Static Routing

Routing Protocols
A router can learn about remote networks in one of two ways:

- Manually - Remote networks are manually entered into the route table using static routes.
- Dynamically - Remote routes are automatically learned using a dynamic routing protocol.
Static Routing
Why Use 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.
Static Routing
Why Use Static Routing? (continued)

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.
Static Routing

When to Use Static Routes

Static routing has three primary uses:

- Providing ease of routing table maintenance in smaller networks that are not expected to grow significantly.

- Routing to and from stub networks. A stub network is a network accessed by a single route, and the router has no other neighbors.

- Using a single default route to represent a path to any network that does not have a more specific match with another route in the routing table. Default routes are used to send traffic to any destination beyond the next upstream router.
Static Route Applications

Static Routes are often used to:

- Connect to a specific network
- Provide a Gateway of Last Resort for a stub network
- Reduce the number of routes advertised by summarizing several contiguous networks as one static route
- Create a backup route in case a primary route link fails
Types of Static Routes

Standard Static Route

Connecting to a Stub Network

No need to use a dynamic routing protocol with R1 to reach 172.16.3.0/24.
I can simply use a static route to reach the stub network.
Types of Static Routes

Default Static Route

- A default static route is a route that matches all packets.

- 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 simply a static route with 0.0.0.0/0 as the destination IPv4 address.
Types of Static Routes

Summary Static Route

Using One Summary Static Route

I can represent all four networks:
- 172.20.0.0/16
- 172.21.0.0/16
- 127.22.0.0/16
- 172.23.0.0/16

Using a single summary route:
- 172.20.0.0/14
Types of Static Routes

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.

- In order to accomplish this, the floating static route is configured with a higher administrative distance than the primary route.

Configuring a Backup Route

1. I prefer to reach the HQ router using the private WAN link.
2. However, if that link ever fails, I can use a floating static route connecting to the Internet as a backup.
Configure IPv4 Static Routes

**ip route Command**

### ip route Command Syntax

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>network-address</td>
<td>Destination network address of the remote network to be added to</td>
</tr>
<tr>
<td></td>
<td>the routing table.</td>
</tr>
<tr>
<td>subnet-mask</td>
<td>• Subnet mask of the remote network to be added to the routing</td>
</tr>
<tr>
<td></td>
<td>table.</td>
</tr>
<tr>
<td></td>
<td>• The subnet mask can be modified to summarize a group of</td>
</tr>
<tr>
<td></td>
<td>networks.</td>
</tr>
<tr>
<td>ip-address</td>
<td>• Commonly referred to as the next-hop router’s IP address.</td>
</tr>
<tr>
<td></td>
<td>• Typically used when connecting to a broadcast media (i.e., Ethernet).</td>
</tr>
<tr>
<td></td>
<td>• Commonly creates a recursive lookup.</td>
</tr>
<tr>
<td>exit-intf</td>
<td>• Use the outgoing interface to forward packets to the destination</td>
</tr>
<tr>
<td></td>
<td>network.</td>
</tr>
<tr>
<td></td>
<td>• Also referred to as a directly attached static route.</td>
</tr>
<tr>
<td></td>
<td>• Typically used when connecting in a point-to-point</td>
</tr>
<tr>
<td></td>
<td>configuration.</td>
</tr>
</tbody>
</table>
Configure IPv4 Static Routes

Next-Hop Options

The next hop can be identified by an IP address, exit interface, or both. How the destination is specified creates one of the three following route types:

- **Next-hop route** - Only the next-hop IP address is specified.
- **Directly connected static route** - Only the router exit interface is specified.
- **Fully specified static route** - The next-hop IP address and exit interface are specified.
Configure IPv4 Static Routes

Configure a Next-Hop Static Route

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.
Configure IPv4 Static Routes

Configure Directly Connected Static Route

R1(config)# ip route 172.16.1.0 255.255.255.0 s0/0/0
R1(config)# ip route 192.168.1.0 255.255.255.0 s0/0/0
R1(config)# ip route 192.168.2.0 255.255.255.0 s0/0/0
R1(config)#

S 172.16.1.0/24 is directly connected, Serial0/0/0
C 172.16.2.0/24 is directly connected, Serial0/0/0
L 172.16.2.1/32 is directly connected, Serial0/0/0
C 172.16.3.0/24 is directly connected, GigabitEthernet0/0
L 172.16.3.1/32 is directly connected, GigabitEthernet0/0
S 192.168.1.0/24 is directly connected, Serial0/0/0
S 192.168.2.0/24 is directly connected, Serial0/0/0
R1#
Configure IPv4 Static Routes

Configure a Fully Specified Static Route

- In a fully specified static route, both the output interface and the next-hop IP address are specified.

- This is another type of static route that is used in older IOS’s, prior to CEF.

- This form of static route is used when the output interface is a multi-access interface and it is necessary to explicitly identify the next hop.

