Routers and Routing Process Overview

Router as a Computer

Basic purpose of a router:

- Computers that specialize in sending packets over the data network;
- Responsible for interconnecting networks by selecting the best path for a packet to travel and forwarding packets to their destination.

Routers - 2 types of connections:

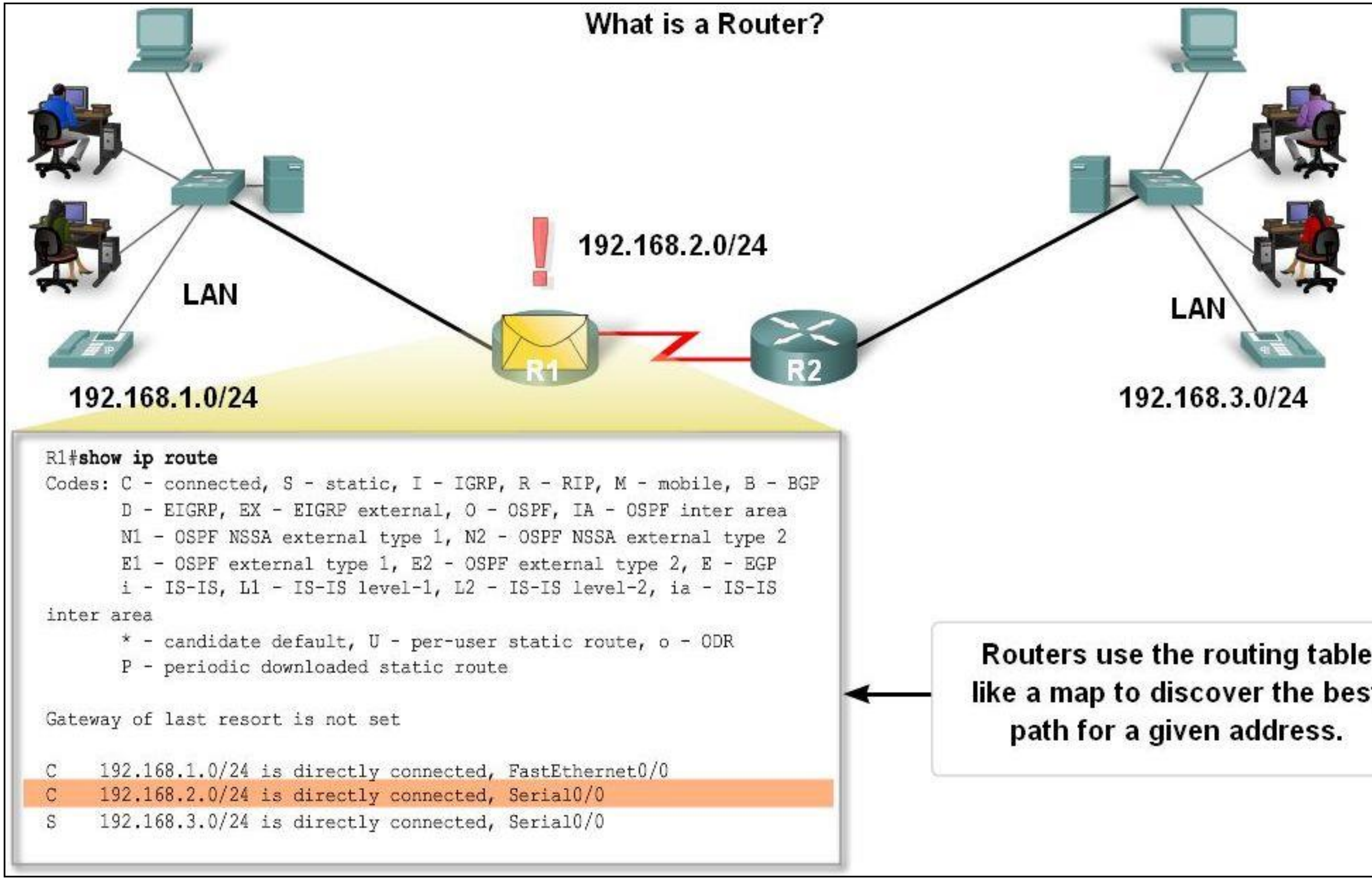
- WAN connection – the connection to the ISP
- LAN connection – the connection with the Internetwork

Router as a Computer

Routers:

- Data is sent in form of packets between 2 end devices;
- are used to direct packet to its destination;
- Examine a packet's destination IP address;
- Determine the best path by enlisting the aid of a routing table

Router as a Computer



Gateway and Next-hop Address

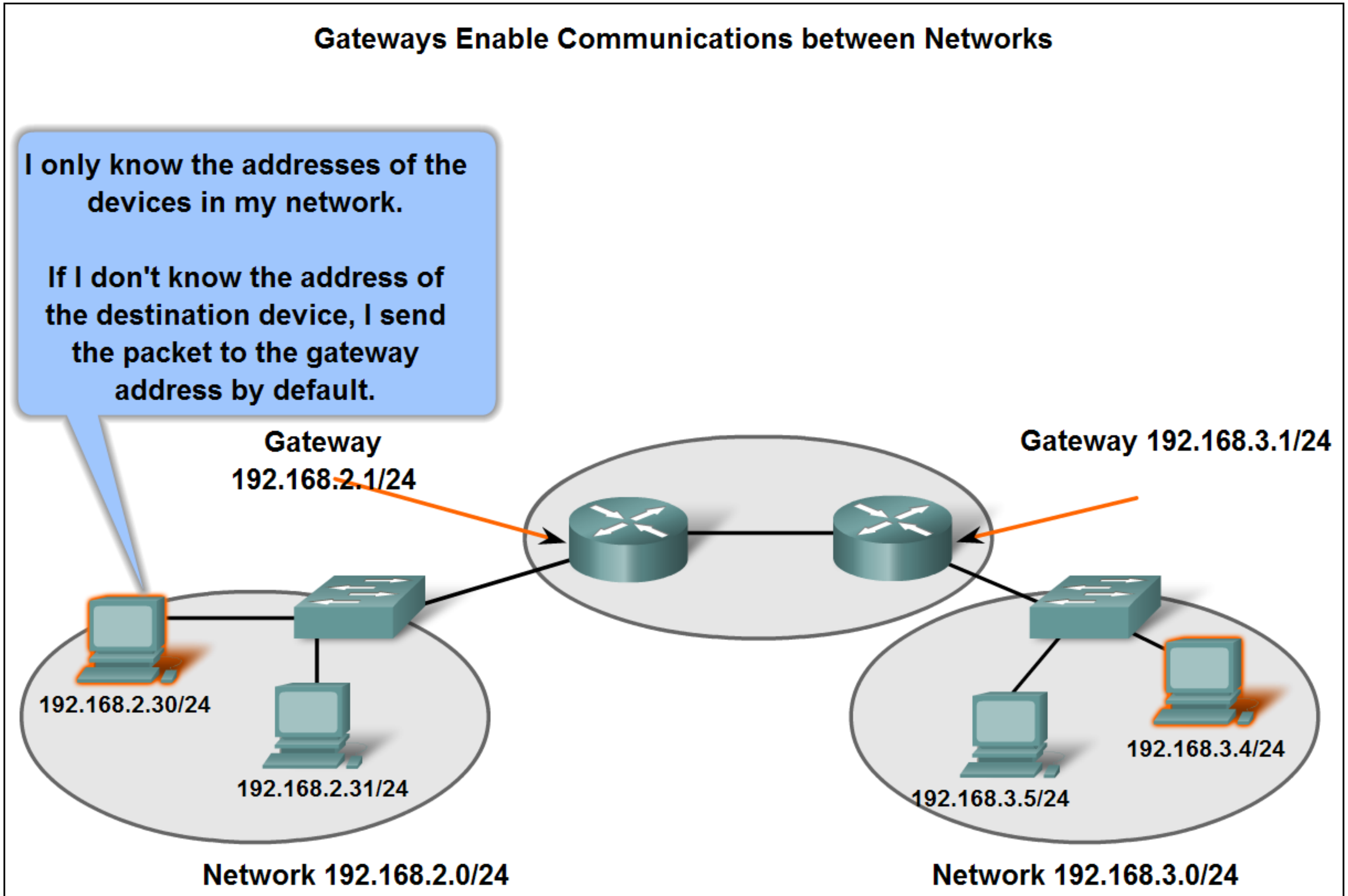
Intermediary gateway device

- allows devices to communicate across sub-divided networks.

Gateway address (default gateway)

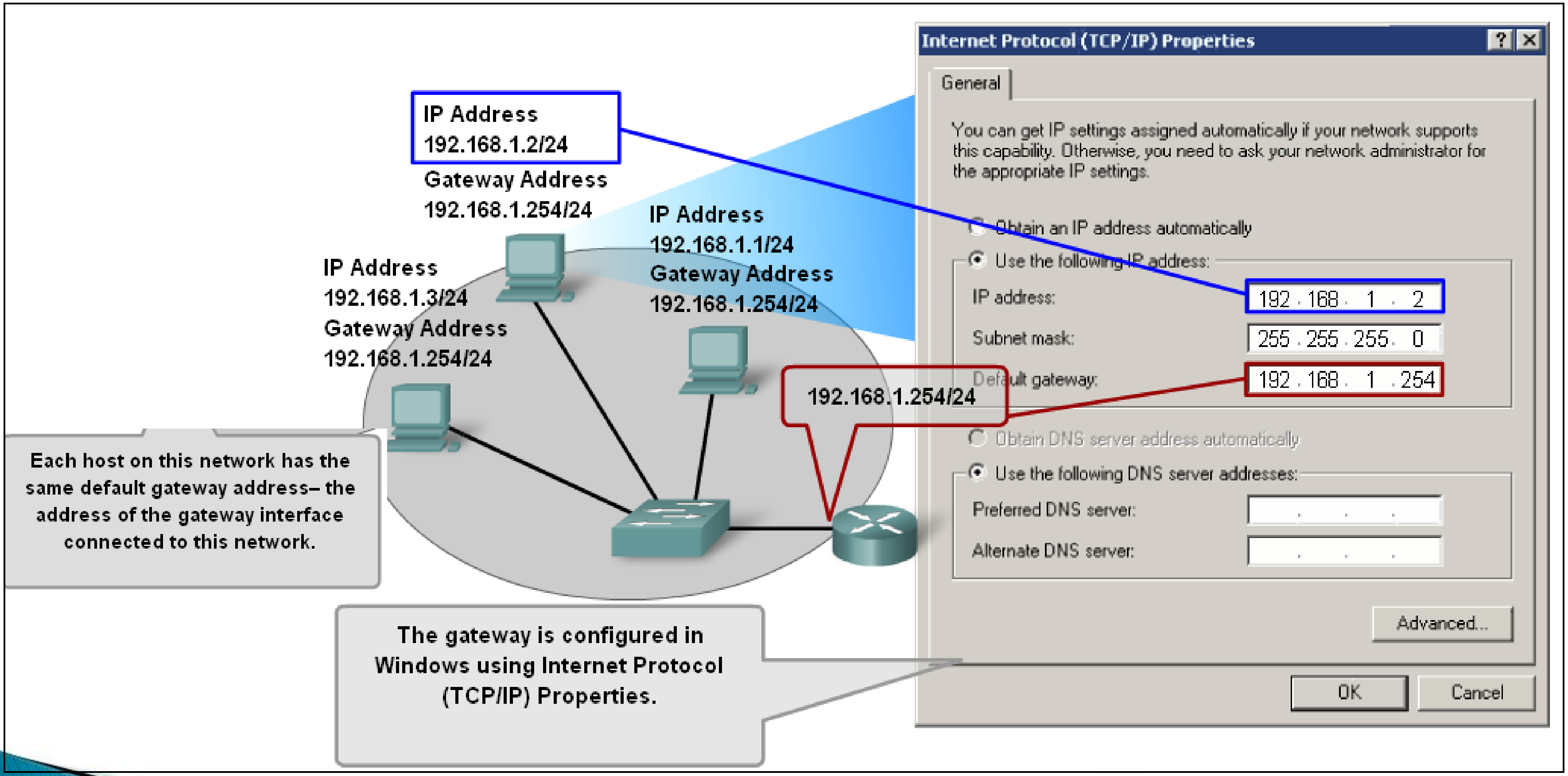
- is the address of a router interface that is connected to the same network as the host;
- is used by the hosts to forward a packet outside the local network.
- **Next-hop address**
- an address of the next-hop router that offers a path to the destination network.

