



Chapter 4: Routing Concepts



Routing & Switching

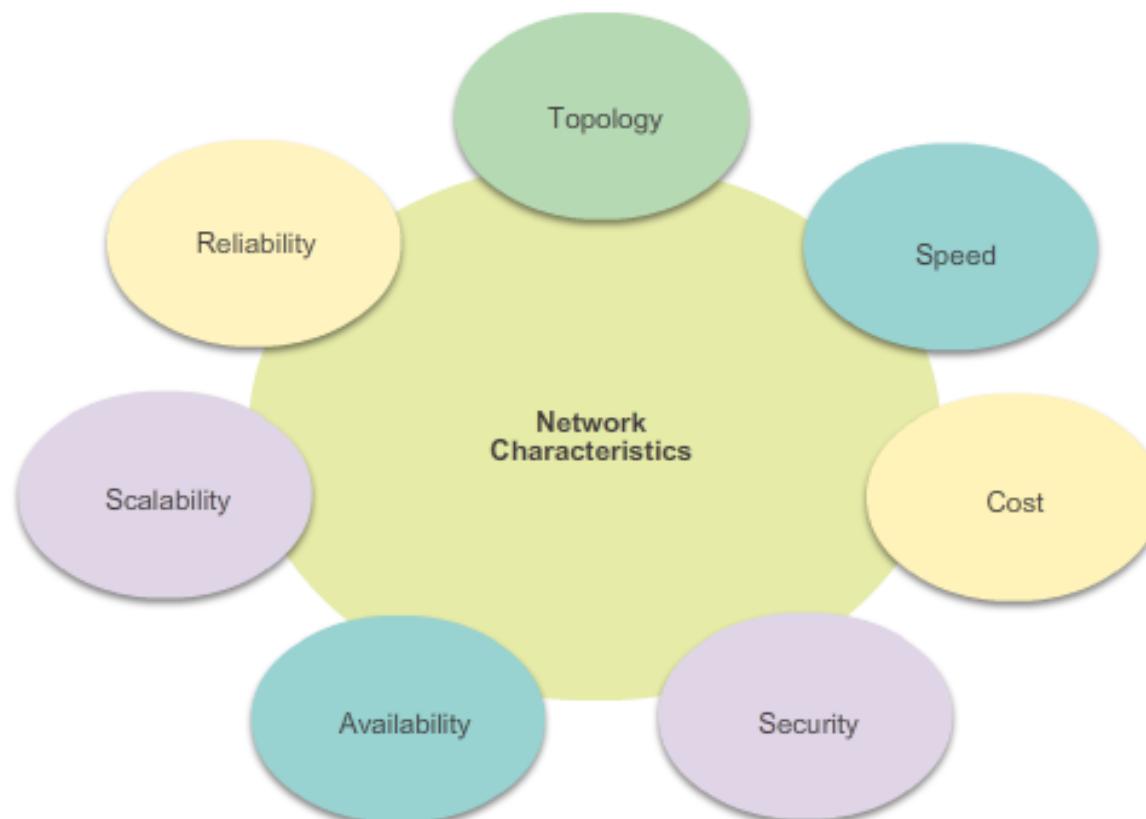
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Functions of a Router

Characteristics of a Network

Network Characteristics



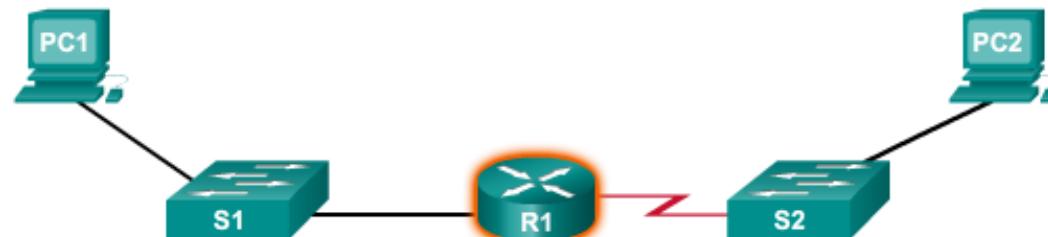


Functions of a Router

Why Routing?

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

Routers Route Packets



```
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.



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)

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 Choose Best Paths

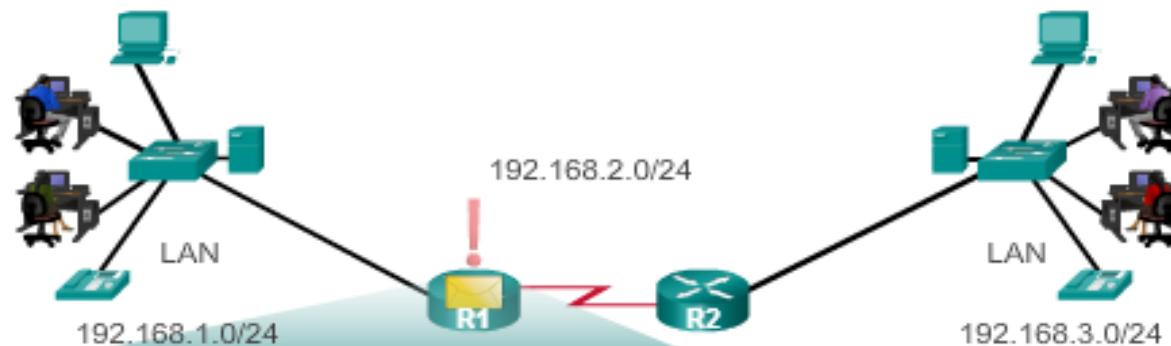
- Routers use static routes and dynamic routing protocols to learn about remote networks and build their routing tables.
- Routers use routing tables to determine the best path to send packets.
- Routers encapsulate the packet and forward it to the interface indicated in routing table.



Functions of a Router

Routers Choose Best Paths

How the Router Works



```
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
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P - periodic downloaded static route