- The next hop must be directly connected to the specified exit interface.
Configure IPv4 Static Routes

Verify a Static Route

Along with **ping** and **traceroute**, useful commands to verify static routes include:

- `show ip route`
- `show ip route static`
- `show ip route network`
Configure IPv4 Default Routes

Default Static Route

Default Static Route Syntax

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0.0.0</td>
<td>Matches any network address.</td>
</tr>
<tr>
<td>0.0.0.0</td>
<td>Matches any subnet mask.</td>
</tr>
</tbody>
</table>
| ip-address | • Commonly referred to as the next-hop router’s IP address.  
           | • Typically used when connecting to a broadcast media (i.e., Ethernet).  
           | • Commonly creates a recursive lookup. |
| exit-intf  | • Use the outgoing interface to forward packets to the destination network.  
           | • Also referred to as a directly attached static route.  
           | • Typically used when connecting in a point-to-point configuration. |
Configure IPv4 Default Routes

Configure a Default Static Route

```
R1(config)# ip route 0.0.0.0 0.0.0.0 172.16.2.2
R1(config)#
```
Configure IPv4 Default Routes
Verify a Default Static Route

Verifying the Routing Table of R1

```
R1#show ip route static
Codes: L - local, C - connected, S - static, R - RIP,
M - mobile, B - BGP, D - EIGRP,
E - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1
N2 - OSPF NSSA external type 2
E1 - EIGRP external type 1
E2 - EIGRP external type 2
L1 - IS-IS Level-1 L2 - IS-IS Level-2
Su - IS-IS summary. Incomplete
Gateway of last resort is 172.16.2.2 to network 0.0.0.0
* 0.0.0.0/0 [1/0] via 172.16.2.2
R1#
```
Classful Addressing

Classful Routing Protocol Example
CIDR

CIDR and Route Summarization

Summarizing Supernet Routes

Customer A
192.168.0.0/23

Customer B
192.168.2.0/23

Customer C
192.168.4.0/22

Customer D
192.168.8.0/21

ISP1
192.168.0.0/20

ISP2
192.168.0.0/21

www.ncp.edu.pk
CIDR

Static Routing CIDR Example

One Summary Static Route

R1(config) #no ip route 172.16.0.0 255.255.0.0 s0/0/0
R1(config) #no ip route 172.17.0.0 255.255.0.0 s0/0/0
R1(config) #no ip route 172.18.0.0 255.255.0.0 s0/0/0
R1(config) #no ip route 172.19.0.0 255.255.0.0 s0/0/0
R1(config) #no ip route 172.20.0.0 255.255.0.0 s0/0/0
R1(config) #no ip route 172.21.0.0 255.255.0.0 s0/0/0
R1(config) #
R1(config) ip route 172.16.0.0 255.255.248.0.0 s0/0/0
R1(config) #
CIDR

Classless Routing Protocol Example

Classless Routing Update

- 172.16.0.0/16
  - R2
  - G0/0
  - S0/0/0: DCE
  - S0/0/1: DCE

- 172.17.0.0/16
  - R1
  - S0/0/0: DCE
  - G0/1

- 172.18.0.0/16
  - R1
  - G0/0

- 192.168.1.0/24
  - Summary Route
  - Update: 172.16.0.0/14

- 10.1.0.0/16
  - R3
  - G0/0

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Configure IPv4 Summary Routes

Route Summarization

- Route summarization, also known as route aggregation, is the process of advertising a contiguous set of addresses as a single address with a less-specific, shorter subnet mask.
- CIDR 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.
Configure IPv4 Summary Routes

Calculate a Summary Route

Calculating a Route Summary

Step 1: List networks in binary format.

<table>
<thead>
<tr>
<th>Network</th>
<th>Binary</th>
<th>Prefix</th>
<th>Mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>172.20.0.0</td>
<td>10101100 . 00010100 . 00000000 . 00000000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>172.21.0.0</td>
<td>10101100 . 00010101 . 00000000 . 00000000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>172.22.0.0</td>
<td>10101100 . 00010110 . 00000000 . 00000000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>172.23.0.0</td>
<td>10101100 . 00010111 . 00000000 . 00000000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Step 2: Count the number of far-left matching bits to determine the mask.

Answer: 14 matching bits = /14 or 255.252.0.0

Step 3: Copy the matching bits and add zero bits to determine the network address.

Answer: 172.20.0.0
Configure IPv4 Summary Routes

Summary Static Route Example

Verify the Routing Table

```
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 [1/0] via 192.168.1.2
S    172.16.2.0 [1/0] via 192.168.1.2
S    172.16.3.0 [1/0] via 192.168.1.2
```

Routes that can be summarized

- First 22 bits are the same
- Some bits are different

<table>
<thead>
<tr>
<th>Route</th>
<th>Summarized into one route</th>
</tr>
</thead>
<tbody>
<tr>
<td>172.16.0.0</td>
<td>192.168.1.0/22</td>
</tr>
<tr>
<td>172.16.0.0</td>
<td>192.168.1.0/22</td>
</tr>
<tr>
<td>255.255.252.0</td>
<td>192.168.0.0/22</td>
</tr>
<tr>
<td>172.16.1.0</td>
<td>192.168.1.0/22</td>
</tr>
<tr>
<td>172.16.2.0</td>
<td>192.168.1.0/22</td>
</tr>
<tr>
<td>172.16.3.0</td>
<td>192.168.1.0/22</td>
</tr>
</tbody>
</table>
Configure Floating Static Routes

Floating Static Routes

- Floating static routes are static routes that have an administrative distance greater than the administrative distance of another static route or dynamic routes.