Default Gateway



Default Gateway

Both the host IPv4 address and the gateway address must have the same network



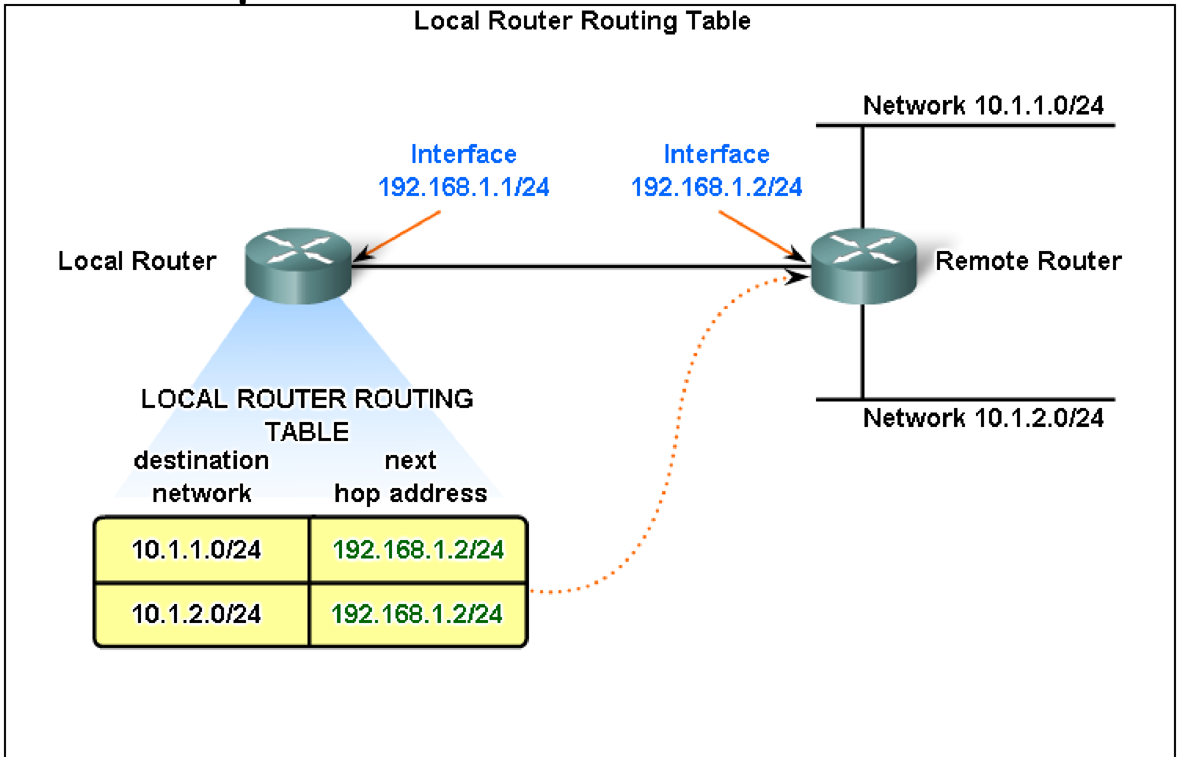
Routing Process

Routing

- router makes a forwarding decision for each packet that arrives at the gateway interface;
- to forward a packet to a destination network, the router requires a route to that network;
- if a route to a destination network does not exist, the packet cannot be forwarded;
- the destination network may be a number of routers or hops away from the gateway;
- the route to that network would only indicate the next-hop router to which the packet is to be forwarded, not the final router.

Routing Process

Routing process uses a route to map the destination network address to the next hop and then forwards the packet to this next-hop address.



The next hop for both networks 10.1.1.0/24 and 10.1.2.0/24 from Local Router is 192.168.1.2/24

Routing Table

Routing table

- stores information about connected and remote networks;

Connected networks

- are directly attached to one of the router interfaces;

Remote networks

- networks that are not directly connected to the router;
- routes to these networks can be:

  - manually configured on the router by the network administrator;

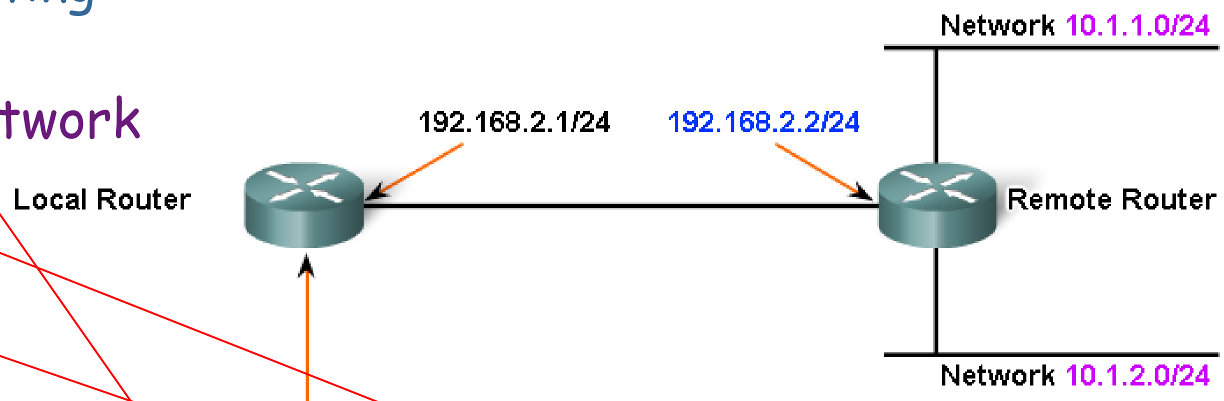
  - learned automatically using dynamic routing protocols.

Routing Table

Main features of the routes in a routing table:

- Destination network
- Next-hop
- Metric

Confirming the Gateway and Route




```
     10.0.0.0/24 is subnetted, 2 subnets
R        10.1.1.0 [120/1] via 192.168.2.2, 00:00:08, FastEthernet0/0
R        10.1.2.0 [120/1] via 192.168.2.2, 00:00:08, FastEthernet0/0
C    192.168.1.0/24 is directly connected, FastEthernet0/0
```

This is the routing table output of Local Router when the "show ip route" is issued.

The next hop for networks 10.1.1.0/24 and 10.1.2.0/24 from Local Router is 192.168.2.2.

Default Route

Default Route

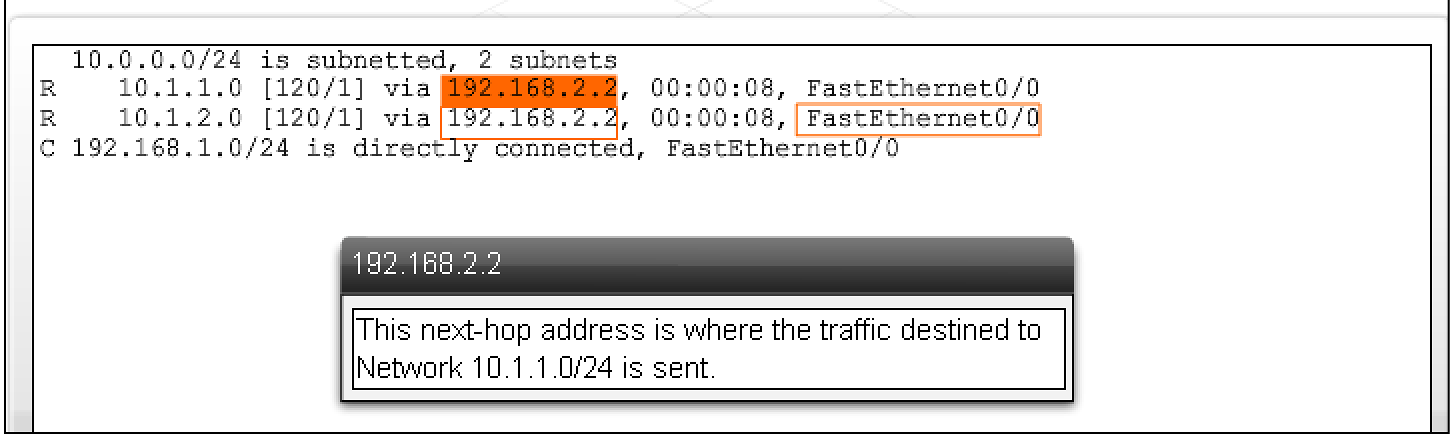
- if a route representing the destination network is not on the routing table, the packet will be dropped (that is, not forwarded);
- is used when the destination network is not represented by any other route in the routing table;
- is used to forward packets for which there is no entry in the routing table for the destination network;
- is a route that will match all destination networks;
- uses the address 0.0.0.0 (in IPv4 networks).

Next Hop Address

Next-hop

- is the address of the device that will process the packet next;
- in the routing table of a router, each route lists a next hop for each destination address that is encompassed by the route;

