



Chapter 4: Routing Concepts



Routing Protocols

Cisco | Networking Academy®
Mind Wide Open™



Chapter 4

4.0 Routing Concepts

4.1 Initial Configuration of a Router

4.2 Routing Decisions

4.3 Routing Operation

4.4 Summary



Chapter 4: Objectives

- 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.



Chapter 4: Objectives (continued)

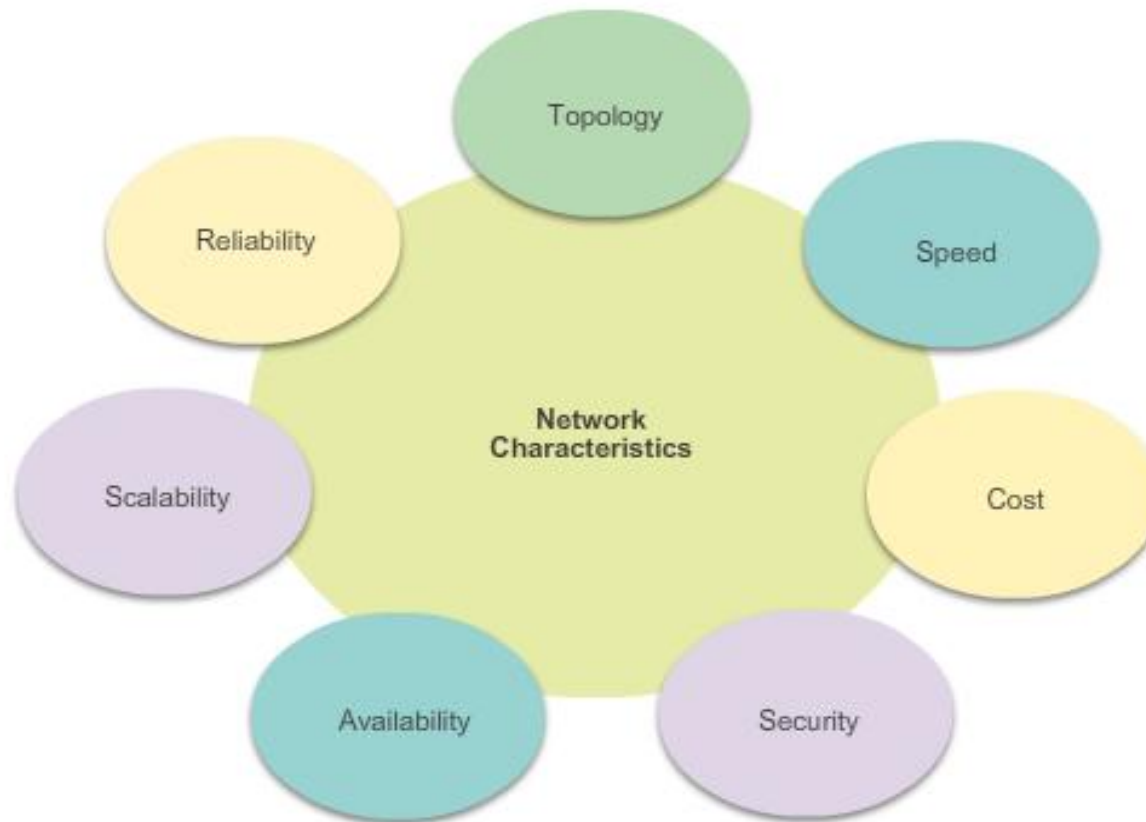
- Explain how a router builds a routing table using static routes.
- Explain how a router builds a routing table using a dynamic routing protocol.



Functions of a Router

Characteristics of a Network

Network Characteristics



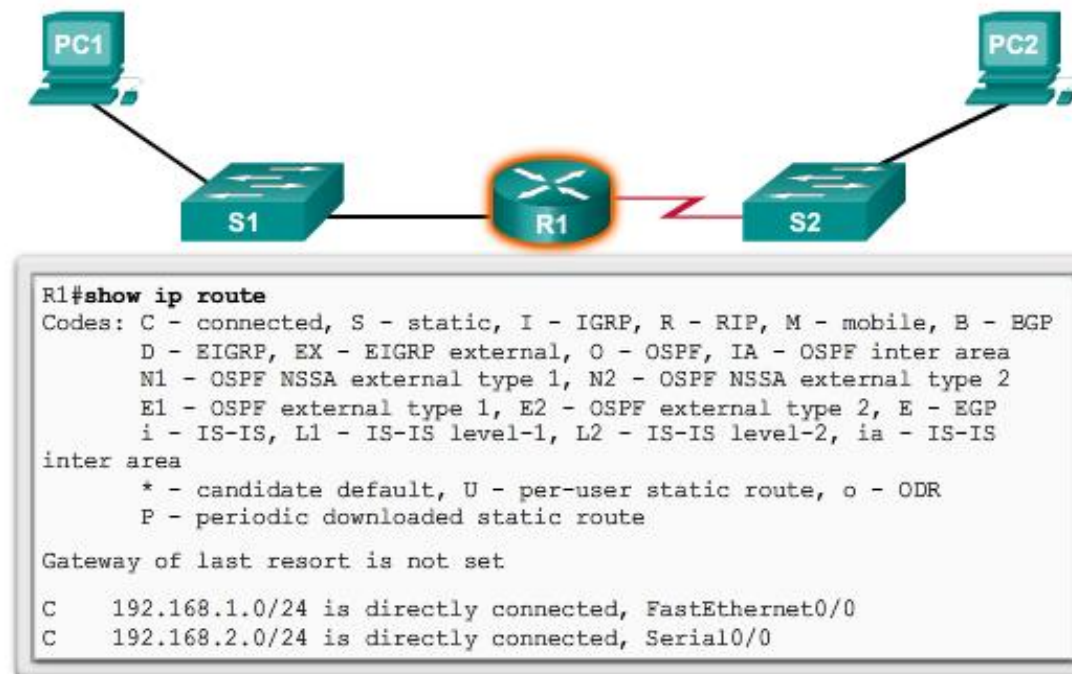


Functions of a Router

Why Routing?

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

Routers Route Packets



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



Functions of a Router

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)
- Routers utilize the following memory:

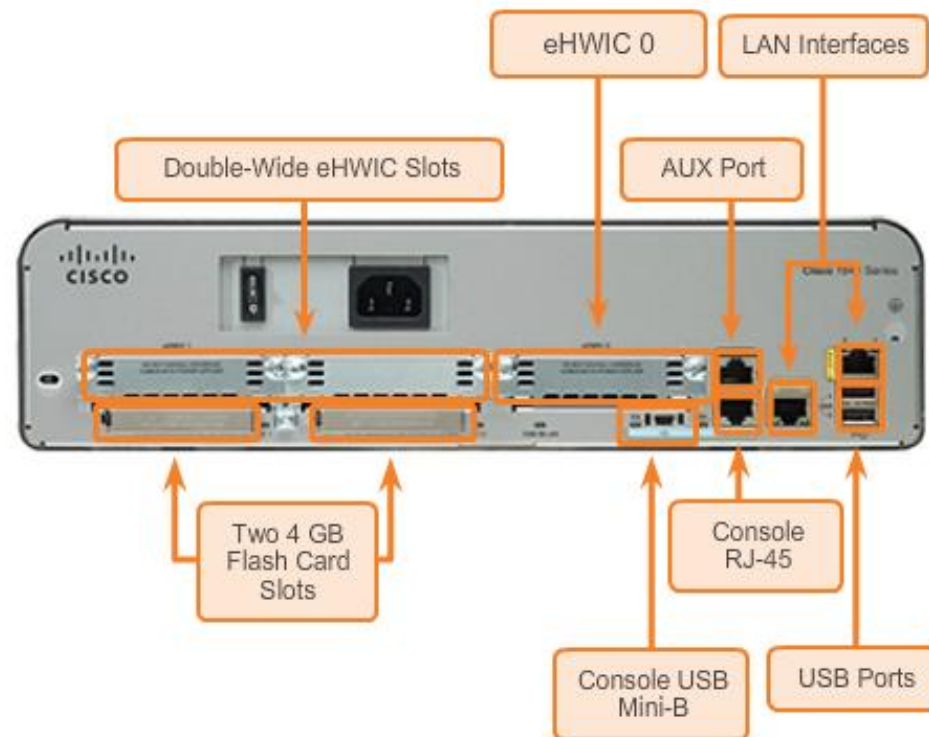
Memory	Volatile / Non-Volatile	Stores
RAM	Volatile	<ul style="list-style-type: none"> Running IOS Running configuration file IP routing and ARP tables Packet buffer
ROM	Non-Volatile	<ul style="list-style-type: none"> Bootup instructions Basic diagnostic software Limited IOS
NVRAM	Non-Volatile	<ul style="list-style-type: none"> Startup configuration file
Flash	Non-Volatile	<ul style="list-style-type: none"> IOS Other system files