- 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.

- In this way, the static route “floats” and is not used when the route with the better administrative distance is active.

- However, if the preferred route is lost, the floating static route can take over, and traffic can be sent through this alternate route.
Configure Floating Static Routes

Configure a Floating Static Route

Configuring a Floating Static Route to R3

R1(config)# ip route 0.0.0.0 0.0.0.0 172.16.2.2
R1(config)# ip route 0.0.0.0 0.0.0.0 10.10.10.2 5
R1(config)#
Configure Floating Static Routes

Test the Floating Static Route

- Use a `show ip route` command to verify that the routing table is using the default static route.
- Use a `traceroute` command to follow the traffic flow out the primary route.
- Disconnect the primary link or shutdown the primary exit interface.
- Use a `show ip route` command to verify that the routing table is using the floating static route.
- Use a `traceroute` command to follow the traffic flow out the backup route.
Routing Dynamically

Routing Protocols
Dynamic Routing Protocol Operation

The Evolution of Dynamic Routing Protocols

- Dynamic routing protocols used in networks since the late 1980s
- Newer versions support the communication based on IPv6

Routing Protocols Classification

<table>
<thead>
<tr>
<th>Interior Gateway Protocols</th>
<th>Link-State</th>
<th>Exterior Gateway Protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPv4</td>
<td>RIPv2</td>
<td>OSPFv2</td>
</tr>
<tr>
<td></td>
<td>EIGRP</td>
<td>IS-IS</td>
</tr>
<tr>
<td>IPv6</td>
<td>RIPng</td>
<td>OSPFv3</td>
</tr>
<tr>
<td></td>
<td>EIGRP for IPv6</td>
<td>IS-IS for IPv6</td>
</tr>
</tbody>
</table>
Dynamic Routing Protocol Operation

Purpose of Dynamic Routing Protocols

- **Routing Protocols**
  - Used to facilitate the exchange of routing information between routers

- **Purpose of dynamic routing protocols includes:**
  - Discovery of remote networks
  - Maintaining up-to-date routing information
  - Choosing the best path to destination networks
  - Ability to find a new best path if the current path is no longer available
Dynamic Routing Protocol Operation

Purpose of Dynamic Routing Protocols

Main components of dynamic routing protocols include:

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

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

- **Algorithm** - Routing protocols use algorithms for facilitating routing information for best path determination.
Dynamic Routing Protocol Operation

The Role of Dynamic Routing Protocols

- **Advantages of dynamic routing**
  - Automatically share information about remote networks
  - Determine the best path to each network and add this information to their routing tables
  - Compared to static routing, dynamic routing protocols require less administrative overhead
  - Help the network administrator manage the time-consuming process of configuring and maintaining static routes

- **Disadvantages of dynamic routing**
  - Dedicate part of a router's resources for protocol operation, including CPU time and network link bandwidth

- **Times when static routing is more appropriate**
Dynamic verses Static Routing  
Using Static Routing

- Networks typically use a combination of both static and dynamic routing

- Static routing has several primary uses
  - Providing ease of routing table maintenance in smaller networks that are not expected to grow significantly
  - Routing to and from a stub network
    - a network with only one default route out and no knowledge of any remote networks
  - Accessing a single default router
    - used to represent a path to any network that does not have a match in the routing table
Dynamic verses Static Routing

Using Static Routing

Router R2 is connected to other networks and to the Internet. It is also my only way out of here. I just use a default static route to reach any network I do not know about.

Router R1 only has two networks that I need to know about so I just use two static routes to reach those networks.
### Static Routing Advantages and Disadvantages

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to implement in a small network.</td>
<td>Suitable only for simple topologies or for special purposes such as a default static route. Configuration complexity increases dramatically as network grows.</td>
</tr>
<tr>
<td>Very secure. No advertisements are sent as compared to dynamic routing protocols.</td>
<td></td>
</tr>
<tr>
<td>Route to destination is always the same.</td>
<td>Manual intervention required to re-route traffic.</td>
</tr>
<tr>
<td>No routing algorithm or update mechanism required; therefore, extra resources (CPU or RAM) are not required.</td>
<td></td>
</tr>
</tbody>
</table>
## Dynamic verses Static Routing

### Dynamic Routing Scorecard

#### Dynamic Routing Advantages and Disadvantages

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suitable in all topologies where multiple routers are required.</td>
<td>Can be more complex to implement.</td>
</tr>
<tr>
<td>Generally independent of the network size.</td>
<td>Less secure. Additional configuration settings are required to secure.</td>
</tr>
<tr>
<td>Automatically adapts topology to reroute traffic if possible.</td>
<td>Route depends on the current topology.</td>
</tr>
<tr>
<td></td>
<td>Requires additional CPU, RAM, and link bandwidth.</td>
</tr>
</tbody>
</table>
Routing Protocol Operating Fundamentals

Dynamic Routing Protocol Operation

In general, the operations of a dynamic routing protocol can be described as follows:

1. The router sends and receives routing messages on its interfaces.

2. The router shares routing messages and routing information with other routers that are using the same routing protocol.