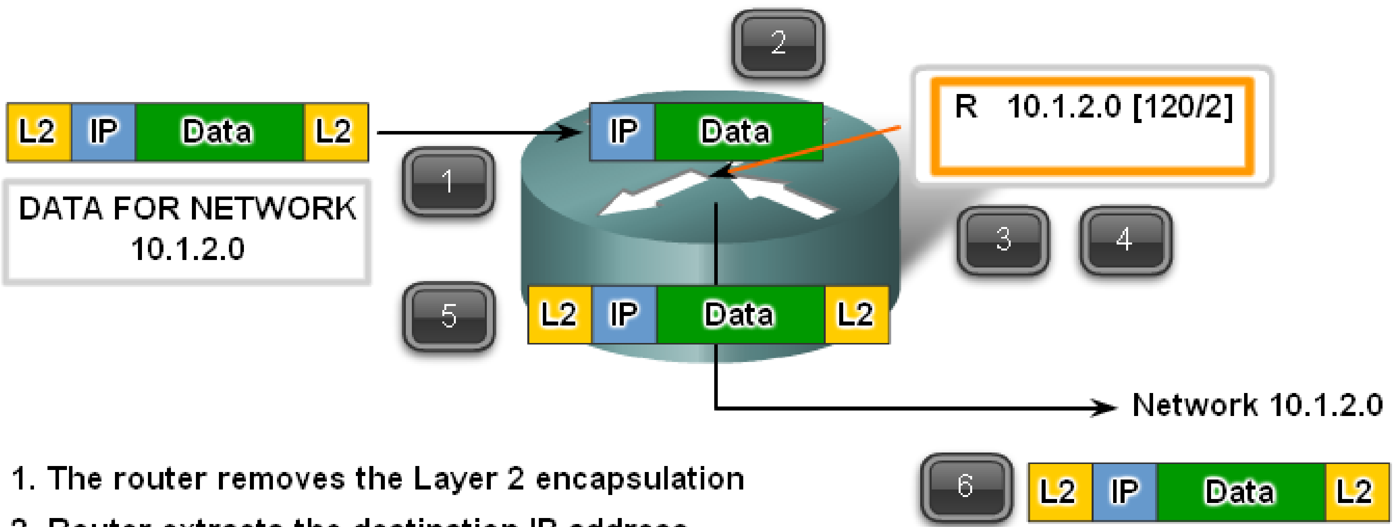
Routing Table Output with Next Hops



Packet Forwarding

Forward the packet to the next-hop router

Route Entry Exists



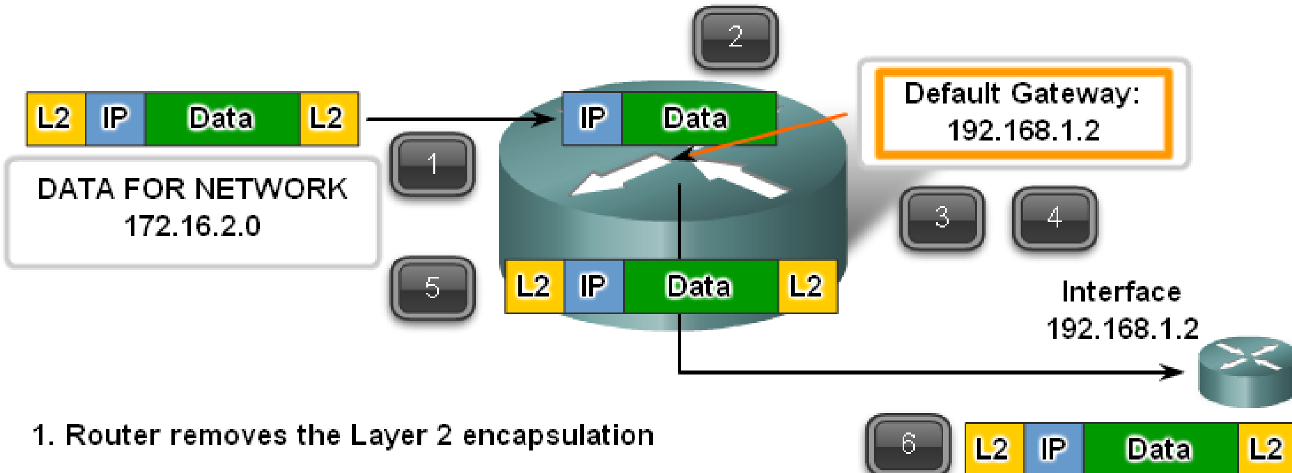
1. The router removes the Layer 2 encapsulation
2. Router extracts the destination IP address
3. Router checks the routing table for a match
4. Network 10.1.2.0 is found in the routing table
5. Router re-encapsulates the packet
6. Packet is sent to Network 10.1.2.0

Packet Forwarding

Forward the packet using the default route

No Route Entry But Default Route Exists

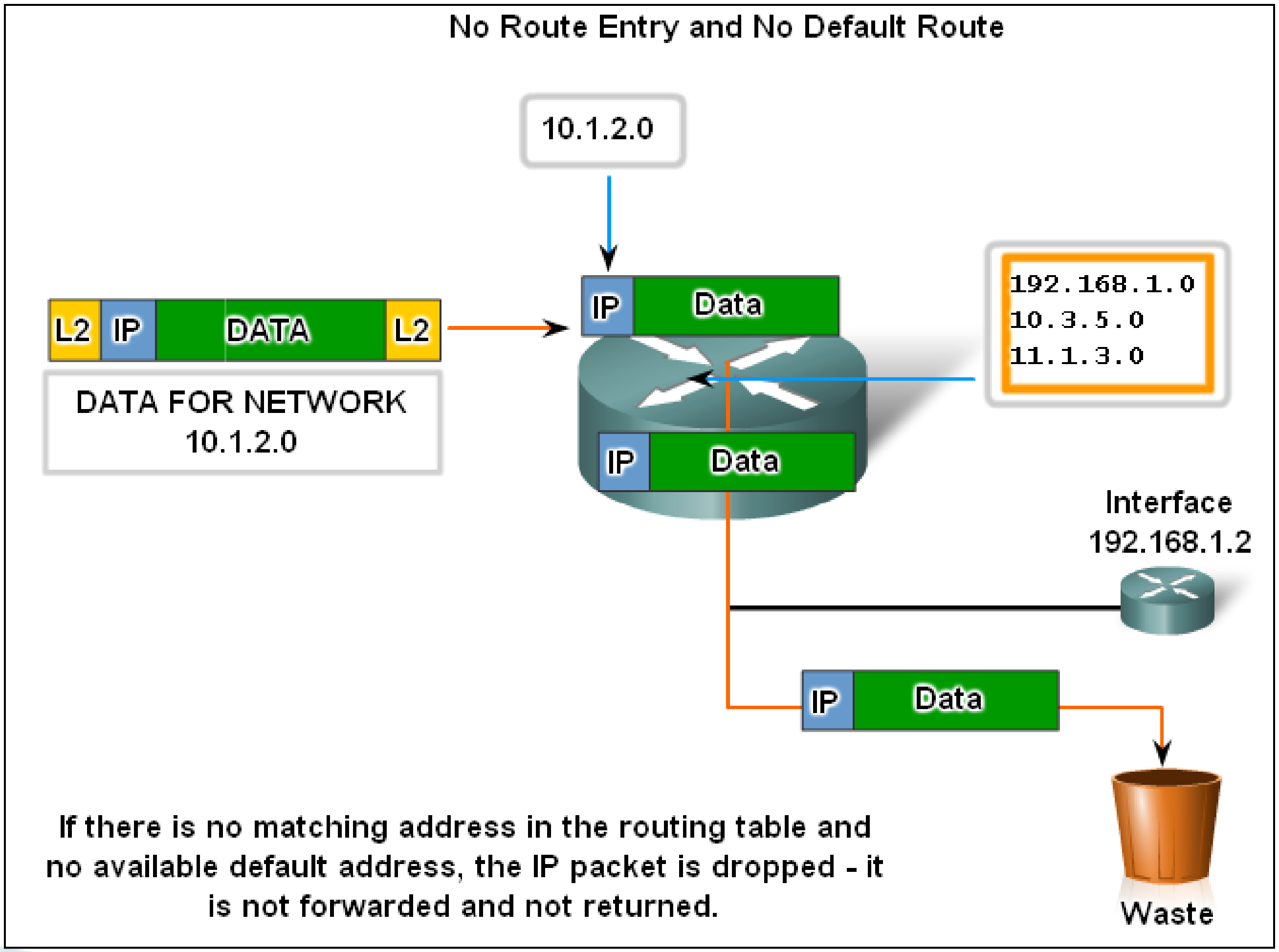
Roll over to see the steps the router takes.



1. Router removes the Layer 2 encapsulation
2. Router extracts IP Address
3. Router checks the routing table for a match
4. Network 172.16.2.0 not in the routing table but default route to 192.168.1.2 exists
5. Router re-encapsulates the packet
6. Packet is sent to Interface 192.168.1.2

Packet Forwarding

Do not forward the packet – IP packet is dropped



Router Paths and Packet Switching

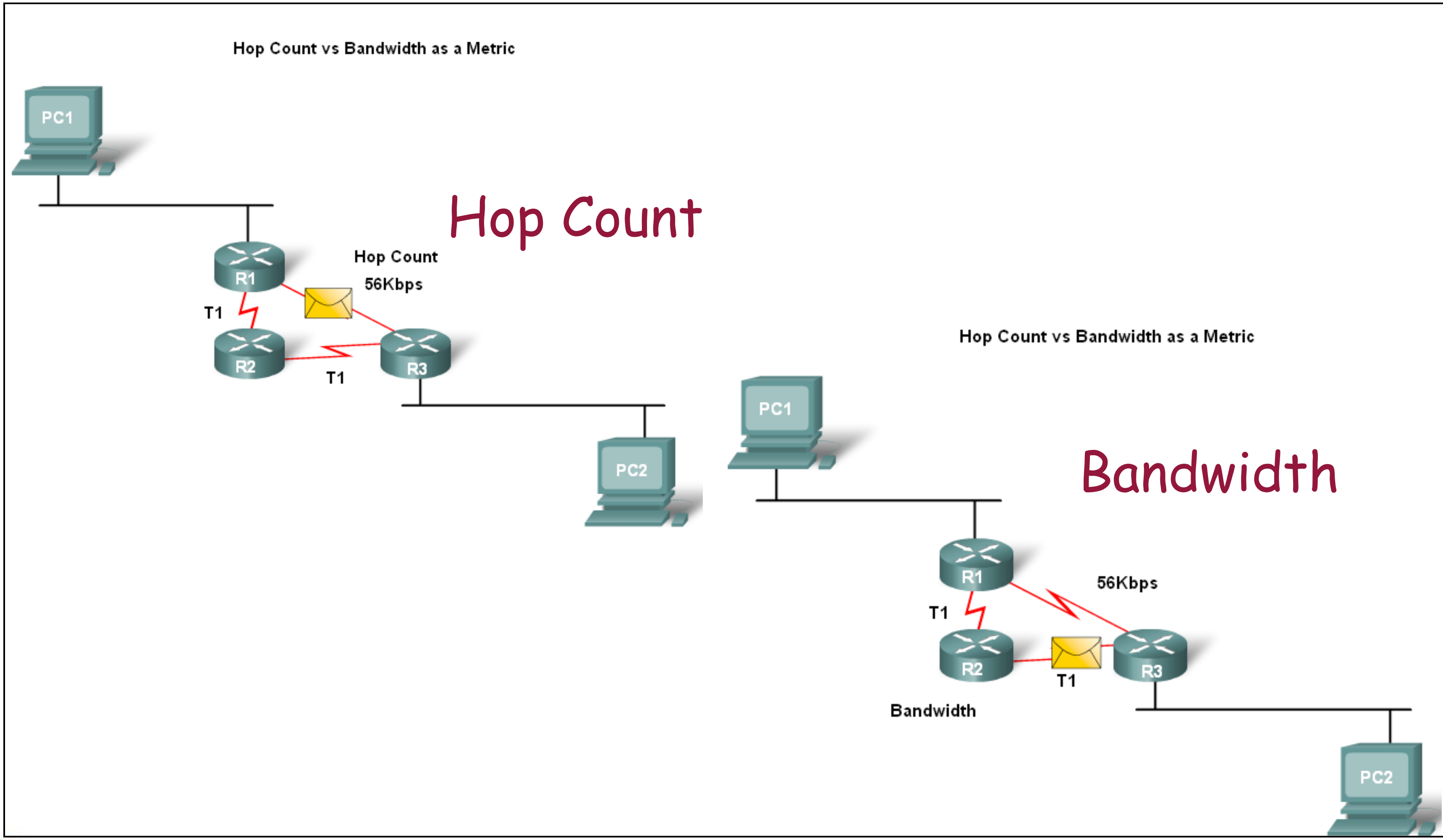
Metric

- is a numerical value used by routing protocols help determine the best path to a destination;
- the smaller the metric value the better the path.

Types of metrics used by routing protocols:

- Hop count - this is the number of routers a packet must travel through to get to its destination;
- Bandwidth - this is the "speed" of a link also known as the data capacity of a link.