Functions of a Router

Routers are Computers

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

Back Panel of a Router

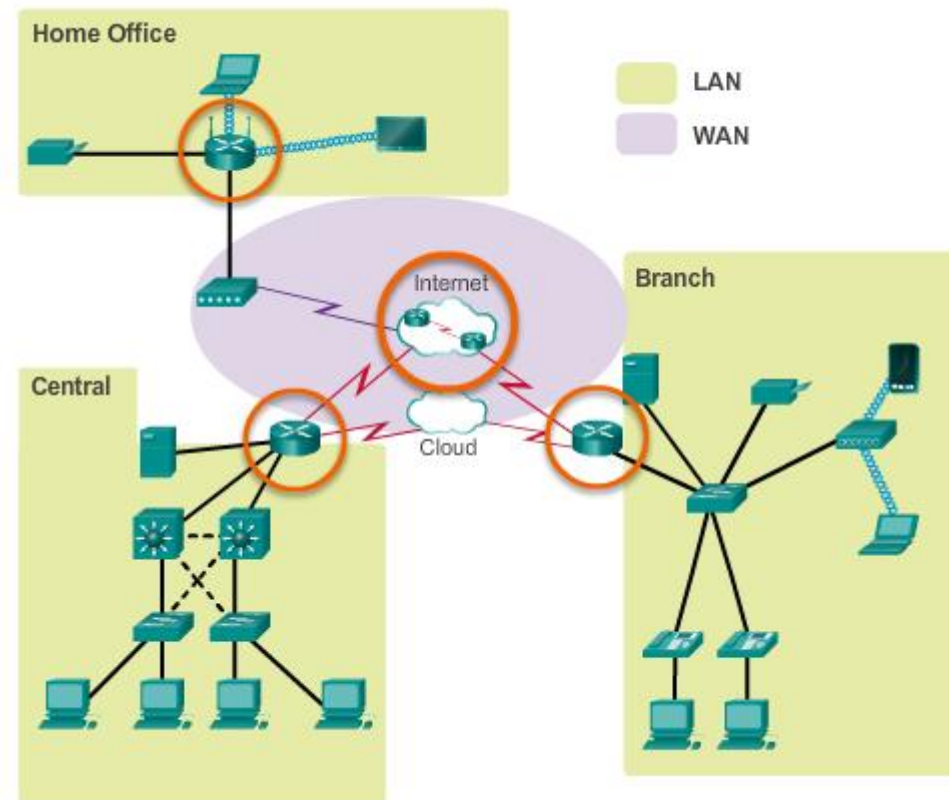




Functions of a Router

Routers Interconnect Networks

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





Functions of a Router

Routers Choose Best Paths

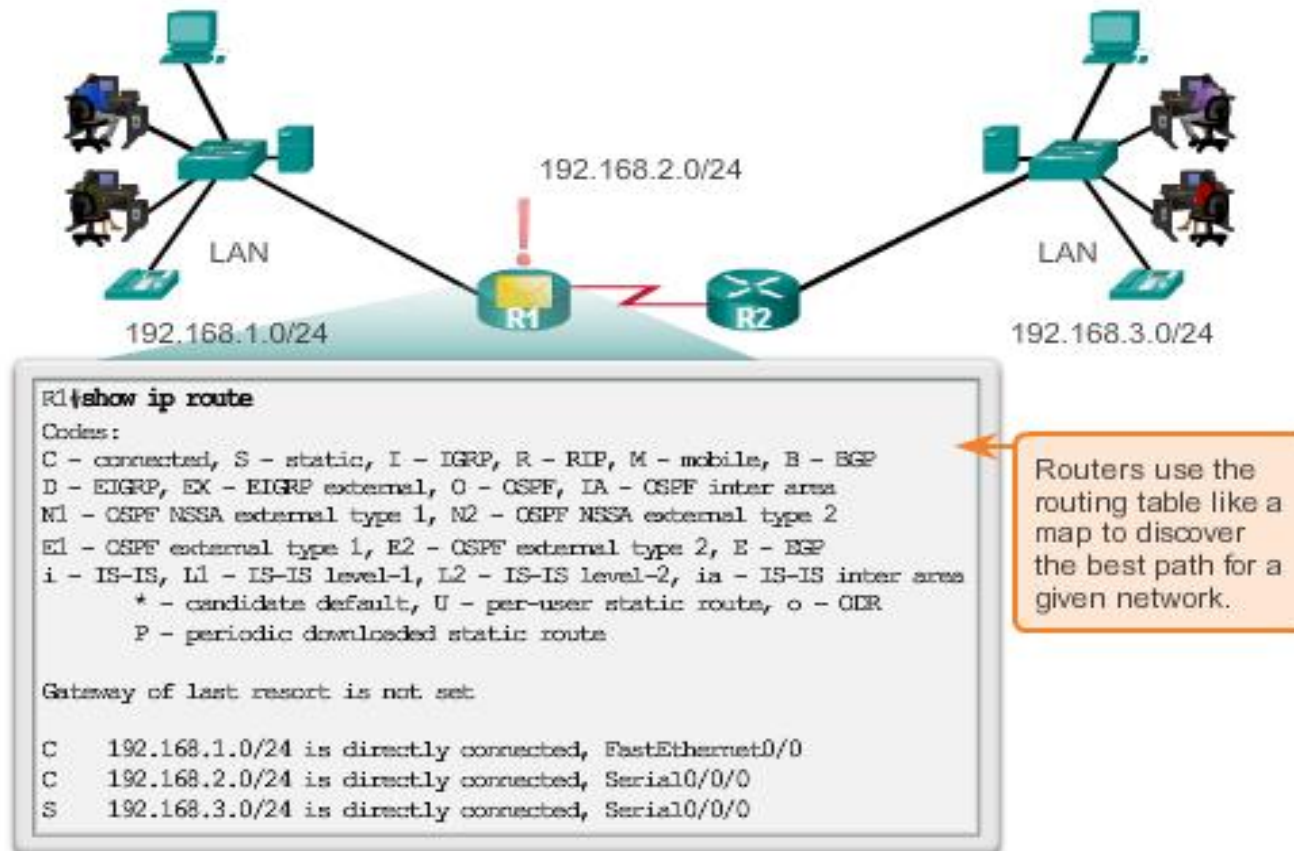
- Determine the best path to send packets
Uses its routing table to determine path
- Forward packets toward their destination
Forwards packet to interface indicated in routing table.
Encapsulates the packet and forwards out toward destination.
- Routers use static routes and dynamic routing protocols to learn about remote networks and build their routing tables.



