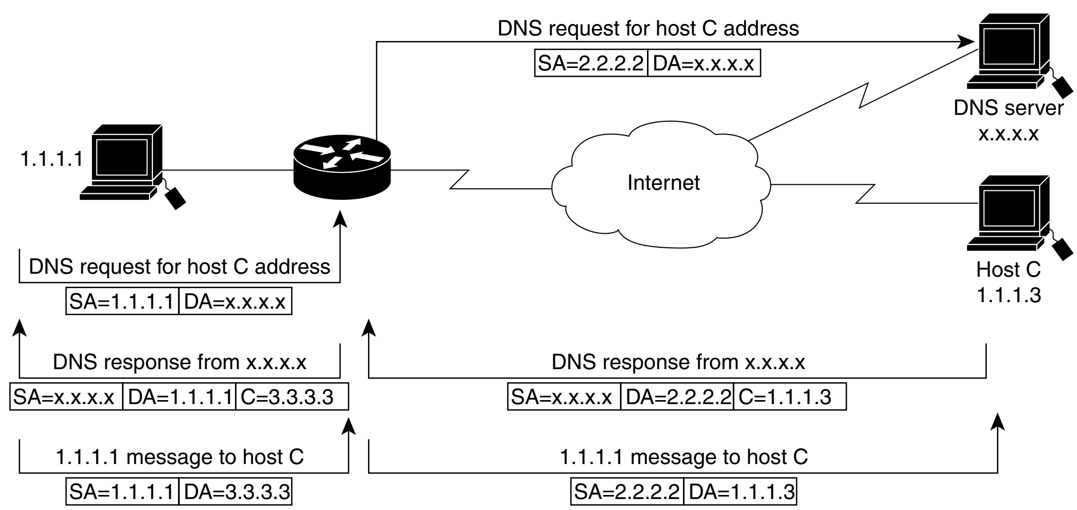
See the "Overloading Inside Global Addresses Example" section at the end of this chapter for an example of overloading inside global addresses.

Translate Overlapping Addresses

The NAT overview discusses translating IP addresses, perhaps because your IP addresses are not legal, officially assigned IP addresses. Perhaps you chose IP addresses that officially belong to another network. The case of an address used both illegally and legally is called *overlapping*. You can use NAT to translate inside addresses that overlap with outside addresses. Use this feature if your IP addresses in the stub network are legitimate IP addresses belonging to another network, and you want to communicate with those hosts or routers.

Figure 7 shows how NAT translates overlapping networks.

Figure 7 NAT Translating Overlapping Addresses



NAT table

Inside Local IP Address	Inside Global IP Address	Outside Global IP Address	Outside Local IP Address
1.1.1.1	2.2.2.2	1.1.1.3	3.3.3.3

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The router performs the following process when translating overlapping addresses:

1 The user at Host 1.1.1.1 opens a connection to Host C by name, requesting a name-to-address lookup from a DNS server.

2 The router intercepts the DNS reply and translates the returned address if there is an overlap (that is, the resulting legal address resides illegally in the inside network). To translate the return address, the router creates a simple translation entry mapping the overlapping address 1.1.1.3 to an address from a separately configured, outside local address pool.

The router examines every DNS reply from everywhere, ensuring that the IP address is not in the stub network. If it is, the router translates the address.

3 Host 1.1.1.1 opens a connection to 3.3.3.3.

4 The router sets up translations mapping inside local and global addresses to each other, and outside global and local addresses to each other.

5 The router replaces the source address with the inside global address and replaces the destination address with the outside global address.

6 Host C receives the packet and continues the conversation.

7 The router does a lookup, replaces the destination address with the inside local address, and replaces the source address with the outside local address.

8 Host 1.1.1.1 receives the packet and the conversation continues, using this translation process.

Configure Static Translation

To configure static outside source address translation, perform the following tasks beginning in global configuration mode:

Task	Command
Establish static translation between an outside local address and an outside global address.	**ip nat outside source static** *global-ip local-ip*
Specify the inside interface.	**interface** *type number*
Mark the interface as connected to the inside.	**ip nat inside**
Specify the outside interface.	**interface** *type number*
Mark the interface as connected to the outside.	**ip nat outside**

Configure Dynamic Translation

To configure dynamic outside source address translation, perform the following tasks beginning in global configuration mode.