Gateway of last resort is not set

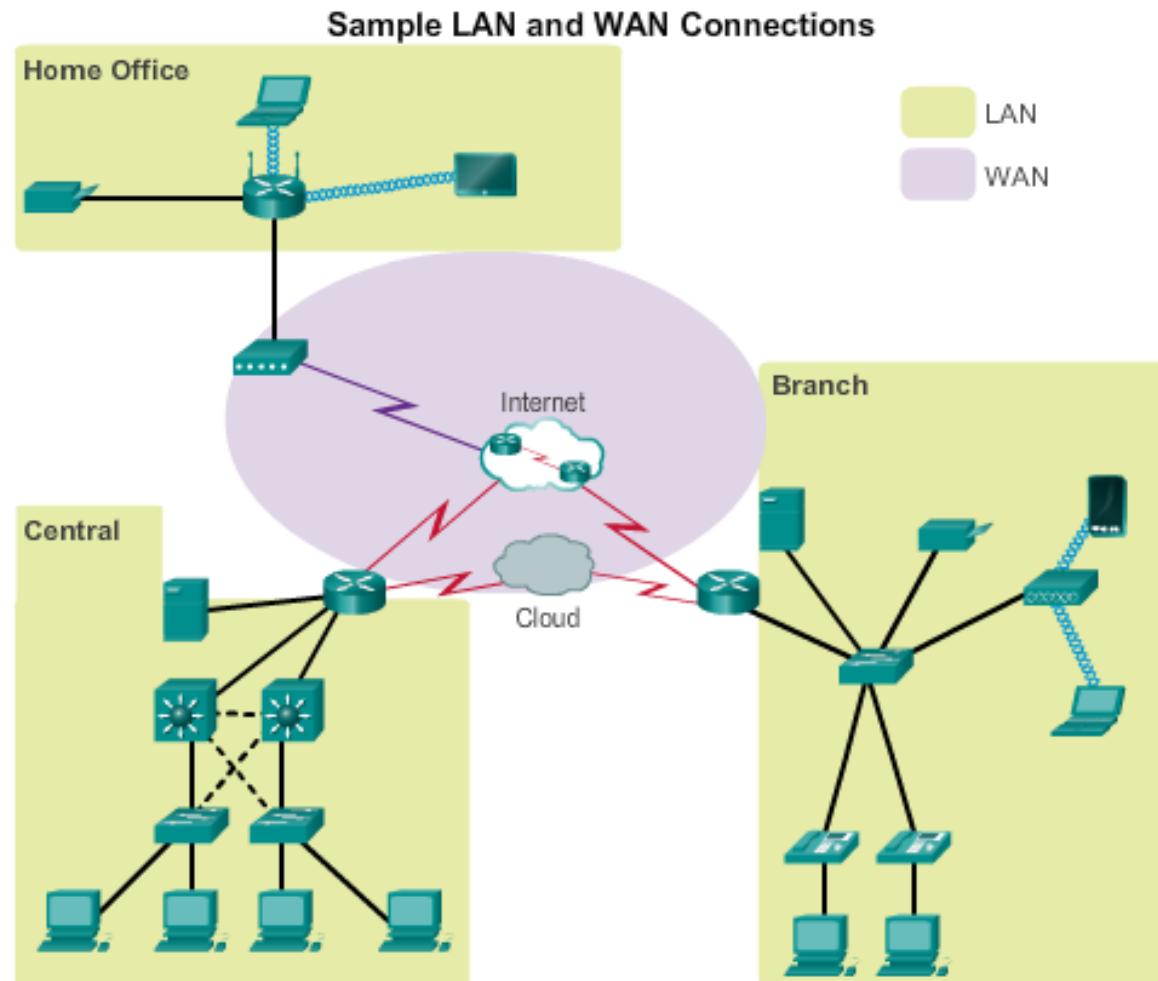
```
C 192.168.1.0/24 is directly connected, FastEthernet0/0
C 192.168.2.0/24 is directly connected, Serial0/0/0
S 192.168.3.0/24 is directly connected, Serial0/0/0
```

Routers use the routing table like a map to discover the best path for a given network.



Connect Devices

Connect to a Network





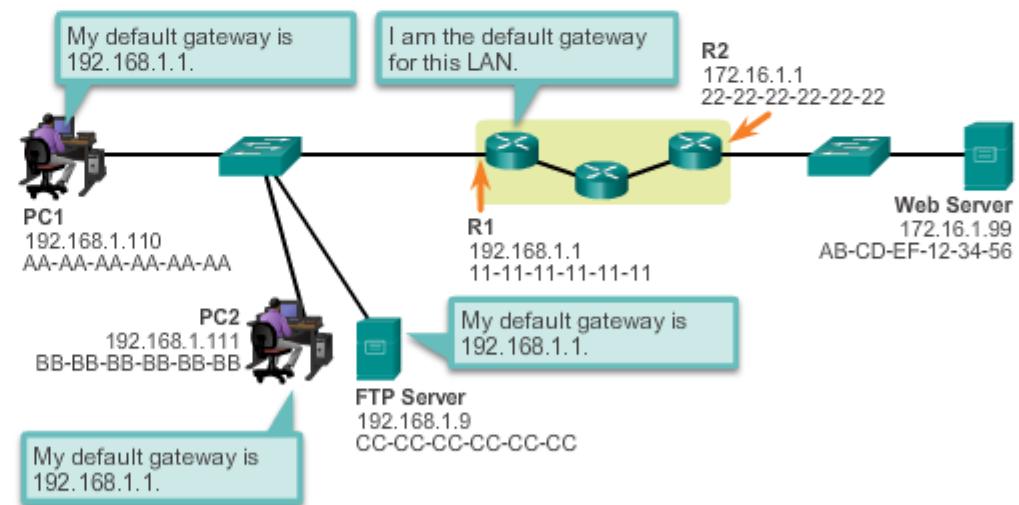
Connect Devices

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 MAC Address	Data
11-11-11-11-11-11	AA-AA-AA-AA-AA-AA	192.168.1.110	172.16.1.99	



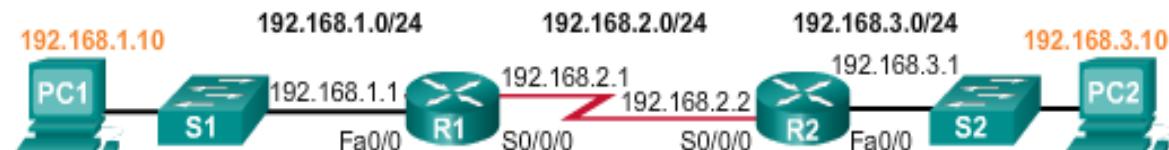


Connect Devices

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 – 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).

