Fundamentals of Telecommunications Networks

ECP 602

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Routing Concepts

Lecture Objectives

Upon completion of this lecture, you will be able to:

- Configure a router to route between multiple directly connected networks
- Describe the primary functions and features of a router.
- Explain how routers use information in data packets to make forwarding decisions in a small- to medium-sized business network.
- Explain the encapsulation and de-encapsulation process used by routers when switching packets between interfaces.
- Compare ways in which a router builds a routing table when operating in a small- to medium-sized business network.
- Explain routing table entries for directly connected networks.
- Explain how a router builds a routing table of directly connected networks.

Lecture Objectives (cont.)

- Explain how a router builds a routing table using static routes.
- Explain how a router builds a routing table using a dynamic routing protocol.

Lecture Overview

Routing Concepts

Initial Configuration of a Router

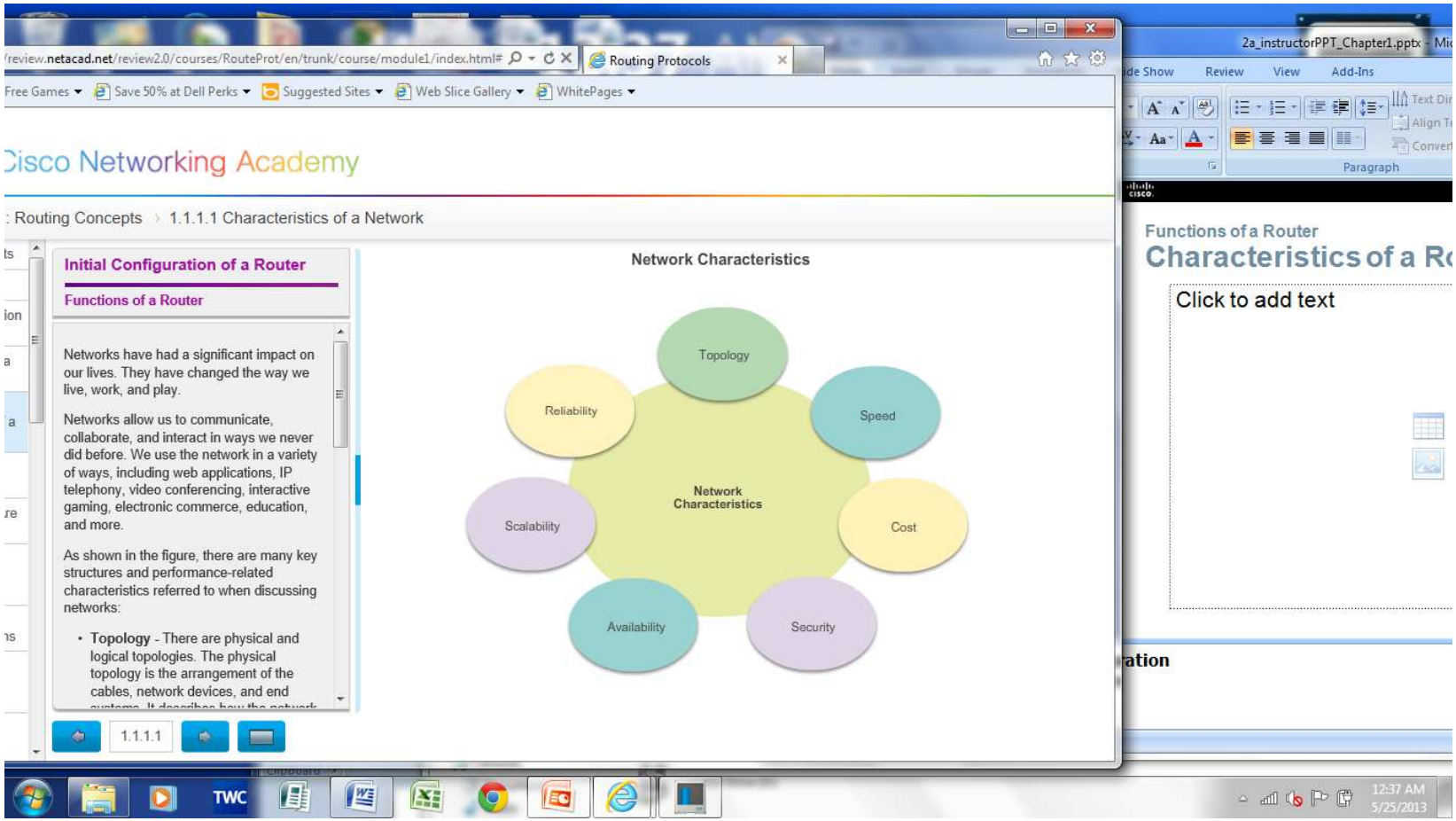
Routing Decisions

Router Operation

Summary

Functions of a Router

Characteristics of a Network



Why Routing?

The router is responsible for the routing of traffic between networks.

Routers Route Packets


```
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
```

Cisco IOS command line interface (CLI) can be used to view the route table.

Routers are Computers

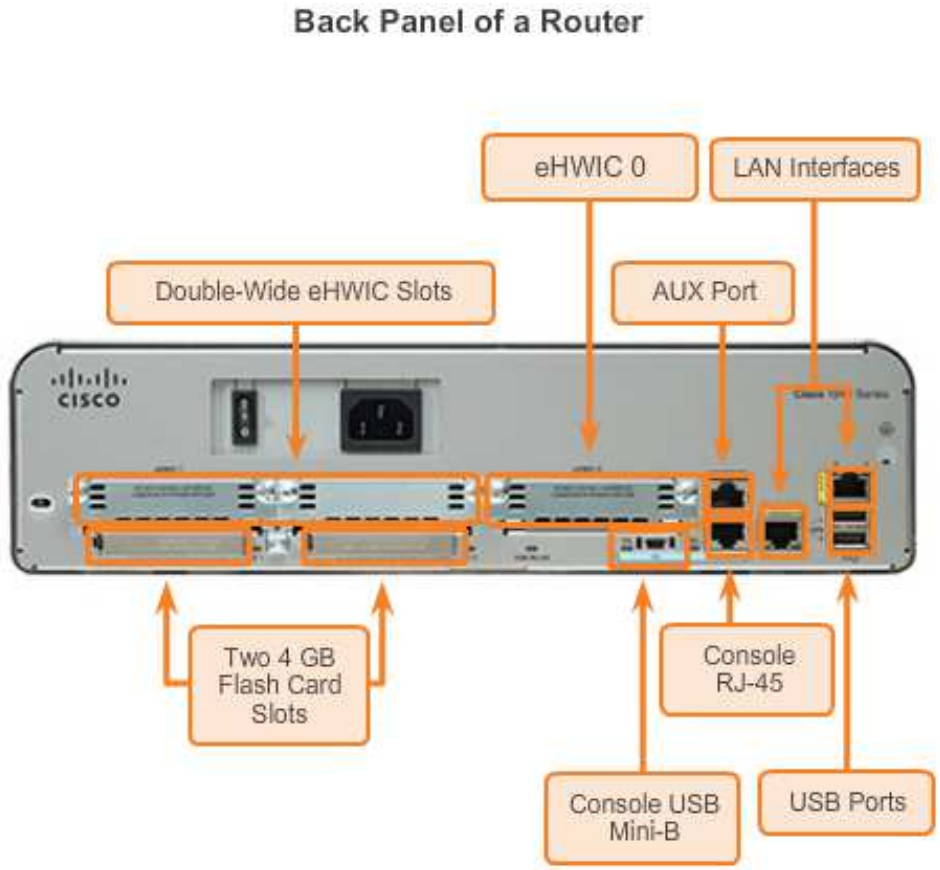
Routers are specialized computers containing the following required components to operate:

- Central processing unit (CPU)
- Operating system (OS) - Routers use Cisco IOS
- Memory and storage (RAM, ROM, NVRAM, Flash, hard drive)

Memory	Volatile / Non-Volatile	Stores
RAM	Volatile	• Running IOS • Running configuration file • IP routing and ARP tables • Packet buffer
ROM	Non-Volatile	• Bootup instructions • Basic diagnostic software • Limited IOS
NVRAM	Non-Volatile	• Startup configuration file
Flash	Non-Volatile	• IOS • Other system files

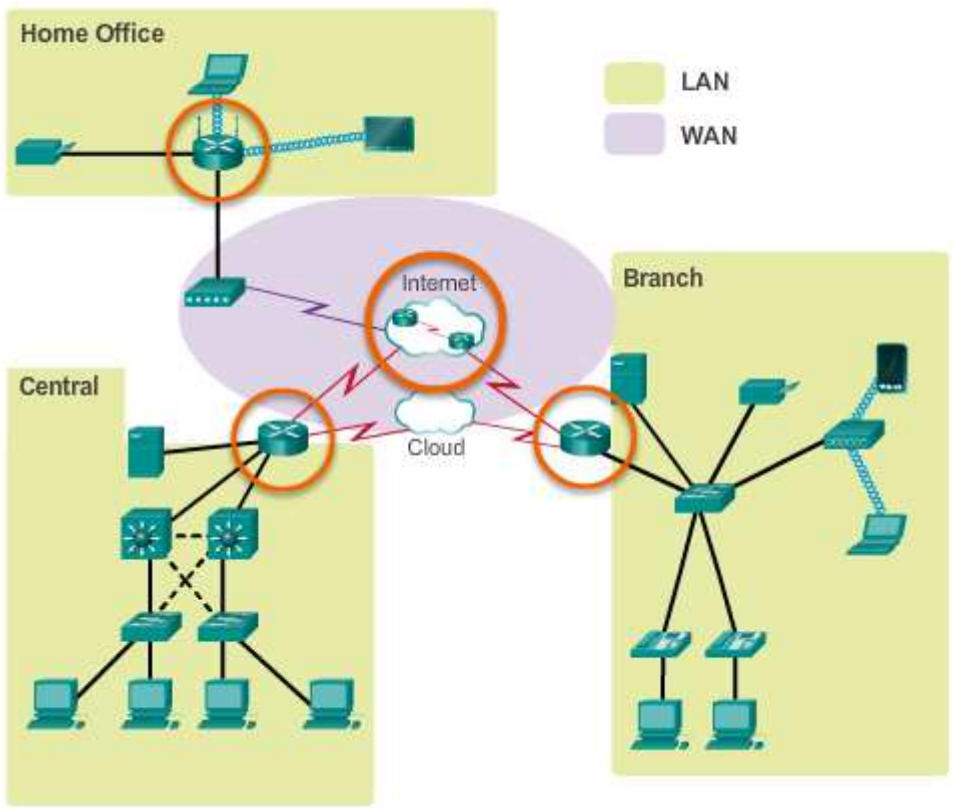
Routers are Computers

Routers use specialized ports and network interface cards to interconnect to other networks.