Functions of a Router

Routers Choose Best Paths

How the Router Works

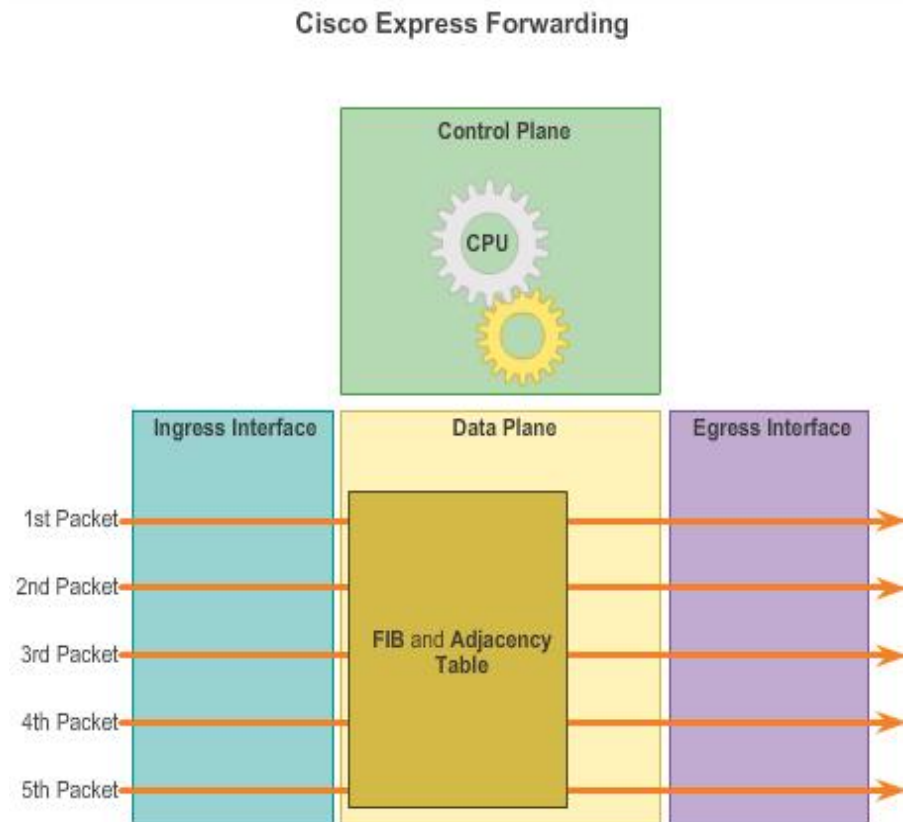




Functions of a Router

Packet Forwarding Methods

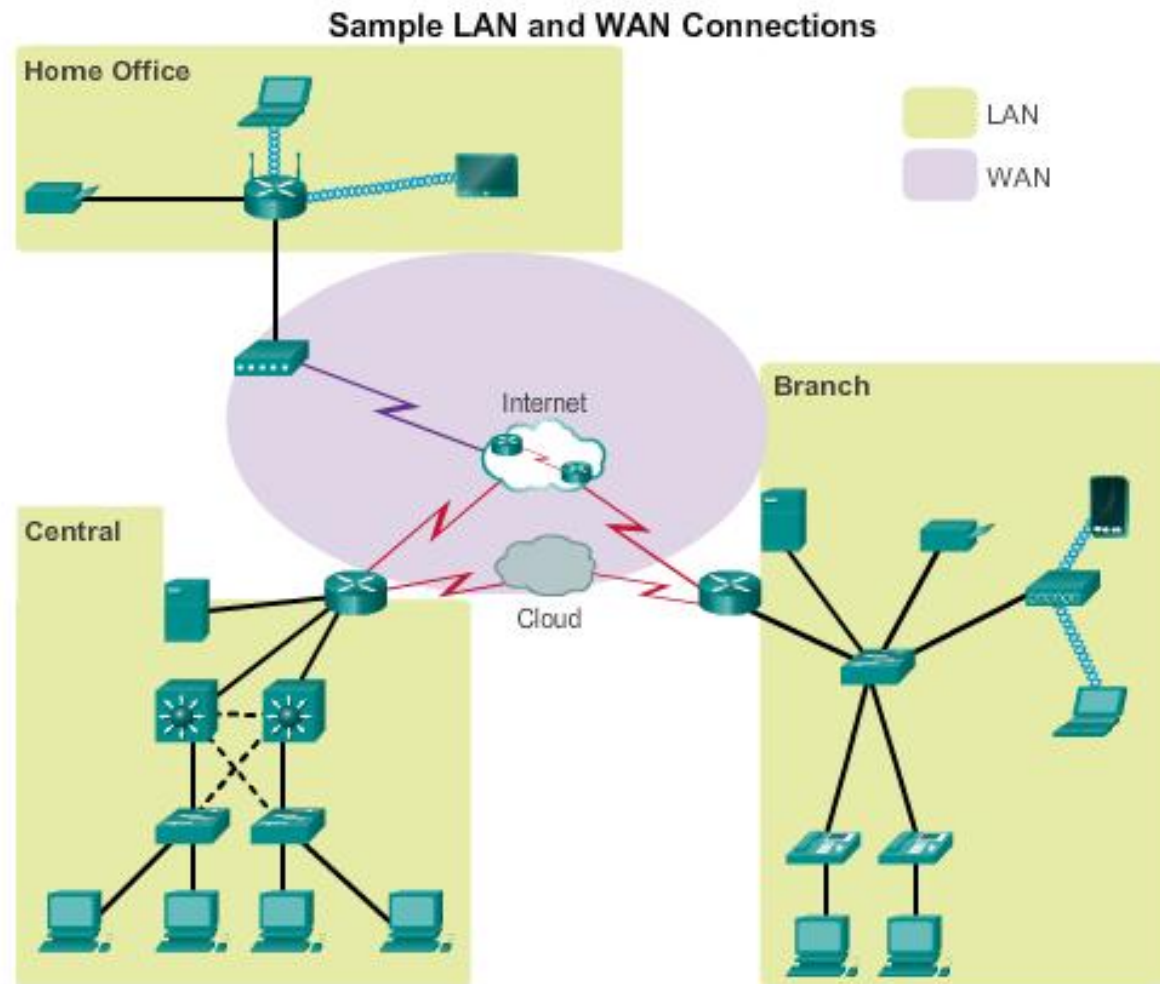
- **Process switching** – An older packet forwarding mechanism still available for Cisco routers.
- **Fast switching** – A common packet forwarding mechanism which uses a fast-switching cache to store next hop information.
- **Cisco Express Forwarding (CEF)** – The most recent, fastest, and preferred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





Connect Devices

Connect to a Network





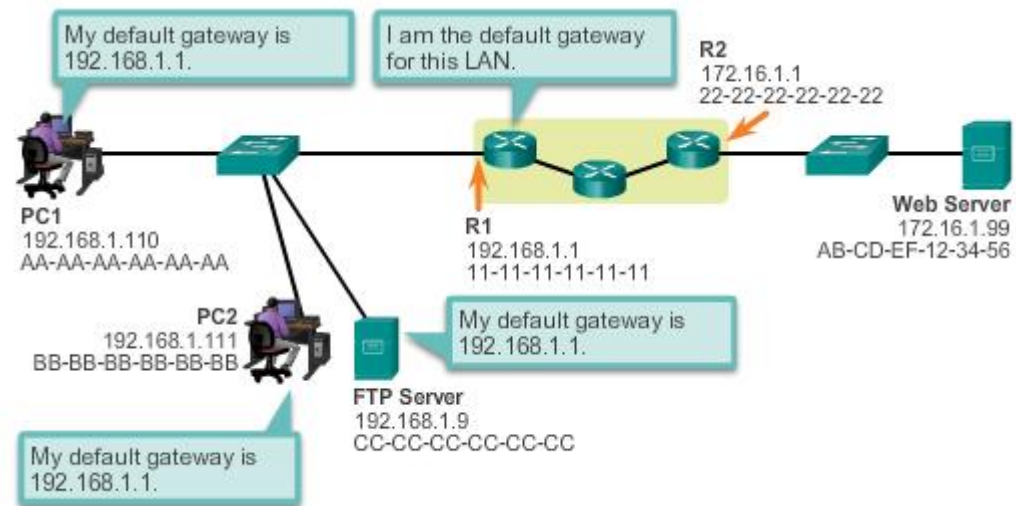
Connect Devices

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 when the destination is not on the same local network subnet.

Destination MAC Address	Source MAC Address	Source IP Address	Destination IP Address	Data
11-11-11-11-11-11	AA-AA-AA-AA-AA-AA	192.168.1.110	172.16.1.99	



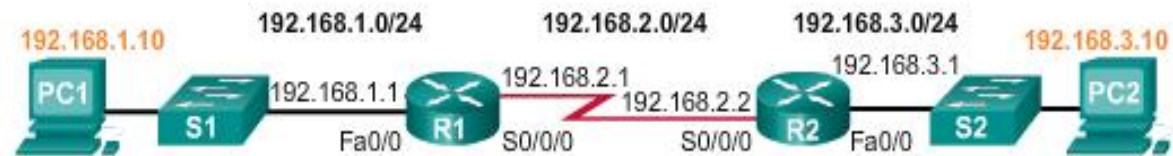


Connect Devices

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



Connect Devices

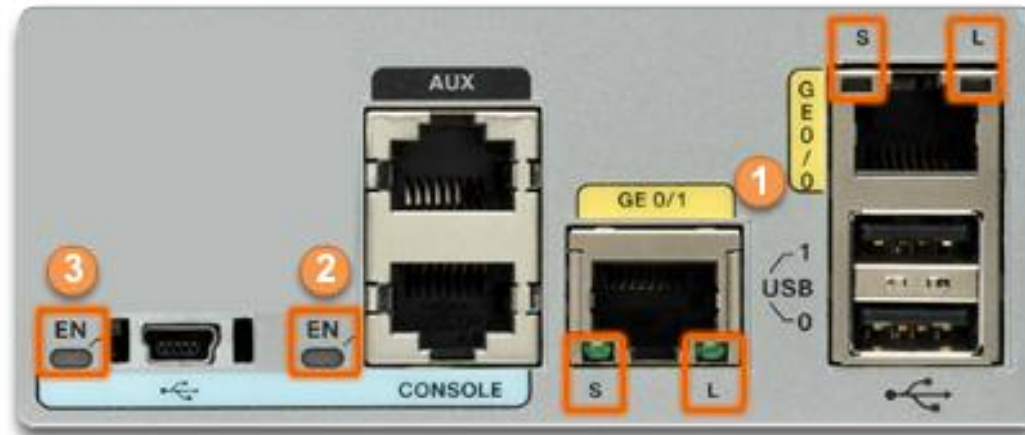
Enable IP on a Host

- **Statically Assigned IP address** – host is manually assigned the IP address, subnet mask and default gateway. 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

Connect Devices

Device LEDs

CISCO 1941 LEDs



#	Port	LED	Color	Description
1	GE0/0 and GE0/1	S (Speed)	1 blink + pause	Port operating at 10 Mb/s
			2 blink + pause	Port operating at 100 Mb/s
			3 blink + pause	Port operating at 1000 Mb/s
		L (Link)	Green	Link is active
			Off	Link is inactive
2	Console	EN	Green	Port is active
			Off	Port is inactive
3	USB	EN	Green	Port is active
			Off	Port is inactive















Connect Devices

Console Access

- **Console access requires:**

Console cable – RJ-45-to-DB-9 console cable

Terminal emulation software – Tera Term, PuTTY, HyperTerminal

Port on Computer	Cable Required	Port on ISR	Terminal Emulation
 Serial Port	 Console Cable	 RJ45 Console Port	 Tera Term
 USB Type-A Port	 USB-to-RS-232 Serial Port Adapter	 RJ45 Console Port	 PuTTY
	 Console Cable	 RJ45 Console Port	
	 USB Type-A to USB Type-B (Mini-B) Cable	 USB Type-B (Mini-B USB) Console Port	

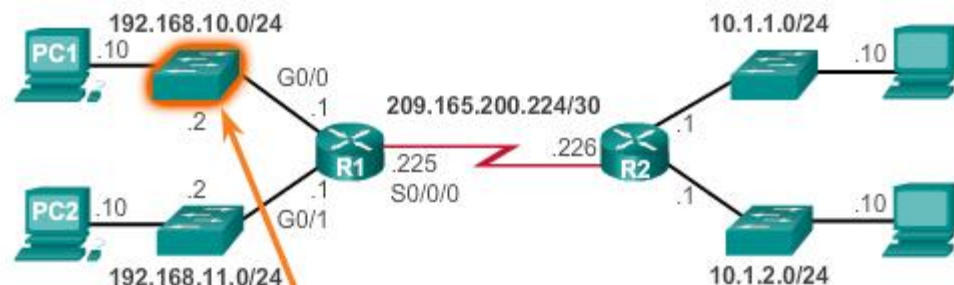


Connect Devices

Enable IP on a Switch

- Network infrastructure devices require IP addresses to enable remote management.
- On a switch the management IP address is assigned on a virtual interface

Configure the Switch Management Interface



```
S1(config)#interface vlan 1
S1(config-if)#ip address 192.168.10.2 255.255.255.0
S1(config-if)#no shutdown
%LINK-5-CHANGED: Interface Vlan1, changed state to up
S1(config-if)#exit
S1(config)#
S1(config)#ip default-gateway 192.168.10.1
S1(config)#
```



Basic Settings on a Router

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.

