ICT259 Computer Networking

Seminar 4: IP Routing

Ms Wong Yoke Moon

IP Routing

Objectives:

- Understanding **Routing Concepts**
- Define and describe **Static** routing
- Define and describe **Dynamic** routing
- Define and describe the various **routing protocols**
- Configure **Routing Information Protocol (RIP)**
- Describe **Load Balancing** over multiple paths
- Describe the differences between **Interior Gateway Protocol (IGP)** and **Exterior Gateway Protocol (EGP)**

When we talk about routing we will be routing a packet.

Routing Concepts

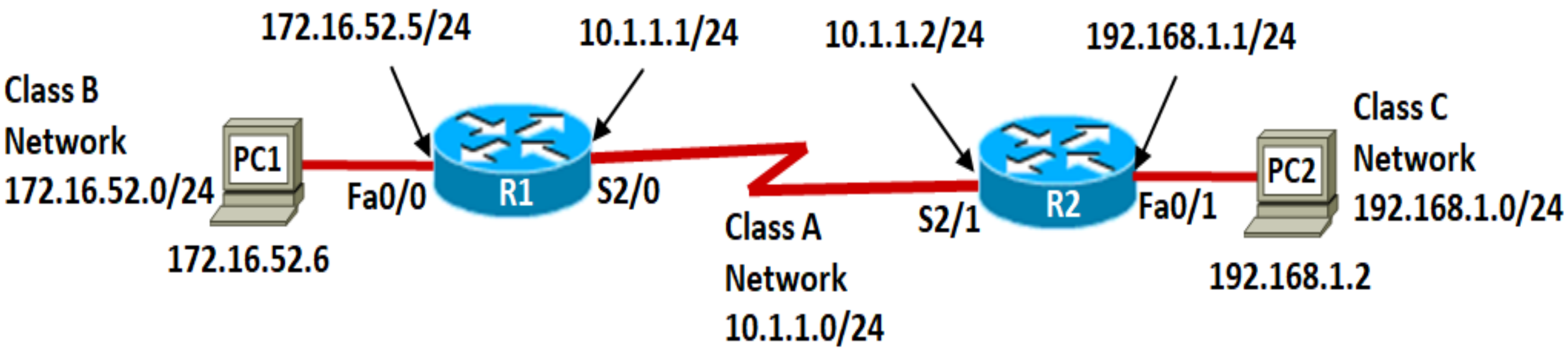
Routing Concepts

There is no default gateways in a serial link

There only is default gateways in LANs

Router Functions

- Router connects networks and the **connections are at the interfaces** of the router.



- When a packet arrives at the interface of a router, the router **consults its routing table** to **determine the interface** to use to forward the packet to the destination.

- To display the routing table on a Cisco router, the ***show ip route*** command is used.

Routing Concepts

Routing Table

A routing table has 3 portions:

1. The **codes** used in the entries in the routing table. This course will focus on C - Connected, S –static and R - RIP.
2. The **gateway of last resort** which will be explained later.
3. **Routing entries** (those that have a code in the first column) and some subnetting information. We will focus on the routing entries.

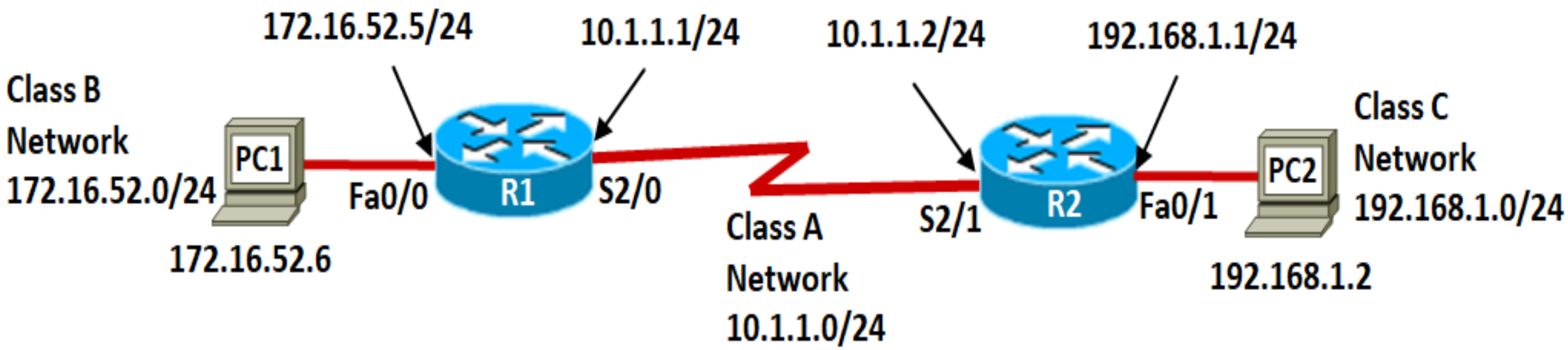
```
R1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2,
       * - candidate default, U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 1 subnets
C       172.16.52.0/24 is directly connected, FastEthernet0/0
     10.0.0.0/24 is subnetted, 1 subnets
C       10.1.1.0/24 is directly connected, Serial2/0
R    192.168.1.0/24 [120/1] via 10.1.1.2, 00:00:07, Serial2/0
```

Routing Concepts

Routing Table Entry



R	192.168.1.0	/24	[120 /	1]	via 10.1.1.2,	00:00:07,	Serial2/0
Code	*Dest Net*	Subnet Mask	*Admin distance*	Metric	*Next-hop IP addr*	Time elapsed since last update	*Outgoing interface*

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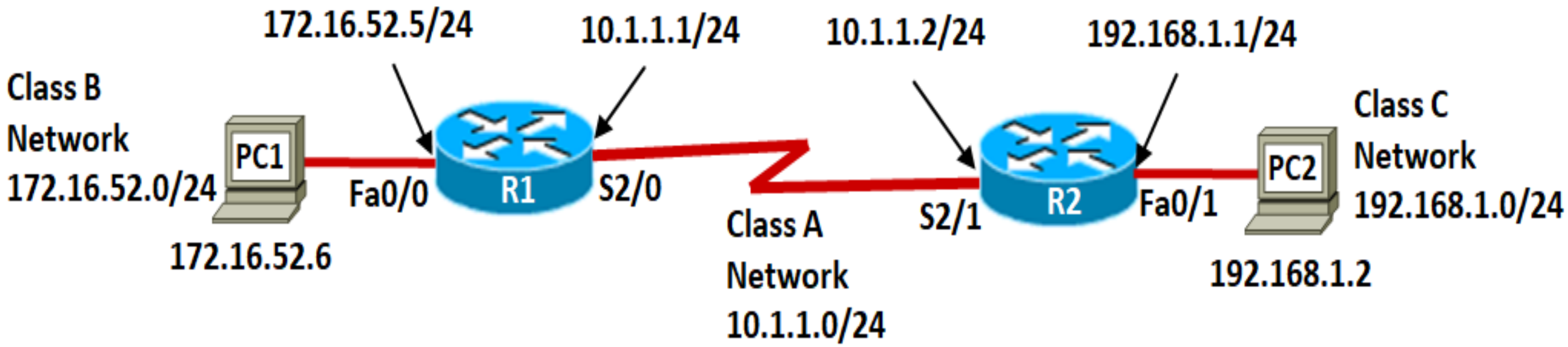
Routing Concepts - Example

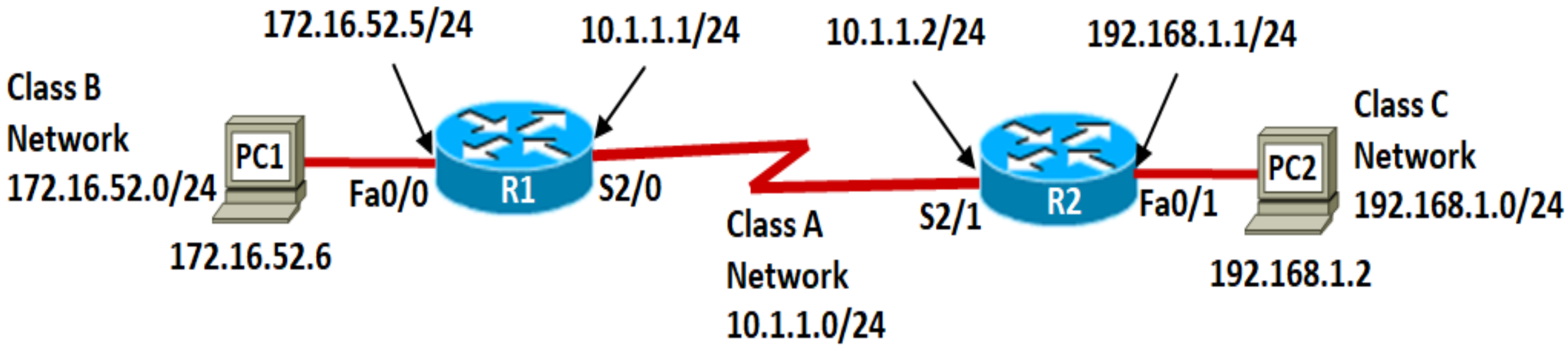


PC1 wants to send data to PC2. Assume the data link layer protocol for LAN is **Ethernet** and for WAN is Point-to-Point Protocol (**PPP**).

Process taken by **PC1 to reach PC2**:

1. PC1 has to determine whether the **destination IP address** is on the **same network as its own**.
   - It determines its **own network address** by performing an AND operation on its own IP address and subnet mask.
   - It performs another AND operation on the **destination IP address** of 192.168.1.2 and PC1's subnet mask.
   - If these **two network addresses are the same**, PC1 **does not use the default gateway** to deliver to the destination.
   - If they are on **different networks**, as is the case for this example, PC1 forwards the frame to its **default gateway** at Fa0/0.

Routing Concepts - Example



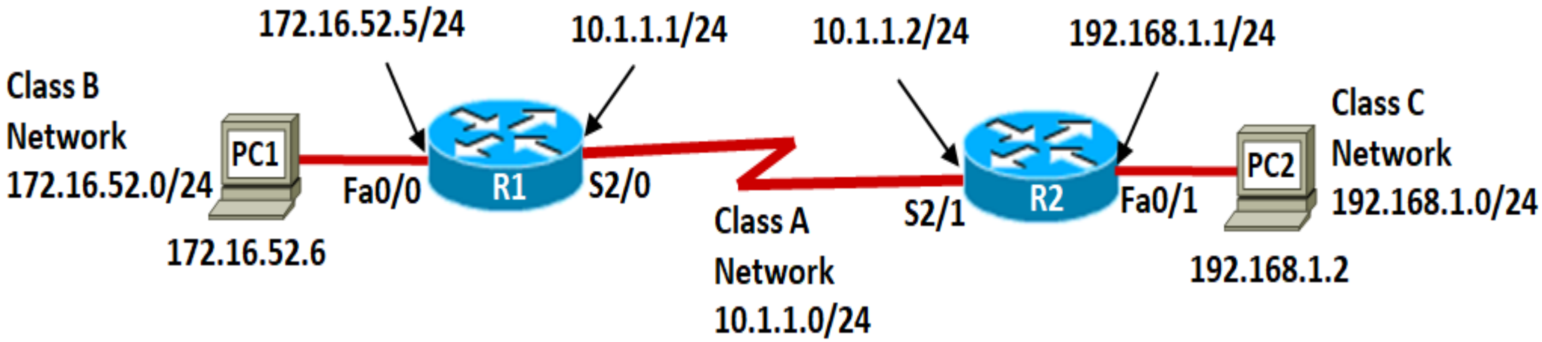
PC1 wants to send data to PC2. Assume the data link layer protocol for LAN is Ethernet and for WAN is Point-to-Point Protocol (PPP).

Process taken by PC1 to reach PC2:

2. **PC1 encapsulates an Ethernet frame** with appropriate layer 2 source and destination MAC addresses and layer 3 source and destination IP addresses.

3. When **R1** receives a layer 2 frame at Fa0/0, it **decapsulates** the frame header and trailer to obtain the Layer 3 packet.

Routing Concepts - Example



Process taken by PC1 to reach PC2:

4. **R1** examines the packet to **obtain the destination IP address**, which is 192.168.1.2, the IP address of PC2. R1 then **searches its routing table** for a destination network that includes 192.168.1.2. In this example, **there is a match** in the last entry of the routing table. The destination host IP address of 192.168.1.2 belongs to the network address 192.168.1.0/24. Based on the routing table entry, R1 with forward the packet with **next-hop IP address of 10.1.1.2** and with outgoing interface **S2/0**.

```
R1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 1 subnets
C       172.16.52.0/24 is directly connected, FastEthernet0/0
     10.0.0.0/24 is subnetted, 1 subnets
C       10.1.1.0/24 is directly connected, Serial2/0
R    192.168.1.0/24 [120/1] via 10.1.1.2, 00:00:07, Serial2/0
```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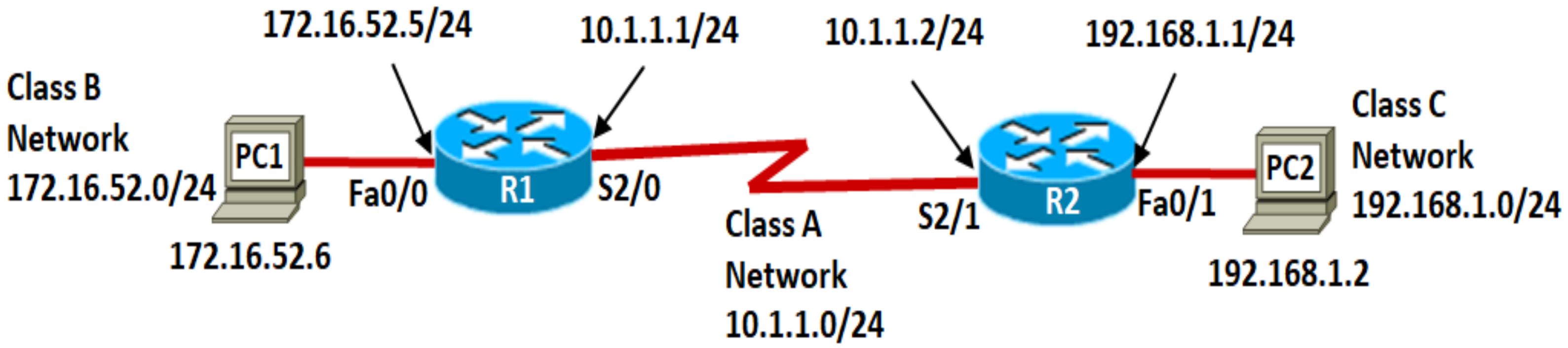
Routing Concepts - Example



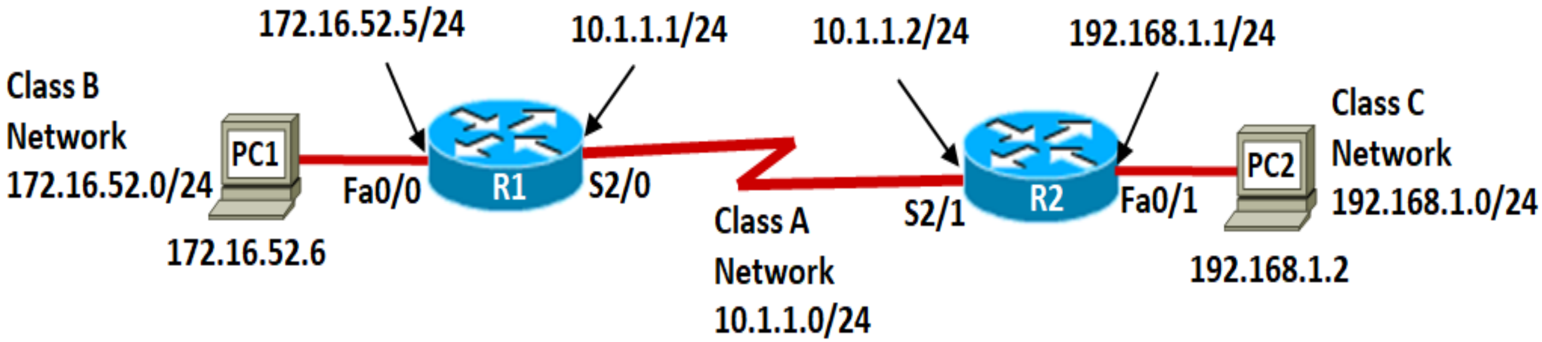
PC1 wants to send data to PC2. Assume the data link layer protocol for LAN is Ethernet and for WAN is Point-to-Point Protocol (PPP).

