Instructor Materials
Chapter 1: Routing Concepts

CCNA Routing and Switching

Routing and Switching Essentials v6.0

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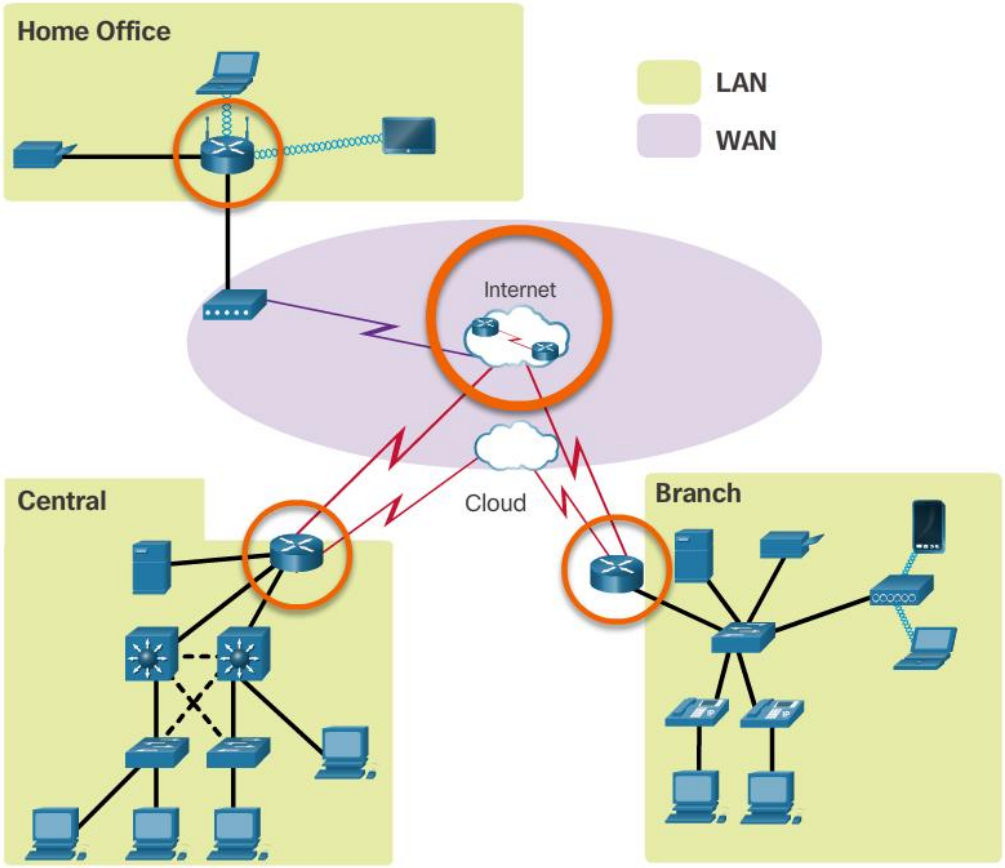
Why Routing?

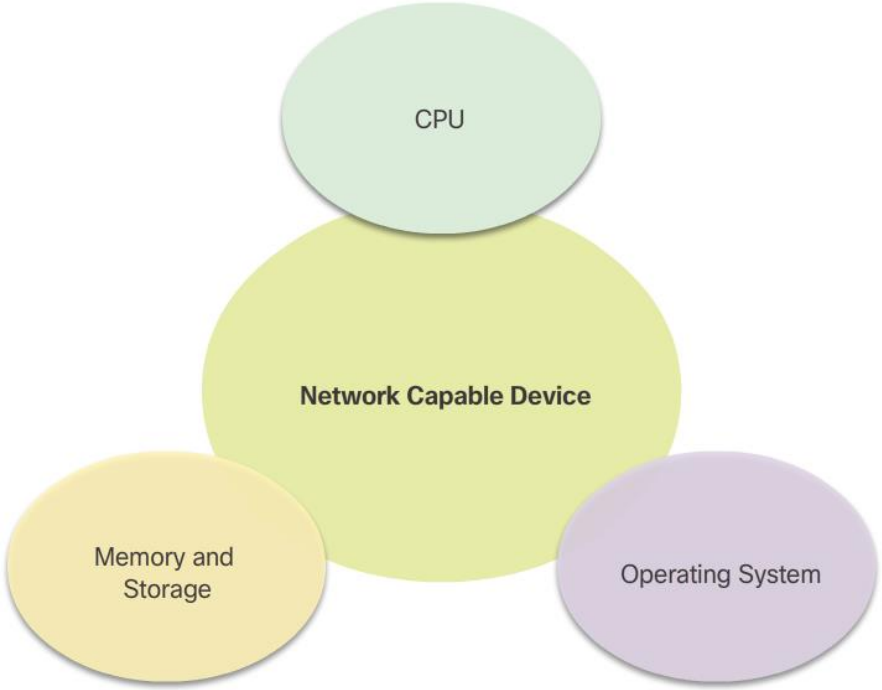
The router is responsible for the routing of traffic between networks.



Routers are Computers

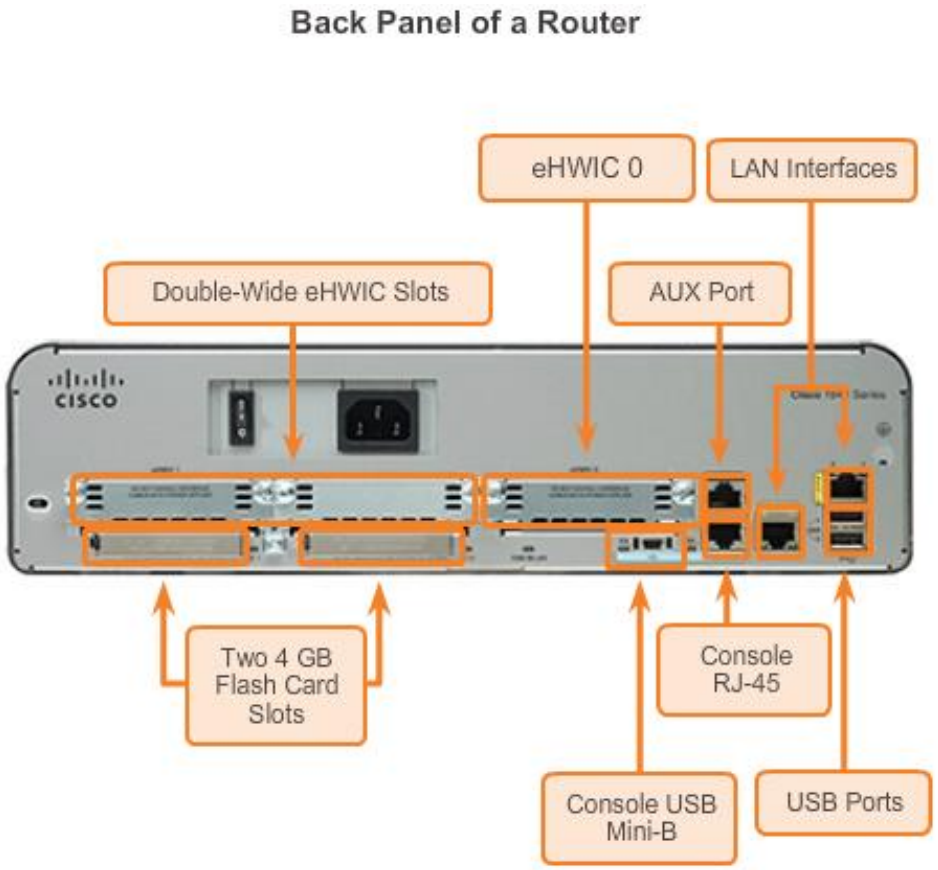
Routers are specialized computers containing the following required components to operate:

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



Routers are Computers (cont.)

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

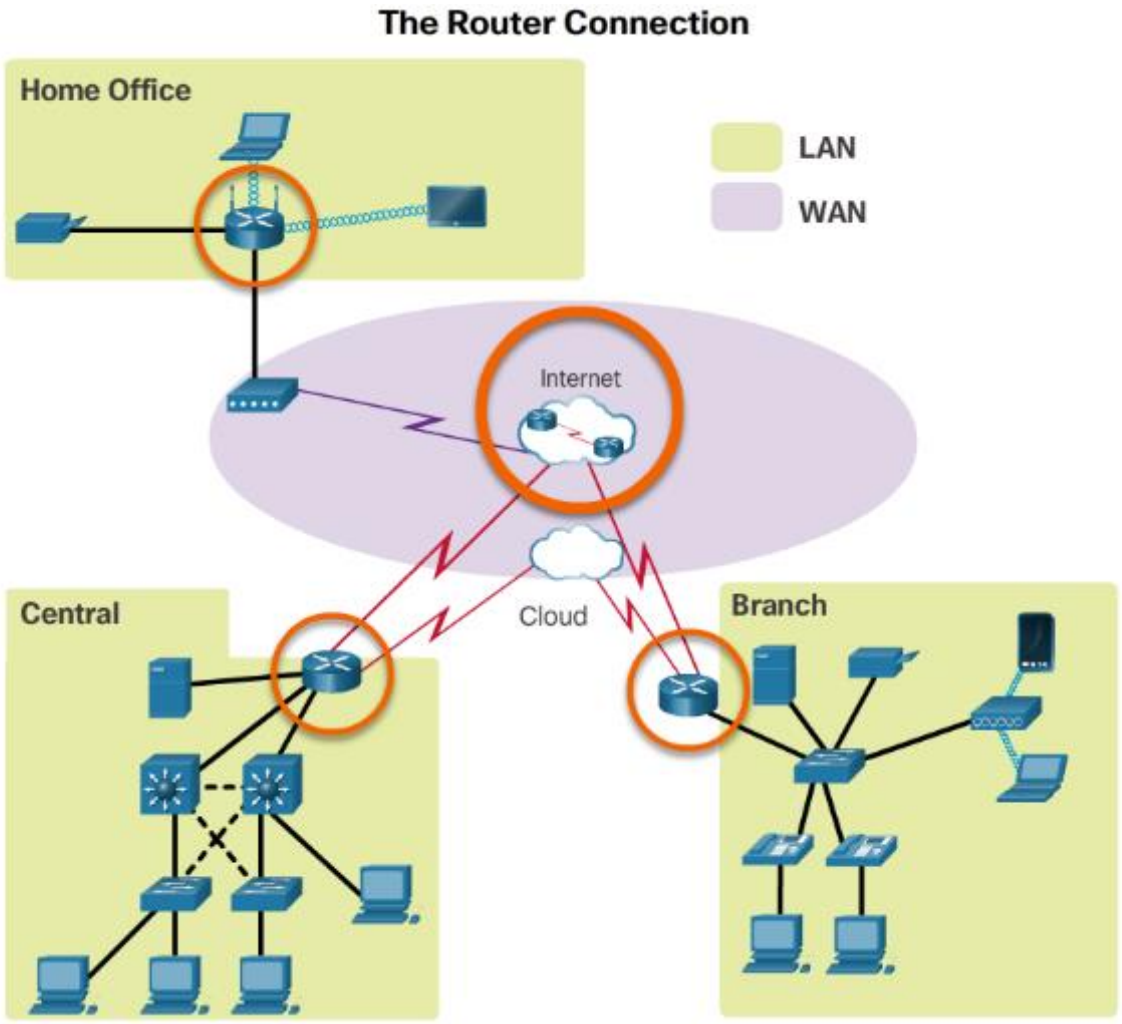


Routers are Computers

Router Memory

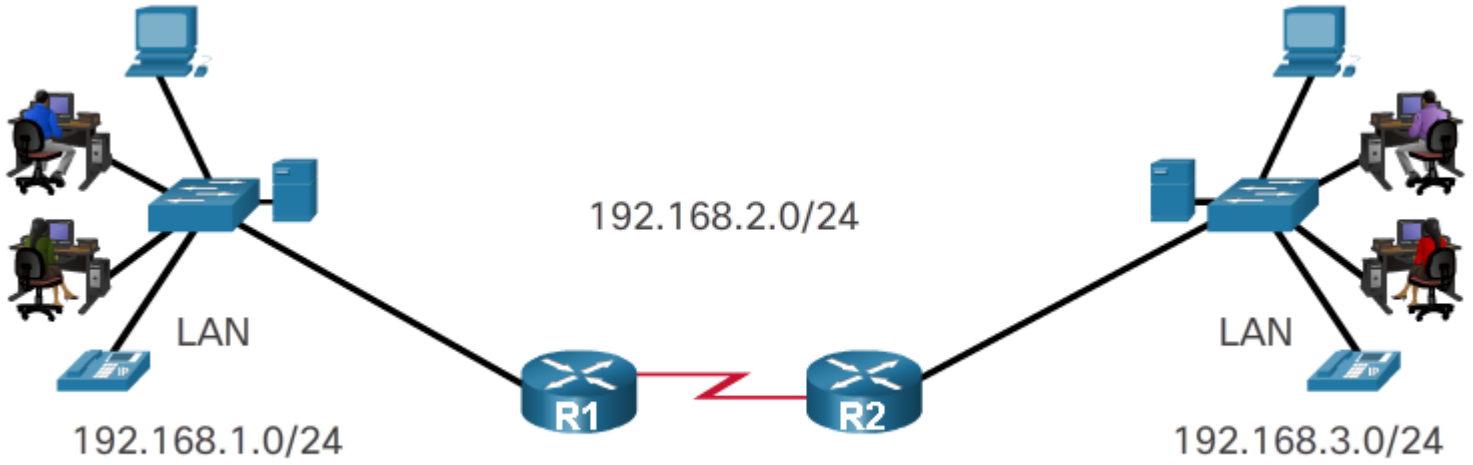
Memory	Description
Random Access Memory (RAM)	Volatile memory that provides temporary storage for various applications and processes including: • Running IOS • Running configuration file • IP routing and ARP tables • Packet buffer
Read-Only Memory (ROM)	Non-volatile memory that provides permanent storage for: • Bootup instructions • Basic diagnostic software • Limited IOS in case the router cannot load the full featured IOS
Non-Volatile Random Access Memory (NVRAM)	Non-volatile memory that provides permanent storage for the: • Startup configuration file
Flash	Non-volatile memory that provides permament storage for: • IOS • Other system-related files

