The University of Jordan, Comp. Eng. Dept.
Networks lab: Handout: Experiment 4
Static Routing (Theory and Practice)

Instructors: Prof. Khalid A. Darabkh and Eng. Muna Al-Akhras

Parts Involved: Need of Routing, Routing Types, Static Routing, Types of Static Routes for IPv4 and IPv6, Next-Hop Options in Static Routes, Static Route Commands, and Practical Problems.

Part I: Need of Routing

- **What is routing?**

Routing is the process of path selection in any network which the data can be transferred from source to the destination. A computer network is made of many machines, called devices, and paths or links that connect those devices. Communication between two nodes in an interconnected network can take place through many different paths. Routing is the process of selecting the best path using some predetermined rules.

- **Why is routing important?**

Routing creates efficiency in network communication. Network communication failures result in long wait times for website pages to load for users. It can also cause website servers to crash because they can't handle a large number of users. Routing helps minimize network failure by managing data traffic so that a network can use as much of its capacity as possible without creating congestion.

- **What is a router?**

Routing is performed by a special device known as a router, which works at the network layer in the OSI model and internet layer in TCP/IP model. A router is a networking device that forwards the packet based on the information available in the packet header and forwarding table. Routers primarily serve three main functions.

1. Path determination

A router determines the path data takes when it moves from a source to a destination. It tries to find the best path by analyzing network metrics such as delay, capacity, and speed.

2. Data forwarding

A router forwards data to the next device on the selected path to eventually reach its destination. The device and router may be on the same network or on different networks.

3. Load balancing

Sometimes the router may send copies of the same data packet by using multiple different paths. It does this to reduce errors due to data losses, create redundancy, and manage traffic volume.

- **What are the main routing protocols?**

A routing protocol is a set of rules that specify how routers identify and forward packets along a network path. Routing protocols are grouped into two distinct categories: interior gateway protocols and exterior gateway protocols. Interior gateway protocols work best within an autonomous system—a network administratively controlled by a single organization. External gateway protocols better manage the transfer of information between two autonomous systems.

- **Routing decision**

The primary function of a router is to forward a packet to its destination. The router achieves this by encapsulating the IP packet with the appropriate data link frame type of the egress port. This encapsulation happens after the router has determined the exit interface associated with the best path to forward that packet.

The path can either be:

- ✓ A directly connected route (the destination address in the IP header belongs to a network connected to one of the router interfaces).
- ✓ A remote network (when the destination IP address of the packet belongs to another network).
- ✓ No route determined (when the destination address is not in the routing table).

- **What is the routing table?**

The routing table is at the heart of making routing decisions. It is important that you understand the information presented in a routing table. The routing table of a router stores information about the following:

- ✓ **Directly connected routes:** These routes come from the active router interfaces. Routers add a directly connected route when an interface is configured with an IP address and is activated.
- ✓ **Remote routes**: These are remote networks connected to other routers. Routes to these networks can be either statically configured or dynamically learned through dynamic routing protocols.

Specifically, a routing table is a data file in RAM that stores route information about directly connected and remote networks. **Figure 1 demonstrates these networks for Router 1.** The routing table contains network or next-hop associations. These associations tell a router that a particular destination can be optimally reached by sending the packet to a specific router that represents the next hop on the way to the final destination. **The next-hop association can also be the outgoing or exit interface to the next destination.**

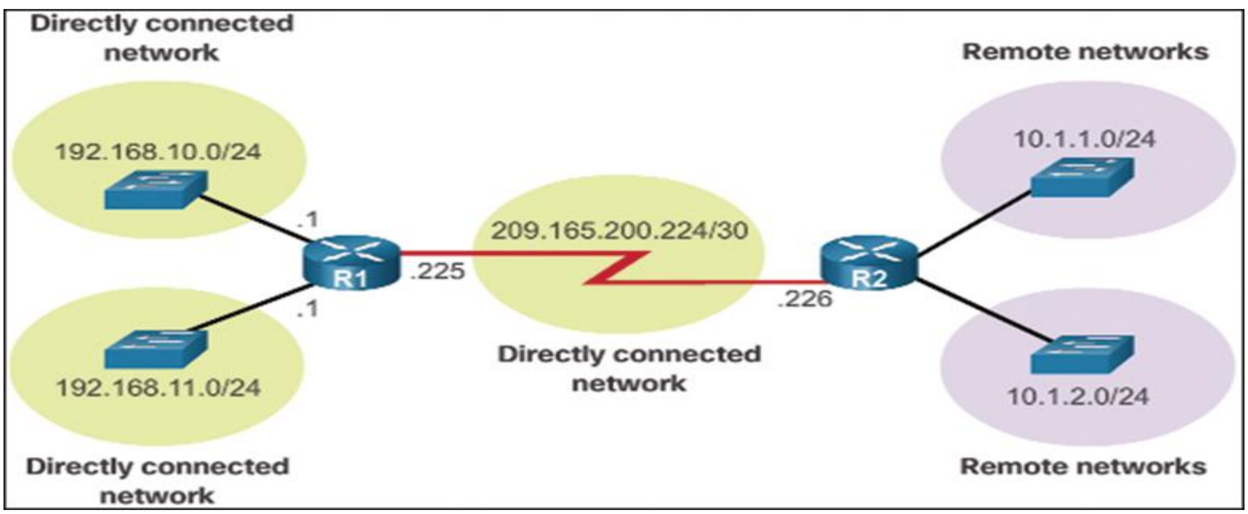


Figure 1. Router 1 (R1) - directly connected and remote networks

- **Routing Table Sources:**

On a Cisco router, the `show ip route` command is used to display the IPv4 routing table of a router, while the `show ipv6 route` command is used to display the IPv6 routing table of a router. A router provides additional route information, including how the route was learned, how long the route has been in the table, and which specific interface to use to get to a predefined destination.

Entries in the routing table can be added as follows:

- ✓ **Local route interfaces**: Added when an interface is configured and active.
- ✓ **Directly connected interfaces**: Added to the routing table when an interface is configured and active.
- ✓ **Static routes:** Added when a route is manually configured and the exit interface is active.
- ✓ **Dynamic routing protocol**: Added when routing protocols that dynamically learn about the network, such as EIGRP and OSPF, are implemented and networks are identified.

Interestingly, the sources of the routing table entries are identified by a code. The code identifies how the route was learned. For instance, common codes include the following:

- ✓ **L**: Identifies the address assigned to a router's interface. This allows the router to efficiently determine when it receives a packet for the interface instead of being forwarded.
- ✓ **C**: Identifies a directly connected network.
- ✓ **S**: Identifies a static route created to reach a specific network.
- ✓ **D**: Identifies a dynamically learned network from another router using EIGRP.
- ✓ **O**: Identifies a dynamically learned network from another router using the OSPF routing protocol.

Part II: Types of Routing

There are two different types of routing to learn about the remote networks, which are based on how the router creates its routing tables:

1. Static routing

In static routing, a network administrator uses static tables to manually configure and select network routes. Static routing is helpful in situations where the network design or parameters are expected to remain constant. The static nature of this routing technique comes with expected drawbacks, such as network congestion. While administrators can configure fallback paths in case a link fails, static routing generally decreases the adaptability and flexibility of networks, resulting in limited network performance.

2. Dynamic routing

In dynamic routing, routers create and update routing tables at runtime based on actual network conditions. They attempt to find the fastest path from the source to the destination by using a dynamic routing protocol, which is a set of rules that create, maintain, and update the dynamic routing table. The biggest advantage of dynamic routing is that it adapts to changing network conditions, including traffic volume, bandwidth, and network failure. Table 1 shows the differnces between the static and dynamic routing.

Table 1. The differences between the static and dynamic routing.

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

Part III: Static Routing

1. Information about static routes

- Static routing is a type of network routing technique. Static routing is not a routing protocol; instead, it is the manual configuration and selection of a network route, usually managed by the network administrator. It is employed in scenarios where the network parameters and environment are expected to remain constant.
- Static routes, which define explicit paths between two routers, cannot be automatically updated.
- You must manually reconfigure static routes when network changes occur.
- You can supplement dynamic routes with static routes where appropriate. You can redistribute static routes into dynamic routing algorithms but you cannot redistribute routing information calculated by dynamic routing algorithms into the static routing table.
- You should use static routes in environments where network traffic is predictable and where the network design is simple.
- You should not use static routes in large, constantly changing networks because static routes cannot react to network changes.
- Most networks use dynamic routes to communicate between routers but may have one or two static routes configured for special cases.
- Static routes are also useful for specifying a gateway of last resort (a default router to which all un routable packets are sent).
- **A static route is identified in the routing table with the code "S".**
- **Static routes have a default administrative distance of 1.**

Figures 2 and 3 summarize the advantages and disadvantages of static routing whereas Figure 4 details the applications or usage of static routing.

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

Figure 2. Summary of advantages of 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.
  - Does not scale well with growing networks; maintenance becomes cumbersome.
  - Requires complete knowledge of the whole network for proper implementation.

Figure 3. Summary of disadvantages of static routing

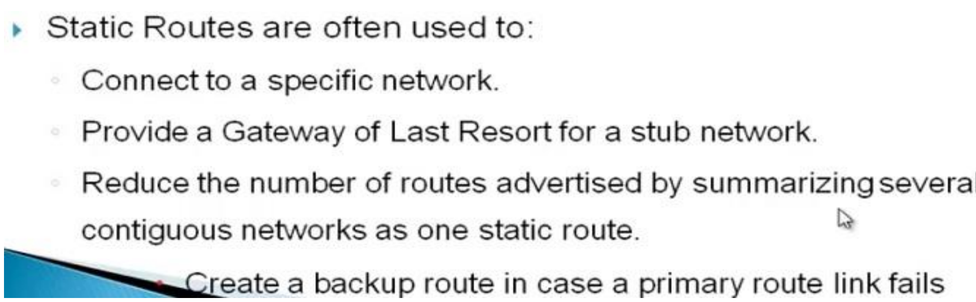


Figure 4. Applications or usage of static routing.

2. Administrative distance

An administrative distance is the metric used by routers to choose the best path when there are two or more routes to the same destination from two different routing protocols. An administrative distance guides the selection of one routing protocol (or static route) over another, when more than one protocol adds the same route to the unicast routing table. Each routing protocol is prioritized in order of most to least reliable using an administrative distance value. **The administrative distance of directly connected networks (i.e., those coded as "C" at the routing table) is 0, while static routes (i.e., those coded as "S" at the routing table) have a default administrative distance of 1.** A router prefers a static route to a dynamic route because the router considers a route with a low number to be the shortest.

Part IV: Types of Static Routes for IPv4 and IPv6

1. **Standard static route**: Connect to a specific network.
2. **Default static route:** Provide a Gateway of Last Resort for a stub network.
3. **Summary static route:** Reduce the number of routes advertised by summarizing several contiguous networks as one static route.
4. **Floating static route:** Create a backup route in case a primary route link fails.

Here, we will explain each type in more details.

A. Standard static route:

This route is useful when connecting to a **specific remote network** regardless whether it is a stub remote network or not. Figure 5 illustrates well the standard static routes. It is worth mentioning that **stub networks represent** an individual LAN or group of networks (LANs) that uses only one router to link to routed topology or Internet service provider (ISP). In other words, a network that has only one interface to the routed topology (or ISP) is called a stub network **(i.e., the network which is connected to a router that has only one exit interface to the routed topology or ISP).** On the other hand, the stub router is the one that has only one exit interface to other topology. Figures 6 and 7 show examples of stub routers and networks. Referring to Fig. 7, there are three stub routers (routers 0, 2, and 3) and three stub networks (10.10.1.0/24 (the one highlighted), 10.10.2.0/24, and 10.10.3.0/24).