Router Paths and Packet Switching



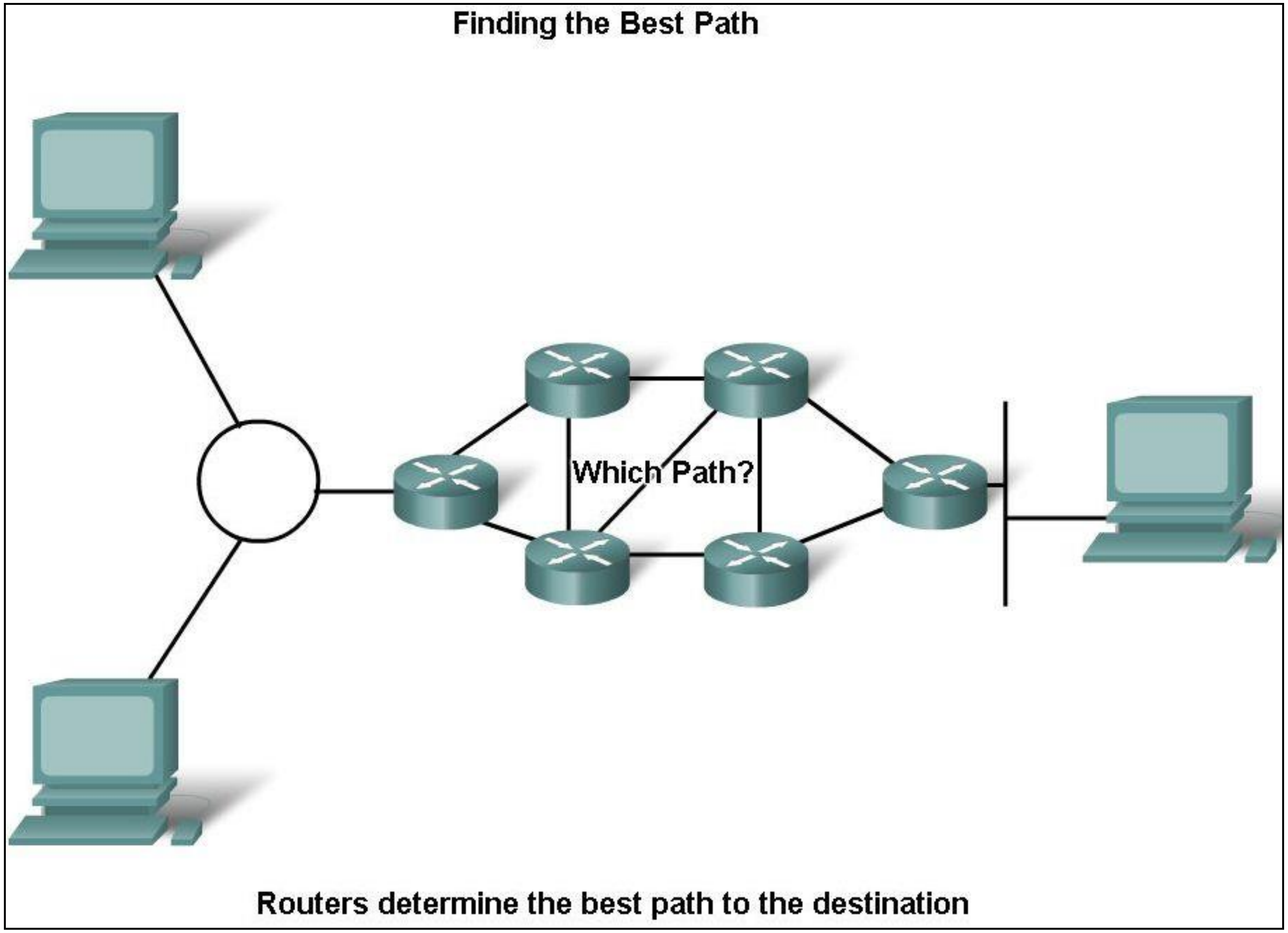
Router Paths and Packet Switching

Path determination

- is a process used by a router to pick the best path to a destination;
- One of 3 path determinations results from searching for the best path:
  - Directly connected network
  - Remote network
  - No route determined

Router Paths and Packet Switching

Path determination



Router Paths and Packet Switching

Switching Function

- is the process used by a router to switch a packet from an incoming interface to an outgoing interface on the same router;

A packet received by a router will do the following:

- Strips off layer 2 headers;
- Examines destination IP address located in Layer 3 header to find best route to destination;
- Re-encapsulates layer 3 packet into layer 2 frame;
- Forwards frame out exit interface.

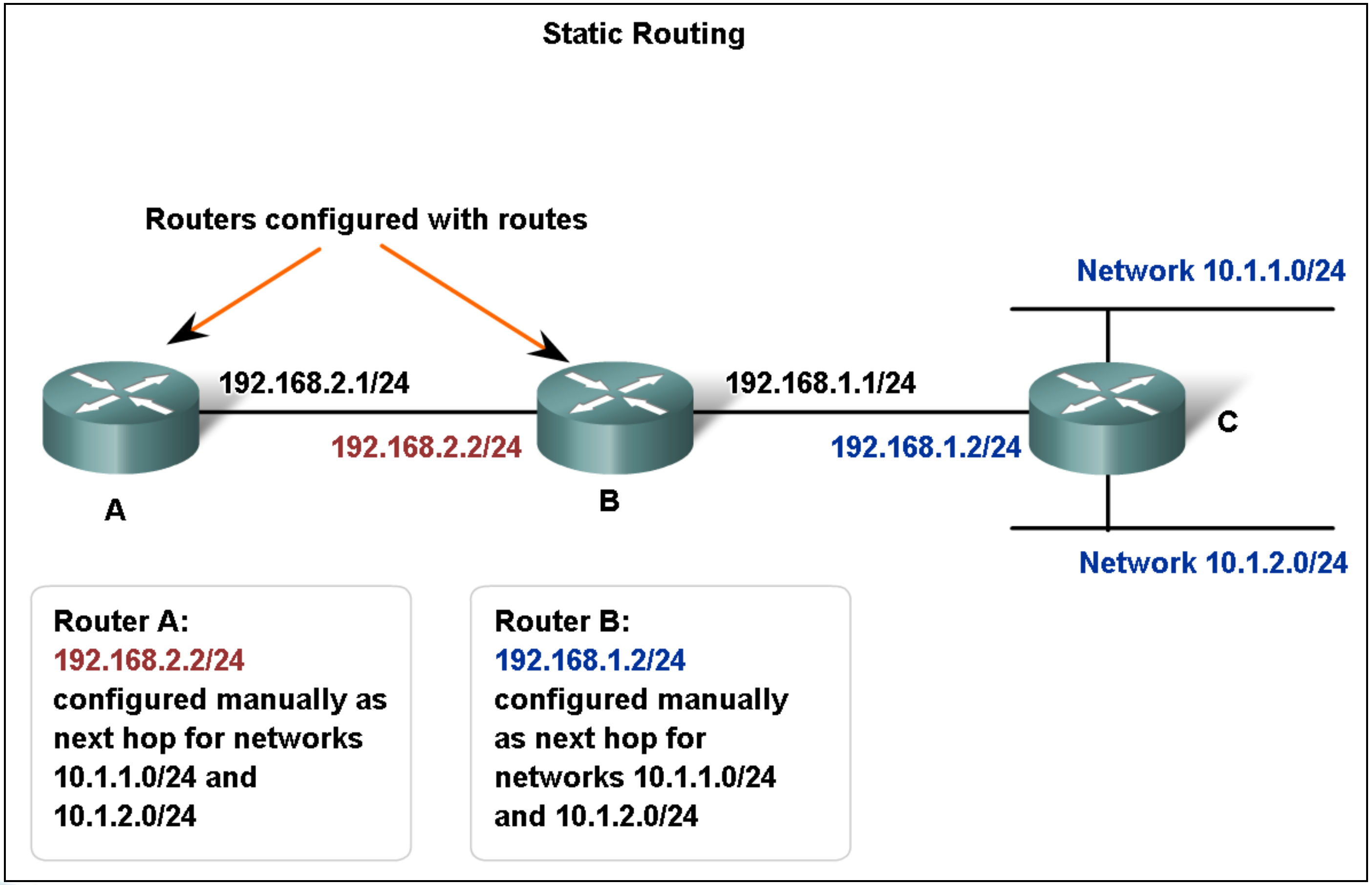
Router Paths and Packet Switching

Packet travels from one networking device to another:

- The Source and Destination IP addresses **NEVER** change;
- The Source & Destination MAC addresses **CHANGE** as packet is forwarded from one router to the next;
- TTL field decrement by one until a value of zero is reached at which point router discards packet (prevents packets from endlessly traversing the network)

Static Routing

Static Routing – depends on manually entered routes in routing table



Static Routing

Static routing primary uses:

- Providing ease of routing table maintenance in smaller networks that are not expected to grow significantly.
- Routing to and from stub networks;

Static Routing

Advantages of static routing

- It can backup multiple interfaces/networks on a router;
- Easy to configure;
- No extra resources are needed;
- Minimal CPU processing;
- Easier for administrator to understand;
- More secure.

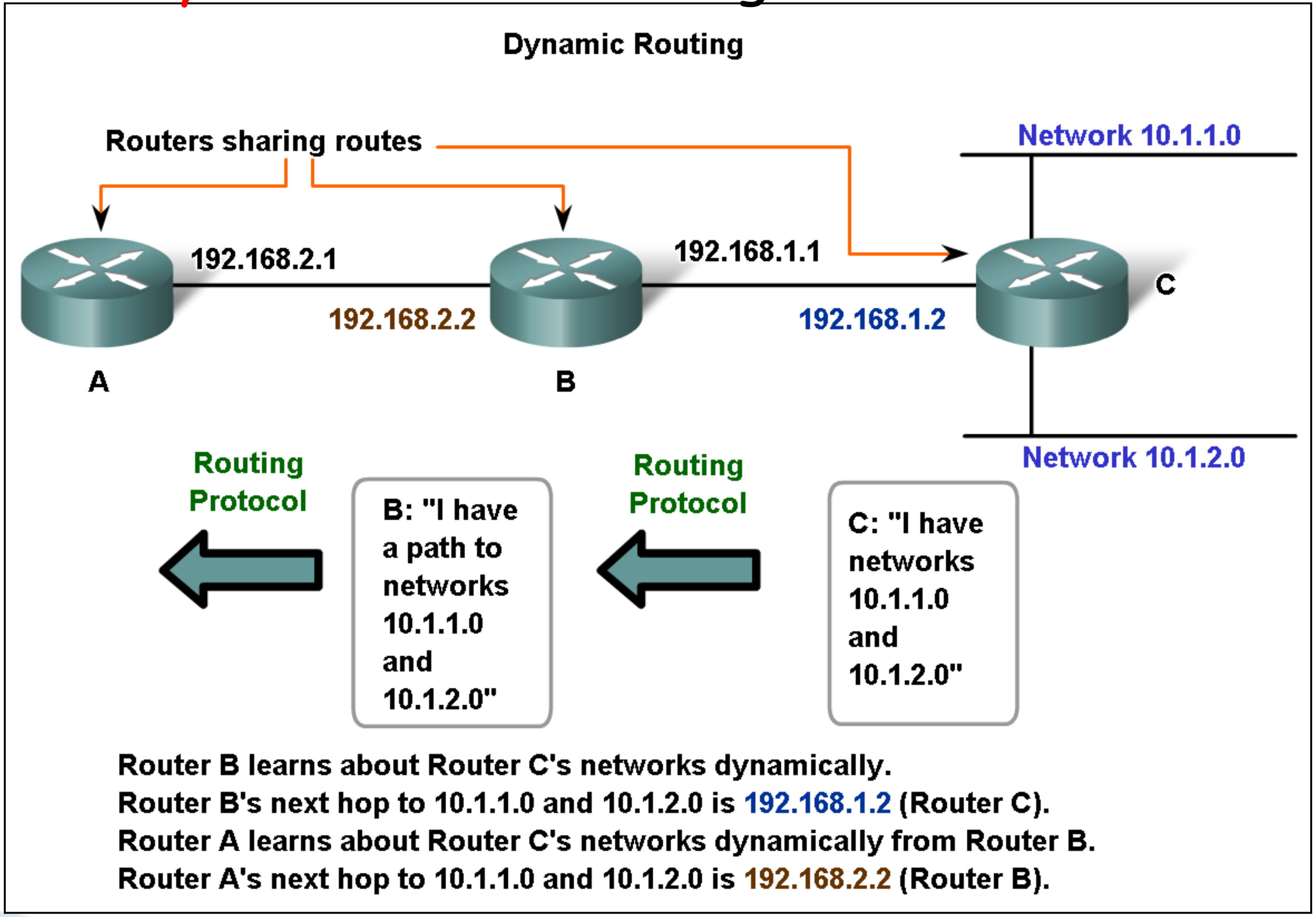
Static Routing

Disadvantages of static routing

- Network changes require manual reconfiguration;
- Administrator intervention is required to maintain changing route information;
- Configuration and maintenance is time-consuming;
- Configuration is error-prone, especially in large networks;
- Requires complete knowledge of the whole network for proper implementation;
- Does not scale well in large topologies.

