Institute of Electrical and Electronic Engineering, University M'Hamed BOUGARA of Boumerdes

Chapter 5
Network Layer

by Hadjira BELAIDI

Objectives

After completing this chapter, you will be able to:

✓Know exactly how the network layer moves a segment from the transport layer of an origin host to the transport layer of the destination host.

✓See that the network layer requires the coordination of each and every host and router in the network.

✓Learn the network layer protocols which are among the most challenging (and therefore interesting!) in the protocol stack.

✓Identify a router as a computer with an operating system (OS) and hardware designed for the routing process.

Chap5 Outlines

- Introduction
- Network Layer Protocols
- Routing
- Routers
- Configuring a Cisco Router

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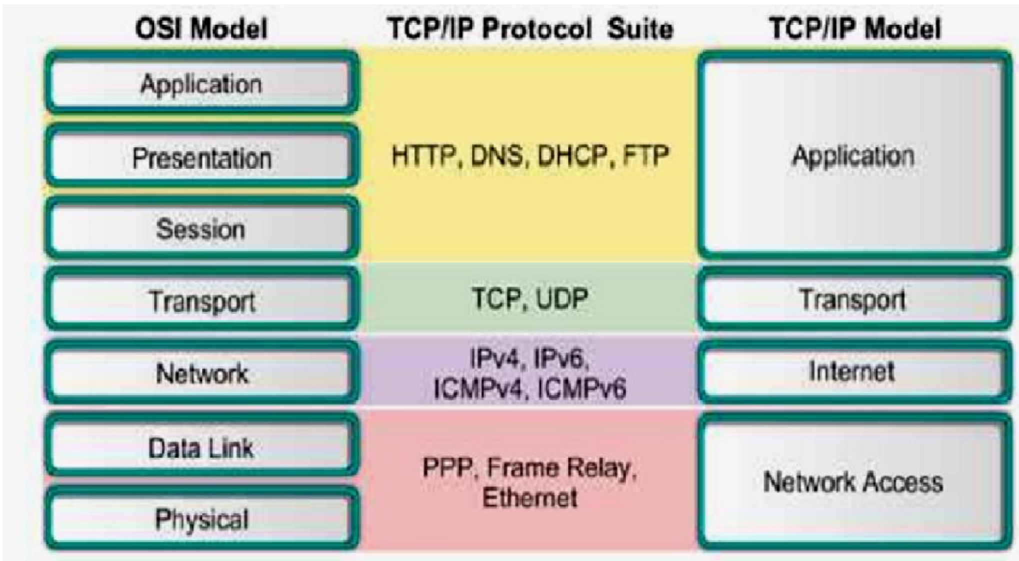
• Network layer provides a communication service between hosts.
• In particular, the network-layer moves transport-layer segments from one host to another.
• At the sending host, the transport layer segment is passed to the network layer. The network layer then "somehow" gets the segment to the destination host and passes the segment up the protocol stack to the transport layer.



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The primary role of the routers is to "switch" packets from input links to output links.

The role of the network layer in a sending host is to begin the packet on its journey to the receiving host.

At the receiving host, the network layer receives the packet from its nearby router and delivers the packet up to the transport layer at the receiving host.

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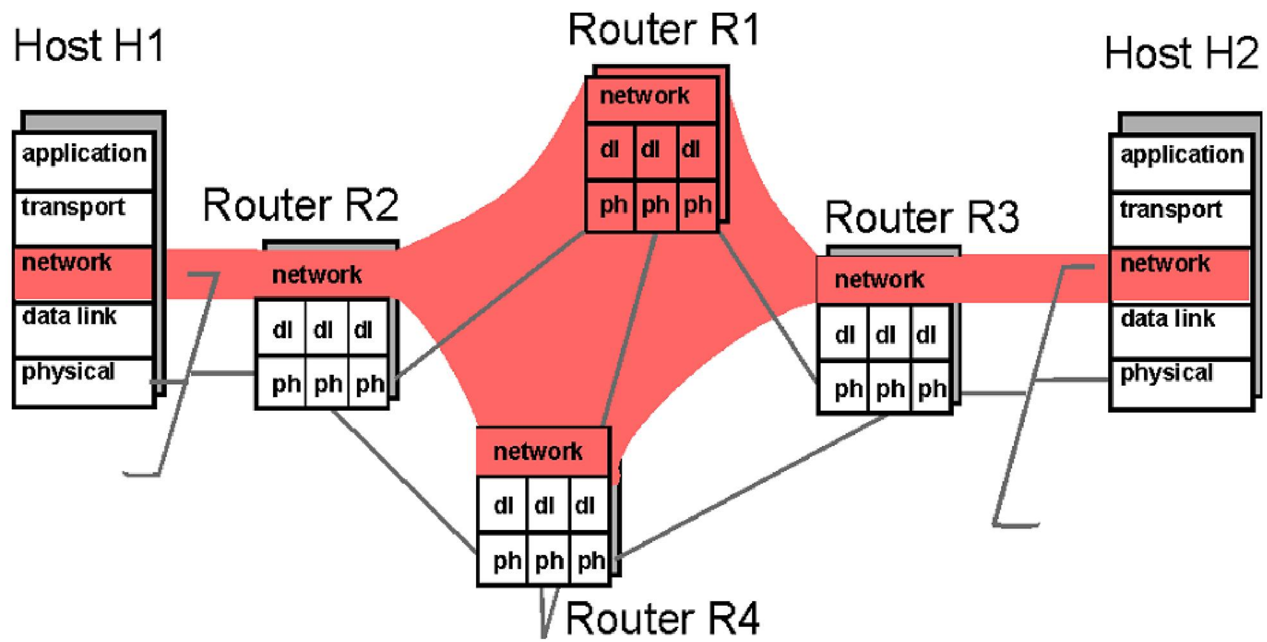
The figure below shows a simple network with two hosts (H1 and H2) and four routers (R1, R2, R3 and R4).
For example, if H1 is sending to H2, the network layer in host H1 transfers these packets to it nearby router, R2.
At the receiving host (H2), the network layer receives the packet from its nearby router (R3) and delivers the packet up to the transport layer at H2.



The network layer

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Network layer function

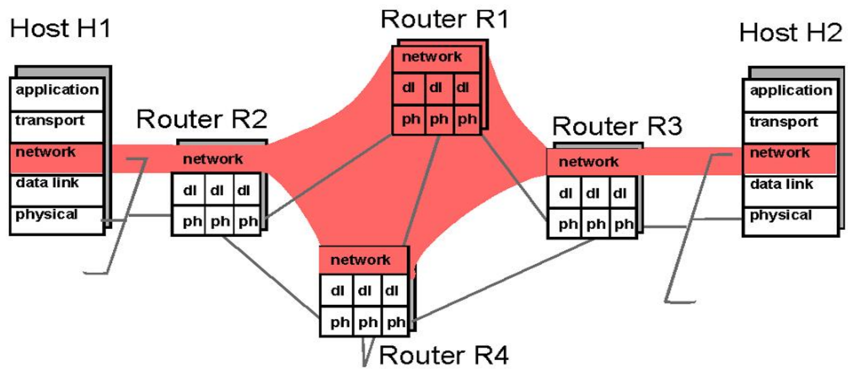
The role of the network layer is to transport packets from a sending host to a receiving host. To do so, three important network layer functions can be identified:

1) **Path Determination**.

✓The network layer must determine the route or path taken by packets as they flow from a sender to a receiver.

✓The algorithms that calculate these paths are referred to as routing algorithms.

✓A routing algorithm would determine, for example, whether packets from H1 to H2 flow along the path R2-R1-R3 or path R2-R4-R3 (or any other path between H1 and H2).



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2) **Switching**

When a packet arrives at the input to a router, the router must move it to the appropriate output link.

For example, a packet arriving from host H1 to router R2 must either be forwarded towards H2 either along the link from R2 to R1 or along the link from R2 to R4.

3) **Call Setup**

In TCP protocol, three-way handshake are required before data actually flowed from sender to receiver. This allowed the sender and receiver to setup the needed state information (e.g., sequence number and initial flow control window size). In an analogous manner, some network layer architectures (e.g., ATM) requires that the routers along the chosen path from source to destination handshake with each other in order to setup state before data actually begins to flow. In the network layer, this process is referred to as call setup. The network layer of the Internet architecture does not perform any such call setup.

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4) **Connectionless communication**

•Often referred to as **CL-mode** communication, It is a data transmission method used in packet switching networks in which each data unit is individually addressed and routed based on information carried in each unit, rather than in the setup information of a prearranged, fixed data channel as in connection-oriented communication.

•Under connectionless communication between two network end points, a message can be sent from one end point to another without prior arrangement. The device at one end of the communication transmits data addressed to the other, without first ensuring that the recipient is available and ready to receive the data.

•Some protocols allow for error correction by requested retransmission. Internet Protocol (IP) and User Datagram Protocol (UDP) are connectionless protocols.

•A packet transmitted in a connectionless mode is frequently called a datagram.

•For example, IP is connectionless, in that a data packet can travel from a sender to a recipient without the recipient having to send an acknowledgement. Connection-oriented protocols exist at other, higher layers of the OSI model.

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5) **Message forwarding**

Since many networks are partitioned into subnetworks and connect to other networks for wide-area communications, networks use specialized hosts, called gateways or routers, to forward packets between networks.

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1. Network Layer Protocols

The Network Layer Protocols include:

1) IPv4/IPv6, Internet Protocol
2) ICMPv4/ ICMPv6, Internet Control Message Protocol
3) CLNP, Connectionless Networking Protocol
4) DDP, Datagram Delivery Protocol
5) EGP, Exterior Gateway Protocol
6) EIGRP, Enhanced Interior Gateway Routing Protocol
7) DVMRP, Distance Vector Multicast Routing Protocol
8) IGMP, Internet Group Management Protocol
9) IPsec, Internet Protocol Security
10) IPX, Internetwork Packet Exchange
11) OSPF, Open Shortest Path First
12) PIM-DM, Protocol Independent Multicast Dense Mode
13) PIM-SM, Protocol Independent Multicast Sparse Mode
14) RIP, Routing Information Protocol
15) RSMLT Routed-SMLT

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2) ICMPv4/ ICMPv6 (Internet Control Message Protocol)

➢ICMP is network diagnostic and error reporting protocol.