Task	Command
Define a pool of local addresses to be allocated as needed.	**ip nat pool** *name start-ip end-ip* {**netmask** *netmask* | **prefix-length** *prefix-length*}
Define a standard access list.	**access-list** *access-list-number* **permit** *source* [*source-wildcard*]
Establish dynamic outside source translation, specifying the access list defined in the prior step.	**ip nat outside source list** *access-list-number* **pool** *name*
Specify the inside interface.	**interface** *type number*
Mark the interface as connected to the inside.	**ip nat inside**
Specify the outside interface.	**interface** *type number*
Mark the interface as connected to the outside.	**ip nat outside**

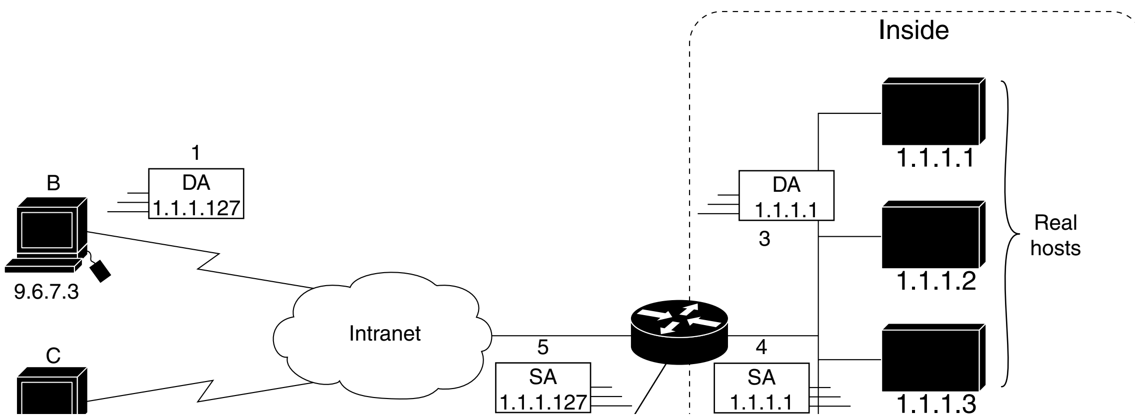
Note The access list must permit only those addresses that are to be translated. (Remember that there is an implicit "deny all" at the end of each access list.) An access list that is too permissive can lead to unpredictable results.

See the "Translating Overlapping Address Example" section at the end of this chapter for an example of translating an overlapping address.

Provide TCP Load Distribution

Another use of NAT is unrelated to Internet addresses. Your organization may have multiple hosts that must communicate with a heavily used host. Using NAT, you can establish a virtual host on the inside network that coordinates load sharing among real hosts. Destination addresses that match an access list are replaced with addresses from a rotary pool. Allocation is done in a round-robin basis, and only when a new connection is opened from the outside to the inside. Non-TCP traffic is passed untranslated (unless other translations are in effect). Figure 8 illustrates this feature.

Figure 8 NAT TCP Load Distribution



The router performs the following process when translating rotary addresses:

1. The user on Host B (9.6.7.3) opens a connection to virtual host at 1.1.1.127.
2. The router receives the connection request and creates a new translation, allocating the next real host (1.1.1.1) for the inside local IP address.
3. The router replaces the destination address with the selected real host address and forwards the packet.
4. Host 1.1.1.1 receives the packet and responds.
5. The router receives the packet, performs a NAT table lookup using the inside local address and port number, and the outside address and port number as the key. The router then translates the source address to the address of the virtual host and forwards the packet.

The next connection request will cause the router to allocate 1.1.1.2 for the inside local address.

To configure destination address rotary translation, perform the following tasks beginning in global configuration mode. This allows you to map one virtual host to many real hosts. Each new TCP session opened with the virtual host will be translated into a session with a different real host.

Task	Command
Define a pool of addresses containing the addresses of the real hosts.	**ip nat pool** *name start-ip end-ip* {**netmask** *netmask* | **prefix-length** *prefix-length*} **type rotary**
Define an access list permitting the address of the virtual host.	**access-list** *access-list-number* **permit** *source* [*source-wildcard*]
Establish dynamic inside destination translation, identifying the access list defined in the prior step.	**ip nat inside destination list** *access-list-number* **pool** *name*
Specify the inside interface.	**interface** *type number*
Mark the interface as connected to the inside.	**ip nat inside**
Specify the outside interface.	**interface** *type number*
Mark the interface as connected to the outside.	**ip nat outside**

Note The access list must permit only those addresses that are to be translated. (Remember that there is an implicit "deny all" at the end of each access list.) An access list that is too permissive can lead to unpredictable results.

See the "TCP Load Distribution Example" section at the end of this chapter for an example of rotary translation.