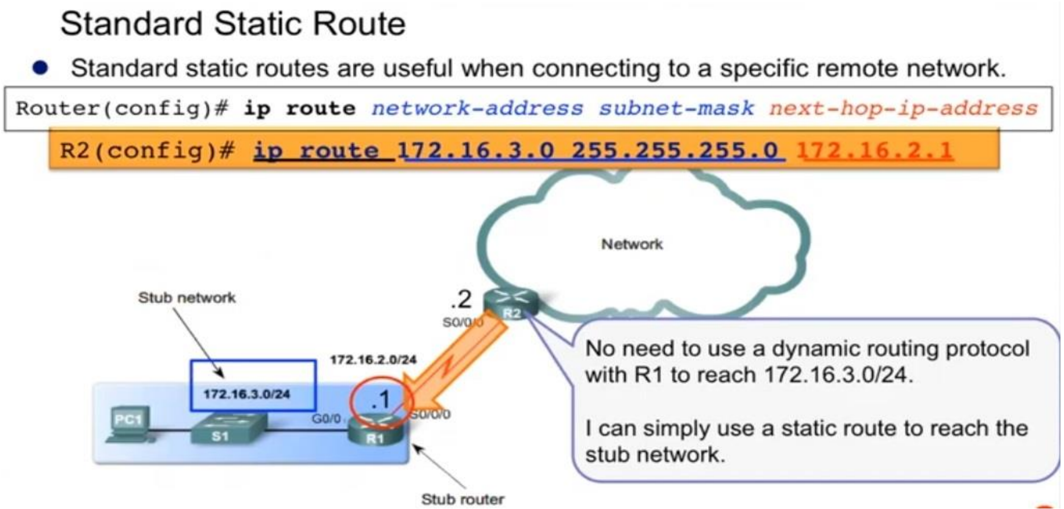


Figure 5. Standard static routes

Figure 6. Stub Routers

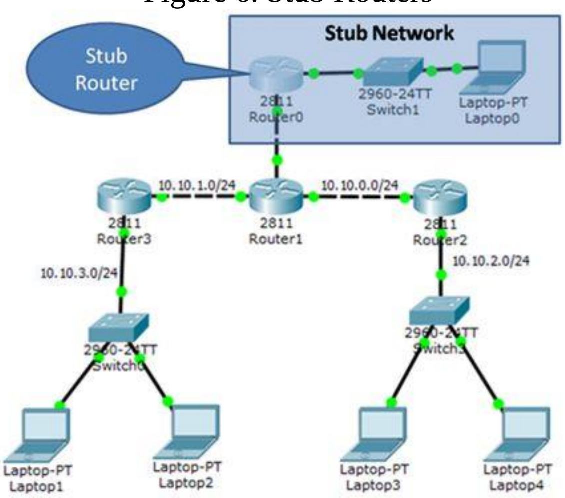


Figure 7. Stub routers and networks

B. A default static route (quad-zero route):

A default route identifies the gateway IP address to which the router sends all IP packets that it does not have a learned or static route. A default static route is a route that matches all packets. **Configuring a default static route creates a *Gateway of Last Resort*. A default static route is used to forward a packet at last as the Gateway of Last Resort when there are no other routes in the routing table match the destination network. In other words, the router will keep the use of the default static route as the last resort (i.e., when no other routes in the routing table match the destination network). Rather than storing all routes to all networks in the routing table, a router can store a single default route to represent any network that is not in the routing table. It is worth mentioning that the default static route is commonly used in edge routers to connect to an ISP since it is so difficult for all local routers (i.e., those available at the**

domain of a certain ISP) to have a knowledge of all remote networks exist all over the world or at the domains of other ISPs. Moreover, it is commonly used at stub routers, like the case described in Fig. 5.

As shown in Figure 8, **a default static route is simply a static route with 0.0.0.0/0 as the destination IPv4 address.** The command syntax for an **IPv6 default static route is similar to any other IPv6 static route, except that the ipv6-prefix/prefix-length is ::/0**, which matches all routes.

Default static routes are used:

- When no other routes in the routing table match the packet destination IP address. In other words, when a more specific match does not exist. A common use is when connecting a company's edge router to the ISP network.
- When a router has only one other router to which it is connected. This condition is known as a stub router.

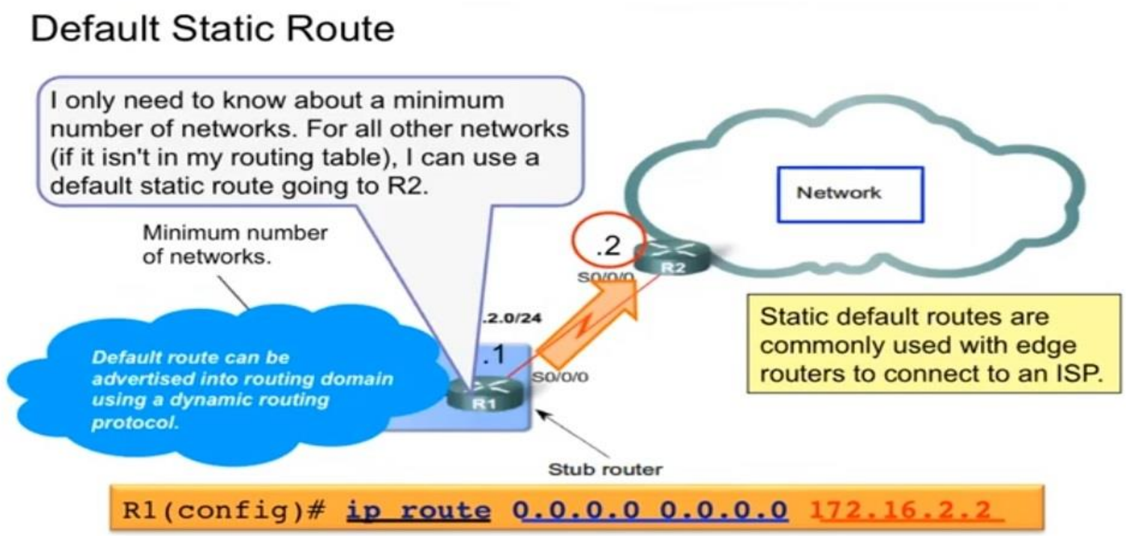


Figure 8. Default static routes

C. Summary static route:

Route summarization, also known as prefix aggregation, is the process of advertising a contiguous set of addresses as a single address with a less-specific, shorter subnet mask. Routes are summarized into a single route to help reduce the number of routing table entries required for many static routes. For instance, one summary static route can replace several specific static route statements. Using summary static routes can also make management of a large number of static routes easier and less prone to errors.

- **Configuring IPv4 Summary Routes:**

A single IPv4 static summary route can be used to replace multiple static routes when those routes can be summarized with a common prefix length. The configuration of a summary static route is similar to the configuration of other IPv4 static routes.

Note: Multiple static routes can be summarized into a single static route if:

- The **destination networks are contiguous** and can be summarized into a single network address.
- The **multiple static routes all use the same exit interface or next-hop IP address**.

CIDR in IPv4 is a form of route summarization and is synonymous with the term supernetting. CIDR ignores the limitation of classful boundaries, and allows summarization with masks that are smaller than that of the default classful mask. This type of summarization helps reduce the number of entries in routing updates and lowers the number of entries in local routing tables. It also helps reduce bandwidth utilization for routing updates and results in faster routing table lookups.

In Figure 9, R1 requires a summary static route to reach networks in the range of 172.20.0.0/16 to 172.23.0.0/16.

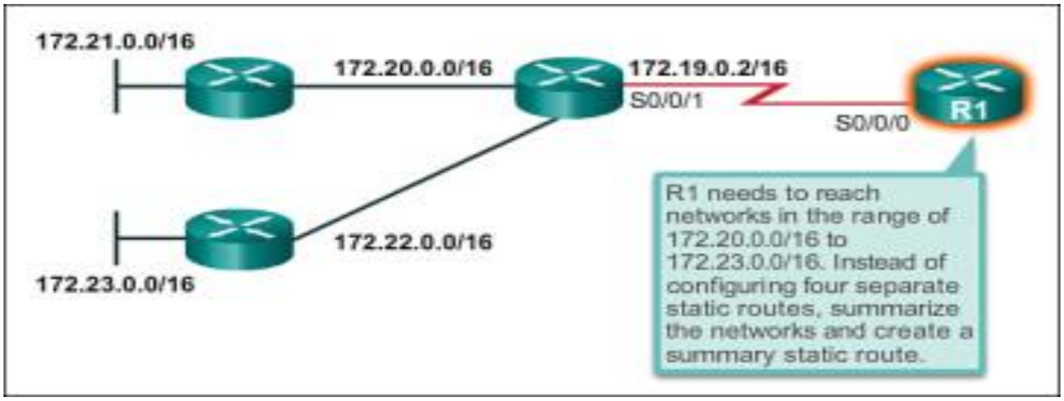


Figure 9. Summary static routes.

- **Calculating a Summary Route:**

Summarizing networks into a single address and mask can be done in three steps:
Step 1: List the networks in binary format. Figure 10 lists networks 172.20.0.0/16 to 172.23.0.0/16 in binary format.

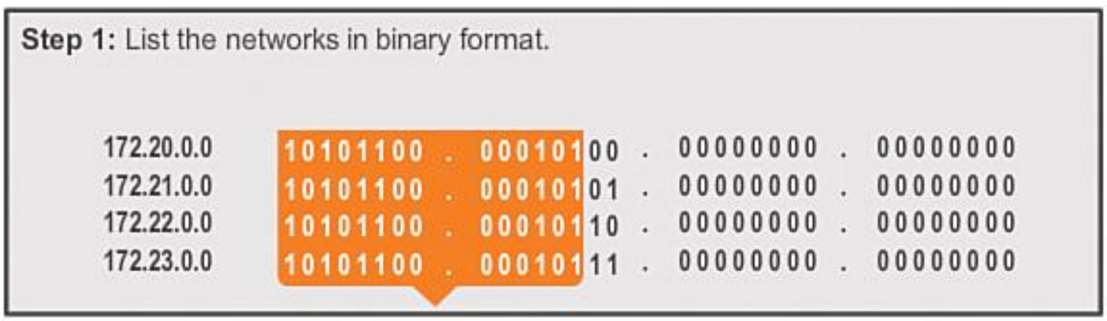


Figure 10. Step1- Calculating a Route Summary

Step 2: Count the number of **<u>far left matching bits</u>** to determine the mask for the summary route. Figure 11 highlights the 14 far left matching bits. This is the prefix, or subnet mask, for the summarized route: /14 or 255.252.0.0.

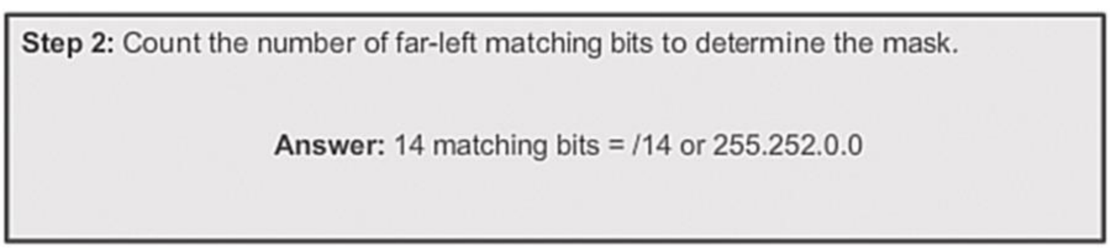


Figure 11. Step 2- Calculating a Route Summary

Step 3: Copy the matching bits and then add zero bits to determine the summarized network address. Figure 12 shows that the matching bits with zeros at the end results in the network address 172.20.0.0. The four networks—172.20.0.0/16, 172.21.0.0/16, 172.22.0.0/16, and 172.23.0.0/16—can be summarized into the single network address and prefix 172.20.0.0/14.

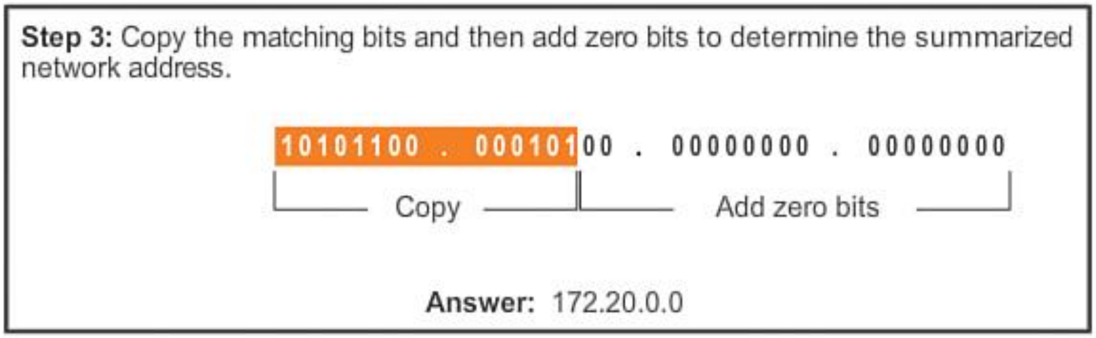


Figure 12. Step 3- Calculating a Route Summary

Figure 13 displays R1 configured with a summary static route to reach networks 172.20.0.0/16 to 172.23.0.0/16.