Dynamic Routing

Routing protocols – the set of rules by which routers dynamically share their routing information



Dynamic Routing

Dynamic routing advantages:

- Administrator has less work maintaining the configuration when adding or deleting networks;
- Protocols automatically react to the topology changes;
- Configuration is less error-prone;
- More scalable, growing the network usually does not present a problem.

Dynamic Routing

Dynamic routing disadvantages:

- Router resources are used (CPU cycles, memory and link bandwidth).
- More administrator knowledge is required:

  - for configuration;

  - for verification;

  - for troubleshooting.

Static & Dynamic Routing

Dynamic versus Static Routing

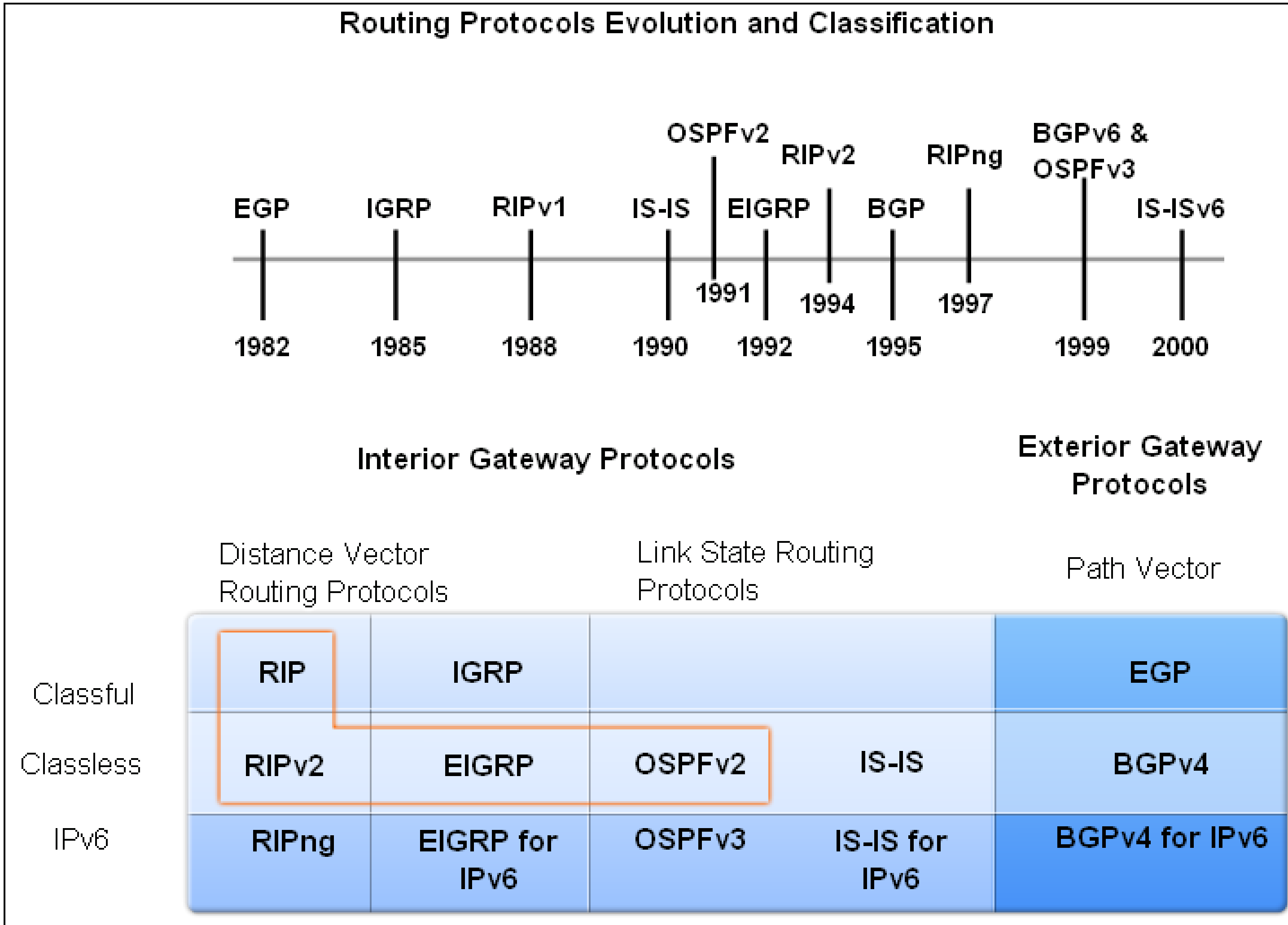
	Dynamic routing	Static routing
Configuration Complexity	Generally independent of the network size	Increases with network size
Required administrator knowledge	Advanced knowledge required	No extra knowledge required
Topology changes	Automatically adapts to topology changes	Administrator intervention required
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

Dynamic Routing Protocols

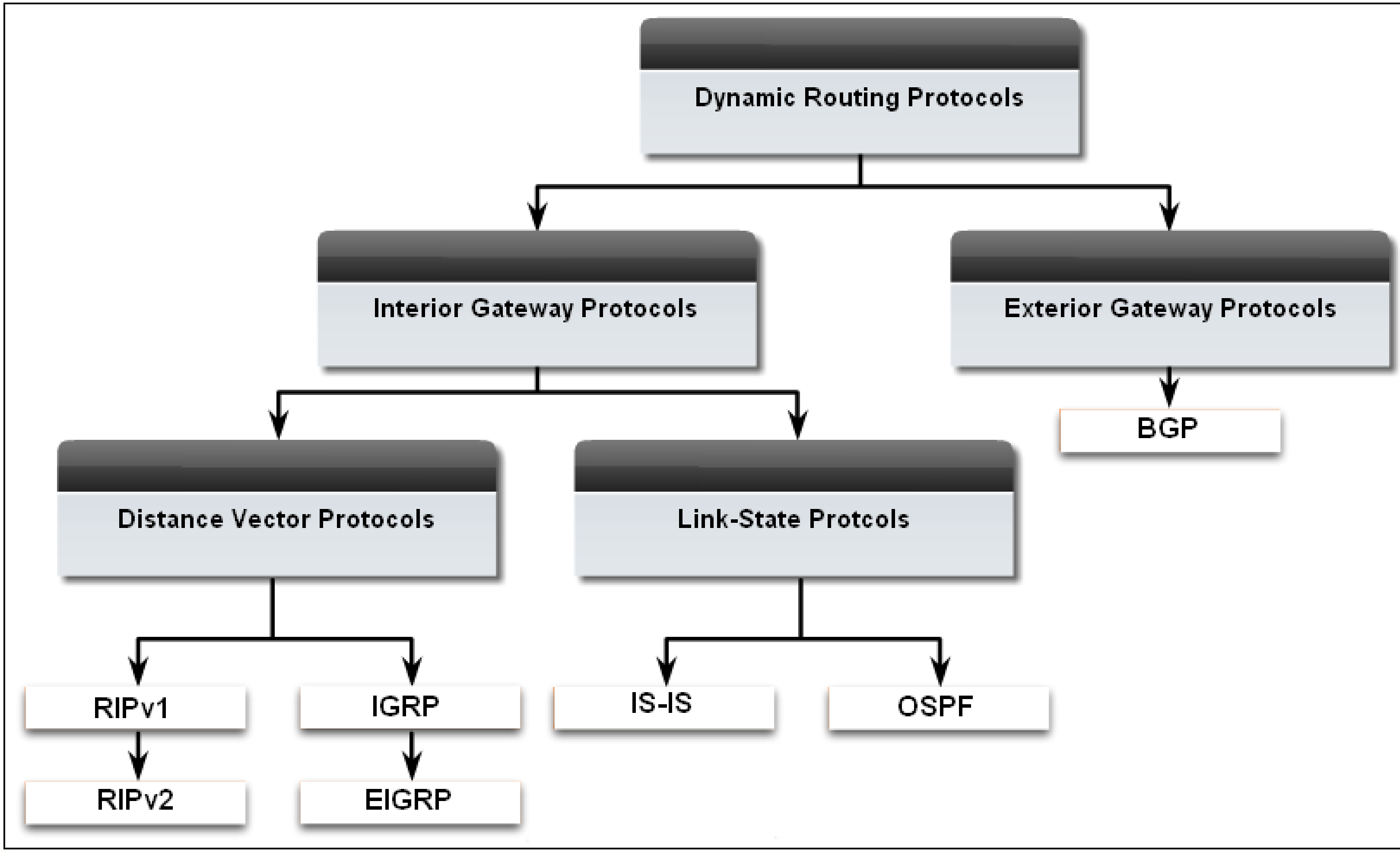
Function of Dynamic Routing Protocols:

- Discover remote networks;
- Dynamically share information between routers;
- Maintaining up-to-date routing information;
- Automatically update routing table when topology changes;
- Determine best path to a destination networks;
- Ability to find a new best path if the current path is no longer available.

Dynamic Routing Protocols



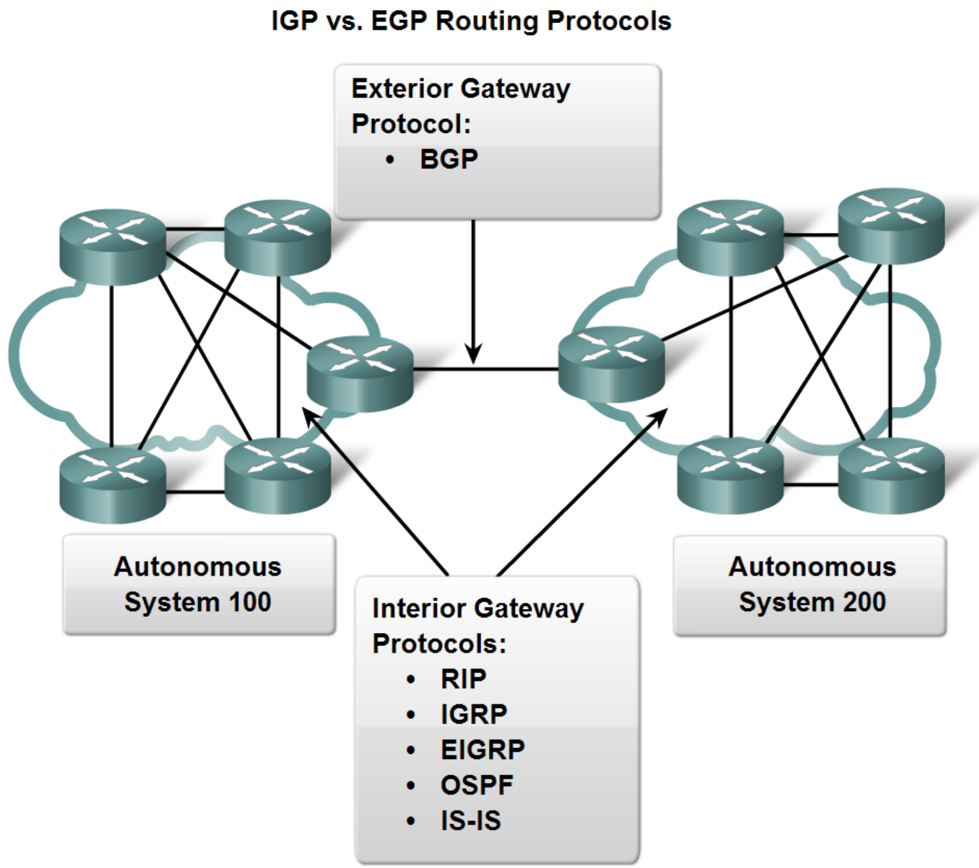
Classifying Routing Protocols



Classifying Routing Protocols

Types of routing protocols:

- **Interior Gateway Protocols (IGP)**
- **Exterior Gateway Protocols (EGP)**



Autonomous System:

a group of routers under the control of a single authority.