➢ICMP belongs to IP protocol suite and uses IP as carrier protocol.

➢After constructing ICMP packet, it is encapsulated in IP packet. Because IP itself is a best-effort non-reliable protocol, so is ICMP.

➢Any feedback about network is sent back to the originating host. If some error in the network occurs, it is reported by means of ICMP.

➢ICMP contains dozens of diagnostic and error reporting messages.

➢ICMP-echo and ICMP-echo-reply are the most commonly used ICMP messages to check the reach-ability of end-to-end hosts. When a host receives an ICMP-echo request, it is bound to send back an ICMP-echo-reply.

➢If there is any problem in the transit network, the ICMP will report that problem.

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- Two basic types of messages:
  - Error control and
  - Querying

For example, every device (such as an intermediate router) forwarding an IP datagram first decrements the time to live (TTL) field in the IP header by one. If the resulting TTL is 0, the packet is discarded and an ICMP time exceeded in transit message is sent to the datagram's source address.

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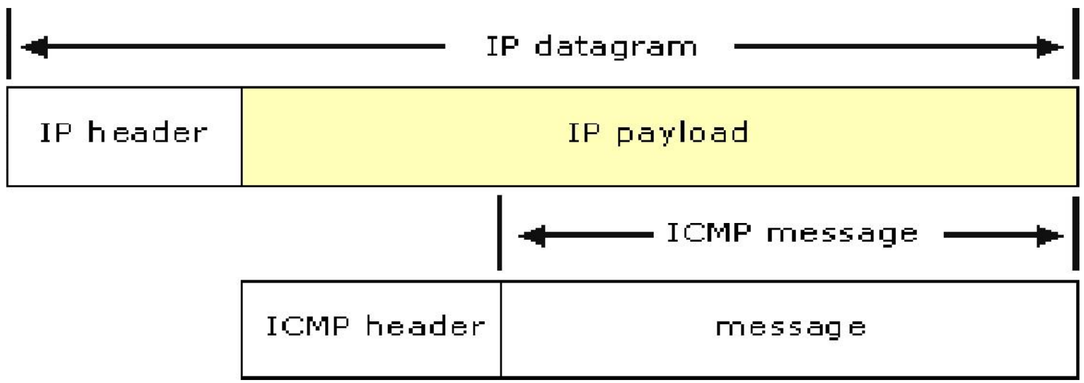
ICMP datagram structure

➢ The ICMP packet is encapsulated in an IPv4 packet. The packet consists of header and data sections.

a) Header

The ICMP header starts after the IPv4 header. All ICMP packets have an 8-byte header and variable-sized data section. The first 4 bytes of the header have fixed format, while the last 4 bytes depend on the type/code of that ICMP packet.



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b) Data

ICMP error messages contain a data section that includes a copy of the entire IPv4 header, plus the first eight bytes of data from the IPv4 packet that caused the error message. This data is used by the host to match the message to the appropriate process. If a higher level protocol uses port numbers, they are assumed to be in the first eight bytes of the original datagram's data.

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3) Connectionless-mode Network Service (CLNS)

Or simply Connectionless Network Service is an OSI Network Layer datagram service that does not require a circuit to be established before data is transmitted, and routes messages to their destinations independently of any other messages. As such it is a "best-effort" rather than a "reliable" delivery service. CLNS is not an Internet service, but provides capabilities in an OSI network environment similar to those provided by the Internet Protocol (IP) and the User Datagram Protocol (UDP).

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4) Exterior Gateway Protocol (EGP)

It is a protocol for exchanging routing information between two neighbor gateway hosts (each with its own router) in a network of autonomous systems. EGP is commonly used between hosts on the Internet to exchange routing table information. The routing table contains a list of known routers, the addresses they can reach, and a cost metric associated with the path to each router so that the best available route is chosen. Each router polls its neighbor at intervals between 120 to 480 seconds and the neighbor responds by sending its complete routing table. EGP-2 is the latest version of EGP.

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5) Enhanced Interior Gateway Routing Protocol (EIGRP)

It is an advanced distance-vector routing protocol that is used on a computer network for automating routing decisions and configuration. The protocol was designed by Cisco Systems as a proprietary protocol, available only on Cisco routers. Partial functionality of EIGRP was converted to an open standard in 2013.

EIGRP is used on a router to share routes with other routers within the same autonomous system.
Unlike other well known routing protocols, such as RIP, EIGRP only sends incremental updates, reducing the workload on the router and the amount of data that needs to be transmitted.

EIGRP replaced the Interior Gateway Routing Protocol (IGRP) in 1993. One of the major reasons for this was the change to classless IPv4 addresses in the Internet Protocol, which IGRP could not support.

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Cisco IOS example

Example of setting up EIGRP on a Cisco IOS router for a private network. The 0.0.15.255 wildcard in this example indicates a subnetwork with a maximum of 4094 hosts—it is the bitwise complement of the subnet mask 255.255.240.0. The **no auto-summary** command prevents automatic route summarization on classful boundaries, which would otherwise result in routing loops in discontiguous networks.

```
Router# configure terminal
Router(config)# router eigrp 1
Router(config-router)# network 10.201.96.0 0.0.15.255
Router(config-router)# no auto-summary
Router(config-router)# exit
```

Outlines

2. Routing

❖Routing is the process that a router uses to forward packets toward the destination network.

❖A router makes decisions based upon the destination IP address of a packet.

❖In order to make the correct decisions, routers must learn the direction to remote networks.

❖When routers use dynamic routing, this information is learned from other routers.

❖When static routing is used, a network administrator configures information about remote networks manually.

2.1. Static route operations

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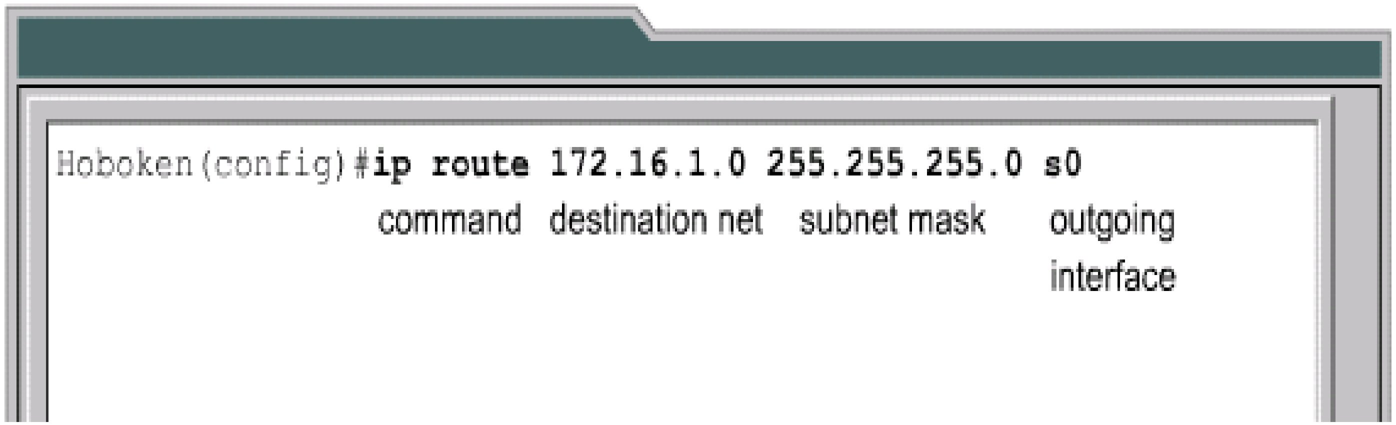
Static route operations can be divided into these three parts:

✓Network administrator configures the route

✓Router installs the route in the routing table

✓Packets are routed using the static route

Since a static route is manually configured, the administrator must configure the static route on the router using the **ip route** command.