Routers Interconnect Networks

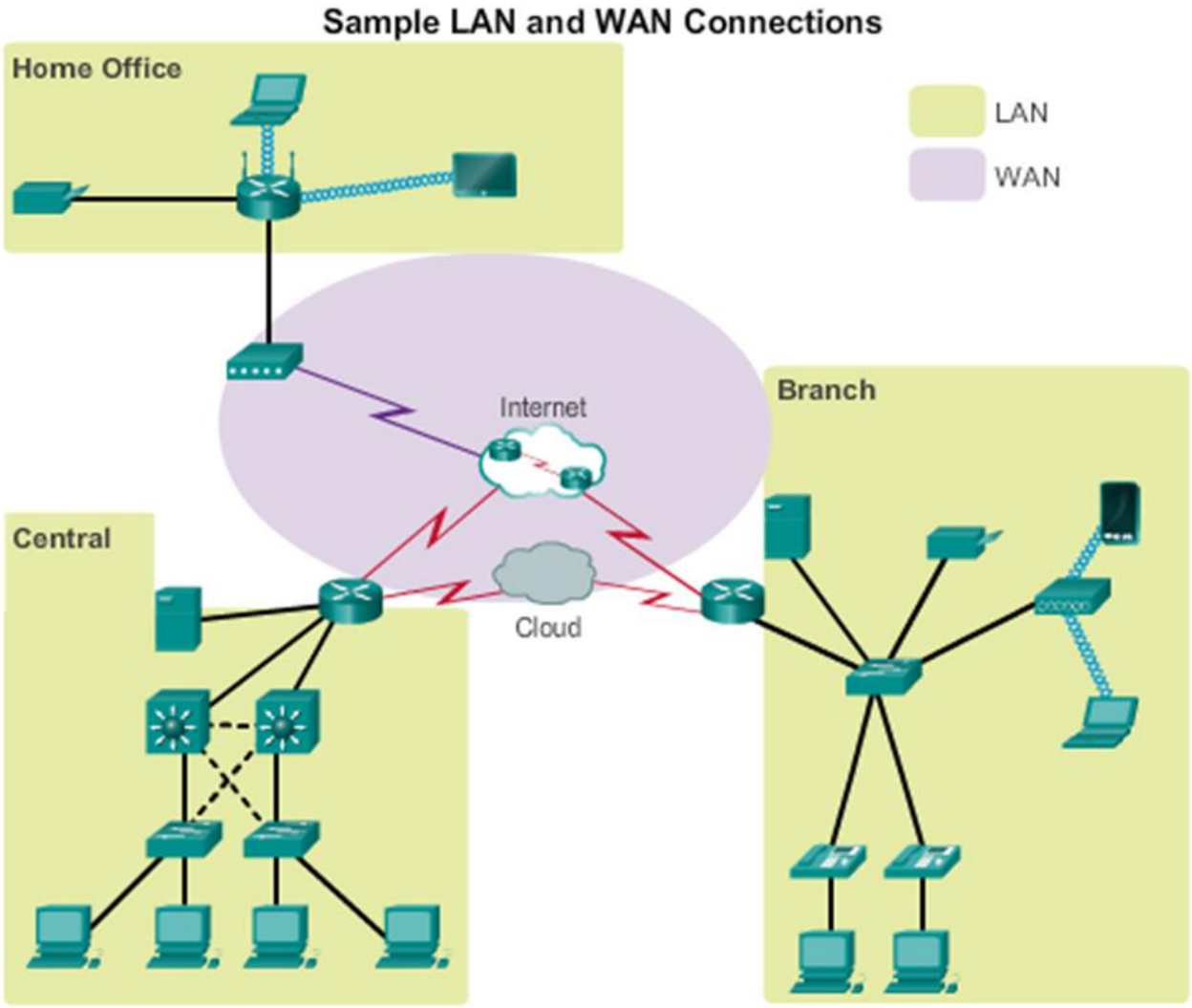


Routers Choose Best Paths

- 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.



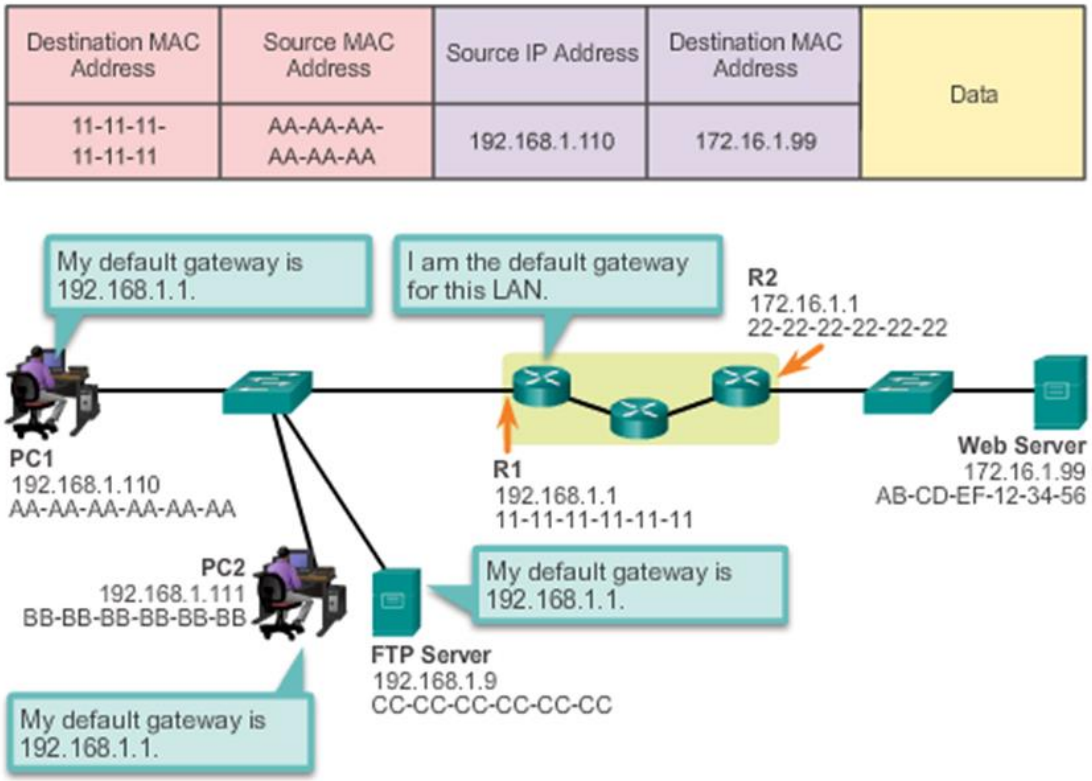
Connect to a Network



Default Gateways

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

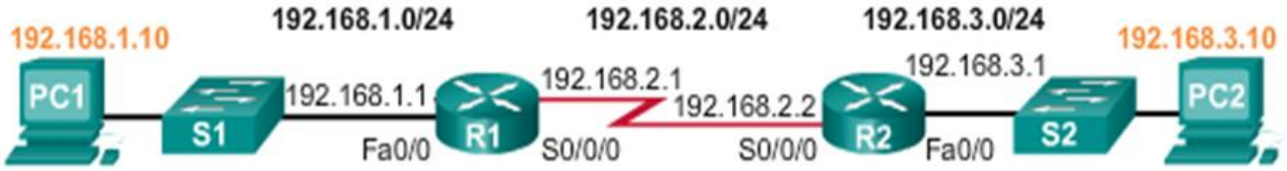
- **IP address** - Identifies a unique host on a local network.
- **Subnet mask** - Identifies the host's network subnet.
- **Default gateway** - Identifies the router a packet is sent to when the destination is not on the same local network subnet.



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 masks
- 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.

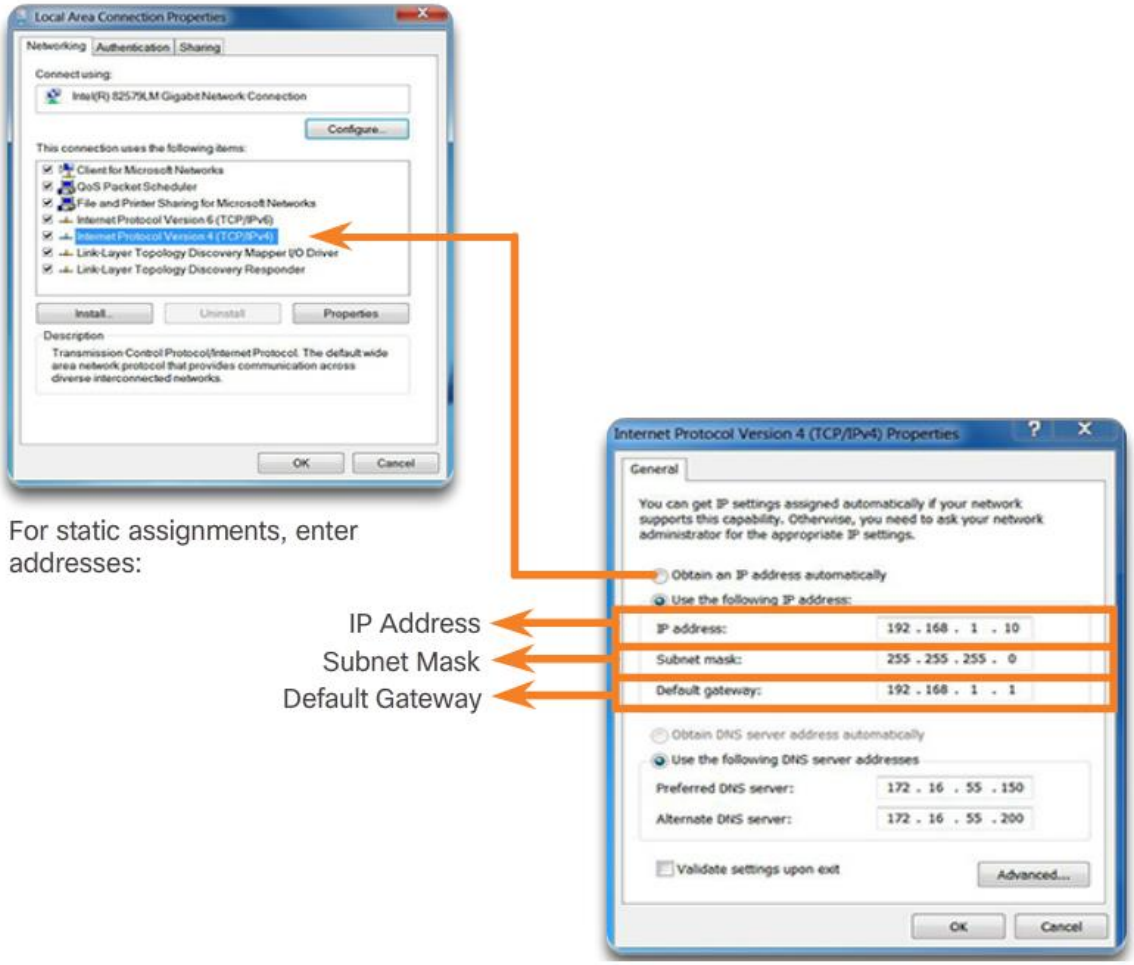
- Used to identify specific network resources such as network servers and printers.
- Can be used in very small networks with few hosts.

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.

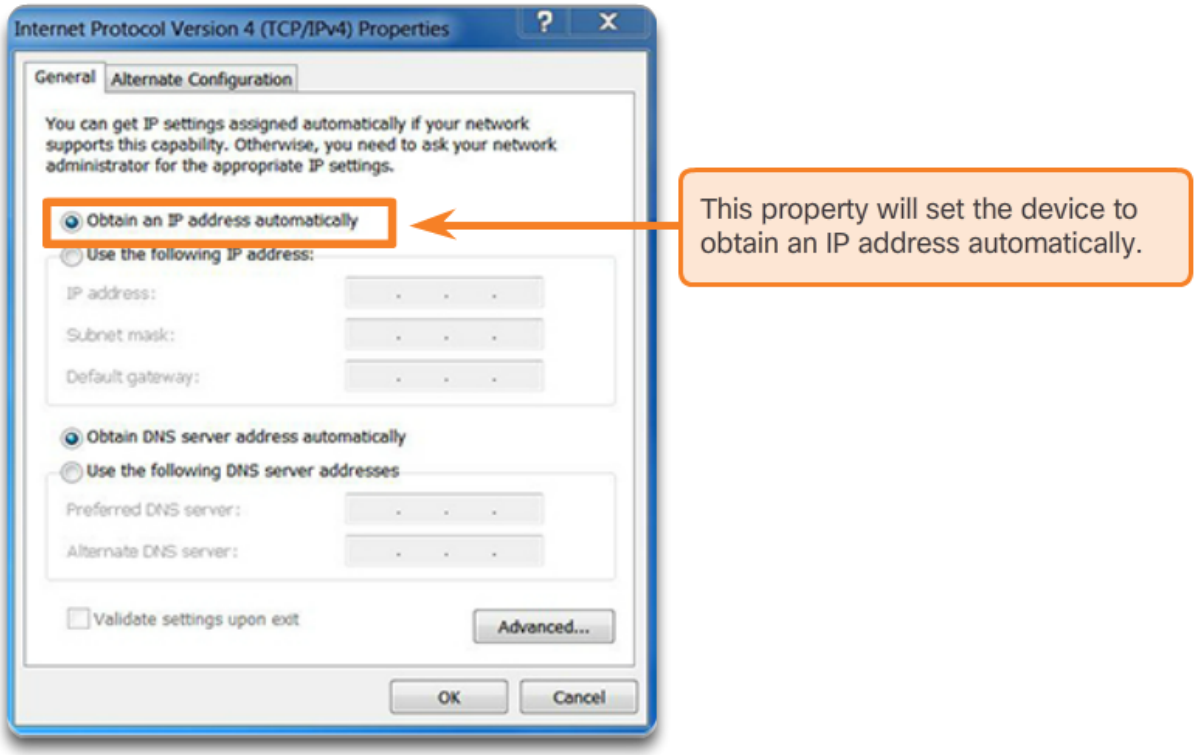
Enable IP on a Host

Statically Assigning an IP Address



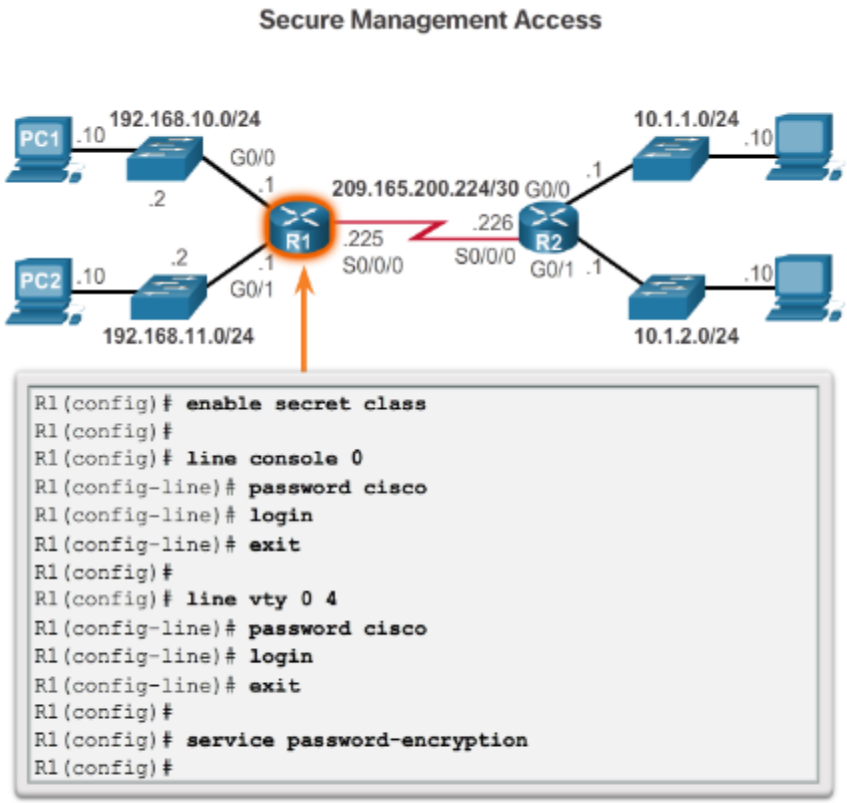
Enable IP on a Host

Dynamically Assigning an IP Address



Configure Router Basic Settings

- **Name the device –** Distinguishes it from other routers
- **Secure management access –** Secures privileged EXEC, user EXEC, and Telnet access, and encrypts passwords .
- **Configure a banner –** Provides legal notification of unauthorized access.
- **Save the Configuration**