Classifying Routing Protocols

Interior Gateway Routing Protocols (IGP)

- Used for routing inside an autonomous system & used to route within the individual networks themselves.
- Examples: RIP, IGRP, EIGRP, OSPF, IS-IS

Exterior Routing Protocols (EGP)

- Used for routing between autonomous systems
- Example: BGPv4

Interior Gateway Routing Protocols

IGP: Comparison of Distance Vector & Link State Routing Protocols

Distance vector

- routes are advertised as vectors of distance & direction;
- incomplete view of network topology;
- Generally, periodic updates.

Interior Gateway Routing Protocols

IGP: Comparison of Distance Vector & Link State Routing Protocols

Link state

- complete view of network topology is created.
- updates are not periodic.

IGP: Distance Vector Routing Protocols

IGP: Distance Vector Routing Protocols

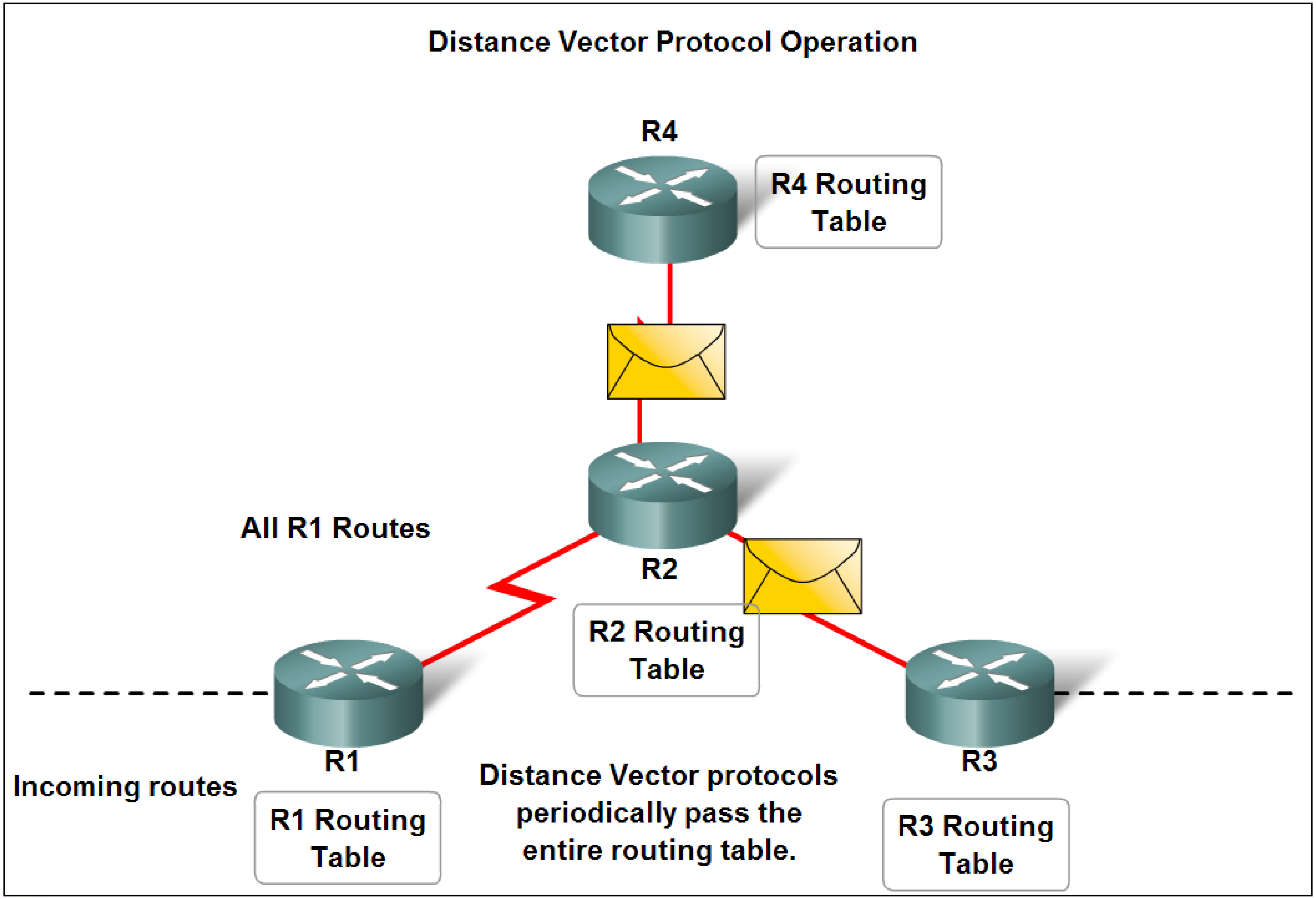
- Distance vector means that routes are advertised as vectors of distance and direction;
- Distance is defined in terms of a metric such as hop count and direction is simply the next-hop router or exit interface;
- Typically use the Bellman-Ford algorithm for the best path route determination;
- Periodically send complete routing tables to all connected neighbors;
- In large networks, these routing updates can become enormous, causing significant traffic on the links;
- Do not have an actual map of the network topology.

IGP: Distance Vector Routing Protocols

IGP: Distance Vector Routing Protocols work best in situations where:

- The network is simple and flat and does not require a special hierarchical design;
- The administrators do not have enough knowledge to configure and troubleshoot link-state protocols;
- Specific types of networks, such as hub-and-spoke networks, are being implemented.
- Worst-case convergence times in a network are not a concern.

IGP: Distance Vector Routing Protocols



IGP: Link State Routing Protocols

IGP: Link State Routing Protocols

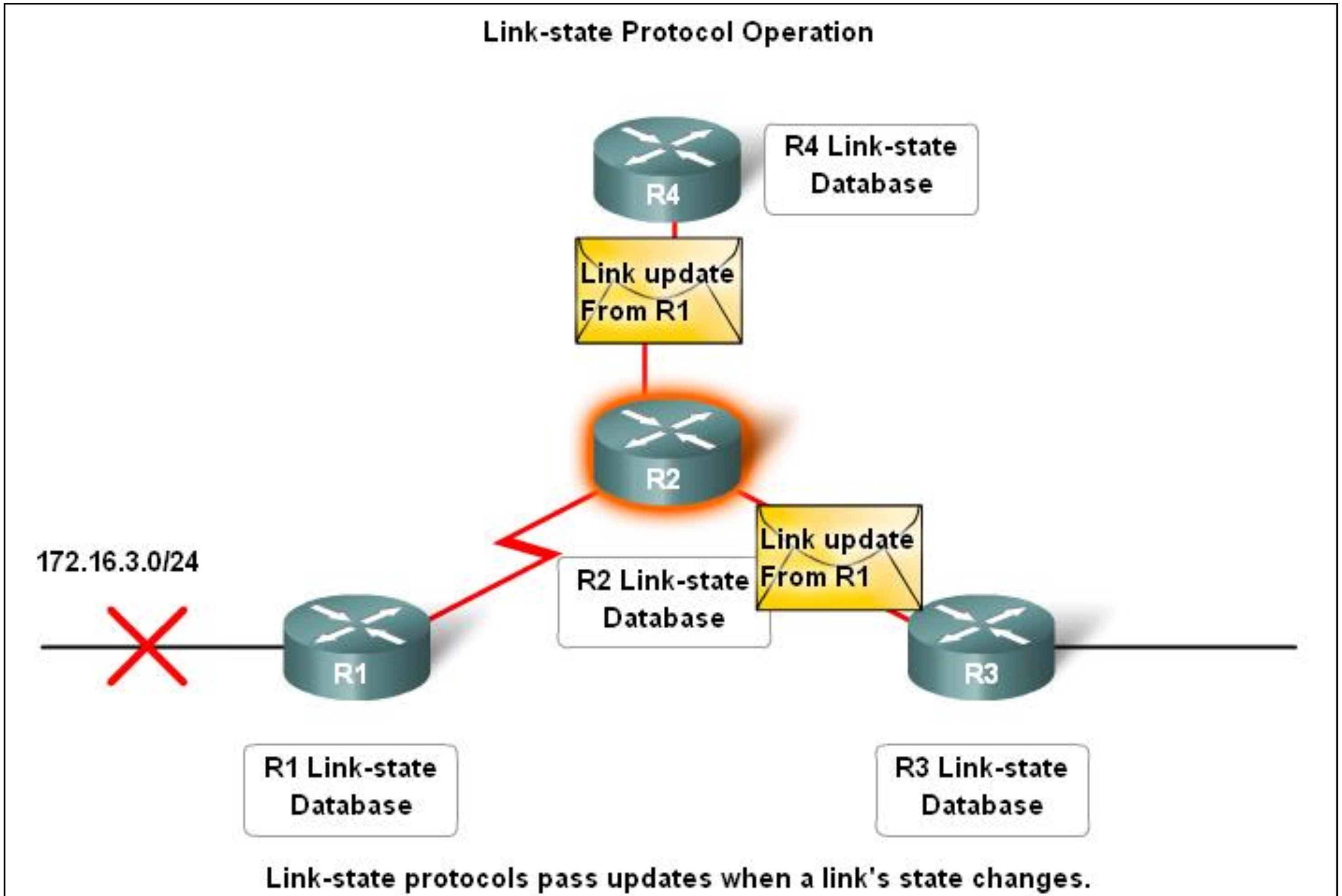
- Create a "complete view" or topology of the network by gathering information from all of the other routers;
- A link-state router uses the link-state information to create a topology map and to select the best path to all destination networks in the topology;
- Link-state routing protocols do not use periodic updates;
- After the network has converged, a link-state update only sent when there is a change in the topology.

IGP: Link State Routing Protocols

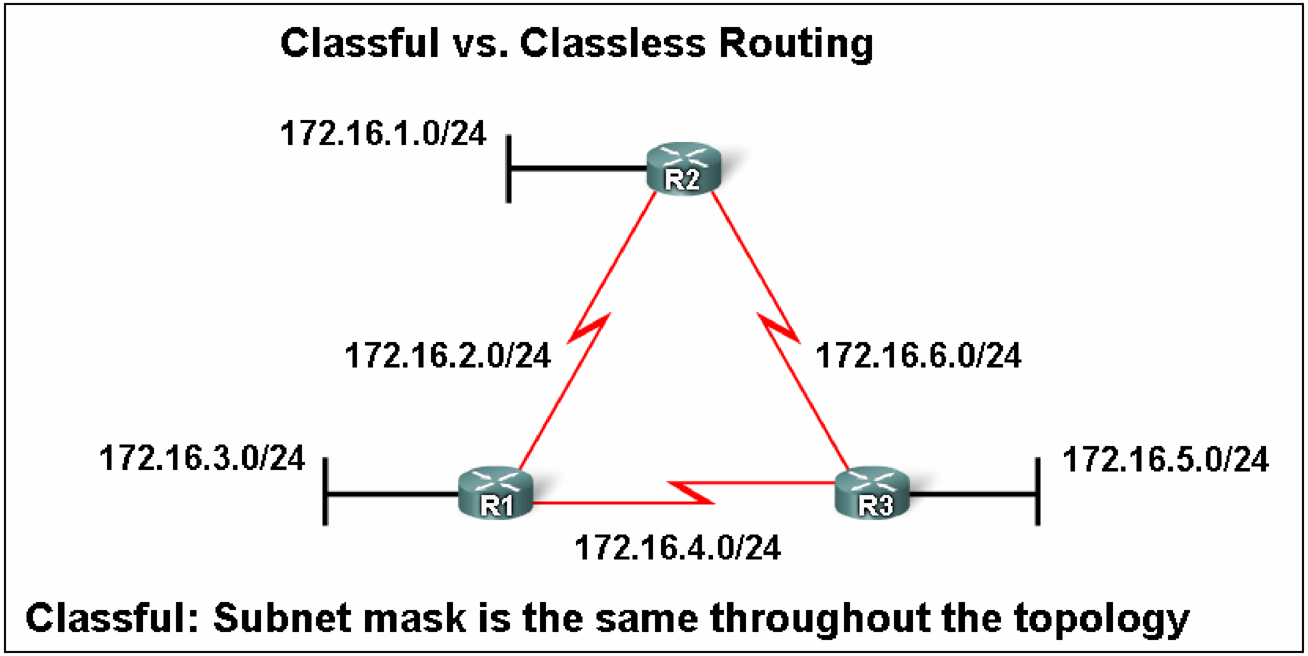
Link-state protocols work best in situations where:

- The network design is hierarchical, usually occurring in large networks;
- The administrators have a good knowledge of the implemented link-state routing protocol.
- Fast convergence of the network is crucial.