3. Routers exchange routing information to learn about remote networks.

4. When a router detects a topology change, the routing protocol can advertise this change to other routers.
Routing Protocol Operating Fundamentals

Cold Start

- R1 adds the 10.1.0.0 network available through interface FastEthernet 0/0 and 10.2.0.0 is available through interface Serial 0/0/0.
- R2 adds the 10.2.0.0 network available through interface Serial 0/0/0 and 10.3.0.0 is available through interface Serial 0/0/1.
- R3 adds the 10.3.0.0 network available through interface Serial 0/0/1 and 10.4.0.0 is available through interface FastEthernet 0/0.

Routers running RIPv2
Routing Protocol Operating Fundamentals
Network Discovery

R1:
- Sends an update about network 10.1.0.0 out the Serial0/0/0 interface
- Sends an update about network 10.2.0.0 out the FastEthernet0/0 interface
- Receives update from R2 about network 10.3.0.0 with a metric of 1
- Stores network 10.3.0.0 in the routing table with a metric of 1

Routers running RIPv2
Routing Protocol Operating Fundamentals
Network Discovery

R2:
- Sends an update about network 10.3.0.0 out the Serial 0/0/0 interface
- Sends an update about network 10.2.0.0 out the Serial 0/0/1 interface
- Receives an update from R1 about network 10.1.0.0 with a metric of 1
- Stores network 10.1.0.0 in the routing table with a metric of 1
- Receives an update from R3 about network 10.4.0.0 with a metric of 1
- Stores network 10.4.0.0 in the routing table with a metric of 1
Routing Protocol Operating Fundamentals
Network Discovery

R3:
- Sends an update about network 10.4.0.0 out the Serial 0/0/1 interface
- Sends an update about network 10.3.0.0 out the FastEthernet0/0
- Receives an update from R2 about network 10.2.0.0 with a metric of 1
- Stores network 10.2.0.0 in the routing table with a metric of 1

Routers running RIPv2
Routing Protocol Operating Fundamentals
Exchanging the Routing Information

R1:
- Sends an update about network 10.1.0.0 out the Serial 0/0/0 interface
- Sends an update about networks 10.2.0.0 and 10.3.0.0 out the FastEthernet0/0 interface
- Receives an update from R2 about network 10.4.0.0 with a metric of 2
- Stores network 10.4.0.0 in the routing table with a metric of 2
- Same update from R2 contains information about network 10.3.0.0 with a metric of 1. There is no change; therefore, the routing information remains the same

Routers running RIPv2
Routing Protocol Operating Fundamentals
Exchanging the Routing Information

R2:
- Sends an update about networks 10.3.0.0 and 10.4.0.0 out of Serial 0/0/0 interface
- Sends an update about networks 10.1.0.0 and 10.2.0.0 out of Serial 0/0/1 interface
- Receives an update from R1 about network 10.1.0.0. There is no change; therefore, the routing information remains the same.
- Receives an update from R3 about network 10.4.0.0. There is no change; therefore, the routing information remains the same.
Routing Protocol Operating Fundamentals
Exchanging the Routing Information

R3:
- Sends an update about network 10.4.0.0 out the Serial 0/0/1 interface
- Sends an update about networks 10.2.0.0 and 10.3.0.0 out the FastEthernet0/0 interface
- Receives an update from R2 about network 10.1.0.0 with a metric of 2
- Stores network 10.1.0.0 in the routing table with a metric of 2
- Same update from R2 contains information about network 10.2.0.0 with a metric of 1. There is no change; therefore, the routing information remains the same.
Routing Protocol Operating Fundamentals

Achieving Convergence

- Network converged when all routers have complete and accurate information about the entire network.

- Convergence time is the time it takes routers to share information, calculate best paths, and update their routing tables.

- A network is not completely operable until the network has converged.

- Convergence properties include the speed of propagation of routing information and the calculation of optimal paths. The speed of propagation refers to the amount of time it takes for routers within the network to forward routing information.

- Generally, older protocols, such as RIP, are slow to converge, whereas modern protocols, such as EIGRP and OSPF, converge more quickly.
Types of Routing Protocols
Classifying Routing Protocols

Routing Protocols Classification

Dynamic Routing Protocols

Interior Gateway Protocols (IGPs)

- Distance Vector Routing Protocols
  - RIPv1
  - RIPv2
- Link-State Routing Protocols
  - EIGRP
  - OSPF
- Path-Vector Routing Protocol
  - IS-IS
  - BGP

Exterior Gateway Protocols (EGPs)
Types of Routing Protocols

IGP and EGP Routing Protocols

**Interior Gateway Protocols (IGP) -**
- Used for routing within an AS
- Include RIP, EIGRP, OSPF, and IS-IS

**Exterior Gateway Protocols (EGP) -**
- Used for routing between AS
- Official routing protocol used by the Internet
Types of Routing Protocols
Distance Vector Routing Protocols

Distance vector IPv4 IGPs:
- **RIPv1** - First generation legacy protocol
- **RIPv2** - Simple distance vector routing protocol
- **IGRP** - First generation Cisco proprietary protocol (obsolete)
- **EIGRP** - Advanced version of distance vector routing

For R1, 172.16.3.0/24 is one hop away (distance) it can be reached through R2 (vector)
Types of Routing Protocols
Distance Vector or Link-State Routing Protocols

Distance vector protocols use routers as signposts along the path to the final destination.