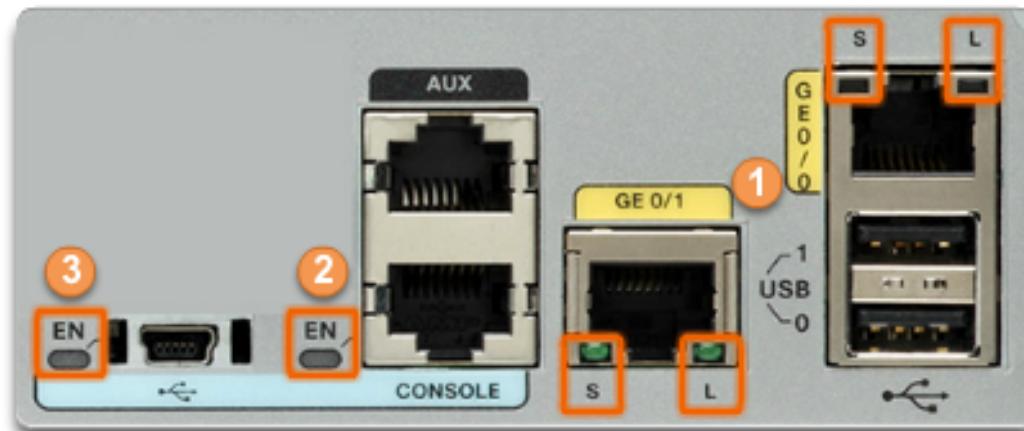
- Most hosts acquire their IP address information through DHCP.
- DHCP services can be provided by Cisco routers.



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

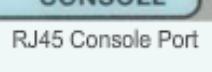


Connect Devices

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	 CONSOLE	 Tera Term
 USB Type-A Port	 USB-to-RS-232 Serial Port Adapter  Console Cable	 RJ45 Console Port	 PuTTY
	 USB Type-A to USB Type-B (Mini-B) Cable	 USB Type-B (Mini-B USB) Console Port	

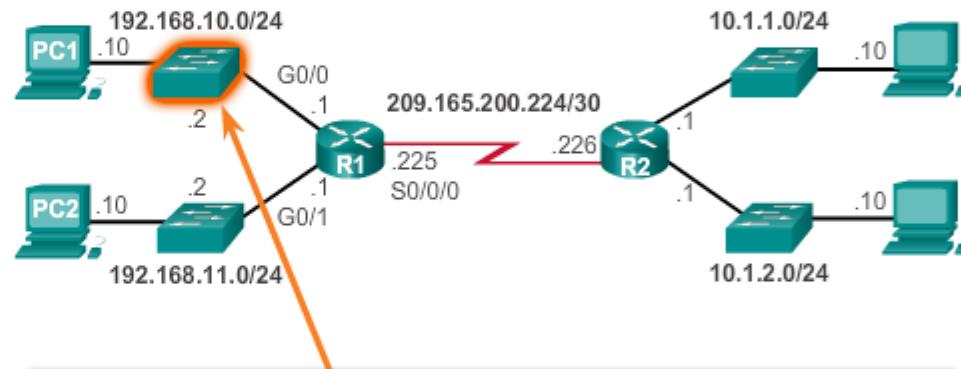


Connect Devices

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.
- **Save the Configuration**

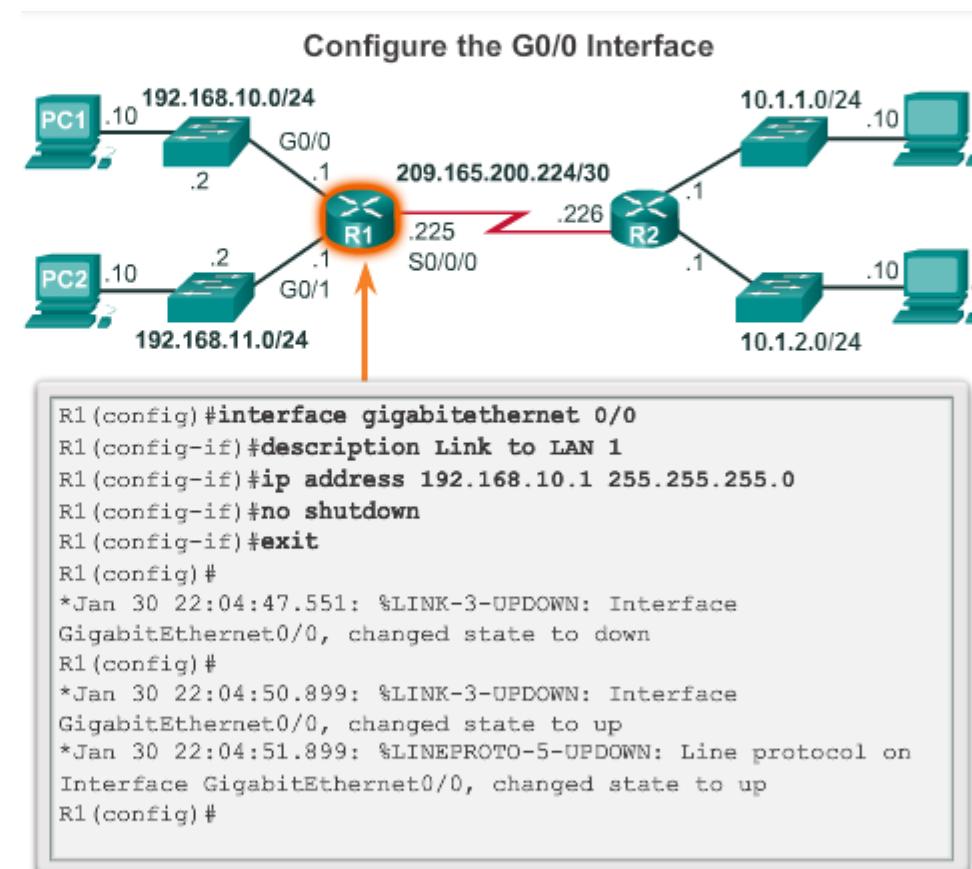


Basic Settings on a Router

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.