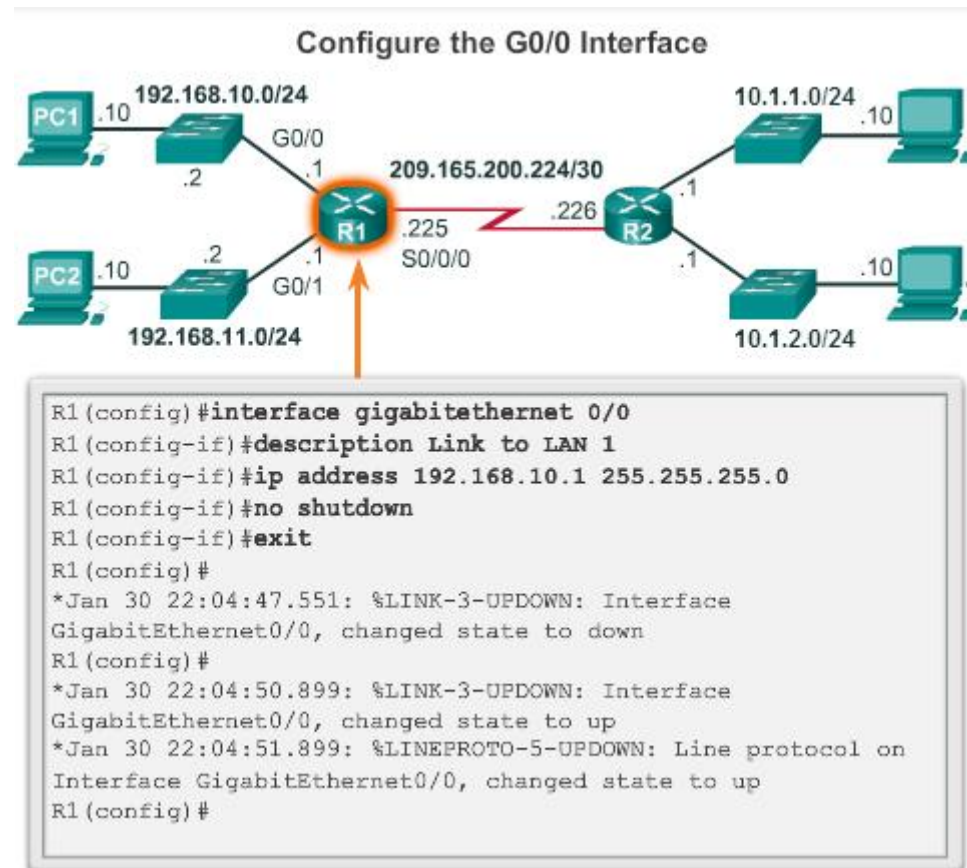


Basic Settings on a Router

Configure Router Interfaces

To be available a router interface must be:

- **Configured with an address and subnet mask .**
- **Activated** – by default LAN and WAN interfaces are not activated. Must be activated using no shutdown command.
- Other parameters - serial cable end labeled DCE must be configured with the **clock rate** command.
- Optional description can be included.





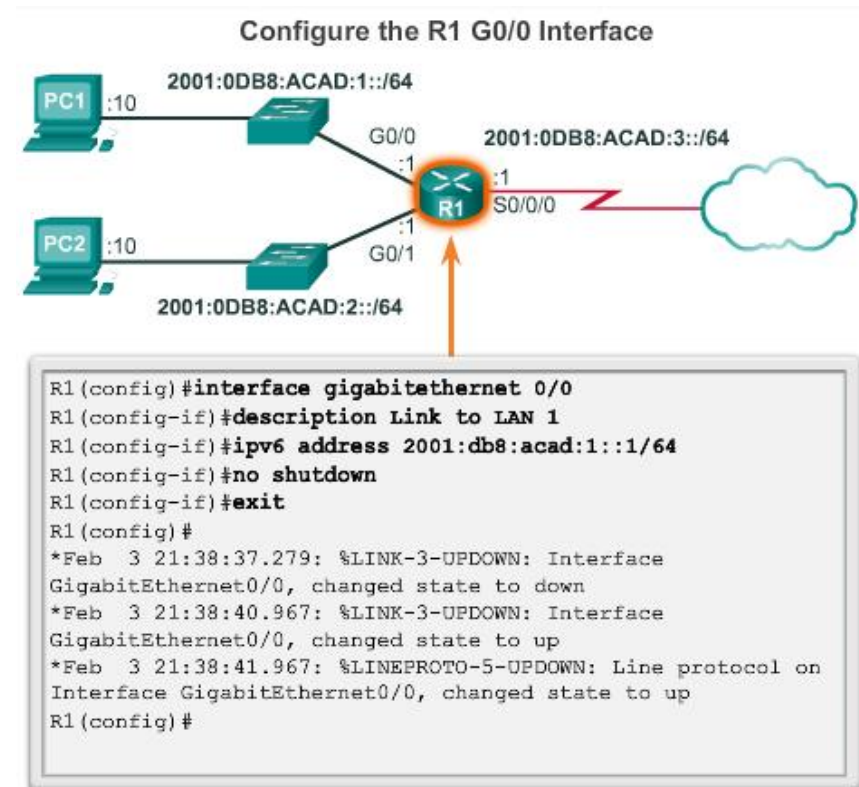
Basic Settings on a Router

Configure an IPv6 Router Interface

- **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 **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*



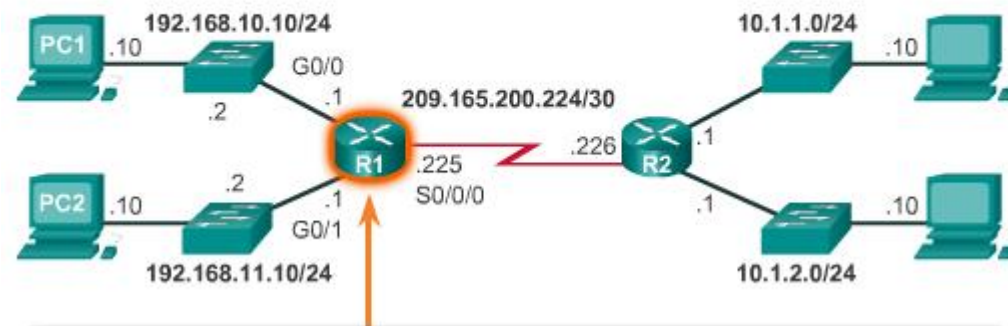


Basic Settings on a Router

Configure a Loopback Interface

- Loopback interface is a logical interface 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.
- Useful for testing and important in the OSPF routing process.

Configure the Loopback0 Interface



```
R2 (config)#interface loopback 0
R2 (config-if)#ip address 10.0.0.1 255.255.255.0
R2 (config-if)#exit
R1 (config)#
*Jan 30 22:04:50.899: %LINK-3-UPDOWN: Interface loopback0,
changed state to up
*Jan 30 22:04:51.899: %LINEPROTO-5-UPDOWN: Line protocol on
Interface loopback0, changed state to up
```



Verify Connectivity of Directly Connected Networks

Verify Interface Settings

Show commands to verify operation and configuration of interface.

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

Show commands to gather more detailed interface information.

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

Verify the Routing Table



```

R1#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - m
<output omitted.
Gateway of last resort is not set

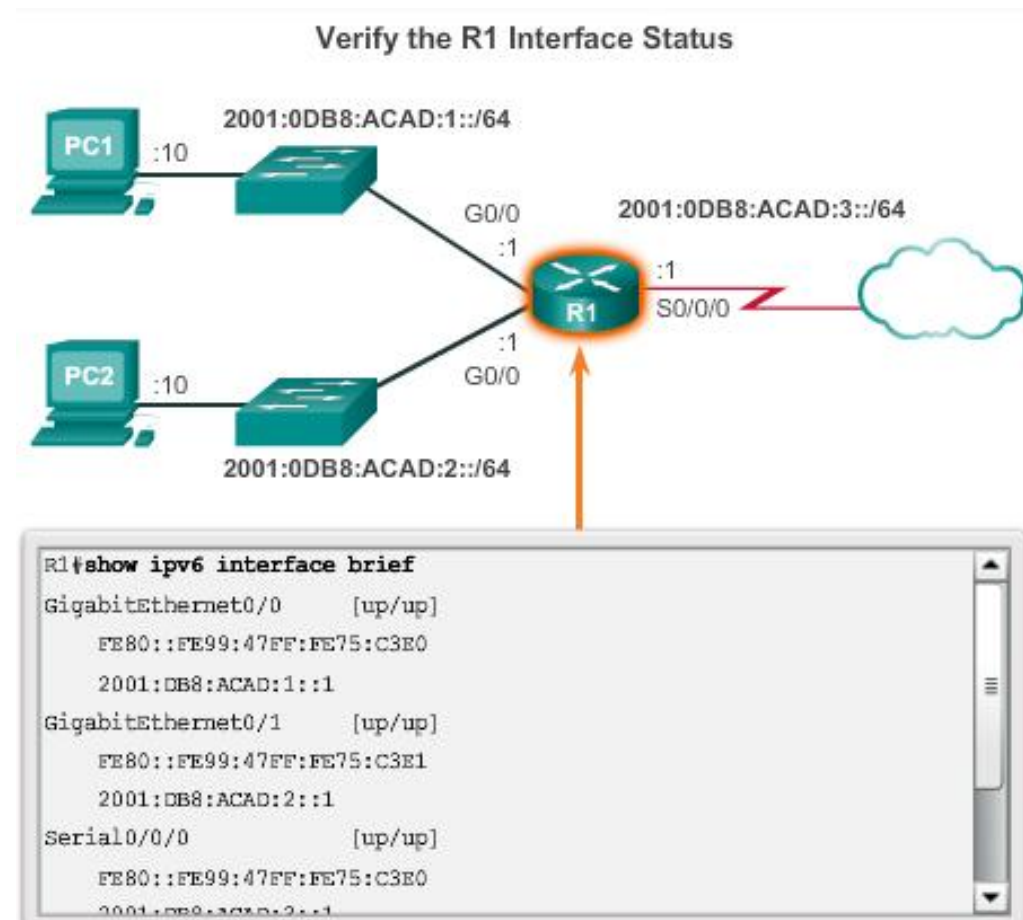
    192.168.10.0/24 is variably subnetted, 2 subnets, 2 ma
C       192.168.10.0/24 is directly connected, GigabitEther
L       192.168.10.1/32 is directly connected, GigabitEther
    192.168.11.0/24 is variably subnetted, 2 subnets, 2 ma
C       192.168.11.0/24 is directly connected, GigabitEther
L       192.168.11.1/32 is directly connected, GigabitEther
    209.165.200.0/24 is variably subnetted, 2 subnets, 2 m
  