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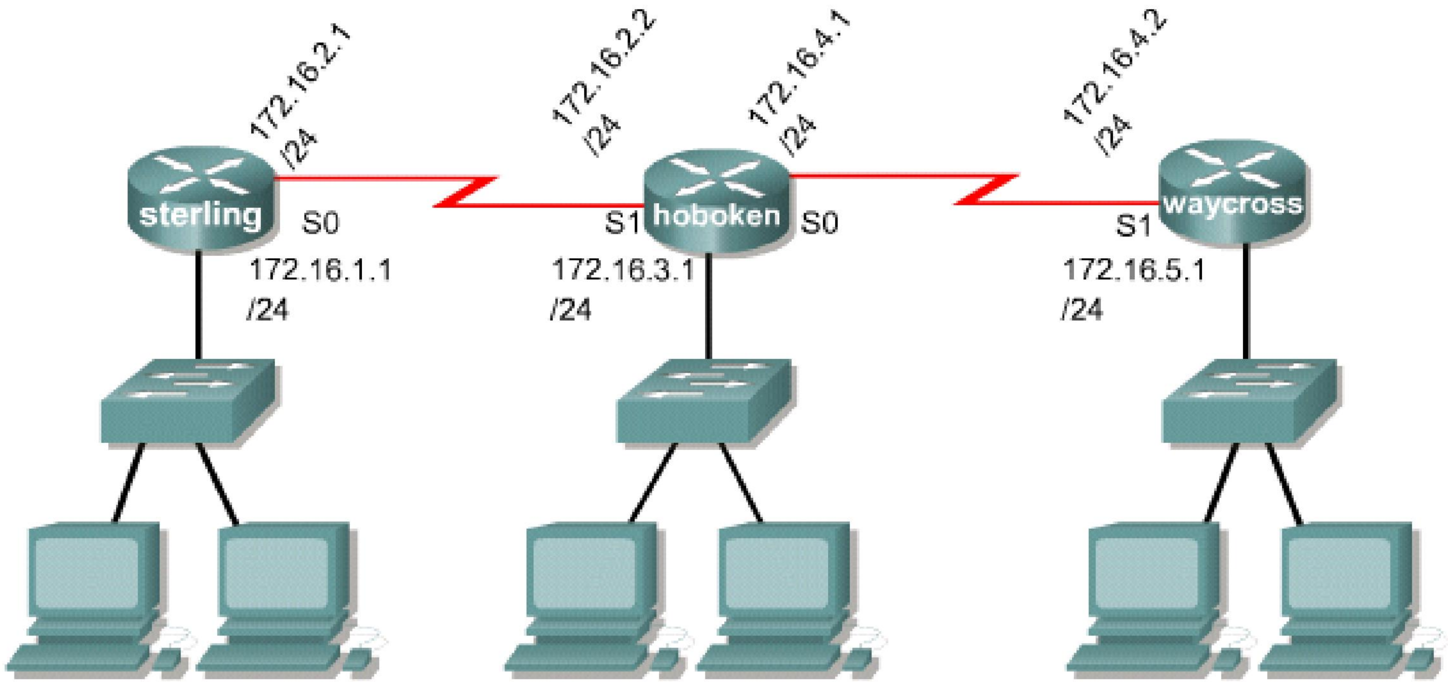


```
Hoboken(config)#ip route 172.16.1.0 255.255.255.0 s1
                command  destination  sub mask     gateway
                           network
Hoboken(config)#ip route 172.16.5.0 255.255.255.0 s0
                command  destination  sub mask     gateway
                           network
```

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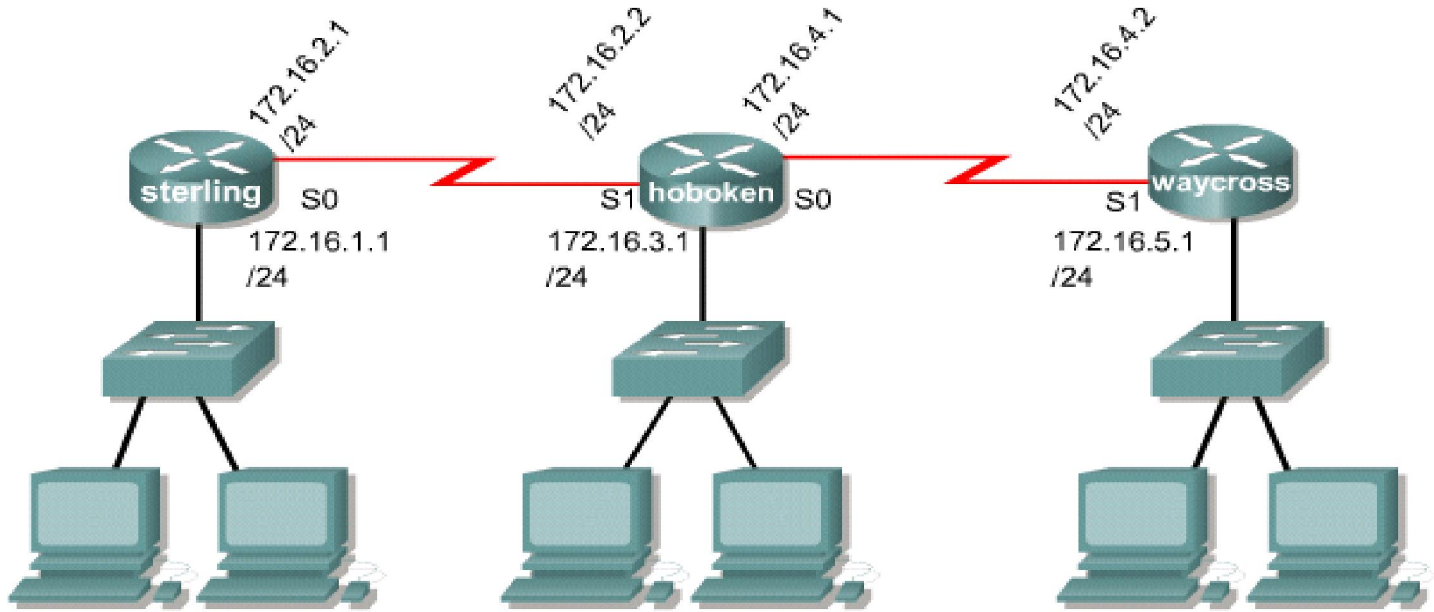


```
Hoboken(config)#ip route 172.16.1.0 255.255.255.0 172.16.2.1
                 command   destination  sub mask     gateway
                             network
Hoboken(config)#ip route 172.16.5.0 255.255.255.0 172.16.4.2
                 command   destination  sub mask     gateway
                             network
```

❖If the router cannot reach the outgoing interface that is being used in the route, the route will not be installed in the routing table.

❖This means if that interface is down, the route will not be placed in the routing table.

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Configuring static routes

Use the following steps to configure static routes:

1. Determine all desired destination networks, their subnet masks, and their gateways. A gateway can be either a local interface or a next hop address that leads to the desired destination.
2. Enter global configuration mode.
3. Type the **ip route** command with a destination address and subnet mask followed by their corresponding gateway from Step one. Including an administrative distance is optional.
4. Repeat Step three for as many destination networks as were defined in Step one.
5. Exit global configuration mode.
6. Save the active configuration to NVRAM by using the **copy running-config startup-config** command.

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- Sometimes static routes are used for backup purposes.
- A static route can be configured on a router that will only be used when the dynamically learned route has failed.
- To use a static route in this manner, simply set the administrative distance higher than that of the dynamic routing protocol being used.

2.2. Configuring default route forwarding

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- Default routes are used to route packets with destinations that do not match any of the other routes in the routing table.
- A default route is actually a special static route that uses this format:

  ip route 0.0.0.0 0.0.0.0 [*next-hop-address* | *outgoing interface*]

Use the following steps to configure default routes:

1. Enter global configuration mode.
2. Type the **ip route** command with 0.0.0.0 for the destination network address and 0.0.0.0 for the subnet mask. The gateway for the default route can be either the local router interface that connects to the outside networks or the IP address of the next-hop router.
3. Exit global configuration mode.
4. Save the active configuration to NVRAM by using the **copy running-config startup-config** command.

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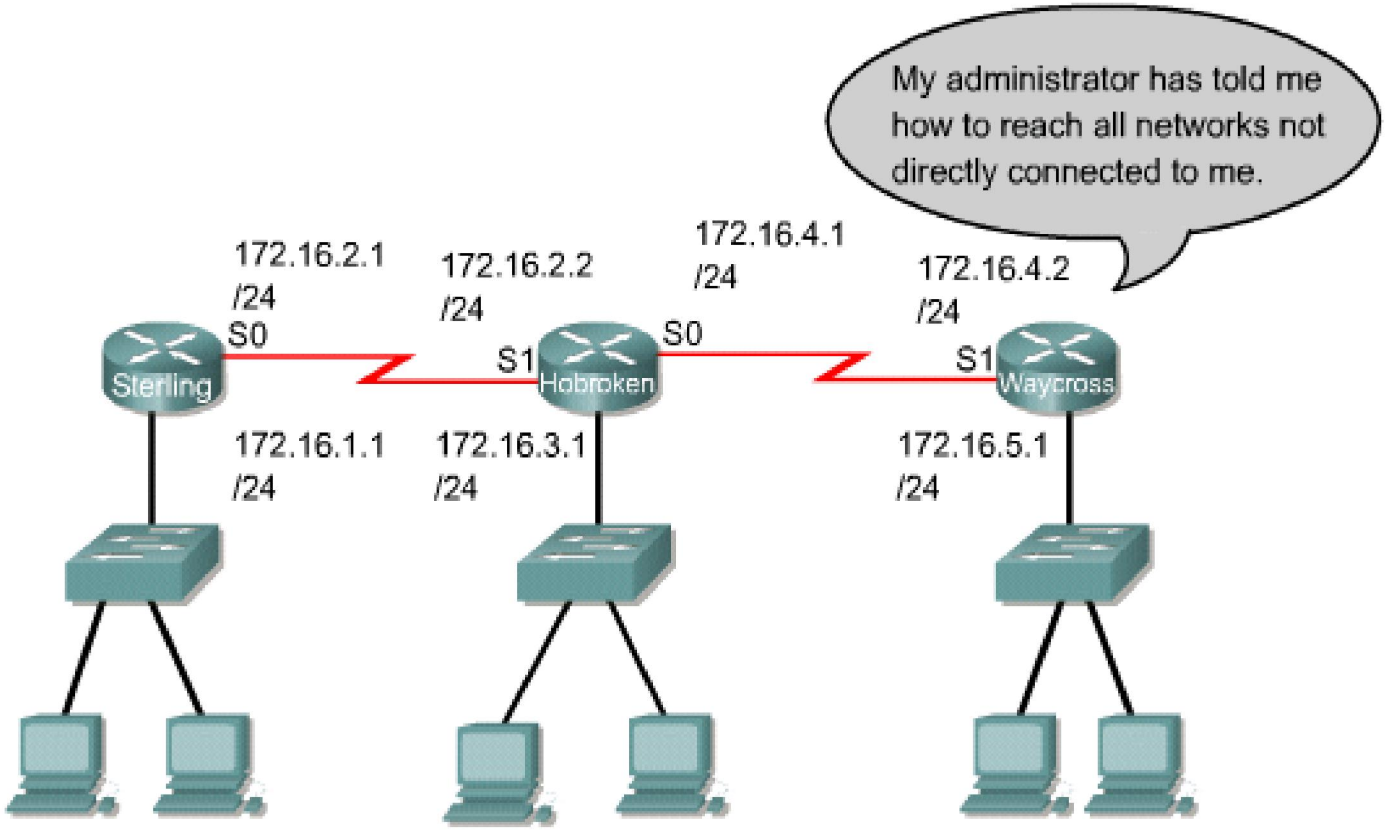


```
Waycross(config)#ip route 0.0.0.0  0.0.0.0 S1
```
This command points to all non-directly-connected networks

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2.3. Verifying static route configuration

- Use the following steps to verify static route configuration:
  - In privileged mode enter the command **show running-config** to view the active configuration.
  - Verify that the static route has been correctly entered.
  - Enter the command **show ip route**.
  - Verify that the route that was configured is in the routing table.