Change Translation Timeouts

By default, dynamic address translations time out after some period of non-use. You can change the default values on timeouts, if necessary. When overloading is not configured, simple translation entries time out after 24 hours. To change this value, perform the following task in global configuration mode:

Task	Command
Change the timeout value for dynamic address translations that do not use overloading.	**ip nat translation timeout** *seconds*

If you have configured overloading, you have finer control over translation entry timeout because each entry contains more context about the traffic that is using it. To change timeouts on extended entries, perform one or more of the following tasks in global configuration mode:

Task	Command
Change the UDP timeout value from 5 minutes.	**ip nat translation udp-timeout** *seconds*
Change the DNS timeout value from 1 minute.	**ip nat translation dns-timeout** *seconds*
Change the TCP timeout value from 24 hours.	**ip nat translation tcp-timeout** *seconds*
Change the Finish and Reset timeout value from 1 minute.	**ip nat translation finrst-timeout** *seconds*

Monitor and Maintain NAT

By default, dynamic address translations will time out from the NAT translation table at some point. You can clear the entries before the timeout by performing one of the following tasks in EXEC mode:

Task	Command
Clear all dynamic address translation entries from the NAT translation table.	**clear ip nat translation ***
Clear a simple dynamic translation entry containing an inside translation, or both inside and outside translation.	**clear ip nat translation inside** *global-ip local-ip* [**outside** *local-ip global-ip*]
Clear a simple dynamic translation entry containing an outside translation.	**clear ip nat translation outside** *local-ip global-ip*
Clear an extended dynamic translation entry.	**clear ip nat translation** *protocol* **inside** *global-ip global-port local-ip local-port* [**outside** *local-ip local-port global-ip global-port*]

You can display translation information by performing one of the following tasks in EXEC mode:

Task	Command
Display active translations.	**show ip nat translations** [**verbose**]
Display translation statistics.	**show ip nat statistics**

Monitor and Maintain IP Addressing

To monitor and maintain your network, perform the tasks in the following sections:

- Clear Caches, Tables, and Databases
- Specify the Format of Network Masks
- Display System and Network Statistics
- Monitor and Maintain NHRP

Clear Caches, Tables, and Databases

You can remove all contents of a particular cache, table, or database. Clearing a cache, table, or database can become necessary when the contents of the particular structure have become or are suspected to be invalid.

The following table lists the tasks associated with clearing caches, tables, and databases. Perform the following tasks as needed in EXEC mode:

Task	Command
Clear the IP ARP cache and the fast-switching cache.	**clear arp-cache**
Remove one or all entries from the host name and address cache.	**clear host** {*name* | *****}
Remove one or more routes from the IP routing table.	**clear ip route** {*network* [*mask*] | *****}

Specify the Format of Network Masks

IP uses a 32-bit mask that indicates which address bits belong to the network and subnetwork fields, and which bits belong to the host field. This is called a *netmask*. By default, **show** commands display an IP address and then its netmask in dotted decimal notation. For example, a subnet would be displayed as 131.108.11.55 255.255.255.0.

You might find it more convenient to display the network mask in hexadecimal format or bitcount format instead. The hexadecimal format is commonly used on UNIX systems. The previous example would be displayed as 131.108.11.55 0XFFFFFF00.

The bitcount format for displaying network masks is to append a slash (/) and the total number of bits in the netmask to the address itself. The previous example would be displayed as 131.108.11.55/24.

To specify the format in which netmasks appear for the current session, perform the following task in EXEC mode:

Task	Command
Specify the format of network masks for the current session.	**term ip netmask-format** {**bit-count** | **decimal** | **hexadecimal**}

To configure the format in which netmasks appear for an individual line, perform the following task in line configuration mode:

Task	Command
Configure the format of network masks for a line.	**ip netmask-format** {**bit-count** | **decimal** | **hexadecimal**}

Display System and Network Statistics

You can display specific statistics such as the contents of IP routing tables, caches, and databases. The resulting information can be used to determine resource utilization and to solve network problems. You also can display information about node reachability and discover the routing path that your device's packets are taking through the network.

These tasks are summarized in the table that follows. See the "IP Addressing Commands" chapter in the *Network Protocols Command Reference, Part 1* for details about the commands listed in these tasks. Perform any of the following tasks in privileged EXEC mode:

Task	Command
Display the entries in the ARP table.	**show arp**
Display the default domain name, style of lookup service, the name server hosts, and the cached list of host names and addresses.	**show hosts**
Display IP addresses mapped to TCP ports (aliases).	**show ip aliases**
Display the IP ARP cache.	**show ip arp**
Display the usability status of interfaces.	**show ip interface** [*type number*]
Display IRDP values.	**show ip irdp**
Display the masks used for network addresses and the number of subnets using each mask.	**show ip masks** *address*
Display the address of a default gateway.	**show ip redirects**

Task	Command
Display the current state of the routing table.	**show ip route** [*address* [*mask*] [**longer-prefixes**]] | [*protocol* [*process-id*]]
Display the current state of the routing table in summary form.	**show ip route summary**
Test network node reachability (privileged).	**ping** [*protocol*] {*host* | *address*}
Test network node reachability using a simple ping facility (user).	**ping** [*protocol*] {*host* | *address*}
Trace packet routes through the network (privileged).	**trace** [*destination*]
Trace packet routes through the network (user).	**trace ip** *destination*

See the "Ping Command Example" section at the end of this chapter for an example of pinging.