Process taken by PC1 to reach PC2:

5. R1 has to **encapsulate** the IP packet into a layer 2 **PPP frame** used for network 10.1.10 before forwarding out of interface S2/0.

6. When **R2** receives the PPP frame at S2/1, it **decapsulates** the frame header and trailer to obtain the Layer 3 packet.

Routing Concepts - Example



Process taken by PC1 to reach PC2:

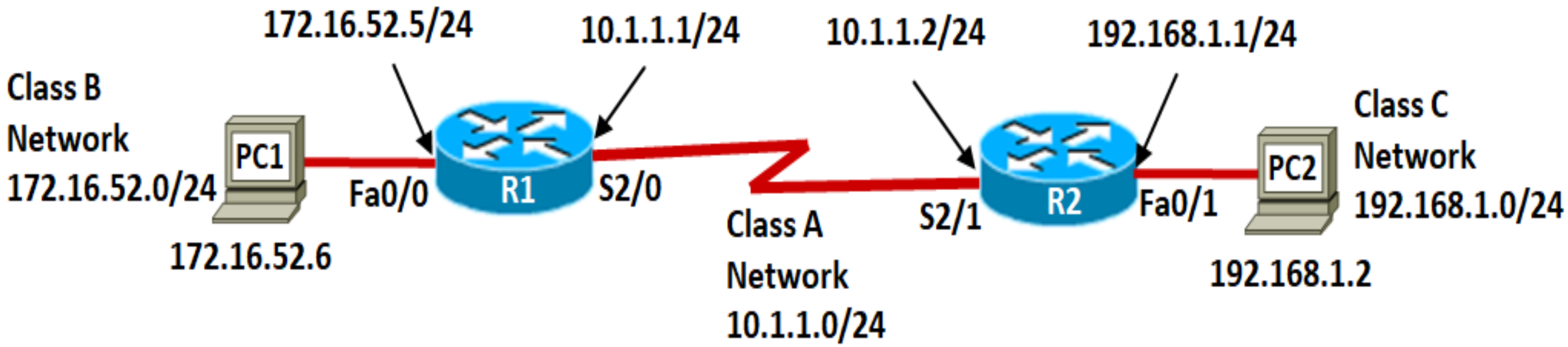
7. **R2** examines the packet to **obtain the destination IP address**, which is 192.168.1.2. R2 then **searches its routing table** for a destination network that includes 192.168.1.2. In this example, **there is a match** in the first entry of the routing table. The destination host IP address of 192.168.1.2 belongs to the network address 192.168.1.0. Based on the routing table entry, R2 is **directly connected to network 192.168.1.0** at interface Fa0/1. Thus R2 will forward the packet out of interface **Fa0/1**.

```
R2#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP

Gateway of last resort is not set

     192.16.1.0/24 is subnetted, 1 subnets
C       192.168.1.0/24 is directly connected, FastEthernet0/1
     10.0.0.0/24 is subnetted, 1 subnets
C       10.1.1.0/24 is directly connected, Serial2/1
R    172.16.52.0/24 [120/1] via 10.1.1.1, 00:00:10, Serial2/1
```

Routing Concepts - Example



PC1 wants to send data to PC2. Assume the data link layer protocol for LAN is Ethernet and for WAN is Point-to-Point Protocol (PPP).

Process taken by PC1 to reach PC2:

8. **R2** has to **encapsulate** the IP packet into an **Ethernet frame** before forwarding out of interface Fa0/1.

9. The frame eventually arrives at PC2.

Static Routing

Routing

- Routers **learn the path** to remote networks by using **static routes** and **dynamic routing protocols**.
- Routers **identify all available routes** either statically or dynamically to a remote network and **install the best route** into the routing table.

Static Routes

- Static route is a **fixed path** from one source to destination.
- Static route has to be determined and **manually entered** into the routing table by the network administrator.
- The network administrator must **manually update** the route whenever there is a topology change.

Dynamic Routing Protocols

- Dynamic routing protocols are implemented using **software**.
- When dynamic routing protocols is used, routers **learn** the routes to remote networks **from other routers**.
- To achieve this, routers have to **share routing information with other routers**.
- This is a **disadvantage** of dynamic routing if **security** is a concern.
- The beauty of dynamic routing is that the routing protocol can **adjust or update the route automatically** if there are topology or traffic changes.

Static Routing vs. Dynamic Routing

- Static routing is suitable for **small organisations** with only a few remote networks.
- Large organisations with **enterprise networks** usually use a **combination of static and dynamic routings**.

Advantages of Static Routes over Dynamic Routing

- Static routes **do not share** routing information over the network, thus **better in security**.
- Static routes **avoid the overhead** of dynamic routing protocols.
- In dynamic routing, **certain amount of user bandwidth** is used for the sharing of routing information between routers.
- The **static path** used to send data **is known**.

Disadvantages of Static Routes

- It is **time consuming to configure** the initial static routes and to update the routes whenever there is a topology change.
- **Human error in configuration is high** especially for large networks.
- **Intervention by network administrator** is required to maintain the static routes.
- **Scalability is a concern** as the network grows and maintenance can be prohibitive.
- A **complete knowledge** of the entire network topology **is required** for proper implementation.

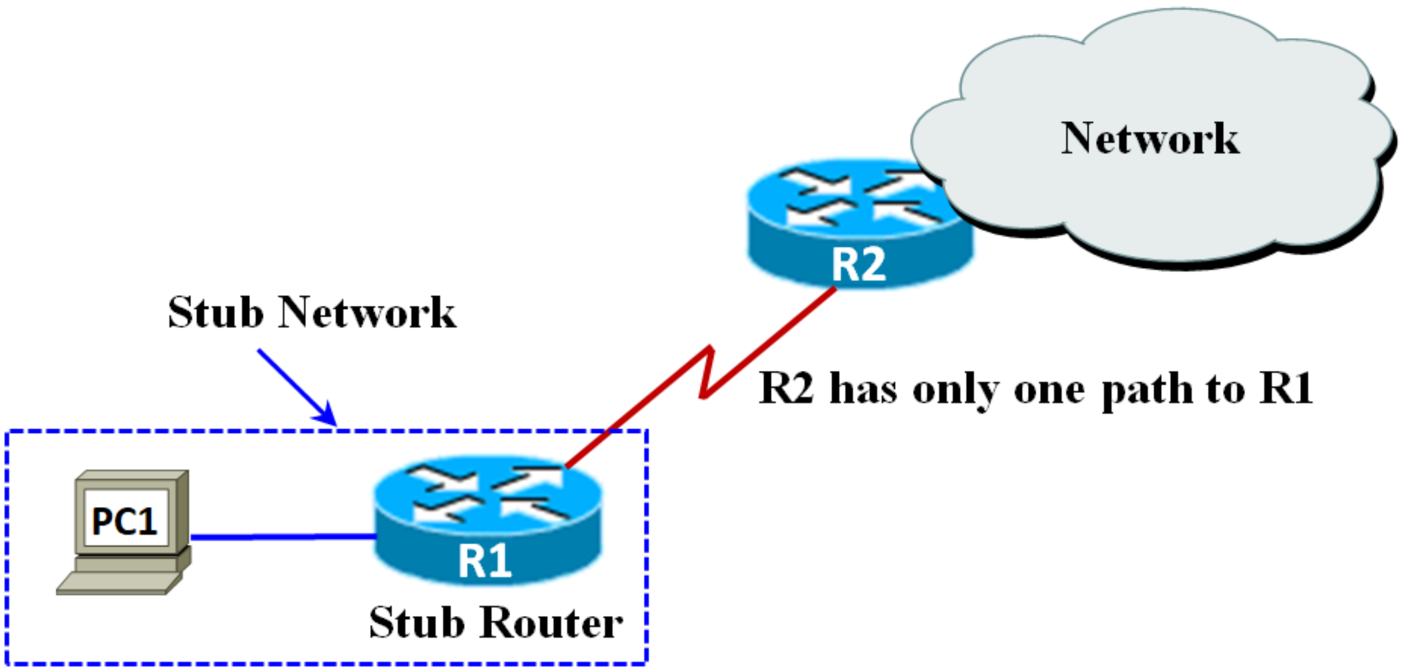
Static Routing vs. Dynamic Routing

Feature	Static Routing	Dynamic Routing
Configuration Complexity	Increases with network size	Independent of network size
Topology Changes	Administrator intervention required	Automatically adapts to topology changes
Scalability	Suitable for simple topologies	Suitable for simple and complex topologies
Resource Usage	No extra resources needed	Uses CPU, memory and link bandwidth to operate
Predictability	Route to destination is fixed	Route based on current topology

Use of Static Routes

Static routes are preferred over dynamic routing under the following circumstances:

- **Small networks** that do not expect to grow significantly.
- There is a need to connect to a specific network for **testing purposes**.
- As a **backup route** in the event of a link failure. How this is being done, will be explained later.
- When a network is accessible by only one path, such a network is called a **stub network**.
- In this example, a static route can be configured on R2 to reach R1 and vice versa.



Administrative Distance (AD)

- Cisco uses a quantitative value known as ***administrative distance*** *(AD)* to measure the "**trustworthiness**" or reliability of a route.
- A **lower AD** value indicates a **more reliable** route.
- A router can be configured with multiple routing protocols and static routes that provide numerous possible routes from the same source to the same destination network.
- Each of these routes has an associated AD.
- The router will **install** the route with the **lowest AD into the routing table**.
- A **directly connected interface** or route has default **AD of 0**, and a **static route** has default **AD of 1**.
- The AD value can be from **0 to 255**.
- Given below are some of the default ADs relevant to this course.

Route Source	Administrative Distance
Connected Interface	0
Static Route	1
Open Shortest Path First (OSPF)	110
Routing Information Protocol (RIP)	120

Types of Static Routes

There are 3 types of Static Routes

1. **Standard** static route
2. **Default** static route
3. **Floating** static route

Standard Static Route

ip route Command

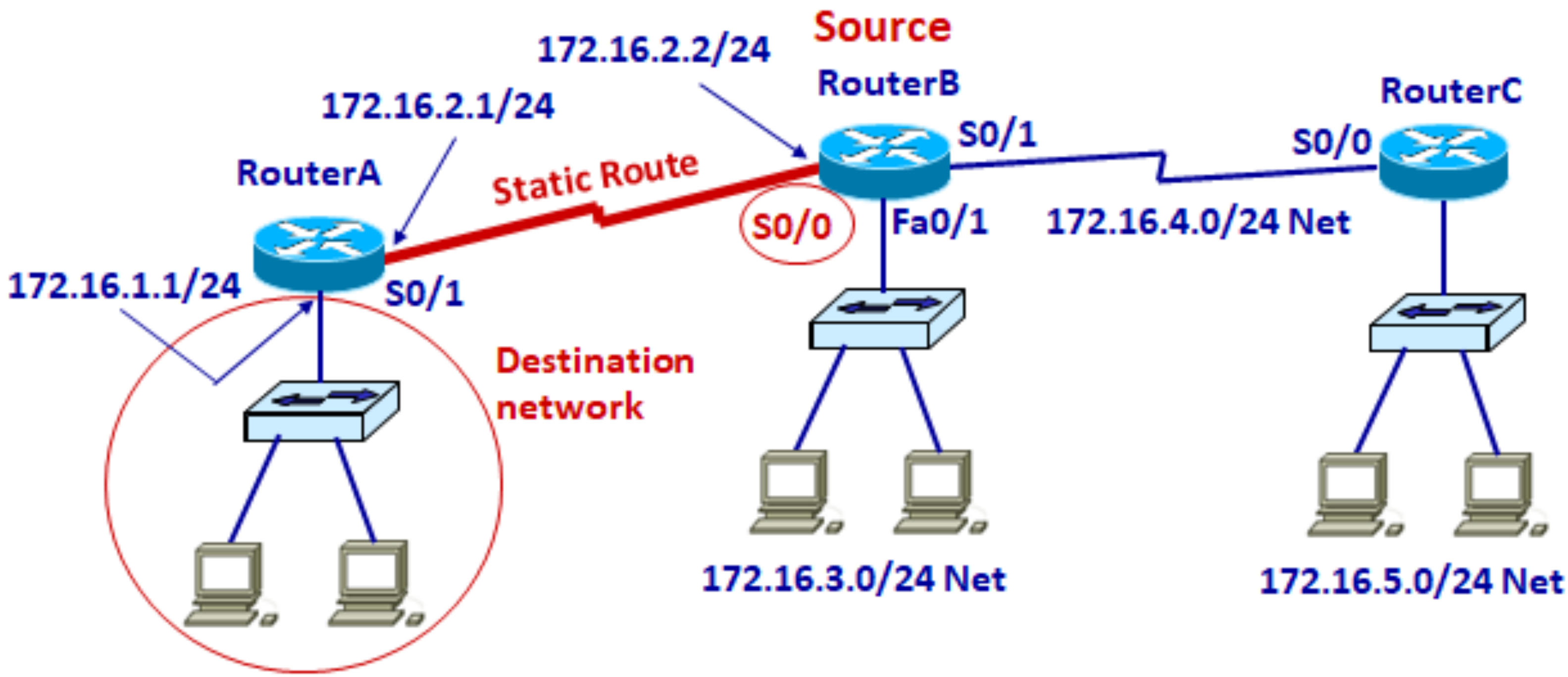
- To configure a static route, we use the *ip route* command.
- The syntax to configure a static route is as follows:

Router(config)#**ip route** <network-address> <subnet-mask> {exit-intf | ip-address} [distance]

- Router(config)# is the prompt on the Command Line Interface (CLI) screen.
- You can configure a static route by using either the **exit interface** or the **next-hop IP address**.

Parameter	Description
ip route	Command
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.
exit-intf	The outgoing interface to use to forward the packet to the next hop.
|	OR
ip-address	The IP address of the connecting router to use to forward the packet to the remote destination network. Also known as the next hop.
distance	[An optional parameter] Administrative distance

Example 1: Standard Static Route Using Exit Interface



Configure a Static Route using Exit Interface from RouterB to Destination Network

/24 => 255.255.255.0

Thus interface 172.16.1.1 is in network 172.16.1.0

```
RouterB(config)#ip route 172.16.1.0 255.255.255.0 s0/0
```

command	destination network	destination subnet mask	exit interface

Example 1: Standard Static Route Using Exit Interface

RouterB's routing table is shown below.