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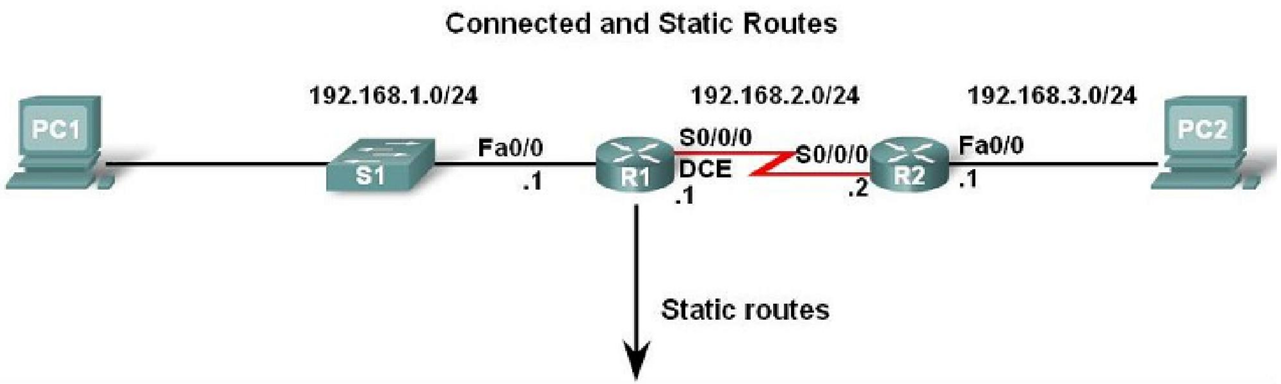


```
R1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0
S    192.168.3.0/24 [1/0] via 192.168.2.2
```

Troubleshooting static route configuration

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```
Hoboken#show ip route
Codes:C-connected,S-static,I-IGRP,R-RIP,M-mobile,B-BGP
D-EIGRP,EX-EIGRP external,O- OSPF,IA-OSPF inter area
N1-OSPF NSSA external type 1,N2-OSPF NSSA external type2
E1-OSPF external type 1,E2-OSPF external type 2, E - EGP
i-IS-IS,L1-IS-IS level-1,L2-IS-IS level-2,ia-IS-IS inter
area
* -candidate default, U - per-user static route, o - ODR
P -periodic downloaded static route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 5 subnets
C        172.16.4.0 is directly connected, Serial0
S        172.16.5.0 is directly connected, Serial0
S        172.16.1.0 is directly connected, Serial1
C        172.16.2.0 is directly connected, Serial1
```

```
Sterling#ping 172.16.5.1
Type escape sequence to abort.
Sending 5,100-byte ICMP Echos to 172.16.5.1,timeout is 2
seconds:
.....
Success rate is 0 percent (0/5)