IGP: Link State Routing Protocols



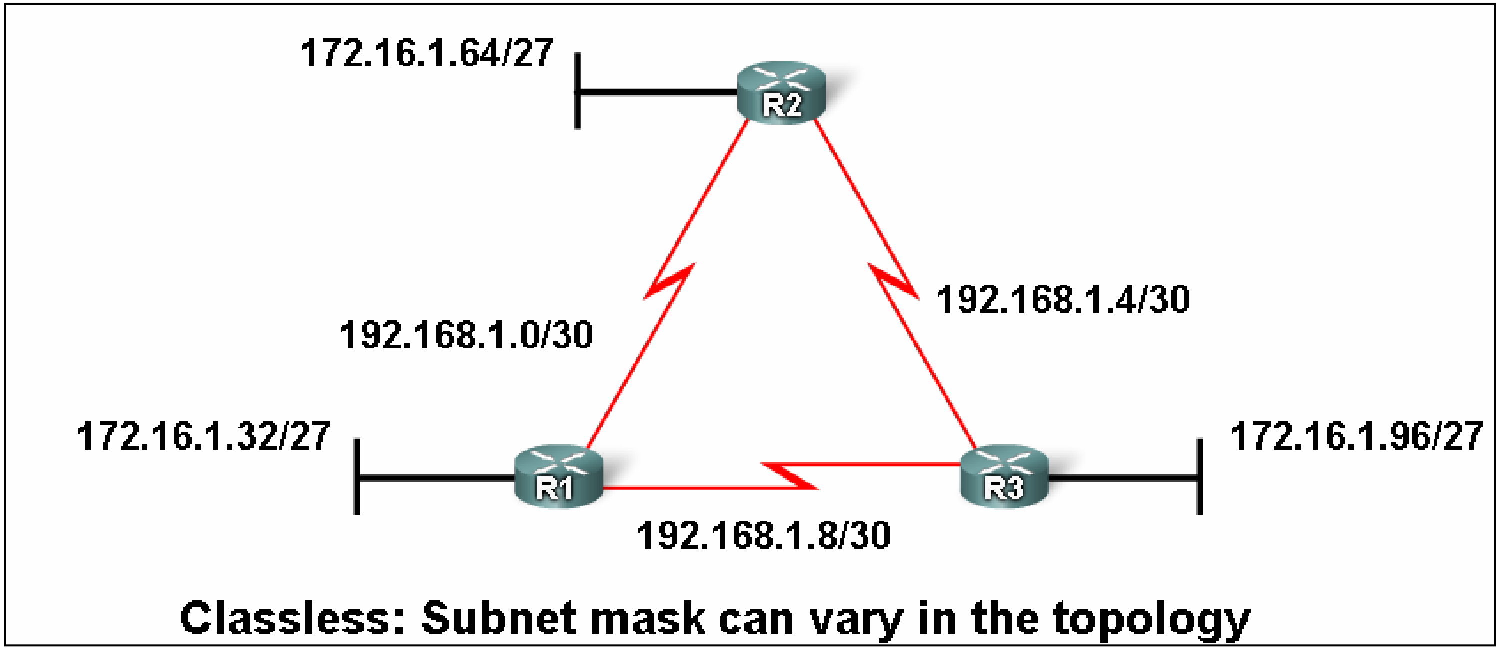
Classful Routing Protocols



Classful routing protocols

- Do NOT send subnet mask in routing updates;
- classful routing protocols do not support variable length subnet masks (VLSM).

Classless Routing Protocols



Classless routing protocols

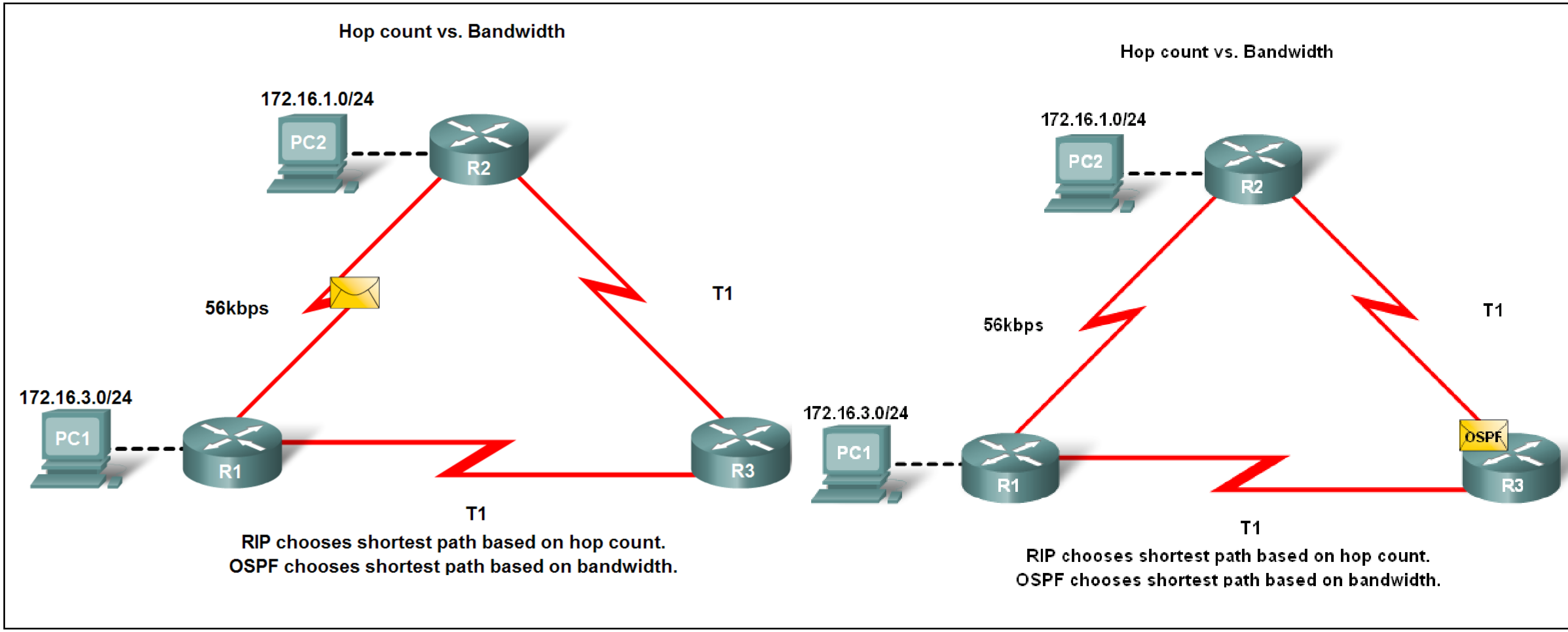
- send subnet mask in routing updates;
- are required in most networks today because of their support for VLSM, discontiguous network

Routing Protocols Metrics

Metrics used in IP routing protocols

- Hop count - A simple metric that counts the number of routers a packet must traverse;
- Bandwidth - Influences path selection by preferring the path with the highest bandwidth;
- Load - Considers the traffic utilization of a certain link;
- Delay - Considers the time a packet takes to traverse a path;
- Reliability - Assesses the probability of a link failure, calculated from the interface error count or previous link failures;
- Cost - A value determined either by the IOS or by the network administrator to indicate preference for a route. Cost can represent a metric, a combination of metrics or a policy.

Routing Protocols Metrics

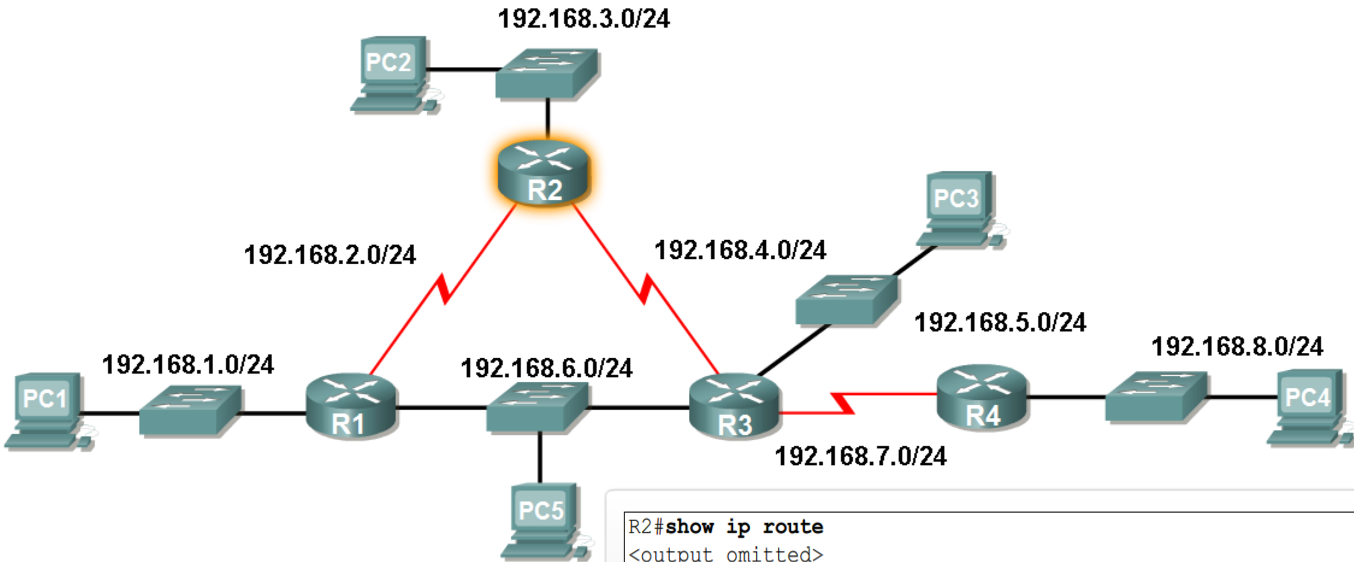


Routing Protocols Metrics

Metric used for each routing protocol

- RIP - hop count
- IGRP & EIGRP - Bandwidth (used by default), Delay (used by default), Load, Reliability
- IS-IS & OSPF – Cost, Bandwidth

Routing Protocols Metrics




```
R2#show ip route
<output omitted>

Gateway of last resort is not set

R    192.168.1.0/24 [120/1] via 192.168.2.1, 00:00:24, Serial0/0
C    192.168.2.0/24 is directly connected, Serial0/0
C    192.168.3.0/24 is directly connected, FastEthernet0/0
C    192.168.4.0/24 is directly connected, Serial0/1
R    192.168.5.0/24 [120/1] via 192.168.4.1, 00:00:26, Serial0/1
R    192.168.6.0/24 [120/1] via 192.168.2.1, 00:00:24, Serial0/0
                    [120/1] via 192.168.4.1, 00:00:26, Serial0/1
R    192.168.7.0/24 [120/1] via 192.168.4.1, 00:00:26, Serial0/1
R    192.168.8.0/24 [120/2] via 192.168.4.1, 00:00:26, Serial0/1
```

