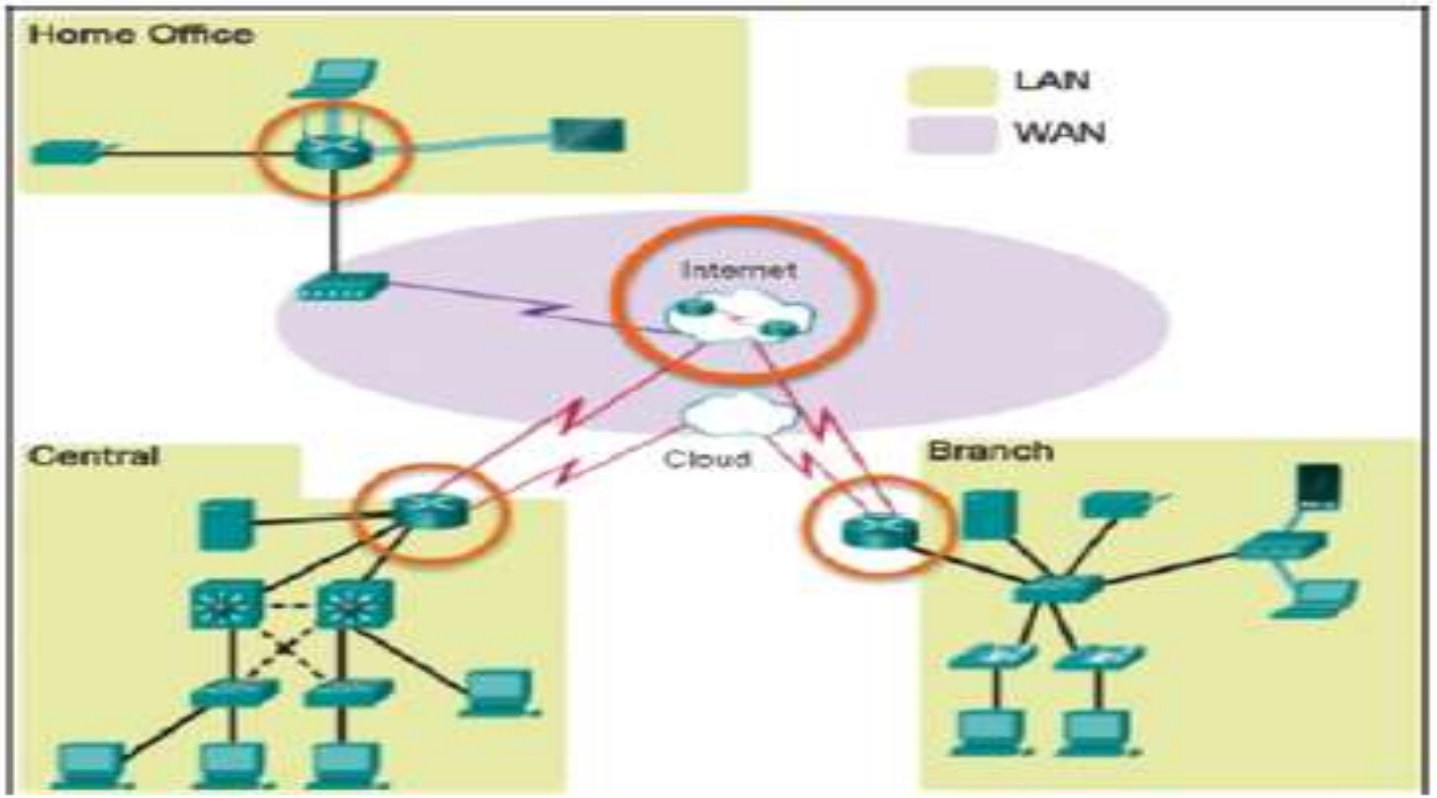
Chapter 3
Router Concepts and Configuration

Outline

- Introduction
- Interconnected Networks
- Routing Protocols

Why Routing?

- Communication between networks would not be possible without a router determining the best path to the destination and forwarding traffic to the next router along that path.
- Router is responsible for the routing of traffic between networks.



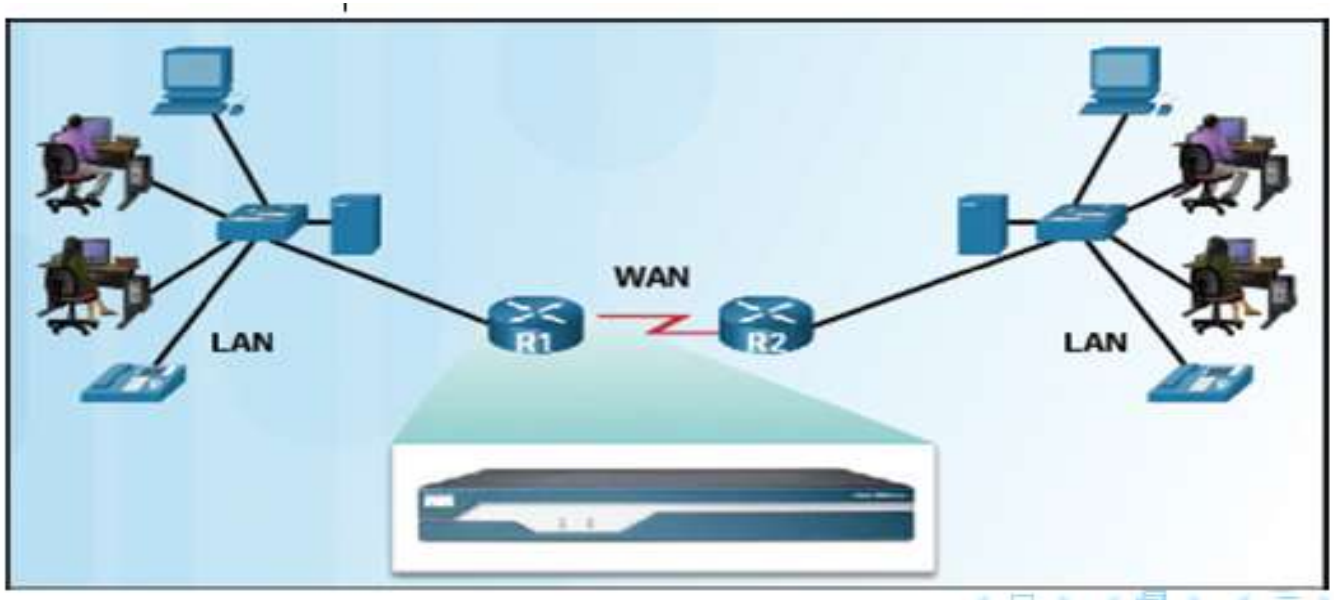
Routers are Computers

- Routers are specialized computers containing the following required components to operate:
  - CPU
  - OS - Routers use Cisco IOS
  - Memory and storage (RAM, ROM, NVRAM, Flash)
- Routers utilize the following memory:

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 Interconnect Networks

- Routers can connect multiple networks.
  - Routers have multiple interfaces that each belong to a different IP network.
- Each network that a router connects to typically requires a separate interface.
- These interfaces are used to connect a combination of both LANs and WANs.



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.
  - **Static Routing**
    - routes are described by fixed paths through a data network.
    - the routes are entered by system administrator.
  - **Dynamic Routing**
    - Protocols and algorithms are used to automatically propagate routing information.
    - Routers will communicate the adjacent routers which informs the network to which each router is connected.
    - These routers adjusts automatically in a network when traffic changes.

Document Network Addressing

- When designing a new network or mapping an existing network, **document the network.**
- Network Documentation should include at least the following in a topology diagram and addressing table:
  - Device names
  - Interfaces used in the design
  - IP addresses and subnet masks
  - Default gateway addresses

- This information is captured by creating two useful network documents:

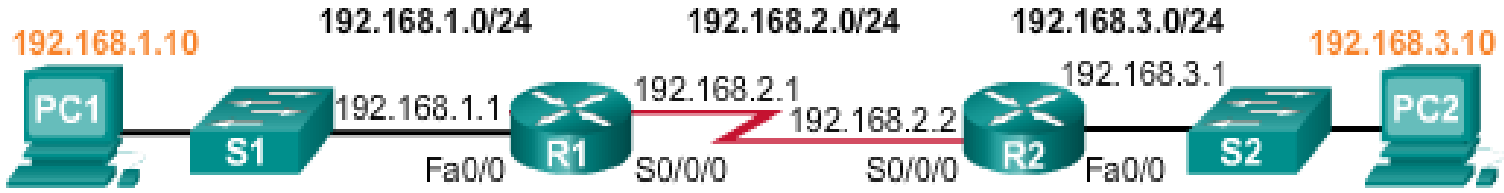
1. Topology diagram

- provides a visual reference that indicates the physical connectivity and logical Layer 3 addressing.
- Often created using diagramming software, such as Microsoft Visio.