Routers Interconnect Networks

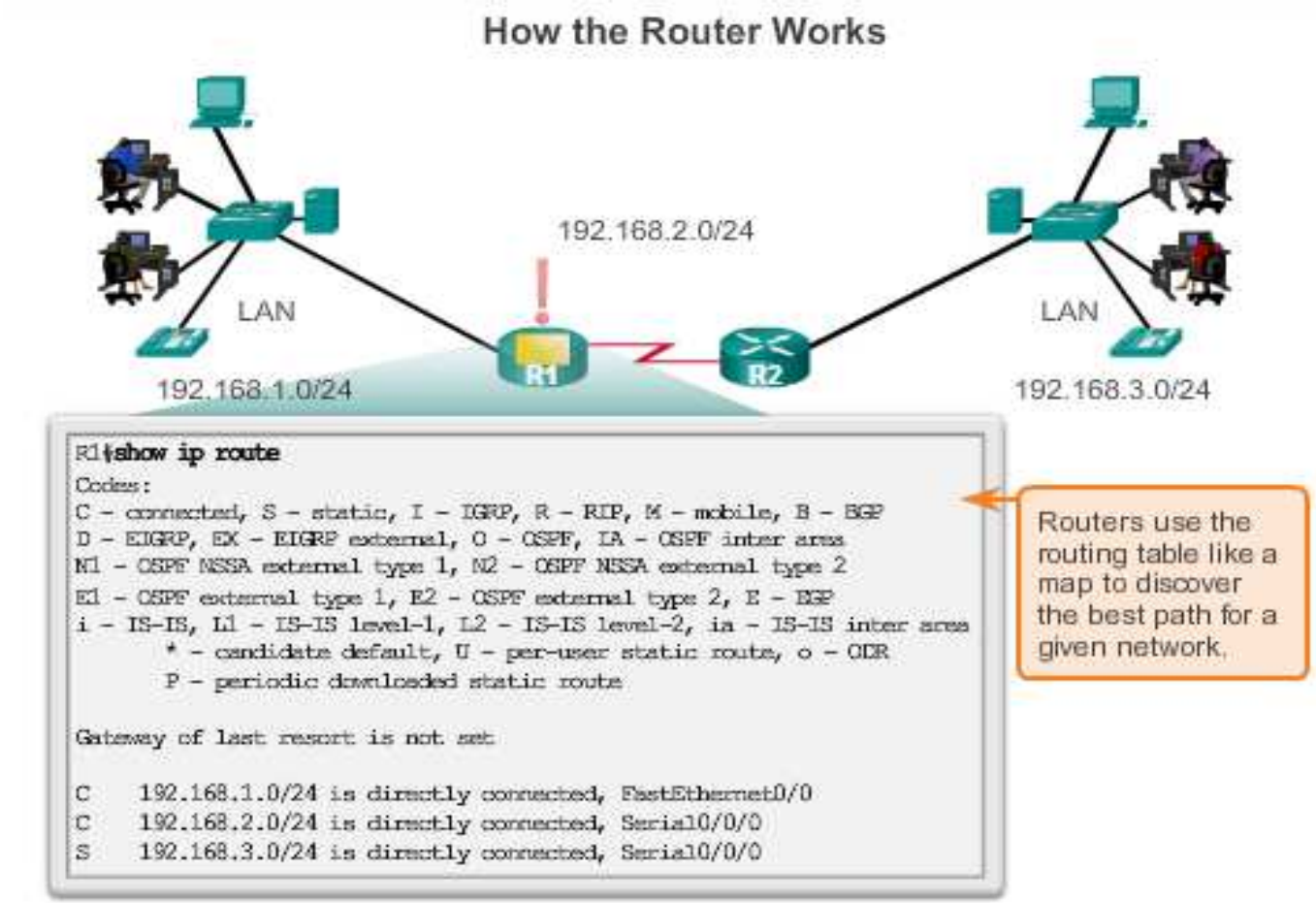
- Routers can connect multiple networks.
- Routers have multiple interfaces, each on a different IP network.



Routers Choose Best Paths

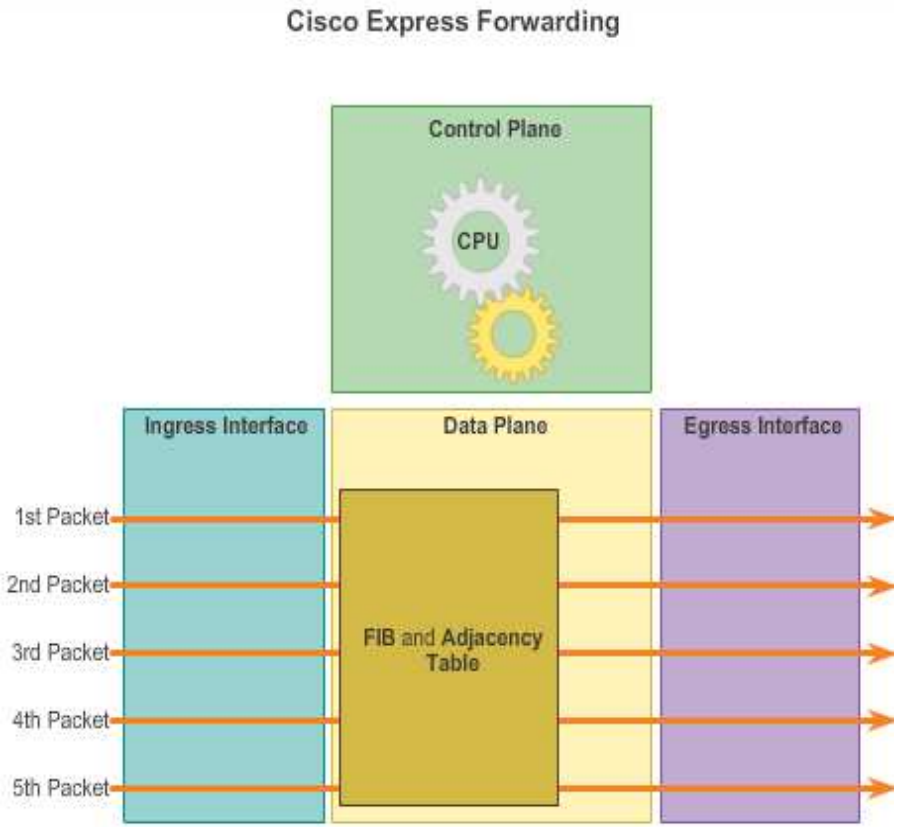
- Routers use static routes and dynamic routing protocols to learn about remote networks and build their routing tables.
- Routers use routing tables to determine the best path to send packets.
- Routers encapsulate the packet and forward it to the interface indicated in routing table.

Routers Choose Best Paths



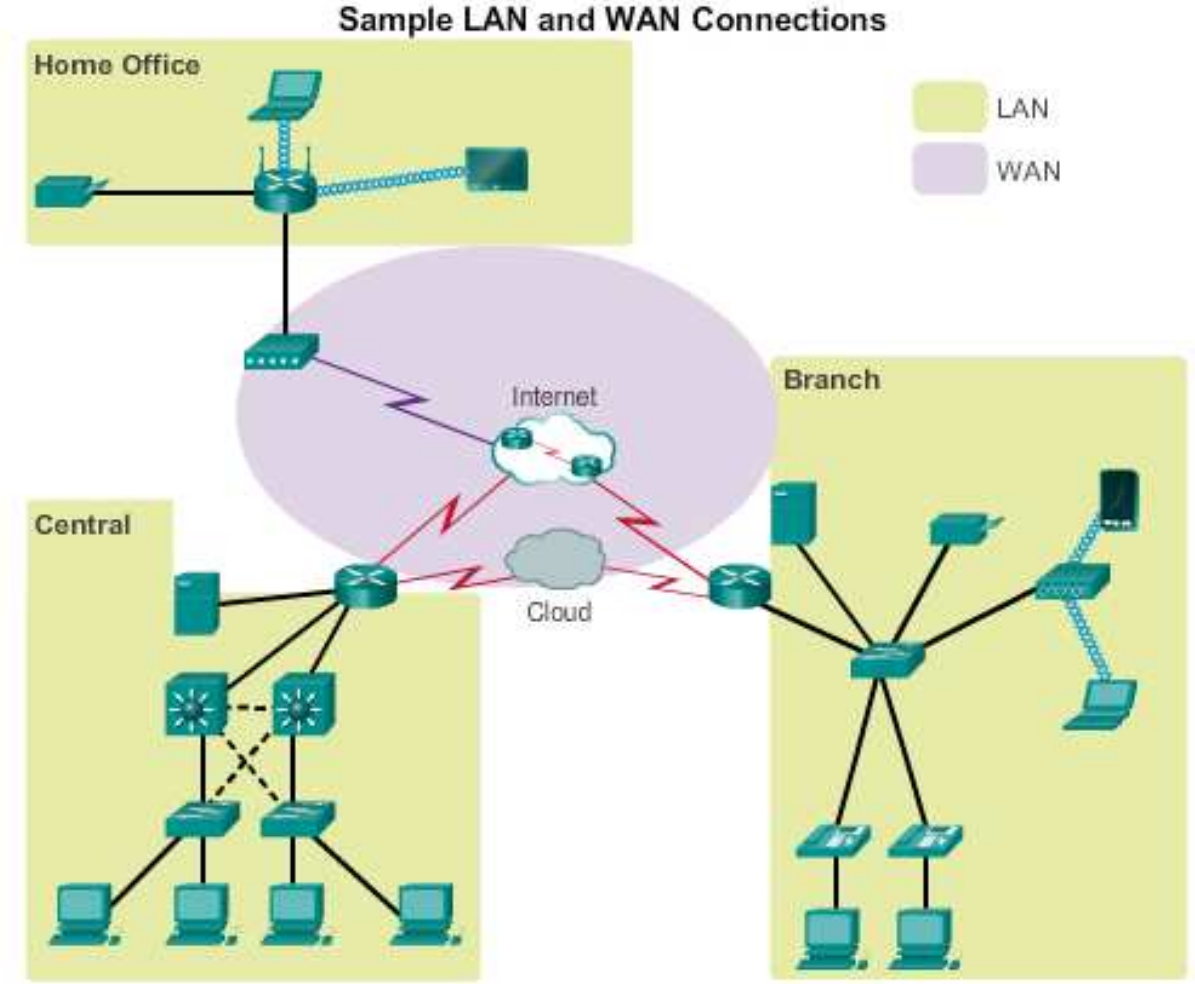
Packet Forwarding Methods

- **Process switching** – An older packet forwarding mechanism still available for Cisco routers.
- **Fast switching** – A common packet forwarding mechanism which uses a fast-switching cache to store next hop information.
- **Cisco Express Forwarding (CEF)** – The most recent, fastest, and preferred Cisco IOS packet-forwarding mechanism. Table entries are not packet-triggered like fast switching but change-triggered.



Connect Devices

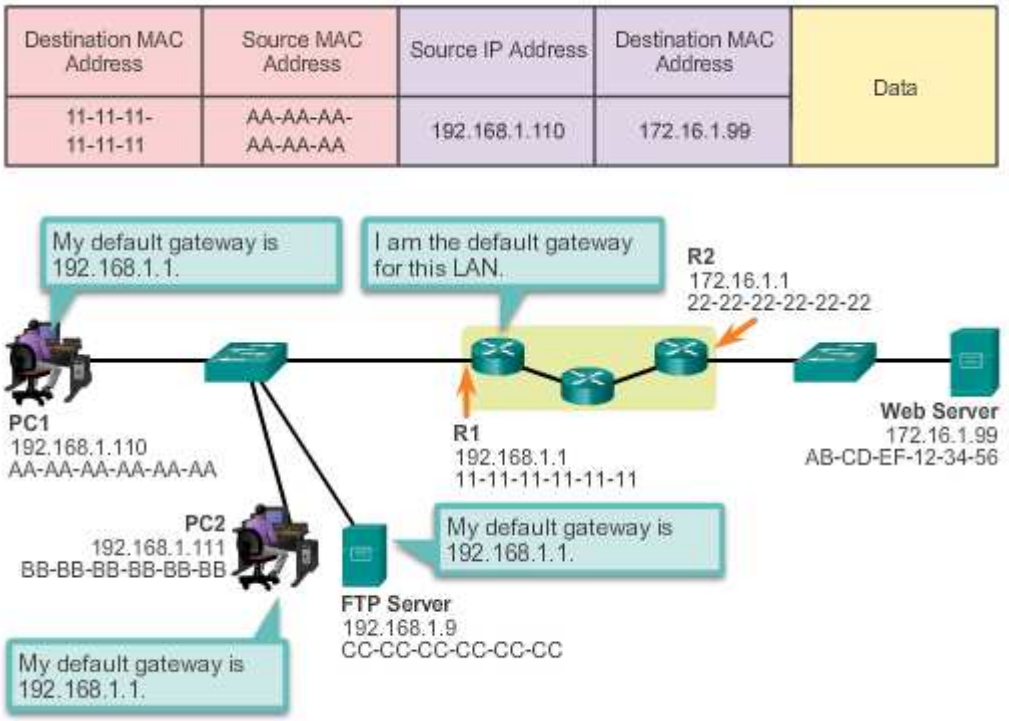
Connect to a Network



Default Gateways

To enable network access devices must be configured with the following IP address information

- **IP address** - Identifies a unique host on a local network.
- **Subnet mask** - Identifies the host's network subnet.
- **Default gateway** - Identifies the router a packet is sent to to when the destination is not on the same local network subnet.