Sterling#traceroute 172.16.5.1
Type escape sequence to abort.
Tracing the route to 172.16.5.1
  1 172.16.2.2 16 msec 16 msec 16 msec
  2 172.16.4.2 32 msec 28 msec *
  3  *   *   *
```

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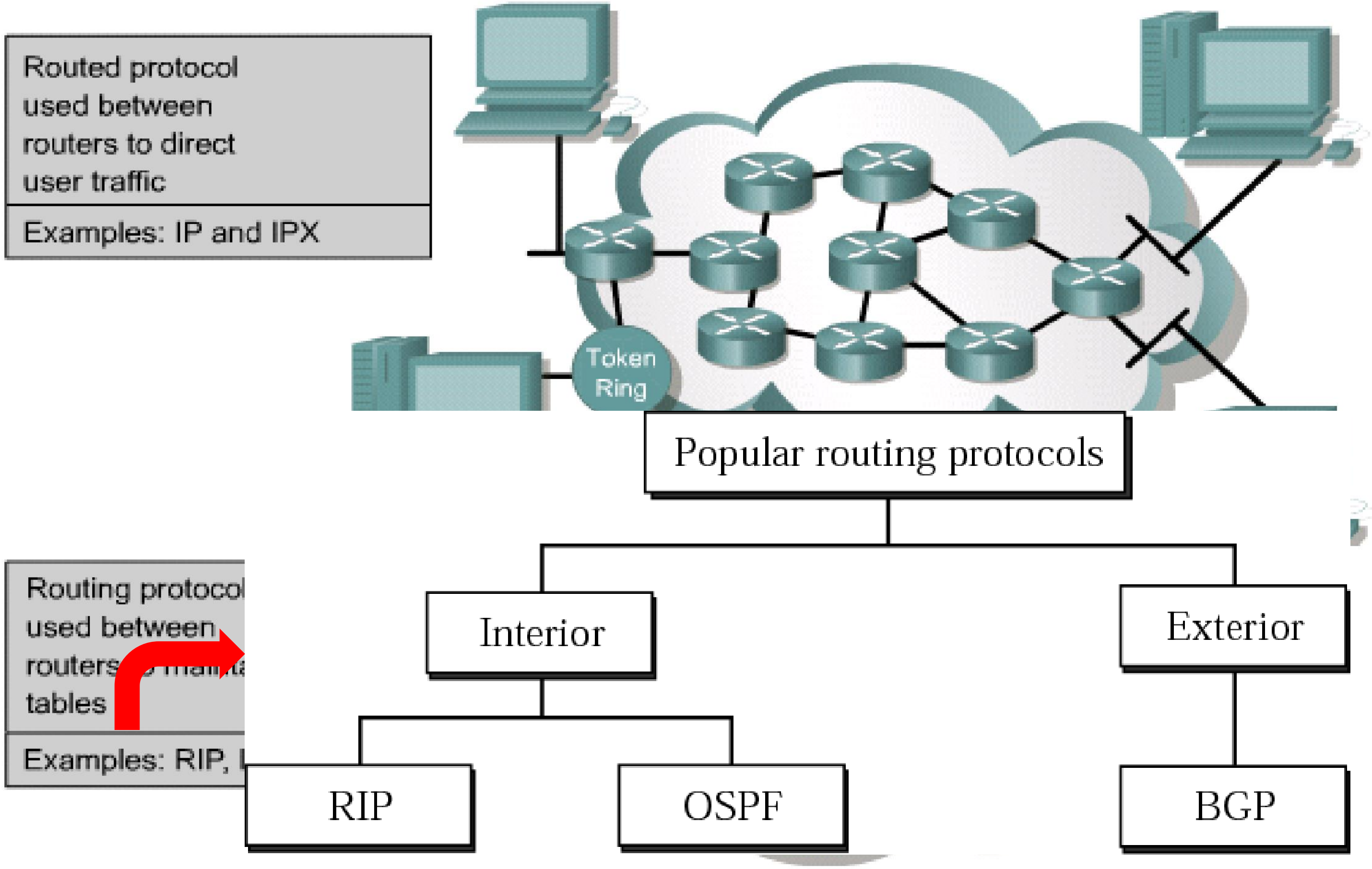
2.4. Dynamic Routing

- A routing protocol is the communication used between routers.



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- Interior routing protocols (IGP) are designed for use in a network whose parts are under the control of a single organization.

- An exterior routing protocol (EGP) is designed for use between two different networks that are under the control of two different organizations.

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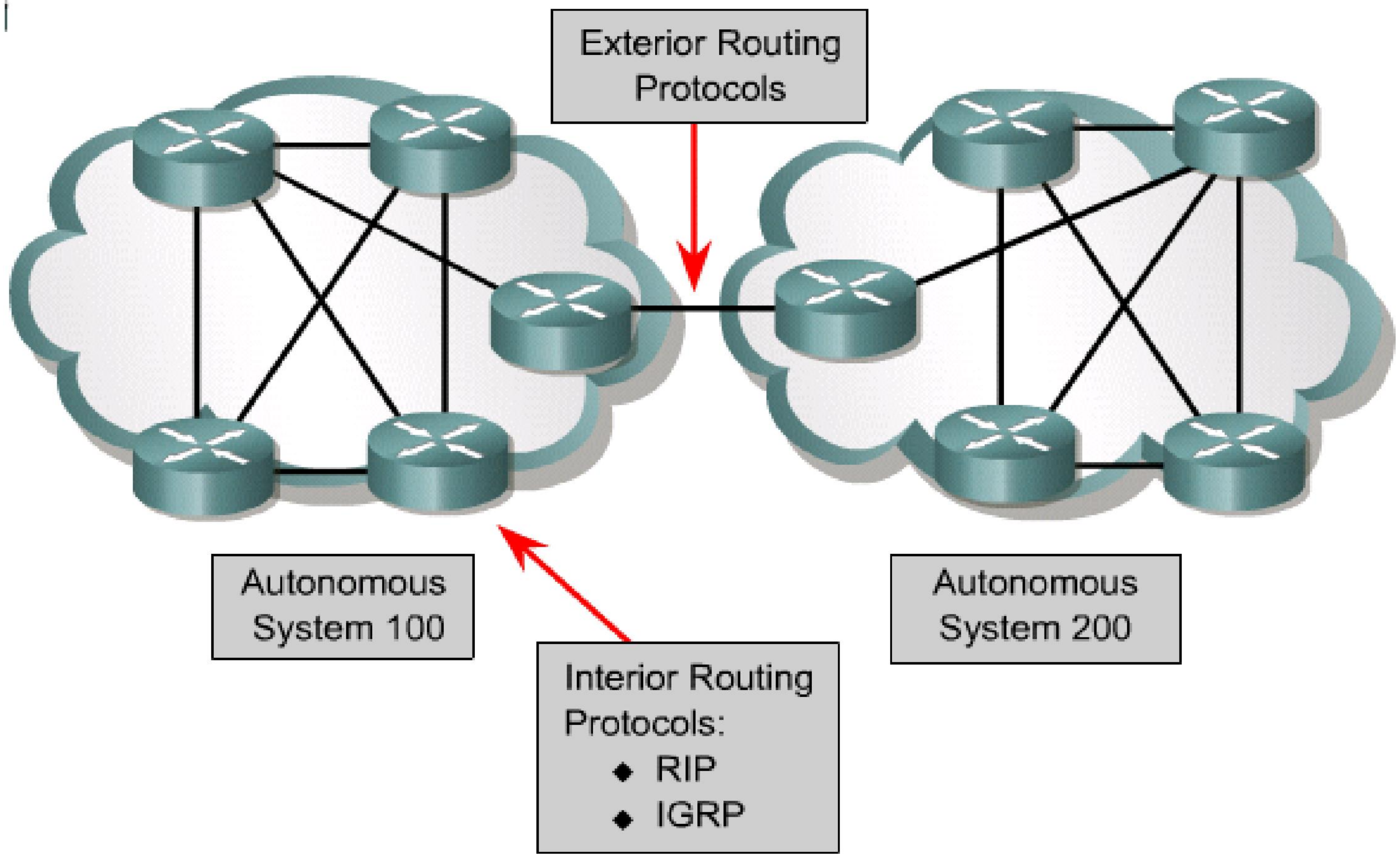

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Path determination

A router determines the path of a packet from one data link to another, using two basic functions:

A path determination function

A switching function

•Path determination occurs at the network layer.

•The path determination function enables a router to evaluate the paths to a destination and to establish the preferred handling of a packet.

•The router uses the routing table to determine the best path and proceeds to forward the packet using the switching function.

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•The switching function is the internal process used by a router to accept a packet on one interface and forward it to a second interface on the same router.

•A key responsibility of the switching function of the router is to encapsulate packets in the appropriate frame type for the next data link.

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Routing configuration

- Enabling an IP routing protocol on a router involves the setting of both global and routing parameters.

- Global tasks include selecting a routing protocol, such as RIP, IGRP, EIGRP or OSPF.

- The major task in the routing configuration mode is to indicate IP network numbers.

Routing configuration

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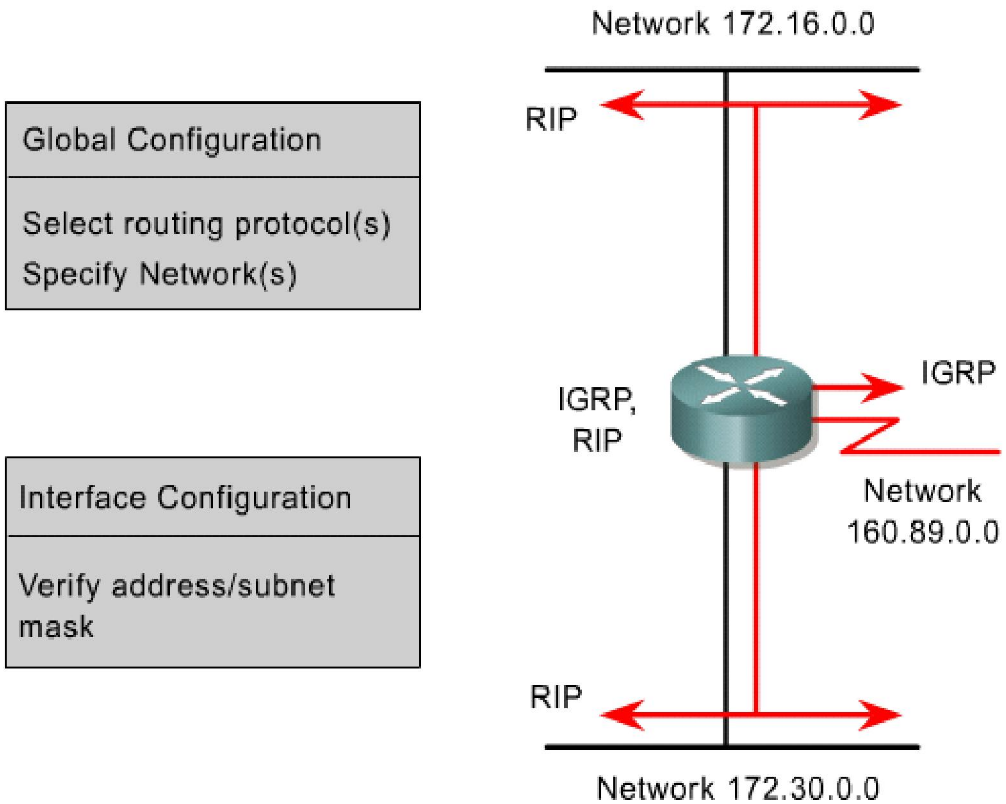

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- The **router** command starts a routing process.
- The **network** command is required because it enables the routing process to determine which interfaces participate in the sending and receiving of routing updates.
- An example of a routing configuration is:

  ROUTER1(config)#**router rip**

  ROUTER1(config-router)#**network 172.16.0.0**

Command

`Router(config)#`**`router`** *`protocol`* `{options}`

Defines an IP routing protocol

Command

`Router(config-router)#`**`network`** *`network-number`*

The network subcommand is a mandatory configuration command for each IP routing process

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Command
`Router(config)#router protocol {options}`

Defines an IP routing protocol

Command
`Router(config-router)#network network-number`

The network subcommand is a mandatory configuration command for each IP routing process

Router command	Description
protocol	IGRP, EIGRP, OSPF, or RIP
options	IGRP **and** EIGRP require an autonomous number. OSPF requires a process ID. RIP does not require either.

Network command	Description
network number	specifies a directly connected network

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OSPF process id

The process ID is the ID of the OSPF process to which the interface belongs. The process ID is local to the router, and two OSPF neighboring routers can have different OSPF process IDs.

This is not true of Enhanced Interior Gateway Routing Protocol [EIGRP], in which the routers need to be in the same autonomous system.

Cisco IOS® Software can run multiple OSPF processes on the same router, and the process ID merely distinguishes one process from the another. The process ID should be a positive integer. For example, the process ID is 1.

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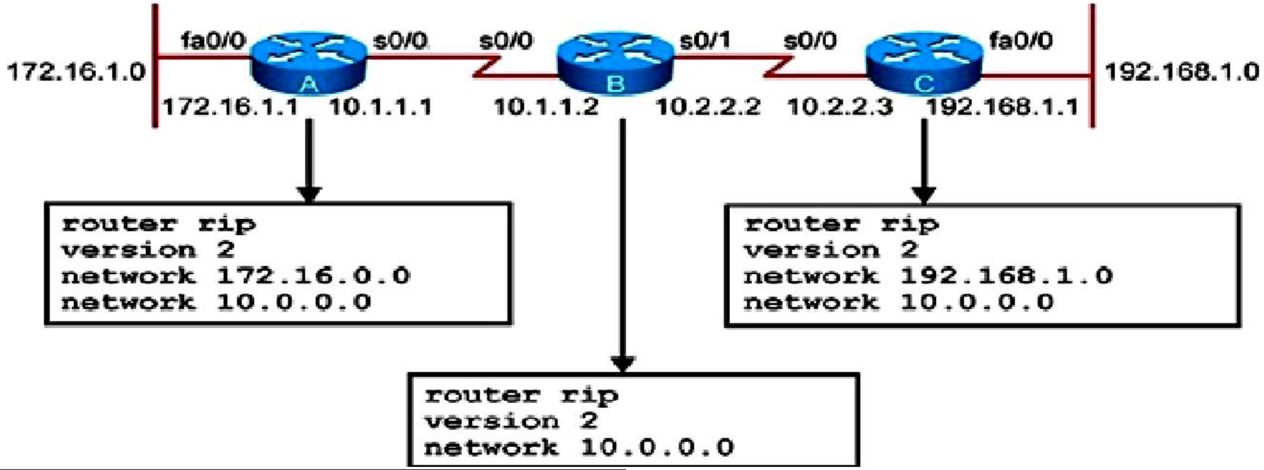
Example of RIP configuration




```
RouterA#
RouterA#conf t
RouterA(config)#router rip
RouterA(config-router)#version 2
RouterA(config-router)#network 172.16.0.0
RouterA(config-router)#network 10.0.0.0
```

```
RouterB#
RouterB#conf t
RouterB(config)#router rip
RouterB(config-router)#version 2
RouterB(config-router)#network 10.0.0.0
```