Document Network Addressing…

2. An addressing table

- Is used to capture device names, interfaces, IPv4 addresses, subnet masks, and default gateway addresses,



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

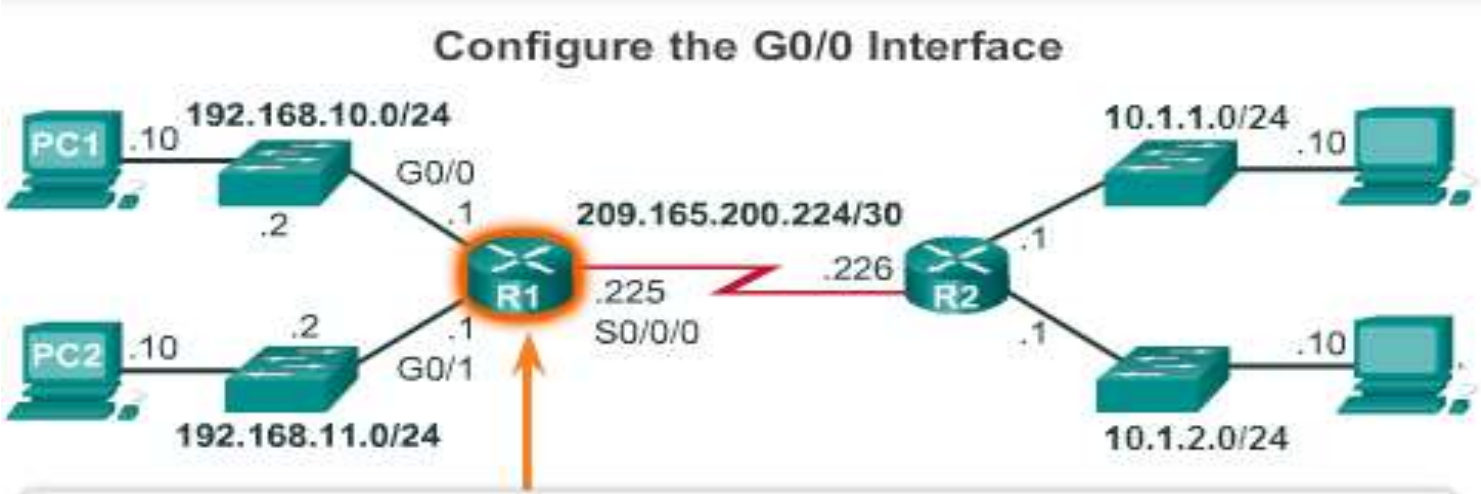
Configure Basic Router Settings…

```
Router# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
Router(config)# hostname R1
R1(config)# enable secret class
R1(config)# line console 0
R1(config-line)# password cisco
R1(config-line)# login
R1(config-line)# exit
R1(config)# line vty 0 4
R1(config-line)# password cisco
R1(config-line)# login
R1(config-line)# exit
R1(config)# service password-encryption
R1(config)# banner motd $ Authorized Access Only! $
R1(config)# end
R1# copy running-config startup-config
Destination filename [startup-config]?
Building configuration... [OK]
R1#
```

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.

Configure Router Interfaces…




```
R1(config)#interface gigabitethernet 0/0
R1(config-if)#description Link to LAN 1
R1(config-if)#ip address 192.168.10.1 255.255.255.0
R1(config-if)#no shutdown
R1(config-if)#exit
R1(config)#
*Jan 30 22:04:47.551: %LINK-3-UPDOWN: Interface
GigabitEthernet0/0, changed state to down
R1(config)#
*Jan 30 22:04:50.899: %LINK-3-UPDOWN: Interface
GigabitEthernet0/0, changed state to up
*Jan 30 22:04:51.899: %LINEPROTO-5-UPDOWN: Line protocol on
Interface GigabitEthernet0/0, changed state to up
R1(config)#
```

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.