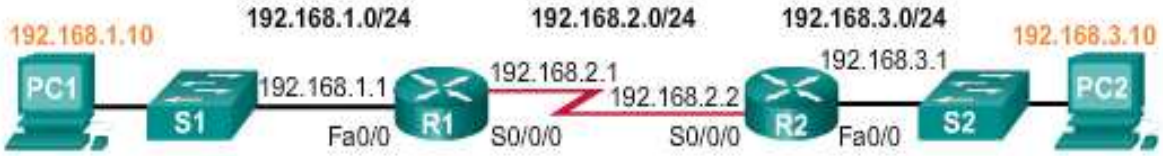


Connect Devices

Document Network Addressing

Network Documentation should include at least the following in a topology diagram and addressing table:

- Device names
- Interfaces
- IP addresses and subnet mask
- Default gateways



Device	Interface	IP Address	Subnet Mask	Default Gateway
R1	Fa0/0	192.168.1.1	255.255.255.0	N/A
	S0/0/0	192.168.2.1	255.255.255.0	N/A
R2	Fa0/0	192.168.3.1	255.255.255.0	N/A
	S0/0/0	192.168.2.2	255.255.255.0	N/A
PC1	N/A	192.168.1.10	255.255.255.0	192.168.1.1
PC2	N/A	192.168.3.10	255.255.255.0	192.168.3.1

Enable IP on a Host

Statically Assigned IP address – The host is manually assigned an IP address, subnet mask and default gateway. A DNS server IP address can also be assigned.

- Used to identify specific network resources such as network servers and printers.
- Can be used in very small networks with few hosts.

Dynamically Assigned IP Address – IP Address information is dynamically assigned by a server using Dynamic Host Configuration Protocol (DHCP).

- Most hosts acquire their IP address information through DHCP.
- DHCP services can be provided by Cisco routers.

Configure Basic Router Settings

Basics tasks that should be first configured on a Cisco Router and Cisco Switch:

- **Name the device** – Distinguishes it from other routers
- **Secure management access** – Secures privileged EXEC, user EXEC, and Telnet access, and encrypts passwords to their highest level

```
R1(config)#enable secret class
R1(config)#
R1(config)#line console 0
R1(config-line)#password cisco
R1(config-line)#login
R1(config-line)#exit
R1(config)#
R1(config)#line vty 0 4
R1(config-line)#password cisco
R1(config-line)#login
R1(config-line)#exit
R1(config)#
R1(config)#service password-encryption
R1(config)#
```

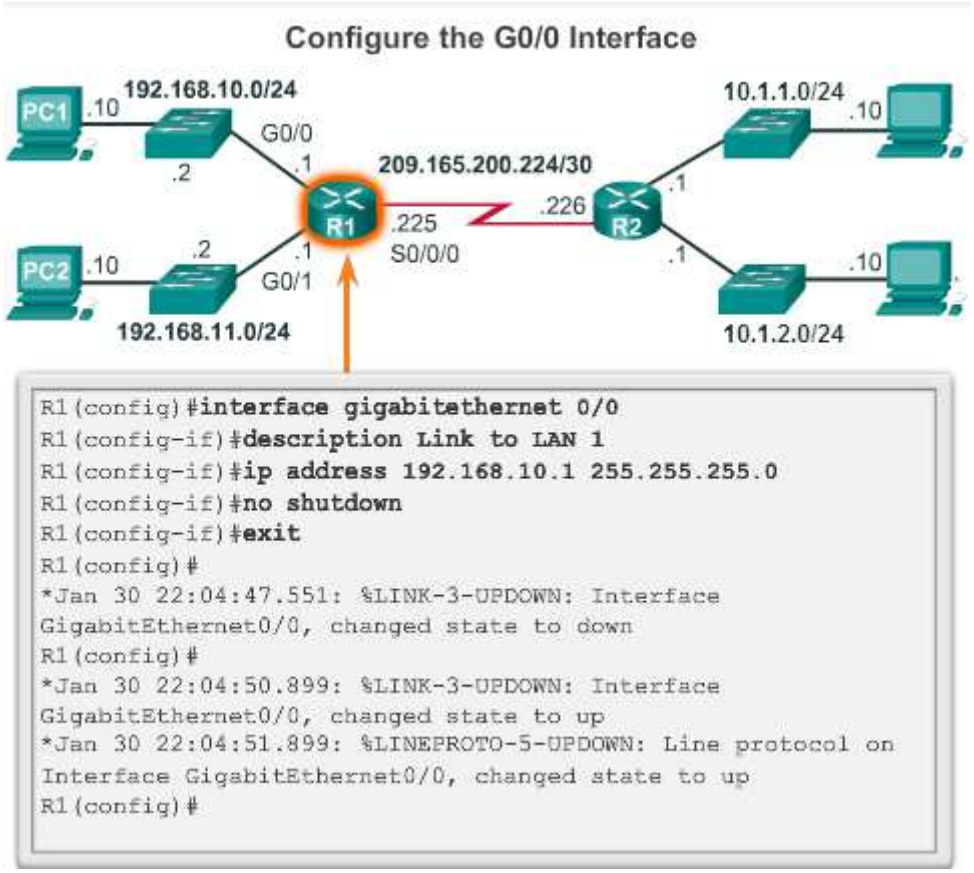
- **Configure a banner** – Provides legal notification of unauthorized access.
- **Save the Configuration**

Basic Settings on a Router

Configure an IPv4 Router Interface

To be available, a router interface must be:

- Configured with an address and subnet mask .
- Must be activated using no shutdown command. By default LAN and WAN interfaces are not activated.
- Serial cable end labeled DCE must be configured with the clock rate command.
- Optional description can be included.



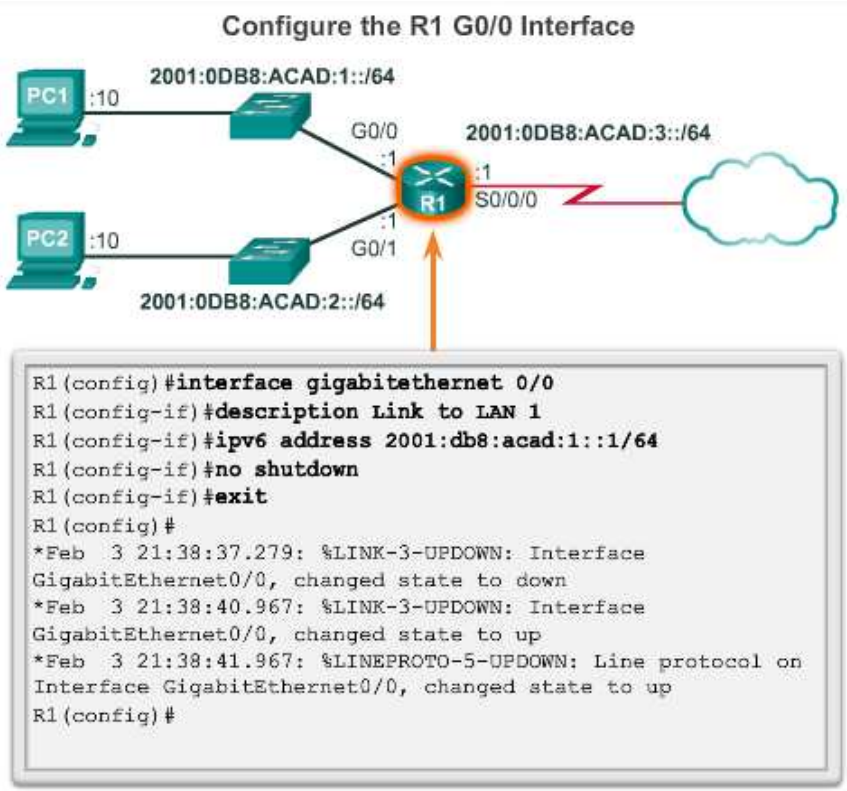
Configure an IPv6 Router Interface

To configure interface with IPv6 address and subnet mask:

- Use the ipv6 address *ipv6-address/ ipv6-length* [link-local | eui-64]interface configuration command.
- Activate using the no shutdown command.

IPv6 interfaces can support more than one address:

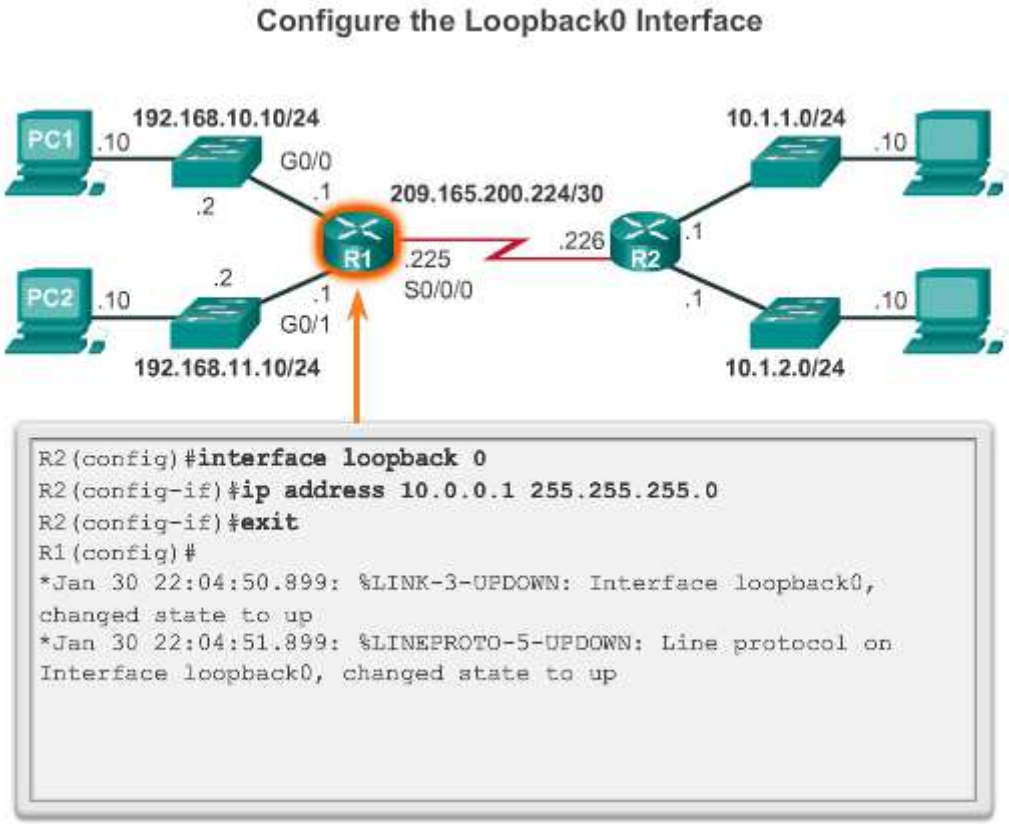
- Configure a specified global unicast - *ipv6-address / ipv6-length*
- Configure a global IPv6 address with an interface identifier (ID) in the low-order 64 bits - *ipv6-address / ipv6-length* eui-64
- Configure a link-local address - *ipv6-address / ipv6-length* link-local



Configure a Loopback Interface

A loopback interface is a logical interface that is internal to the router:

- It is not assigned to a physical port, it is considered a software interface that is automatically in an UP state.
- A loopback interface is useful for testing.
- It is important in the OSPF routing process.