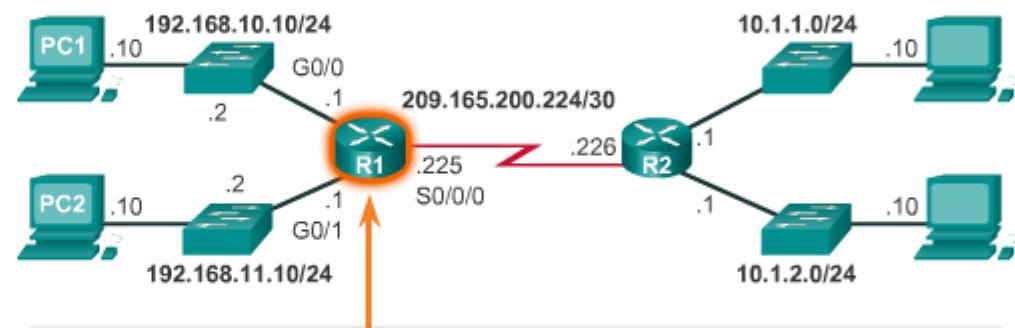
Basic Settings on a Router

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.

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

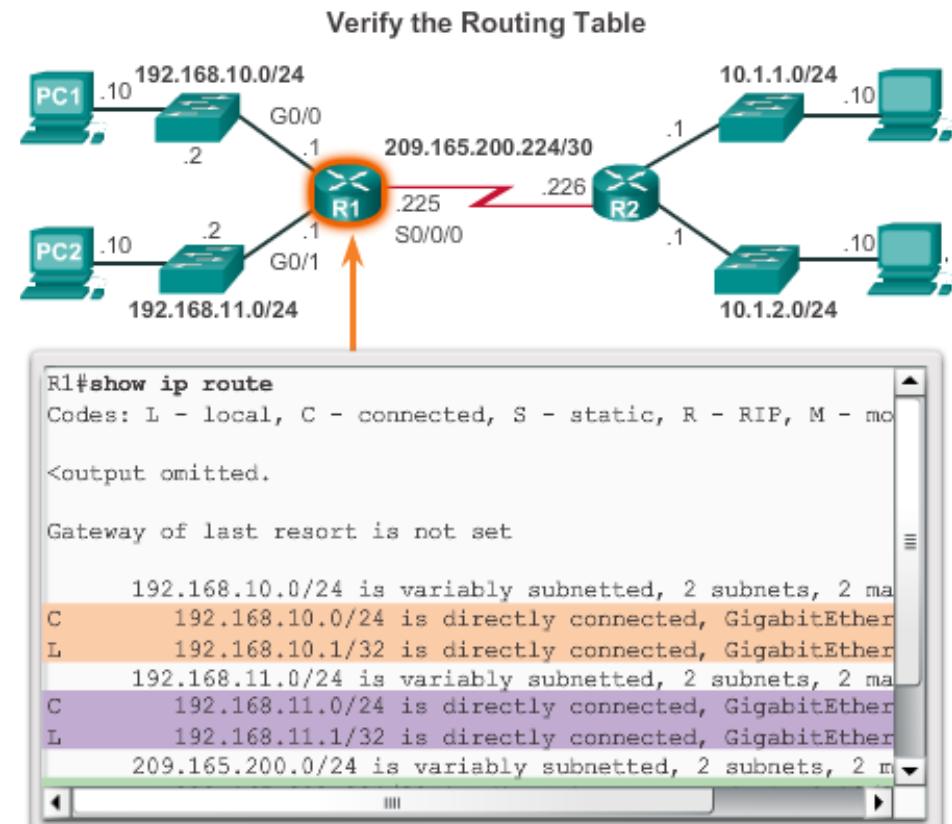
Verify Interface Settings

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

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

Show commands are used to gather more detailed interface information:

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





Verify Connectivity of Directly Connected Networks

Command History Feature

The command history feature temporarily stores a list of executed commands for access:

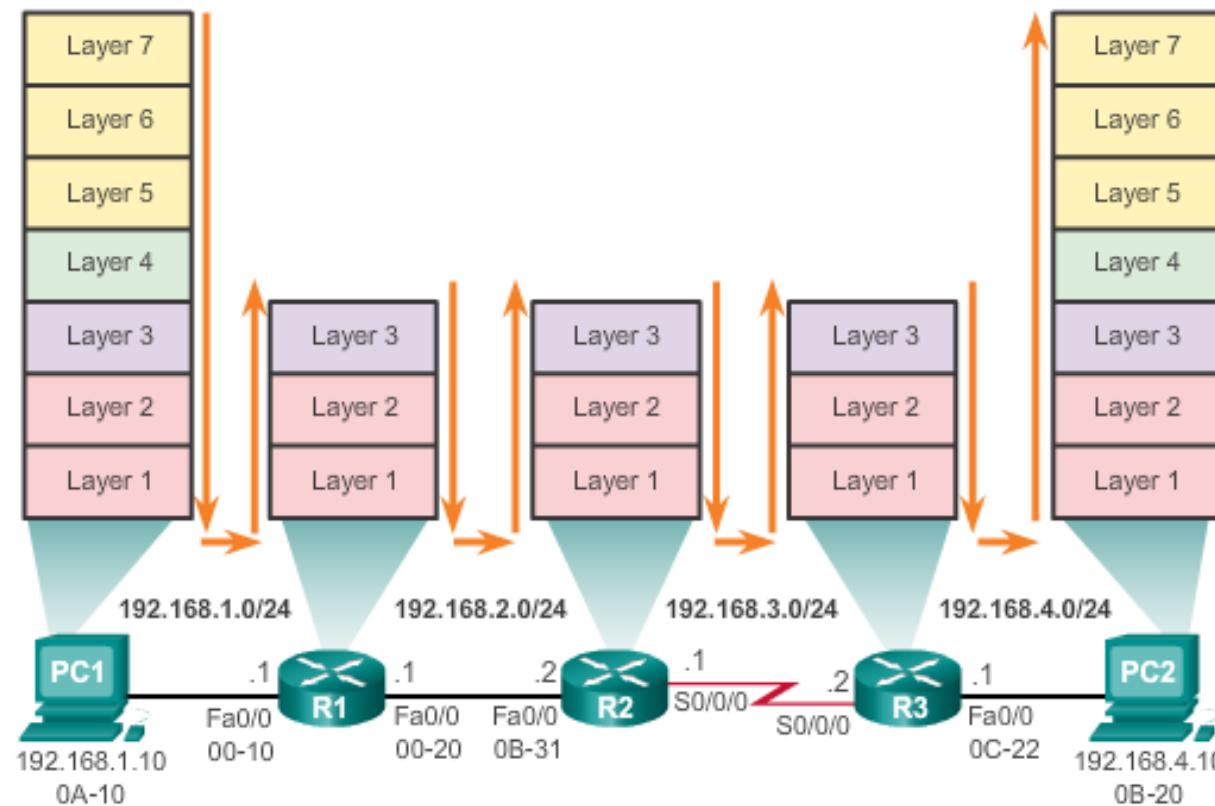
- To recall commands press **Ctrl+P** or the **UP Arrow**.
- To return to more recent commands press **Ctrl+N** or the **Down Arrow**.
- By default, command history is enabled and the system captures the last 10 commands in the buffer. Use the **show history** privileged EXEC command to display the buffer contents.
- Use the **terminal history size** user EXEC command to increase or decrease size of the buffer.