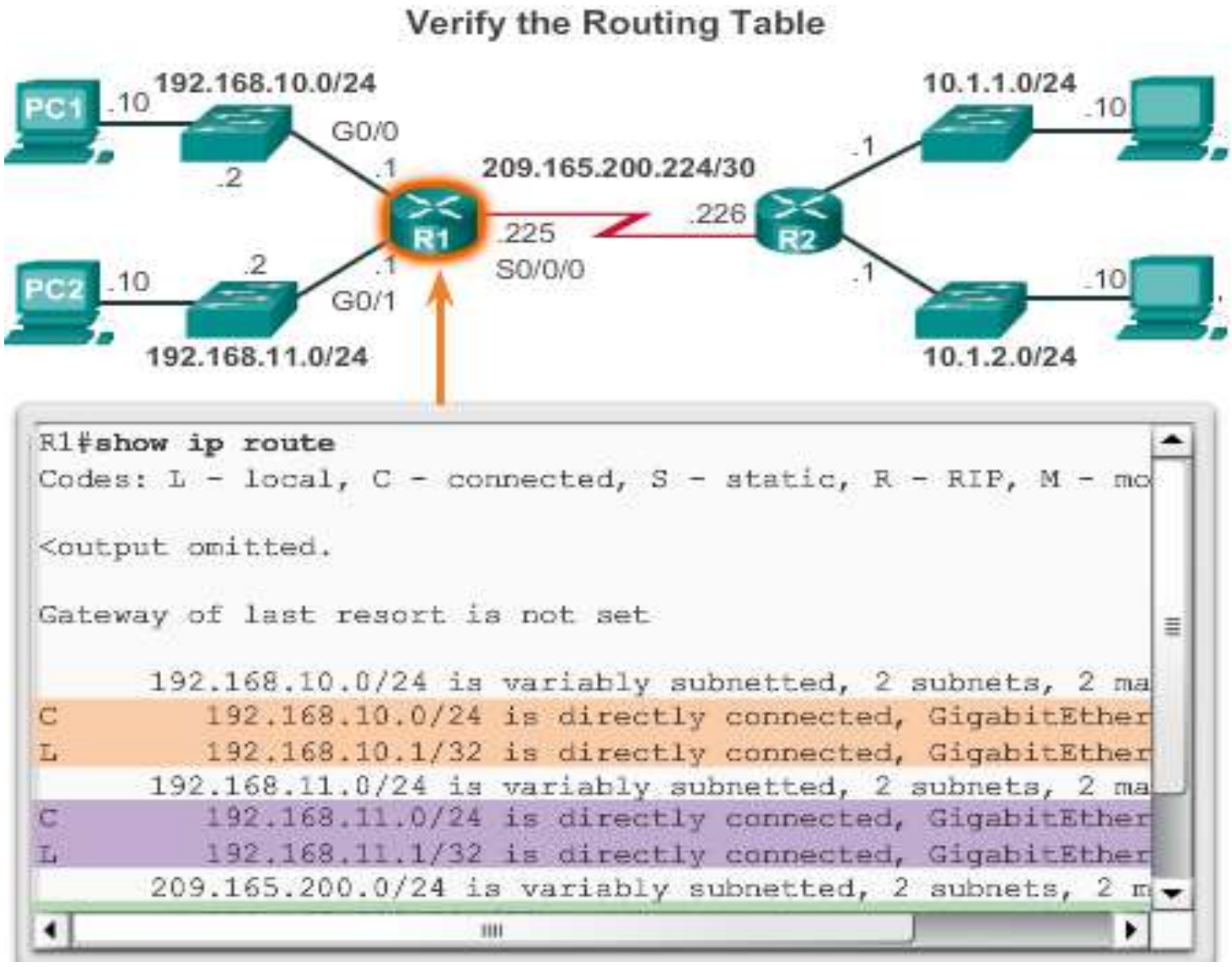
Configure the Loopback0 Interface


```
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 Interface Settings

- It is always important to know how to troubleshoot and verify whether a device is configured correctly.
- There are several **privileged EXEC mode *show*** commands that can be used to verify the operation and configuration of an interface.
  - **show ip interfaces brief**
    - *Displays a summary for all interfaces.*
  - **show ip route**
    - *Displays the contents of the IPv4 routing table stored in RAM.*
  - **show running-config interface**
    - *Displays the commands configured on the specified interface.*
  - **show** commands to gather more detailed interface information.
    - **show interfaces**
    - **show ip interfaces**

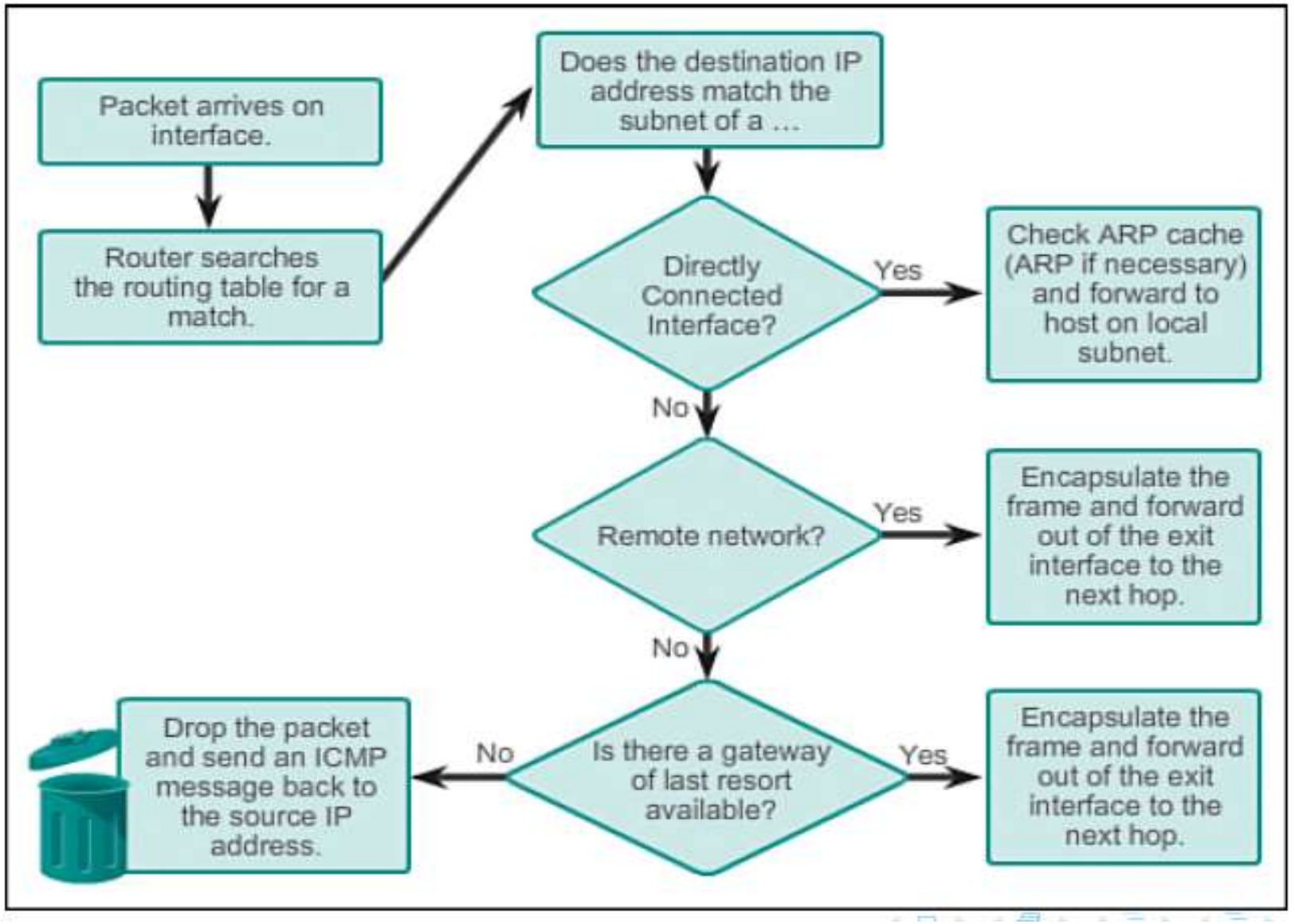
Verify Interface Settings…



Routing Decisions

- A primary function of a router is to **determine the best path** to use to send packets.
- To determine the best path, the router searches its routing table for a network address that matches the destination IP address of the packet.
- Search results in one of three **path determinations**:
  - **Directly connected network**
  - **Remote network**
  - **No route determined**

Routing Decisions…

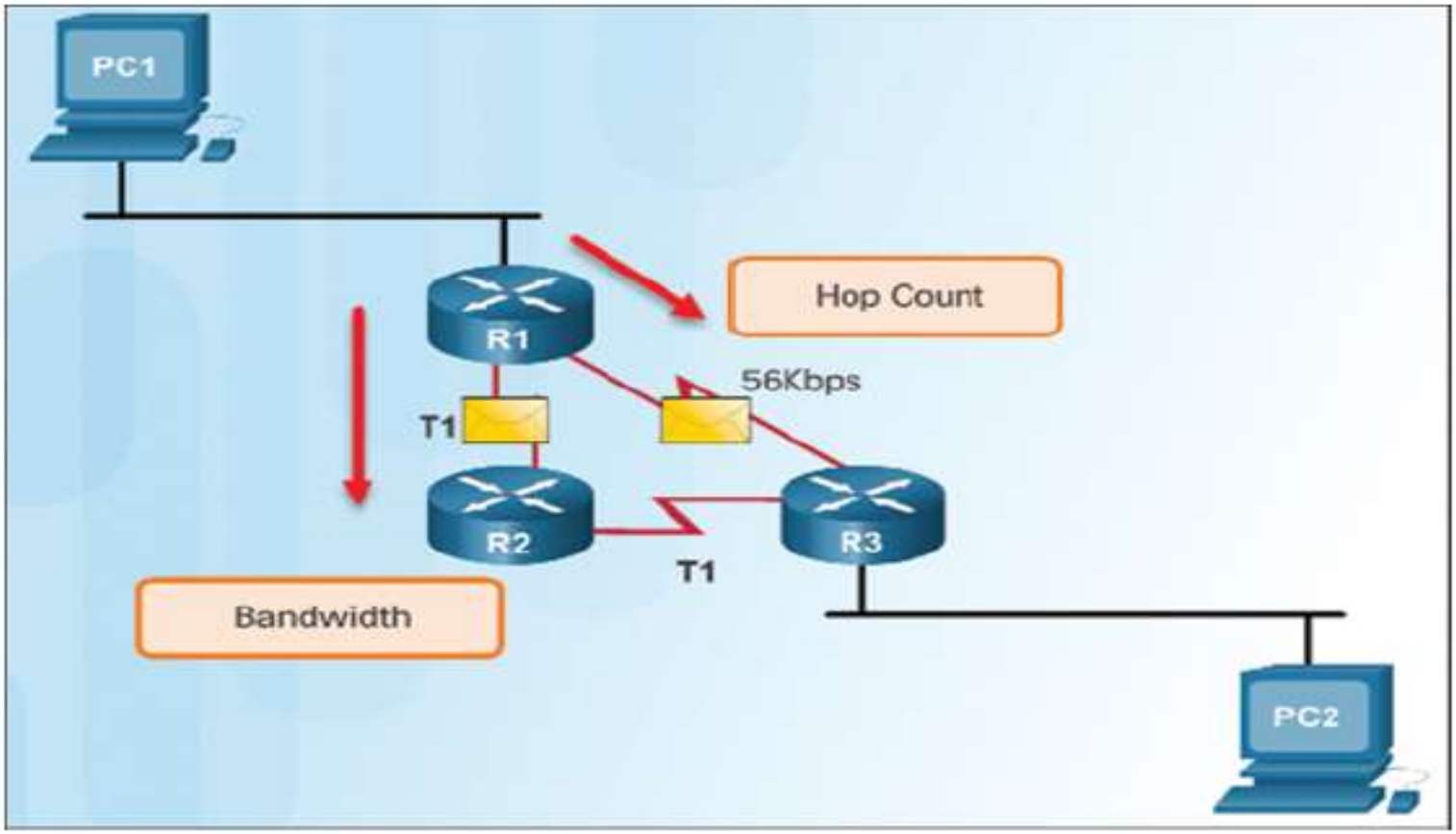


Best Path

- 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 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

Best Path…

Path depending on the metric



Paths with identical metrics???

Administrative Distance

- A router can be configured with multiple routing protocols (RIP, OSPF, EIGRP,…)
- The routing table may have more than one route source for the same destination network
- Each routing protocol may decide on a different path to reach the destination based on the metrics of that routing protocol
- How does the router know which route to use?
- Cisco IOS uses what is known as the AD to determine the route to install into the IP routing table

Administrative Distance

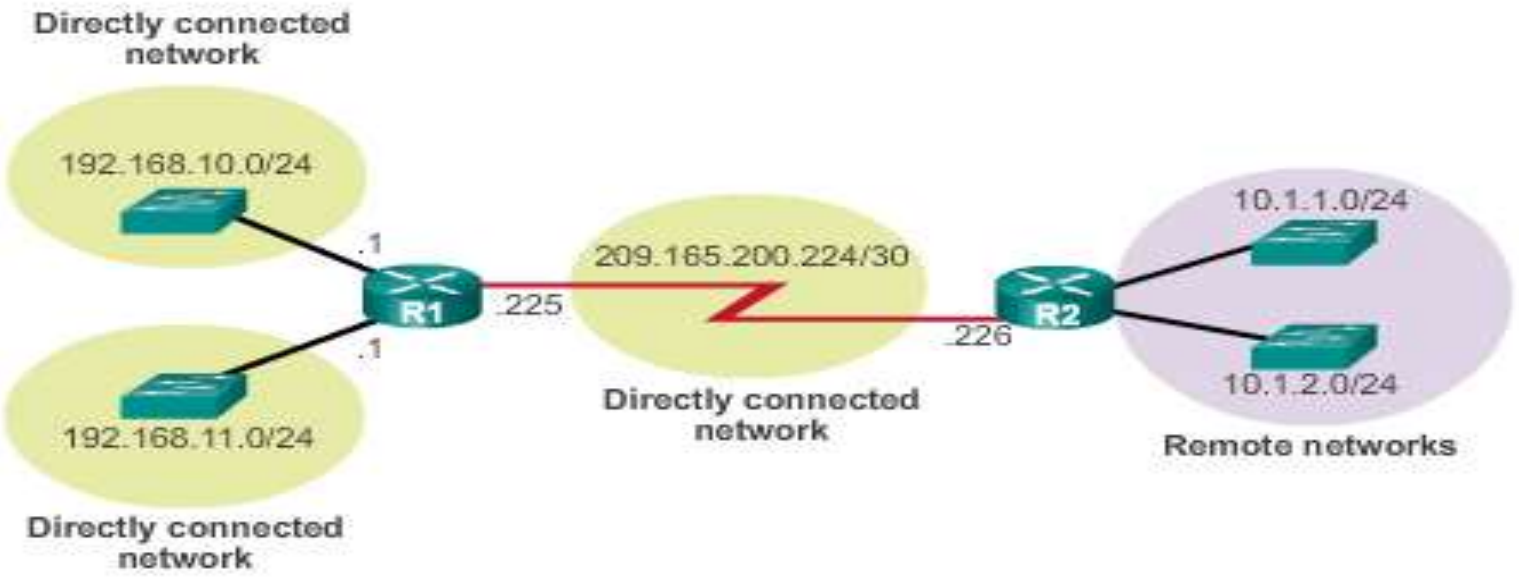
- Administrative Distance (AD) represents the "trustworthiness" of the route source