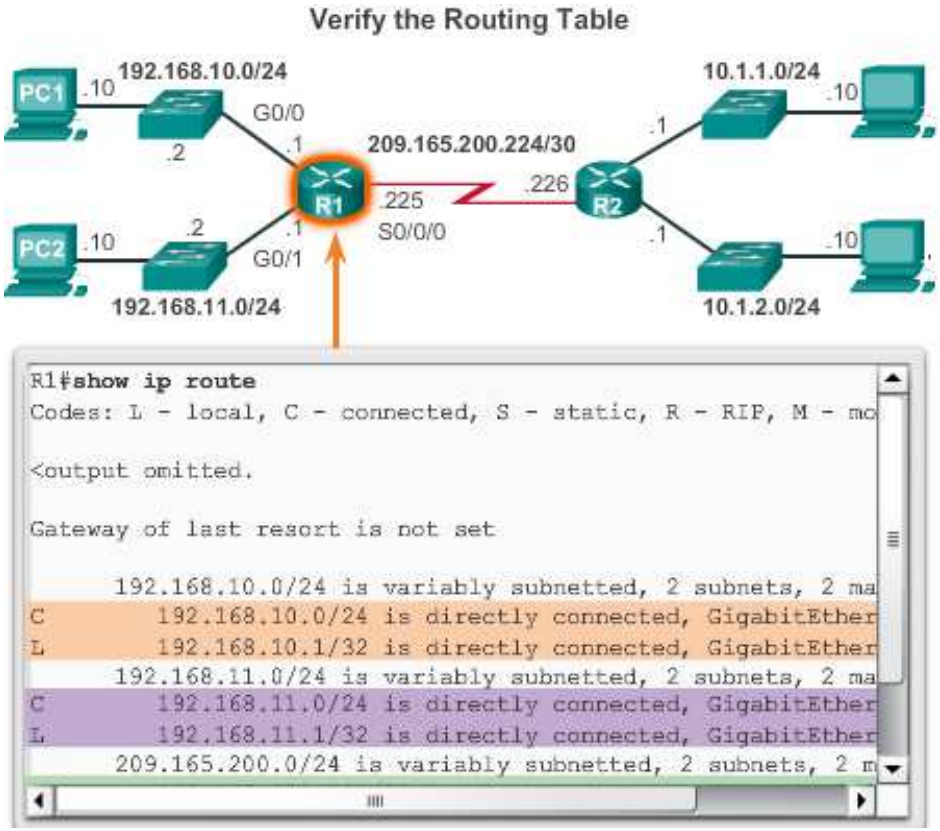
Verify Interface Settings

Show commands are used to verify operation and configuration of interface:

- **show ip interfaces brief**
- **show ip route**
- **show running-config**

Show commands are used to gather more detailed interface information:

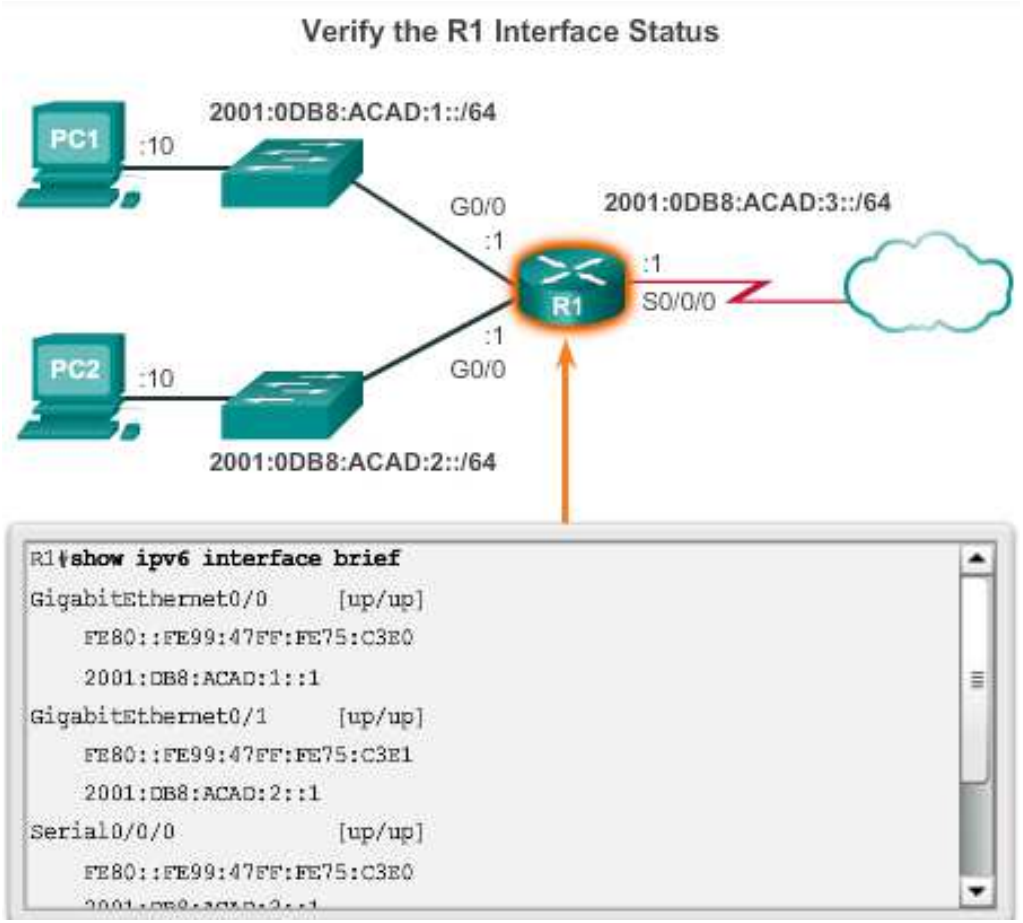
- **show interfaces**
- **show ip interfaces**



Verify Interface Settings

Some of the common commands to verify the IPv6 interface configuration are:

- **show ipv6 interface brief** - displays a summary for each of the interfaces.
- **show ipv6 interface gigabitethernet 0/0** - displays the interface status and all the IPv6 addresses for this interface.
- **show ipv6 route** - verifies that IPv6 networks and specific IPv6 interface addresses have been installed in the IPv6 routing table.



Filter Show Command Output

Show command output can be managed using the following command and filters:

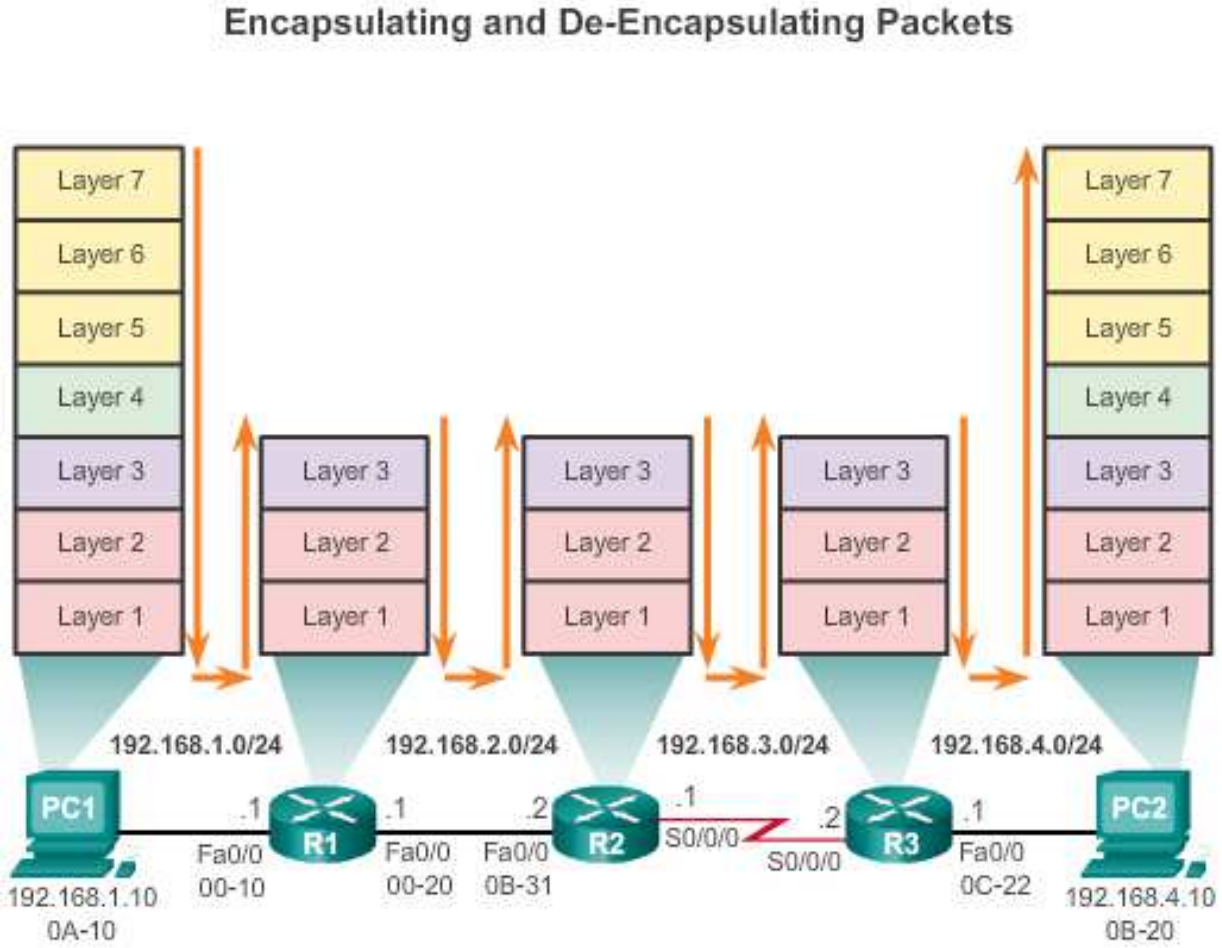
- Use the **terminal length** *number* command to specify the number of lines to be displayed. A value of 0 (zero) prevents the router from pausing between screens of output.
- To filter specific output of commands use the **(|)pipe character** after show command. Parameters that can be used after pipe include:
  - **section, include, exclude, begin**

```
R1#show ip interface brief
Interface                  IP-Address      OK? Method Status
Embedded-Service-Engine0/0 unassigned      YES unset  admini
GigabitEthernet0/0         192.168.10.1    YES manual up
GigabitEthernet0/1         192.168.11.1    YES manual up
Serial0/0/0                209.165.200.225 YES manual up
Serial0/0/1                unassigned      YES unset  admini

R1#show ip interface brief | exclude unassigned
Interface                  IP-Address      OK? Method Status
GigabitEthernet0/0         192.168.10.1    YES manual up
GigabitEthernet0/1         192.168.11.1    YES manual up
Serial0/0/0                209.165.200.225 YES manual up
```

```
R1#show ip interface brief
Interface                  IP-Address      OK? Method Status
Embedded-Service-Engine0/0 unassigned      YES unset  administ
GigabitEthernet0/0         192.168.10.1    YES manual up
GigabitEthernet0/1         192.168.11.1    YES manual up
Serial0/0/0                209.165.200.225 YES manual up
Serial0/0/1                unassigned      YES unset  administ
R1#
R1#show ip interface brief | include up
GigabitEthernet0/0         192.168.10.1    YES manual up
GigabitEthernet0/1         192.168.11.1    YES manual up
Serial0/0/0                209.165.200.225 YES manual up
R1#
```