Configure a Static Route using Exit Interface from RouterB to Destination Network
/24 => 255.255.255.0
Thus interface 172.16.1.1 is in network 172.16.1.0

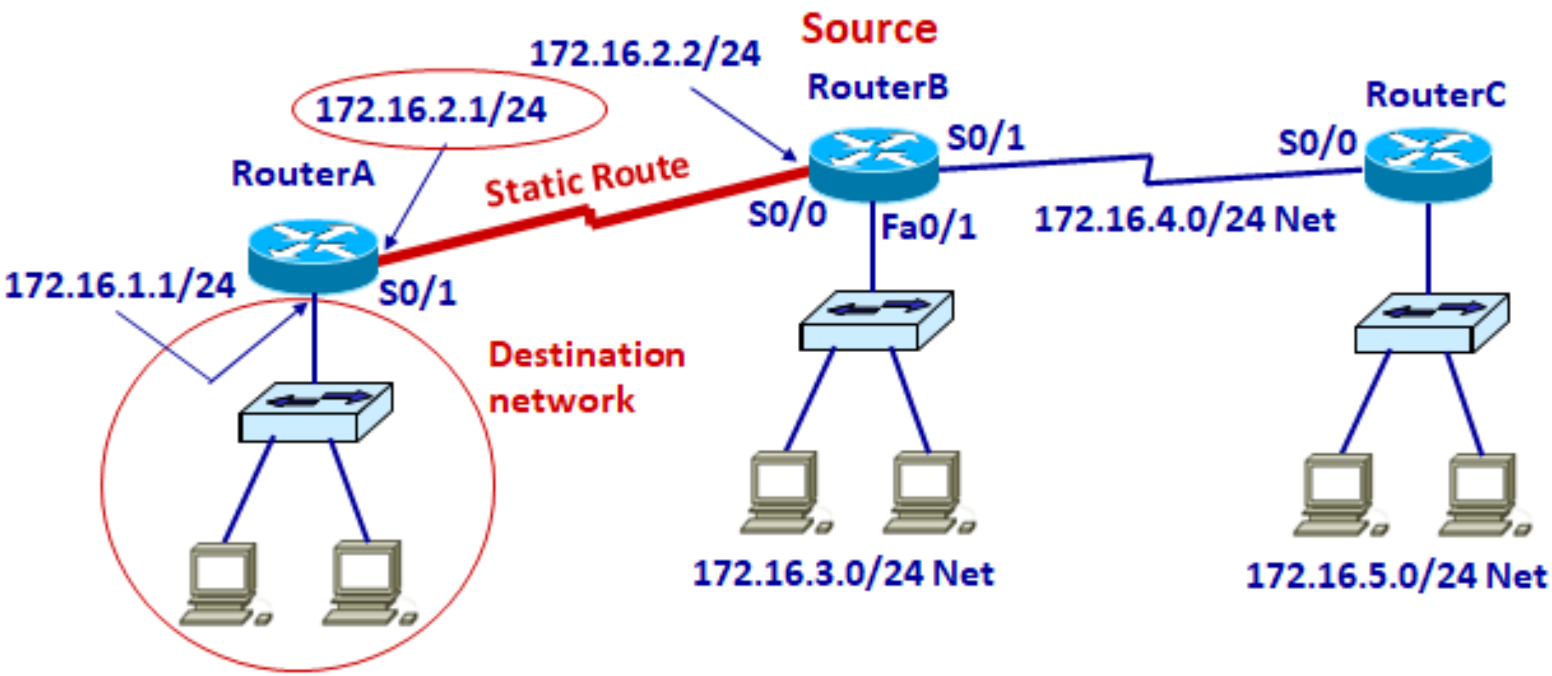
```
RouterB(config)#ip route 172.16.1.0 255.255.255.0 s0/0
                command  destination destination  exit
                         network     subnet mask  interface
```

```
RouterB#show ip route
Output of codes and Gateway of last resort eliminated

     172.16.0.0/16 is subnetted, 5 subnets
S       172.16.1.0/24 is directly connected, Serial0/0
C       172.16.2.0/24 is directly connected, Serial0/0
C       172.16.3.0/24 is directly connected, FastEthernet0/1
C       172.16.4.0/24 is directly connected, Serial0/1
```

- In this example the optional administrative distance is not set.
- If it is not set, this static route will have the default AD of 1 because the AD of static route is 1, even though it is indicated as "directly connected."

Example 2: Standard Static Route Using Next-Hop IP Address



Configure a Static Path using Next-hop IP from RouterB to Destination Network
/24 => 255.255.255.0
Thus interface 172.16.1.1 is in network 172.16.1.0

```
RouterB(config)#ip route 172.16.1.0 255.255.255.0 172.16.2.1
```

ip route	172.16.1.0	255.255.255.0	172.16.2.1
command	destination network	destination subnet mask	next-hop ip address

Example 2: Standard Static Route Using Next-Hop IP Address

RouterB's routing table is shown below.

Configure a Static Path using Next-hop IP from RouterB to Destination Network
/24 => 255.255.255.0
Thus interface 172.16.1.1 is in network 172.16.1.0

```
RouterB(config)#ip route 172.16.1.0 255.255.255.0 172.16.2.1
```

command	destination network	destination subnet mask	next-hop ip address

```
RouterB#show ip route
Output of codes and Gateway of last resort eliminated

     172.16.0.0/16 is subnetted, 5 subnets
S       172.16.1.0/24 [1/0] via 172.16.2.1
C       172.16.2.0/24 is directly connected, Serial0/0
C       172.16.3.0/24 is directly connected, FastEthernet0/1
C       172.16.4.0/24 is directly connected, Serial0/1
```

- Similar to Example 1, the optional administrative distance is not set.
- If it is not set, this static route will have the default AD of 1.

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Default Static Route

- A default static route is used when the **destination network is not listed in the routing table**.
- It is also used for **internet-bound traffic** as it is impossible for internal routers to maintain knowledge of all the networks in the internet.
- For simplicity, default static route is also known as **default route**.
- When a default route is configured, the Gateway of Last Resort is set. Thus it is also known as the default route.
- If the destination network is not listed in the routing table and the **Gateway of Last Resort is not set**, the router will **discard the packet**.
- The syntax to configure a default route is as follows:

Router(config)#**ip route** 0.0.0.0 0.0.0.0 {exit-intf | ip-address} [distance]

Default Static Route

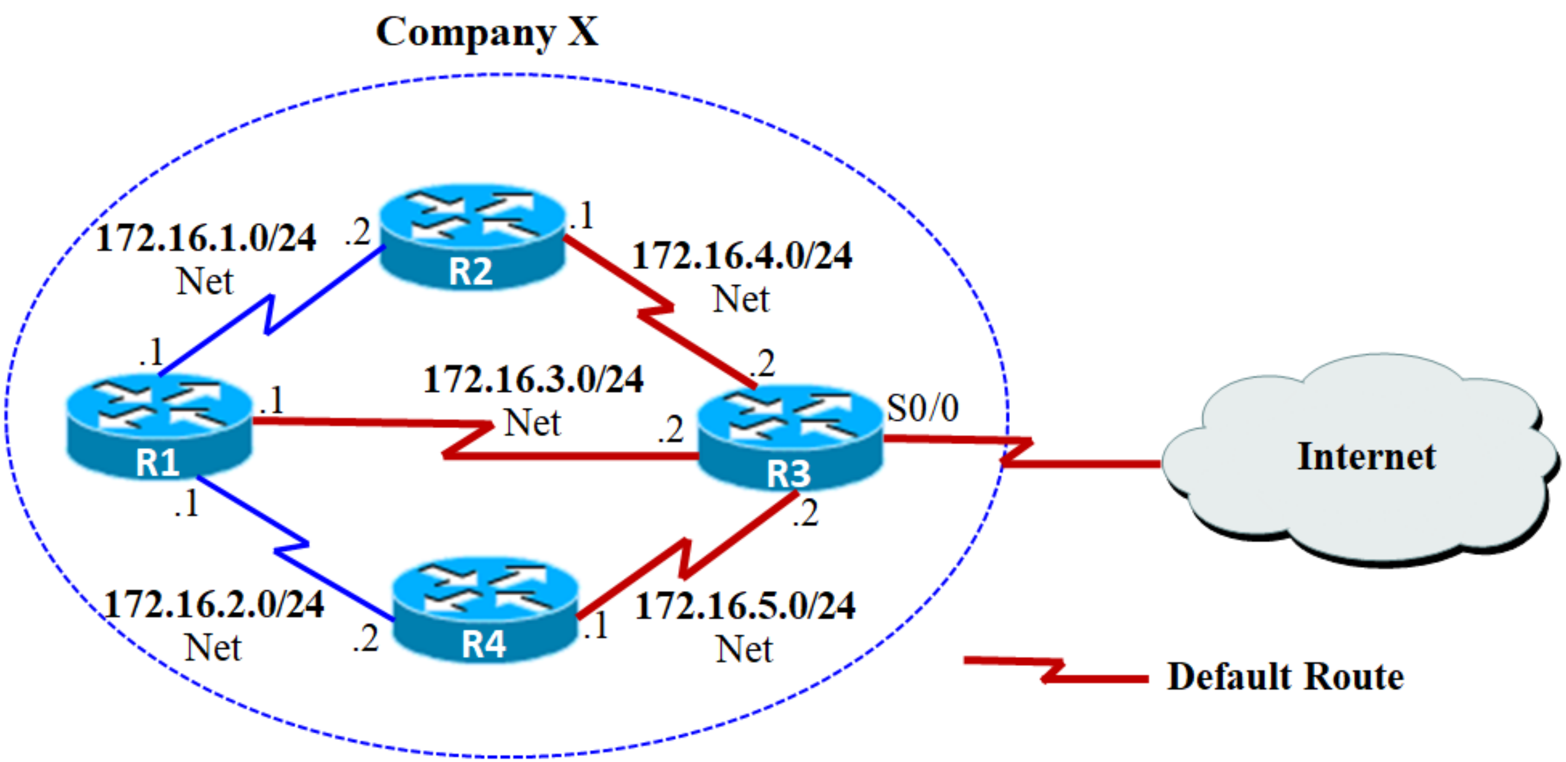
- The syntax to configure a default route is as follows:

Router(config)#**ip route** 0.0.0.0 0.0.0.0 {exit-intf | ip-address} [distance]

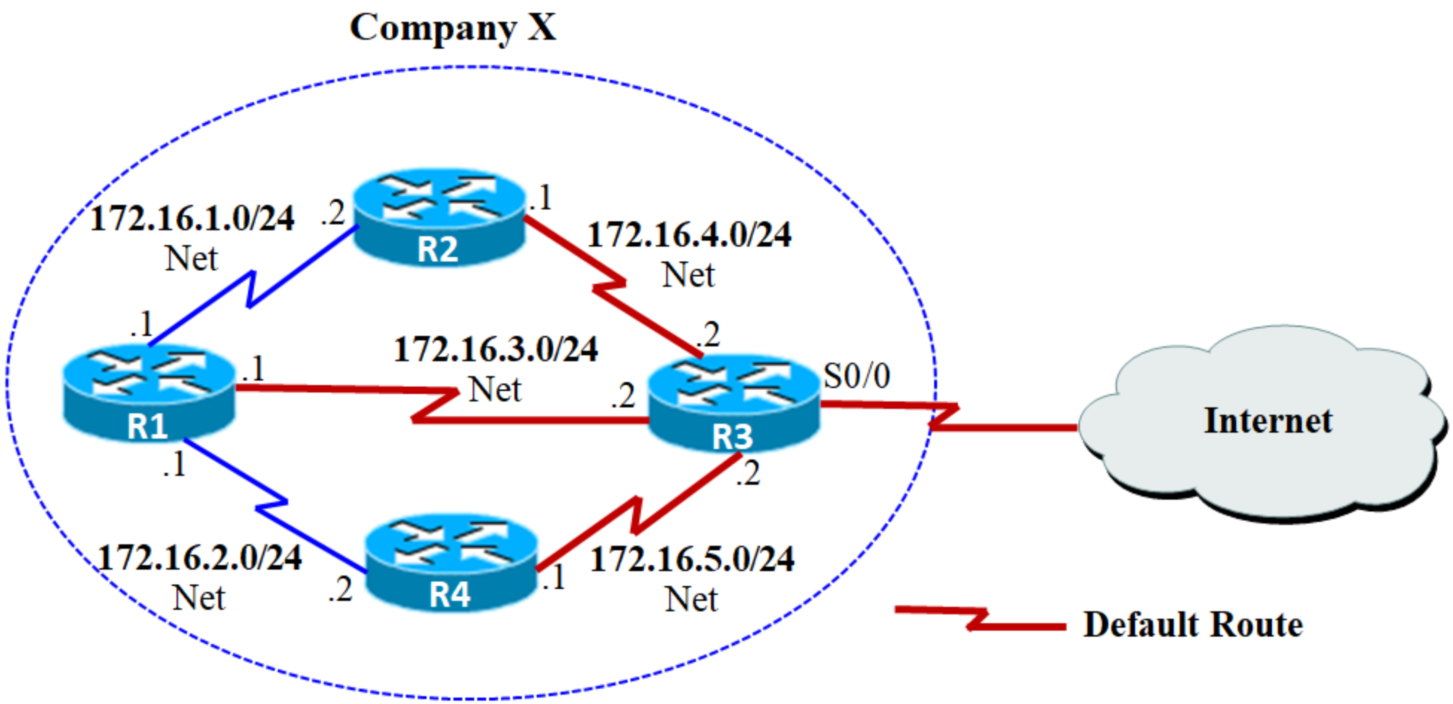
- For default route, the destination network address and subnet mask are both 0.0.0.0.
- You can interpret the first set of 0.0.0.0 as any network.
- The second set of 0.0.0.0 is the subnet mask or /0 mask.
- The subnet mask in a routing table is used to decide the number of bits that must match between destination address in the IP packet and the entry in the routing table.
- A **binary 1** in the subnet mask indicates the **bits must match**.
- A **binary 0** indicates it **does not have to match**.
- A subnet mask of all zeros means no matching is required.
- The descriptions for the rest of the parameters in the *ip route* command are the same as previous explained.

Example 3: Default Route

- The network topology of Company X with a connection to the internet is shown.
- Company X routers have knowledge of the topology of networks within the company, but not external networks.
- It is impossible, unnecessary and unreasonable to maintain knowledge of every network outside the organization.
- Instead of maintaining knowledge of external networks on the routers of Company X, each router in Company X is informed of the default route that it can use to reach any unknown destination by directing the packet to the internet.



Example 3: Default Route



- R3 is an edge route, a router that connects to an external network.
- For R1, R2 and R4 to reach any unknown destination, there must be a default route on each of these routers to direct packets to R3, then to the outside.
- Given below is the default route configuration on **R1**.
- This default route is using the next-hop IP address.

R1(config)#**ip route** 0.0.0.0 0.0.0.0 172.16.3.2

Example 3: Default Route

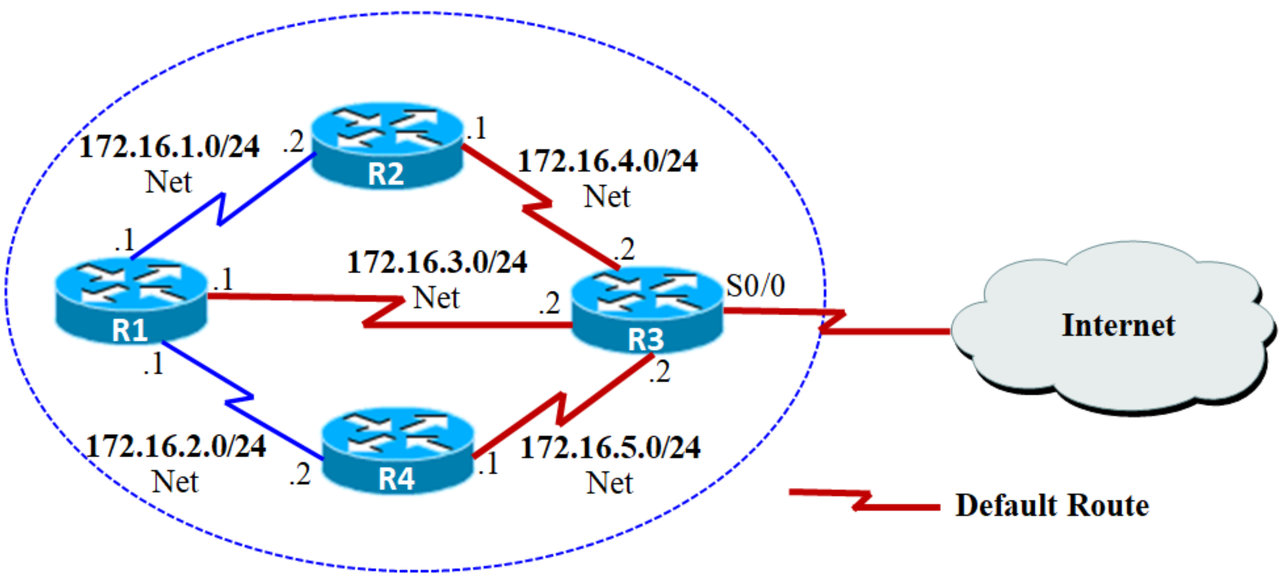
- Shown below is the default route configuration on **R1** and its routing table.
- This configuration generates an '**S***' entry in the routing table.
- **S** denotes **static route** and * indicates the **possibility** of **this route being a** candidate for **default route**.
- This static route has been chosen as the default route as indicated by the Gateway of Last Resort.

```
R1(config)# ip route  0.0.0.0  0.0.0.0  172.16.3.2
R1(config)# exit
R1#
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,
       * - candidate default, U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is 172.16.3.2 to network 0.0.0.0

     172.16.0.0/16 is subnetted, 5 subnets
S*      0.0.0.0/0 [1/0] via 172.16.3.2
. . .
Irrelevant routing table entries eliminated
```

Example 3: Default Route

- Shown below is the default route configuration on **R2** and its routing table.