```




Verify Connectivity of Directly Connected Networks

Verify Interface Settings

- **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** - verify that IPv6 networks and specific IPv6 interface addresses have been installed in the IPv6 routing table.
- **show interface**
- **show ipv6 routers**





Verify Connectivity of Directly Connected Networks

Filter Show Command Output

- Use the **terminal lengthnumber** 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#
```



Verify Connectivity of Directly Connected Networks

Command History Feature

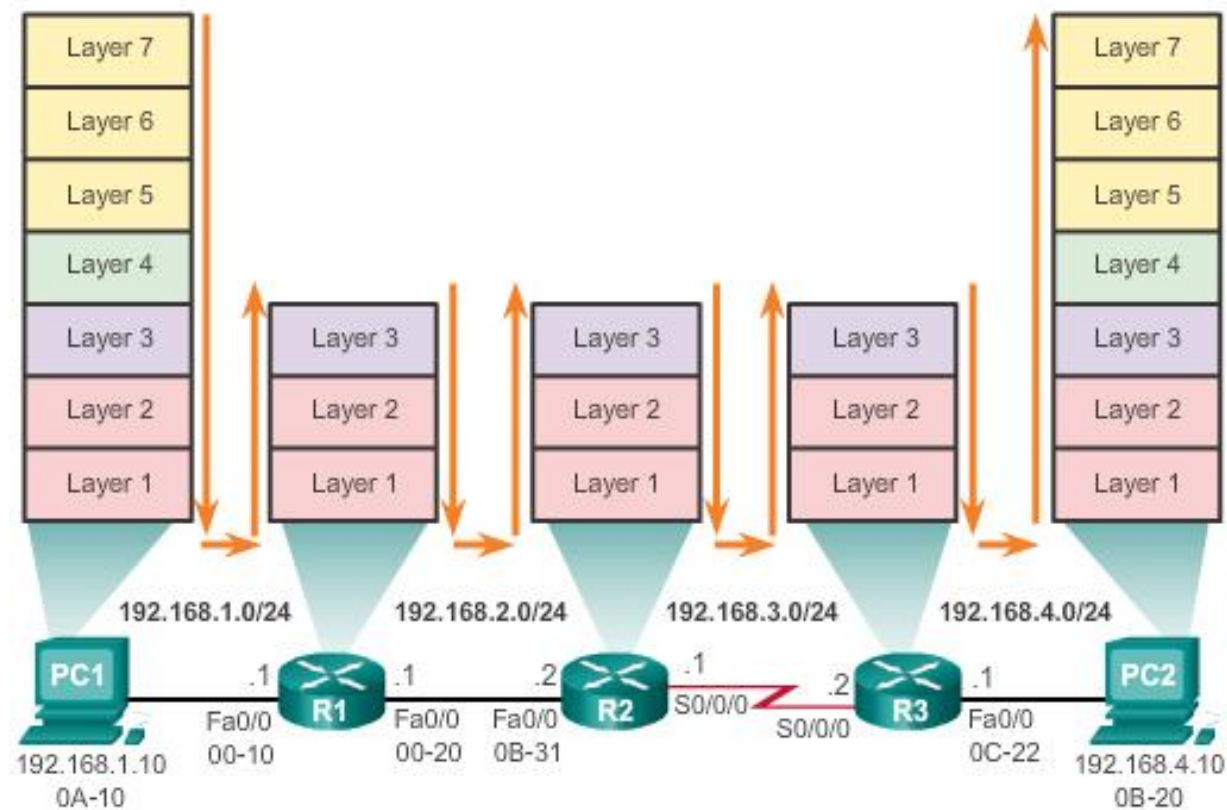
- Recall commands – **Ctrl+P** or the **UP Arrow**
- To return to more recent commands – **Ctrl+N** or **Down Arrow**
- Command history is enabled and captures the last 10 commands in buffer – **show history** displays contents
- Use **terminal history size** to increase or decrease size of the buffer.



Switching Packets between Networks

Router Switching Functions

Encapsulating and De-Encapsulating Packets

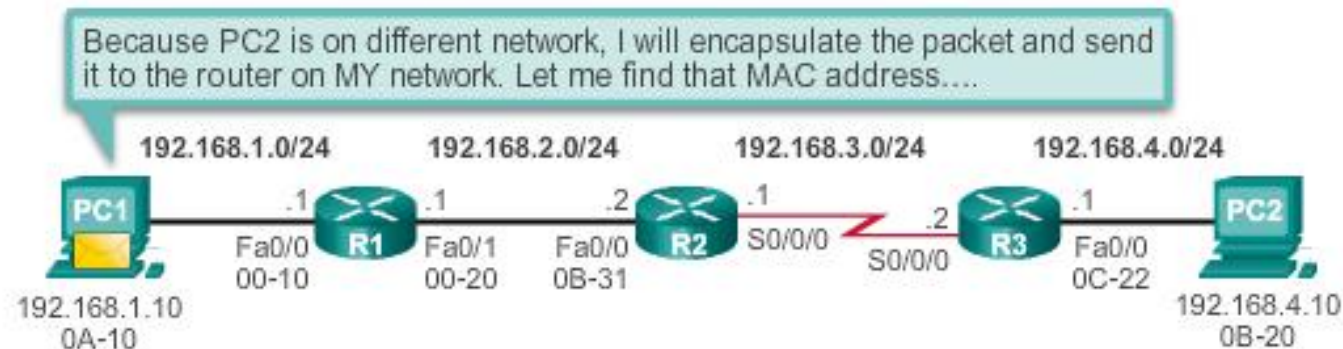




Switching Packets between Networks

Send a Packet

PC1 Sends a Packet to PC2



Layer 2 Data Link Frame

Dest. MAC	Source MAC	Type	Source IP	Dest. IP	IP fields	Data	Trailer
00-10	0A-10	800	192.168.1.10	192.168.4.10			

Packet's Layer 3 data

PC1's ARP Cache for R1

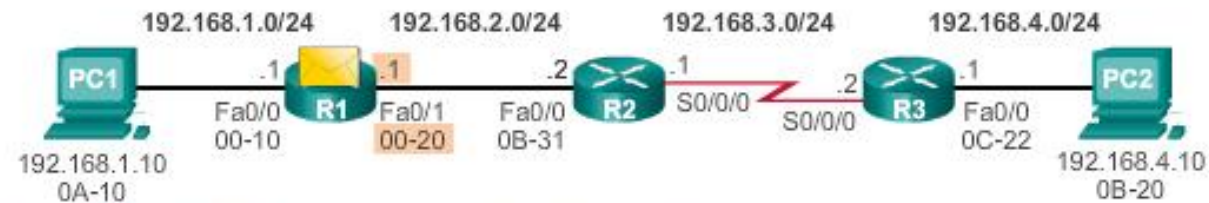
IP Address	MAC Address
192.168.1.1	00-10



Switching Packets between Networks

Forward to the Next Hop

R3 Forwards the Packet to PC2



Layer 2 Data Link Frame

Packet's Layer 3 data

Dest. MAC 0B-31	Source MAC 00-20	Type 800	Source IP 192.168.1.10	Dest. IP 192.168.4.10	IP fields	Data	Trailer
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R1's Routing Table

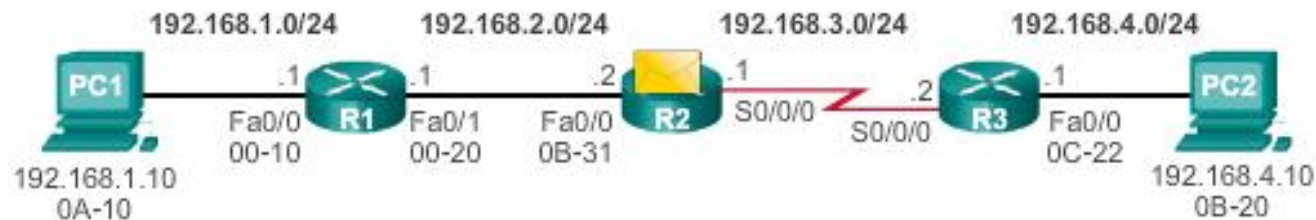
Network	Hops	Next-hop-IP	Exit Interface
192.168.1.0/24	0	Dir. Connect.	Fa0/0
192.168.2.0/24	0	Dir. Connect.	Fa0/1
192.168.3.0/24	1	192.168.2.2	Fa0/1
192.168.4.0/24	2	192.168.2.2	Fa0/1



Switching Packets between Networks

Packet Routing