Monitor and Maintain NHRP

To monitor the NHRP cache or traffic, perform either of the following tasks in EXEC mode:

Task	Command
Display the IP NHRP cache, optionally limited to dynamic or static cache entries for a specific interface.	**show ip nhrp** [**dynamic** | **static**] [*type number*]
Display NHRP traffic statistics.	**show ip nhrp traffic**

The NHRP cache can contain static entries caused by statically configured addresses and dynamic entries caused by the Cisco IOS software learning addresses from NHRP packets. To clear static entries, use the **no ip nhrp map** command. To clear the NHRP cache of dynamic entries, perform the following task in EXEC mode:

Task	Command
Clear the IP NHRP cache of dynamic entries.	**clear ip nhrp**

IP Addressing Examples

The following sections provide IP configuration examples:

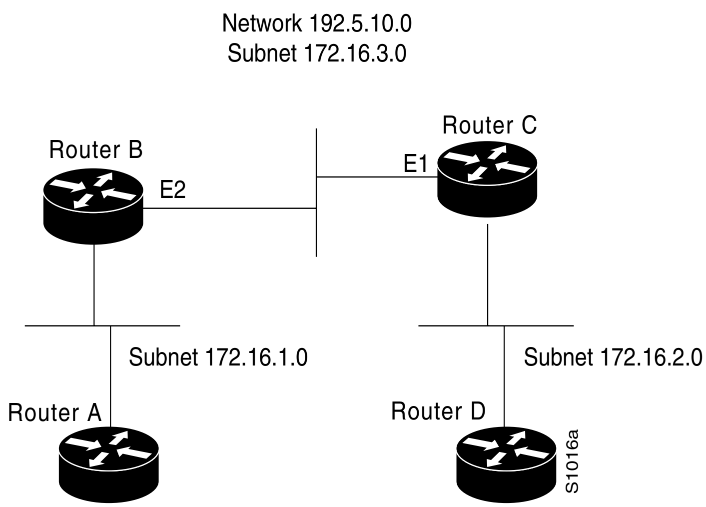
- Creating a Network from Separated Subnets Example
- Serial Interfaces Configuration Example
- IP Domains Example
- Dynamic Lookup Example
- HP Hosts on a Network Segment Example
- Logical NBMA Example
- NHRP over ATM Example
- NHRP on a Multipoint Tunnel Example
- Broadcasting Examples

- Helper Addresses Example
- NAT Configuration Examples
- Ping Command Example

Creating a Network from Separated Subnets Example

In the following example, subnets 1 and 2 of network 131.108.0.0 are separated by a backbone, as shown in Figure 9. The two networks are brought into the same logical network through the use of secondary addresses.

Figure 9 Creating a Network from Separated Subnets



The following examples show the configurations for Routers B and C.

Configuration for Router B

```
interface ethernet 2
 ip address 192.5.10.1 255.255.255.0
 ip address 131.108.3.1 255.255.255.0 secondary
```

Configuration for Router C

```
interface ethernet 1
 ip address 192.5.10.2 255.255.255.0
 ip address 131.108.3.2 255.255.255.0 secondary
```

Serial Interfaces Configuration Example

In the following example, the second serial interface (serial 1) is given Ethernet 0's address. The serial interface is unnumbered.

```
interface ethernet 0
 ip address 145.22.4.67 255.255.255.0
interface serial 1
 ip unnumbered ethernet 0
```

IP Domains Example

The example that follows establishes a domain list with several alternate domain names.

```
ip domain-list csi.com
ip domain-list telecomprog.edu
ip domain-list merit.edu
```

Dynamic Lookup Example

A cache of host name-to-address mappings is used by **connect**, **telnet**, **ping**, **trace**, **write net**, and **configure net** EXEC commands to speed the process of converting names to addresses. The commands used in this example specify the form of dynamic name lookup to be used. Static name lookup also can be configured.

The following example configures the host name-to-address mapping process. IP DNS-based translation is specified, the addresses of the name servers are specified, and the default domain name is given.

```
! IP Domain Name System (DNS)-based host name-to-address translation is enabled
ip domain-lookup
! Specifies host 131.108.1.111 as the primary name server and host 131.108.1.2
! as the secondary server
ip name-server 131.108.1.111 131.108.1.2
! Defines cisco.com as the default domain name the router uses to complete
! unqualified host names
ip domain-name cisco.com
```