- The Lower the AD the more trustworthy the route.

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

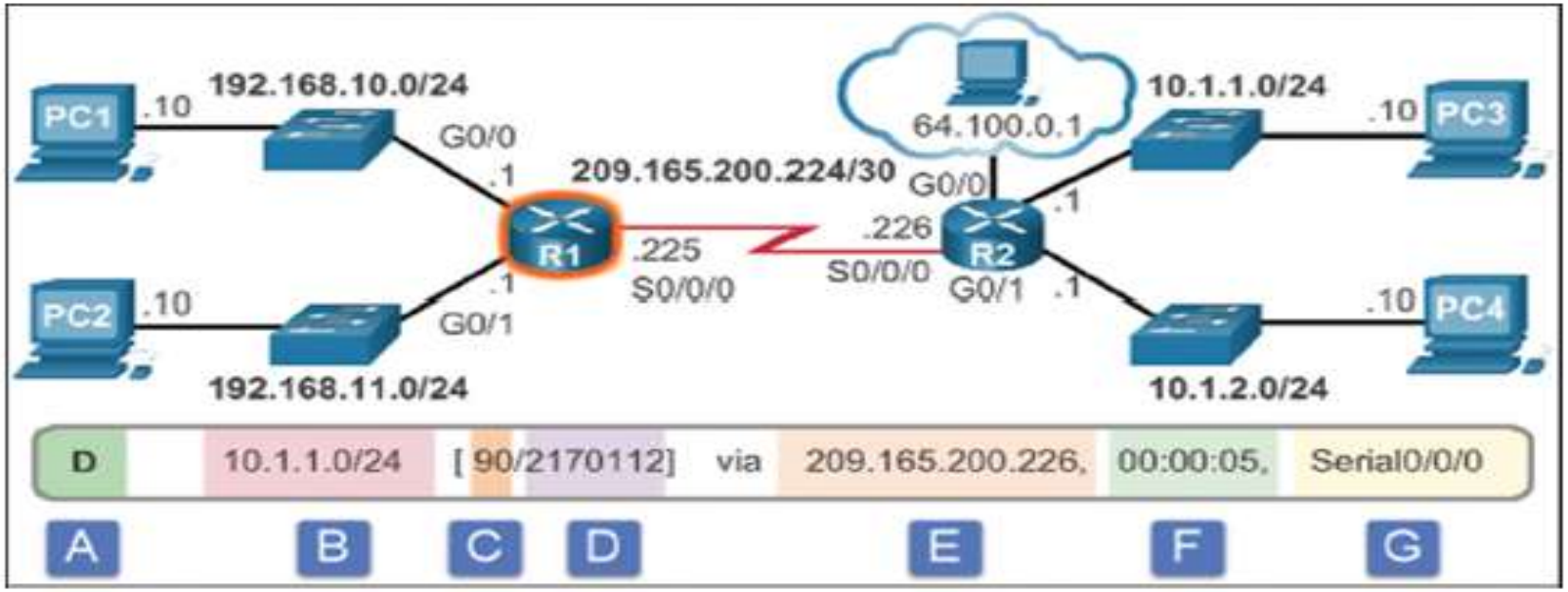
The Routing Table

- Is at the heart of making routing decisions
- Is a file stored in RAM that contains information about
  - Directly Connected Routes
  - Remote Routes
  - Network or Next hop Associations



Remote Network Routing Entry Identifiers

- The figure below displays an IPv4 routing table entry on R1 for the route to remote network 10.1.1.0



The entry identifies the following information:

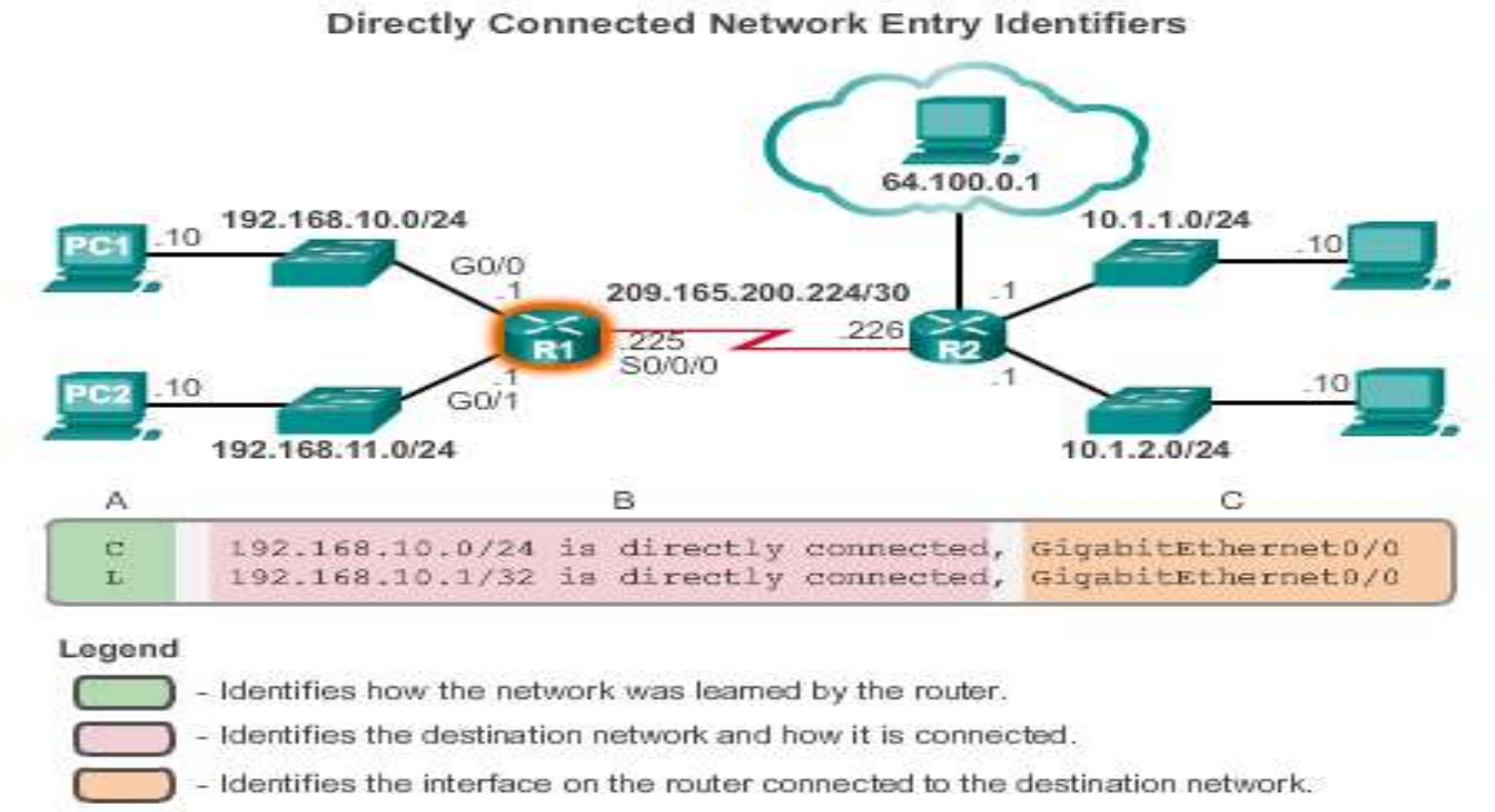
- **Route source** (**A**)
  - Identifies how the route was learned.
- **Destination network** (**B**)
  - Identifies the address of the remote network.

Remote Network Routing Entry Identifiers

- **Administrative distance** (**C**)
  - Identifies the trustworthiness of the route source.
  - Lower values indicate preferred route source.
- **Metric** (**D**)
  - Identifies the value assigned to reach the remote network.
  - Lower values indicate preferred routes.
- **Next-hop** (**E**)
  - Identifies the IPv4 address of the next router to forward the packet to.
- **Route timestamp** (**F**)
  - Identifies how much time has passed since the route was learned.
- **Outgoing interface** (**G**)
  - Identifies the exit interface to use to forward a packet toward the final destination.

Directly Connected Routes

- 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 Routes…

- The routing table entry for directly connected interface is simpler than the entries for remote networks

Directly Connected Network Entry Identifiers

- **Route Source (A)**
  - Identifies how the network was learned by the router.
  - Directly connected interfaces have two route source codes.
    - ‘C’ identifies a directly connected network.
    - ‘L’ identifies the IPv4 address assigned to the router’s interface.
- **Destination Network (B)**
  - Identifies the destination network and how it is connected.
- **Outgoing Interface (C)**
  - Identifies the exit interface to use when forwarding packets to the destination network.