Switching Packets between Networks

Router Switching Functions

Encapsulating and De-Encapsulating Packets



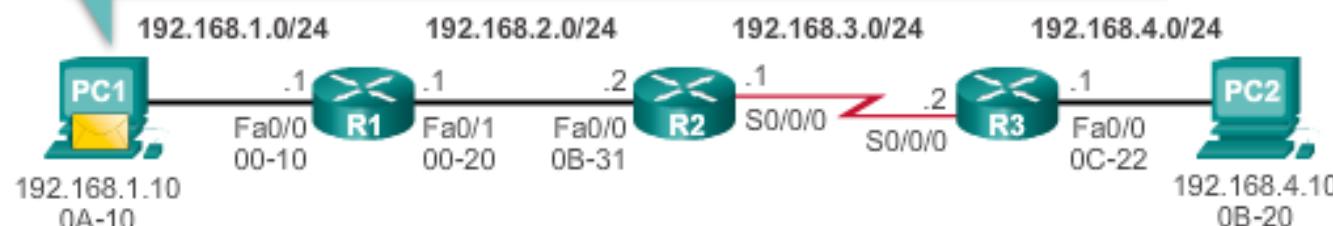


Switching Packets between Networks

Send a Packet

PC1 Sends a Packet to PC2

Because PC2 is on different network, I will encapsulate the packet and send it to the router on MY network. Let me find that MAC address....



Layer 2 Data Link Frame

Packet's Layer 3 data

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

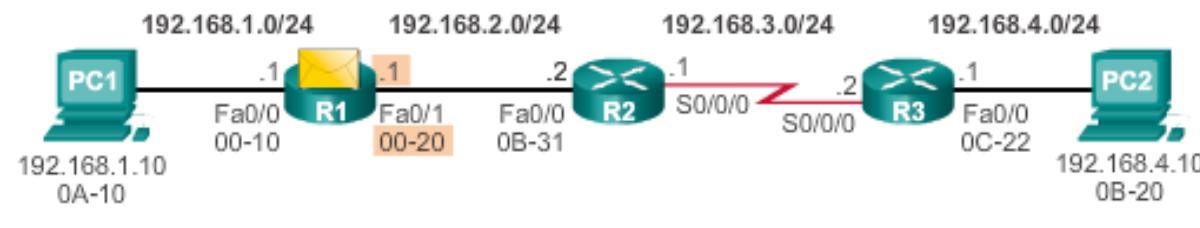
PC1's ARP Cache for R1

IP Address	MAC Address
192.168.1.1	00-10



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

R1's Routing Table

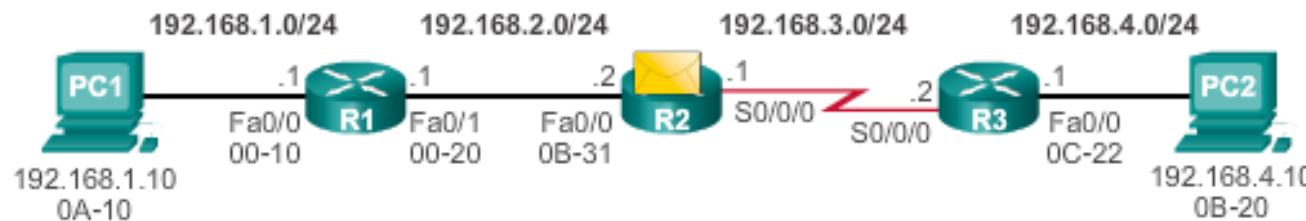
Network	Hops	Next-hop-IP	Exit Interface
192.168.1.0/24	0	Dir. Connect.	Fa0/0
192.168.2.0/24	0	Dir. Connect.	Fa0/1
192.168.3.0/24	1	192.168.2.2	Fa0/1
192.168.4.0/24	2	192.168.2.2	Fa0/1



Switching Packets between Networks

Packet Routing

R2 Forwards the Packet to R3



Layer 2 Data Link Frame

Packet's Layer 3 data

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

R2's Routing Table

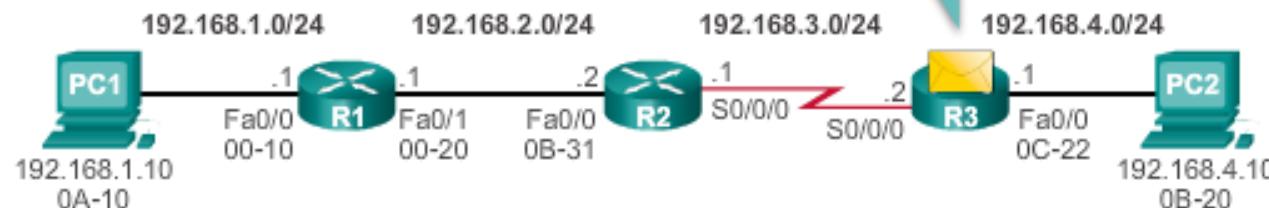
Network	Hops	Next-hop-IP	Exit Interface
192.168.1.0/24	1	192.168.3.1	Fa/0/0
192.168.2.0/24	0	Dir. Connect.	Fa/0/0
192.168.3.0/24	0	Dir. Connect.	S0/0/0
192.168.4.0/24	1	192.168.3.2	S0/0/0



Switching Packets between Networks Reach the Destination

R3 Forwards the Packet to PC2

My ARP table tells me that PC2 uses MAC address 0B-20.