HP Hosts on a Network Segment Example

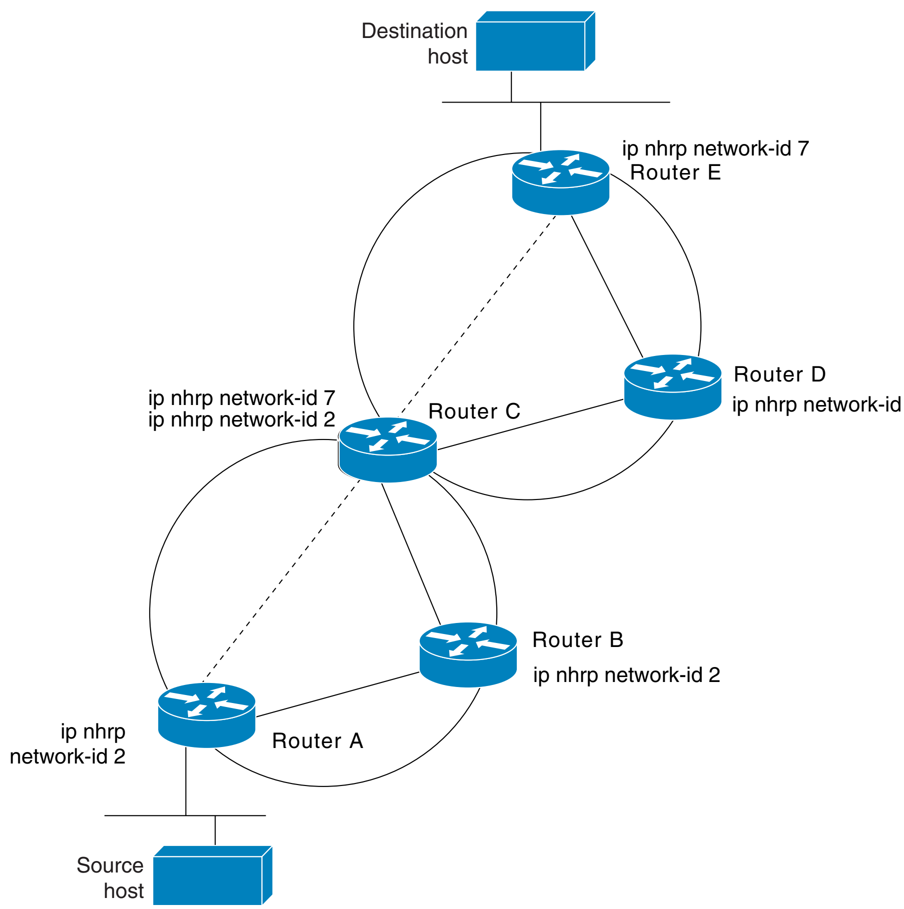
The following example has a network segment with Hewlett-Packard devices on it. The commands in this example customize the first Ethernet port to respond to Probe name requests for bl4zip and to use Probe as well as ARP.

```
 ip hp-host bl4zip 131.24.6.27
interface ethernet 0
 arp probe
 ip probe proxy
```

Logical NBMA Example

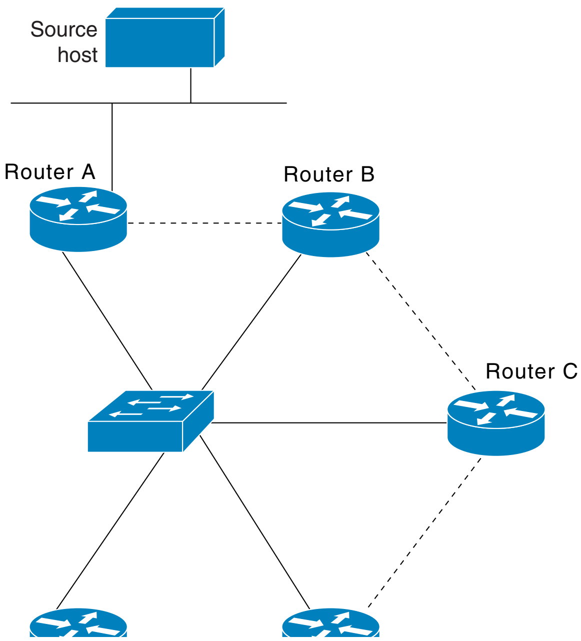
A logical NBMA network is considered the group of interfaces and hosts participating in NHRP and having the same network identifier. Figure 10 illustrates two logical NBMA networks (shown as circles) configured over a single physical NBMA network. Router A can communicate with Routers B and C because they share the same network identifier (2). Router C can also communicate with Routers D and E, as they share network identifier 7. After address resolution is complete, Router A can send IP packets to Router C in one hop, and Router C can send them to Router E in one hop, as shown by the dotted lines.

Figure 10 Two Logical NBMA Networks over One Physical NBMA Network



The physical configuration of the five routers in Figure 10 might actually be that shown in Figure 11. The source host is connected to Router A and the destination host is connected to Router E. The same switch serves all five routers, making one physical NBMA network.