R2 Forwards the Packet to R3



Layer 2 Data Link Frame

Packet's Layer 3 data

Address	Control	Type	Source IP	Dest. IP	IP fields	Data	Trailer
0x8F	0x00	800	192.168.1.10	192.168.4.10			

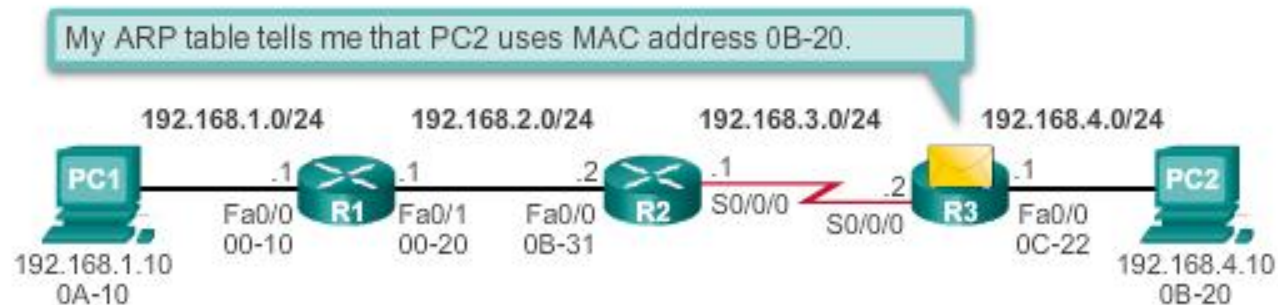
R2's Routing Table

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

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

Packet's Layer 3 data

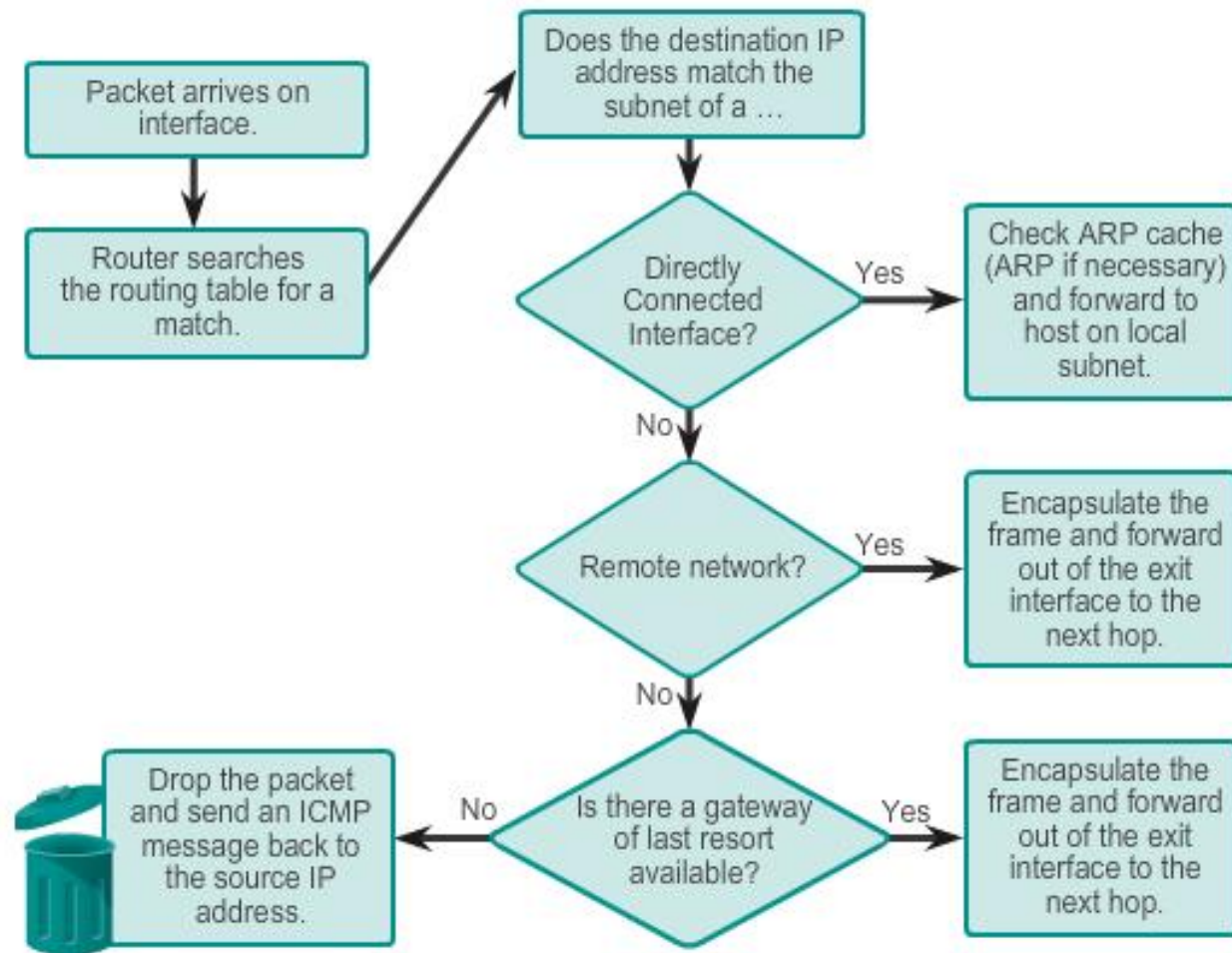
R3's ARP Cache	
IP Address	MAC Address
192.168.4.10	0B-20

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

Packet Forwarding Decision Process





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 for example:

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



Path Determination

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.



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 best Administrative Distance (AD).
- Administrative Distance is the “trustworthiness”
- The Lower the AD the more trustworthy the route.

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



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 best (lowest) Administrative Distance (AD).
- Administrative Distance is the “trustworthiness” of the route
- The Lower the AD the more trustworthy the route.

Default Administrative Distances

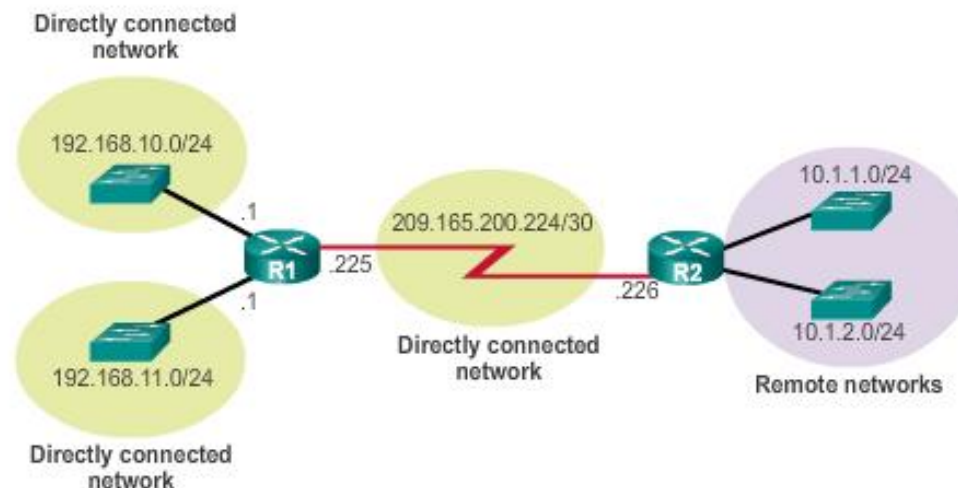
Route Source	Administrative Distance
Connected	0
Static	1
EIGRP summary route	5
External BGP	20
Internal EIGRP	90
IGRP	100
OSPF	110
IS-IS	115
External EIGRP	170
Internal BGP	200



The Routing Table

The Routing Table

- Routing Table is a file stored in RAM that contains information about
 - Directly Connected Routes
 - Remote Routes
 - Network or Next hop Associations





The Routing Table

Routing Table Sources

- Show ip route command is used to display the contents of the routing table
- **Link local 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 EIGRP or OSPF are implemented and networks are identified.



The Routing Table

Routing Table Sources

Routing Table of R1