```
RouterC#
RouterC#conf t
RouterC(config)#router rip
RouterC(config-router)#version 2
RouterC(config-router)#network 192.168.1.0
RouterC(config-router)#network 10.0.0.0
```

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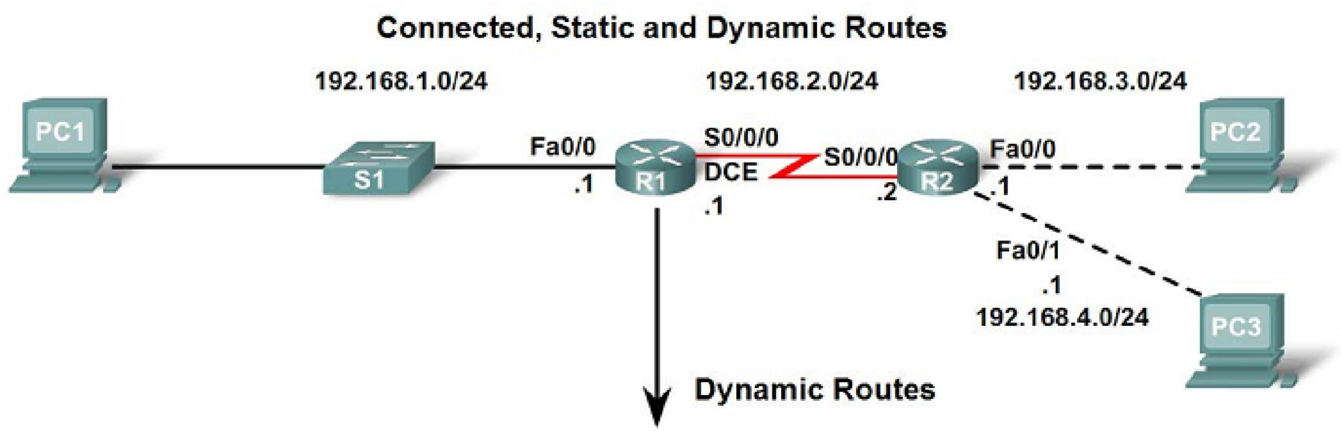