Figure 11 Physical Configuration of a Sample NBMA Network



Refer again to Figure 10. Initially, before NHRP has resolved any NBMA addresses, IP packets from the source host to the destination host travel through all five routers connected to the switch before reaching the destination. When Router A first forwards the IP packet toward the destination host, Router A also generates an NHRP request for the destination host's IP address. The request is forwarded to Router C, whereupon a reply is generated. Router C replies because it is the egress router between the two logical NBMA networks.

Similarly, Router C generates an NHRP request of its own, to which Router E replies. In this example, subsequent IP traffic between the source and the destination still requires two hops to traverse the NBMA network, since the IP traffic must be forwarded between the two logical NBMA networks. Only one hop would be required if the NBMA network were not logically divided.

NHRP over ATM Example

The following example shows a configuration of three routers using NHRP over ATM. Additionally, subinterfaces and dynamic routing are used. Router A obtains an OSPF route that it can use to reach the LIS where Router B resides. Router A can then initially reach Router B through Router C. Router A and Router B are able to directly communicate without Router C once NHRP has resolved Router A's and Router C's respective NSAP addresses.

The significant portions of the configurations for Routers A, B, and C follow.

Router A

```
interface ATM0/0
 ip address 10.1.0.1 255.255.0.0
 ip nhrp network-id 1
 map-group a
 atm nsap-address 11.1111.11.111111.1111.1111.1111.1111.1111.1111.11
 atm rate-queue 1 10
 atm pvc 1 0 5 qsaal

router ospf 1
 network 10.0.0.0 0.255.255.255 area 0

map-list a
 ip 10.1.0.3 atm-nsap 33.3333.33.333333.3333.3333.3333.3333.3333.3333.33
```

Router B

```
interface ATM0/0
 ip address 10.2.0.2 255.255.0.0
 ip nhrp network-id 1
 map-group a
 atm nsap-address 22.2222.22.222222.2222.2222.2222.2222.2222.2222.22
 atm rate-queue 1 10
 atm pvc 2 0 5 qsaal

router ospf 1
 network 10.0.0.0 0.255.255.255 area 0

map-list a
 ip 10.2.0.3 atm-nsap 33.3333.33.333333.3333.3333.3333.3333.3333.3333.33
```

Router C

```
interface ATM0/0
 no ip address
 atm rate-queue 1 10
 atm pvc 2 0 5 qsaal

interface ATM0/0.1 multipoint
 ip address 10.1.0.3 255.255.0.0
 ip nhrp network-id 1
 map-group a
 atm nsap-address 33.3333.33.333333.3333.3333.3333.3333.3333.3333.33
 atm rate-queue 1 10

interface ATM0/0.2 multipoint
 ip address 10.2.0.3 255.255.0.0
 ip nhrp network-id 1
 map-group b
 atm nsap-address 33.3333.33.333333.3333.3333.3333.3333.3333.3333.33
 atm rate-queue 1 10

router ospf 1
 network 10.0.0.0 0.255.255.255 area 0
 neighbor 10.1.0.1 priority 1
 neighbor 10.2.0.2 priority 1

map-list a
 ip 10.1.0.1 atm-nsap 11.1111.11.111111.1111.1111.1111.1111.1111.1111.11

map-list b
ip 10.2.0.2 atm-nsap 22.2222.22.222222.2222.2222.2222.2222.2222.2222.22
```

NHRP on a Multipoint Tunnel Example

With multipoint tunnels, a single tunnel interface may be connected to multiple neighboring routers. Unlike point-to-point tunnels, a tunnel destination need not be configured. In fact, if configured, the tunnel destination must correspond to an IP multicast address. Broadcast or multicast packets to be sent over the tunnel interface can then be transmitted by sending the GRE packet to the multicast address configured as the tunnel destination.

Multipoint tunnels require that you configure a tunnel key. Otherwise, unexpected GRE traffic could easily be received by the tunnel interface. For simplicity, it is recommended that the tunnel key correspond to the NHRP network identifier.

In the following example, Routers A, B, C, and D all share a common Ethernet segment. Minimal connectivity over the multipoint tunnel network is configured, thus creating a network that can be treated as a partially meshed NBMA network. Due to the static NHRP map entries, Router A knows how to reach Router B, Router B knows how to reach Router C, Router C knows how to reach Router D, and Router D knows how to reach Router A.

When Router A initially attempts to send an IP packet to Router D, the packet is forwarded through Routers B and C. Through NHRP, the routers quickly learn each other's NBMA addresses (in this case, IP addresses assigned to the underlying Ethernet network). The partially meshed tunnel network readily becomes fully meshed, at which point any of the routers can directly communicate over the tunnel network without their IP traffic requiring an intermediate hop.

The significant portions of the configurations for Routers A, B, C, and D follow.