Layer 2 Data Link Frame

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 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	192.168.3.1	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

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



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:

- 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

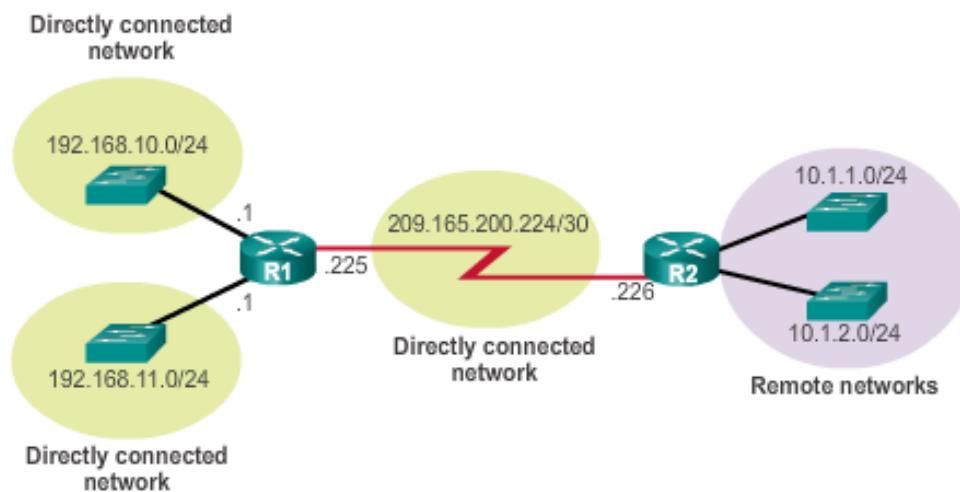


The Routing Table

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





The Routing Table

Routing Table Sources

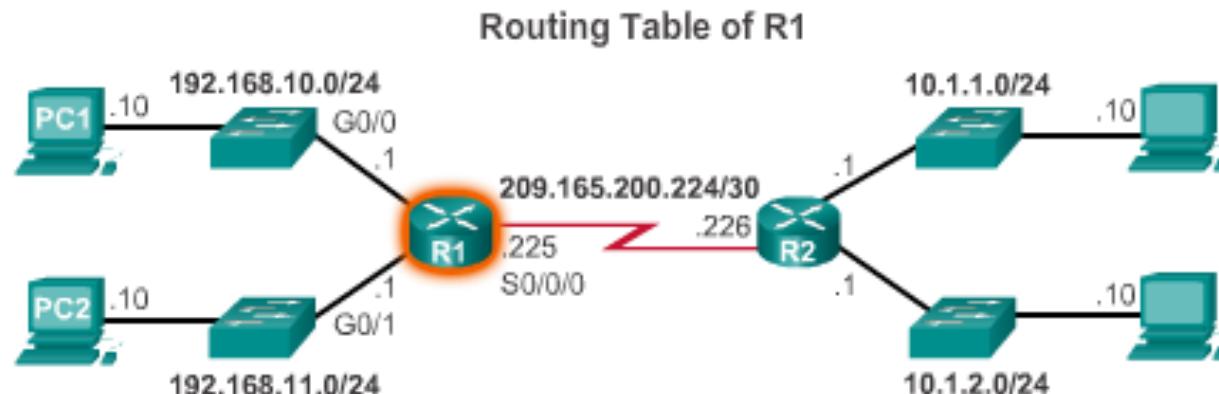
The **show ip route** command is used to display the contents of the routing table:

- **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 EIGRP or OSPF are implemented and networks are identified.