```
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

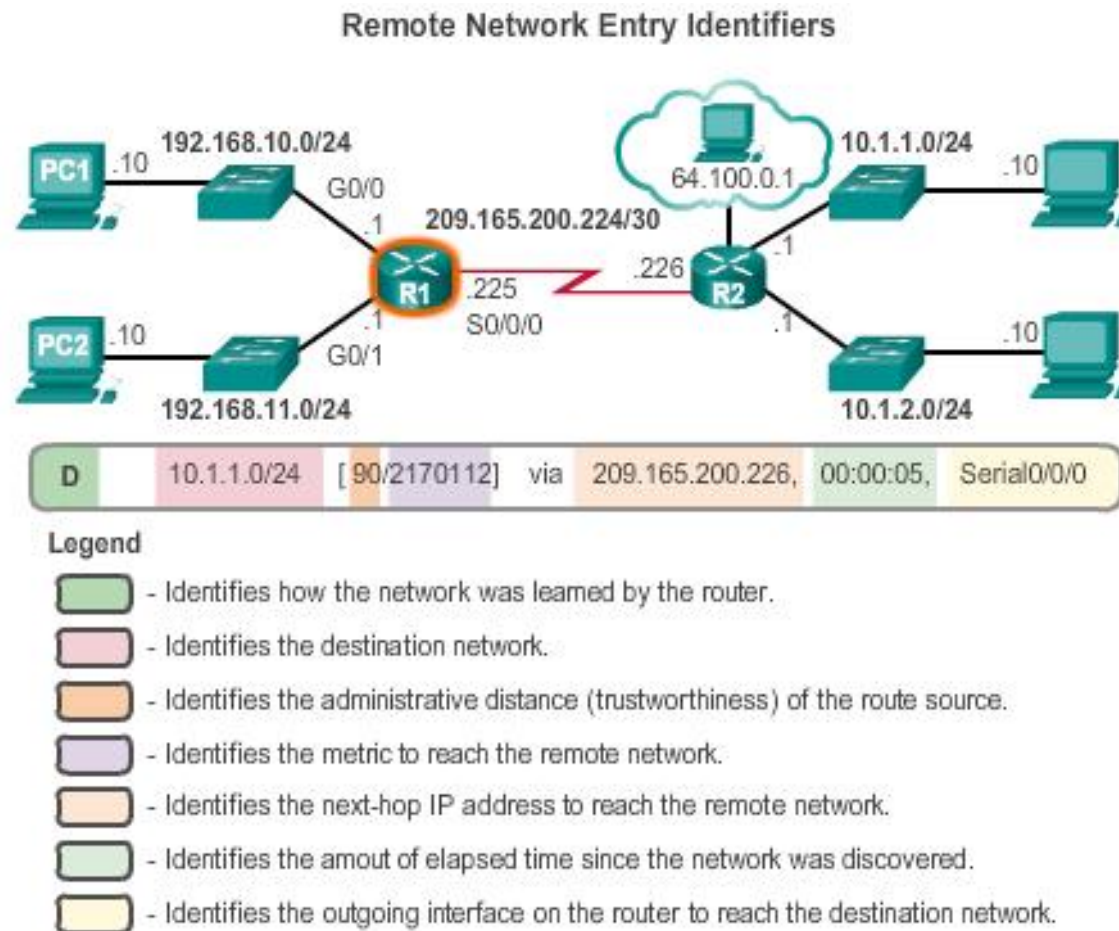
D 10.1.1.0/24 [90/2170112] via 209.165.200.226, 00:00:05,



The Routing Table

Remote Network Routing Entries

- Interpreting the entries in the routing table.



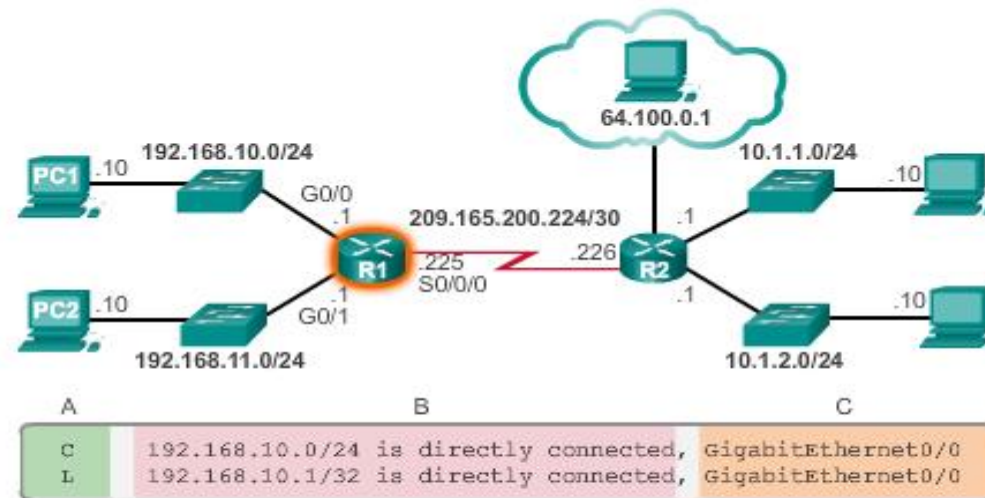


Directly Connected Routes

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) and Directly Connected (C)

Directly Connected Network Entry Identifiers



Legend

- Identifies how the network was learned by the router.
- Identifies the destination network and how it is connected.
- Identifies the interface on the router connected to the destination network.

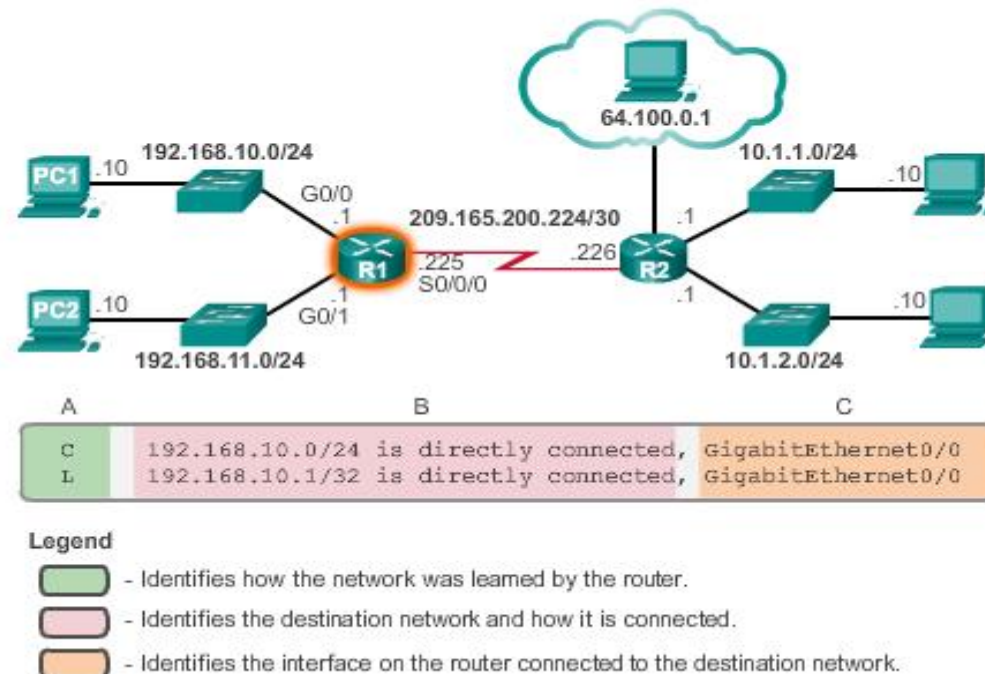


Directly Connected Routes

Directly Connected Interfaces

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Directly Connected Network Entry Identifiers

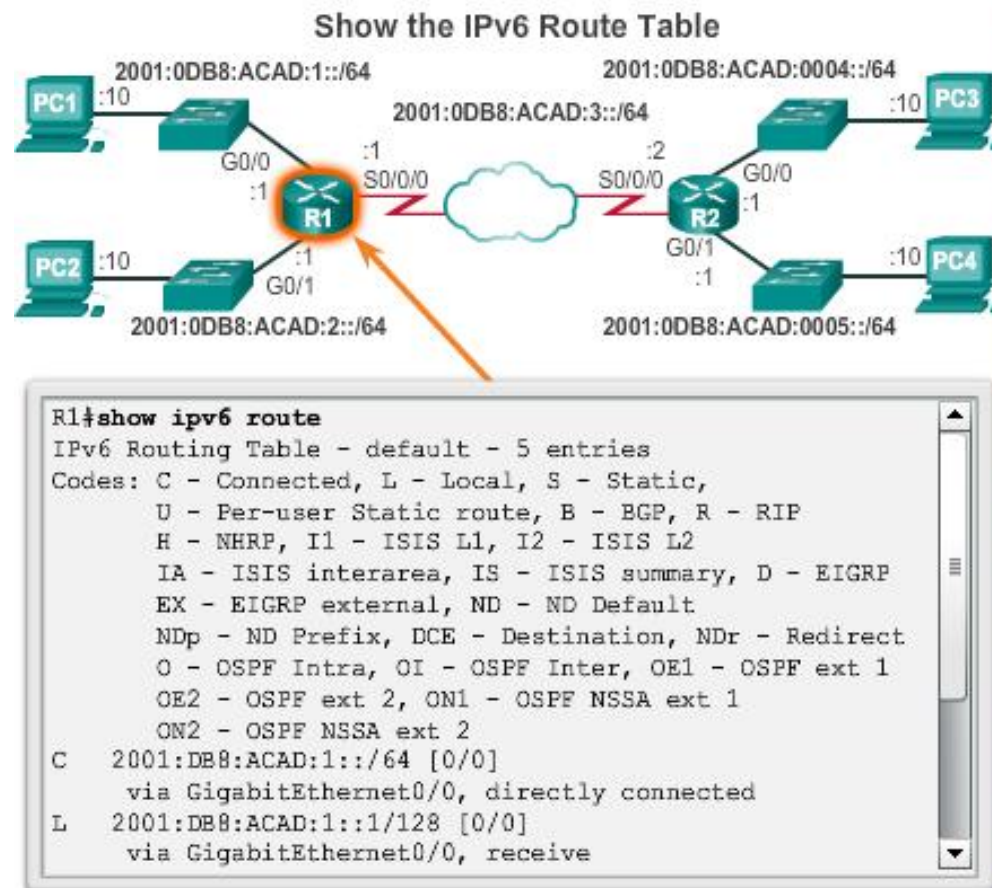




Directly Connected Routes

Directly Connected IPv6 Example

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





Statically Learned Routes

Static Routes

- Manually configured
- Define an explicit path between two networking devices.
- Must be manually updated if the topology changes.
- Benefits include improved security and control of resources.
- Static route to a specific network.
`ip route networkmask {next-hop-ip | exit-intf}`
- Default Static Route used when the routing table does not contain a path for a destination network.
`ip route 0.0.0.0 0.0.0.0 {exit-intf | next-hop-ip}`