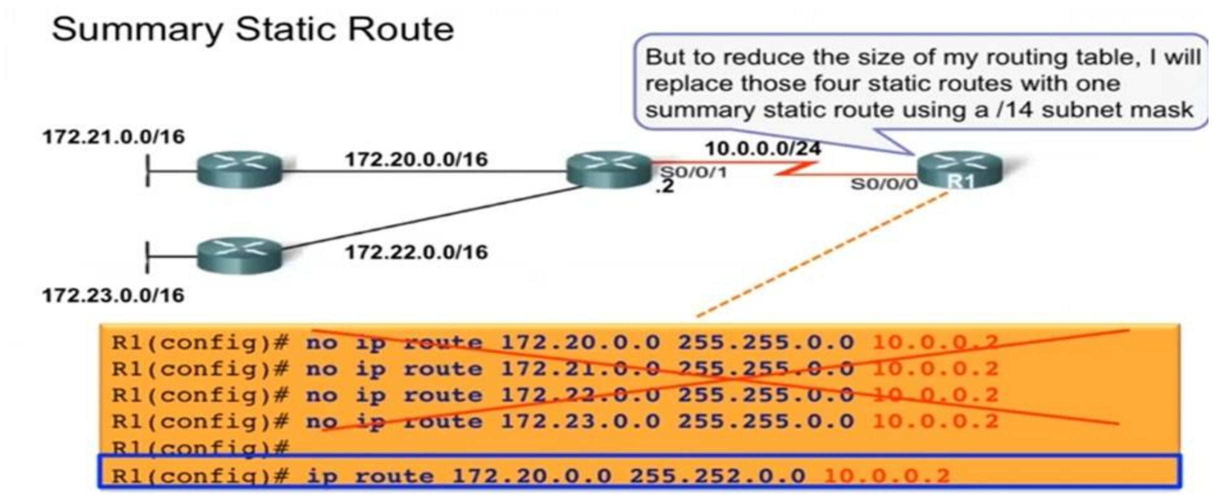


Figure 13. Summary static routes

Figure 14 displays R2 configured with a summary static route to reach networks 192.186.0.0/24 to 192.186.3.0/24.

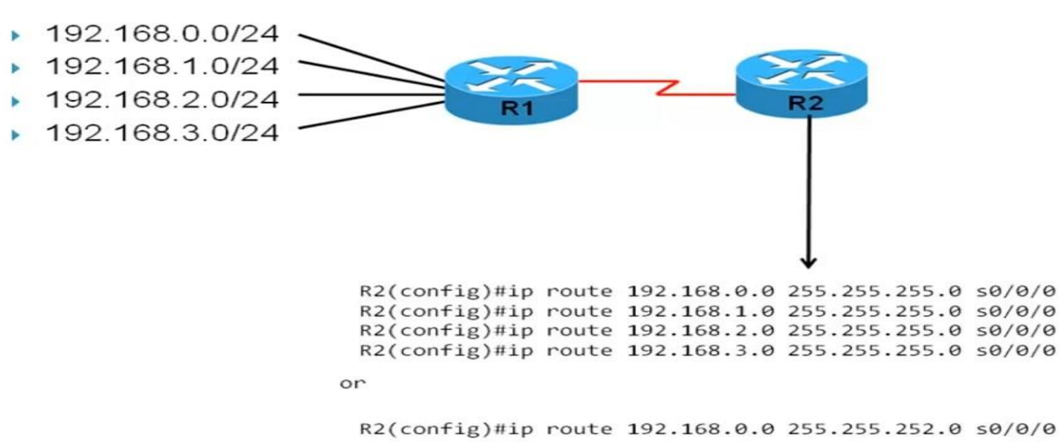


Figure 14. Summary static routes (second example)

The process of finding out the summary route of the networks, shown in Figure 14, is detailed in Figure 15:

```
192.168.0.0 /24
192.168.1.0 /24
192.168.2.0 /24
192.168.3.0 /24

11000000.10101000.000000   00.00000000
11000000.10101000.000000   01.00000000
11000000.10101000.000000   10.00000000
11000000.10101000.000000   11.00000000


192.168.0.0/22
```

Figure 15. Summary route calculation at R2

Figure 16 shows a plain calculation of a router summary route to reach other four contiguous networks.

```
192.168.1.128
192.168.1.129
192.168.1.130
192.168.1.131

192.168.1.   100000  00
192.168.1.   100000  01
192.168.1.   100000  10
192.168.1.   100000  11

192.168.1.128/30
```

Figure 16. Plain summary route calculation of contiguous networks (third example)

To get the idea much better, consider another summary static route example in Figure 17. All routers have connectivity using static routes.

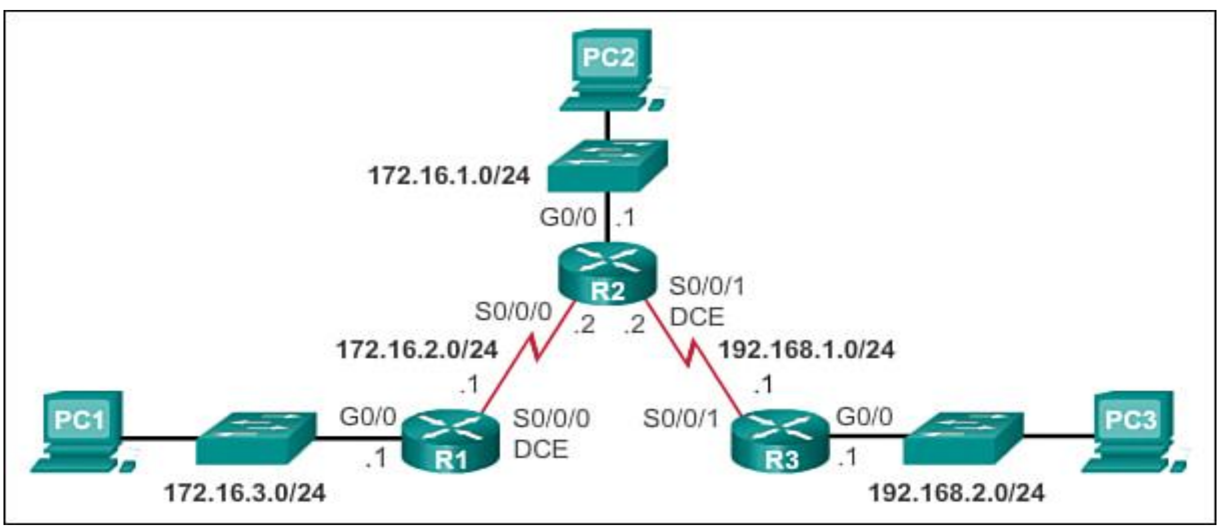


Figure 17. Summary static routes (fourth example)

The following output displays **the static routing table entries for R3.** Notice that it has three static routes that can be summarized because they share the same two first octets.

```
R3# show ip route static | begin Gateway
Gateway of last resort is not set
         172.16.0.0/24 is subnetted, 3 subnets
S        172.16.1.0 is directly connected, Serial0/0/1
S        172.16.2.0 is directly connected, Serial0/0/1
S        172.16.3.0 is directly connected, Serial0/0/1
R3#
```

Figure 18 displays the steps to summarize those three networks:

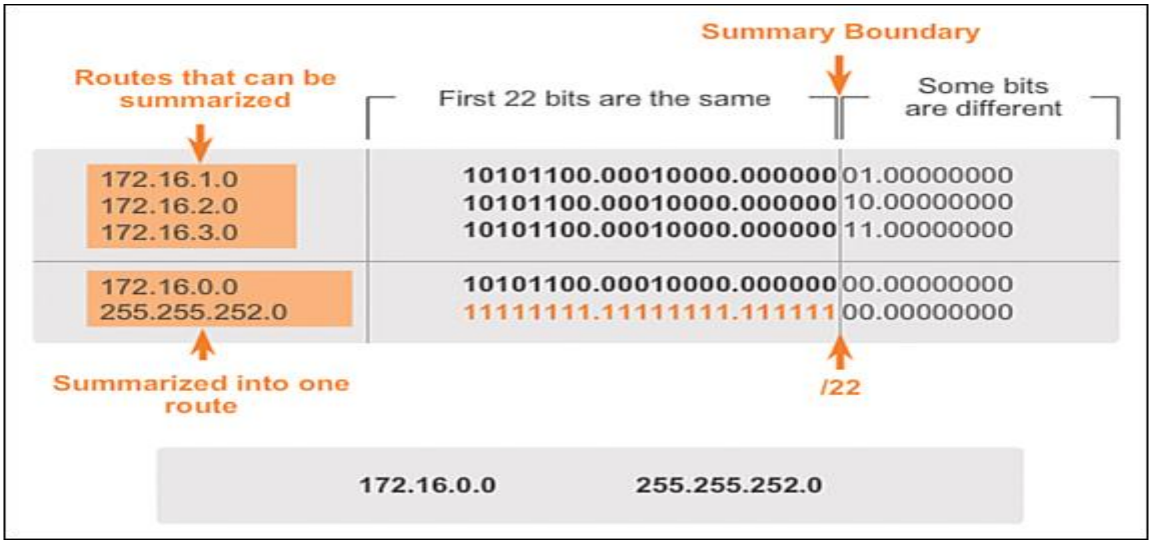


Figure 18. Calculating summary static route (fourth example)

Step 1: Write out the networks to summarize in binary.
Step 2: To find the subnet mask for summarization, start with the far left bit, work to the right, finding all the bits that match consecutively until a column of bits that do not match is found, identifying the summary boundary.
Step 3: Count the number of far left matching bits; in our example, it is 22. This number identifies the subnet mask for the summarized route as /22 or 255.255.252.0.
Step 4: To find the network address for summarization, copy the matching 22 bits and add all 0 bits to the end to make 32 bits.
After the summary route is identified, replace the existing routes with the one summary route.

The following output shows how the three existing routes are removed and then the new summary static route is configured:

```
R3(config)# no ip route 172.16.1.0 255.255.255.0 s0/0/1
R3(config)# no ip route 172.16.2.0 255.255.255.0 s0/0/1
R3(config)# no ip route 172.16.3.0 255.255.255.0 s0/0/1
R3(config)# ip route 172.16.0.0 255.255.252.0 s0/0/1
R3(config)#
```

The following output confirms that the summary static route is in the routing table of R3:

```
R3# show ip route static | begin Gateway
```

```
Gateway of last resort is not set

      172.16.0.0/22 is subnetted, 1 subnets

S        172.16.0.0 is directly connected, Serial0/0/1

R3#
```

- **Configuring IPv6 Summary Routes**

Similar to IPv4, a single IPv6 static summary route can be used to replace multiple IPv6 static routes with a common prefix length. The calculation and configuration of an IPv6 summary static route is similar to the configuration of an IPv4 static summary route. Examples of configuring IPv6 summary routes will be provided shortly.

- **Summarizing IPv6 Network Addresses**

Aside from the fact that IPv6 addresses are 128 bits long and written in hexadecimal, summarizing IPv6 addresses is actually similar to the summarization of IPv4 addresses. It just requires a few extra steps due to the abbreviated IPv6 addresses and hex conversion.

Multiple static IPv6 routes can be summarized into a single static IPv6 route if:

- **The destination networks are contiguous** and can be summarized into a single network address.
- **The multiple static routes all use the same exit interface or next-hop IPv6 address.**

Refer to the network in Figure 19. R1 currently has four static IPv6 routes to reach networks 2001:DB8:ACAD:1::/64 to 2001:DB8:ACAD:4::/64.