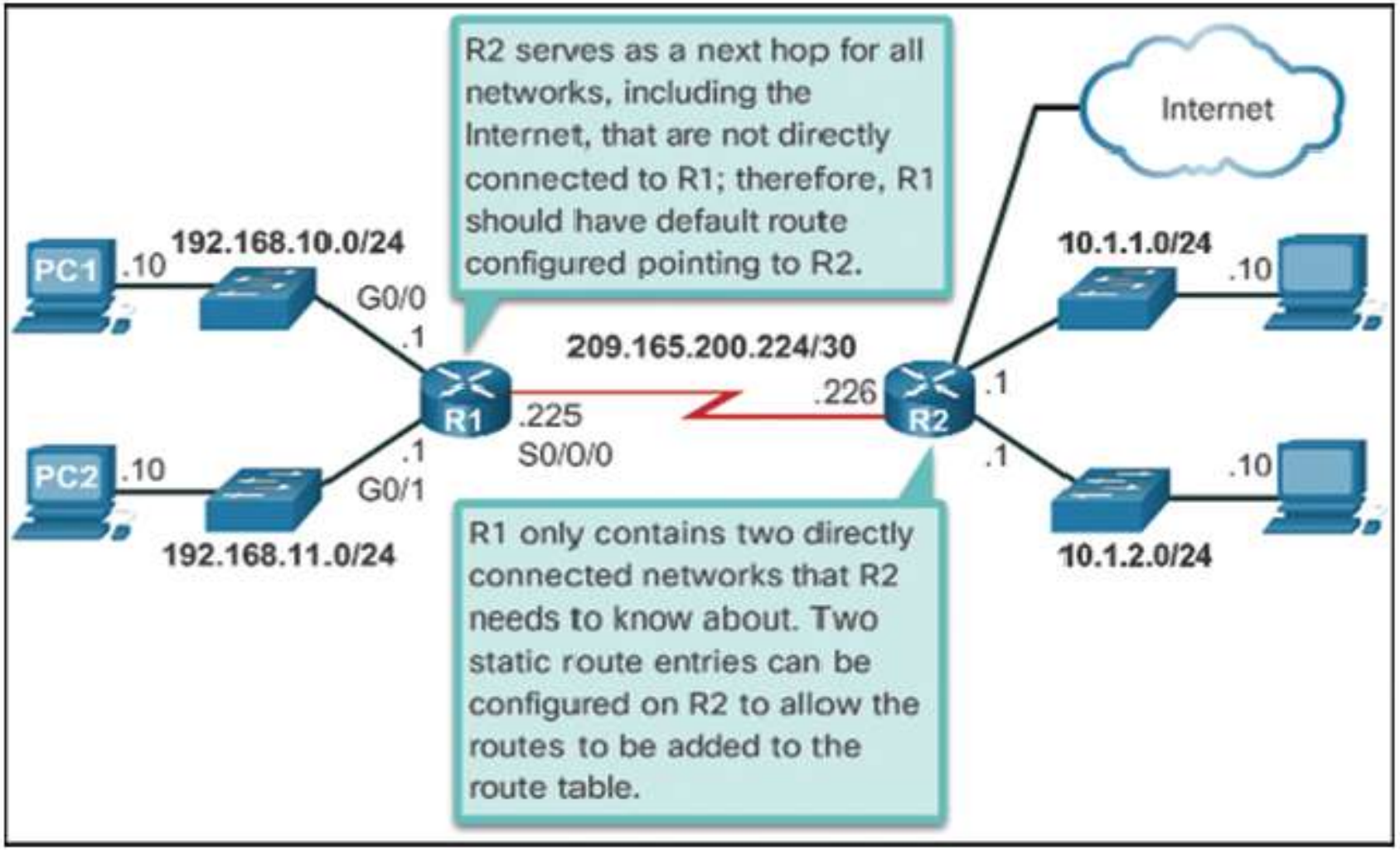
Statically Learned Routes

Static Routes

- After directly connected interfaces are configured and added to the routing table, static or dynamic routing can be implemented.
- 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.
- Two common types of static routes in the routing table:
  - Static route to a specific network
    - **ip route** network-mask 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

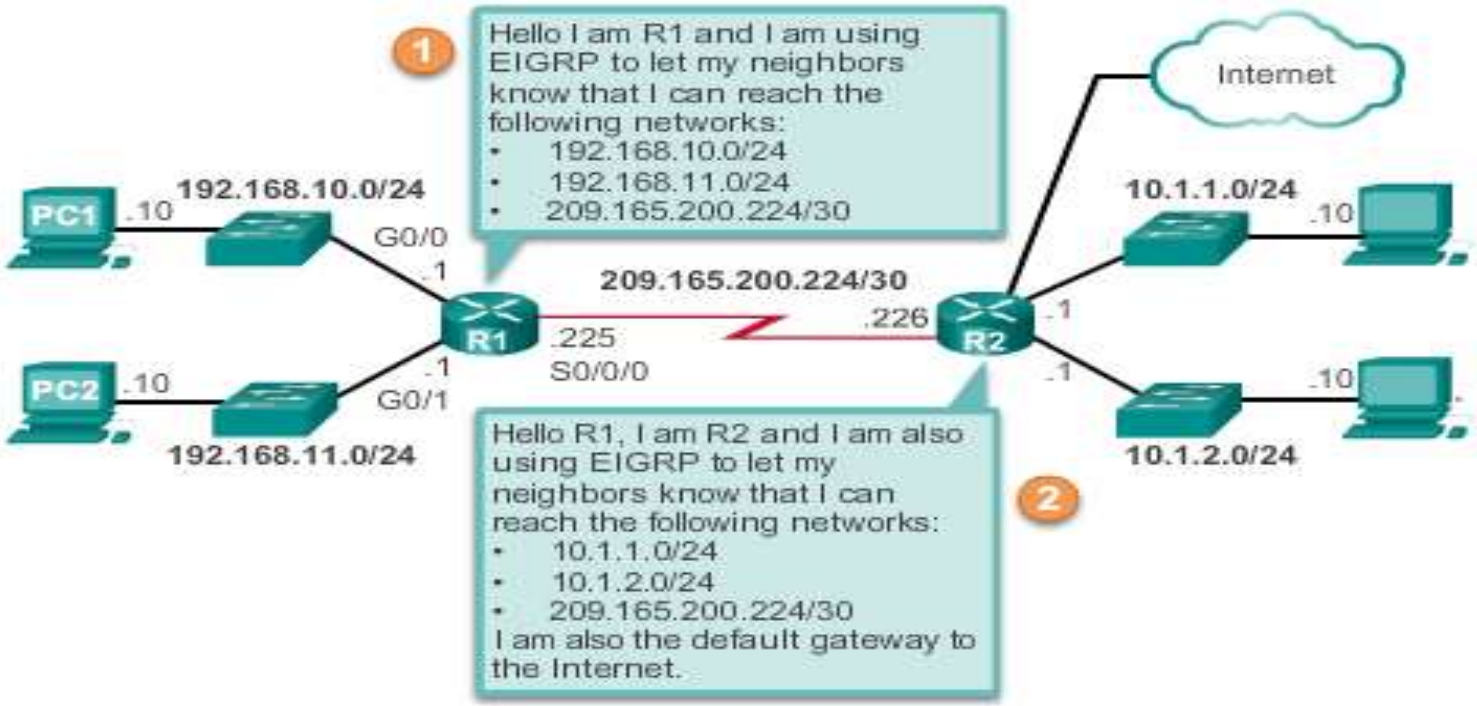
Statically Learned Routes

Static and Default Route



Dynamic Routing Protocols

- 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

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)

Why Use Static Routing?

Static routing provides some advantages over dynamic routing, including:

- Easy to implement in a small network.
- 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.
- No routing algorithm or update mechanisms are required.
  - Therefore, extra resources (CPU and memory) are not required.

Why Use Static Routing…

Static routing has the following disadvantages:

- Initial configuration and maintenance is time-consuming.
- Configuration is error-prone, especially in large networks.
- Administrator intervention is required to maintain changing route information.
- If a link fails, a static route cannot reroute traffic.
  - Therefore, manual intervention is required to re-route traffic.
- Does not scale well with growing networks; maintenance becomes cumbersome.
- Requires complete knowledge of the whole network for proper implementation.

When to Use Static Routes

Static routing has three primary uses:

- Providing ease of routing table maintenance in smaller networks that are not expected to grow significantly.
- Routing to and from stub networks.
  - A stub network is a network accessed by a single route, and the router has no other neighbors.
- Accessing 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.
  - Default routes are used to send traffic to any destination beyond the next upstream router.

Static Routes

IP route command syntax