A link-state routing protocol is like having a complete map of the network topology. The signposts along the way from source to destination are not necessary, because all link-state routers are using an identical map of the network. A link-state router uses the link-state information to create a topology map and to select the best path to all destination networks in the topology.
Types of Routing Protocols

Link-State Routing Protocols

Link-state IPv4 IGPs:

- **OSPF** - Popular standards based routing protocol
Types of Routing Protocols

Classful Routing Protocols

- Classful routing protocols do not send subnet mask information in their routing updates
  - Only RIPv1 and IGRP are classful
  - Created when network addresses were allocated based on classes (class A, B, or C)
  - Cannot provide variable length subnet masks (VLSMs) and classless interdomain routing (CIDR)
  - Create problems in discontiguous networks
Types of Routing Protocols

Classless Routing Protocols

- Classless routing protocols include subnet mask information in the routing updates
  - RIPv2, EIGRP, OSPF, and IS-IS
  - Support VLSM and CIDR
  - IPv6 routing protocols
## Types of Routing Protocols

### Routing Protocol Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Distance Vector</th>
<th>Link State</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RIPv1</td>
<td>RIPv2</td>
</tr>
<tr>
<td>Speed Convergence</td>
<td>Slow</td>
<td>Slow</td>
</tr>
<tr>
<td>Scalability - Size of Network</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>Use of VLSM</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Resource Usage</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Implementation and Maintenance</td>
<td>Simple</td>
<td>Simple</td>
</tr>
</tbody>
</table>
Types of Routing Protocols

Routing Protocol Metrics

A metric is a measurable value that is assigned by the routing protocol to different routes based on the usefulness of that route

- Used to determine the overall “cost” of a path from source to destination
- Routing protocols determine the best path based on the route with the lowest cost
Distance vector routing protocols
- Share updates between neighbors
- Not aware of the network topology
- Some send periodic updates to broadcast IP 255.255.255.255 even if topology has not changed
- Updates consume bandwidth and network device CPU resources
- RIPv2 and EIGRP use multicast addresses
- EIGRP will only send an update when topology has changed
Distance Vector Routing Protocol Operation

Distance Vector Algorithm

RIP uses the Bellman-Ford algorithm as its routing algorithm

IGRP and EIGRP use the Diffusing Update Algorithm (DUAL) routing algorithm developed by Cisco
Types of Distance Vector Routing Protocols
Routing Information Protocol

RIPv1 versus RIPv2

<table>
<thead>
<tr>
<th>Characteristics and Features</th>
<th>RIPv1</th>
<th>RIPv2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric</td>
<td>Both use hop count as a simple metric. The maximum number of hops is 15.</td>
<td></td>
</tr>
<tr>
<td>Updates Forwarded to Address</td>
<td>255.255.255.255</td>
<td>224.0.0.9</td>
</tr>
<tr>
<td>Supports VLSM</td>
<td>❌</td>
<td>✓</td>
</tr>
<tr>
<td>Supports CIDR</td>
<td>❌</td>
<td>✓</td>
</tr>
<tr>
<td>Supports Summarization</td>
<td>❌</td>
<td>✓</td>
</tr>
<tr>
<td>Supports Authentication</td>
<td>❌</td>
<td>✓</td>
</tr>
</tbody>
</table>

RIPng is based on RIPv2 with a 15 hop limitation and the administrative distance of 120

Routing updates broadcasted every 30 seconds
Updates use UDP port 520

www.ncp.edu.pk
RIP Routing
Configuring the RIP Protocol

Router RIP Configuration Mode

Advertising Networks

R1(config)# router rip
R1(config-router)#

R1(config-router)# network 192.168.1.0
R1(config-router)# network 192.168.2.0
R1(config-router)#

www.ncp.edu.pk
Configuring the RIP Protocol
Examining Default RIP Settings

Verifying RIP Settings on R1

```bash
R1# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "rip"
Outgoing update filter list for all interfaces is not set
Incoming update filter list for all interfaces is not set
Sending updates every 30 seconds, next due in 16 seconds
Invalid after 180 seconds, hold down 180, flushed after 240

Redistributing: rip

Default version control: send version 1, receive any version
Interface SendRecv Triggered RIPCKey-chain
GigabitEthernet0/0 1 1 2
Serial0/0/0 1 1 2

Automatic network summarization is in effect

Maximum path: 4
Routing for Networks:
192.168.1.0
192.168.2.0

Routing Information Sources:

Gateway Distance Last Update
192.168.2.2 120 00:00:15

Distance: (default is 120)
```