Router A

```
interface tunnel 0
 no ip redirects
 ip address 11.0.0.1 255.0.0.0
 ip nhrp map 11.0.0.2 10.0.0.2
 ip nhrp network-id 1
 ip nhrp nhs 11.0.0.2
 tunnel source ethernet 0
 tunnel mode gre multipoint
 tunnel key 1

interface ethernet 0
 ip address 10.0.0.1 255.0.0.0
```

Router B

```
interface tunnel 0
 no ip redirects
 ip address 11.0.0.2 255.0.0.0
 ip nhrp map 11.0.0.3 10.0.0.3
 ip nhrp network-id 1
 ip nhrp nhs 11.0.0.3
 tunnel source ethernet 0
 tunnel mode gre multipoint
 tunnel key 1

interface ethernet 0
 ip address 10.0.0.2 255.0.0.0
```

Router C

```
interface tunnel 0
 no ip redirects
 ip address 11.0.0.3 255.0.0.0
 ip nhrp map 11.0.0.4 10.0.0.4
 ip nhrp network-id 1
 ip nhrp nhs 11.0.0.4
 tunnel source ethernet 0
 tunnel mode gre multipoint
 tunnel key 1

interface ethernet 0
 ip address 10.0.0.3 255.0.0.0
```

Router D

```
interface tunnel 0
 no ip redirects
 ip address 11.0.0.4 255.0.0.0
 ip nhrp map 11.0.0.1 10.0.0.1
 ip nhrp network-id 1
 ip nhrp nhs 11.0.0.1
 tunnel source ethernet 0
 tunnel mode gre multipoint
 tunnel key 1

interface ethernet 0
 ip address 10.0.0.4 255.0.0.0
```

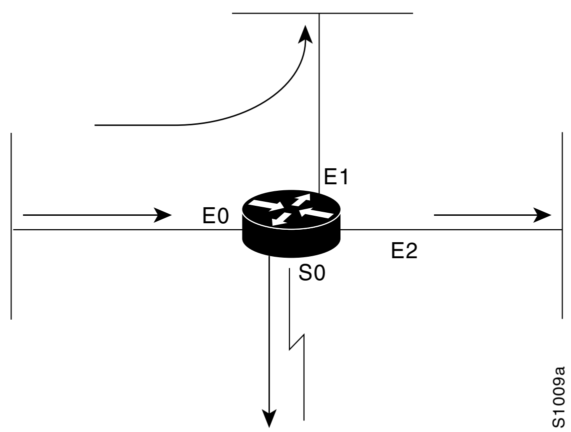
Broadcasting Examples

The Cisco IOS software supports two types of broadcasting: directed broadcasting and flooding. A directed broadcast is a packet sent to a specific network or series of networks, while a flooded broadcast packet is sent to every network. The following examples describe configurations for both types of broadcasting.

Flooded Broadcast Example

Figure 12 shows a flooded broadcast packet being sent to every network. The packet that is incoming from interface E0 is flooded to interfaces E1, E2, and S0.

Figure 12 IP Flooded Broadcast



A directed broadcast address includes the network or subnet fields. For example, if the network address is 128.1.0.0, the address 128.1.255.255 indicates all hosts on network 128.1.0.0. This would be a directed broadcast. If network 128.1.0.0 has a subnet mask of 255.255.255.0 (the third octet is the subnet field), the address 128.1.5.255 specifies all hosts on subnet 5 of network 128.1.0.0—another directed broadcast.

Flooding of IP Broadcasts Example

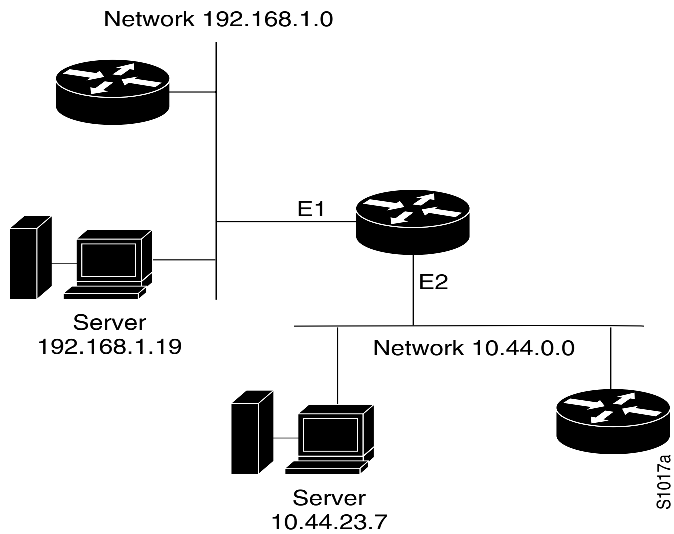
In the following example, flooding of IP broadcasts is enabled on all interfaces (two Ethernet and two serial). No bridging is permitted. The access list denies all protocols. No specific UDP protocols are listed by a separate **ip forward-protocol udp** interface configuration command, so the default protocols (TFTP, DNS, Time, NetBIOS, and BOOTP) will be flooded.

```
ip forward-protocol spanning-tree
 bridge 1 protocol dec
access-list 201 deny 0x0000 0xFFFF
 interface ethernet 0
 bridge-group 1
 bridge-group 1 input-type-list 201
interface ethernet 1
 bridge-group 1
 bridge-group 1 input-type-list 201
interface serial 0
 bridge-group 1
 bridge-group 1 input-type-list 201
interface serial 1
 bridge-group 1
 bridge-group 1 input-type-list 201
```