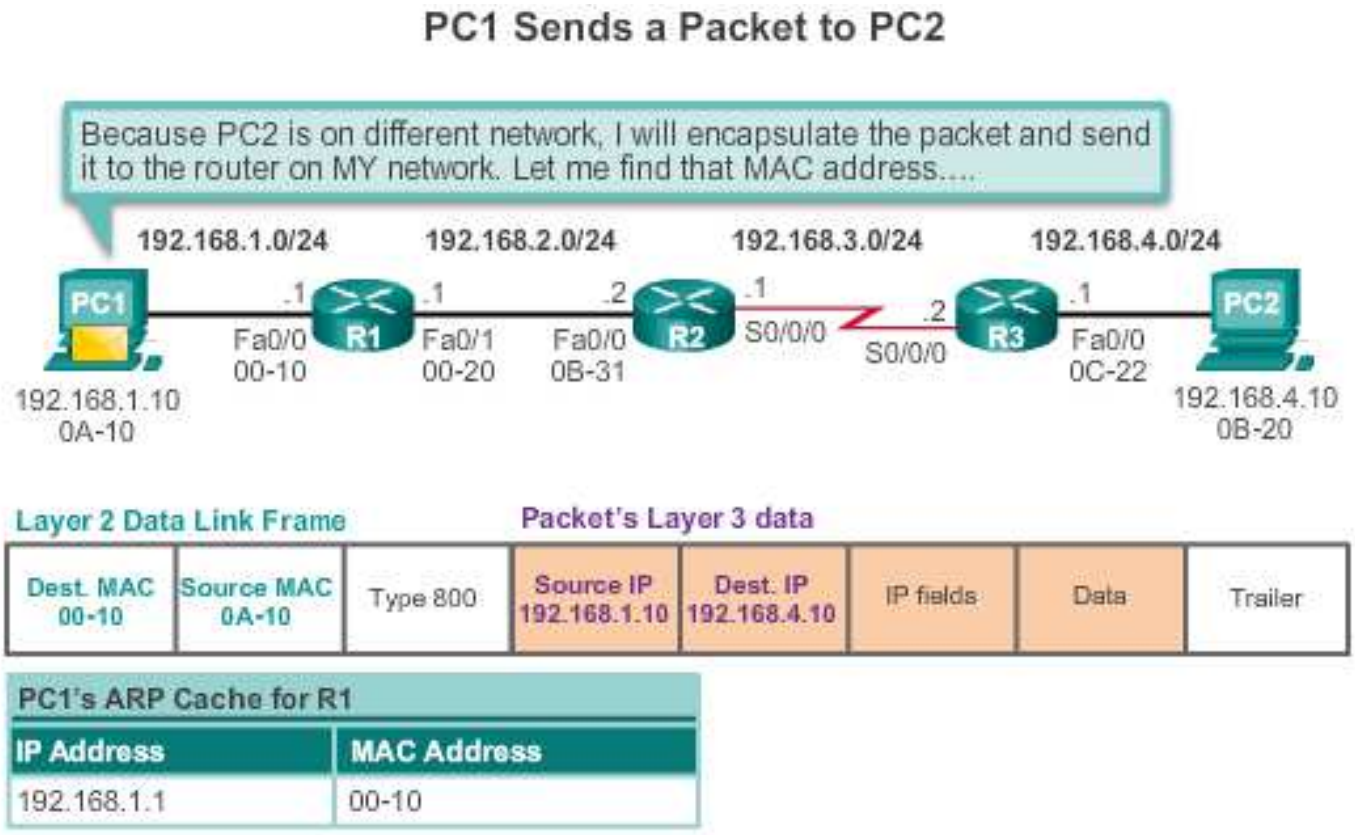
Switching Packets between Networks

Router Switching Functions



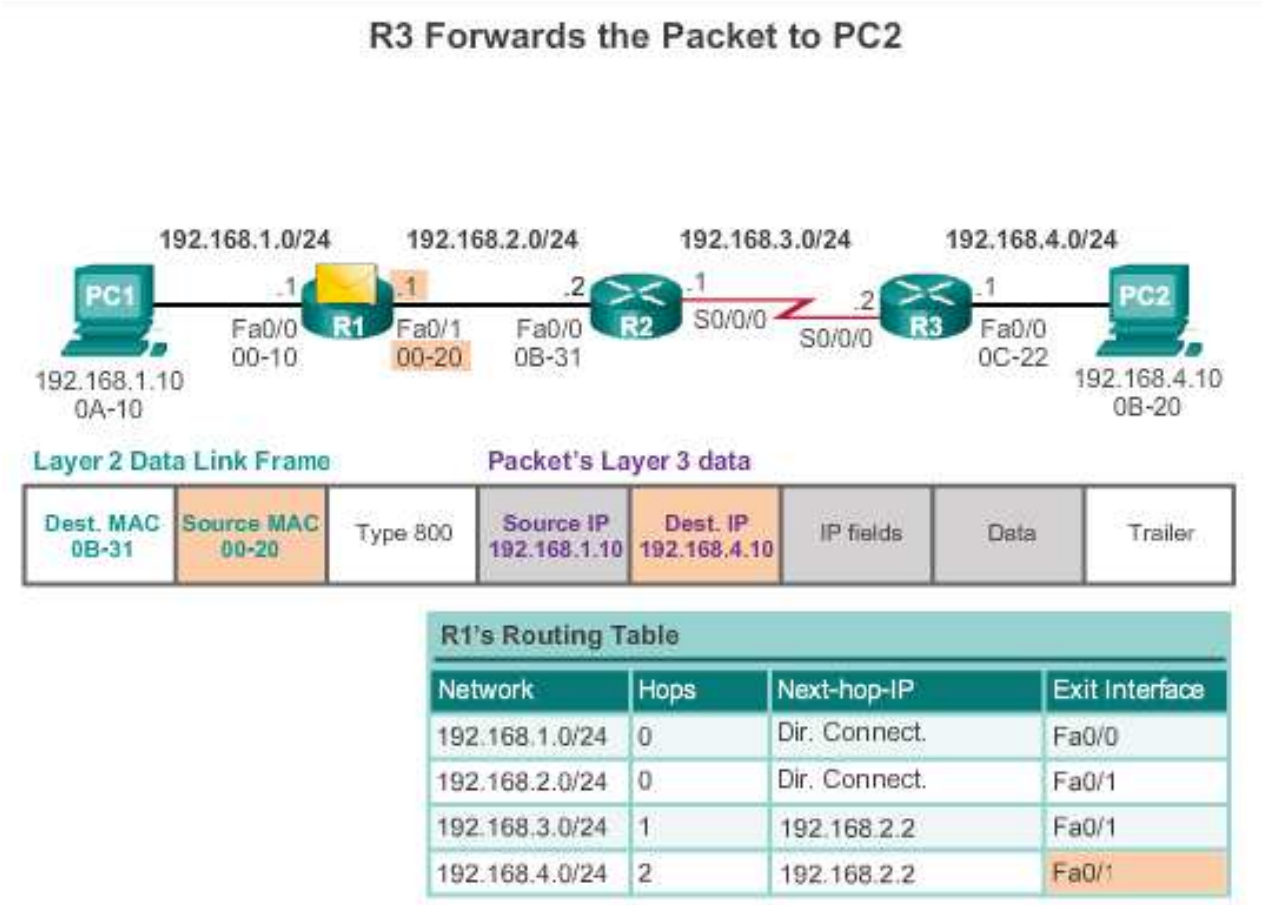
Switching Packets between Networks

Send a Packet



Switching Packets between Networks

Forward to the Next Hop



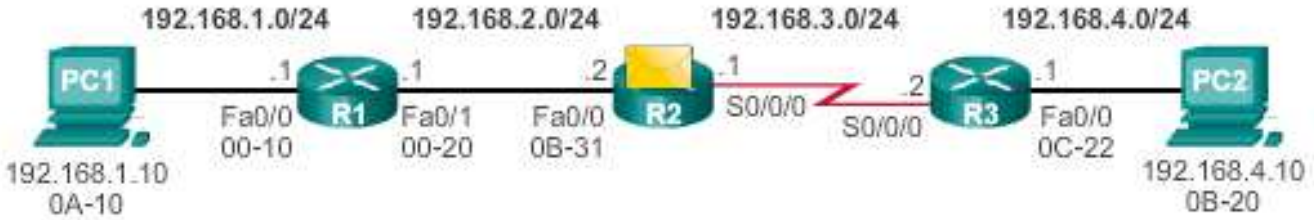
R1's Routing Table

Network	Hops	Next-hop-IP	Exit Interface
192.168.1.0/24	0	Dir. Connect.	Fa0/0
192.168.2.0/24	0	Dir. Connect.	Fa0/1
192.168.3.0/24	1	192.168.2.2	Fa0/1
192.168.4.0/24	2	192.168.2.2	Fa0/1

Switching Packets between Networks

Packet Routing

R2 Forwards the Packet to R3



Layer 2 Data Link Frame | Packet's Layer 3 data

Address Ox8F	Control 0x00	Type 800	Source IP 192.168.1.10	Dest. IP 192.168.4.10	IP fields	Data	Trailer

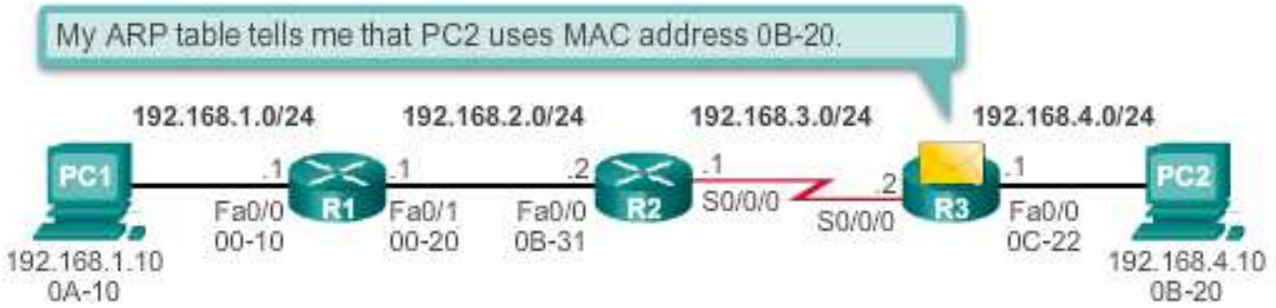
R2's Routing Table

Network	Hops	Next-hop-IP	Exit Interface
192.168.1.0/24	1	192.168.3.1	Fa/0/0
192.168.2.0/24	0	Dir. Connect.	Fa/0/0
192.168.3.0/24	0	Dir. Connect.	S0/0/0
192.168.4.0/24	1	192.162.3.2	S0/0/0

Switching Packets between Networks

Reach the Destination

R3 Forwards the Packet to PC2



Layer 2 Data Link Frame | **Packet's Layer 3 data**

Dest. MAC 0B-20	Source MAC 0C-22	Type 800	Source IP 192.168.1.10	Dest. IP 192.168.4.10	IP fields	Data	Trailer