```
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         D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
         N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
         E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
         i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter
         area
         * - candidate default, U - per-user static route, o - ODR
         P - periodic downloaded static route
Gateway of last resort is not set
C     192.168.1.0/24 is directly connected, FastEthernet0/0
C     192.168.2.0/24 is directly connected, Serial0/0/0
S     192.168.3.0/24 [1/0] via 192.168.2.2
R     192.168.4.0/24 [120/1] via 192.168.2.2, 00:00:20, Serial0/0/0
```

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Exercise

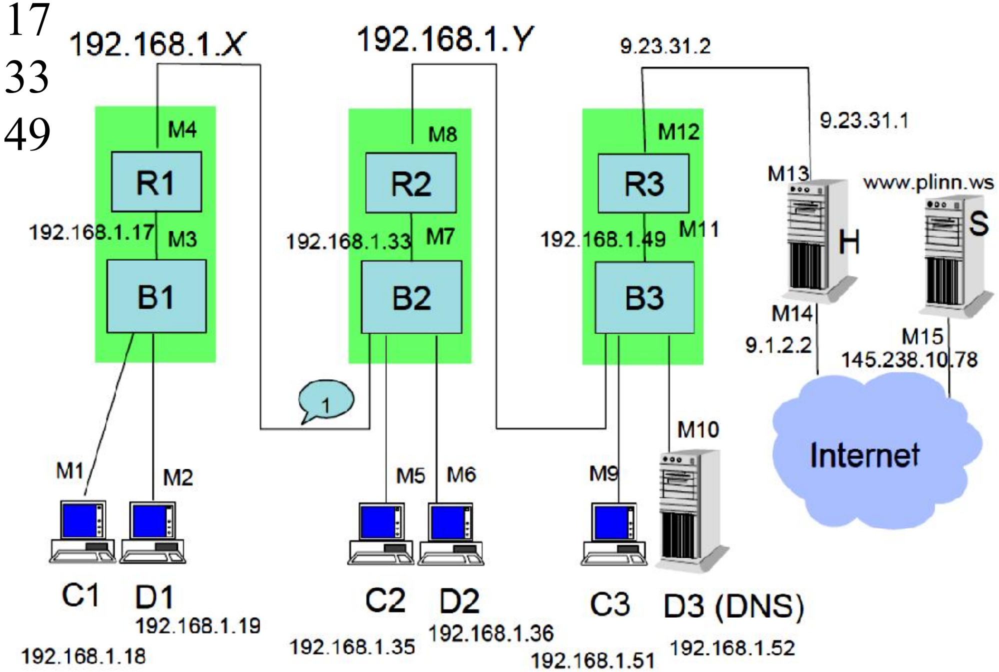
Consider the network in Figure below. The IP addresses are shown explicitly; M1 to M15 mean MAC addresses. B1, B2 and B3 are bridges; R1, R2 and R3 are routers.

D3 is the DNS server for this network. The machines C1, D1, C2, D2, and C3 are configured with DNS server address = 192.168.1.52.

All interfaces that have IP addresses of the form 192.168.x.y are configured with netmask = 255.255.255.240.

The default gateways are configured as follows

- at C1 and D1: 192.168.1.17
- at C2 and D2: 192.168.1.33
- at C3 and D3: 192.168.1.49



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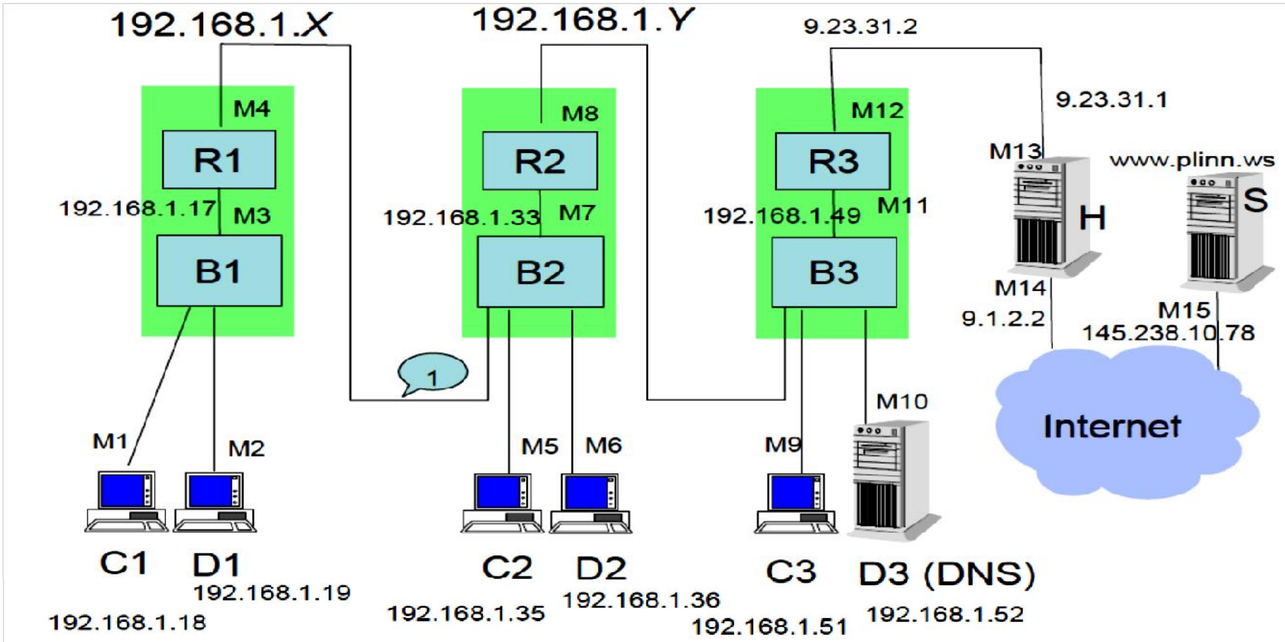

1. Give a possible value for the X in the IP address of the interface M4 of router R1 (i.e. give a possible value for the address marked 192.168.1.X on the figure). Justify your answer. Same question for the Y in the IP address of the interface M8 of router R2.

Solution:

The M4 interface must belong to the same subnet as C2 and D2. Since the mask is over 28 bits, X must lie in the interval [33, 46] (the host parts b0000 [X = 32] and b1111 [X = 47] are not possible). The value must also not be already allocated. A possible value is 34. Similarly, Y must lie in the interval [49, 62]; a possible value is 50.

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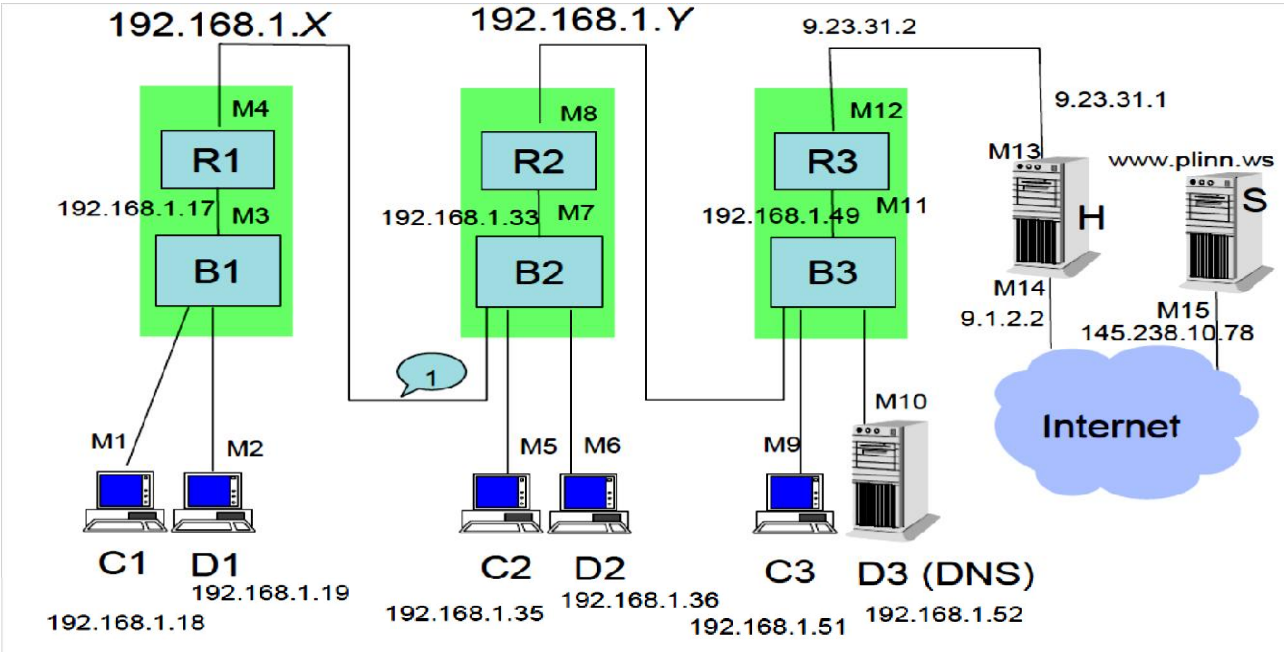

2. We assume that R1, R2 and R3 are manually configured, i.e. they do not run any routing protocol. Put in the table below the routing table entries that needs to be written in these three routers (to use static route i.e in R2). Give only the entries for destination prefixes that are not on-link with this router.

(Manual Configu-ration)	*Destination prefix*	*Destination mask*	*Next hop*
R1			
R2			
R3			

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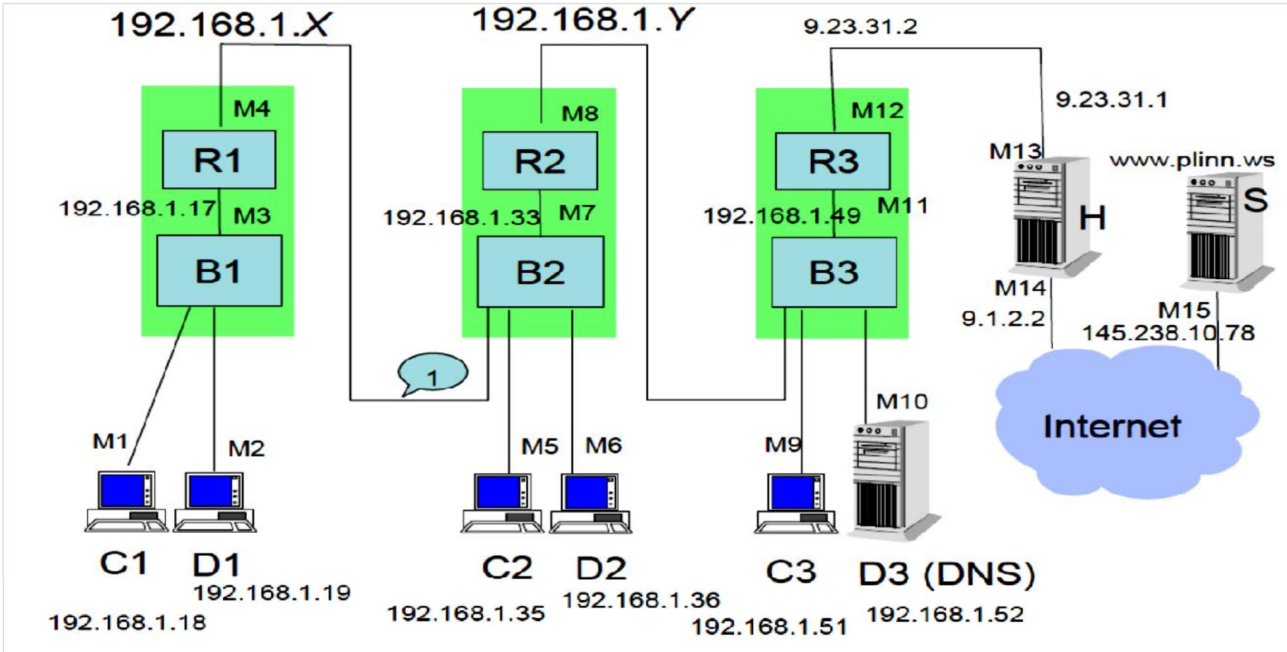

(Manual Configu-ration)	*Destination prefix*	*Destination mask*	*Next hop*
R1	0.0.0.0	0.0.0.0	192.168.1.33
R2	192.168.1.16 9.23.31.0	255.255.255.240 255.255.255.240	192.168.1.34 192.168.1.49
R3	0.0.0.0	0.0.0.0	192.168.1.50

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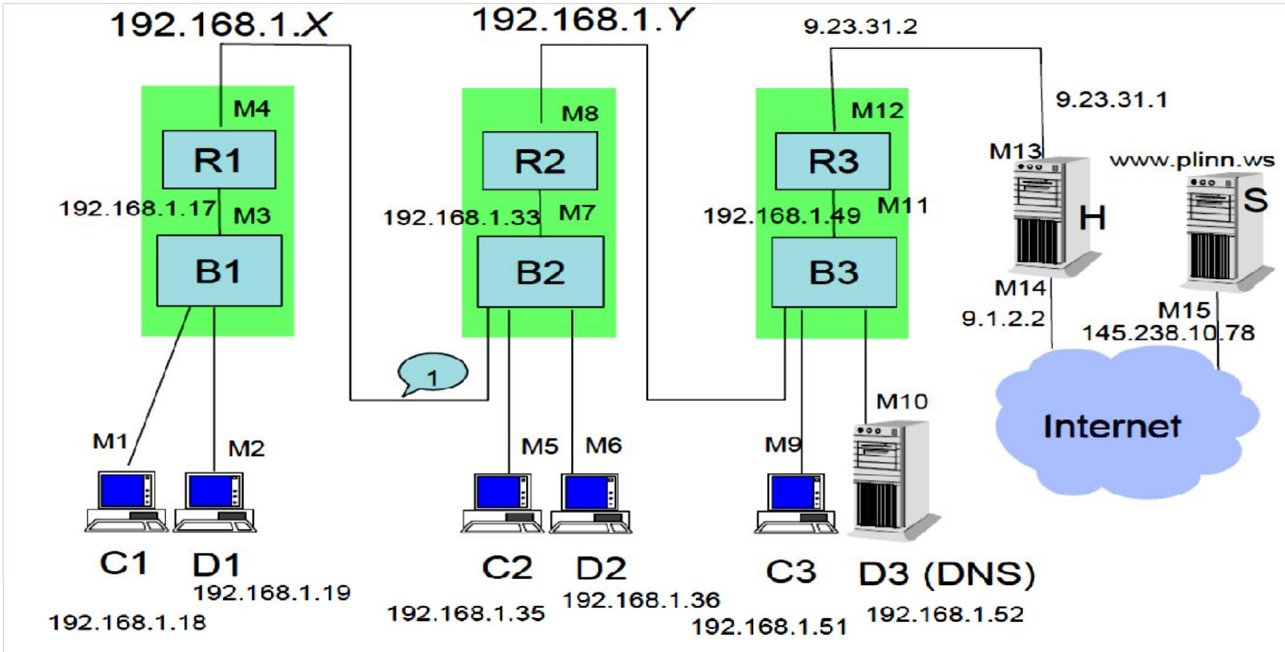

3. Instead of manual configuration as in question 2, routers R1 R2 and R3 use now RIP. After RIP has converged, what are the routing tables at each router? Give only the entries for destination prefixes that are not on-link with this router.

(RIP, Figure 1)	*Destination prefix*	*Destination mask*	*Next hop*
R1			
R2			
R3			

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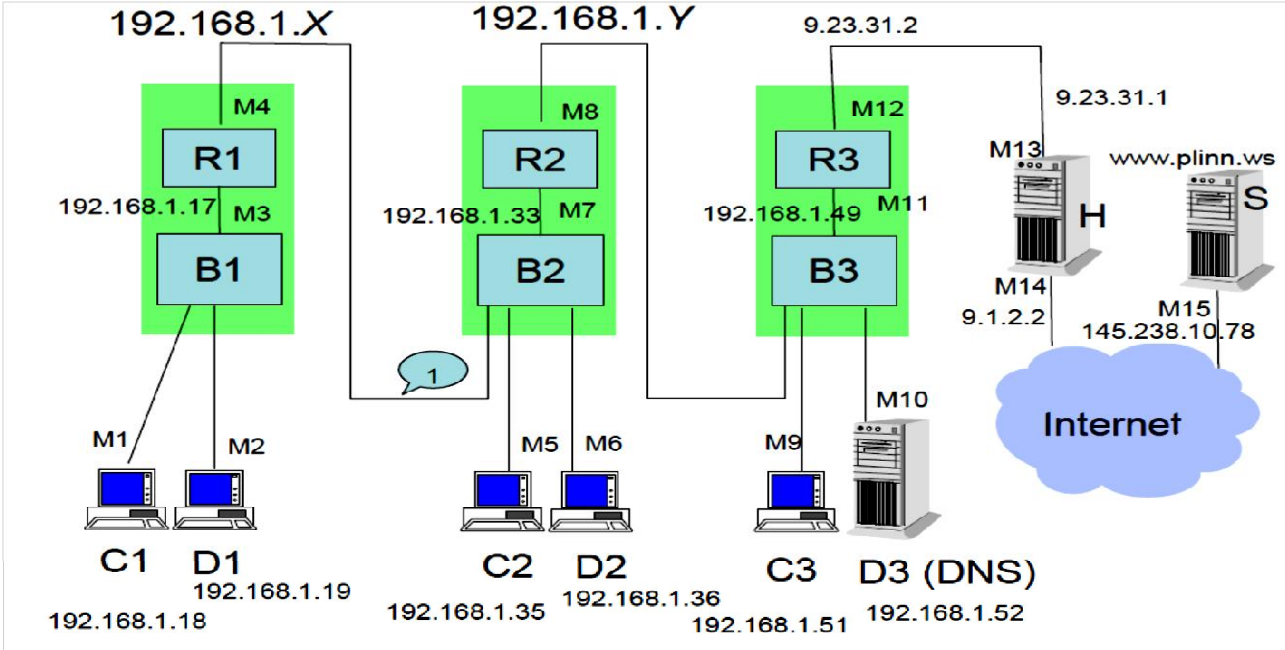

(RIP, Figure 1)	Destination prefix	Destination mask	Next hop
R1	192.168.1.48 9.23.31.0	255.255.255.240 255.255.255.240	192.168.1.33 192.168.1.33
R2	192.168.1.16 9.23.31.0	255.255.255.240 255.255.255.240	192.168.1.34 192.168.1.49
R3	192.168.1.32 192.168.1.16	255.255.255.240 255.255.255.240	192.168.1.50 192.168.1.50

3. Routers

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- Special type of computer
- A router has many of the same components as the computer:
  - CPU
  - Memory
  - I/O Interfaces (mostly network interfaces)
  - Operating System
- Connect and allow communication between two networks
- Determine the best path through the network
- Configuration files to control the traffic
- Generally have two connection types:
  - WAN connection
  - LAN connection

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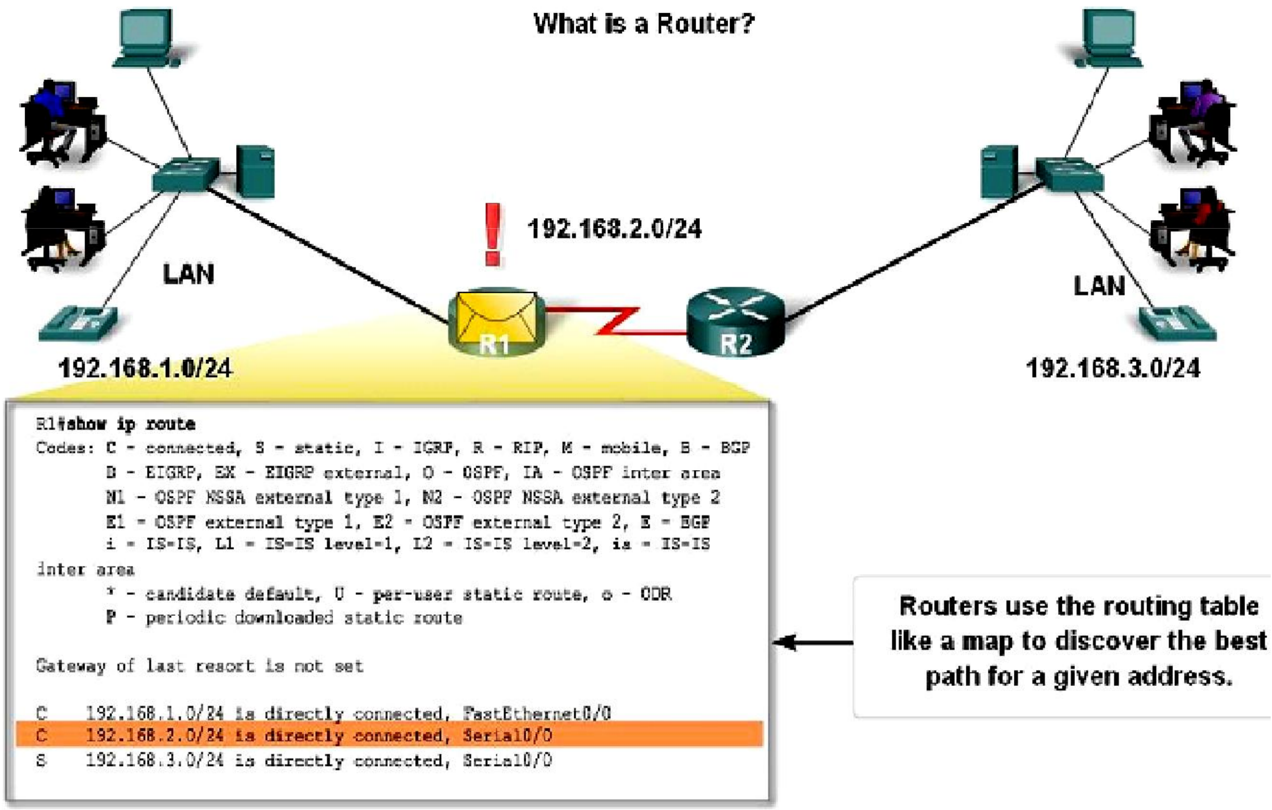
•Data is sent in form of packets between two end devices
•Routers are used to direct packets to its destination
•Routers examine a packets destination IP address and determine the best path by using a routing table



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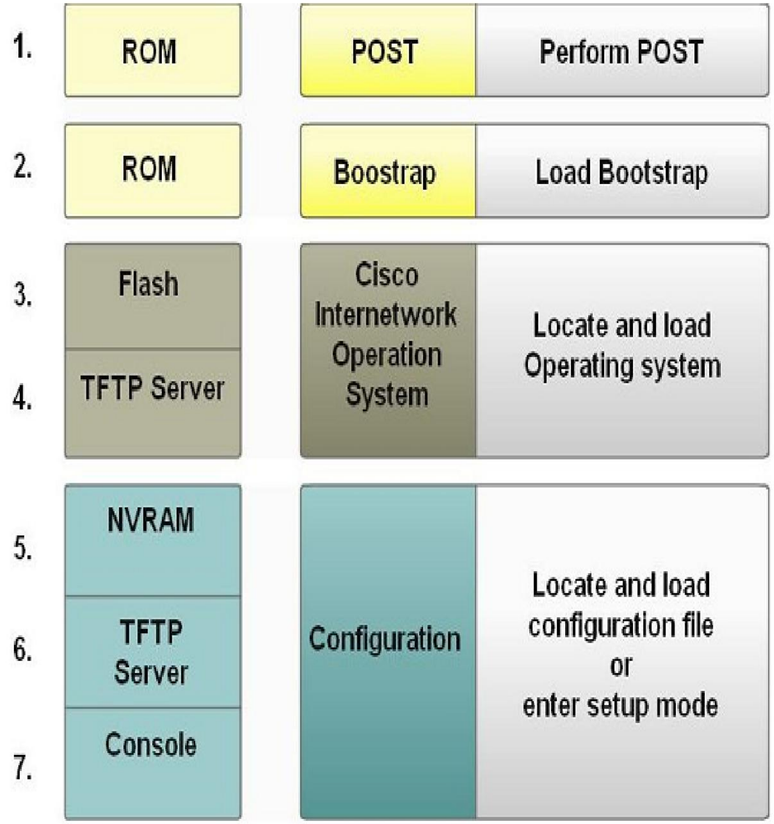
3.1. Router Boot-up process

Major phases to the router boot-up process

- Test router hardware