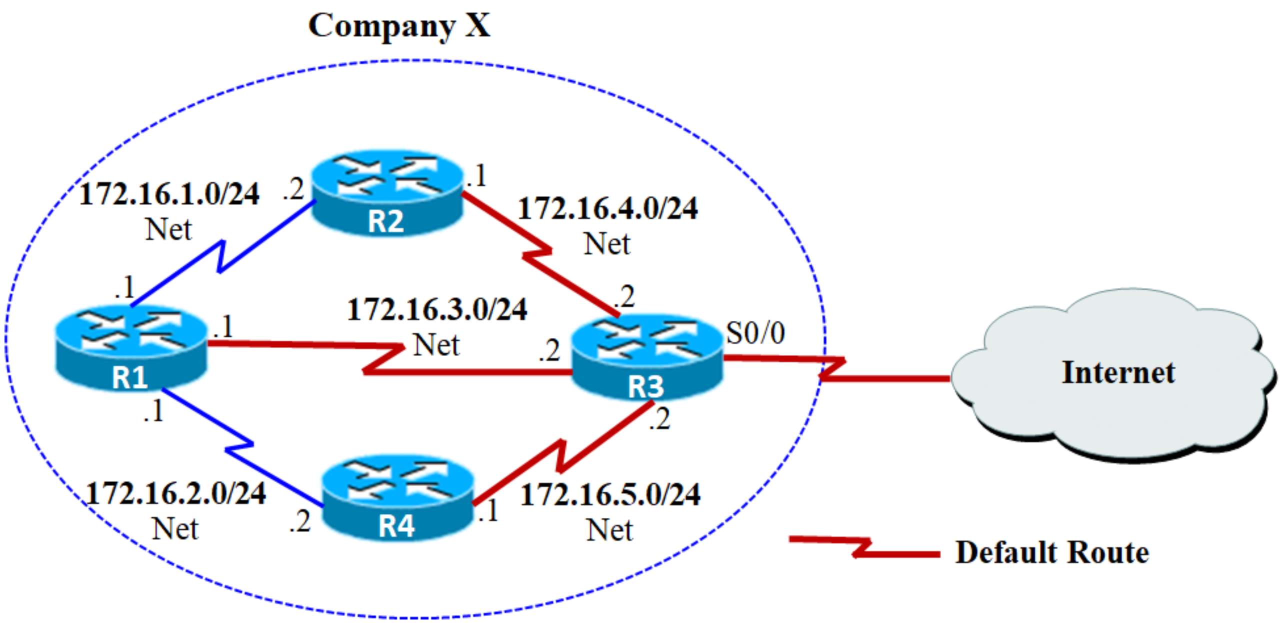
Company X




```
R2(config)# ip route  0.0.0.0  0.0.0.0  172.16.4.2
. . .
R2#show ip route
Output of codes eliminated

Gateway of last resort is 172.16.4.2 to network 0.0.0.0

     172.16.0.0/16 is subnetted, 5 subnets
S*       0.0.0.0/0 [1/0] via 172.16.4.2
. . .
Irrelevant routing table entries eliminated
```

Example 3: Default Route

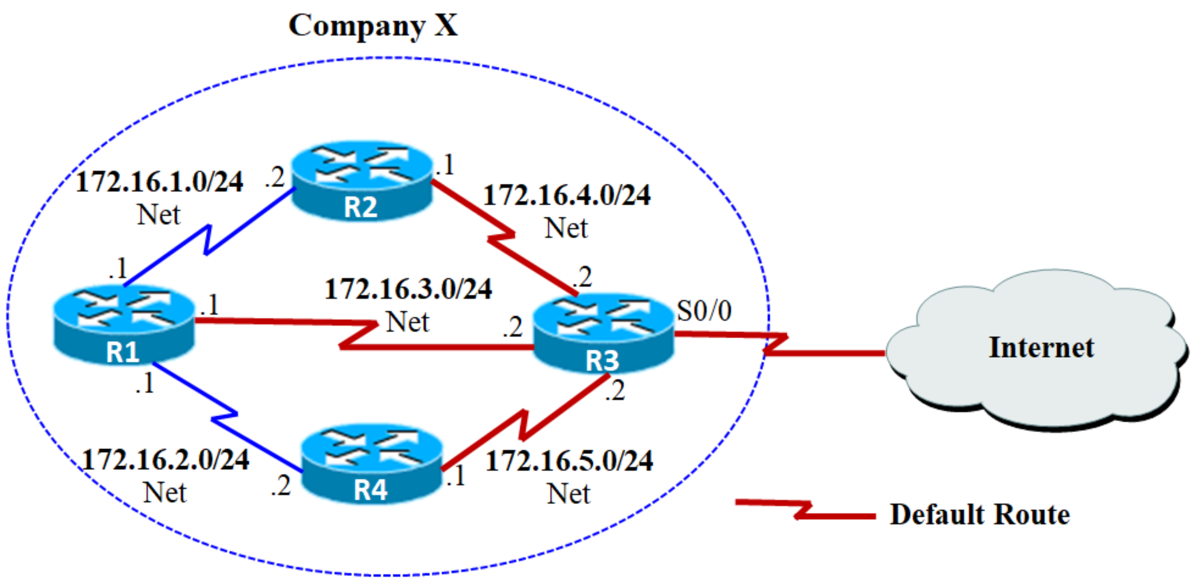
- Shown below is the default route configuration on **R4** and its routing table.




```
R4(config)# ip route  0.0.0.0  0.0.0.0  172.16.5.2
. . .
R4#show ip route
Output of codes eliminated

Gateway of last resort is 172.16.5.2 to network 0.0.0.0

     172.16.0.0/16 is subnetted, 5 subnets
S*       0.0.0.0/0 [1/0] via 172.16.5.2
. . .
Irrelevant routing table entries eliminated
```

Example 3: Default Route

- Finally, a default route is configured at **R3** to direct any unknown destination to the internet. This default route is using the exit interface of the router.




```
R3(config)# ip route  0.0.0.0  0.0.0.0  S0/0
. . .
R3#show ip route
Output of codes eliminated

Gateway of last resort is 0.0.0.0 to network 0.0.0.0

     172.16.0.0/16 is subnetted, 5 subnets
S*       0.0.0.0/0 directly connected, Serial0/0
. . .
Irrelevant routing table entries eliminated
```

Floating Static Route

- Floating static routes are used as a **backup route** to a primary dynamic or static route in case of link failure.
- As mentioned previously, a router will install the route with the lowest AD into its routing table.
- To **use a static route as a backup**, you need to **set** the optional **AD** parameter of the *ip route* command to a value that is **higher than the primary route**.
- For example, if the primary route to a destination network is learned through Routing Information Protocol (RIP), which has AD of 120, then the floating static route must be configured with AD higher than 120.
- This causes the route learned through RIP to be installed into the routing table, but in the event of failure of this route, the floating static route will be used.
- Floating static route can be used to backup standard static route or default static route.

Dynamic Routing

Evolution of Dynamic Routing Protocols

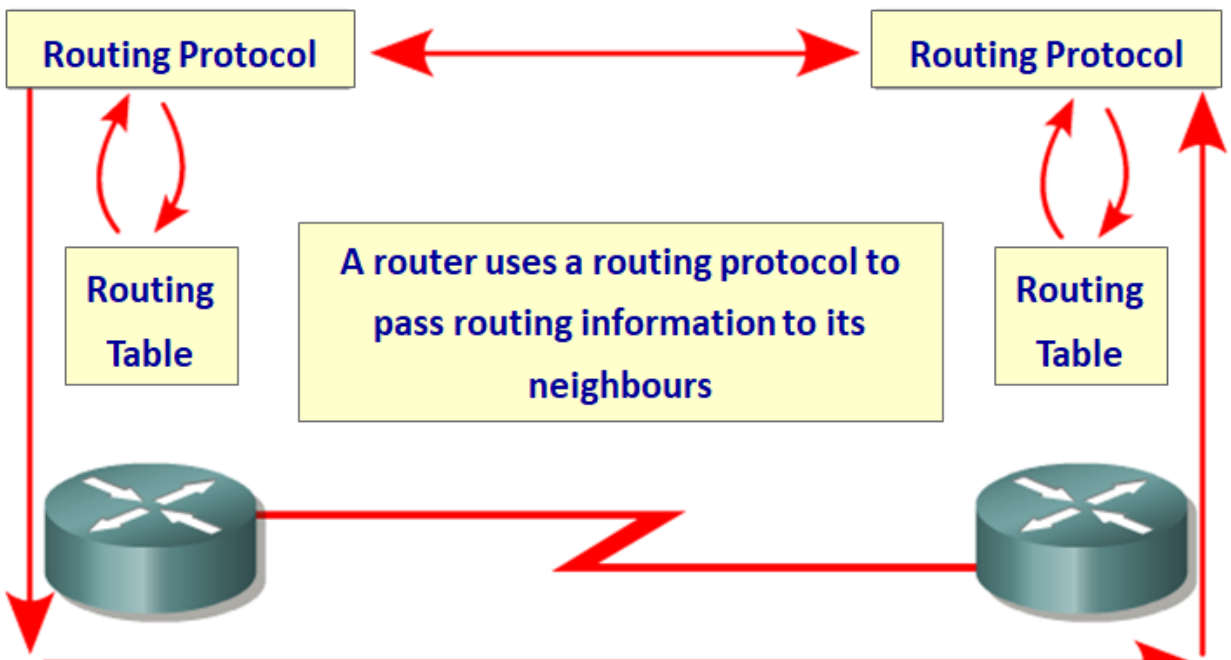
- *Routing Information Protocol (RIP)* was one of the first dynamic routing protocols developed in the late 1980s.
- *RIP version 1 (RIPv1)* was released in 1988.
- Due to the increasing complexity of networks, RIPv1 was upgraded to RIPv2 to cater to the growing needs of networks.
- RIP was designed for small networks and does not scale well for larger network.
- Thus two advanced dynamic routing protocols suitable for large networks were developed. They are:
  - *Open Shortest Path First (OSPF)*
  - *Intermediate System-to-Intermediate System (IS-IS)*.

Operations of Dynamic Routing Protocol

- A routing protocol defines a set of rules used by a router to communicate with other routers.
- Routers using dynamic routing protocols share information with other routers about the accessibility and status of remote networks.
- The **purposes of dynamic routing protocols** are:
  - Discovery of remote networks
  - Maintenance of latest routing information
  - Determining the best route to destination networks
  - Determine the next best route in the event that the current best route is not available.
- The components of dynamic routing protocols include:
  - ***Data structures*** – Routing protocols usually have a collection of topological databases stored in RAM for it to operate.
  - ***Routing protocol messages*** – Many types of messages are passed between routers to discover remote networks and timely distribution of routing updates to other routers.
  - ***Algorithm*** – An algorithm is a step-by-step procedure to perform a task. Routing protocols use algorithms to determine the best path.

Operations of Dynamic Routing Protocol

- Figure shows how routing protocol facilitates routers to pass routing information to other routers and also to use this information to update their own routing tables.
- Routing protocols identify all available routes to each network and install the best route into the routing table.
- One major **benefit of dynamic routing** protocols is that it allows routers to automatically adjust its best route and update their routing tables when there is a topology change.



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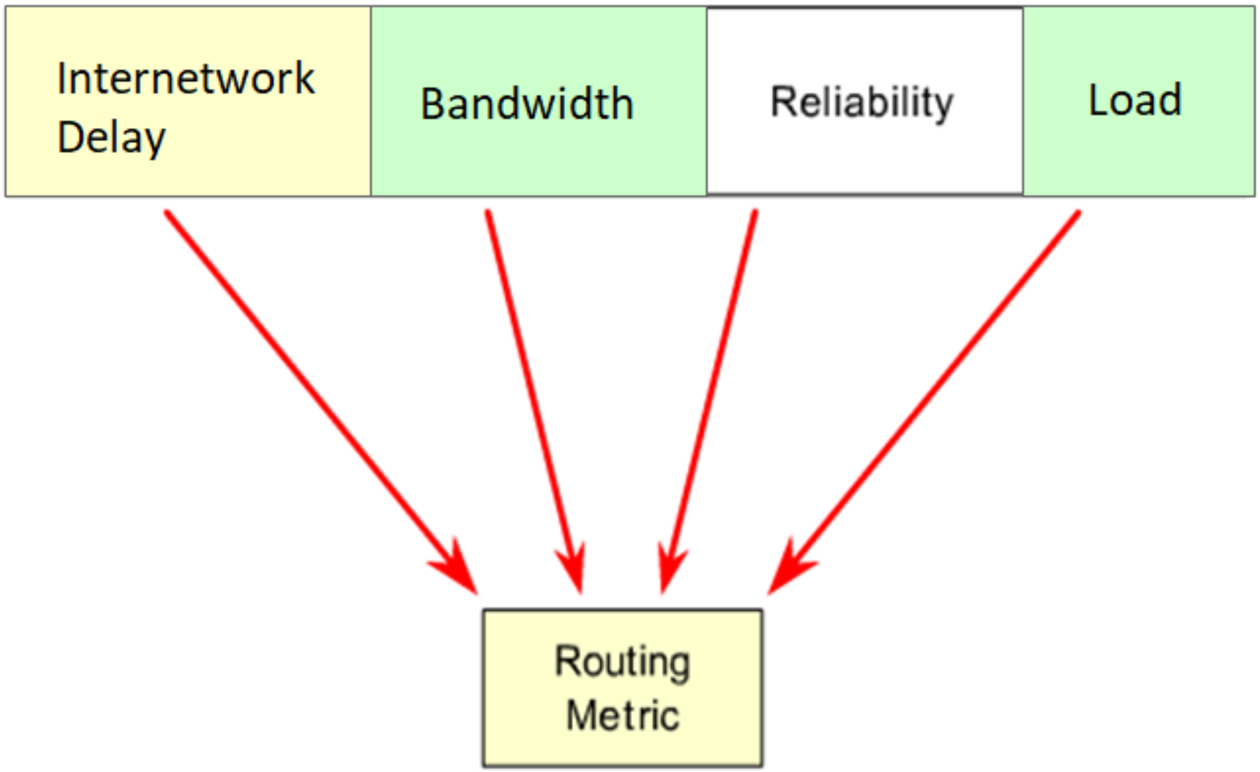
Routing Metrics

- A ***metric*** is a numeric value to indicate **how good a path is**.
- The **lower the metric**, the **better the path** is.
- The routing protocol generates a metric value for each path to the destination network.
- When there are multiple routes to the same destination, the routing protocol selects the best path based on the lowest metric.
- Each routing protocol interprets what is best in its own way.
- The metrics most commonly used by routers are as follows:
  - **Bandwidth** – The data capacity of the link.
  - **Delay** – The time required to move a packet along each link from source to destination.
  - **Load** - The amount of activity on a network resource such as a router or a link.
  - **Reliability** – The error rate of each network link.
  - **Hop count** – The number of routers that a packet must travel through before reaching its destination.
  - **Ticks** – The delay on a data link using IBM PC clock ticks.
  - **Cost** – An arbitrary value, usually based on bandwidth, monetary expense, or other measurement, i.e. assigned by a network administrator.

Routing Metrics

- Metrics can be calculated based on a single characteristic such as hop count, or by a combination of several characteristics.



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Classes of Dynamic Routing Protocols

- Three classes of dynamic routing protocols classified according to their characteristics.

- ***Distance vector***
  - Routers determine the best path based on the direction (vector) and the distance of their routers to the destination network.
  - Routing updates are sent to neighbouring routers.

- ***Link state***
  - Uses the *Shortest Path First (SPF)* algorithm to determine the best path.
  - Routers using link state routing protocols have a complete view of the entire network topology.
  - Routing updates are sent to all other routers.

- ***Hybrid***
  - Combines features of distance vector and link state.