Helper Addresses Example

In the following example, one router is on network 191.24.1.0 and the other is on network 110.44.0.0, and you want to permit IP broadcasts from hosts on either network segment to reach both servers. Figure 13 illustrates how to configure the router that connects network 110 to network 191.24.1.

Figure 13 IP Helper Addresses



The following example shows the configuration:

```
ip forward-protocol udp
!
interface ethernet 1
 ip helper-address 110.44.23.7
interface ethernet 2
 ip helper-address 191.24.1.19
```

NAT Configuration Examples

The following are NAT configuration examples.

Dynamic Inside Source Translation Example

The following example translates all source addresses passing access list 1 (having a source address from 192.168.1.0/24) to an address from the pool named net-208. The pool contains addresses from 171.69.233.208 to 171.69.233.233.

```
ip nat pool net-208 171.69.233.208 171.69.233.233 netmask 255.255.255.240
ip nat inside source list 1 pool net-208
!
interface serial 0
 ip address 171.69.232.182 255.255.255.240
 ip nat outside
!
interface ethernet 0
 ip address 192.168.1.94 255.255.255.0
 ip nat inside
!
access-list 1 permit 192.168.1.0 0.0.0.255
```

Overloading Inside Global Addresses Example

The following example creates a pool of addresses named net-208. The pool contains addresses from 171.69.233.208 to 171.69.233.233. Access list 1 allows packets having the source address from 192.168.1.0 to 192.168.1.255. If no translation exists, packets matching access list 1 are translated to an address from the pool. The router allows multiple local addresses (192.168.1.0 to 192.168.1.255) to use the same global address. The router retains port numbers to differentiate the connections.

```
ip nat pool net-208 171.69.233.208 171.69.233.233 netmask 255.255.255.240
ip nat inside source list 1 pool net-208 overload
!
interface serial0
 ip address 171.69.232.182 255.255.255.240
 ip nat outside
!
interface ethernet0
 ip address 192.168.1.94 255.255.255.0
 ip nat inside
!
access-list 1 permit 192.168.1.0 0.0.0.255
```

Translating Overlapping Address Example

In the following example, the addresses in the local network are being used legitimately by someone else on the Internet. An extra translation is required to access that external network. Pool net-10 is a pool of outside local IP addresses. The statement `ip nat outside source list 1 pool net-10` translates the addresses of hosts from the outside overlapping network to addresses in that pool.

```
ip nat pool net-208 171.69.233.208 171.69.233.223 prefix-length 28
ip nat pool net-10 10.0.1.0 10.0.1.255 prefix-length 24
ip nat inside source list 1 pool net-208
ip nat outside source list 1 pool net-10
!
interface serial 0
 ip address 171.69.232.192 255.255.255.240
 ip nat outside
!
interface ethernet0
 ip address 192.168.1.94 255.255.255.0
 ip nat inside
!
access-list 1 permit 192.168.1.0 0.0.0.255
```

TCP Load Distribution Example

In the following example, the goal is to define a virtual address, connections to which are distributed among a set of real hosts. The pool defines the addresses of the real hosts. The access list defines the virtual address. If a translation does not already exist, TCP packets from serial 0 (the outside interface) whose destination matches the access list are translated to an address from the pool.

```
ip nat pool real-hosts 192.168.15.2 192.168.15.15 prefix-length 28 type rotary
ip nat inside destination list 2 pool real-hosts
!
interface serial 0
 ip address 192.168.15.129 255.255.255.240
 ip nat outside
!
```

```
interface ethernet 0
 ip address 192.168.15.17 255.255.255.240
 ip nat inside
!
access-list 2 permit 192.168.15.1
```

Ping Command Example

You can specify the address to use as the source address for ping packets. In the following example, it is 131.108.105.62:

```
Sandbox# ping
Protocol [ip]:
Target IP address: 131.108.1.111
Repeat count [5]:
Datagram size [100]:
Timeout in seconds [2]:
Extended commands [n]: yes
Source address: 131.108.105.62
Type of service [0]:
Set DF bit in IP header? [no]:
Data pattern [0xABCD]:
Loose, Strict, Record, Timestamp, Verbose[none]:
Sweep range of sizes [n]:
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 131.108.1.111, timeout is 2 seconds:
!!!!!
Success rate is 100 percent, round-trip min/avg/max = 4/4/4 ms
```