```
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.

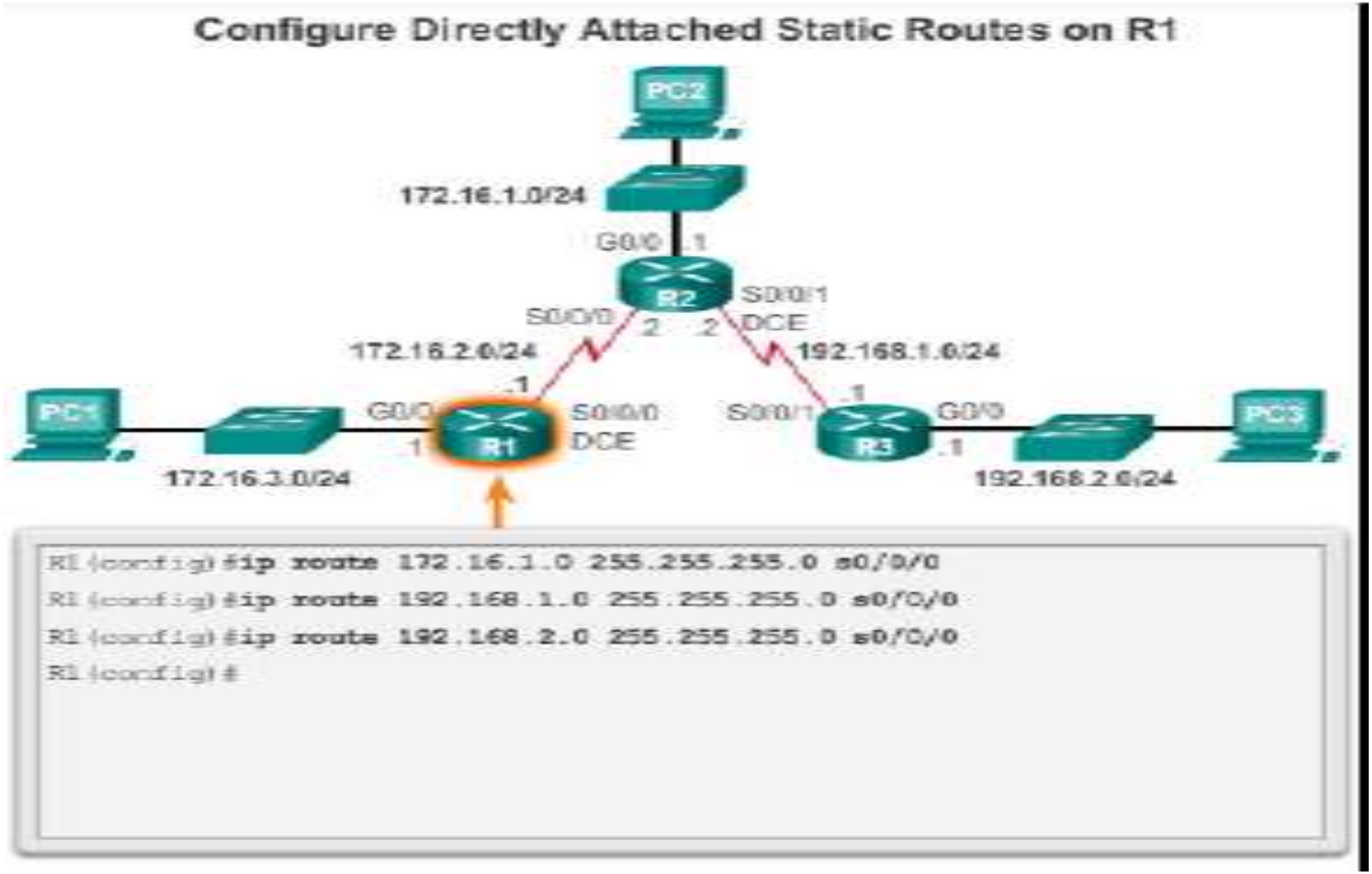
Configure IPv4 Static Routes

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 IPv4 Default Routes

Configure a Next-HOP Static Route



Configure IPv4 Static Routes…

Configure Default Static Route

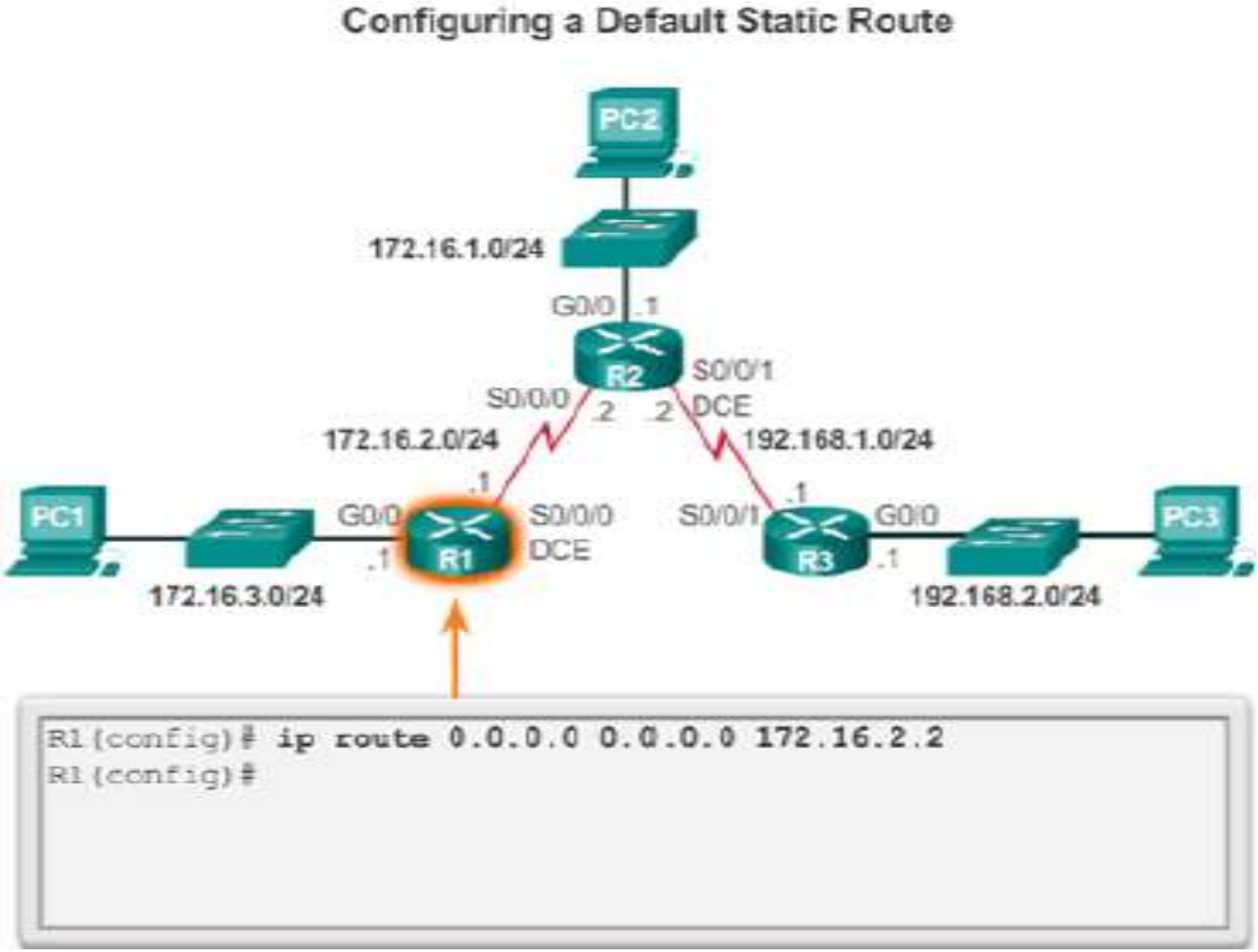
Default Static Route Syntax

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

Parameter	Description
0.0.0.0	Matches any network address.
0.0.0.0	Matches any subnet mask.
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 IPv4 Static Routes…

Default Static Route



Troubleshoot IPv4 Static and Default Route Configuration

Common IOS trouble-shooting commands include:

- *ping*
- *traceroute*
- *show ip route*
- *show ip interface brief*
- *show cdp neighbors detail*

Dynamic Routing Protocol

- **Routing Protocols**
  - Allow routers to dynamically share information about remote networks and automatically add this information to their own routing tables.
  - Used to facilitate the exchange of routing information between routers
  - Used to facilitate the exchange of routing information between routers
- Purpose of dynamic routing protocols includes:
  - Discovery of remote networks
  - Maintaining up-to-date routing information
  - Choosing the best path to destination networks
  - Ability to find a new best path if the current path is no longer available

Dynamic Routing Protocol Operation

Main components of dynamic routing protocols include:

1. Data structures

- Routing protocols typically use tables or databases for its operations. This information is kept in RAM.