  - •Power-On Self Test (POST)
  - •Execute bootstrap loader
- Locate & load Cisco IOS software
  - •Locate IOS
  - •Load IOS
- Locate & load startup configuration file or enter setup mode
  -Bootstrap program looks for configuration file



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3.2. Router interfaces

Interface: a physical connector on the router, main purpose to receive and forward packets.

LAN interfaces

- Ethernet, fastEthernet
- Connects the router to a LAN

WAN interfaces

- Serial, ISDN, Frame Relay
- Connects the router to external networks, interconnect LANs

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4. Configuring a Cisco Router

•Router configuration controls the operation of the router's:

- -Interface IP address and netmask
- -Routing information (static, dynamic or default)
- -Boot and startup information
- -Security (passwords and authentication)

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4.1. Where is the Configuration?

Router always has two configurations:

1. Running configuration
   - In RAM, determines how the router is currently operating
   - Is modified using the `configure` command
   - To see it: `show running-config`

2. Startup confguration
   - In NVRAM, determines how the router will operate after next reload
   - Is modified using the `copy` command
   - To see it: `show startup-config`

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- Can also be stored in more permanent places:
  - External hosts, using TFTP (Trivial File Transfer Protocol)
  - In flash memory in the router
- Copy command is used to move it around

copy run start	copy run tftp
copy start tftp	copy tftp start
copy flash start	copy start flash

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- **Config-Register**

– controls how router boots;

– value can be seen with “show version” command;

– is typically 0x2102, which tells the router to load the IOS from flash memory and the startup-config file from NVRAM

- Save configuration parameters to NVRAM one can use the command:

  `RouterA#copy running-config startup-config`

  (or **`write memory`**)

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- **Reasons why you would want to modify the config-register:**
  - Force the router into ROM Monitor Mode
  - Select a boot source and default boot filename
  - Enable/Disable the Break function
  - Control broadcast addresses
  - Set console terminal baud rate
  - Load operating software from ROM
  - Enable booting from a TFTP server

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4.2. Router Access Modes

- User EXEC mode – limited examination of router
  - Router>
- Privileged EXEC mode – detailed examination of router, debugging, testing, file manipulation (router prompt changes to an octothorp)
  - Router#
- ROM Monitor – useful for password recovery & new IOS upload session
- Setup Mode – available when router has no startup-config file

4.3. External Configuration Sources

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- Console
  - Direct PC serial access
- Auxiliary port
  - Modem access
- Virtual terminals
  - Telnet/SSH access

- TFTP Server
  - Copy configuration file into router RAM
- Network Management Software
  - e.g. CiscoWorks

4.4. Changing the Configuration

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- Configuration statements can be entered interactively
  - changes are made (almost) immediately, to the running configuration
- Can use direct serial connection to console port, or
- Telnet/SSH to vty's ("virtual terminals"), or
- Modem connection to aux port, or
- Edited in a text file and uploaded to the router at a later time via tftp; copy tftp start or config net

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4.5. Router Prompts – How to tell where you are on the router

- You can tell in which area of the router's configuration you are by looking at the router prompts:
  - **Router>** – USER prompt mode
  - **Router#** – PRIVILEGED EXEC prompt mode
  - **Router(config)** – terminal configuration prompt
  - **Router(config-if)** – interface configuration prompt
  - **Router(config-subif)** – sub-interface configuration prompt
  - **Router(config-route-map)#** – route-map configuration prompt
  - **Router(config-router)#** – router configuration prompt
  - **Router(config-line)#** – line configuration prompt
  - **rommon 1**> - ROM Monitor mode

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4.6. Deleting your Router’s Configuration

- To delete your router’s configuration

Router#erase startup-config

OR

Router#write erase

Router#reload

– Router will start up again, but in setup mode, since startup-config file does not exists