The Routing Table

Routing Table Sources



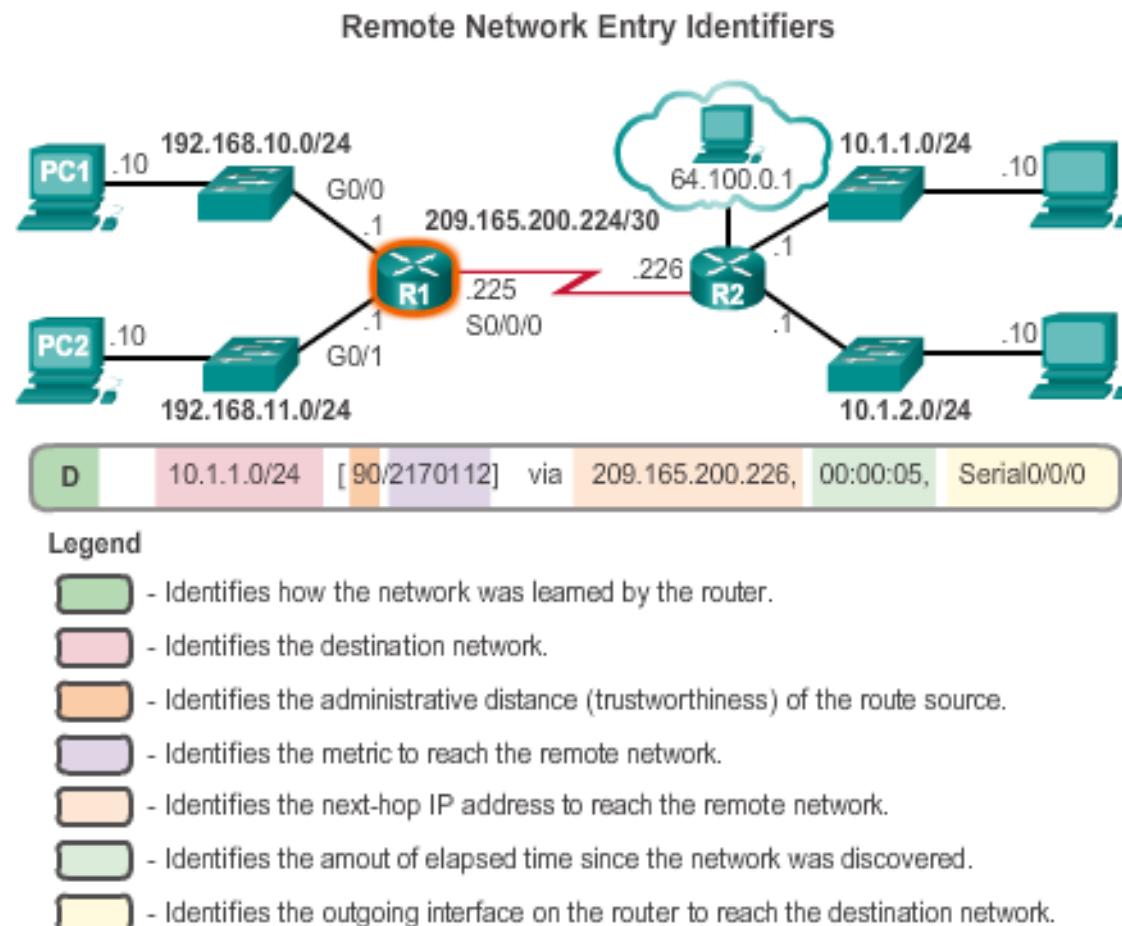
```
R1#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
      D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
      N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
      E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
      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.



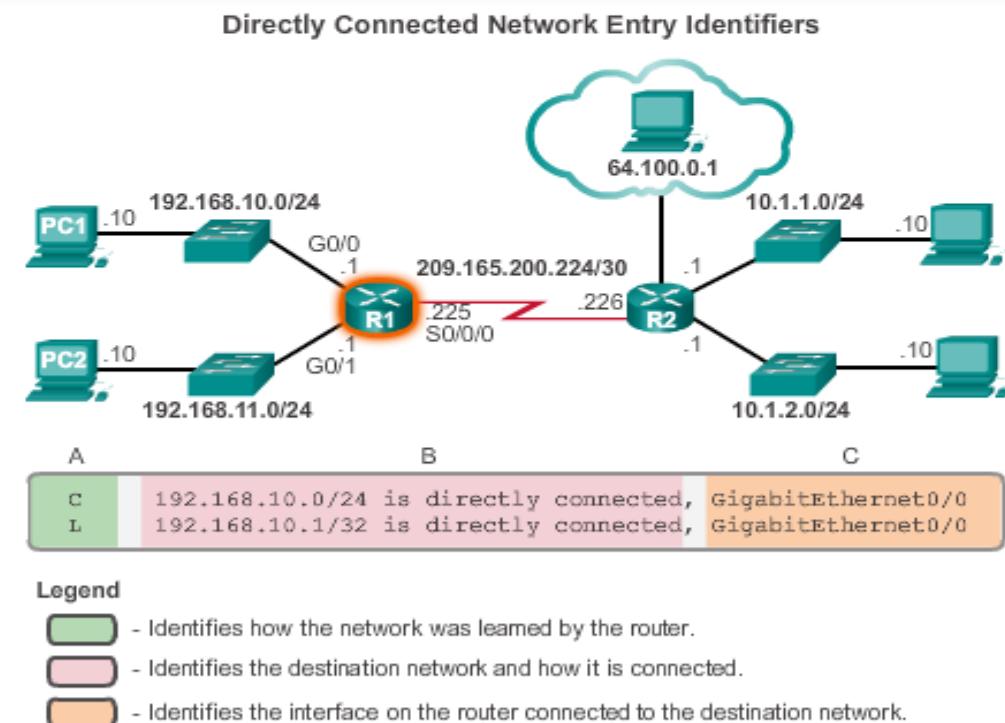


Directly Connected Routes

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)
- Directly Connected (C)

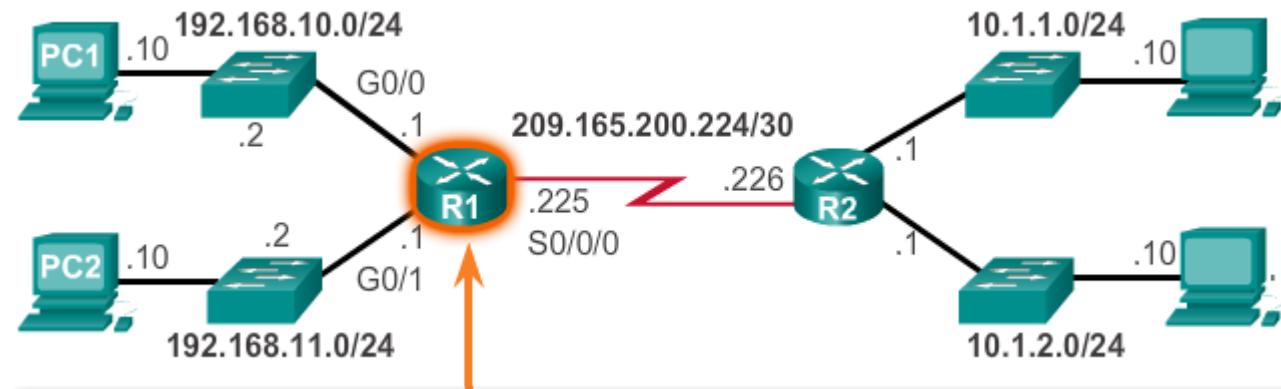




Directly Connected Routes

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
```



Statically Learned Routes

Static Routes

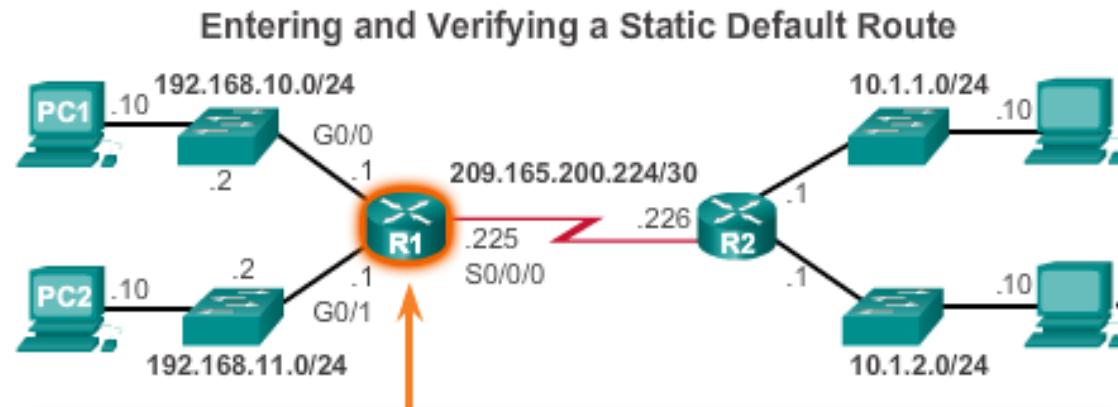
Static routes and default static routes can be implemented after directly connected interfaces are added to the routing table:

- 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

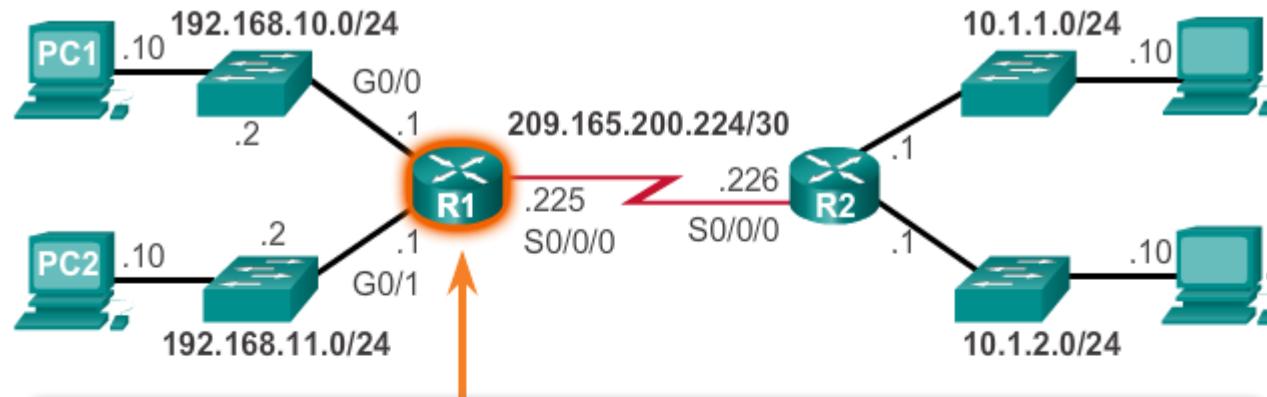
R1#show ip route | begin Gateway
Gateway of last resort is 0.0.0.0 to network 0.0.0.0

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
```



Statically Learned Routes

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

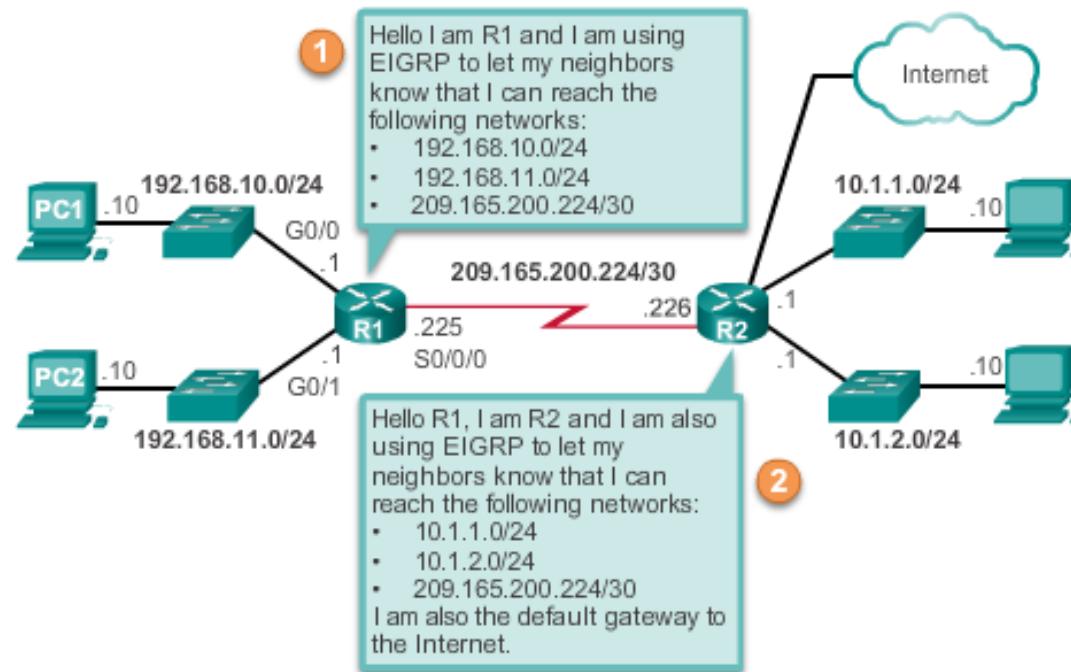
S* 0.0.0.0/0 is directly connected, Serial0/0/0
    192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C      192.168.10.0/24 is directly connected, GigabitEthernet0/0
L      192.168.10.1/32 is directly connected, GigabitEthernet0/0
    192.168.11.0/24 is variably subnetted, 2 subnets, 2 masks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



Dynamic Routing Protocols

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.





Dynamic Routing Protocols

IPv4 Routing Protocols

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

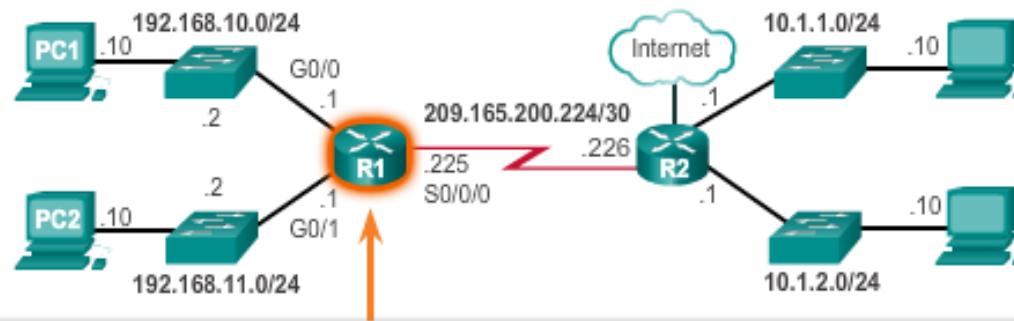
- **EIGRP** – Enhanced Interior Gateway Routing Protocol
- **OSPF** – Open Shortest Path First
- **IS-IS** – Intermediate System-to-Intermediate System
- **RIP** – Routing Information Protocol



Dynamic Routing Protocols

IPv4 Routing Protocols

Verify Dynamic Routes



```
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#
```