Statically Learned Routes

Static Routes Example

Entering and Verifying a Static Default Route



```
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

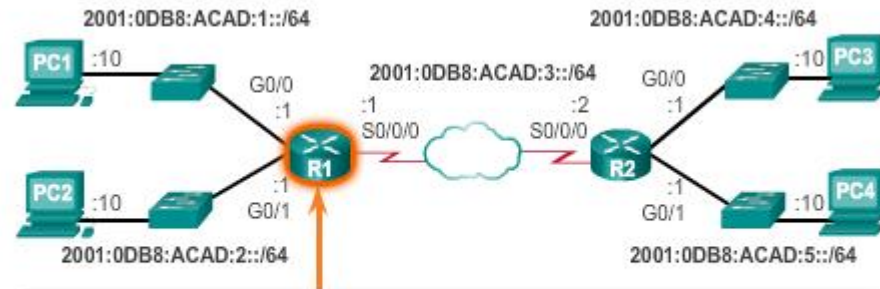
S* 0.0.0.0/0 is directly connected, Serial0/0/0
  192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C   192.168.10.0/24 is directly connected, GigabitEthernet0/0
L   192.168.10.1/32 is directly connected, GigabitEthernet0/0
  192.168.11.0/24 is variably subnetted, 2 subnets, 2 masks
C   192.168.11.0/24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




Statically Learned Routes

Static IPv6 Routes Example

Entering and Verifying an IPv6 Static Default Route



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

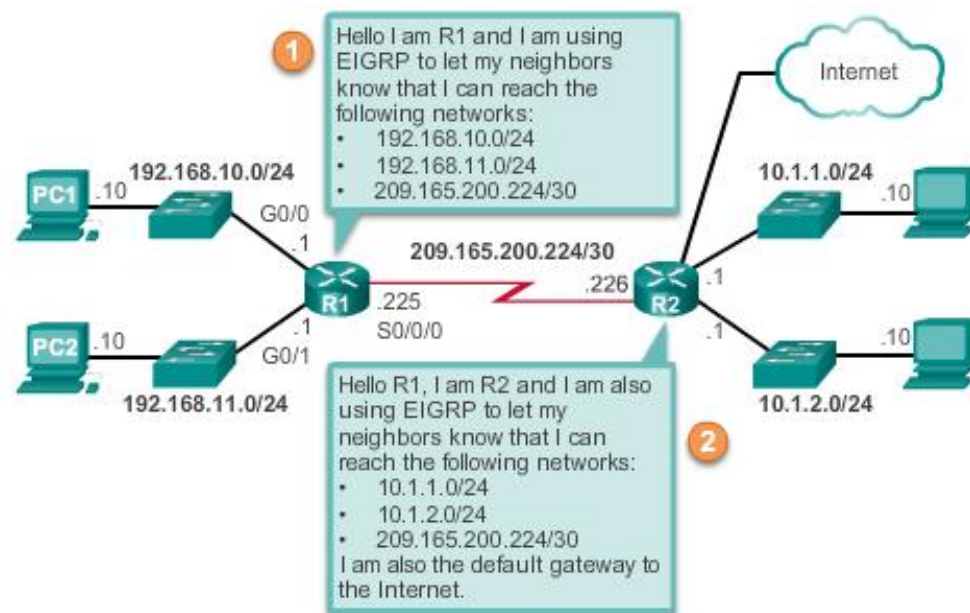
```
R1#show ipv6 route
IPv6 Routing Table - default - 8 entries
Codes: C - Connected, L - Local, S - Static,
       U - Per-user Static route
       B - BGP, R - RIP, H - NHRP, I1 - ISIS L1
       I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary,
       D - EIGRP
       EX - EIGRP external, ND - 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 Protocols

Dynamic Routing

- Used by routers to share information about the reachability and status of remote networks.
- Performs network discovery and maintaining routing tables.





Dynamic Routing Protocols

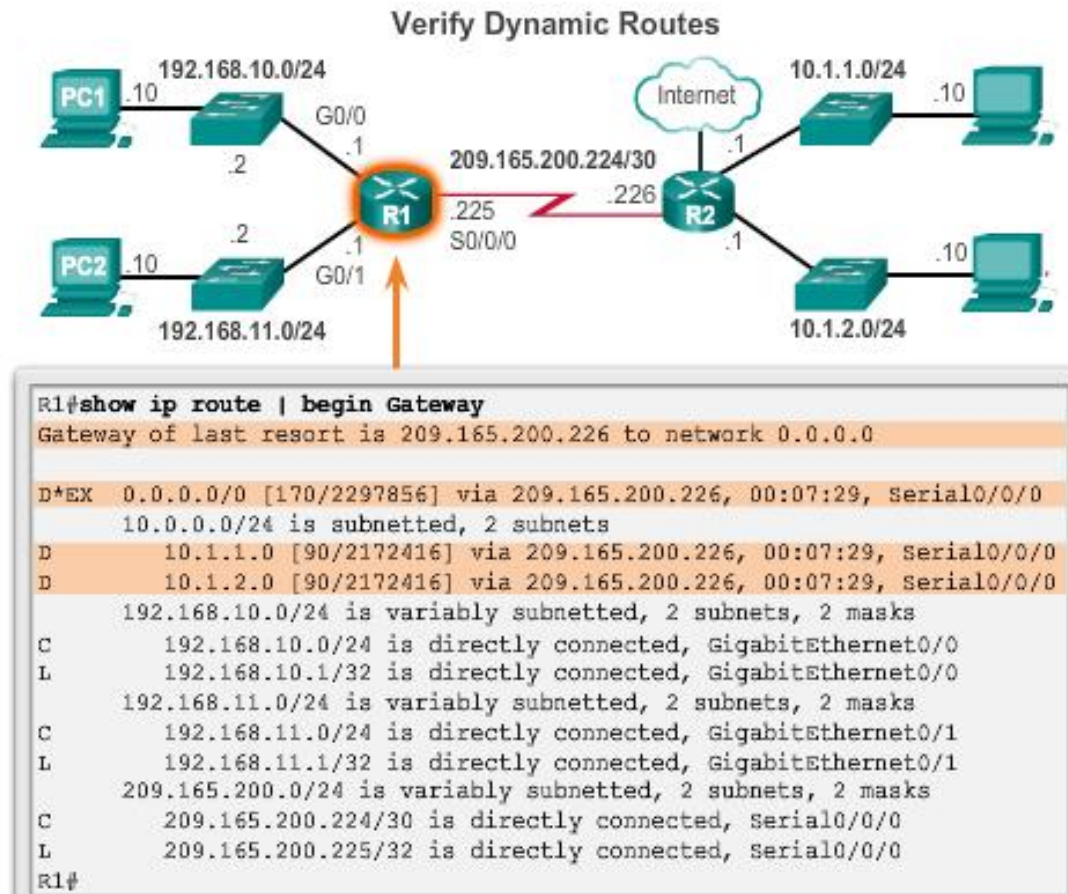
IPv4 Routing Protocols

- 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



Dynamic Routing Protocols

IPv4 Routing Protocols





Dynamic Routing Protocols

IPv6 Routing Protocols

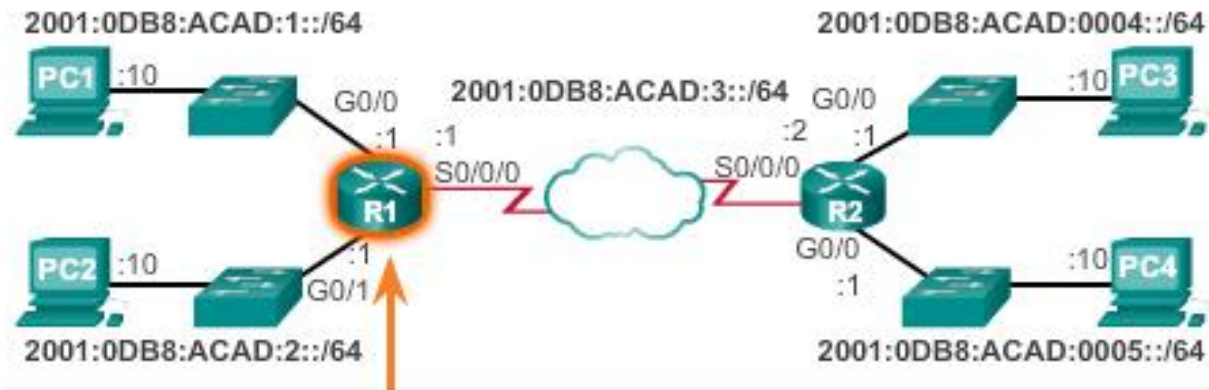
- Cisco ISR routers can support a variety of dynamic IPv6 routing protocols including:
- RIPng (RIP next generation)
- **OSPF v3**
- EIGRP for IPv6
- MP-BGP4 (Multicast Protocol-Border Gateway Protocol)



Dynamic Routing Protocols

IPv6 Routing Protocols

Verify Dynamic Routes



```
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]
```




Chapter 4: Summary