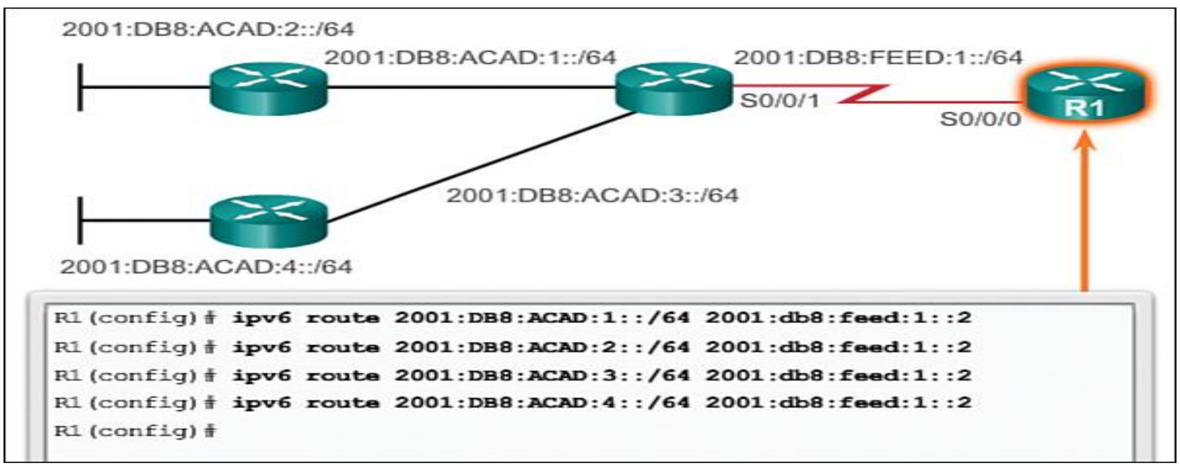


Figure 19. IPv6 summary static routes

The following output displays the IPv6 static routes installed in the IPv6 routing table:

```
R1# show ipv6 route static
IPv6 Routing Table - default - 7 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
       IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP external
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
S   2001:DB8:ACAD:1::/64 [1/0] via 2001:DB8:FEED:1::2
S   2001:DB8:ACAD:2::/64 [1/0] via 2001:DB8:FEED:1::2
S   2001:DB8:ACAD:3::/64 [1/0] via 2001:DB8:FEED:1::2
S   2001:DB8:ACAD:4::/64 [1/0] via 2001:DB8:FEED:1::2
R1#
```

- **Calculating IPv6 Summary Route:**

Summarizing IPv6 networks into a single IPv6 prefix and prefix length can be done in seven steps as shown in Figures 20-26.

- **Step 1.** List the network addresses (prefixes) and identify the part where the addresses differ.
- **Step 2.** Expand the IPv6 if it is abbreviated.
- **Step 3.** Convert the differing section from hex to binary.
- **Step 4.** Count the number of far left matching bits to determine the prefix length for the summary route.
- **Step 5.** Copy the matching bits and then add zero bits to determine the summarized network address (prefix).
- **Step 6.** Convert the binary section back to hex.
- **Step 7.** Append the prefix of the summary route (result of Step 4).

2001:0DB8:ACAD:1::/64
2001:0DB8:ACAD:2::/64
2001:0DB8:ACAD:3::/64
2001:0DB8:ACAD:4::/64

Figure 20. Identify the Part Where the Addresses Differ

2001:0DB8:ACAD:0001::/64
2001:0DB8:ACAD:0002::/64
2001:0DB8:ACAD:0003::/64
2001:0DB8:ACAD:0004::/64

Figure 21. Identify the Part Where the Addresses Differ – Expanded View

2001:0DB8:ACAD:0000000000000001::/64
2001:0DB8:ACAD:0000000000000010::/64
2001:0DB8:ACAD:0000000000000011::/64
2001:0DB8:ACAD:0000000000000100::/64

Figure 22. Convert the Section from Hex to Binary

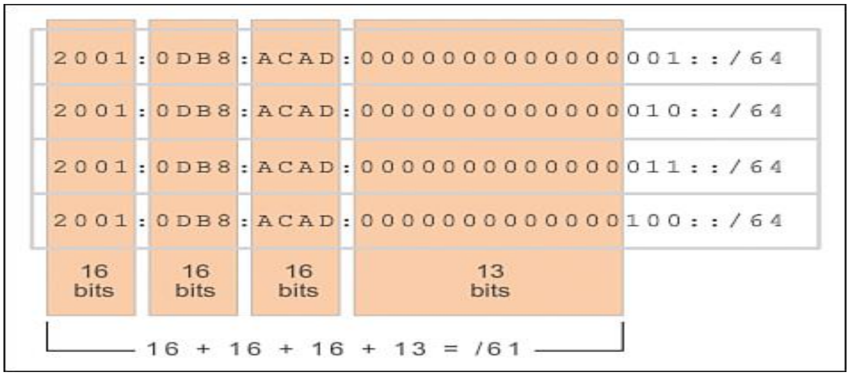


Figure 23. Count the Number of Far Left Matching Bits

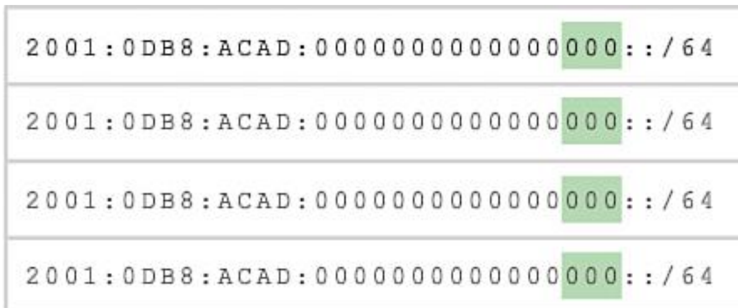


Figure 24. Add Zero Bits to Determine the Summarized Network Address

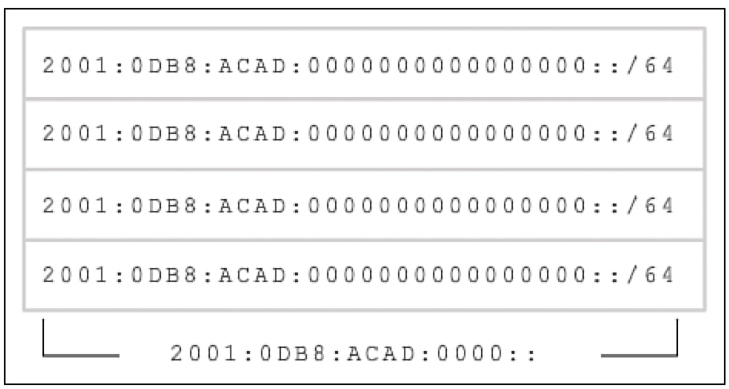


Figure 25. Convert the Binary Section Back to Hex

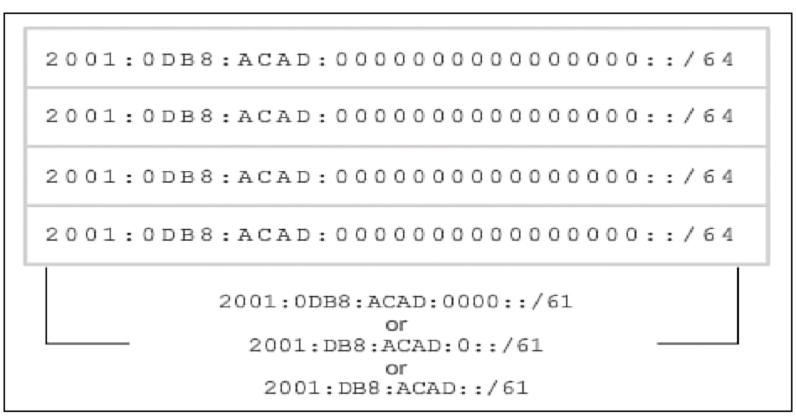


Figure 26. Count the Number of Far Left Matching Bits

Figure 27 displays R2 configured with a summary IPv6 static route to reach networks 2001:db8:caf0:1::/64 to 2001:db8:caf3:1::/64.

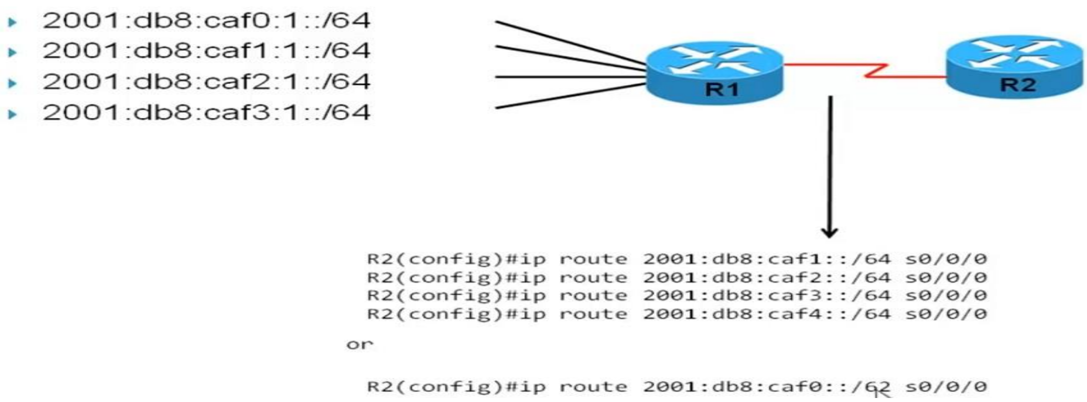


Figure 27. IPv6 summary static routes (second example)

The process of finding out the summary route of the networks, shown in Figure 27, is detailed in Figure 28:

```
2001:db8:caf  0:1::/64   (00 00)
2001:db8:caf  1:1::/64   (00 01)
2001:db8:caf  2:1::/64   (00 10)
2001:db8:caf  3:1::/64   (00 11)

2001:db8:caf0::/46
```

Figure 28. Summary route calculation at R2 (second example)

Figure 29 shows a plain calculation of a router IPV6 summary route to reach other four contiguous networks.

```
2001:db8:1::/64
2001:db8:2::/64
2001:db8:3::/64
2001:db8:4::/64

2001:0db8:000 1::/64   (0 001)
2001:0db8:000 2::/64   (0 010)
2001:0db8:000 3::/64   (0 011)
2001:0db8:000 4::/64   (0 100)

2001:0db8::/45
```

Figure 29. IPV6 plain summary route calculation of contiguous networks (third example) – Compresed as **2001:db8::/45**

- **Configuring an IPv6 Summary Route:**

After the summary route is identified, replace the existing routes with the single summary route. Figure 30 displays how the four existing routes are removed and then the new summary static IPv6 route is configured.

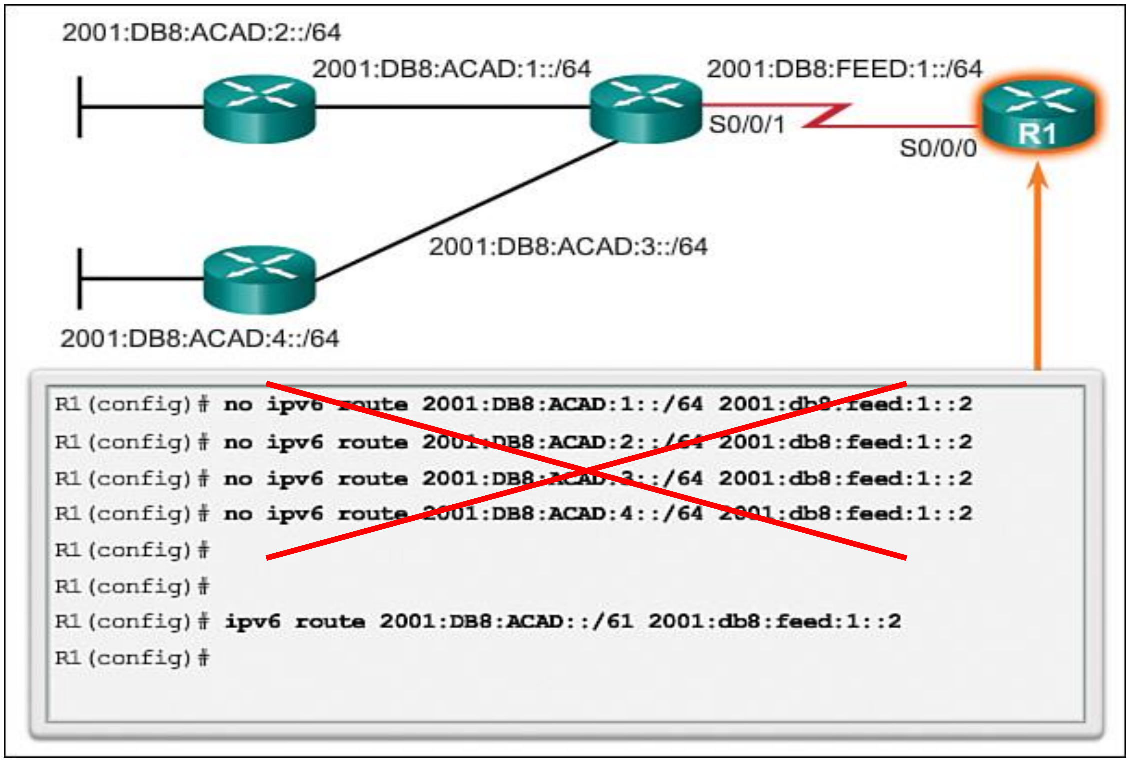


Figure 30. Remove Static Routes and Configure Summary IPv6 Route

The following output confirms that the summary static route is in the routing table of R1:

```
R1# show ipv6 route static
IPv6 Routing Table - default - 4 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
       IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP external
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
S   2001:DB8:ACA8::/45 [1/0] via 2001:DB8:FEED:1::2
R1#
```

D. Floating static route:

Floating static routes are static routes that are used to provide a backup path to a primary static or dynamic route, in the event of a link failure. The floating static route is only used when the primary route is not available. To accomplish this, the floating static route is configured with **a higher administrative distance** than the primary route. By default, static routes have an administrative distance of 1, making them preferable over routes learned from dynamic routing protocols. The administrative distance of a static route can be increased to make the route less desirable than that of another static route or a route learned through a dynamic routing protocol. Floating static routes are configured using the IP route global configuration command and specifying an administrative distance. Figures 31 and 32 details this kind of static routes.