Verifying RIP Routes on R1

```bash
R1# show ip route | begin Gateway
Gateway of last resort is not set

192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C 192.168.1.0/24 is directly connected, GigabitEthernet0/0
L 192.168.1.1/32 is directly connected, GigabitEthernet0/0
192.168.2.0/24 is variably subnetted, 2 subnets, 2 masks
C 192.168.2.0/24 is directly connected, Serial0/0/0
L 192.168.2.1/32 is directly connected, Serial0/0/0
R 192.168.3.0/24 [120/1] via 192.168.2.2, 00:00:24, Serial0/0/0
R 192.168.4.0/24 [120/1] via 192.168.2.2, 00:00:24, Serial0/0/0
R 192.168.5.0/24 [120/2] via 192.168.2.2, 00:00:24, Serial0/0/0
R1#```
Configuring the RIP Protocol
Enabling RIPv2

Verifying RIP Settings on R1

```
R1# show ip protocols
*** IP Routing is NSF aware ***
Routing Protocol is "rip"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Sending updates every 30 seconds, next due in 16 seconds
  Invalid after 180 seconds, hold down 180, flushed after 240
  Redistributing: rip
Default version control: send version 1, receive any version
  Interface    Send  Recv  Triggered RIP  Key-chain
  GigabitEthernet0/0  1   1       2
  Serial0/0/0       1   1       2
Automatic network summarization is in effect
Maximum path: 4
Routing for Networks:
  192.168.1.0
  192.168.2.0
Routing Information Sources:
  Gateway    Distance  Last Update
```

Enable and Verify RIPv2 on R1