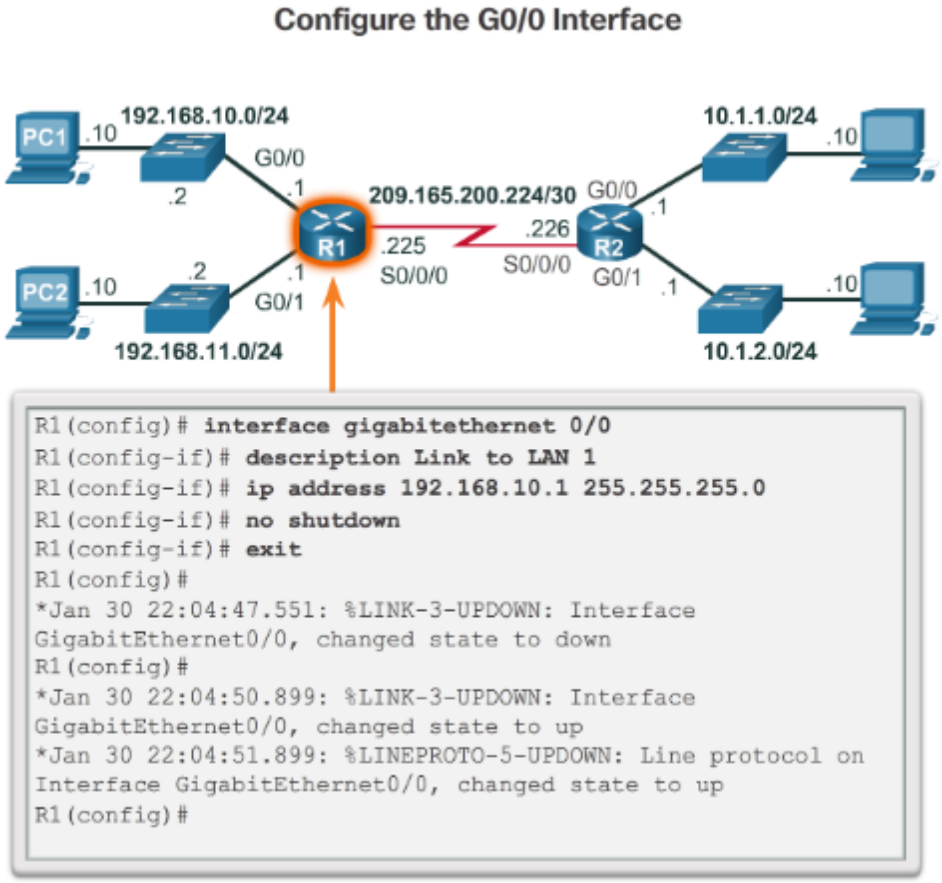


Configure an IPv4 Router Interface

To be available, a router interface must be:

- Configured with an address and subnet mask.
- Activated using **no shutdown** command. By default LAN and WAN interfaces are not activated.
- Configured with the clock rate command on the Serial cable end labeled DCE.

Optional description can be included.

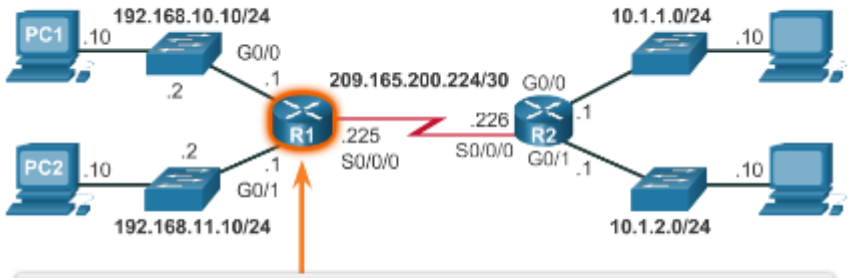


Configure an IPv4 Loopback Interface

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.

Configure the Loopback0 Interface




```
R1(config)# interface loopback 0
R1(config-if)# ip address 10.0.0.1 255.255.255.0
R1(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
```

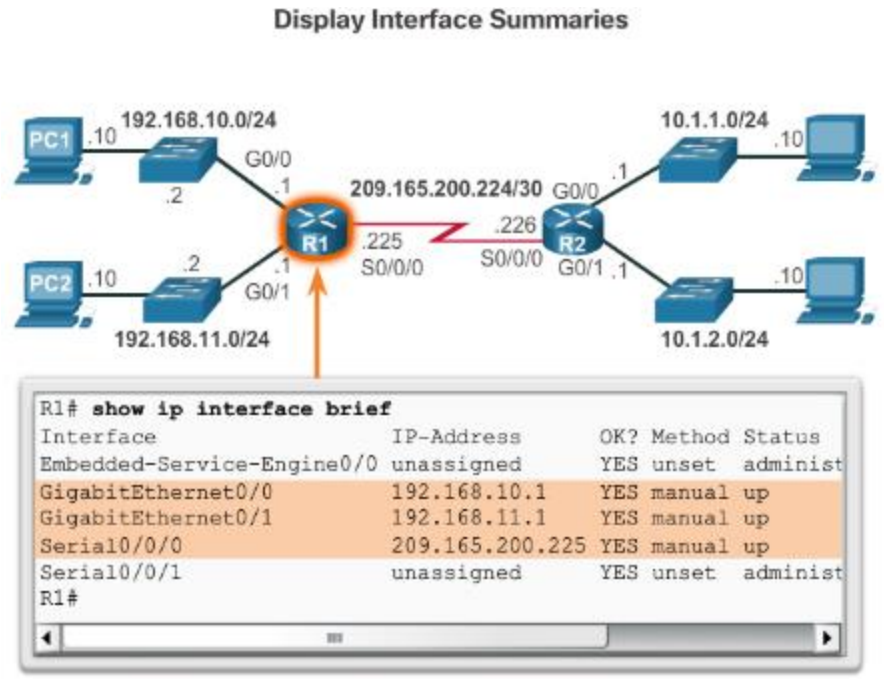
Verify Interface Settings

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

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

Show commands that are used to gather more detailed interface information:

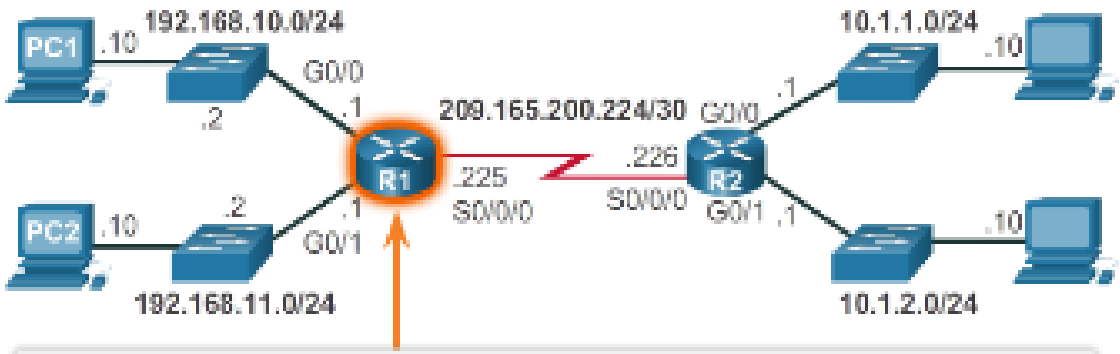
- **show interfaces**
- **show ip interfaces**



Verify Connectivity of Directly Connected Networks

Verify Interface Settings (cont.)

Verify the Routing Table




```
R1# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mo

<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
```

1.2 Routing Decisions

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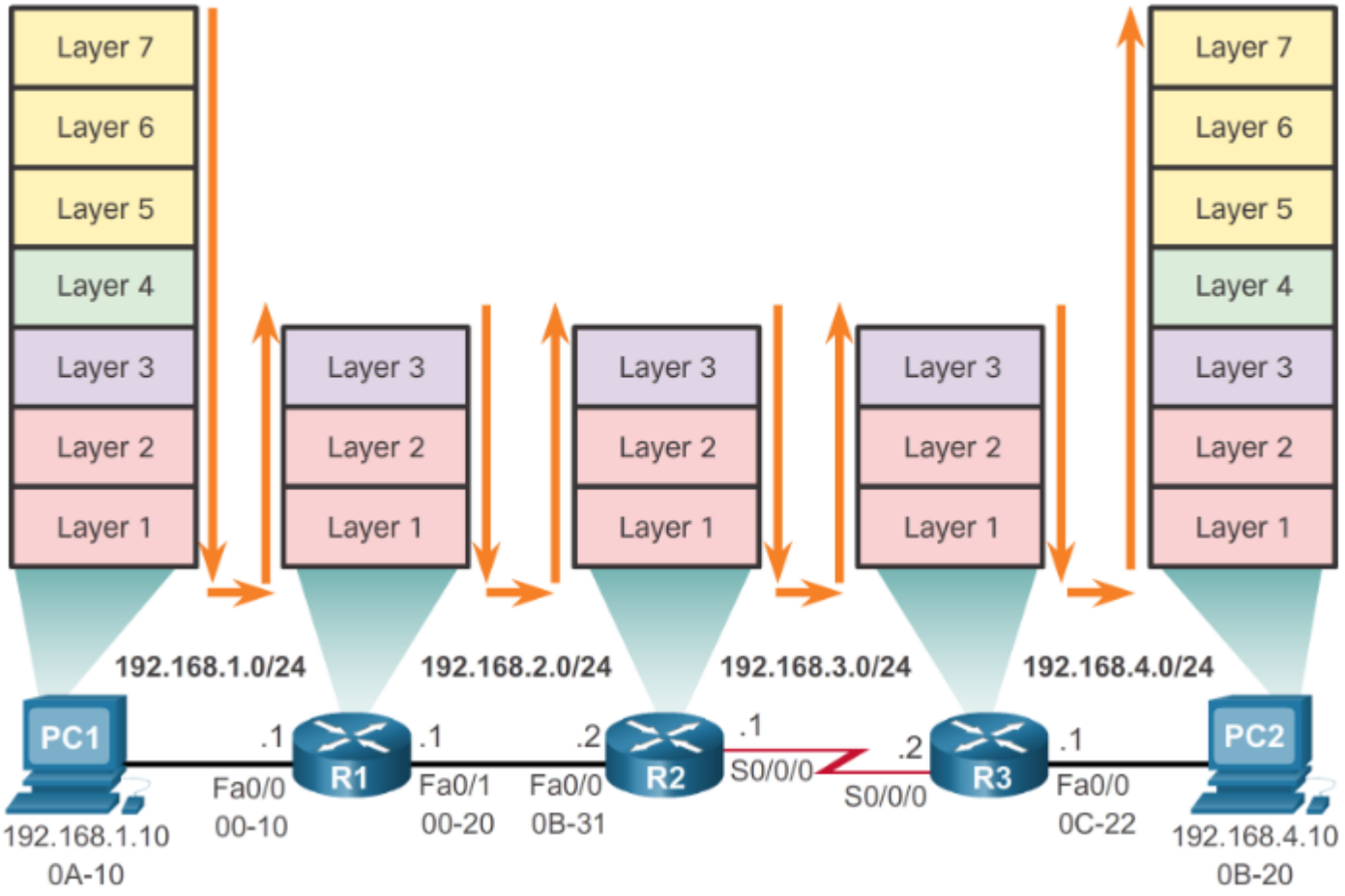
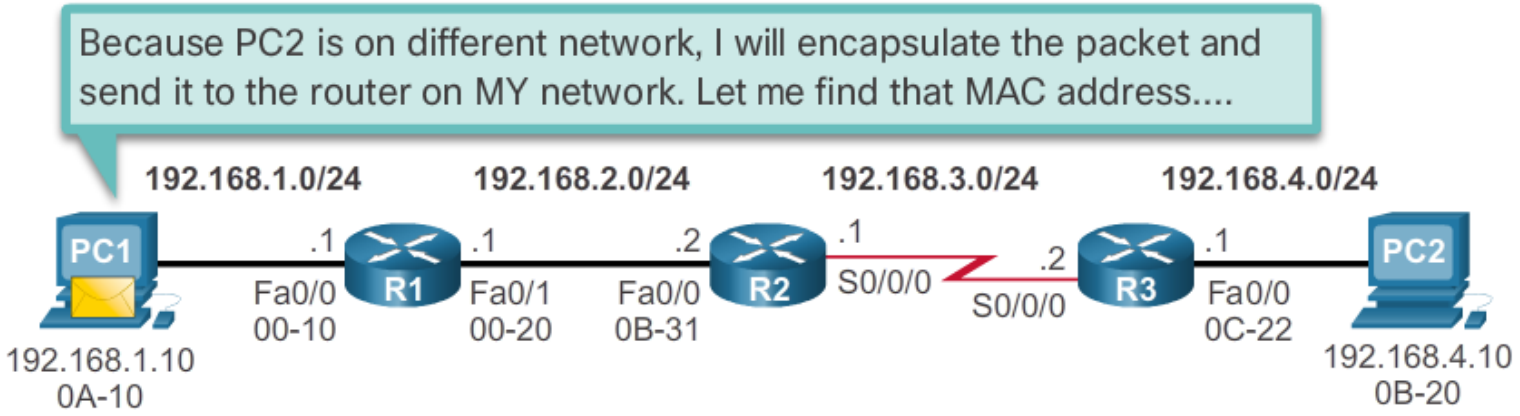
Router Switching Function

Encapsulating and De-Encapsulating Packets



Send a Packet

PC1 Sends a Packet to PC2



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

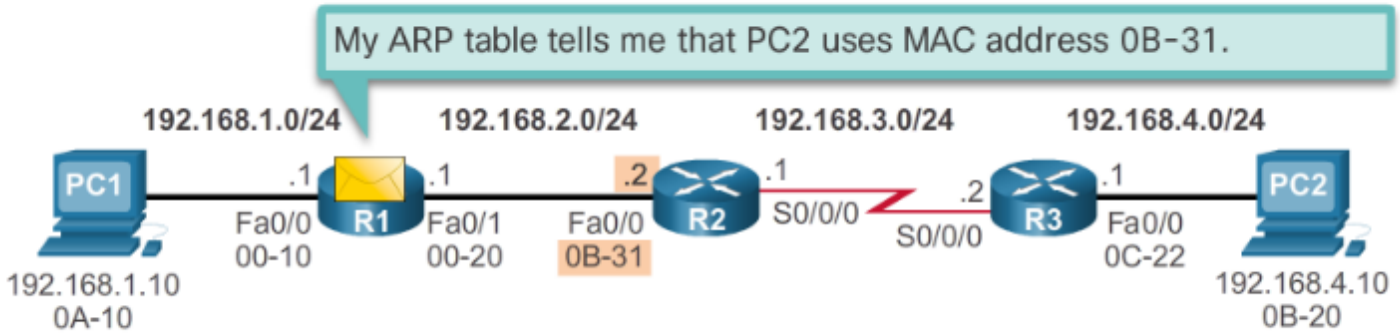
Dest. MAC 00-10	Source MAC 0A-10	Type 0x800	Source IP 192.168.1.10	Dest. IP 192.168.4.10	IP fields	Data	Trailer

PC1's ARP Cache for R1

IP Address	MAC Address
192.168.1.1	00-10

Forward to Next Hop

R1 Forwards the Packet to PC2



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

Dest. MAC 0B-31		Type 0x800	Source IP 192.168.1.10	Dest. IP 192.168.4.10	IP fields	Data	Trailer