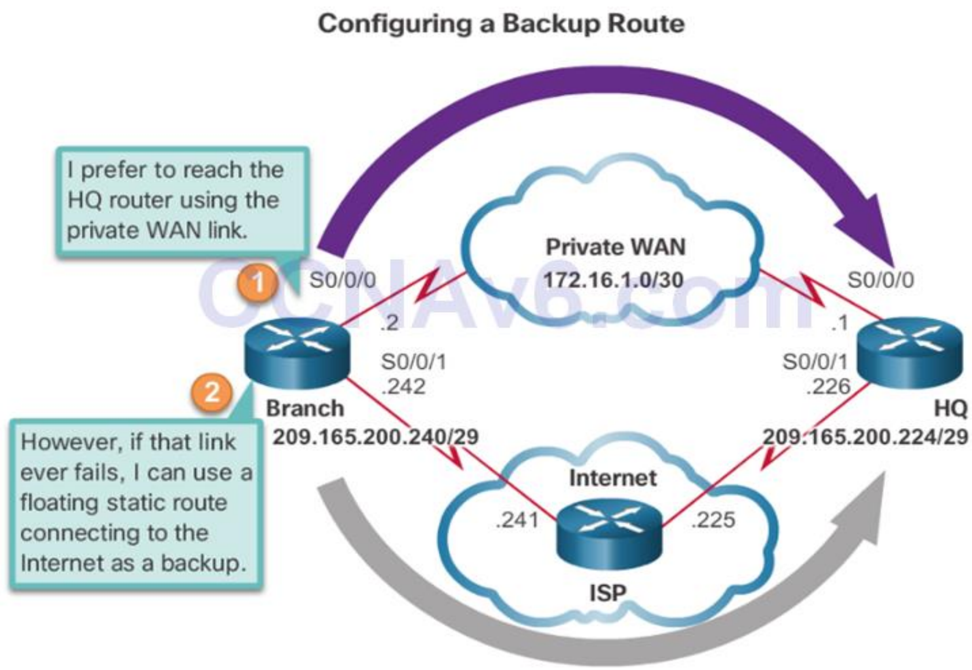


Figure 31. Floating static routes usage.

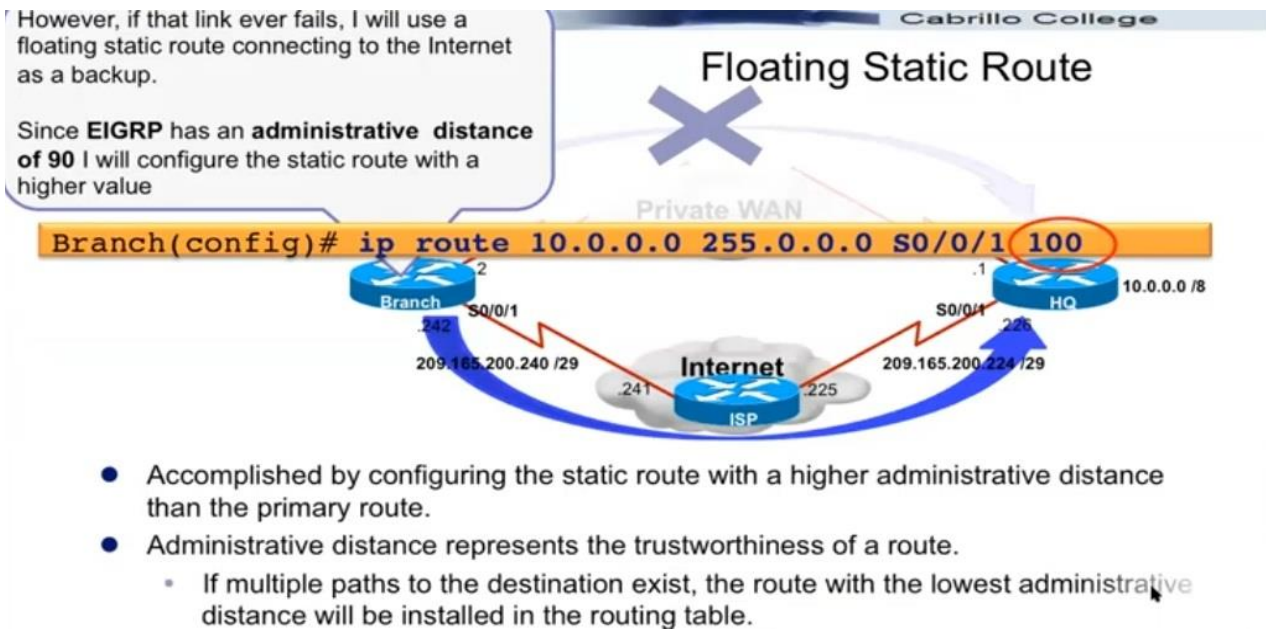


Figure 32. Floating static routes usage (Cont.).

Part V: Next-Hop Options in Static Routes:

There are three options available to configure static routes, which are illustrated as follows:

A. Directly attached static routes:

- A directly attached static route is a route that that uses only **the exit interface**. This route requires that the exit interface be in an up state for the route to be installed in the routing table. This type allows the routing table to **resolve the exit interface in a single search.**

- The routing table entry indicates these routes as "directly connected", **but the administrative distance is 1 since it is a static route (i.e., coded as "S" at the routing table).**
- Complete examples are shown in Figures 33, 34, and 35.

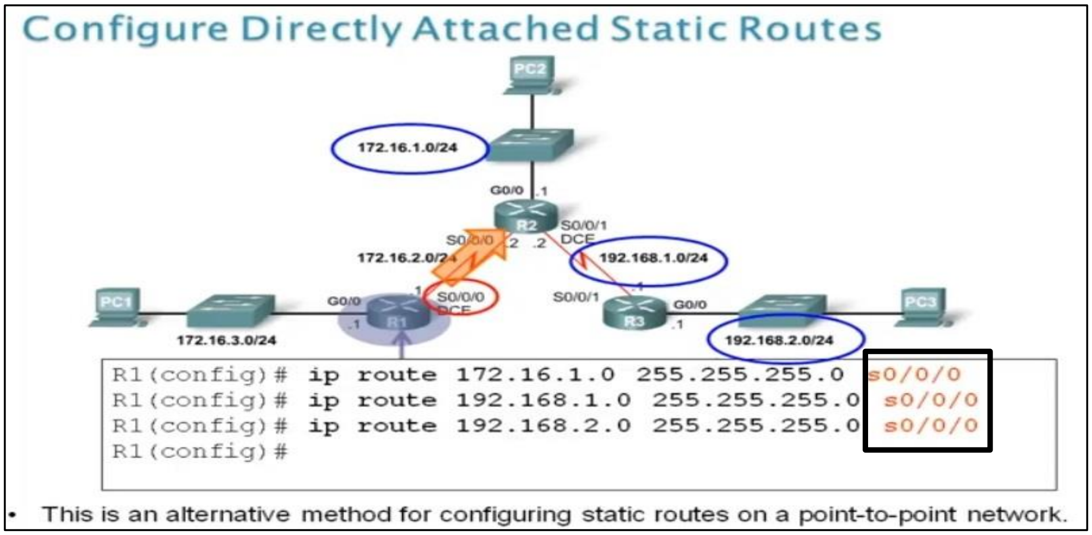


Figure 33. Directly attached static routes (IPv4)

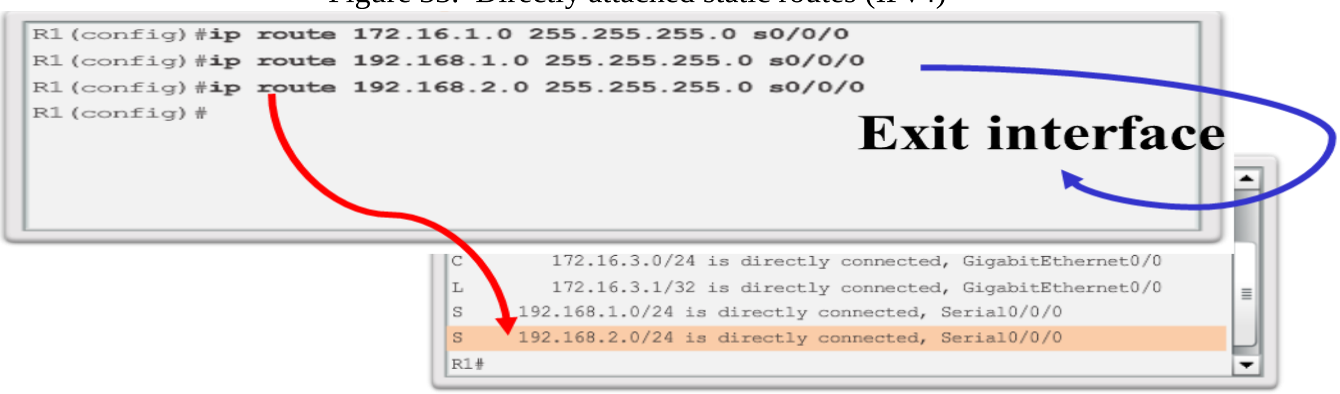


Figure 34. Directly attached static routes (IPv4, Cont.)

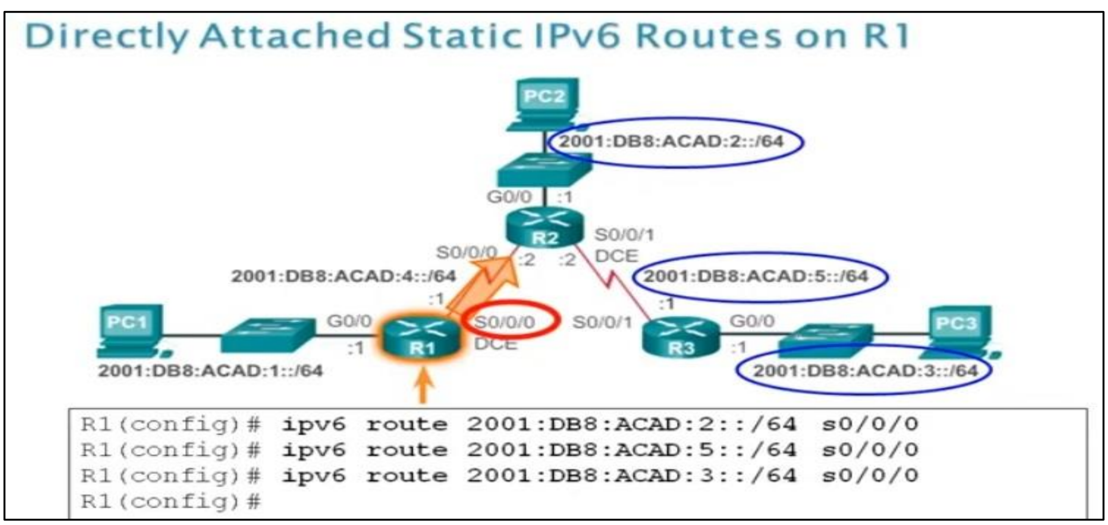


Figure 35. Directly attached static routes (IPv6)

B. Recursive static routes:

- This type of route uses the **ip address of the next-hop address**. This recursive lookup happens when the router queries the routing table, or Routing Information Base (RIB), to locate the route to the next hop address.
- Recursive static routes require the next-hop address to exist in the routing table to install the route.
- Configuring a recursive static route with the next hop router IP allows the routing table to **resolve the path in two searches.** The first one to search on the requested network ID in the routing table, while the second to search for the interface to reach this network. Figures 36 and 37 show the way to configure using next-hop address in IPv4.