```
R1(config)# router rip
R1(config-router)# version 2
R1(config-router)# ^Z
R1# show ip protocols | section Default
Default version control: send version 2, receive version 2
  Interface    Send  Recv  Triggered RIP  Key-chain
  GigabitEthernet0/0  2   2
  Serial0/0/0       2   2
R1#
```
Configuring the RIP Protocol

Configuring Passive Interfaces

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

- Wasted Bandwidth
- Wasted Resources
- Security Risk
Configuring the RIP Protocol

Propagating a Default Route

R1(config)# ip route 0.0.0.0 0.0.0.0 S0/0/1 209.165.200.226
R1(config)# router rip
R1(config-router)# default-information originate
R1(config-router)# ^Z

R1# show ip route | begin Gateway
Gateway of last resort is 209.165.200.226 to network 0.0.0.0

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

Shortest Path First Protocols

Diagram:

- **Interior Gateway Protocols (IGP)**
  - **Distance Vector Routing Protocols**
    - RIPv1
    - IGRP
    - RIPv2
    - EIGRP
  - **Link-State Routing Protocols**
    - OSPF
    - IS-IS
Link-State Routing Protocol Operation
Dijkstra’s Algorithm

**Dijkstra's Shortest Path First Algorithm**

Shortest Path for host on R2 LAN to reach host on R3 LAN:
R2 to R1 (20) + R1 to R3 (5) + R3 to LAN (2) = 27
Link-State Updates

**Link-State Routing Process**

- Each router learns about each of its own directly connected networks.
- Each router is responsible for "saying hello" to its neighbors on directly connected networks.
- Each router builds a Link State Packet (LSP) containing the state of each directly connected link.
- Each router floods the LSP to all neighbors who then store all LSP's received in a database.
- Each router uses the database to construct a complete map of the topology and computers the best path to each destination networks.
The first step in the link-state routing process is that each router learns about its own links, its own directly connected networks.

**Link 1**
- Network: 10.1.0.0/16
- IP address: 10.1.0.1
- Type of network: Ethernet
- Cost of that link: 2
- Neighbors: None

**Link 2**
- Network: 10.2.0.0/16
- IP address: 10.2.0.1
- Type of network: Serial
- Cost of that link: 20
- Neighbors: R2
Link-State Updates

Say Hello

The second step in the link-state routing process is that each router is responsible for meeting its neighbors on directly connected networks.
The third step in the link-state routing process is that each router builds a link-state packet (LSP) containing the state of each directly connected link.

1. R1; Ethernet network
   10.1.0.0/16; Cost 2
2. R1 -> R2; Serial point-to-point network;
   10.2.0.0/16; Cost 20
3. R1 -> R3; Serial point-to-point network;
   10.3.0.0/16; Cost 5
4. R1 -> R4; Serial point-to-point network;
   10.4.0.0/16; Cost 20
Link-State Updates
Flooding the LSP

The fourth step in the link-state routing process is that each router floods the LSP to all neighbors, who then store all LSPs received in a database.
Link-State Updates
Building the Link-State Database

The final step in the link-state routing process is that each router uses the database to construct a complete map of the topology and computes the best path to each destination network.

Contents of the Link-State Database

<table>
<thead>
<tr>
<th>R1 Link-State Database</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R1 Link-states:</strong></td>
</tr>
<tr>
<td>• Connected to network 10.1.0.0/16, cost = 2</td>
</tr>
<tr>
<td>• Connected to R2 on network 10.2.0.0/16, cost = 20</td>
</tr>
<tr>
<td>• Connected to R3 on network 10.3.0.0/16, cost = 5</td>
</tr>
<tr>
<td>• Connected to R4 on network 10.4.0.0/16, cost = 20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R2 Link-states:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Connected to network 10.5.0.0/16, cost = 2</td>
</tr>
<tr>
<td>• Connected to R1 on network 10.2.0.0/16, cost = 20</td>
</tr>
<tr>
<td>• Connected to R5 on network 10.9.0.0/16, cost = 10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R3 Link-states:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Connected to network 10.6.0.0/16, cost = 2</td>
</tr>
<tr>
<td>• Connected to R1 on network 10.3.0.0/16, cost = 5</td>
</tr>
<tr>
<td>• Connected to R4 on network 10.7.0.0/16, cost = 10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R4 Link-states:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Connected to network 10.8.0.0/16, cost = 2</td>
</tr>
<tr>
<td>• Connected to R1 on network 10.4.0.0/16, cost = 20</td>
</tr>
<tr>
<td>• Connected to R3 on network 10.7.0.0/16, cost = 10</td>
</tr>
<tr>
<td>• Connected to R5 on network 10.10.0.0/16, cost = 10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R5 Link-states:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Connected to network 10.11.0.0/16, cost = 2</td>
</tr>
<tr>
<td>• Connected to R2 on network 10.9.0.0/16, cost = 10</td>
</tr>
<tr>
<td>• Connected to R4 on network 10.10.0.0/16, cost = 10</td>
</tr>
</tbody>
</table>
Link-State Updates
Building the SPF Tree

Identify the Directly Connected Networks

<table>
<thead>
<tr>
<th>R1 Link-State Database</th>
<th>SPF Tree</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R1 Link-states:</strong></td>
<td></td>
</tr>
<tr>
<td>• Connected to network 10.1.0.0/16, cost = 2</td>
<td></td>
</tr>
<tr>
<td>• Connected to R2 on network 10.2.0.0/16, cost = 20</td>
<td></td>
</tr>
<tr>
<td>• Connected to R3 on network 10.3.0.0/16, cost = 5</td>
<td></td>
</tr>
<tr>
<td>• Connected to R4 on network 10.4.0.0/16, cost = 20</td>
<td></td>
</tr>
<tr>
<td><strong>R2 Link-states:</strong></td>
<td></td>
</tr>
<tr>
<td>• Connected to network 10.5.0.0/16, cost = 2</td>
<td></td>
</tr>
<tr>
<td>• Connected to R1 on network 10.2.0.0/16, cost = 20</td>
<td></td>
</tr>
<tr>
<td>• Connected to R5 on network 10.9.0.0/16, cost = 10</td>
<td></td>
</tr>
<tr>
<td><strong>R3 Link-states:</strong></td>
<td></td>
</tr>
<tr>
<td>• Connected to network 10.6.0.0/16, cost = 2</td>
<td></td>
</tr>
<tr>
<td>• Connected to R1 on network 10.3.0.0/16, cost = 5</td>
<td></td>
</tr>
<tr>
<td>• Connected to R4 on network 10.7.0.0/16, cost = 10</td>
<td></td>
</tr>
<tr>
<td><strong>R4 Link-states:</strong></td>
<td></td>
</tr>
<tr>
<td>• Connected to network 10.8.0.0/16, cost = 2</td>
<td></td>
</tr>
<tr>
<td>• Connected to R1 on network 10.4.0.0/16, cost = 20</td>
<td></td>
</tr>
<tr>
<td>• Connected to R3 on network 10.7.0.0/16, cost = 10</td>
<td></td>
</tr>
<tr>
<td>• Connected to R5 on network 10.10.0.0/16, cost = 10</td>
<td></td>
</tr>
<tr>
<td><strong>R5 Link-states:</strong></td>
<td></td>
</tr>
<tr>
<td>• Connected to network 10.11.0.0/16, cost = 2</td>
<td></td>
</tr>
<tr>
<td>• Connected to R2 on network 10.9.0.0/16, cost = 10</td>
<td></td>
</tr>
<tr>
<td>• Connected to R4 on network 10.10.0.0/16, cost = 10</td>
<td></td>
</tr>
</tbody>
</table>
Link-State Updates

Building the SPF Tree

Resulting SPF Tree of R1

<table>
<thead>
<tr>
<th>Destination</th>
<th>Shortest Path</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.5.0.0/16</td>
<td>R1 → R2</td>
<td>22</td>
</tr>
<tr>
<td>10.6.0.0/16</td>
<td>R1 → R3</td>
<td>7</td>
</tr>
<tr>
<td>10.7.0.0/16</td>
<td>R1 → R3</td>
<td>15</td>
</tr>
<tr>
<td>10.8.0.0/16</td>
<td>R1 → R3 → R4</td>
<td>17</td>
</tr>
<tr>
<td>10.9.0.0/16</td>
<td>R1 → R2</td>
<td>30</td>
</tr>
<tr>
<td>10.10.0.0/16</td>
<td>R1 → R3 → R4</td>
<td>25</td>
</tr>
<tr>
<td>10.11.0.0/16</td>
<td>R1 → R3 → R4 → R5</td>
<td>27</td>
</tr>
</tbody>
</table>
## Link-State Updates

### Adding OSPF Routes to the Routing Table

#### Populate the Routing Table

<table>
<thead>
<tr>
<th>Destination</th>
<th>Shortest Path</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.5.0.0/16</td>
<td>R1 → R2</td>
<td>22</td>
</tr>
<tr>
<td>10.6.0.0/16</td>
<td>R1 → R3</td>
<td>7</td>
</tr>
<tr>
<td>10.7.0.0/16</td>
<td>R1 → R3</td>
<td>15</td>
</tr>
<tr>
<td>10.8.0.0/16</td>
<td>R1 → R3 → R4</td>
<td>17</td>
</tr>
<tr>
<td>10.9.0.0/16</td>
<td>R1 → R2</td>
<td>30</td>
</tr>
<tr>
<td>10.10.0.0/16</td>
<td>R1 → R3 → R4</td>
<td>25</td>
</tr>
<tr>
<td>10.11.0.0/16</td>
<td>R1 → R3 → R4 → R5</td>
<td>27</td>
</tr>
</tbody>
</table>

#### R1 Routing Table

- **Directly Connected Networks**
  - 10.1.0.0/16 Directly Connected Network
  - 10.2.0.0/16 Directly Connected Network
  - 10.3.0.0/16 Directly Connected Network
  - 10.4.0.0/16 Directly Connected Network

- **Remote Networks**
  - 10.5.0.0/16 via R2 serial 0/0/0, cost=22
  - 10.6.0.0/16 via R3 serial 0/0/1, cost=7
  - 10.7.0.0/16 via R3 serial 0/0/1, cost=15
  - 10.8.0.0/16 via R3 serial 0/0/1, cost=17
  - 10.9.0.0/16 via R2 serial 0/0/0, cost=30
  - 10.10.0.0/16 via R3 serial 0/0/1, cost=25
  - 10.11.0.0/16 via R3 serial 0/0/1, cost=27
Why Use Link-State Routing Protocols

Why Use Link-State Protocols?

Advantages of Link-State Routing Protocols

- Each router builds its own topological map of the network to determine the shortest path.
- Immediate flooding of LSPs achieves faster convergence.
- LSPs are sent only when there is a change in the topology and contain only the information regarding that change.
- Hierarchical design used when implementing multiple areas.

Disadvantages compared to distance vector routing protocols:

- Memory Requirements
- Processing Requirements
- Bandwidth Requirements
Why Use Link-State Routing Protocols

Disadvantages of Link-State Protocols

Create Areas to Minimize Router Resource Usage

- LSP not flooded to these areas. SPF algorithm does not have to be rerun in these areas.
- LSP flooded only within this area
- Rerun SPF algorithm
The Routing Table
Parts of an IPv4 Route Entry

Routing Table Entries

Routing Table of R1