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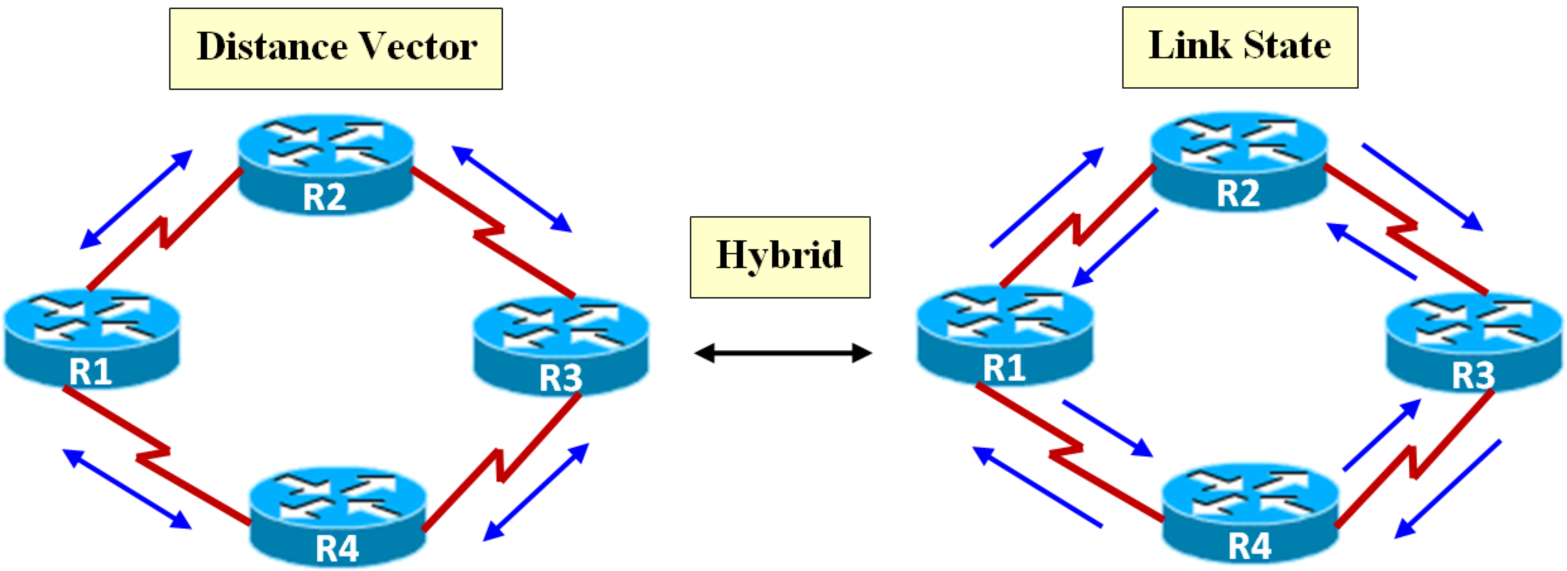
Classes of Dynamic Routing Protocols

- The three classes of dynamic routing protocols:



- The arrows shown for distance vector depict updates are sent to neighbouring routers only, whereas for link state the arrows depict updates are flooded to all routers.

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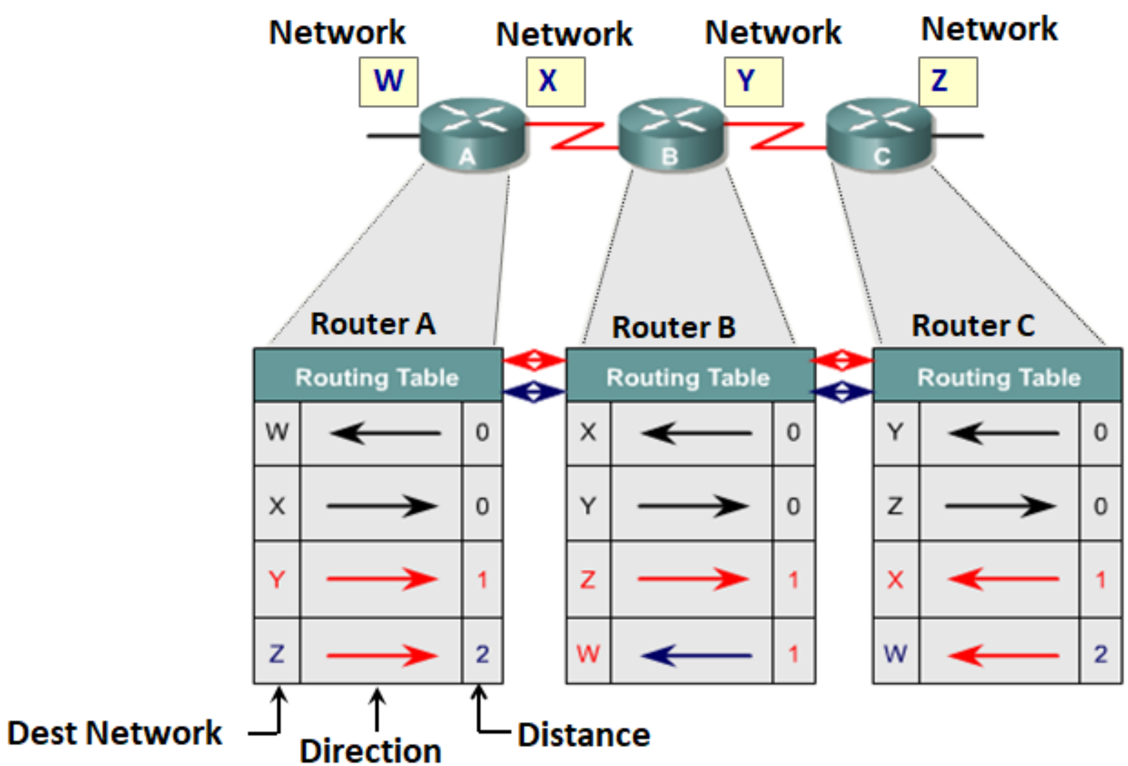
Distance Vector Concepts

- Routers A, B and C are separated by Networks W, X, Y and Z.
- Each router has its own routing table.
- The name distance vector implies that the algorithm is based on distance and direction.
- Distance is defined using a metric and direction refers to the direction of the next hop router.
- E.g. destination network Z is a distance of 2 hops away from Router A, in the direction of next-hop Router B. In this example, the metric used is hop count.



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Distance Vector Network Discovery

- Each router begins by identifying its neighbours.
- The interface that leads to each **directly connected network** has a **distance of 0**.
- Each router learns routes based on the information they receive from each neighbour, which the neighbours in turn learned from their neighbours, and so on.
- Each router sends an update based on information about itself.
- This routing **update** is from **router to router**.
- Each receiving router makes a copy of it and independently computes its best path based on the updated information.
- The updated routing table will be forwarded to the next router. After the entire router to router **update is completed**, all routers will have **same knowledge** about the internetwork.
- Distance vector routing protocol accumulates network distances so that it can create and maintain a database of network topology.
- However, it does not give routers a complete view of the entire network topology as each router is **aware** of **only its neighbouring routers**.

Distance Vector

Examples of Distance Vector Routing Protocols

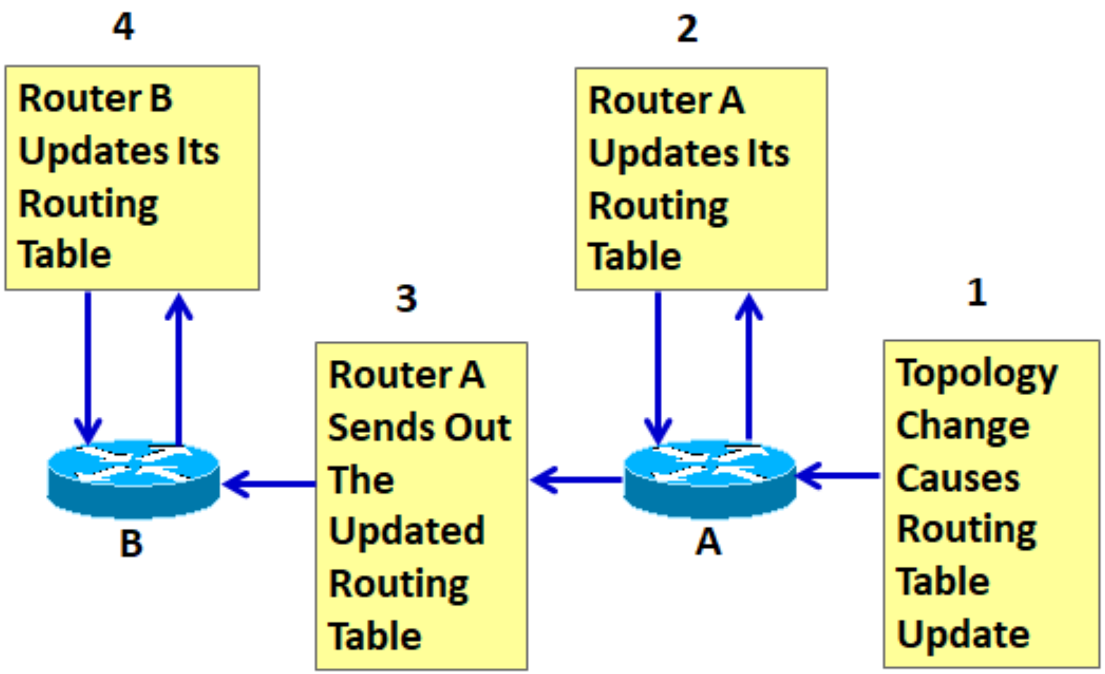
- Routing Information Protocol (**RIP**)
- Interior Gateway Routing Protocol (IGRP) – Developed by Cisco and will not be discussed any further in this course.

Periodic Updates

- In distance vector routing, each router periodically passes its entire routing table to its directly connected neigbouring routers.
- This is referred to as **periodic routing update**.
- For RIP, the routing table is **updated every 30 seconds**.

Distance Vector Topology Changes

- When there is a **topology change**, **routing table updates occur**.
- The updates will proceed from routers to routers as shown below.



Time to Converge

- Convergence is a process and it takes time.
- A network is said to have **converged** if all the routers have a consistent or **same view of the network topology**.
- After a topology change due either to growth, redesign or failure, the routers must re-determine the paths.
- This new information must be advertised to all routers.
- **Convergence** is the process required for **all routers** to be **informed of the change** and has its routing table updated.
- The procedure and **time required** for routers **to converge varies with routing protocols**.
- Due to the neighbour updates neighbours nature of distance vector routing, this class of routing protocols has slow convergence.

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Link State Concepts

- Link state routing protocols use the Shortest Path First (**SPF**) algorithm **to determine the best path**.
- It creates and maintains a complex database of network topology, which means having full knowledge of remote routers and how they are interconnected.
- Link state routing protocols have the following four elements:
  - ***Link-state advertisements (LSAs)*** – Small packets of routing information that are sent between routers.
  - ***Topological database*** – A collection of information gathered from LSAs.
  - ***SPF algorithm*** – A calculation performed on the database resulting in the SPF tree.
  - ***Routing table*** – A list of known routes and interfaces to each destination network.

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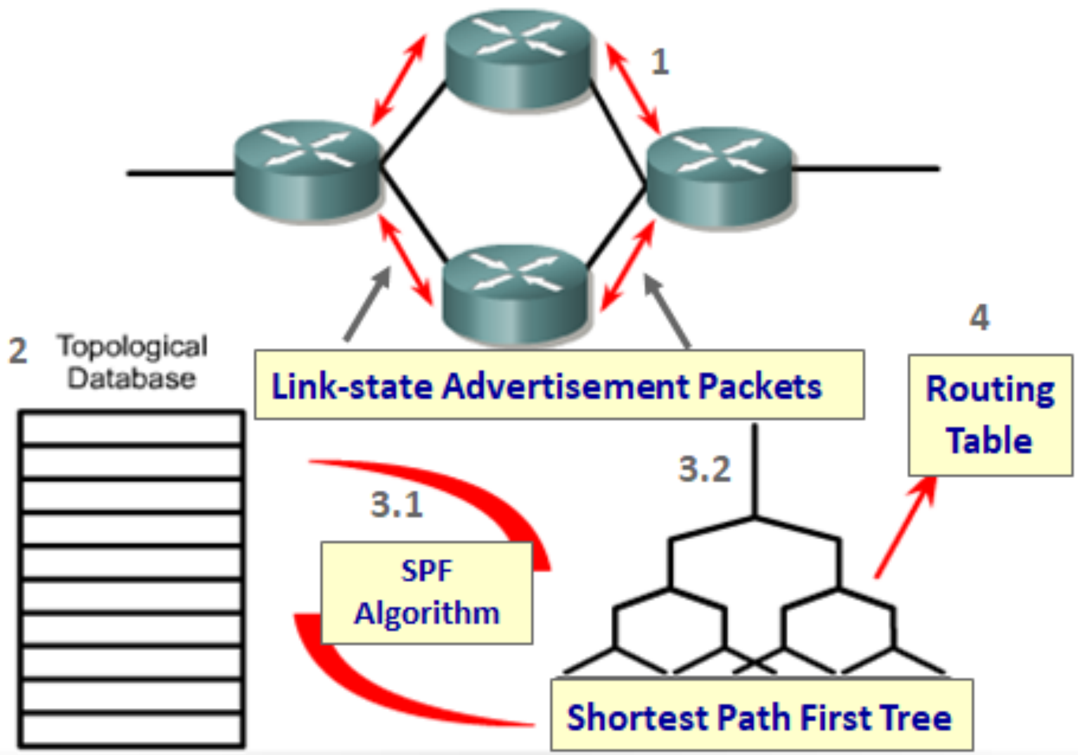
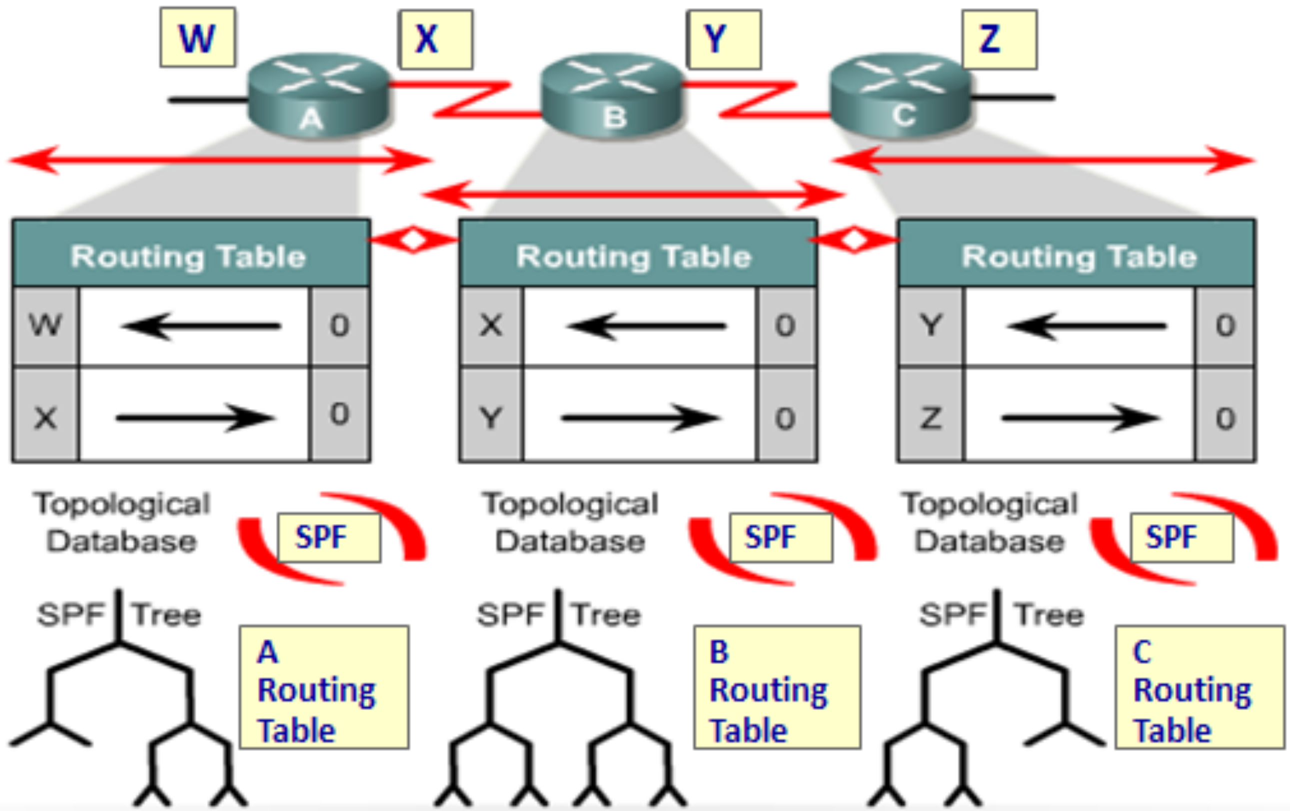
Link State Concepts



Routers send LSAs to their neighbours. The LSAs are used to build a topological database. The SPF algorithm is used to calculate the SPF tree in which the root is the individual router and then a routing table is created.