R3's ARP Cache

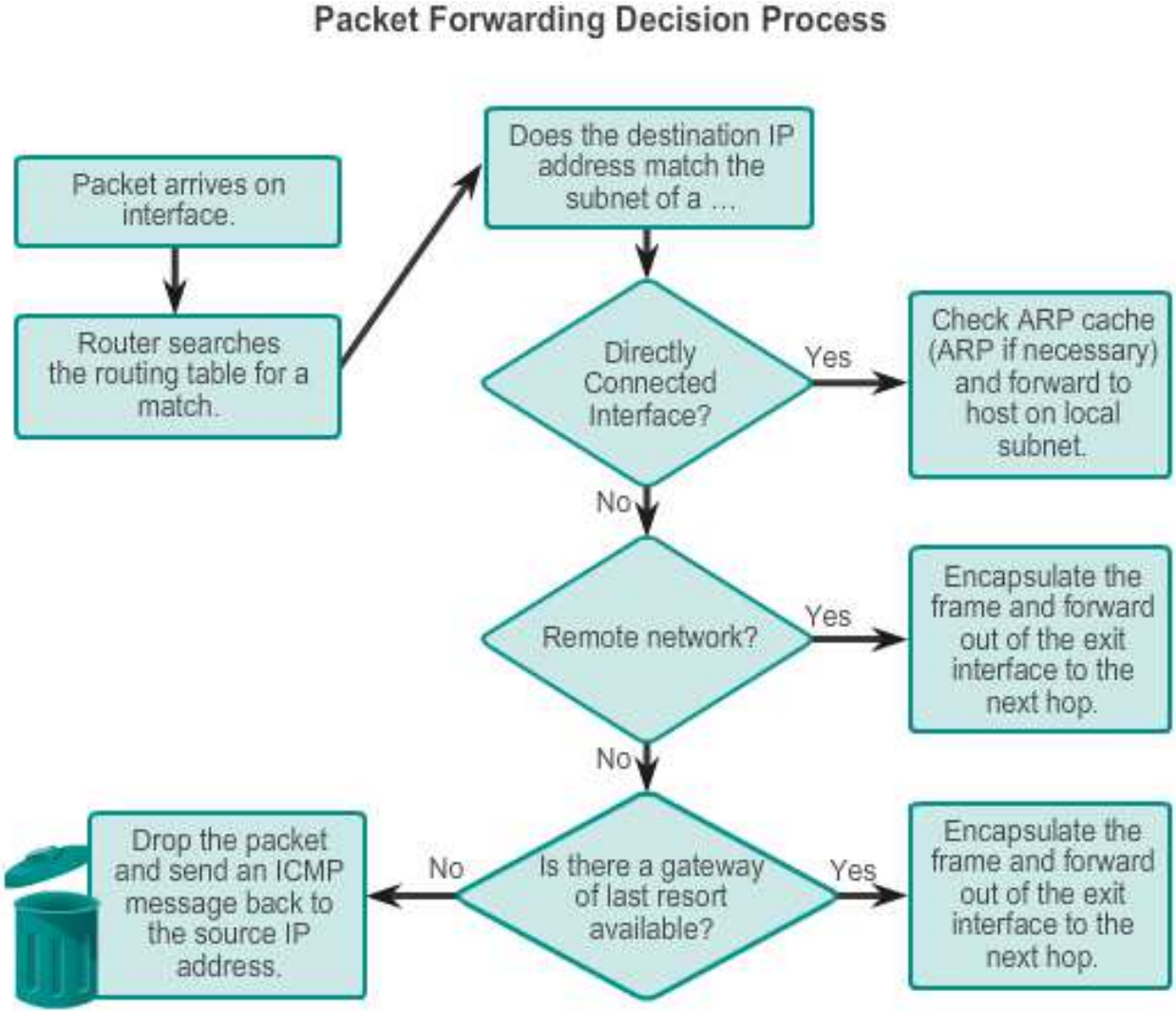
IP Address	MAC Address
192.168.4.10	0B-20

R3's Routing Table

Network	Hops	Next-hop-IP	Exit Interface
192.168.1.0/24v	2	192.168.3.1	S0/0/0
192.168.2.0/24	1	192.162.3.1	S0/0/0
192.168.3.0/24	0	Dir. Connect.	S0/0/0
192.168.4.0/24	0	Dir. Connect.	Fa0/0

Path Determination

Routing Decisions



Path Determination

Best Path

Best path is selected by a routing protocol based on the value or metric it uses to determine the distance to reach a network:

- A metric is the value used to measure the distance to a given network.
- Best path to a network is the path with the lowest metric.

Dynamic routing protocols use their own rules and metrics to build and update routing tables:

- Routing Information Protocol (RIP) - Hop count
- Open Shortest Path First (OSPF) - Cost based on cumulative bandwidth from source to destination
- Enhanced Interior Gateway Routing Protocol (EIGRP) - Bandwidth, delay, load, reliability

Load Balancing

When a router has two or more paths to a destination with equal cost metrics, then the router forwards the packets using both paths equally:

- Equal cost load balancing can improve network performance.
- Equal cost load balancing can be configured to use both dynamic routing protocols and static routes.
- RIP, OSPF and EIGRP support equal cost load balancing.

Path Determination of the route

Administrative Distance

If multiple paths to a destination are configured on a router, the path installed in the routing table is the one with the lowest Administrative Distance (AD):

- A static route with an AD of 1 is more reliable than an EIGRP-discovered route with an AD of 90.
- A directly connected route with an AD of 0 is more reliable than a static route with an AD of 1.

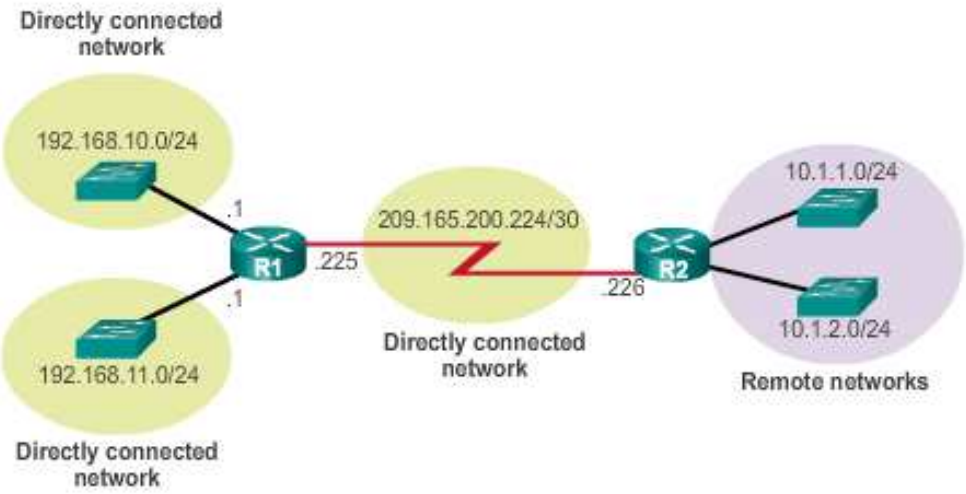
Default Administrative Distances

Route Source	Administrative Distance
Connected	0
Static	1
EIGRP summary route	5
External BGP	20
Internal EIGRP	90
IGRP	100
OSPF	110
IS-IS	115
External EIGRP	170
Internal BGP	200

The Routing Table

A routing table is a file stored in RAM that contains information about:

- Directly connected routes
- Remote routes
- Network or next hop associations

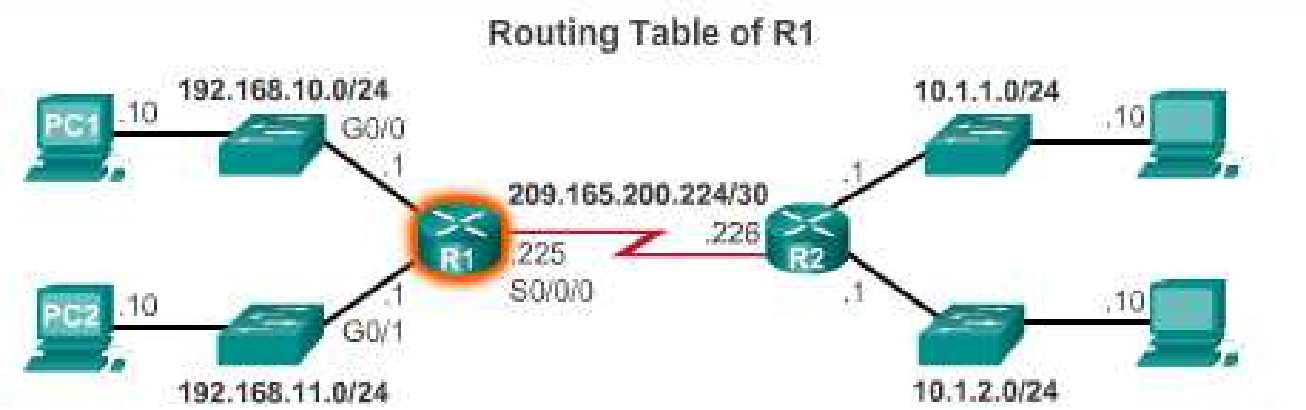


Routing Table Sources

The **show ip route** command is used to display the contents of the routing table:

- **Local route interfaces** - Added to the routing table when an interface is configured. (displayed in IOS 15 or newer)
- **Directly connected interfaces** - Added to the routing table when an interface is configured and active.
- **Static routes** - Added when a route is manually configured and the exit interface is active.
- **Dynamic routing protocol** - Added when

Routing Table Sources

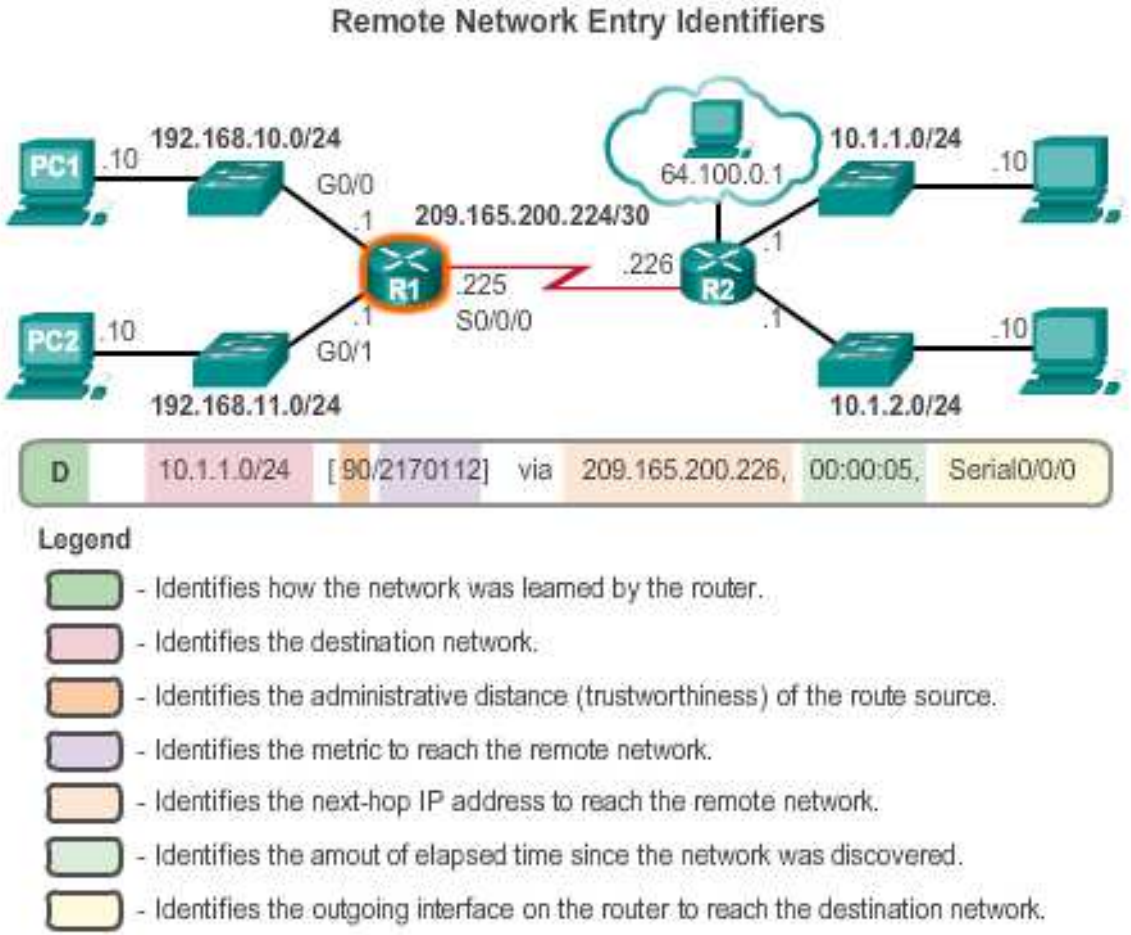



```
R1#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       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
     10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
D       10.1.1.0/24 [90/2170112] via 209.165.200.226, 00:00:05,
```