R1's ARP Cache

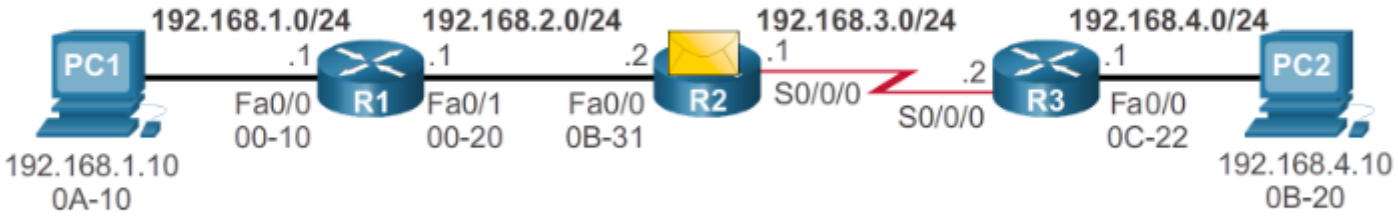
IP Address	MAC Address
192.168.2.2	0B-31

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

Packet Routing

R2 Forwards the Packet to R3



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

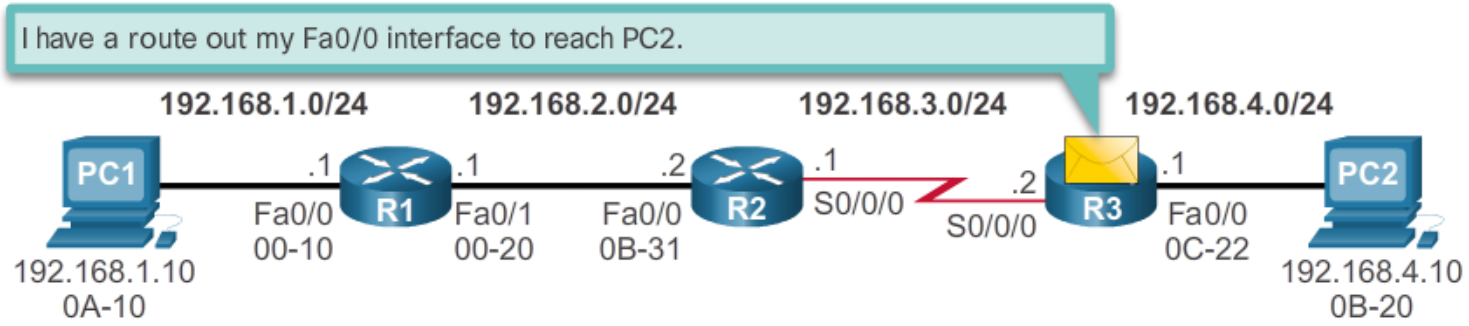
			Source IP 192.168.1.10	Dest. IP 192.168.4.10	IP fields	Data	Trailer

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

Reach the Destination

R3 Forwards the Packet to PC2



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

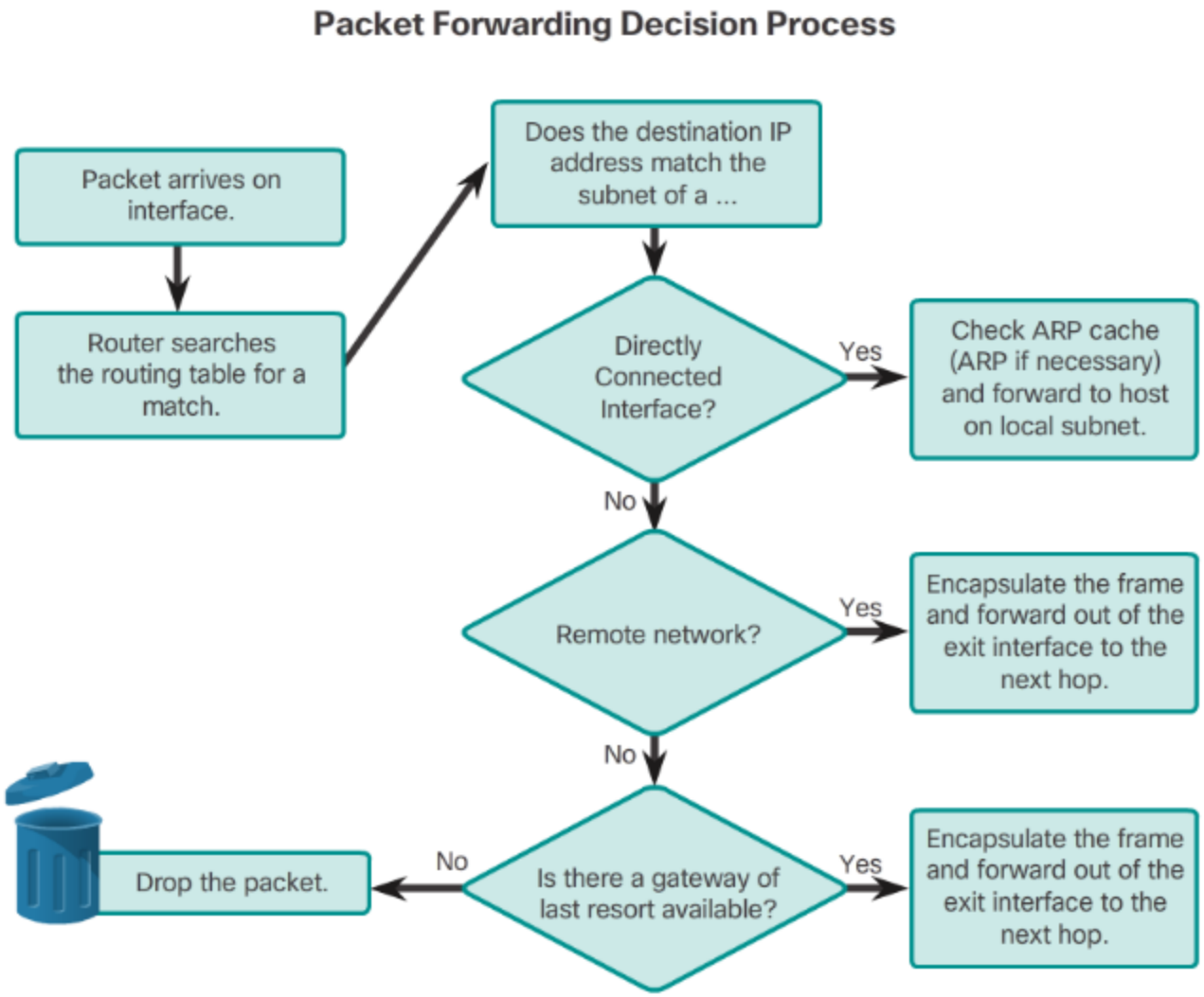
		Type 0x800	Source IP 192.168.1.10	Dest. IP 192.168.4.10	IP fields	Data	Trailer

R3's Routing Table

Network	Hops	Next-hop-IP	Exit Interface
192.168.1.0/24	2	192.168.3.1	S0/0/0
192.168.2.0/24	1	192.168.3.1	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

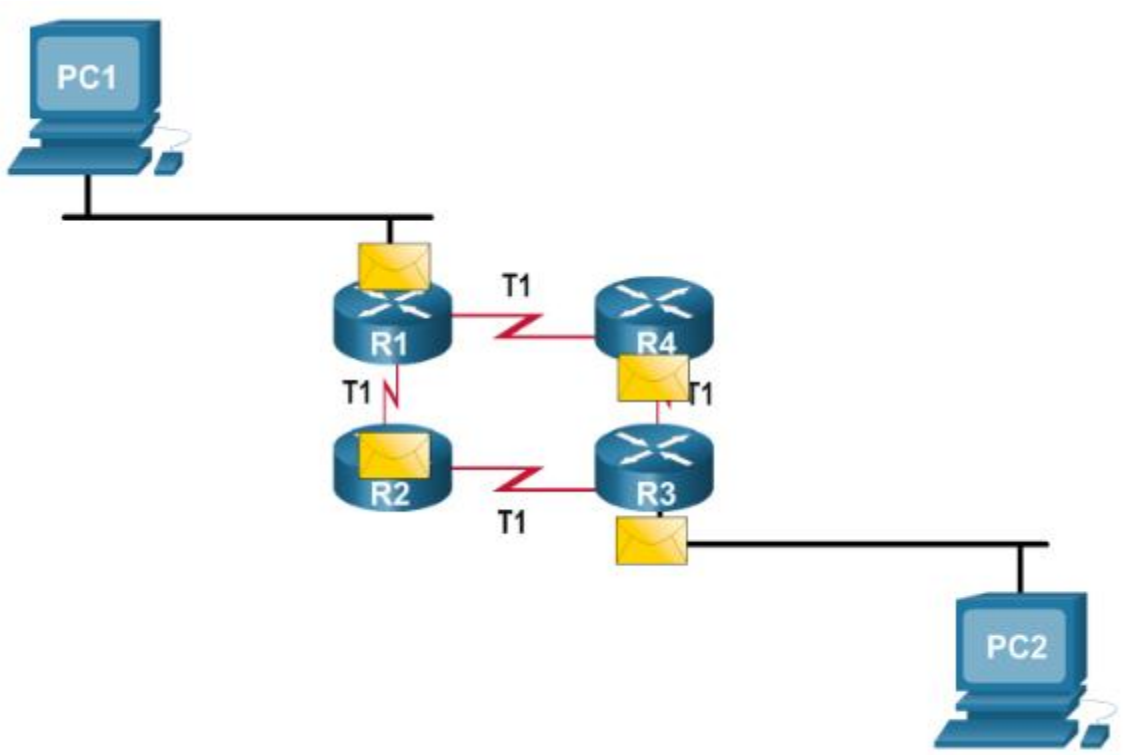


Best Path

- **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.



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.

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
RIP	120
External EIGRP	170
Internal BGP	200

1.3 Router Operation

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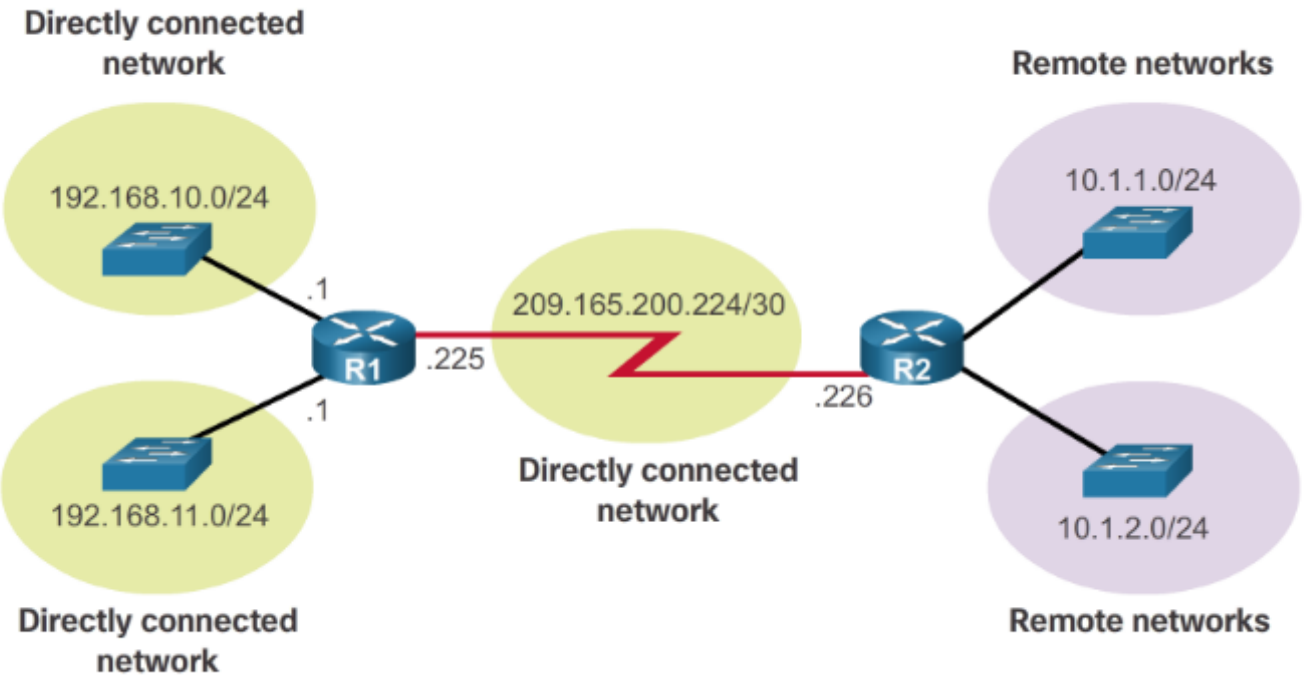
The Routing Table

- A routing table is a file stored in RAM that contains information about:
  - Directly connected routes
  - Remote routes

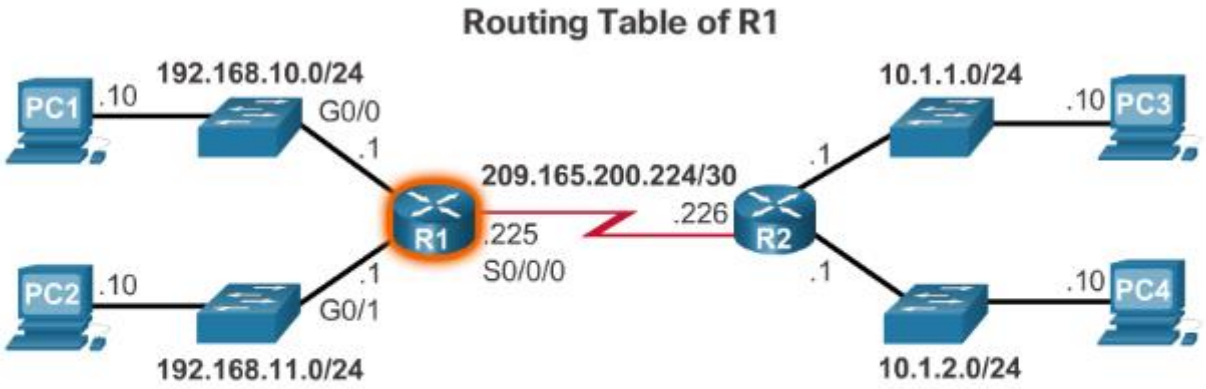


Routing Table Sources

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 for IPv4 routes and all IOS releases for IPv6 routes.)
- **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.