Link State Network Discovery



Each router has its own topological database on which the Shortest Path First algorithm is run.

Link State Network Discovery

The process of link state network discovery:

1. Each router starts by establishing an adjacency with its neighbours.
2. Each router sends LSAs to its adjacent routers.
3. Each router stores a copy of all the LSAs it received in a database. Then, immediately forwards the received LSAs to its adjacent routers without performing route calculation. This greatly improves the convergence time. The contents of the LSAs are not altered as it passes from router to router. Thus, all routers have the same databases.
4. After all the LSAs have been sent, the topological database is complete. This topological database provides a complete view of the internetwork. Each router uses the SPF algorithm to run its own topological database. The result is a SPF tree, with itself as the root, with shortest path from the root to all other routers.
5. Each router creates its own routing table and enters the best routes and interfaces to each destination network.

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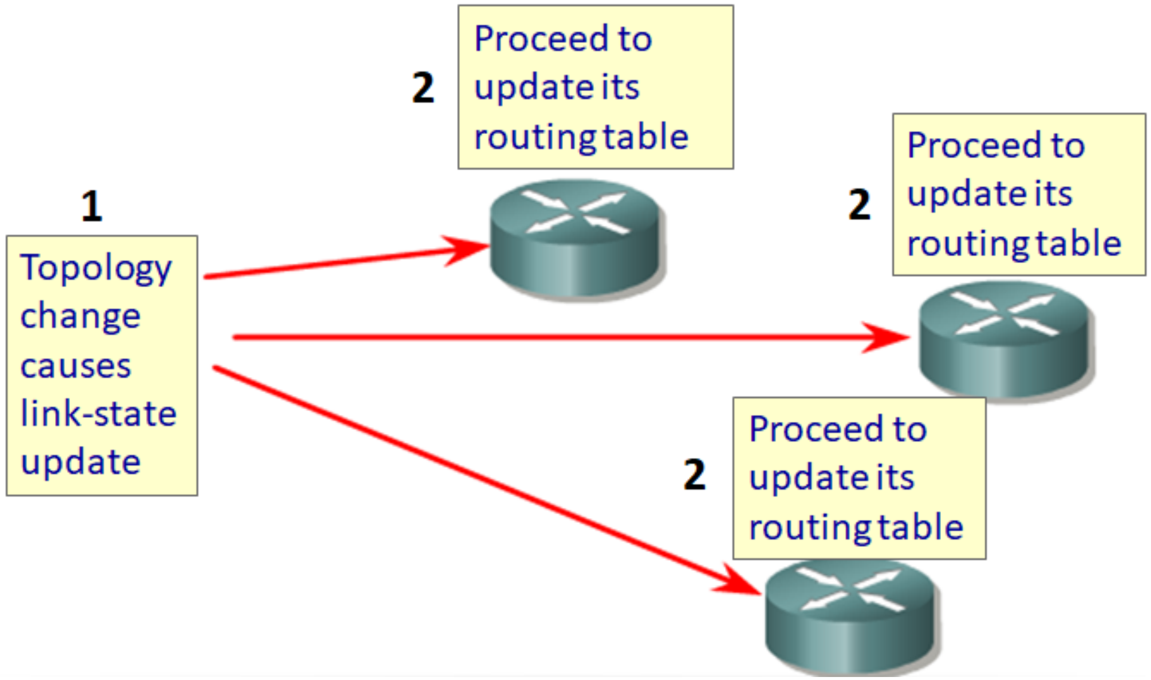
Examples of Link State Routing Protocols

Examples of Link State Routing Protocols

- Open Shortest Path First (OSPF)
- Intermediate System-to-Intermediate System (IS-IS) – This course will not discuss this protocol any further.

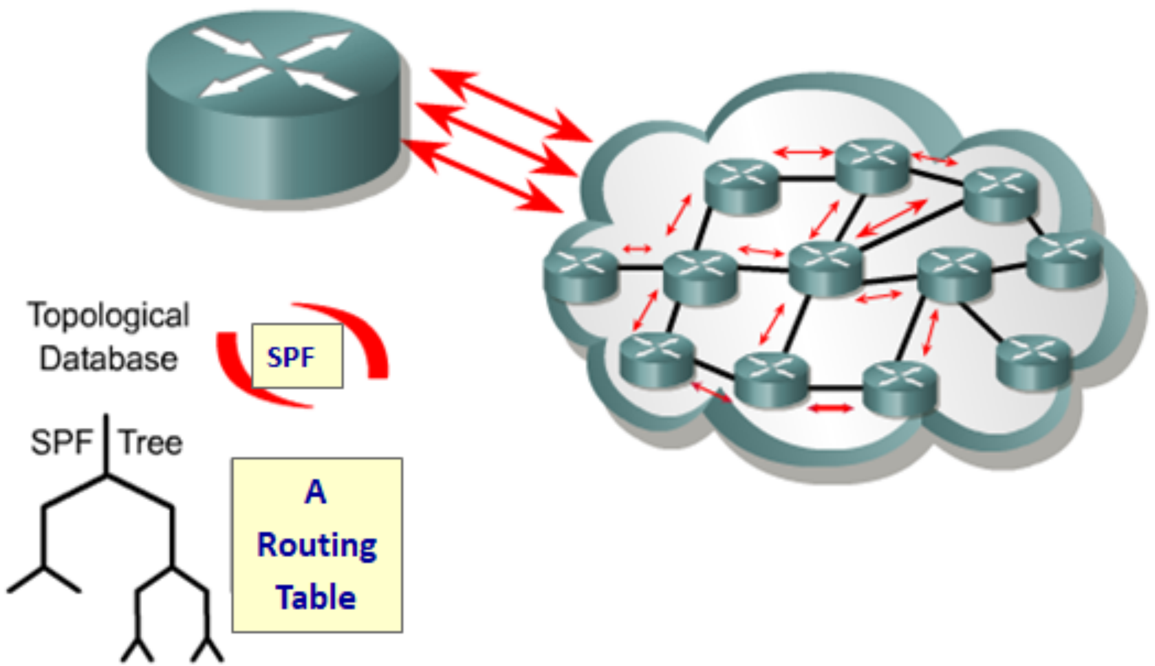
Link State Topology Changes and Event Triggered Updates

- In link state, **routing update** is performed **only when there is a topology change**. This is referred to as **event-triggered updates**.
- In comparison, distance vector is based on periodic updates.
- In link state, when there is a topology change, the router that detected the change forwards this information to all other routers through LSAs.
- The rest of the link state network discovery process mentioned previously still holds.



Disadvantages of Link State Routing Protocols

- There are three **disadvantages** with running link state routing protocols as it is resource intensive.



1. Processing requirements are increased for link-state routing.
2. Memory requirements are increased for link-state routing.
3. Bandwidth is consumed during the initial link-state flooding of LSAs.

Disadvantages of Link State Routing Protocols

The three disadvantages are:

- **Processor requirements**
  - Link state routing protocols perform more processing than distance vector routing protocols.
  - The SPF algorithm requires more processing time than distance vector routing protocols as it needs to run the topological database to create the SPF tree.
- **Memory requirements**
  - Routers running link state routing protocols require more memory than distance vector routing protocols as each router must have enough memory to hold all the information from the topological database, SPF tree and routing table.
- **Bandwidth consumption**
  - **Initial link state flooding** of LSAs **consumes bandwidth**.
  - During the initial discovery process, all routers send LSAs to all other routers.
  - This action floods the internetwork and temporarily reduces the bandwidth available for traffic carrying user data.
  - After the initial flooding, link state routing protocols generally require only minimal bandwidth to send infrequent or event-triggered LSA due to topology changes.

Comparing Distance Vector and Link State Routing Protocols

Distance Vector	Link-State
View network topology from **neighbour's perspective**	Gets **common view** of entire network topology
Adds distance vectors from router to router	Calculates the **shortest path** to other routers
Frequent **periodic updates**	**Event-triggered** updates
Slow convergence	**Fast** convergence
Passes copies of routing tables **to neighbour routers**	Passes link state routing updates **to other routers**

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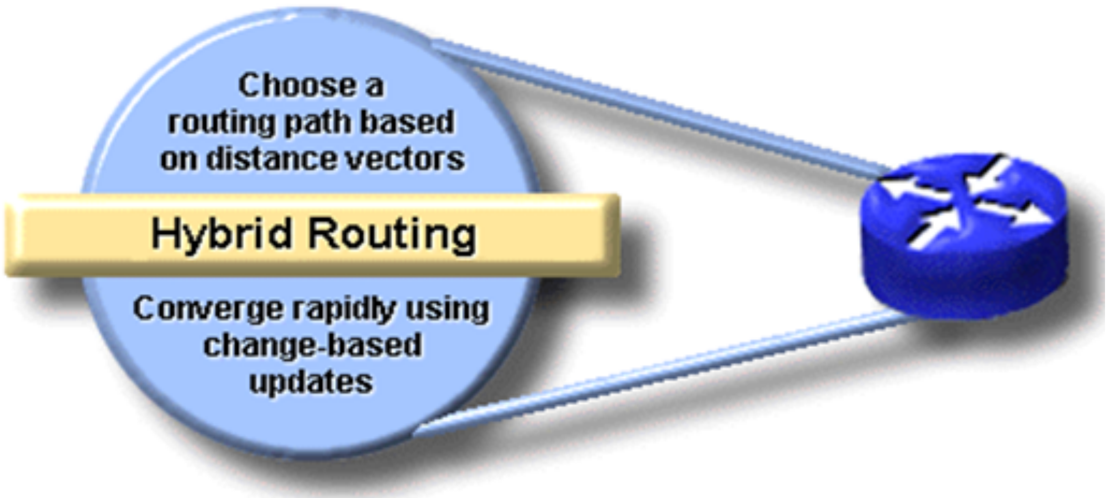
Hybrid Routing Protocol

- Combines strengths of both distance vector and link state routing protocols.
- It uses distance vector to determine the best path to destination networks.
- It uses link state event triggered updates to achieve fast convergence.
- In terms of resources, it has less processor overhead, uses less memory and consumes less bandwidth than link state.
- Example of hybrid routing protocol is Cisco developed Enhanced Interior Gateway Routing Protocol (EIGRP). This course will not discuss this protocol any further.



Share attributes of both distance vector and link state routing

Routing Information Protocol (RIP)

Differences between RIPv1 and RIPv2

RIPv1	**RIPv2**
A classful routing protocol • Supports only networks which are not subnetted • Does not support VLSM • Does not send subnet mask information with routing updates	A classless routing protocol • Allows the use of subnetted networks • Supports VLSM • Includes the subnet mask in the routing updates
Routing updates are broadcasted with IP address 255.255.255.255	Routing updates are forwarded to multicast address 224.0.0.9

Routing Information Protocol (RIP)

Characteristics of RIP

Both RIPv1 and RIPv2 have the following characteristics:

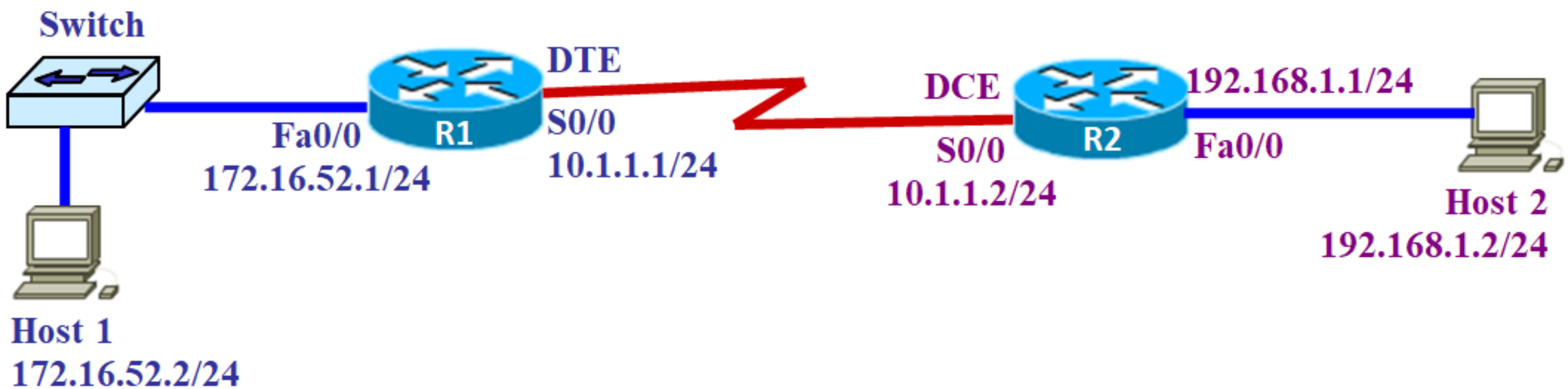
- A distance vector routing protocol.
- **Uses hop count as metric** for path determination.
- If hop count is greater than 15, the packet is discarded.
- By default, sends routing **updates every 30 seconds**.

Configuring an IPv4 Router Interface

For an interface on a router to be available, i.e. able to transmit and receive data, the following two steps must be performed on the interface:

1. Configured with an IP address and subnet mask.
2. Activated by using the *no shutdown* command. By default, all interfaces on a router are shutdown or inactive.

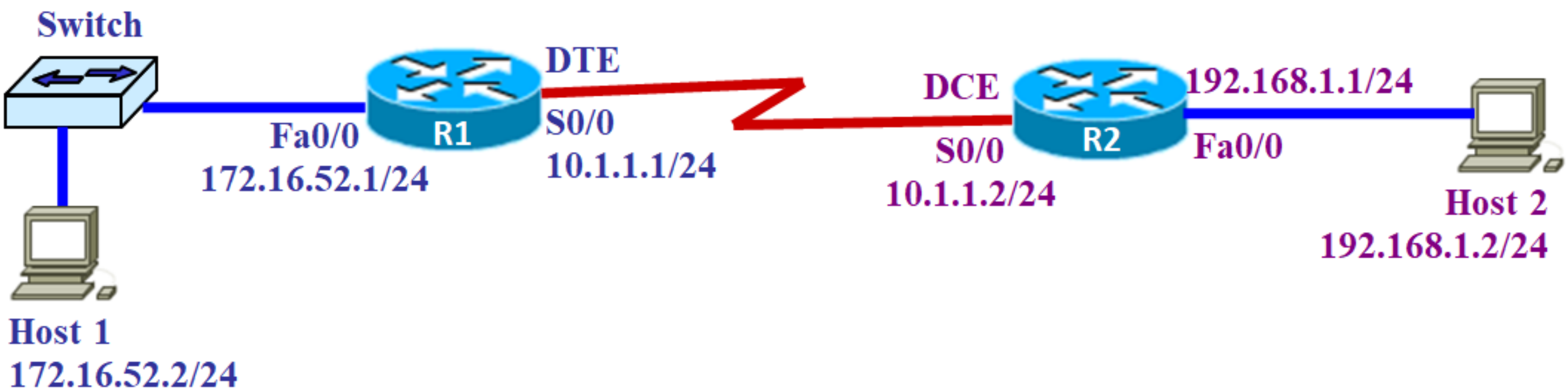
Example: Configure Router Interface



- The router interface configuration for **R1** is shown below.
- The two interfaces on each router need to be configured.
- For this course, you are not expected to remember or reproduce the router interface configuration steps. The DTE and DCE indicated in the figure is beyond the scope of this course.

```
R1(config)#interface fa0/0
R1(config-if)#ip address 172.16.52.1 255.255.255.0
R1(config-if)#no shutdown
R1(config-if)#interface s0/0
R1(config-if)#ip address 10.1.1.1 255.255.255.0
R1(config-if)#no shutdown
R1(config-if)#exit
R1(config)#exit
R1#
```