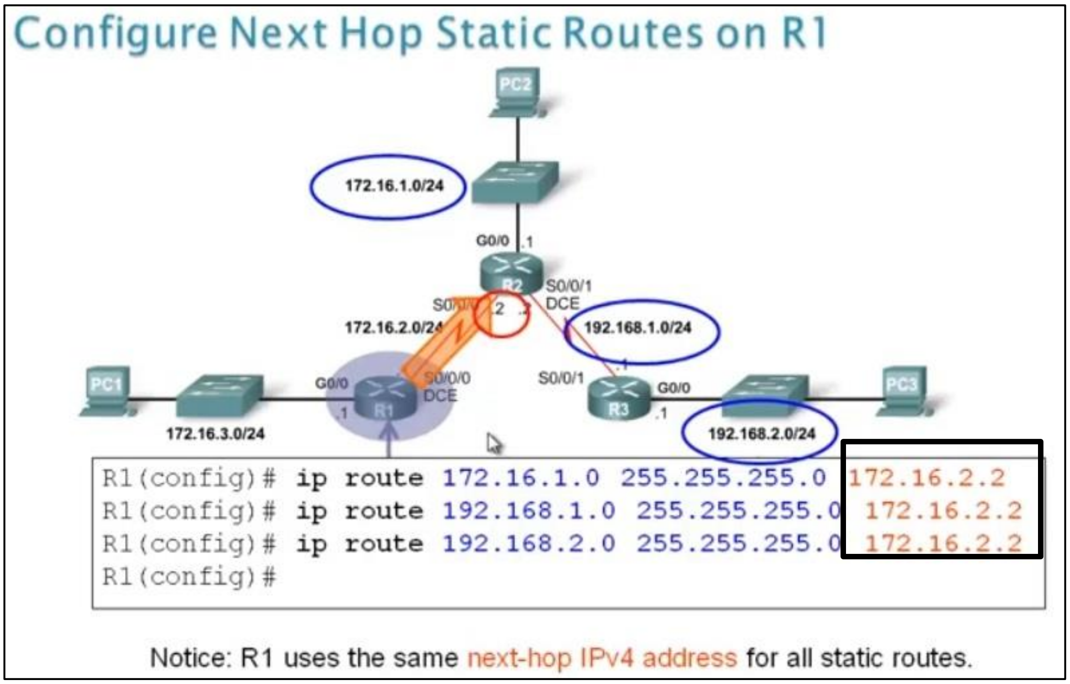


Figure 36. Configuring next hop static routes on R1

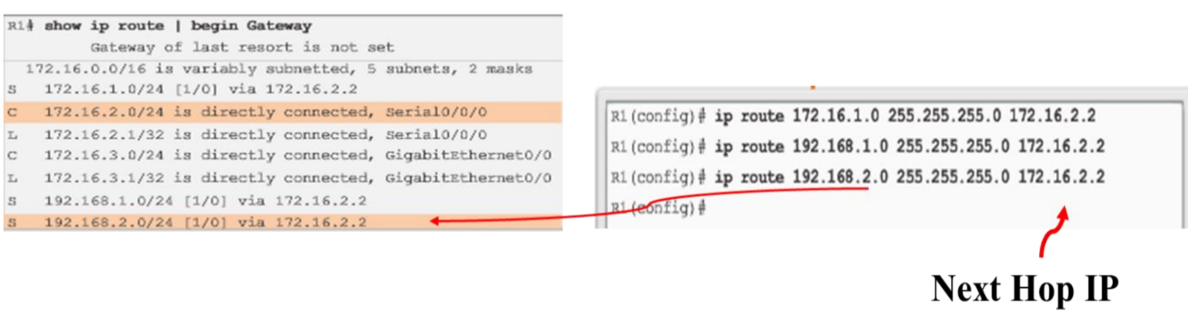


Figure 37. Recursive static routes (IPv4)

When a packet is destined for the 192.168.2.0/24 network, R1:

1. Looks for a match in the routing table and finds that it has to forward the packets to the next-hop IPv4 address 172.16.2.2.
2. R1 must now determine how to reach 172.16.2.2; therefore, it searches a second time for a 172.16.2.2 match, as shown in Figure 38.

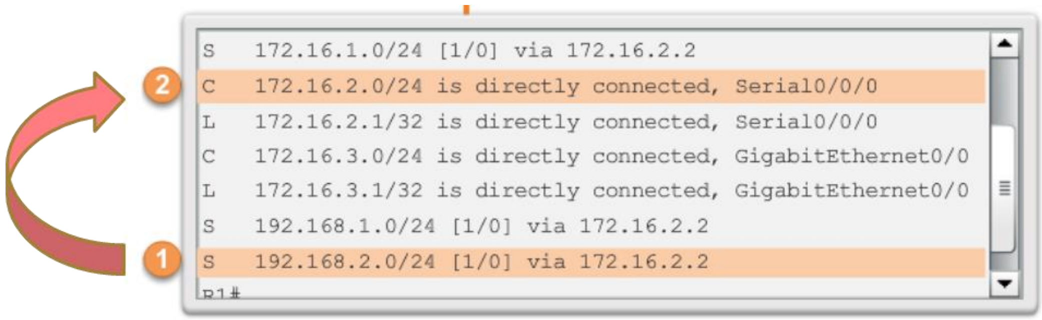


Figure 38. Recursive static routes ((IPv4, Cont.)

Figure 39 shows how to configure the next hop static IPv6 routes.

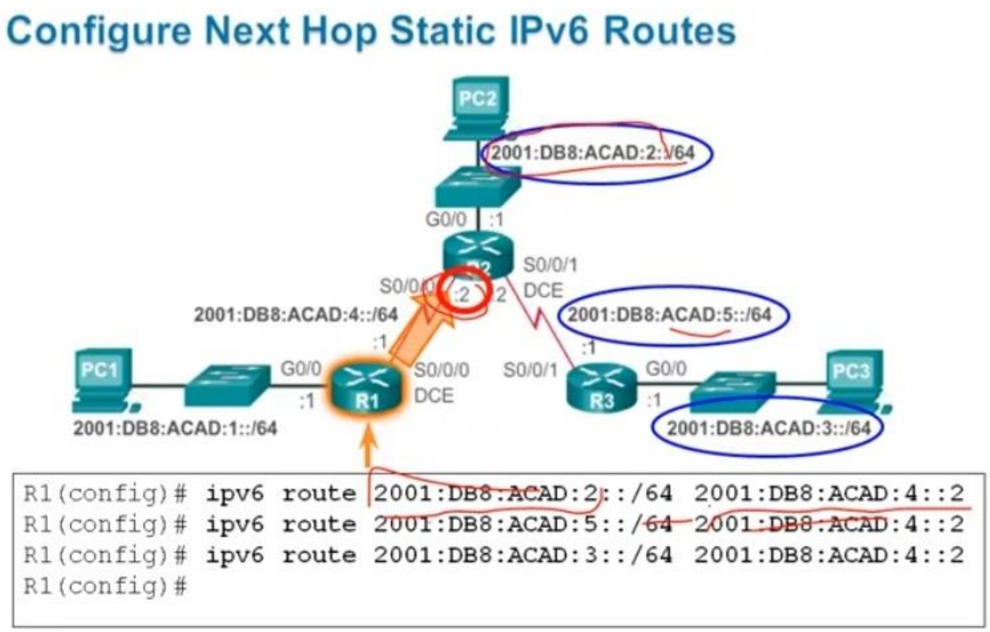


Figure 39. Recursive static routes (IPv6)

C. Fully specified static routes:

They are described in Figure 40 and illustrated as follows:

- Both **the exit interface and the next-hop IP address** are specified called Fully specified static route.
- Specifying the next-hop address and along with the exit interface **removes the recursive lookup** that happens with recursive static routes.

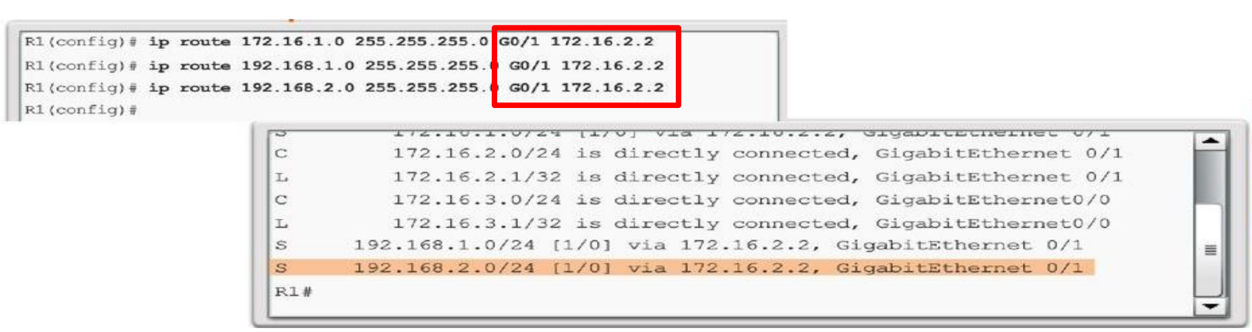


Figure 40. Fully specified static routes (IPv4)

Figure 41 shows the IPv6 static routes which are identical to those of IPv4.

- **Next Hop Static Route**
  `ipv6 route ipv6-prefix/prefix-length ipv6-address`
- **Directly Attached Static Route**
  `ipv6 route ipv6-prefix/prefix-length exit-intf`
- **Fully Specified Static Route**
  `ipv6 route ipv6-prefix/prefix-length exit-intf ipv6-address`

Figure 41. Types of IPv6 static routes (the same as those of IPv4)

Part VI: Static Route Commands:

A. Static route commands for IPv4:

1. **To Configure IPv4 Static Routes,** we use the following command, which is also detailed in Figure 42.

```
R1(config)# ip route network-address subnet-mask {ip-address | exit-interface}
```

- **ip route:** State that the route being configured is a **static route. It is used in the configuration mode.**

Configure IPv4 Static Routes

ip route Command

`ip route network-add subnet {ip-address | exit-intf [ip-address]} [distance]`

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

Figure 42. IPv4 static route command

2. **In a default route,** either the next-hop IP address or exit interface can be specified. To configure a default static route, use the following syntax, which is also detailed in Figure 43:

```
R1(config)# ip route 0.0.0.0 0.0.0.0 {ip-address | exit-interface}
```

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.

Figure 43. IPv4 default static route command

3. **Configure IPv4 Floating** Static Routes, wit administrative distance 100:

```
R1(config)# ip route 10.0.0.0 255.0.0.0 S0/0/1 100
```

4. **Examine the routing table entries in IPv4, using the following commnad.**

```
R1# show ip route
```

B. IPv6 static route commands

1. The **ipv6 unicast-routing** global configuration command must be configured to enable the router to forward IPv6 packets (i.e., packet forwarding).

```
R1(config)# ipv6  unicast-routing
```

2. Configure IPv6 Static Routes, use the following syntax, which is also detailed in Figure 44:

```
R1(config)# ipv6 route ipv6-prefix/prefix-length {ipv6-address | exit-interface}
```

Parameter	Description
ipv6-prefix	Destination network address of the remote network to be added to the routing table.
prefix-length	Prefix length of the remote network to be added to the routing table.
ipv6-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.

Figure 44. IPv6 static route command

3. Configure IPv6 Default Static Routes, use the following syntax, which is also detailed in Figure 45:

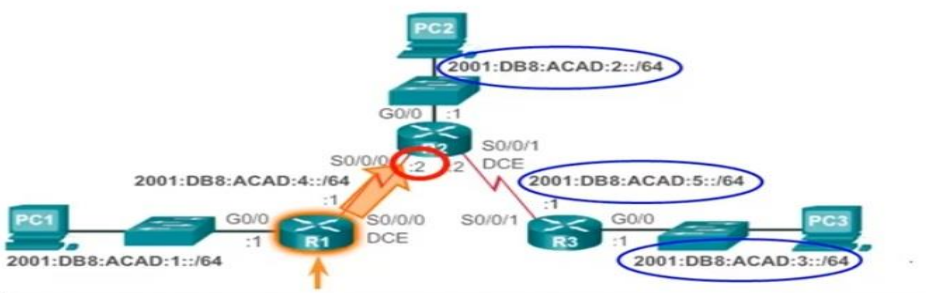
```
R1(config)# ipv6 route ::/0 {ipv6-address | exit-interface }
```

Parameter	Description
::/0	Matches any IPv6 prefix regardless of prefix length.
ipv6-address	• Commonly referred to as the next-hop router's IPv6 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.

Figure 45. Configuring a default static IPv6 route

Figure 46 shows the way to configure a default static IPv6 route.