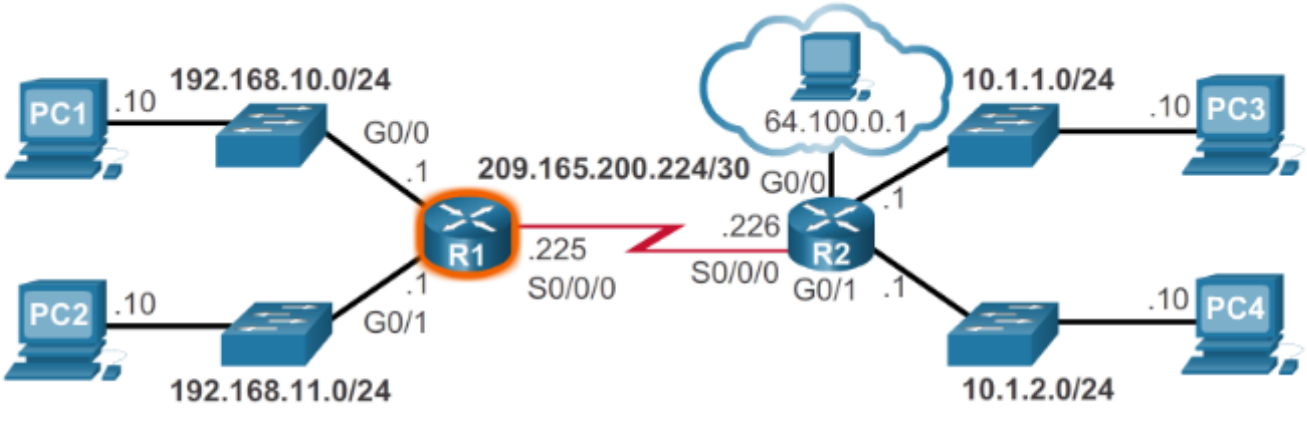
Routing Table Sources (cont.)




```
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,
```

Remote Network Routing Entries

Interpreting the entries in the routing table



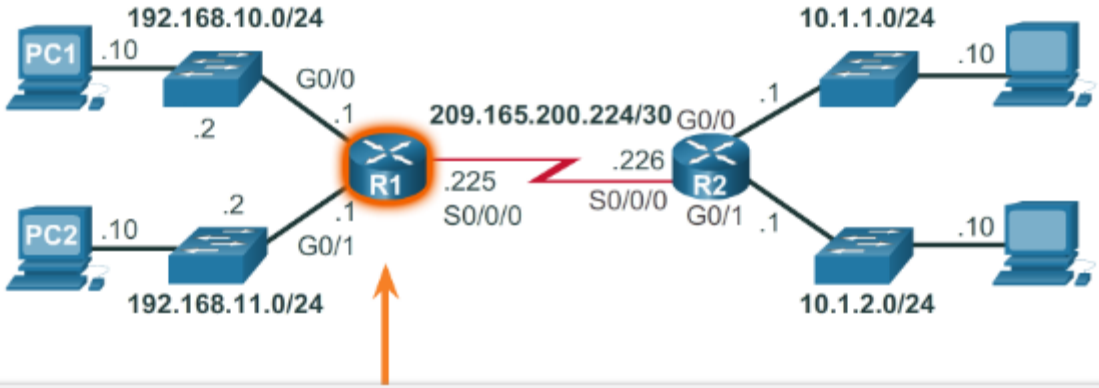
Legend

- Identifies how the network was learned by the router.
- Identifies the destination network.
- Identifies the administrative distance (trustworthiness) of the route source.
- Identifies the metric to reach the remote network.
- Identifies the next-hop IP address to reach the remote network.
- Identifies the amout of elapsed time since the network was discovered.
- Identifies the outgoing interface on the router to reach the destination network.

Directly Connected Interfaces

A newly deployed router, without any configured interfaces, has an empty routing table.

Empty Routing Table



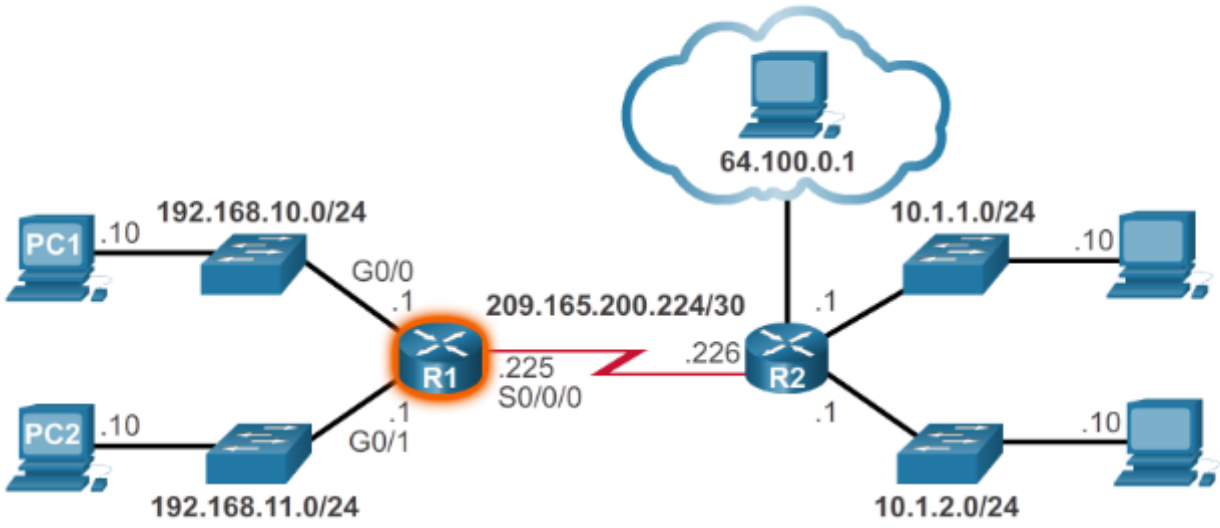

```
R1# show ip route
Codes:L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
      D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
      N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
      E1 - OSPF external type 1, E2 - OSPF external type 2
      i - IS-IS, su - IS-IS summary, 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, H - NHRP, l - LISP
      + - replicated route, % - next hop override

Gateway of last resort is not set

R1#
```

Directly Connected Routing Table Entries

Directly Connected Network Entry Identifiers

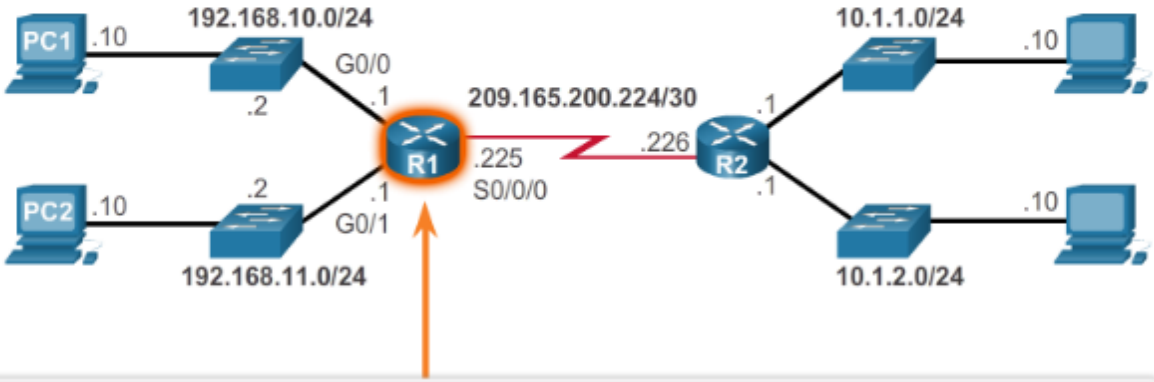


Legend

- 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 Example

Verifying the Directly Connected Routing Table Entries



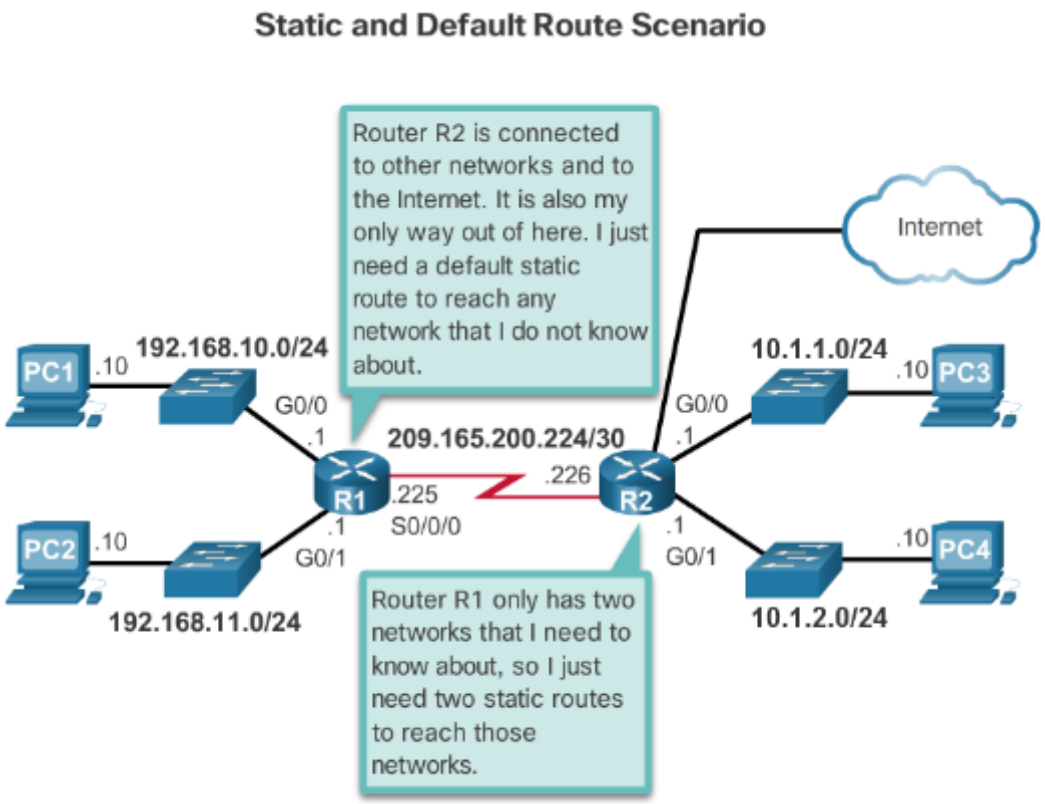

```
R1# show ip route | begin Gateway
Gateway of last resort is not set

      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
      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#
```

Reach Remote Networks

A router can learn about remote networks in one of two ways:

- **Manually** - Remote networks are manually entered into the route table using static routes.
- **Dynamically** - Remote routes are automatically learned using a dynamic routing protocol.



Why Use Static Routing?

Static routing provides some advantages over dynamic routing, including:

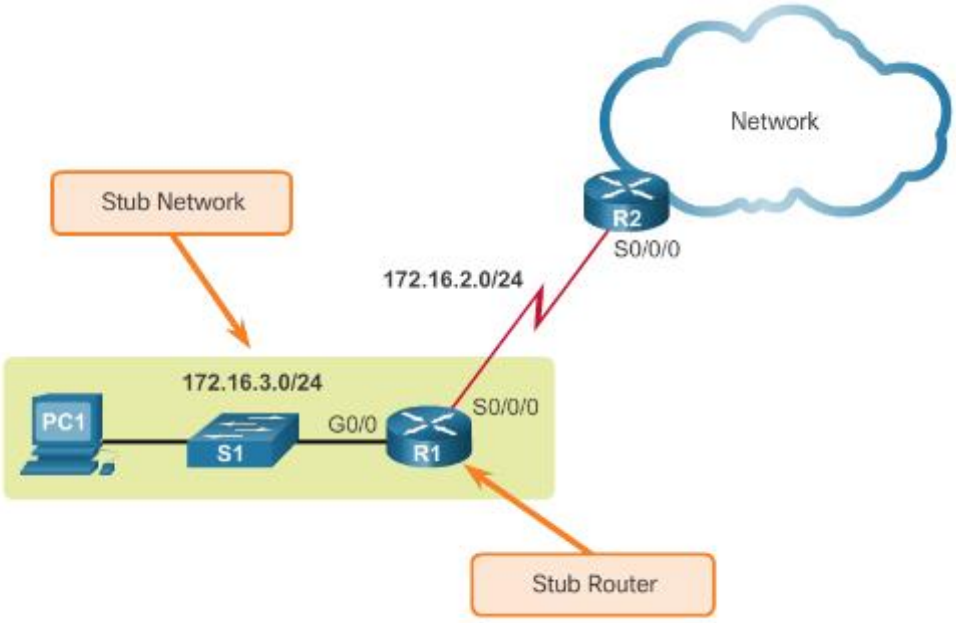
- Static routes are not advertised over the network, resulting in better security.
- Static routes use less bandwidth than dynamic routing protocols, no CPU cycles are used to calculate and communicate routes.
- The path a static route uses to send data is known.

	Dynamic Routing	Static Routing
Configuration Complexity	Generally independent of the network size	Increases with network size
Topology Changes	Automatically adapts to topology changes	Administrator intervention required
Scaling	Suitable for simple and complex topologies	Suitable for simple topologies
Security	Less secure	More secure
Resource Usage	Uses CPU, memory, link bandwith	No extra resources needed
Predictability	Route depends on the current topology	Route to destination is always the same

When to Use Static Routes

Static routing has three primary uses:

- Providing ease of routing table maintenance in smaller networks.
- Routing to and from stub networks. A stub network is a network accessed by a single route, and the router has no other neighbors.
- Using a single default route to represent a path to any network that does not have a more specific match with another route in the routing table.

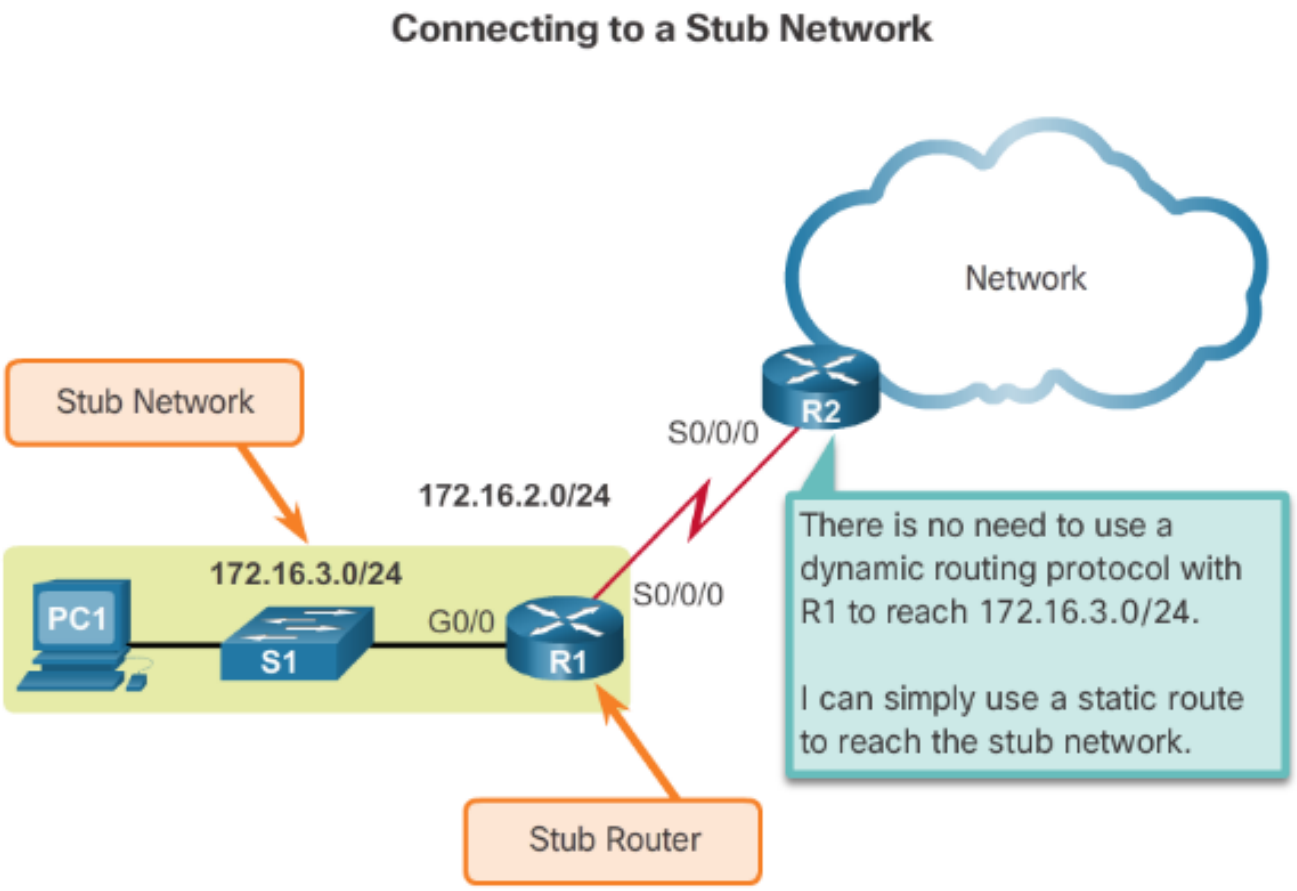


Static Route Applications

Static Routes are often used to:

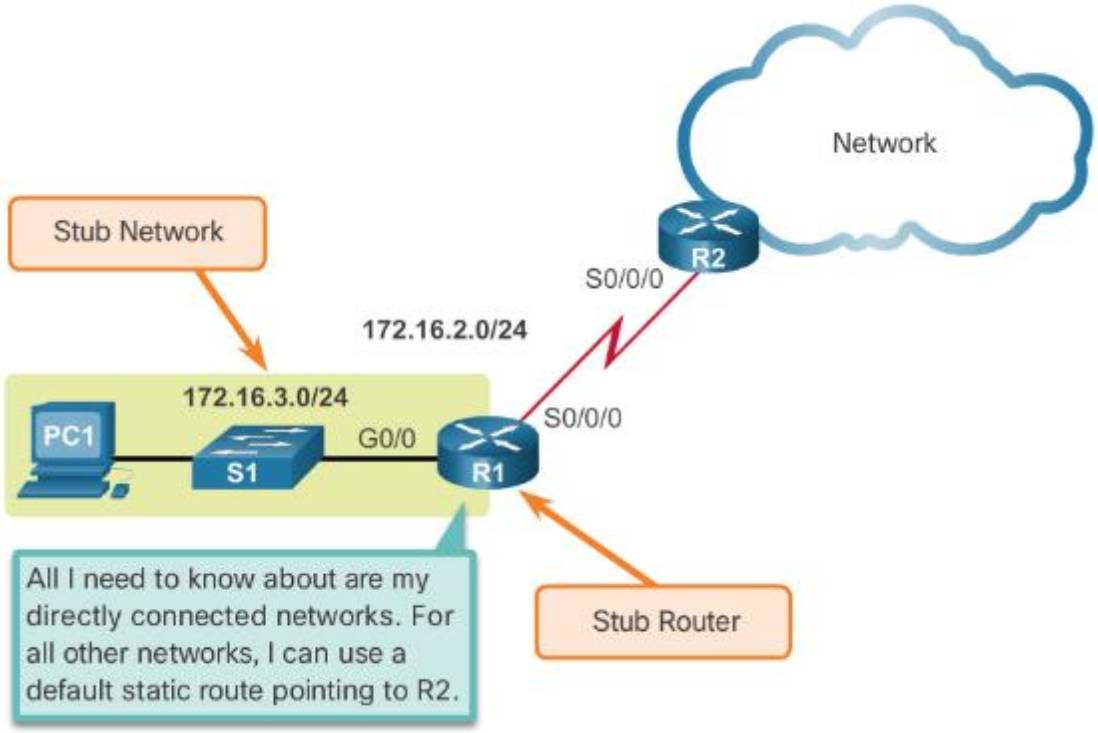
- Connect to a specific network.
- Provide a Gateway of Last Resort for a stub network.
- Reduce the number of routes advertised by summarizing several contiguous networks as one static route.
- Create a backup route in case a primary route link fails.

Standard Static Route

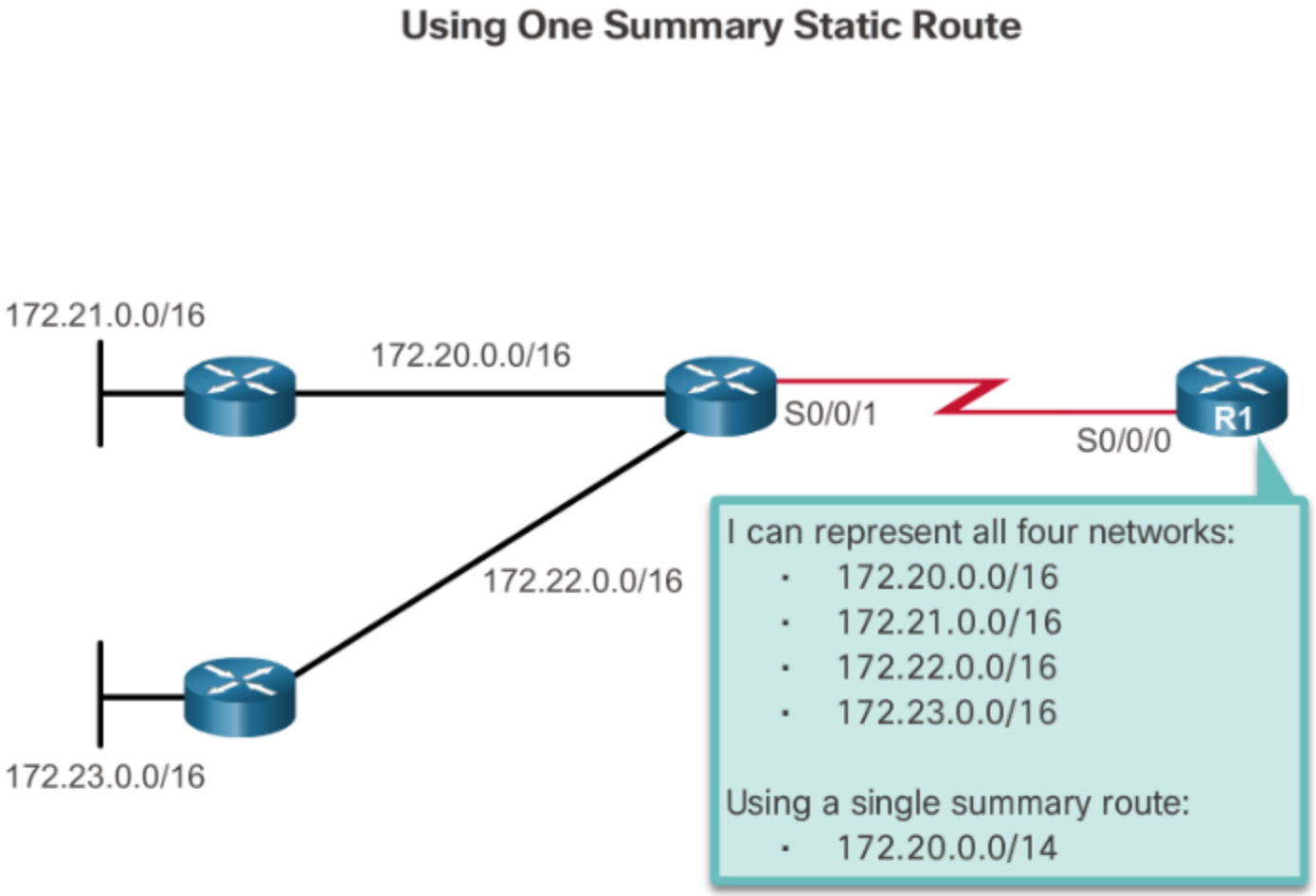


Default Static Route

- A default static route is a route that matches all packets.
- A default route identifies the gateway IP address to which the router sends all IP packets that it does not have a learned or static route.
- A default static route is simply a static route with 0.0.0.0/0 as the destination IPv4 address.

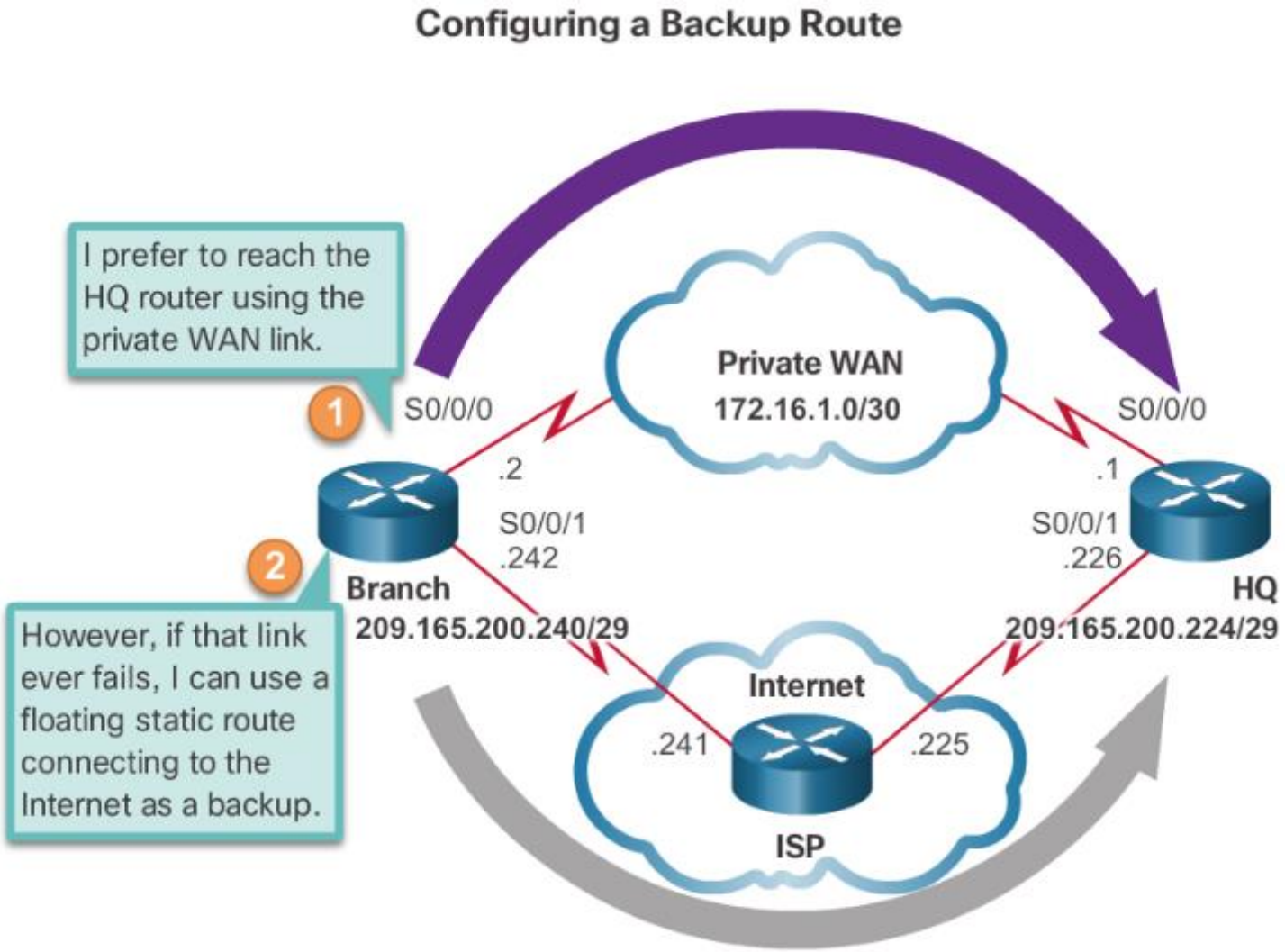


Summary Static Route



Types of Static Routes

Floating Static Route



6.2 Configure Static and Default Routes

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Configure IPv4 Static Routes

ip route Command

```
Router(config)# ip route network-address subnet-mask
{ip-address | exit-intf}
```

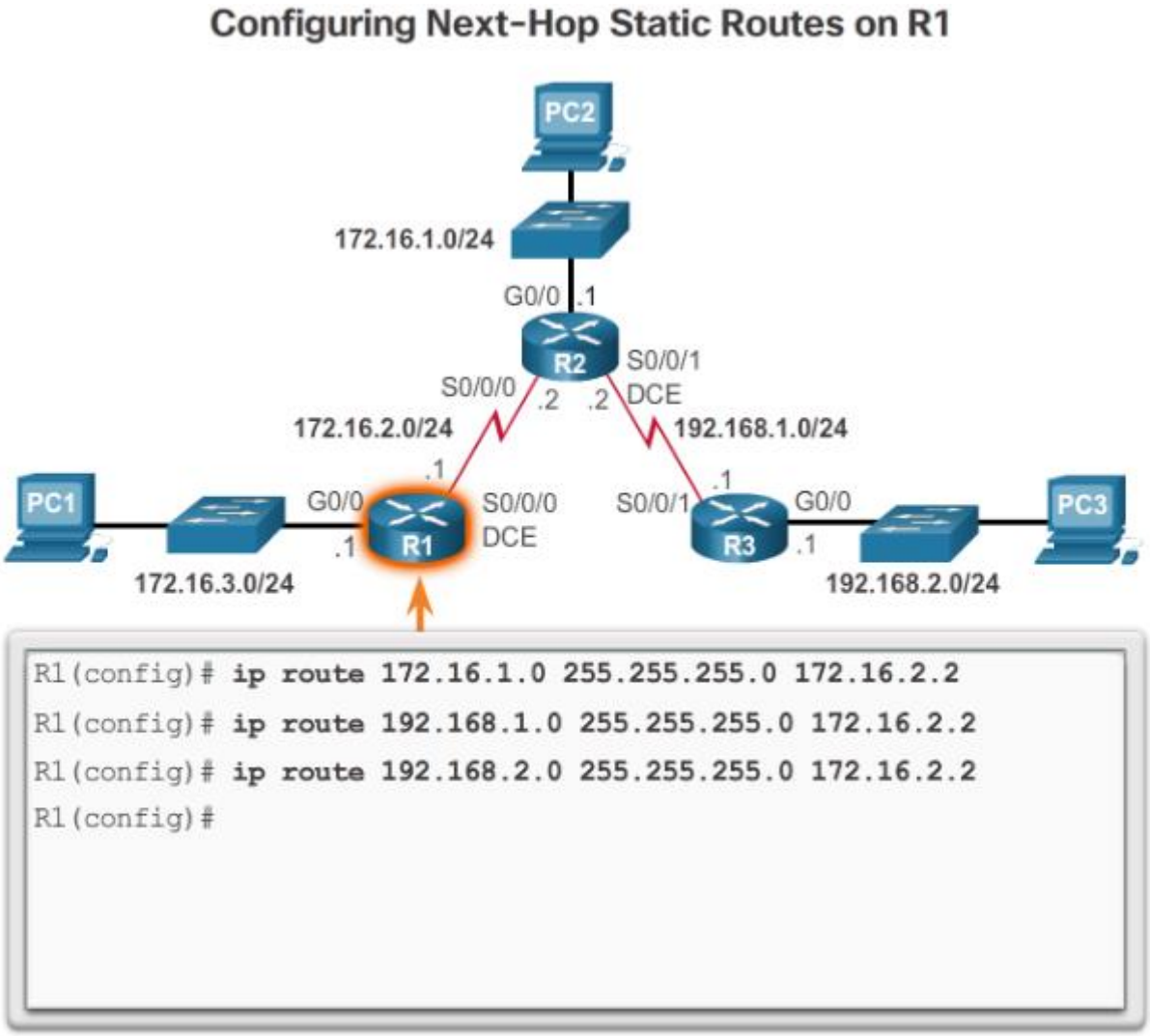
Parameter	Description
network-address	Destination network address of the remote network to be added to the routing table
subnet-mask	• Subnet mask of the remote network to be added to the routing table • The subnet mask can be modified to summarize a group of networks
ip-address	• Commonly referred to as the next-hop router's IP address • Typically used when connecting to a broadcast media (i.e., Ethernet) • Commonly creates a recursive lookup
exit-intf	• Use the outgoing interface to forward packets to the destination network • Also referred to as a directly attached static route • Typically used when connecting in a point-to-point configuration
distance	• (Optional) Configures an administrative distance • Typically used to configure a floating static route