Example: Configure Router Interface



- The router interface configuration for **R2** is shown below.
- The two interfaces on each router need to be configured.
- The clock rate in the configuration are beyond the scope of this course.

```
R2(config)#interface fa0/0
R2(config-if)#ip address 192.168.1.1 255.255.255.0
R2(config-if)#no shutdown
R2(config-if)#interface s0/0
R2(config-if)#ip address 10.1.1.2 255.255.255.0
R2(config-if)#clock rate 56000
R2(config-if)#no shutdown
R2(config-if)#exit
R2(config)#exit
R2#
```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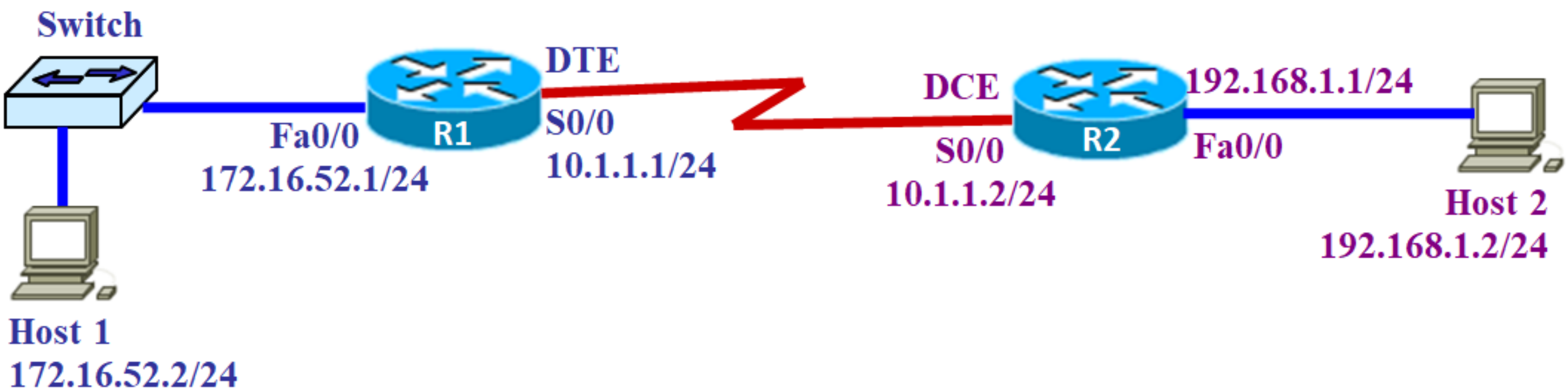
Example: Configure Router Interface



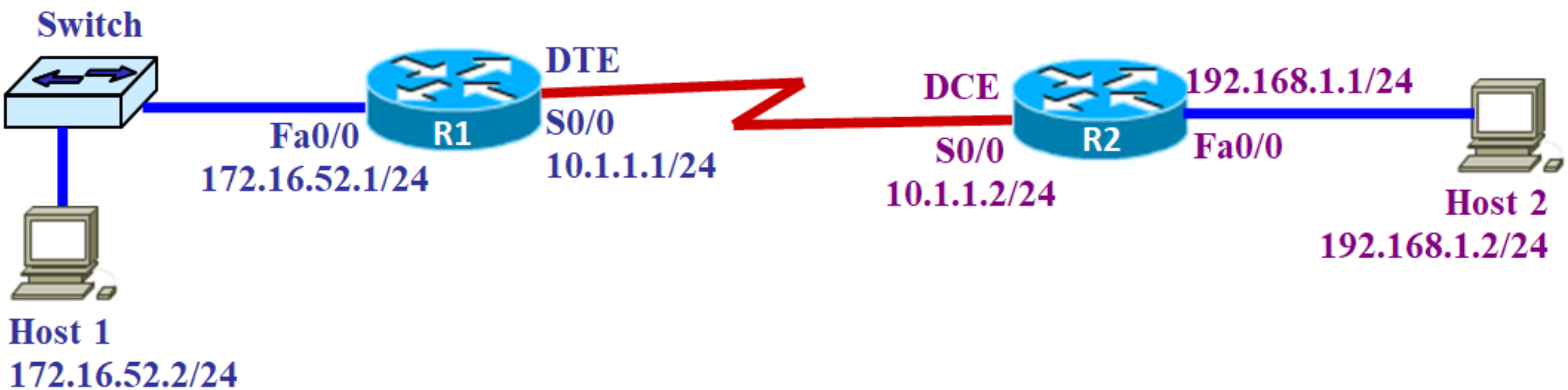
- After completing the router interface configurations, the *show ip route* command is issued on **R1** to display the **routing table**.

```
R1#show ip route
Output of codes eliminated

Gateway of last resort is not set

   172.16.0.0/24 is subnetted, 1 subnets
C     172.16.52.0/24 is directly connected, FastEthernet0/0
   10.0.0.0/24 is subnetted, 1 subnets
C     10.1.1.0/24 is directly connected, Serial0/0
```

Example: Configure Router Interface



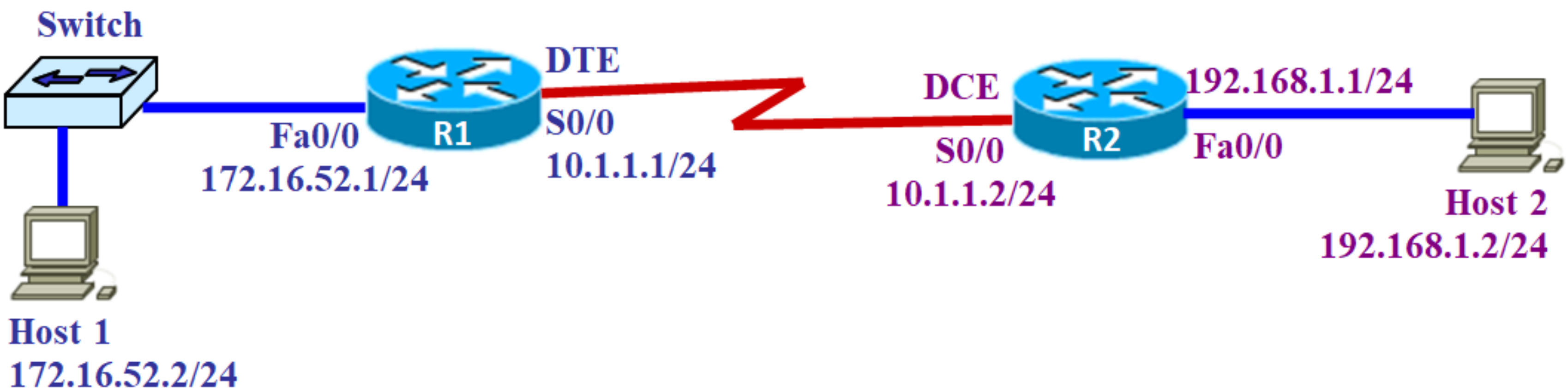
- After completing the router interface configurations, the *show ip route* command is issued on **R2** to display the **routing table**.

```
R2#show ip route
Output of codes eliminated

Gateway of last resort is not set

   10.0.0.0/24 is subnetted, 1 subnets
C     10.1.1.0/24 is directly connected, Serial0/0
C     192.168.1.0/24 is directly connected, FastEthernet0/0
```

Example: Configure Router Interface

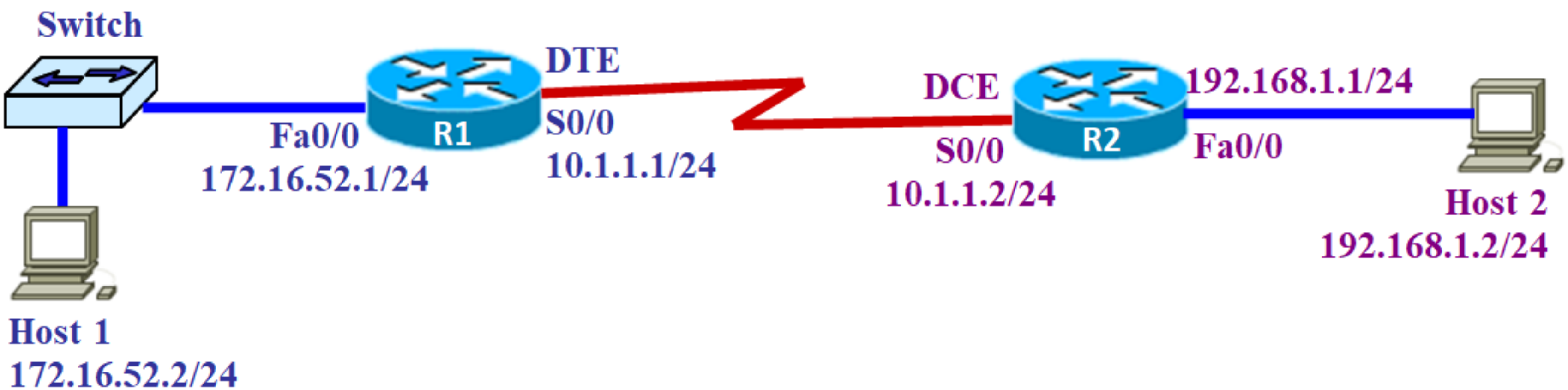


- You may notice that the routing table for **R1** has two directly connected network entries.
- These two networks are directly connected to R1.
- If a network has an **entry in R1's routing table**, it means it is **reachable from R1**.
- Can R1 reach network 192.168.1.0? Since there is **no entry** of network 192.168.1.0 in the routing table of R1, it is **unreachable** from R1.
- For R1 to reach network that is beyond its directly connected networks, some form of routing is needed either statically or dynamically. The same explanation applies for R2.

```
R1#show ip route

    172.16.0.0/24 is subnetted, 1 subnets
C      172.16.52.0/24 is directly connected, FastEthernet0/0
    10.0.0.0/24 is subnetted, 1 subnets
C      10.1.1.0/24 is directly connected, Serial0/0
```

Example: Configure Router Interface




```
R2#show ip route

    10.0.0.0/24 is subnetted, 1 subnets
C      10.1.1.0/24 is directly connected, Serial0/0
C      192.168.1.0/24 is directly connected, FastEthernet0/0
```

- **By default**, after configuring the interfaces of a router, the **router can reach only its directly connected networks**.
- In the next section, we will introduce configuration of RIPv2 so that a router can reach beyond its directly connected networks.

Configuring RIPv2

- For dynamic routing configuration, this course will only focus on RIPv2.
- To activate RIPv2 on a router, just issue the following commands:

Router(config)#**router rip**
Router(config-router)#**version 2**
Router(config-router)#**network** <network-number>

- Router(config)# and Router(config-router)# are the prompts on the Command Line Interface (CLI) screen. You are not expected to remember these prompts for exams.

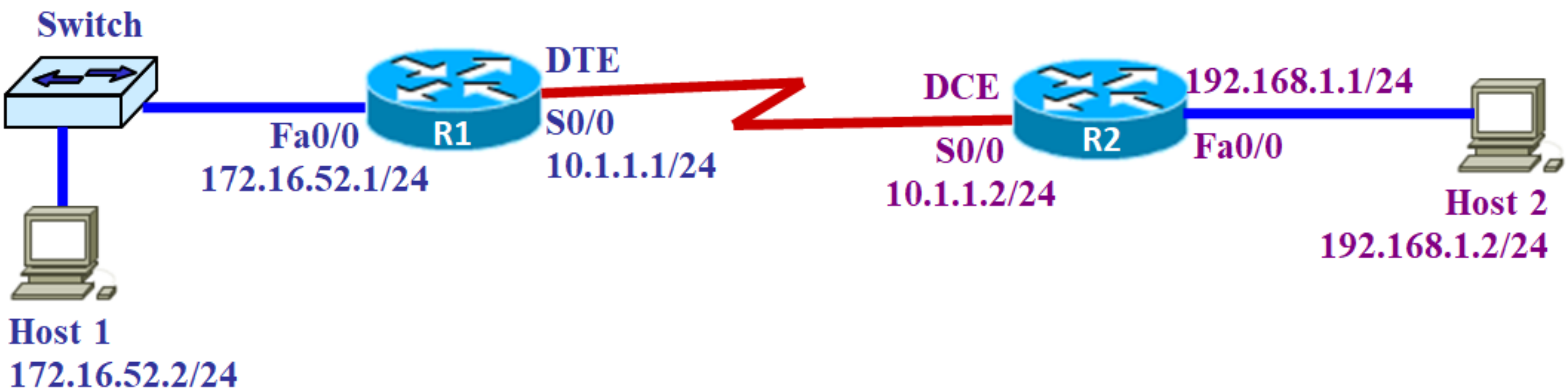
Command	Parameter	Description
router rip		Activate RIP
version 2		Instruct the router to use RIPv2
network	*<network-number>*	This **network** command tells RIP that the network indicated by *<network-number>* will participate in the routing process. One **network** command for each participating network. The *<network-number>* refers to the classful network address (network address without subnet information) of the network physically attached to the router and involved in the routing information exchange.

Configuring RIPv2

- Give the ***network-number*** for the subnet addresses shown below.

Class	Subnet Address	network-number
A	10.1.1.0	10. 0. 0. 0
B	172.16.52.0	172. 16. 0. 0
C	192.168.1.160	192. 168. 1. 0

Configuring RIPv2



- Assume that the router interface configurations have been done. We will now **activate RIPv2** on **R1 and R2**.

```
R1(config)#router rip
R1(config-router)#version 2
R1(config-router)#network 172.16.0.0
R1(config-router)#network 10.0.0.0
```

```
R2(config)#router rip
R2(config-router)#version 2
R2(config-router)#network 10.0.0.0
R2(config-router)#network 192.168.1.0
```

For each router, you need to enter one ***network*** command for each directly connected network.

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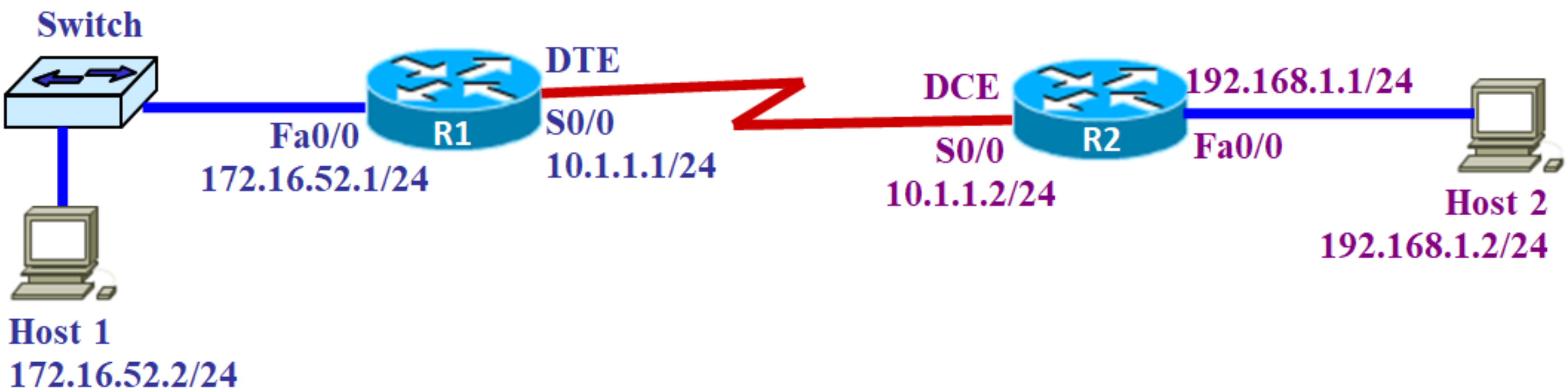
Configuring RIPv2



R1's routing table has a new entry learned using RIP.

```
R1(config)#router rip
R1(config-router)#version 2
R1(config-router)#network 172.16.0.0
R1(config-router)#network 10.0.0.0
```

Source Network Address

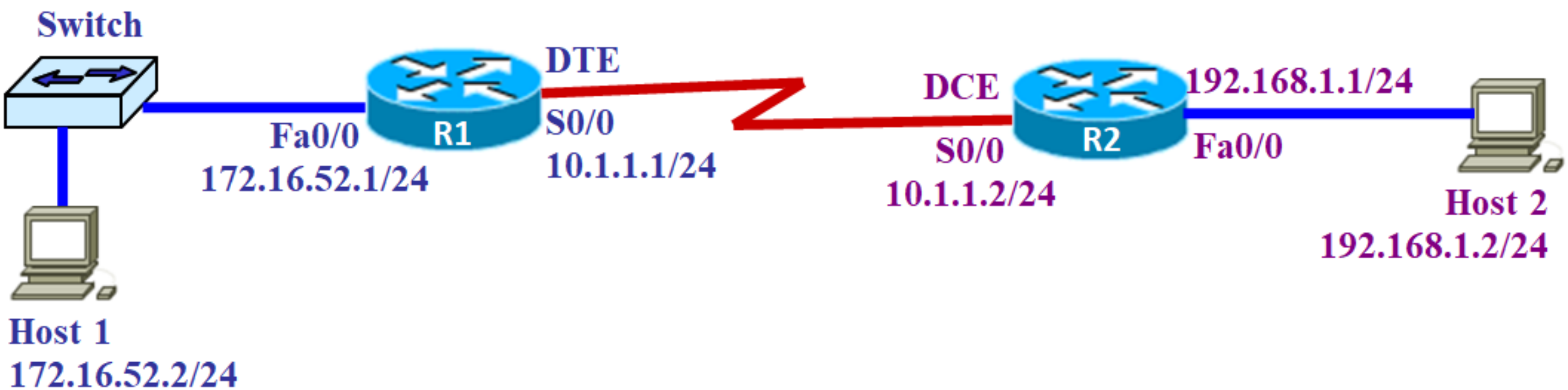
Next Hop Network Address

```
R1#show ip route
Output of codes eliminated

Gateway of last resort is not set

    172.16.0.0/24 is subnetted, 1 subnets
C      172.16.52.0/24 is directly connected, FastEthernet0/0
    10.0.0.0/24 is subnetted, 1 subnets
C      10.1.1.0/24 is directly connected, Serial0/0
R   192.168.1.0/24 [120/1] via 10.1.1.2, 00:00:22, Serial0/0
```