Metric in the Routing Table

It is 2 hops from R2 to 192.168.8.0/24

Administrative Distance of a Route

Purpose of a metric

- It's a calculated value used to determine the best path to a destination

Purpose of Administrative Distance

- It's a numeric value that specifies the preference of a particular route

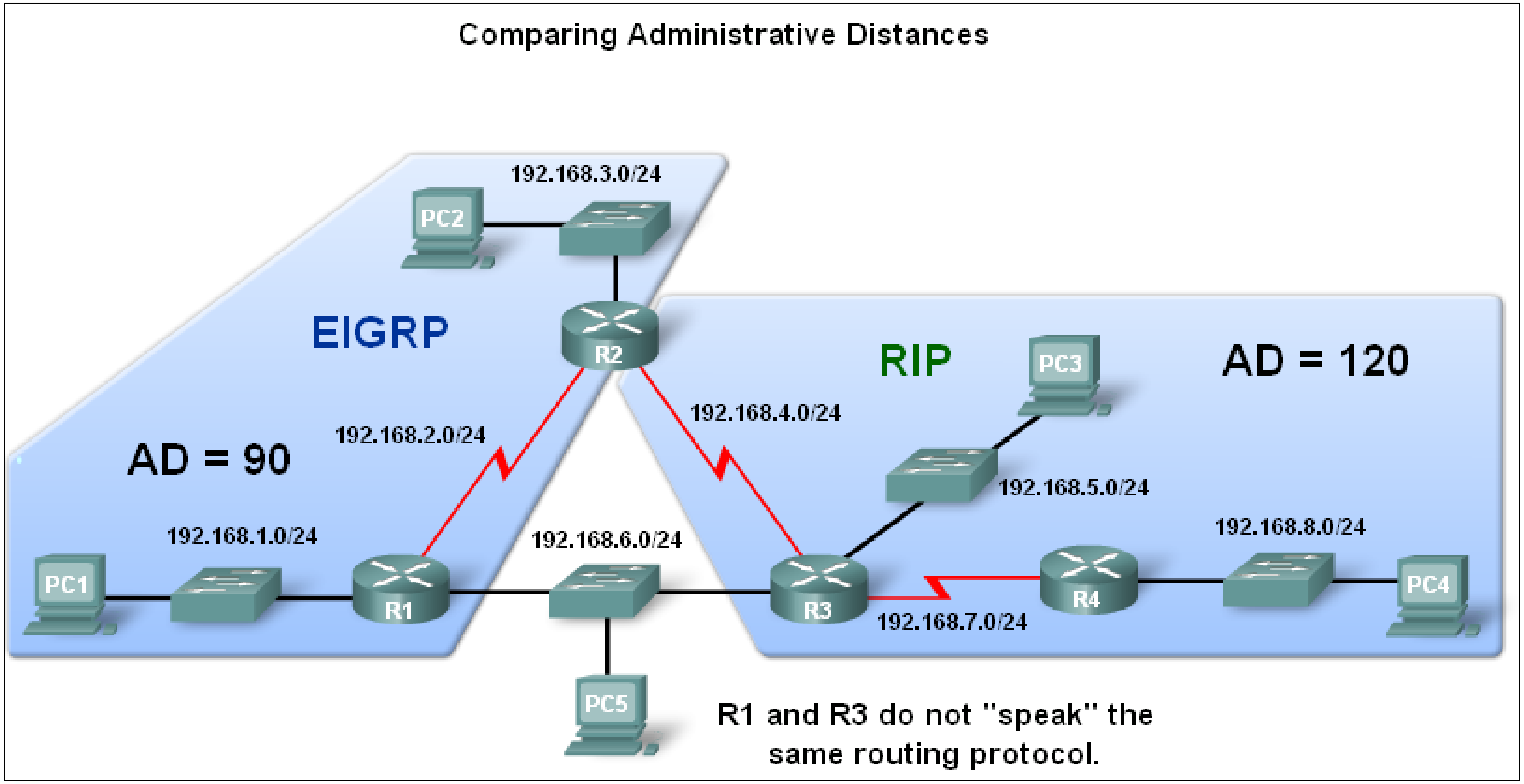
Administrative Distance of a Route

Administrative distance (AD)

- defines the preference of a routing source;
- is an integer value from 0 to 255;
- the lower the value the more preferred the route source;
- an administrative distance of 0 is the most preferred;
- only a directly connected network has an administrative distance of 0, which cannot be changed.

Administrative Distance of a Route

Administrative distance (AD)



Administrative Distance of a Route

Administrative Distance (AD)

- in the routing table is the first number in the brackets

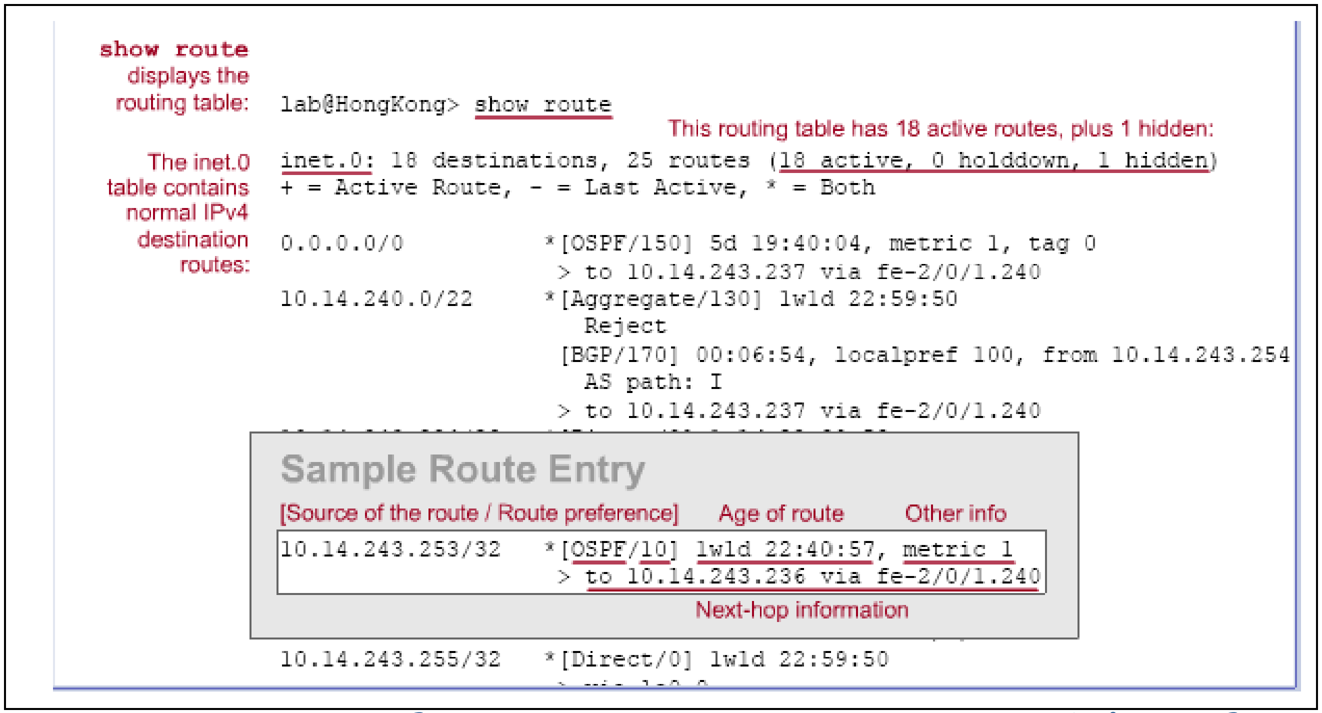
```
R2#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       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

D    192.168.1.0/24 [90/2172416] via 192.168.2.1, 00:00:24, Serial0/0/0
C    192.168.2.0/24 is directly connected, Serial0/0/0
C    192.168.3.0/24 is directly connected, FastEthernet0/0
C    192.168.4.0/24 is directly connected, Serial0/0/1
R    192.168.5.0/24 [120/1] via 192.168.4.1, 00:00:08, Serial0/0/1
D    192.168.6.0/24 [90/2172416] via 192.168.2.1, 00:00:24, Serial0/0/0
R    192.168.7.0/24 [120/1] via 192.168.4.1, 00:00:08, Serial0/0/1
R    192.168.8.0/24 [120/2] via 192.168.4.1, 00:00:08, Serial0/0/1
```

Administrative Distance (AD) in a routing table of the Cisco router

Route Preference in the JUNOS

Route Preference in the JUNOS

- in the routing table is the number in the brackets



Route Preference in a routing table of the Juniper router

Administrative Distance & Route Preference of Dynamic Routing Protocols

AD in the Cisco IOS

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

Route Preference in the Juniper JUNOS

Route Preference Values

Source	Default Preference
Direct	0
Local	0
Static	5
OSPF internal	10
RIP	100
Aggregate	130
OSPF AS external	150
BGP (both EGBP and IBGP)	170

Administrative Distance & Route Preference

Directly connected routes

- Have a default AD of 0 (Cisco IOS) and Route preference of 0 (Juniper JUNOS)

Static Routes

- Administrative distance of a static route has a default value of 1 (Cisco IOS) and Route preference of 5 (Juniper JUNOS)

```
R2#show ip route 172.16.3.0
Routing entry for 172.16.3.0/24
Known via "static", distance 1, metric 0 (connected)
  Routing Descriptor Blocks:
  * directly connected, vi
      Route metric is 0, t
```

Cisco IOS

```
radi@Core-SW-EX2200> show route 192.168.0.0

inet.0: 30 destinations, 30 routes (30 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

192.168.0.0/16     *[Static/5] 3d 10:15:13
                    Reject
```

Juniper JUNOS

Directly connected routes

Directly connected routes

- immediately appear in the routing table as soon as the interface is configured

```
R2#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 rout
       P - periodic downloaded static route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 3 subnets
C       172.16.1.0 is directly connected, FastEthernet
C       172.16.2.0 is directly connected, Serial0/0/0
S       172.16.3.0 is directly connected, Serial0/0/0
C    192.168.1.0/24 is directly connected, Serial0/0/1
S    192.168.2.0/24 [1/0] via 192.168.1.1
```

Cisco IOS

show route displays the routing table:

```
lab@HongKong> show route
```

The inet.0 table contains normal IPv4 destination routes:

```
inet.0: 18 destinations, 25 routes (18 active, 0 holddown, 1 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/150] 5d 19:40:04, metric 1, tag 0
                    > to 10.14.243.237 via fe-2/0/1.240
10.14.240.0/22     *[Aggregate/130] 1w1d 22:59:50
                      Reject
                    [BGP/170] 00:06:54, localpref 100, from 10.14.243.254
                      AS path: I
                    > to 10.14.243.237 via fe-2/0/1.240
10.14.243.224/28   *[Direct/0] 1w1d 22:20:58
                    > via fe-2/0/1.240
10.14.243.238/32   *[Local/0] 1w1d 22:20:58
                      Local via fe-2/0/1.240
10.14.243.253/32   *[OSPF/10] 1w1d 22:40:57, metric 1
                    > to 10.14.243.236 via fe-2/0/1.240
10.14.243.254/32   *[OSPF/10] 5d 19:40:10, metric 1
                    > to 10.14.243.237 via fe-2/0/1.240
10.14.243.255/32   *[Direct/0] 1w1d 22:59:50
```

Juniper JUNIOS

Thank You!