The Routing Table

Remote Network Routing Entries

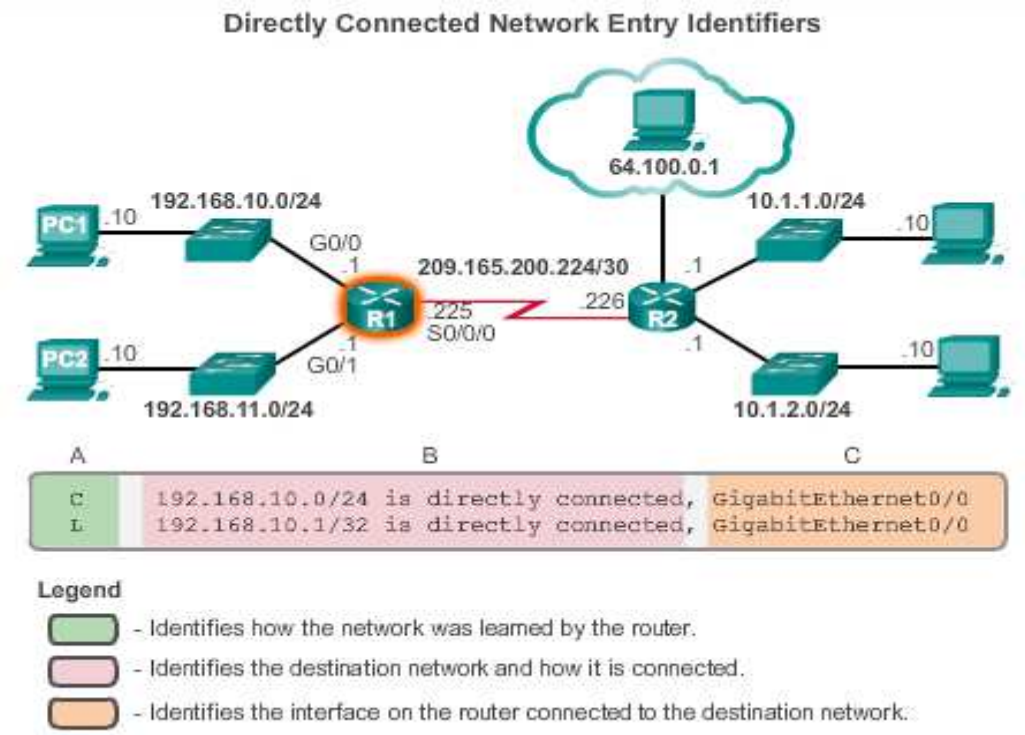
Interpreting the entries in the routing table.



Directly Connected Interfaces

A newly deployed router, without any configured interfaces, has an empty routing table. An active, configured, directly connected interface creates two routing table entries:

- Link Local (L)
- Directly Connected (C)



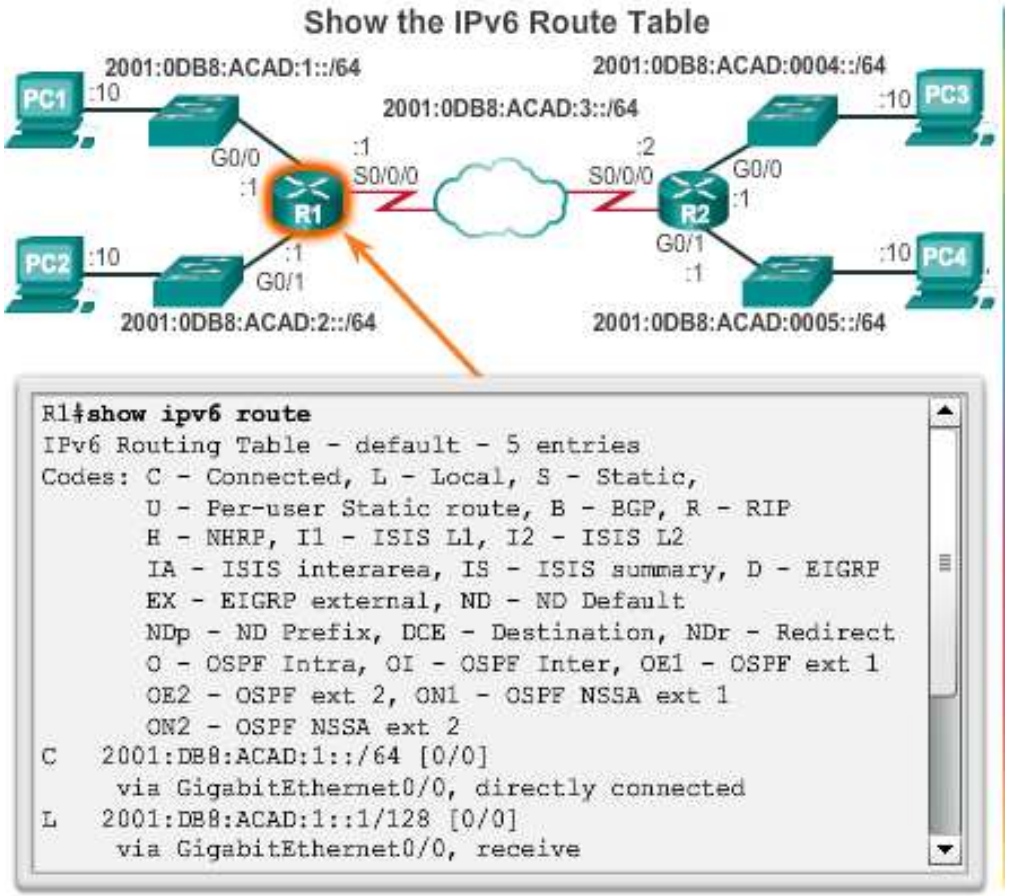
Directly Connected Example

A routing table with the directly connected interfaces of R1 configured and activated.


```
R1# show ip route | begin Gateway
Gateway of last resort is not set

      192.168.10.0/24 is variably subnetted, 2 subnets, 2
masks
C        192.168.10.0/24 is directly connected,
GigabitEthernet0/0
L        192.168.10.1/32 is directly connected,
GigabitEthernet0/0
      192.168.11.0/24 is variably subnetted, 2 subnets, 2
masks
C        192.168.11.0/24 is directly connected,
GigabitEthernet0/1
L        192.168.11.1/32 is directly connected,
GigabitEthernet0/1
```

Directly Connected IPv6 Example

The **show ipv6 route** command shows the ipv6 networks and routes installed in the routing table.



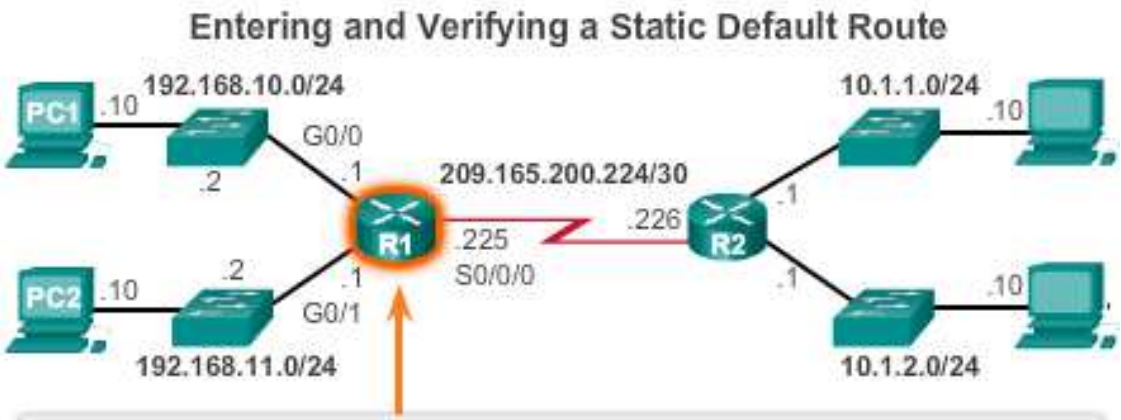
Static Routes

Static routes and default static routes can be implemented after directly connected interfaces are added to the routing table:

- Static routes are manually configured
- They define an explicit path between two networking devices.
- Static routes must be manually updated if the topology changes.
- Their benefits include improved security and control of resources.
- Configure a static route to a specific network using the **ip route** *network mask* {*next-hop-ip* | *exit-intf*} command.
- A default static route is used when the routing table does not contain a path for a destination network.
- Configure a default static route using the **ip route** 0.0.0.0 0.0.0.0 {*exit-intf* | *next-hop-ip*} command.

Statically Learned Routes

Default Static Routes Example

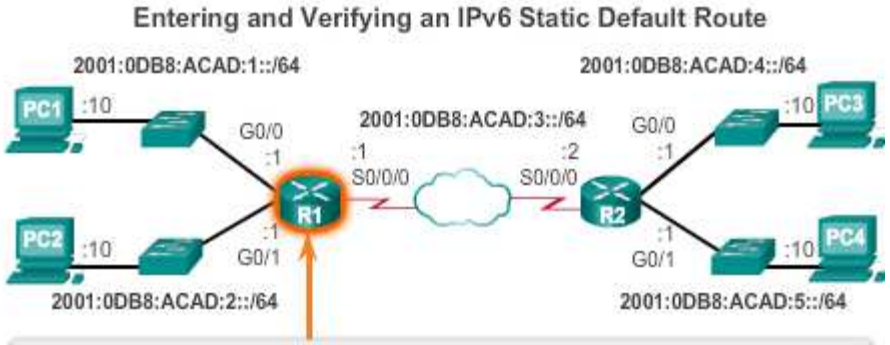



```
R1(config)#ip route 0.0.0.0 0.0.0.0 Serial0/0/0
R1(config)#exit
R1#
*Feb  1 10:19:34.483: %SYS-5-CONFIG_I: Configured from console
by console

R1#show ip route | begin Gateway
Gateway of last resort is 0.0.0.0 to network 0.0.0.0

S* 0.0.0.0/0 is directly connected, Serial0/0/0
   192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C     192.168.10.0/24 is directly connected, GigabitEthernet0/0
L     192.168.10.1/32 is directly connected, GigabitEthernet0/0
      192.168.11.0/24 is variably subnetted, 2 subnets, 2 masks
C     192.168.11.0/24 is directly connected, GigabitEthernet0/1
L     192.168.11.1/32 is directly connected, GigabitEthernet0/1
```