Configuring a Default Static IPv6 Route




```
R1(config)# ipv6 route ::/0 2001:DB8:ACAD:4::2
R1(config)#
```

Figure 46. Configuring a default static IPv6 route

4. **Examine the routing table entries of IPv6,** as shown in Figure 47.

```
R1# show ipv6 route
```

Configure Next Hop Static IPv6 Routes

```
R3(config)#ipv6 route 2001:DB8:ACAD:2::/64 2001:DB8:ACAD:5::2
R3(config)#ipv6 route 2001:DB8:ACAD:4::/64 2001:DB8:ACAD:5::2
R3(config)#ipv6 route 2001:DB8:ACAD:1::/64 2001:DB8:ACAD:5::2
R3(config)#exit
R3#show ipv6 route
<Output omitted>

S    2001:DB8:ACAD:1::/64 [1/0]
      via 2001:DB8:ACAD:5::2
S    2001:DB8:ACAD:2::/64 [1/0]
      via 2001:DB8:ACAD:5::2
C    2001:DB8:ACAD:3::/64 [0/0]
      via GigabitEthernet0/0, directly connected
L    2001:DB8:ACAD:3::1/128 [0/0]
      via GigabitEthernet0/0, receive
S    2001:DB8:ACAD:4::/64 [1/0]
      via 2001:DB8:ACAD:5::2
C    2001:DB8:ACAD:5::/64 [0/0]
      via Serial0/0/1, directly connected
L    2001:DB8:ACAD:5::1/128 [0/0]
      via Serial0/0/1, receive
L    FF00::/8 [0/0]
      via Null0, receive
```

Figure 47. Examine the routing table entries of IPv6

Part VII: Configuring IPv4 and IPv6 static routing (Practical part):

A. IPv4 Standard, Default and Summarized Route Configuration (Packet Tracer)

- Consider the following scenario in Figure 2.1, which helps you practice configuring IPv4 static routing on routers, followed by the addressing table for each interface, as shown Table 2.

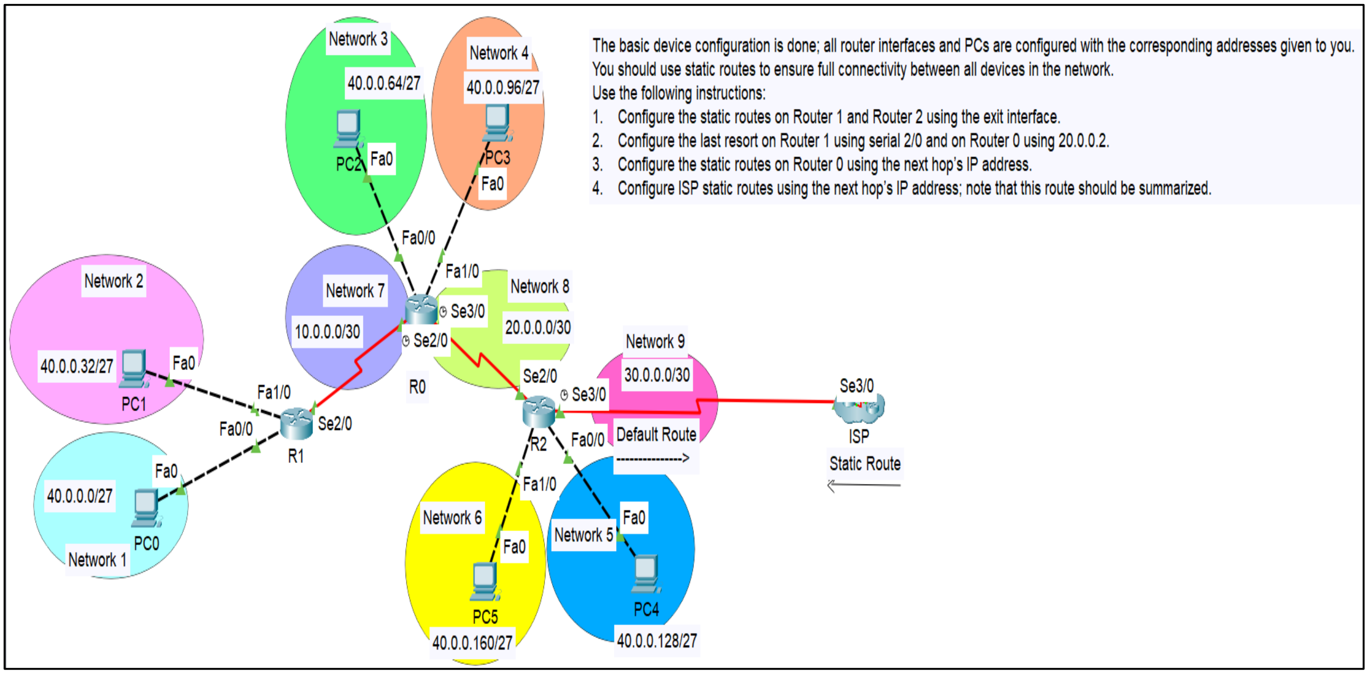


Fig 2.1. Network topolgy to configure IPv4 static routes.

Table 2: Addressing table for IPv4 scenario

Device	Interface	IPv4 Address	Subnet mask	Default Gateway
R0	F0/0	40.0.0.65	255.255.255.224	--
	F0/1	40.0.0.97	255.255.255.224	--
	S2/0	10.0.0.1	255.255.255.252	--
	S3/0	20.0.0.1	255.255.255.252	--
R1	F0/0	40.0.0.1	255.255.255.224	--
	F0/1	40.0.0.33	255.255.255.224	--
	S2/0	10.0.0.2	255.255.255.252	--
R2	F0/0	40.0.0.129	255.255.255.224	--
	F0/1	40.0.0.161	255.255.255.224	--
	S2/0	20.0.0.2	255.255.255.252	--
	S3/0	30.0.0.1	255.255.255.252	--
ISP	S2/0	30.0.0.2	255.255.255.252	--
PC0	Fa0	40.0.0.2	255.255.255.224	40.0.0.1
PC1	Fa0	40.0.0.34	255.255.255.224	40.0.0.33
PC2	Fa0	40.0.0.66	255.255.255.224	40.0.0.65
PC3	Fa0	40.0.0.98	255.255.255.224	40.0.0.97
PC4	Fa0	40.0.0.130	255.255.255.224	40.0.0.129
PC5	Fa0	40.0.0.162	255.255.255.224	40.0.0.161

On Router 1:

- The directly connected networks are: Network 1, Network 2, and Network 7.
- The remote networks: Network 3, Network 4, Network 5, Network 6, Network 8, and Network 9.
- We configured the remote network as shown in the figure below.

- Configure using exit interface, as shown in Figure 2.2.

```
Router1>en
Router1#config t
Enter configuration commands, one per line.  End with CNTL/Z.
Router1(config)#ip route 40.0.0.64 255.255.255.224 Serial2/0
Router1(config)#ip route 40.0.0.96 255.255.255.224 Serial2/0
Router1(config)#ip route 40.0.0.160 255.255.255.224 Serial2/0
Router1(config)#ip route 40.0.0.128 255.255.255.224 Serial2/0
Router1(config)#ip route 20.0.0.0 255.255.255.252 Serial2/0
Router1(config)#ip route 30.0.0.0 255.255.255.252 Serial2/0
Router1(config)#ip route 0.0.0.0 0.0.0.0 Serial2/0
Router1(config)#
```

Fig 2.2. Configuring IPv4 static routes in Router 1.

- Figure 2.3 shows the configured static routes. Note the static routes are denoted by **"S"**, and the default static routes denoted by **"S*"**

```
Router1>en
Router1#show ip route
Gateway of last resort is 0.0.0.0 to network 0.0.0.0

     10.0.0.0/30 is subnetted, 1 subnets
C       10.0.0.0 is directly connected, Serial2/0
     20.0.0.0/30 is subnetted, 1 subnets
S       20.0.0.0 is directly connected, Serial2/0
     30.0.0.0/30 is subnetted, 1 subnets
S       30.0.0.0 is directly connected, Serial2/0
     40.0.0.0/27 is subnetted, 6 subnets
C       40.0.0.0 is directly connected, FastEthernet0/0
C       40.0.0.32 is directly connected, FastEthernet1/0
S       40.0.0.64 is directly connected, Serial2/0
S       40.0.0.96 is directly connected, Serial2/0
S       40.0.0.128 is directly connected, Serial2/0
S       40.0.0.160 is directly connected, Serial2/0
S*   0.0.0.0/0 is directly connected, Serial2/0
```

Fig 2.3. IPv4 routing table in Router 1.

<u>On Router 2:</u>

- The directly connected networks are: Network 5, Network 6, Network 8, and Network 9.
- The remote networks: Network 1, Network 2, Network 3, Network 4, and Network 7.
- We configured the remote network as shown in the figure below.
- Configure using exit interface, as shown in Figure 2.4

```
Router2>enable
Router2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router2(config)#ip route 40.0.0.0 255.255.255.224 Serial2/0
Router2(config)#ip route 40.0.0.32 255.255.255.224 Serial2/0
Router2(config)#ip route 40.0.0.64 255.255.255.224 Serial2/0
Router2(config)#ip route 40.0.0.96 255.255.255.224 Serial2/0
Router2(config)#ip route 10.0.0.0 255.255.255.252 Serial2/0
Router2(config)#ip route 0.0.0.0 0.0.0.0 Serial3/0
Router2(config)#
```

Fig 2.4. Configuring IPv4 static routes in Router 2.

- Figure 2.5 shows the configured static routes. Note the static routes are denoted by **“S”**, and the default static routes denoted by **“S*”.**

```
Router2>enable
Router2#show ip route
Gateway of last resort is 0.0.0.0 to network 0.0.0.0

     10.0.0.0/30 is subnetted, 1 subnets
S       10.0.0.0 is directly connected, Serial2/0
     20.0.0.0/30 is subnetted, 1 subnets
C       20.0.0.0 is directly connected, Serial2/0
     30.0.0.0/30 is subnetted, 1 subnets
C       30.0.0.0 is directly connected, Serial3/0
     40.0.0.0/27 is subnetted, 6 subnets
S       40.0.0.0 is directly connected, Serial2/0
S       40.0.0.32 is directly connected, Serial2/0
S       40.0.0.64 is directly connected, Serial2/0
S       40.0.0.96 is directly connected, Serial2/0
C       40.0.0.128 is directly connected, FastEthernet0/0
C       40.0.0.160 is directly connected, FastEthernet1/0
S*   0.0.0.0/0 is directly connected, Serial3/0
```

Fig 2.5. IPv4 routing table in Router 2.

<u>On Router 0:</u>

- The directly connected networks are: Network 3, Network 4, Network 7, and Network 8.
- The remote networks: Network 1, Network 2, Network 5, Network 6, and Network 9.
- We configured the remote network as shown in the figure below (Fig. 2.6).
- Configure a Recursive Static Route (next hop router IP), as shown in Figure 2.6.

```
Router0>enable
Router0#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router0(config)#ip route 40.0.0.0 255.255.255.224 10.0.0.2
Router0(config)#ip route 40.0.0.32 255.255.255.224 10.0.0.2
Router0(config)#ip route 40.0.0.128 255.255.255.224 20.0.0.2
Router0(config)#ip route 40.0.0.160 255.255.255.224 20.0.0.2
Router0(config)#ip route 0.0.0.0 0.0.0.0 20.0.0.2
Router0(config)#
```

Fig 2.6. Configuring IPv4 static routes in Router 0.

- Figure 2.7 shows the configured static routes.

```
Router0>enable
Router0#show ip route
Gateway of last resort is 20.0.0.2 to network 0.0.0.0

     10.0.0.0/30 is subnetted, 1 subnets
C       10.0.0.0 is directly connected, Serial2/0
     20.0.0.0/30 is subnetted, 1 subnets
C       20.0.0.0 is directly connected, Serial3/0
     40.0.0.0/27 is subnetted, 6 subnets
S       40.0.0.0 [1/0] via 10.0.0.2
S       40.0.0.32 [1/0] via 10.0.0.2
C       40.0.0.64 is directly connected, FastEthernet0/0
C       40.0.0.96 is directly connected, FastEthernet1/0
S       40.0.0.128 [1/0] via 20.0.0.2
S       40.0.0.160 [1/0] via 20.0.0.2
S*   0.0.0.0/0 [1/0] via 20.0.0.2
```

Fig 2.7. IPv4 routing table in Router 0.

On ISP Router:

- We configured the remote network as shown in the figure below.
- Configure a Recursive Static Route (next hop router IP), as shown in Figure 2.8.

```
ISP>enable
ISP#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
ISP(config)#ip route 40.0.0.0 255.255.255.0 30.0.0.1
ISP(config)#ip route 20.0.0.0 255.255.255.252 30.0.0.1
ISP(config)#ip route 10.0.0.0 255.255.255.252 30.0.0.1
ISP(config)#
```

Fig 2.8. Configuring IPv4 static routes in ISP router.

Verify Network Connectivity

- After configuring the proper static routing on routers, the ping should be successful, as presented in Figure 2.9.