Configuring RIPv2



R2's routing table has a new entry learned using RIP.

```
R2(config)#router rip
R2(config-router)#version 2
R2(config-router)#network 10.0.0.0
R2(config-router)#network 192.168.1.0
```

Source Network Address

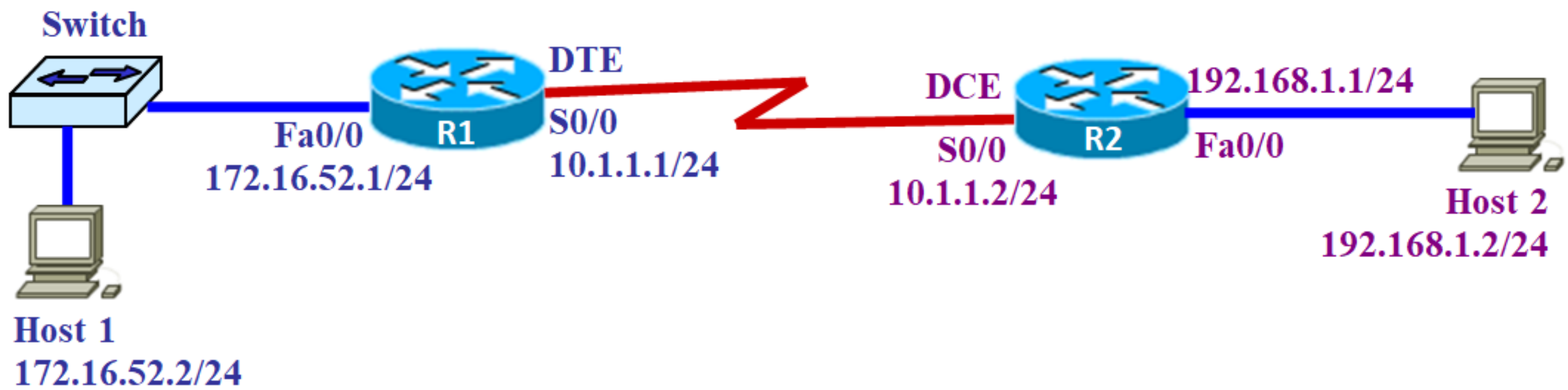
Next Hop Network Address

```
R2#show ip route
Output of codes eliminated

Gateway of last resort is not set

    10.0.0.0/24 is subnetted, 1 subnets
C      10.1.1.0/24 is directly connected, Serial0/0
C      192.168.1.0/24 is directly connected, FastEthernet0/0
    172.16.0.0/24 is subnetted, 1 subnets
R   172.16.52.0/24 [120/1] via 10.1.1.1, 00:00:24, Serial0/0
```

Configuring RIPv2



- Let's examine the new dynamic routing entry of R1.
- Destination network **192.168.1.0/24** is reachable from R1 using a route learned using **RIP**.
- To get to this destination, R1 forwards the packet to **outgoing interface S0/0** via **next-hop IP address 10.1.1.2**.
- RIP has administrative distance of 120 and the metric of this route is 1.
- Since RIP uses hop count as metric, the destination network is 1 hop count from R1.
- 22 seconds has passed since the last routing table update. Since RIP updates its routing table every 30 seconds, the next update will be 8 seconds later.

```
R      192.168.1.0   /24   [120 / 1]   via 10.1.1.2,   00:00:22,      Serial0/0
Code   Dest Net      Subnet Mask   Admin distance   Metric   Next-hop IP addr   Time elapsed since last update   Outgoing interface
```

Load Balancing over Multiple Paths

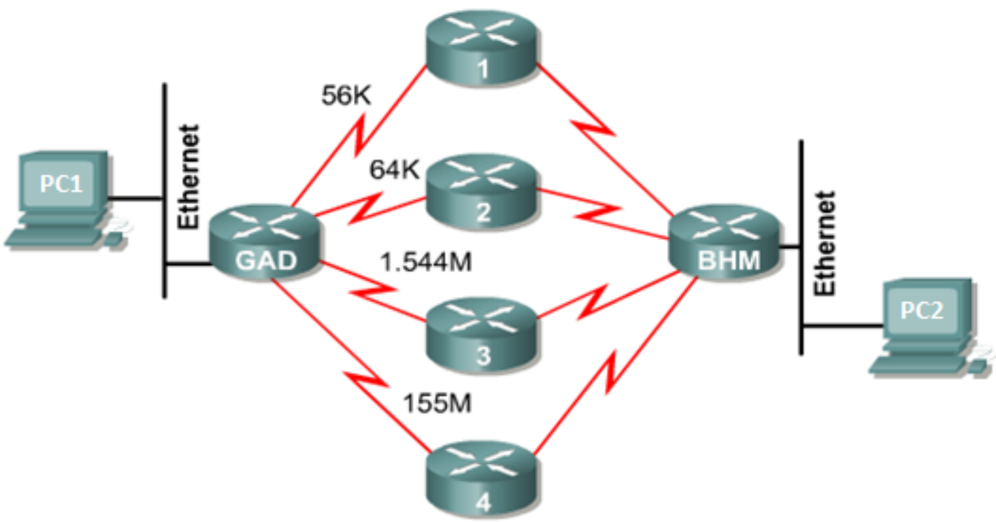
- Load balancing describes the capability of a router to transmit packets to a destination over multiple paths.
- The paths are derived either by static routes or dynamic routing protocols.
- When there are **multiple paths** to a destination network, the router installs the path with the **lowest administrative distance** (AD) into the routing table.
- If all the multiple paths **have the same AD**, the path with the **lowest metric** is chosen.
- If all the paths have the **same AD and same metric,** then **load balancing** occurs over the multiple paths.

Example on Load Balancing over Multiple Paths

- **PC1** wants **to** reach **PC2**.
- If all the routers are **activated with RIP only**, **which path will router GAD take**?

The following are the steps taken by GAD to make the routing decision:

1. There are 4 paths to destination network. Since these 4 paths are learned using RIP, all the paths have AD of 120.
2. Since all the paths have the same AD, GAD will next consider the metric of each path. Since RIP uses hop count as the metric, all the 4 paths require 2 hops to get to the destination network.
3. Since all the 4 paths have the **same AD and same metric**, **load balancing** is used. RIP performs a *round robin* load balancing, which means that RIP takes turns forwarding packets over the multiple paths.



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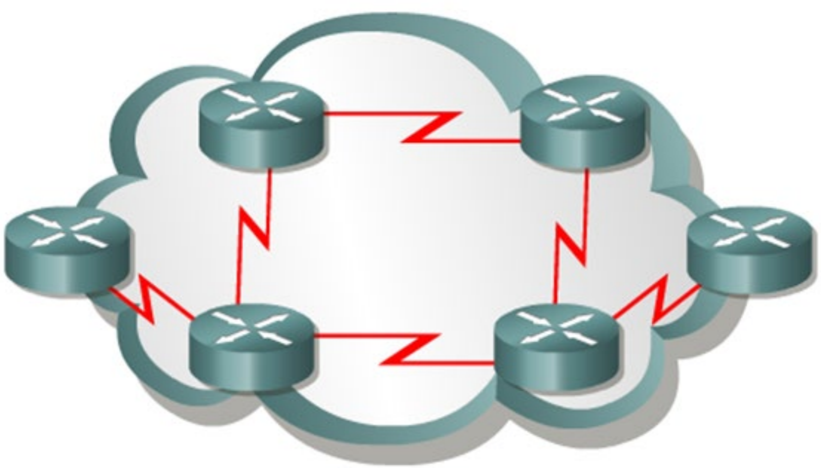
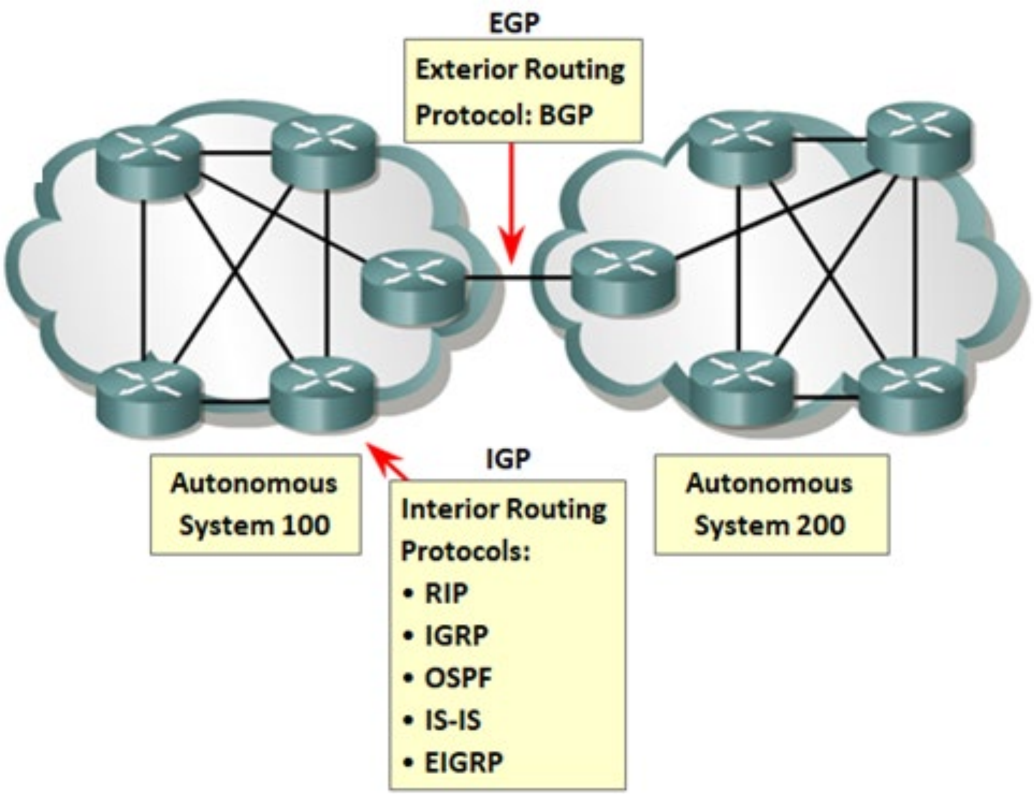
Autonomous System (AS)

- An autonomous system (AS) is a group of networks managed by a **single organisation** that share the **same routing methodology**.
- **Each AS** has its own set of rules, polices and a globally **unique 16 bits AS number**.
- The following Cisco developed routing protocols require unique autonomous system number for configuration:
  - ➢ Interior Gateway Routing Protocol (IGRP)
  - ➢ Enhanced IGRP (EIGRP)
- The below figure shows routers within the same autonomous system.



Interior Gateway Protocol (IGP) vs. Exterior Gateway Protocol (EGP)

- IGP and EGP are two groups of routing protocols classified **based on purpose**.
- Their differences are:
  - **IGP** – Designed for **routing within an AS**. Routing protocols under IGP include RIP, IGRP, OSPF, IS-IS and EIGRP.
  - **EGP** – Designed for **routing between autonomous systems**. Typically used between Internet Service Providers (ISPs) and large corporations. Currently, Border Gateway Protocol (**BGP**) is the only routing protocol under EGP.



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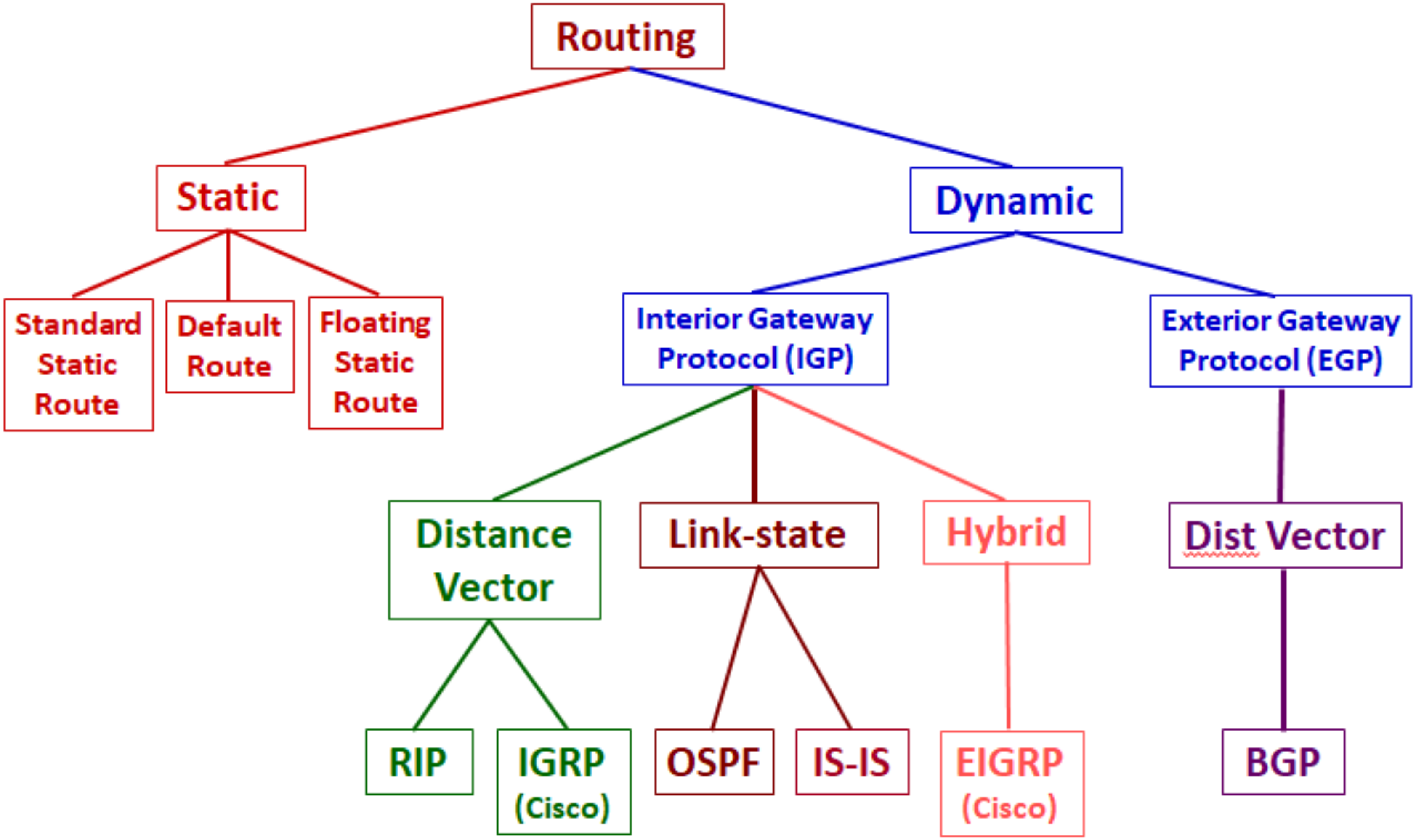
Summary


Routing
Static
Dynamic
Standard Static Route
Default Route
Floating Static Route
Interior Gateway Protocol (IGP)
Exterior Gateway Protocol (EGP)
Distance Vector
Link-state
Hybrid
Dist Vector
RIP
IGRP (Cisco)
OSPF
IS-IS
EIGRP (Cisco)
BGP

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Thank You.