Next-Hop Options

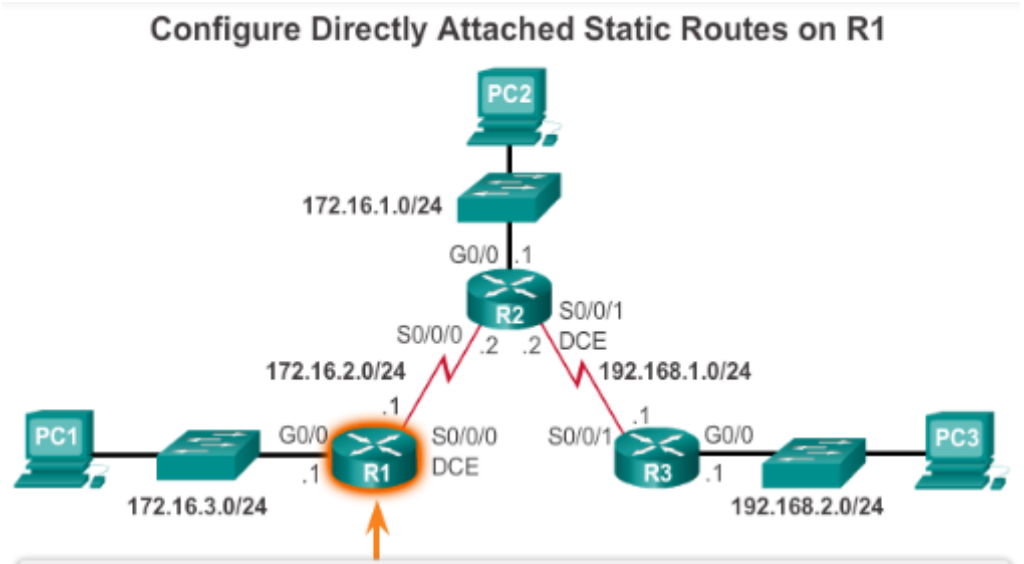
The next hop can be identified by an IP address, exit interface, or both. How the destination is specified creates one of the three following route types:

- **Next-hop route** - Only the next-hop IP address is specified.
- **Directly connected static route** - Only the router exit interface is specified.
- **Fully specified static route** - The next-hop IP address and exit interface are specified.

Configure a Next-Hop Static Route

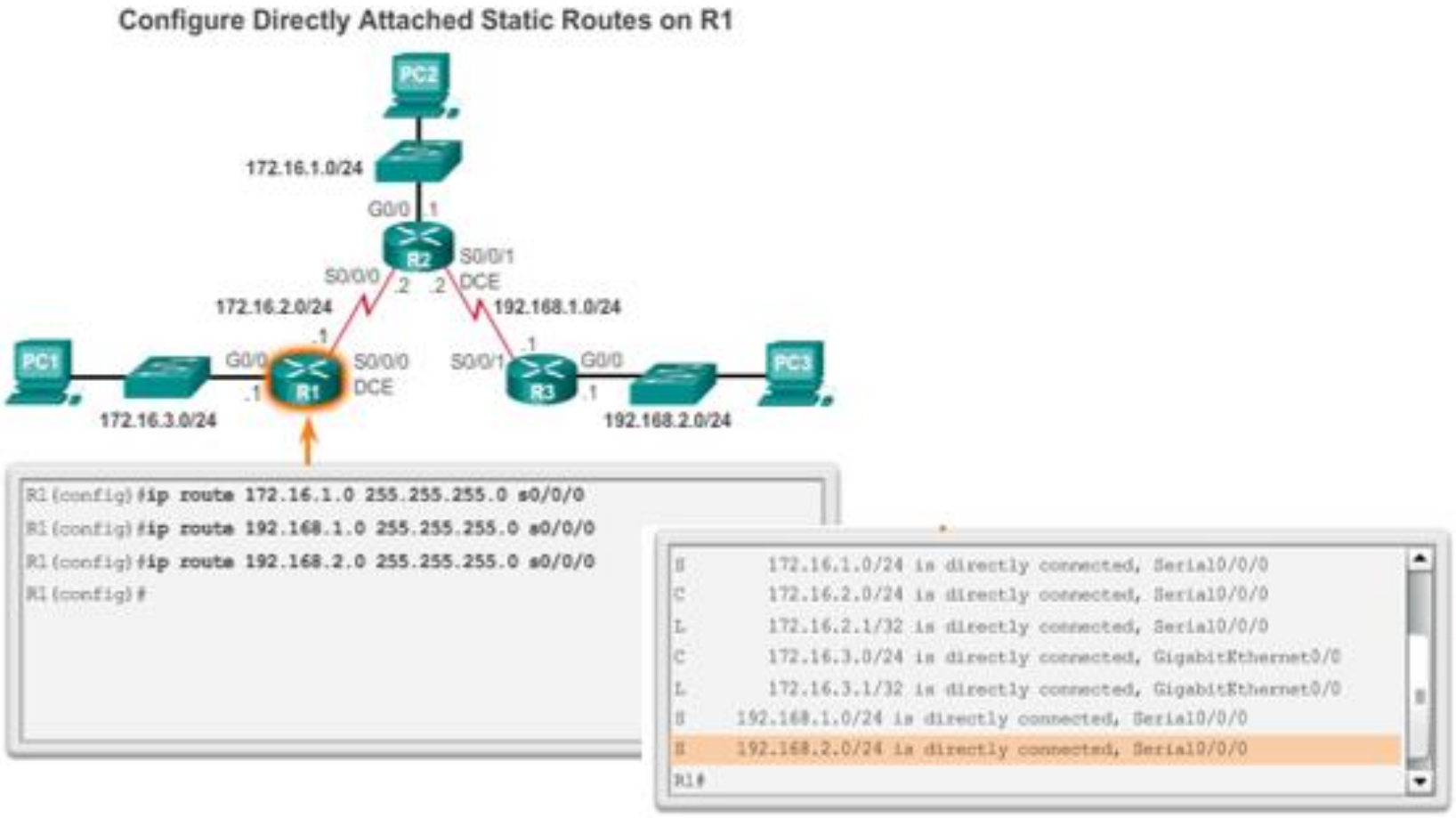


Configure Directly Connected Static Route

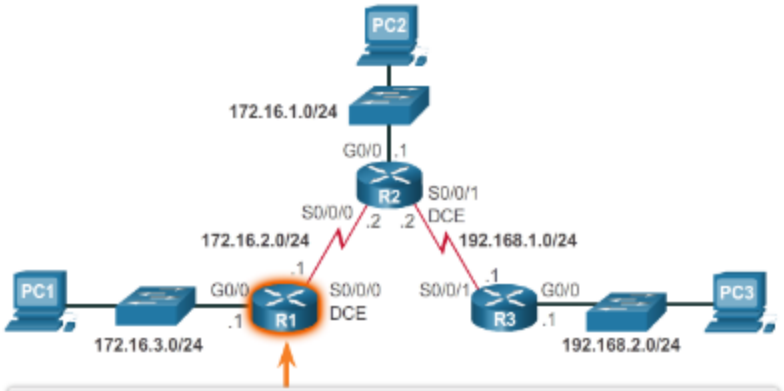



```
S       172.16.1.0/24 is directly connected, Serial0/0/0
C       172.16.2.0/24 is directly connected, Serial0/0/0
L       172.16.2.1/32 is directly connected, Serial0/0/0
C       172.16.3.0/24 is directly connected, GigabitEthernet0/0
L       172.16.3.1/32 is directly connected, GigabitEthernet0/0
S    192.168.1.0/24 is directly connected, Serial0/0/0
S    192.168.2.0/24 is directly connected, Serial0/0/0
R1#
```

Configure a Fully Specified Static Route



Verify a Static Route




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

      172.16.0.0/16 is variably subnetted, 5 subnets, 2 masks
S        172.16.1.0/24 [1/0] via 172.16.2.2
S     192.168.1.0/24 [1/0] via 172.16.2.2
S     192.168.2.0/24 [1/0] via 172.16.2.2
R1#
```

```
R1# show ip route 192.168.2.1
Routing entry for 192.168.2.0/24
  Known via "static", distance 1, metric 0
  Routing Descriptor Blocks:
    * 172.16.2.2
      Route metric is 0, traffic share count is 1
R1#
```