Fire	Last Status	Source	Destination	Type	Color	Time(sec	Periodic	Num
	Successful	PC1	PC2	ICMP		0.000	N	0
	Successful	PC0	PC3	ICMP		0.000	N	1
	Successful	PC2	PC5	ICMP		0.000	N	2
	Successful	PC3	PC4	ICMP		0.000	N	3
	Successful	ISP	PC3	ICMP		0.000	N	4
	Successful	ISP	PC1	ICMP		0.000	N	5
	Successful	PC0	ISP	ICMP		0.000	N	6
	Successful	PC5	ISP	ICMP		0.000	N	7
	Successful	ISP	PC4	ICMP		0.000	N	8

Fig 2.9. The results after applying ping command.

B. Configuring IPv6 (Practical part):

- Consider the following scenario, as in Figure 2.10, which helps you practice configuring IPv4 static routing on routers, followed by the addressing table for each interface, as shown Table 3.

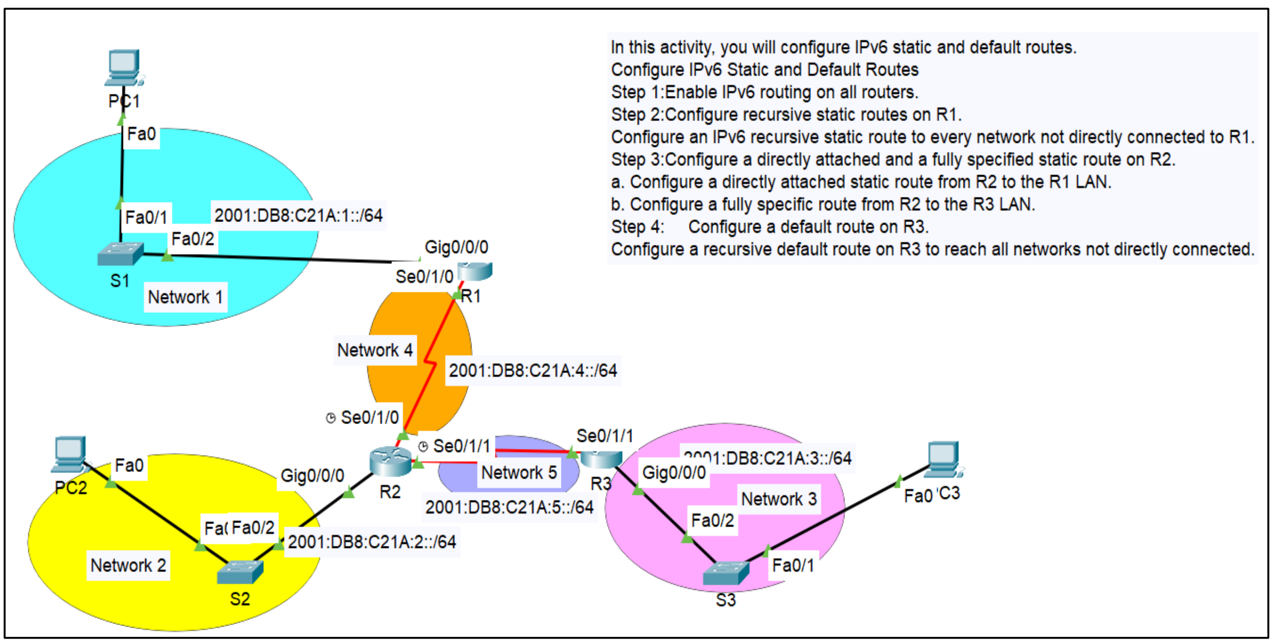


Fig 2.10. Network topolgy to configure IPv6 static routes

Table 3: Addressing table for IPv6 scenario

Device	Interface	IPv6 Address	Default Gateway
R1	G0/0/0	2001:DB8:C21A:1::2/64	--
	S0/1/0	2001:DB8:C21A:4::1/64	--
R2	G0/0/0	2001:DB8:C21A:2::2/64	--
	S0/1/0	2001:DB8:C21A:4::2/64	--
	S0/1/1	2001:DB8:C21A:5::1/64	--
R3	G0/0/0	2001:DB8:C21A:3::2/64	--
	S0/1/1	2001:DB8:C21A:5::2/64	--
PC1	NIC	2001:DB8:C21A:1::1/64	FE80::1
PC2	NIC	2001:DB8:C21A:2::1/64	FE80::2
PC3	NIC	2001:DB8:C21A:3::1/64	FE80::3

Configure recursive static routes on R1.

- Configure an IPv6 recursive static route to every network not directly connected to R1.
- Networks 2, 3, and 5 are the remote networks.

```
Router1(config)#ipv6 route 2001:DB8:C21A:2::/64 2001:DB8:C21A:5::1
Router1(config)#ipv6 route 2001:DB8:C21A:5::/64 2001:DB8:C21A:5::1
Router1(config)#ipv6 route 2001:DB8:C21A:3::/64 2001:DB8:C21A:5::1
```

- Figure 2.11 shows the configured static routes.

```
Router1>en
Router1#show ipv6 route
IPv6 Routing Table - 8 entries
Codes: C - Connected, L - Local, S - Static, R - RIP, B - BGP
       U - Per-user Static route, M - MIPv6
       I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF intra, OI - OSPF inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
       D - EIGRP, EX - EIGRP external
C   2001:DB8:C21A:1::/64 [0/0]
     via GigabitEthernet0/0/0, directly connected
L   2001:DB8:C21A:1::2/128 [0/0]
     via GigabitEthernet0/0/0, receive
S   2001:DB8:C21A:2::/64 [1/0]
     via 2001:DB8:C21A:4::2
     via 2001:DB8:C21A:5::1
S   2001:DB8:C21A:3::/64 [1/0]
     via 2001:DB8:C21A:4::2
     via 2001:DB8:C21A:5::1
C   2001:DB8:C21A:4::/64 [0/0]
     via Serial0/1/0, directly connected
L   2001:DB8:C21A:4::1/128 [0/0]
     via Serial0/1/0, receive
S   2001:DB8:C21A:5::/64 [1/0]
     via 2001:DB8:C21A:4::2
L   FF00::/8 [0/0]
     via Null0, receive
```

Fig 2.11. IPv6 routing table in Router 1.

Configure a directly attached and a fully specified static route on R2.

- Configure an IPv6 recursive static route to every network not directly connected to R1.
- Networks 1 and 3 are the remote networks.

```
Router2(config)#ipv6 route 2001:DB8:C21A:1::/64 s0/1/0
Router2(config)#ipv6 route 2001:DB8:C21A:3::/64 s0/1/1
```

- Figure 2. 12 shows the configured static routes.

```
Router2>en
Router2#show ipv6 route
S    2001:DB8:C21A:1::/64 [1/0]
      via Serial0/1/0, directly connected
C    2001:DB8:C21A:2::/64 [0/0]
      via GigabitEthernet0/0/0, directly connected
L    2001:DB8:C21A:2::2/128 [0/0]
      via GigabitEthernet0/0/0, receive
S    2001:DB8:C21A:3::/64 [1/0]
      via Serial0/1/1, directly connected
C    2001:DB8:C21A:4::/64 [0/0]
      via Serial0/1/0, directly connected
L    2001:DB8:C21A:4::2/128 [0/0]
      via Serial0/1/0, receive
C    2001:DB8:C21A:5::/64 [0/0]
      via Serial0/1/1, directly connected
L    2001:DB8:C21A:5::1/128 [0/0]
      via Serial0/1/1, receive
L    FF00::/8 [0/0]
      via Null0, receive
Router2#
```

Fig 2. 12. IPv6 routing table in Router 2.

Configure a default route on R3.

- Configure a recursive default route on R3 to reach all networks not directly connected.

```
R3(config)#ipv6 route ::/0 2001:DB8:C21A:5::1
```

- Figure 2.13 shows the configured default static routes.

```
Router3>en
Router3#show ipv6 route
S    ::/0 [1/0]
      via 2001:DB8:C21A:5::1
C    2001:DB8:C21A:3::/64 [0/0]
      via GigabitEthernet0/0/0, directly connected
L    2001:DB8:C21A:3::2/128 [0/0]
      via GigabitEthernet0/0/0, receive
C    2001:DB8:C21A:5::/64 [0/0]
      via Serial0/1/1, directly connected
L    2001:DB8:C21A:5::2/128 [0/0]
      via Serial0/1/1, receive
L    FF00::/8 [0/0]
      via Null0, receive
```

Fig 2.13. IPv6 routing table in Router 3.

Verify Network Connectivity

- Every device should now be able to ping every other device. If not, review your static and default route configurations. Figure 2.14 show the results of ping PC1 from PC3.

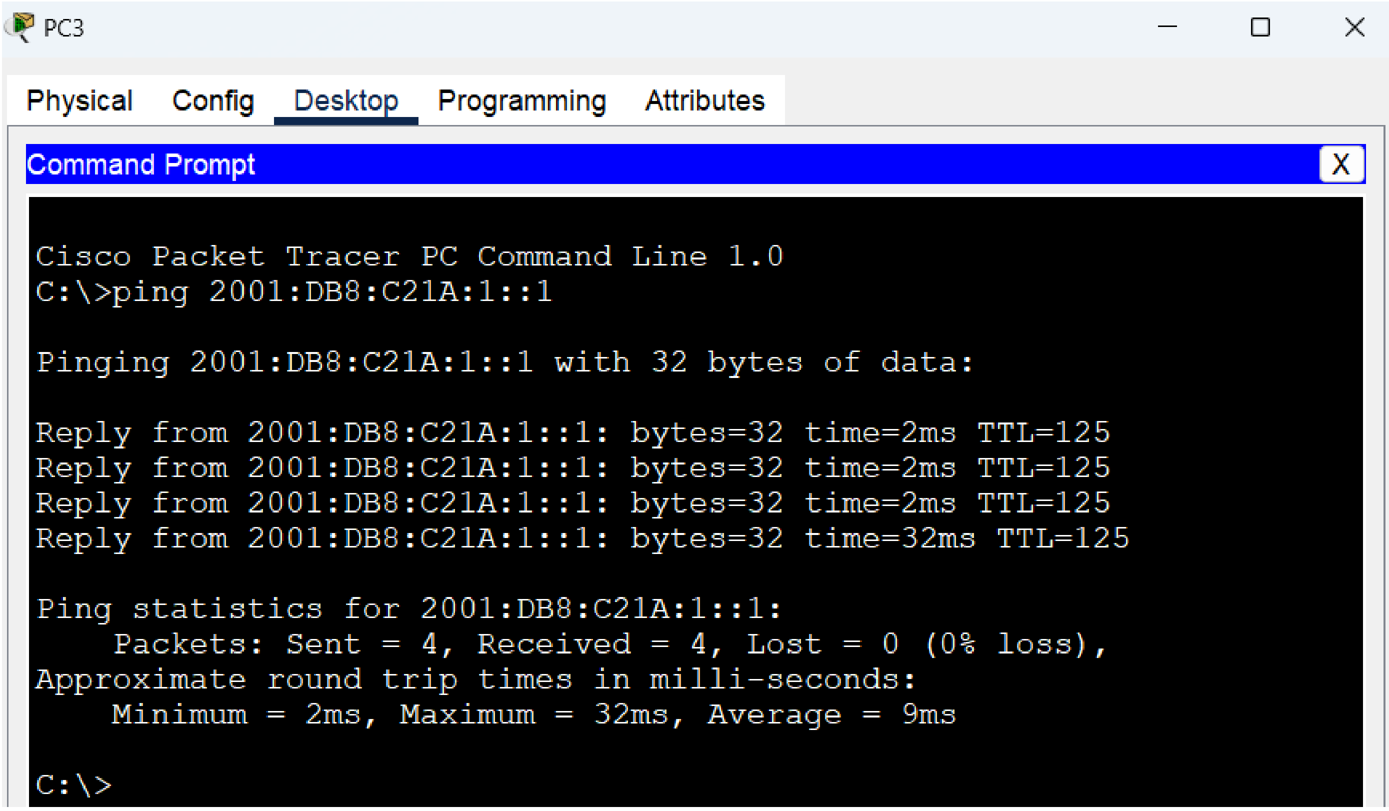


Fig 2.14. IPv6 routing table in Router 3.

Important Note: Some parts of this handout have been collected from several trustable sites, books, and published videos/slides and the other parts have been prepared and written by the instructors. As a matter of fact, this handout is made to be so straight forward, understandable, and so attractive whereas the students can do the required activities and solve the problems in a systematic and easy way, but still the instructors are expected to discuss some important material during the labs' sessions.