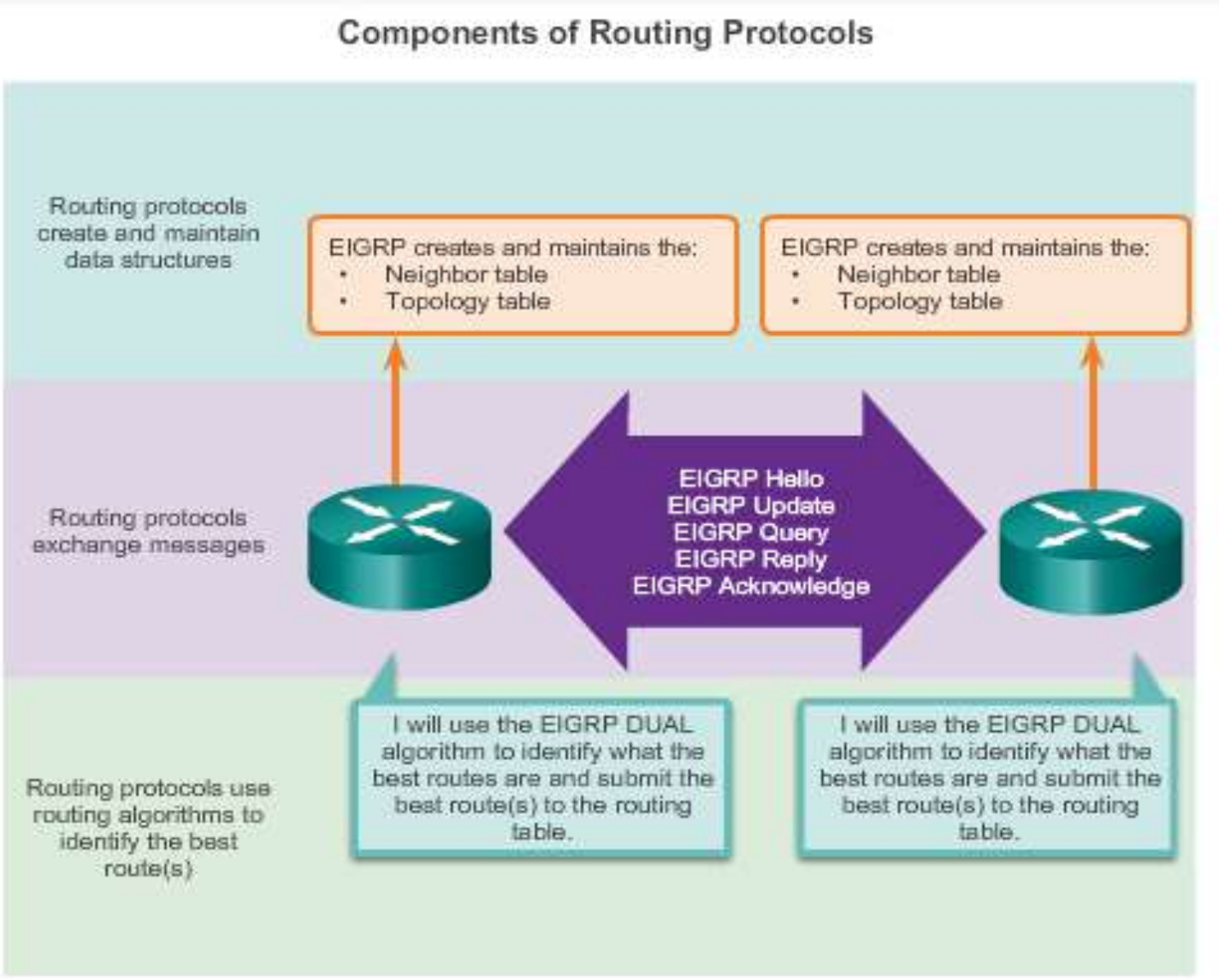
2. Routing protocol messages

- Routing protocols use various types of messages to discover neighboring routers, exchange routing information, and other tasks to learn and maintain accurate information about the network.

3. Algorithm

- Routing protocols use algorithms for facilitating routing information for best path determination.

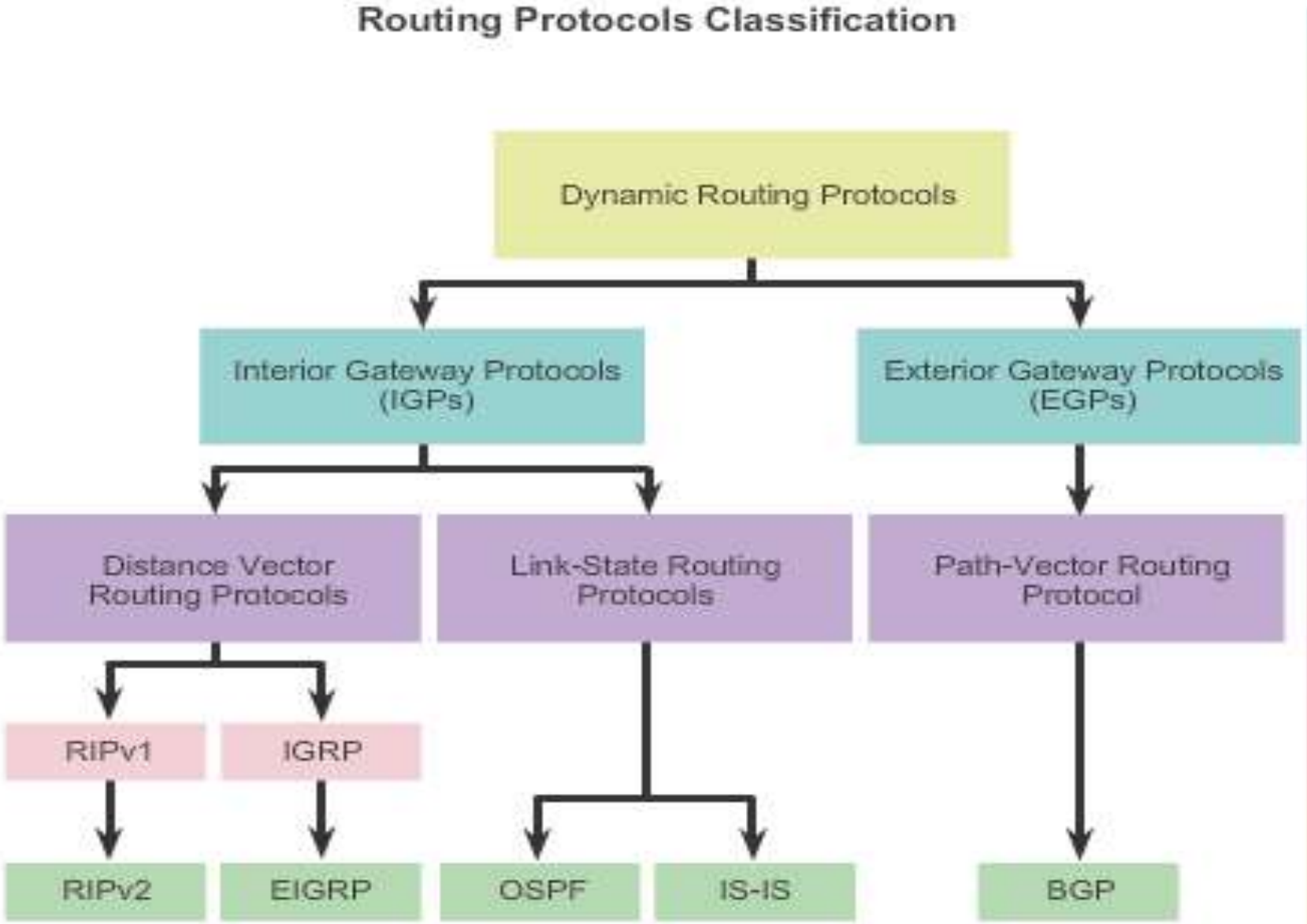
Dynamic Routing Protocol Operation…



Dynamic Routing Advantages and Disadvantages

- **Advantages**
  - Automatically share information about remote networks
  - Determine the best path to each network and add this information to their routing tables
  - Compared to static routing, dynamic routing protocols require less administrative overhead
  - Help the network administrator manage the time-consuming process of configuring and maintaining static routes
  - Suitable in all topologies where multiple routers are required
- **Disadvantages**
  - Dedicate part of a routers resources for protocol operation, including CPU time and network link bandwidth
  - More administrator knowledge is required for configuration, verification, and troubleshooting
  - Times when static routing is more appropriate

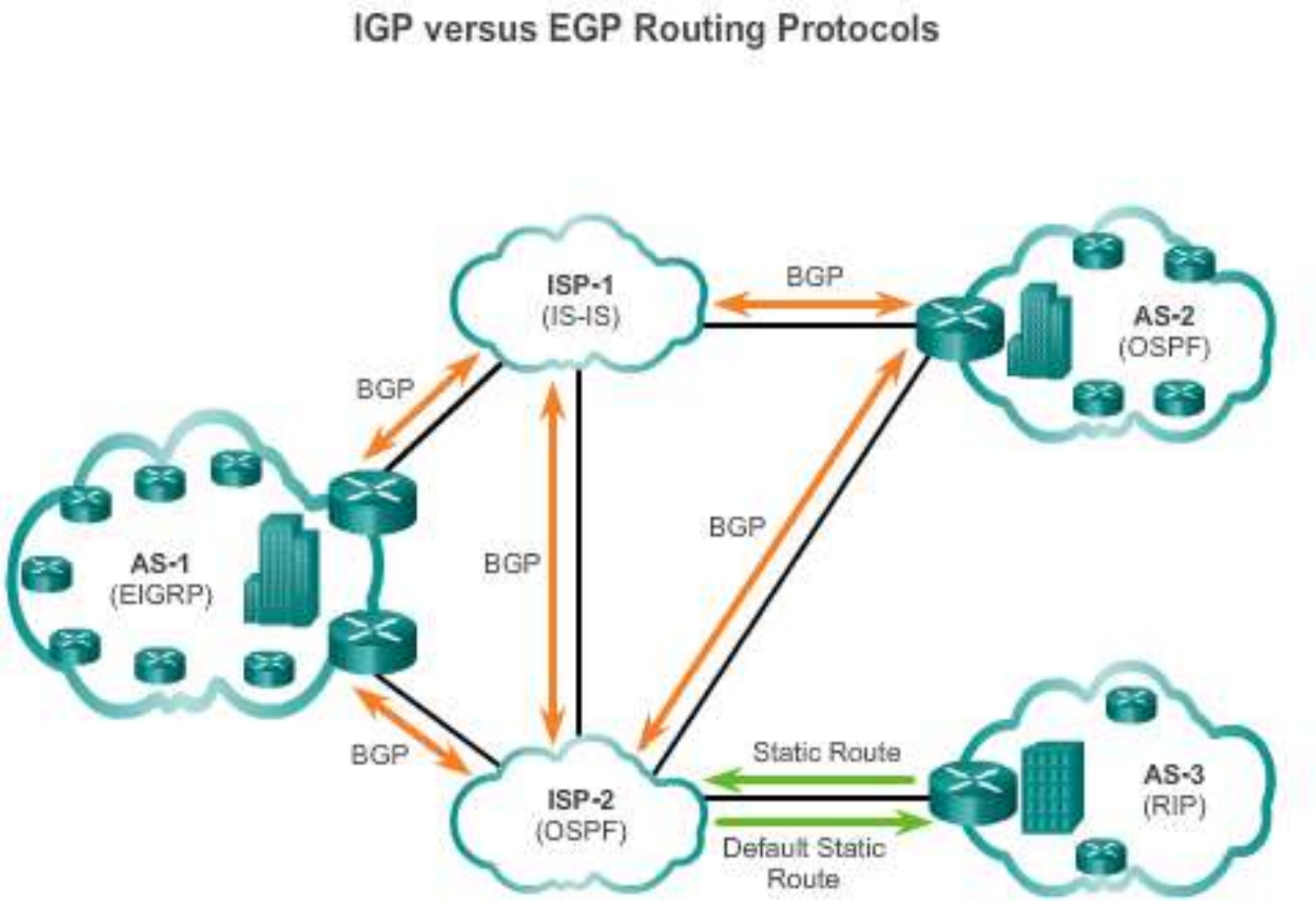
Types of Routing Protocols



Types of Routing Protocols….