Static Routes Example


```
R1(config)# ip route 0.0.0.0 0.0.0.0 Serial0/0/0
R1(config)# exit
R1#
*Feb  1 10:19:34.483: %SYS-5-CONFIG_I: Configured from console
by console

R1# show ip route | begin Gateway
Gateway of last resort is 0.0.0.0 to network 0.0.0.0

S* 0.0.0.0/0 is directly connected, Serial0/0/0
   192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C     192.168.10.0/24 is directly connected, GigabitEthernet0/0
L     192.168.10.1/32 is directly connected, GigabitEthernet0/0
   192.168.11.0/24 is variably subnetted, 2 subnets, 2 masks
C     192.168.11.0/24 is directly connected, GigabitEthernet0/1
L     192.168.11.1/32 is directly connected, GigabitEthernet0/1
```

Static IPv6 Routes Example

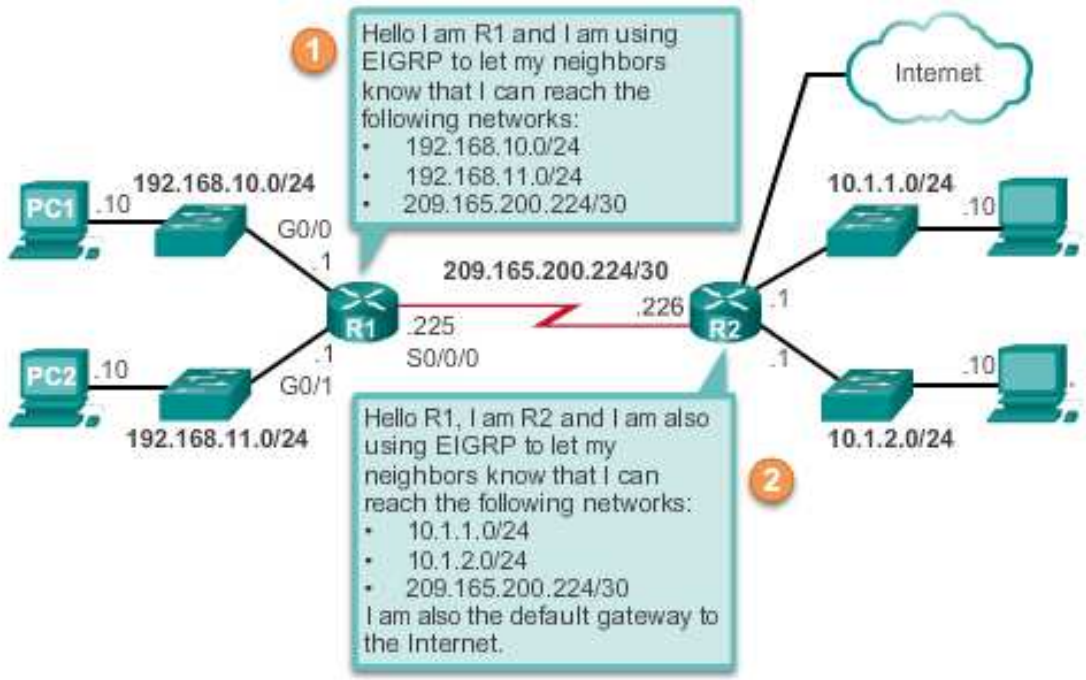



```
R1(config)#ipv6 route ::/0 s0/0/0
R1(config)#exit
R1#
```

```
R1#show ipv6 route
IPv6 Routing Table - default - 8 entries
Codes: C - Connected, L - Local, S - Static,
       U - Per-user Static route
       B - BGP, R - RIP, H - NHRP, I1 - ISIS L1
       I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary,
       D - EIGRP
       EX - EIGRP external, ND - ND Default, NDp - ND Prefix,
       DCE - Destination
       NDr - Redirect, O - OSPF Intra, OI - OSPF Inter,
       OE1 - OSPF ext 1
       OE2 - OSPF ext 2, ON1 - OSPF NSSA ext 1,
       ON2 - OSPF NSSA ext 2
S   ::/0 [1/0]
     via Serial0/0/0, directly connected
C   2001:DB8:ACAD:1::/64 [0/0]
     via GigabitEthernet0/0, directly connected
```

Dynamic Routing

Dynamic routing is used by routers to share information about the reachability and status of remote networks. It performs network discovery and maintains routing tables.

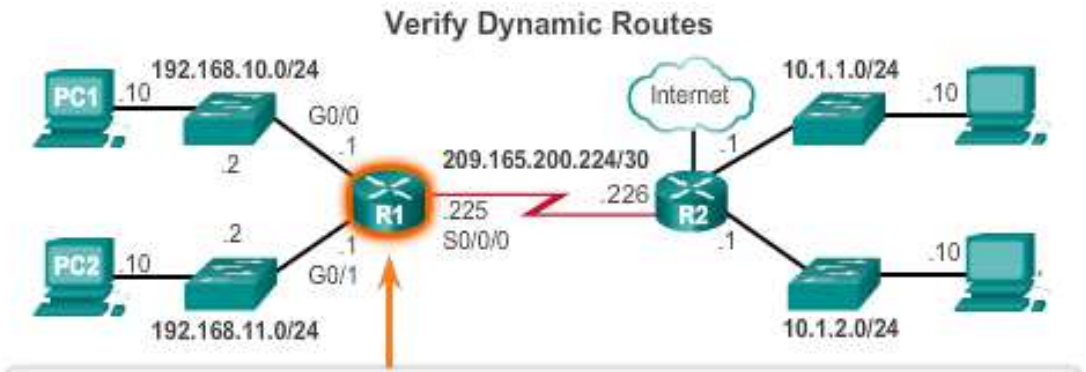


IPv4 Routing Protocols

Cisco ISR routers can support a variety of dynamic IPv4 routing protocols including:

- **EIGRP** – Enhanced Interior Gateway Routing Protocol
- **OSPF** – Open Shortest Path First
- **IS-IS** – Intermediate System-to-Intermediate System
- **RIP** – Routing Information Protocol

IPv4 Routing Protocols



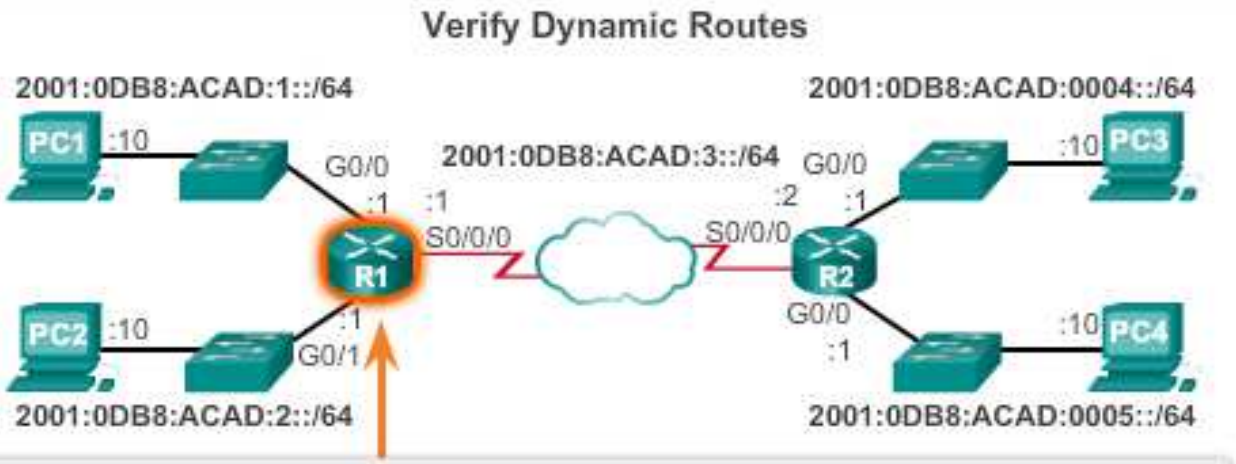

```
R1#show ip route | begin Gateway
Gateway of last resort is 209.165.200.226 to network 0.0.0.0

D*EX  0.0.0.0/0 [170/2297856] via 209.165.200.226, 00:07:29, Serial0/0/0
      10.0.0.0/24 is subnetted, 2 subnets
D        10.1.1.0 [90/2172416] via 209.165.200.226, 00:07:29, Serial0/0/0
D        10.1.2.0 [90/2172416] via 209.165.200.226, 00:07:29, Serial0/0/0
      192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.10.0/24 is directly connected, GigabitEthernet0/0
L        192.168.10.1/32 is directly connected, GigabitEthernet0/0
      192.168.11.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.11.0/24 is directly connected, GigabitEthernet0/1
L        192.168.11.1/32 is directly connected, GigabitEthernet0/1
      209.165.200.0/24 is variably subnetted, 2 subnets, 2 masks
C        209.165.200.224/30 is directly connected, Serial0/0/0
L        209.165.200.225/32 is directly connected, Serial0/0/0
R1#
```

IPv6 Routing Protocols

Cisco ISR routers can support a variety of dynamic IPv6 routing protocols including:

- **RIPng** - RIP next generation
- **OSPFv3**
- **EIGRP** for IPv6
- **MP-BGP4** - Multicast Protocol-Border Gateway Protocol

IPv6 Routing Protocols




```
R1#show ipv6 route
IPv6 Routing Table - default - 9 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, R - RIP, H - NHRP, I1 - ISIS L1
       I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary, D - EIGRP
       EX - EIGRP external, ND - ND Default, NDp - ND Prefix, DCE -
Destination
       NDr - Redirect, O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1
       OE2 - OSPF ext 2, ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
C   2001:DB8:ACAD:1::/64 [0/0]
     via GigabitEthernet0/0, directly connected
L   2001:DB8:ACAD:1::1/128 [0/0]
     via GigabitEthernet0/0, receive
C   2001:DB8:ACAD:2::/64 [0/0]
     via GigabitEthernet0/1, directly connected
L   2001:DB8:ACAD:2::1/128 [0/0]
```

Summary

Summary

In this lecture, you learned that:

- There are many key structures and performance-related characteristics referred to when discussing networks: topology, speed, cost, security, availability, scalability, and reliability.
- Cisco routers and Cisco switches have many similarities. They support a similar modal operating system, similar command structures, and many of the same commands.
- One distinguishing feature between switches and routers is the type of interfaces supported by each.
- The main purpose of a router is to connect multiple networks and forward packets from one network to the next. This means that a router typically has multiple interfaces. Each interface is a member or host on a different IP network.

Summary (cont.)

- The routing table is a list of networks known by the router.
- A remote network is a network that can only be reached by forwarding the packet to another router.
- Remote networks are added to the routing table in two ways: either by the network administrator manually configuring static routes or by implementing a dynamic routing protocol.
- Static routes do not have as much overhead as dynamic routing protocols; however, static routes can require more maintenance if the topology is constantly changing or is unstable.
- Dynamic routing protocols automatically adjust to changes without any intervention from the network administrator. Dynamic routing protocols require more CPU processing and also use a certain amount of link capacity for routing updates and messages.

Summary (cont.)

- Routers make their primary forwarding decision at Layer 3, the Network layer. However, router interfaces participate in Layers 1, 2, and 3. Layer 3 IP packets are encapsulated into a Layer 2 data link frame and encoded into bits at Layer 1.
- Router interfaces participate in Layer 2 processes associated with their encapsulation. For example, an Ethernet interface on a router participates in the ARP process like other hosts on that LAN.
- Components of the IPv6 routing table are very similar to the IPv4 routing table. For instance, it is populated using directly connected interfaces, static routes and dynamically learned routes.