```
R1# show running-config | section ip route
ip route 172.16.1.0 255.255.255.0 172.16.2.2
ip route 192.168.1.0 255.255.255.0 172.16.2.2
ip route 192.168.2.0 255.255.255.0 172.16.2.2
R1#
```

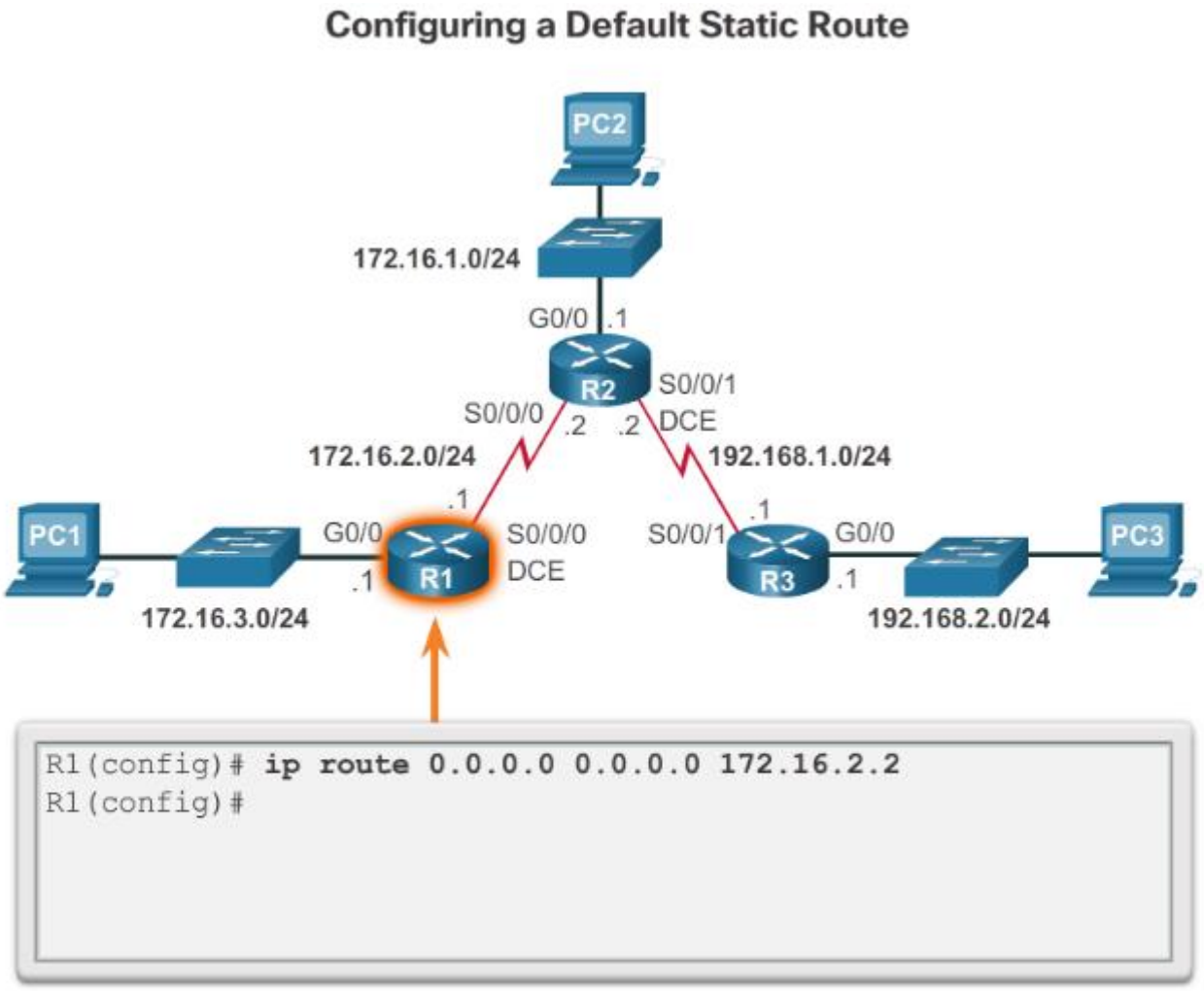
Default Static Route

Default Static Route Syntax

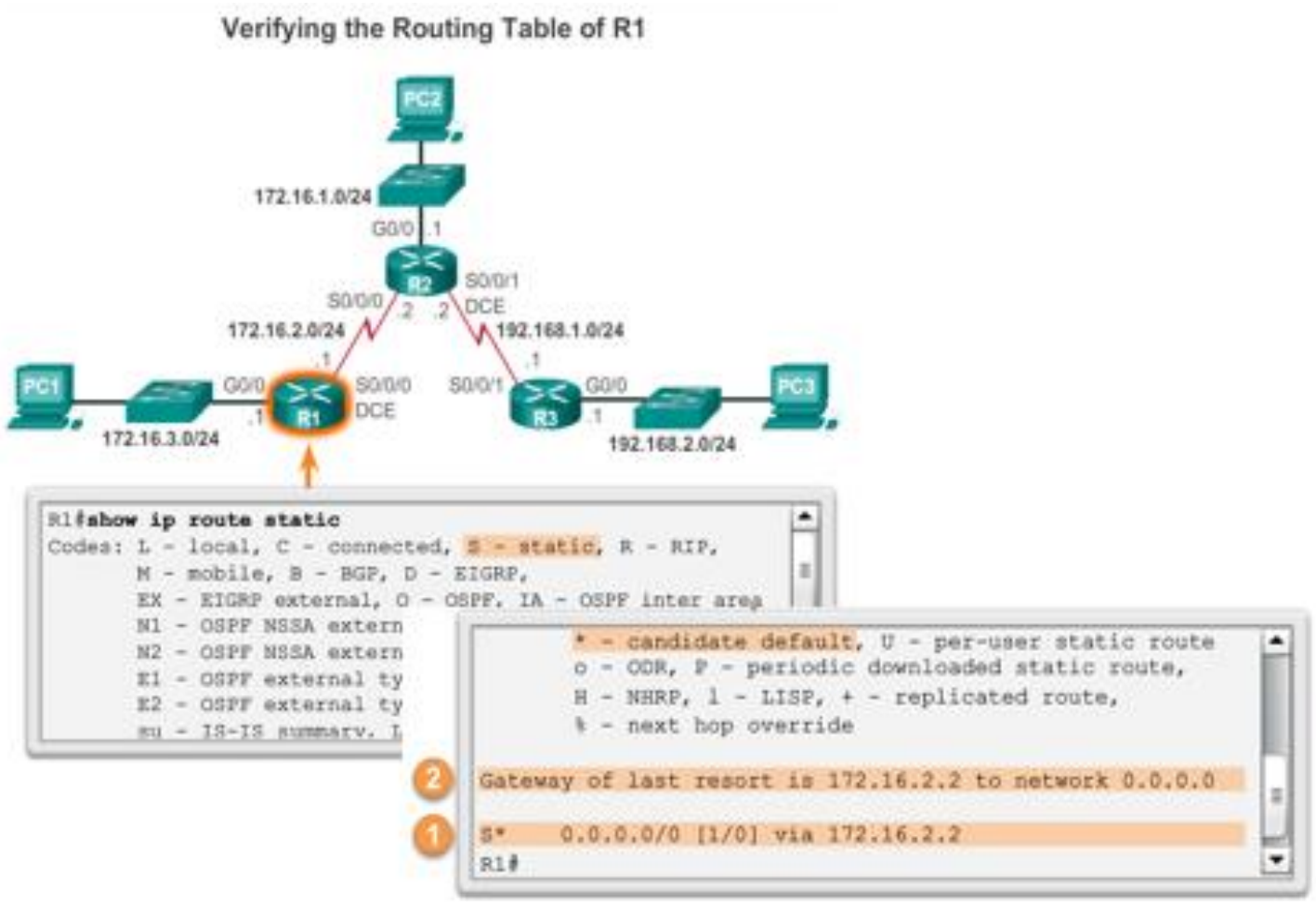
```
Router(config)#ip route 0.0.0.0 0.0.0.0 {ip-address | exit-intf}
```

Parameter	Description
0.0.0.0 0.0.0.0	Matches any network address.
ip-address	• Commonly referred to as the next-hop router's IP address. • Typically used when connecting to a broadcast media (i.e., Ethernet). • Commonly creates a recursive lookup.
exit-intf	• Use the outgoing interface to forward packets to the destination network. • Also referred to as a directly attached static route. • Typically used when connecting in a point-to-point configuration.

Configure a Default Static Route



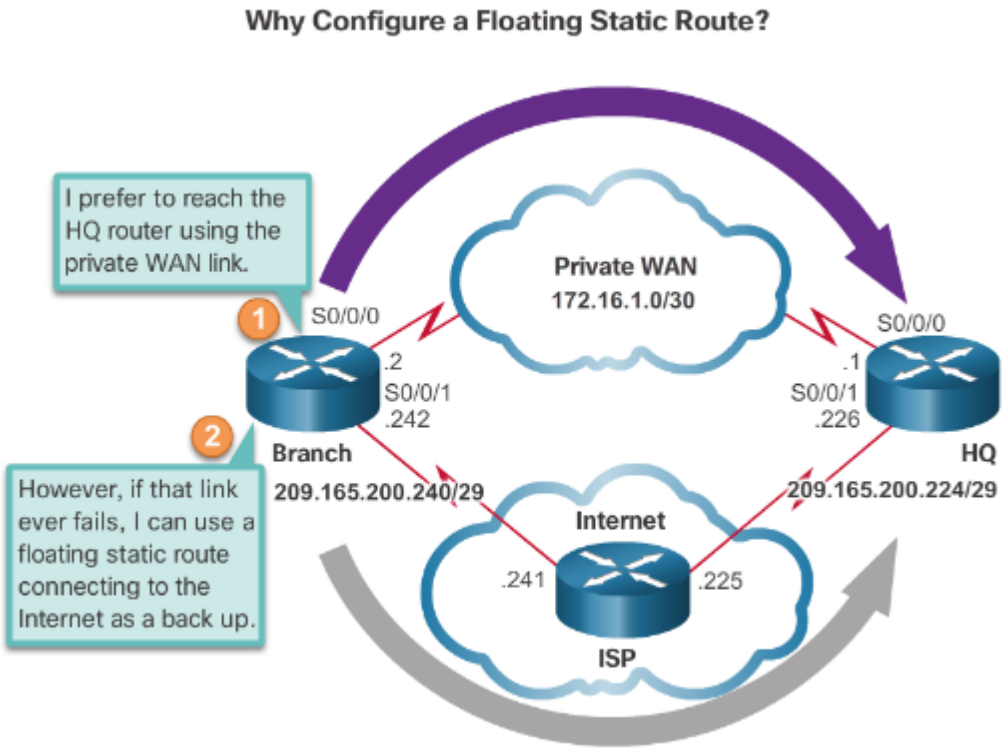
Verify a Default Static Route



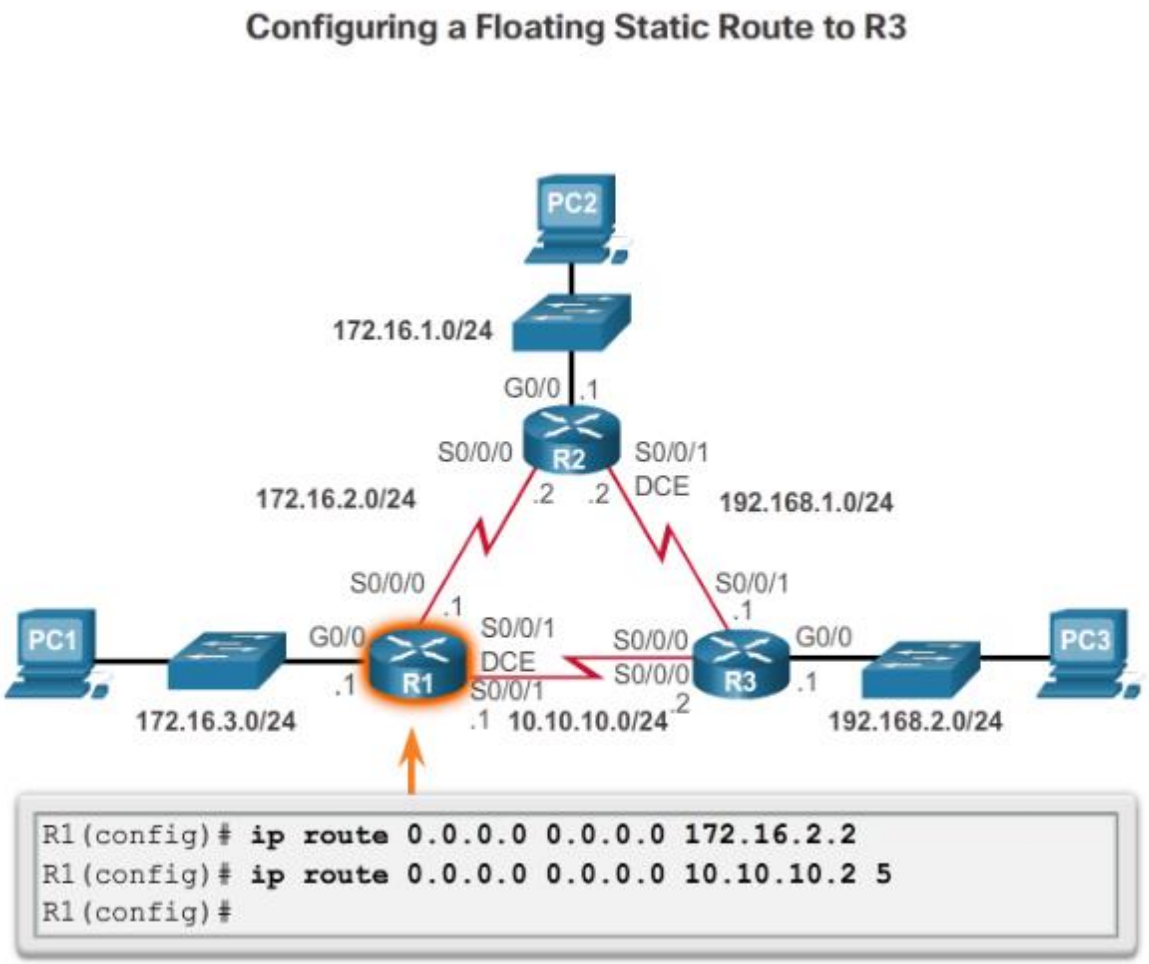
Floating Static Routes

Floating static routes have an administrative distance greater than the administrative distance of another static route or dynamic routes.

- The static route “floats” and is not used when the route with the better administrative distance is active.
- If the preferred route is lost the floating static route can take over.



Configure an IPv4 Floating Static Route

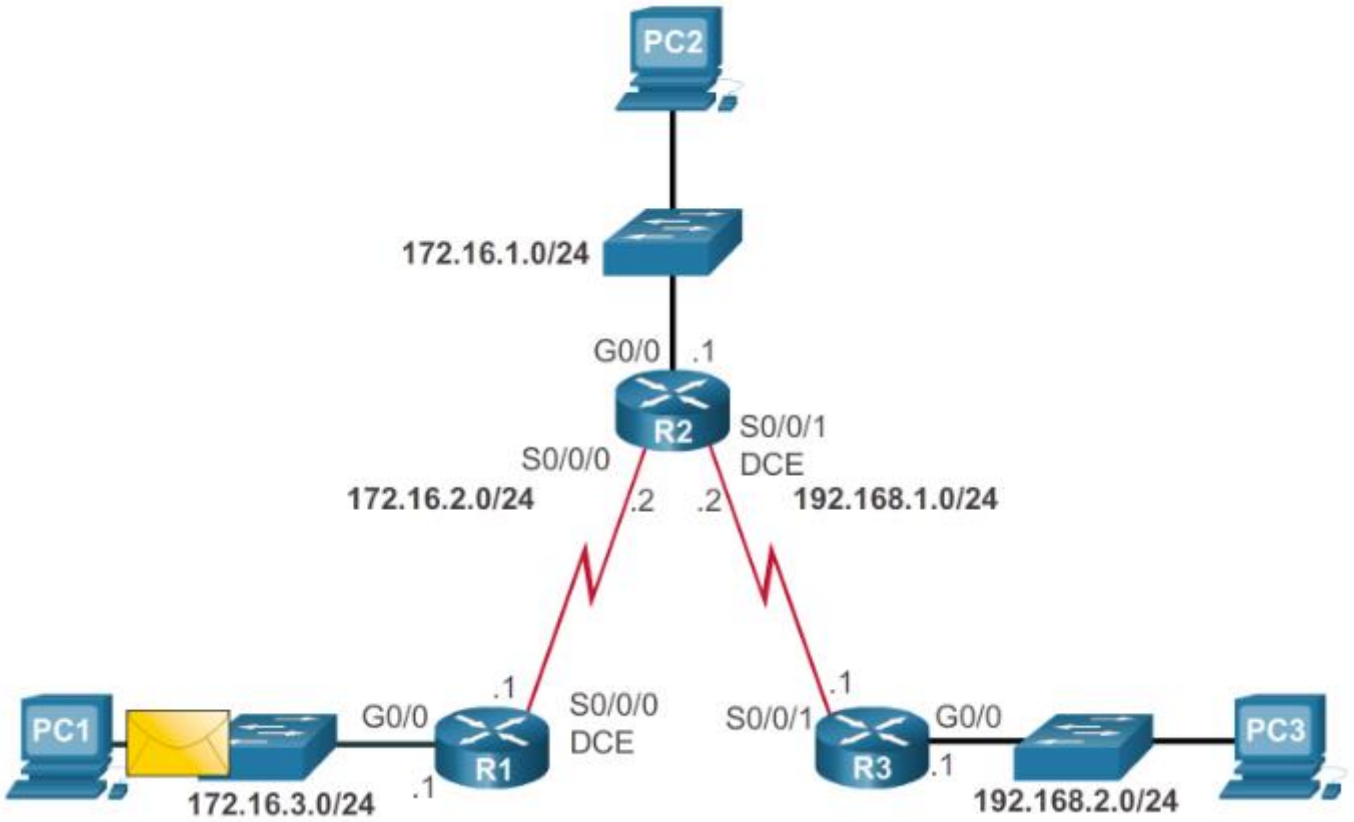


Test the IPv4 Floating Static Route

To test a floating static route:

- Use the **`show ip route`** command to verify that the routing table is using the default static route.
- Use the **`traceroute`** command to follow the traffic flow out the primary route.
- Disconnect the link or shutdown the primary interface(s). In the curriculum example the serial interfaces on R2 are shutdown.
- Use a **`show ip route`** command to verify that the routing table is using the floating static route.
- Use a **`traceroute`** command to follow the traffic flow out the backup route.

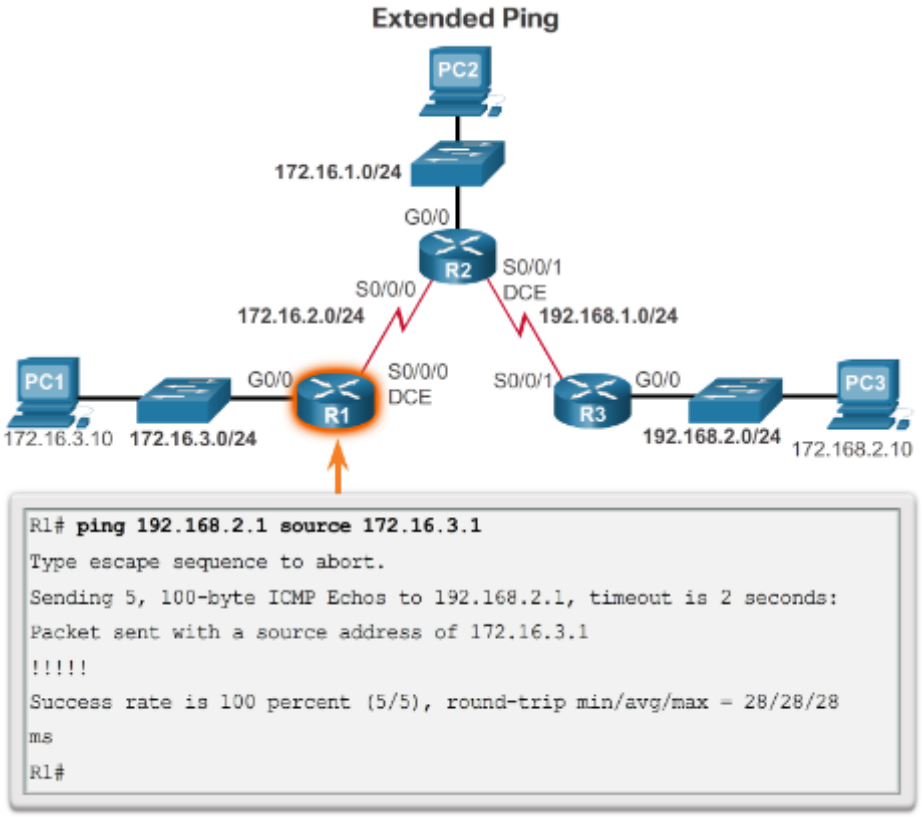
Static Routes and Packet Forwarding



Troubleshoot a Missing Route

IOS troubleshooting commands include:

- **ping**
- Extended **ping** enables you to specify the source IP address for the ping packets.
- **traceroute**
- **show ip route**
- **show ip interface brief**
- **show cdp neighbors detail**



Solve a Connectivity Problem

- Finding a missing (or misconfigured) route requires using the right tools in a methodical manner.
- Use the **ping** command to confirm the destination can't be reached.
- A **traceroute** would also reveal the closest router (or hop) that fails to respond as expected. In this case, the router would then send an Internet Control Message Protocol (ICMP) destination unreachable message back to the source.
- The next step is to investigate the routing table using the **show ip route** command. Look for missing or misconfigured routes.
- Incorrect static routes are a common cause of routing problems.