- An **autonomous system** (AS) is a collection of routers under a common administration such as a company or an organization.
- An AS is also known as a routing domain.
- The Internet is based on the AS concept; therefore, two types of routing protocols are required:
  - **Interior Gateway Protocols (IGP)**
    - Used for routing within an AS
    - Include RIP, EIGRP, OSPF, and IS-IS
  - **Exterior Gateway Protocols (EGP)**
    - Used for routing between AS
    - Official routing protocol used by the Internet

Types of Routing Protocols…



Routing Protocol Characteristics

Routing protocols can be compared based on the following characteristics:

1. Speed of Convergence

- Defines how quickly the routers in the network topology share routing information and reach a state of consistent knowledge.
- The faster the convergence, the more preferable the protocol.
- Routing loops can occur when inconsistent routing tables are not updated due to slow convergence in a changing network.

2. Scalability

- Defines how large a network can become, based on the routing protocol that is deployed.
- The larger the network is, the more scalable the routing protocol needs to be.

Routing Protocol Characteristics…

3. Classful or Classless (Use of VLSM)

- Classful routing protocols do not include the subnet mask and cannot support VLSM.
- Classless routing protocols include the subnet mask in the updates.
- Classless routing protocols support VLSM and better route summarization.

4. Resource Usage

- Includes the requirements of a routing protocol such as memory space (RAM), CPU utilization, and link bandwidth utilization.
- Higher resource requirements necessitate more powerful hardware to support the routing protocol operation, in addition to the packet forwarding processes.

Routing Protocol Characteristics…

5. Implementation and Maintenance

- Describes the level of knowledge that is required for a network administrator to implement and maintain the network based on the routing protocol deployed.

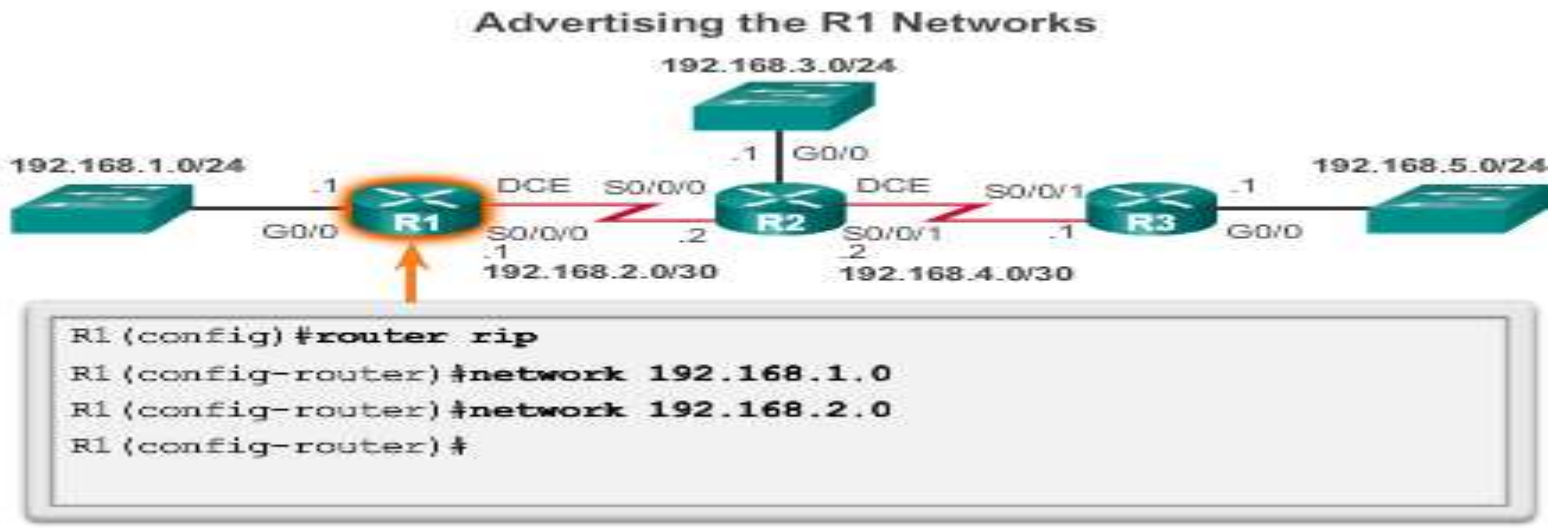
Routing Protocol Characteristics – Summary

	Distance Vector				Link State	
	RIPv1	RIPv2	IGRP	EIGRP	OSPF	IS-IS
Speed Convergence	Slow	Slow	Slow	Fast	Fast	Fast
Scalability - Size of Network	Small	Small	Small	Large	Large	Large
Use of VLSM	No	Yes	No	Yes	Yes	Yes
Resource Usage	Low	Low	Low	Medium	High	High
Implemenation and Maintenance	Simple	Simple	Simple	Complex	Complex	Complex

Configuring the RIP Protocol

Router RIP Configuration Mode Advertising Networks

```
R1# conf t
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)# router rip
R1(config-router)#
```



Configuring Passive Interfaces

Sending out unneeded updates on a LAN impacts the network in three ways:

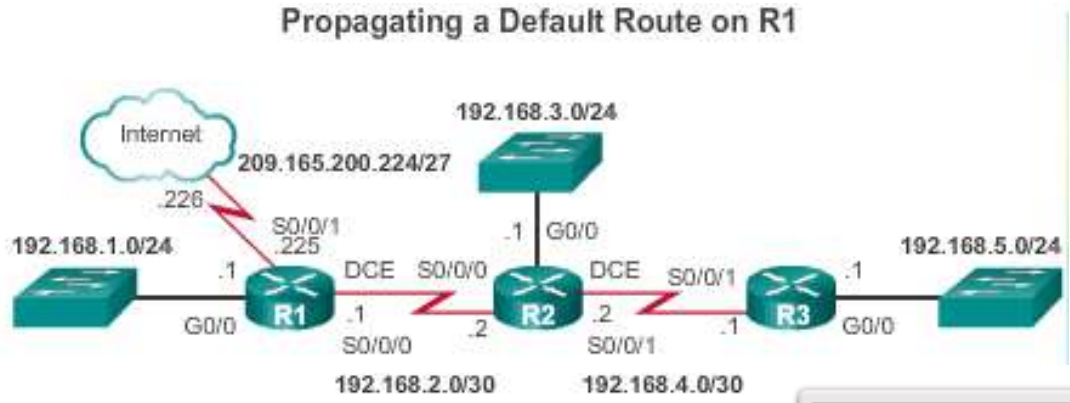
- **Wasted Bandwidth**
- **Wasted Resources**
- **Security Risk**

```
R1(config)# router rip
R1(config-router)# passive-interface g0/0
R1(config-router)# end
R1#
R1# show ip protocols | begin Default
  Default version control: send version 2, receive version 2
    Interface              Send  Recv  Triggered RIP  Key-chain
    Serial0/0/0            2     2
  Automatic network summarization is not in effect
  Maximum path: 4
  Routing for Networks:
    192.168.1.0
    192.168.2.0
  Passive Interface(s):
    GigabitEthernet0/0
  Routing Information Sources:
    Gateway         Distance      Last Update
    192.168.2.2           120      00:00:06
  Distance: (default is 120)

R1#
```

Configuring the RIP Protocol

Propagating a Default Route




```
R1(config)# ip route 0.0.0.0 0.0.0.0 S0/0/1 209.165.200.226
R1(config)# router rip
R1(config-router)# default-information originate
R1(config-router)# ^Z
R1#
*Mar 10 23:33:51.801: %SYS-5-CONFIG_I: Configured from
console by console
R1# show ip route | begin Gateway
Gateway of last resort is 209.165.200.226 to network
0.0.0.0

S*    0.0.0.0/0 [1/0] via 209.165.200.226, Serial0/0/1
      192.168.1.0/24 is variably subnetted, 2 subnets, 2
masks
C        192.168.1.0/24 is directly connected,
GigabitEthernet0/0
L        192.168.1.1/32 is directly connected,
GigabitEthernet0/0
      192.168.2.0/24 is variably subnetted, 2 subnets, 2
masks
C        192.168.2.0/24 is directly connected, Serial0/0/0
L        192.168.2.1/32 is directly connected, Serial0/0/0
R     192.168.3.0/24 [120/1] via 192.168.2.2, 00:00:08,
```