```
R1#show ip route | begin Gateway
Gateway of last resort is 209.165.200.234 to network 0.0.0.0
S* 0.0.0.0/0 [1/0] via 209.165.200.234, Serial0/0/1
    is directly connected, Serial0/0/1
    172.16.0.0/16 is variably subnetted, 5 subnets, 3 masks
C 172.16.1.0/24 is directly connected, GigabitEthernet0/0
L 172.16.1.1/32 is directly connected, GigabitEthernet0/0
R 172.16.2.0/24 [120/1] via 209.165.200.226, 00:00:12, Serial0/0/0
R 172.16.3.0/24 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
R 172.16.4.0/28 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
R 192.168.0.0/16 [120/2] via 209.165.200.226, 00:00:03, Serial0/0/0
    209.165.200.0/24 is variably subnetted, 5 subnets, 2 masks
C 209.165.200.224/30 is directly connected, Serial0/0/0
L 209.165.200.225/32 is directly connected, Serial0/0/0
R 209.165.200.228/30 [120/1] via 209.165.200.226, 00:00:12,
    Serial0/0/0
C 209.165.200.232/30 is directly connected, Serial0/0/1
L 209.165.200.233/30 is directly connected, Serial0/0/1
```
### Parts of an IPv4 Route Entry

#### Directly Connected Entries

#### Directly Connected Interfaces of R1

```bash
R1# show ip route | begin Gateway
Gateway of last resort is 209.165.200.234 to network 0.0.0.0

S* 0.0.0.0/0 [1/0] via 209.165.200.234, Serial0/0/1
    is directly connected, Serial0/0/1
    172.16.0.0/16 is variably subnetted, 5 subnets, 3 masks
C 172.16.1.0/24 is directly connected, GigabitEthernet0/0
L 172.16.1.1/32 is directly connected, GigabitEthernet0/0
R 172.16.2.0/24 [120/1] via 209.165.200.226, 00:00:12, Serial0/0/0
R 172.16.3.0/24 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
R 172.16.4.0/28 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
R 192.168.0.0/16 [120/2] via 209.165.200.226, 00:00:03, Serial0/0/0
    209.165.200.24 is variably subnetted, 5 subnets, 2 masks
C 209.165.200.224/30 is directly connected, Serial0/0/0
L 209.165.200.225/32 is directly connected, Serial0/0/0
R 209.165.200.228/30 [120/1] via 209.165.200.226, 00:00:12, Serial0/0/0
C 209.165.200.232/30 is directly connected, Serial0/0/1
L 209.165.200.233/32 is directly connected, Serial0/0/1
R1$
```
Parts of an IPv4 Route Entry

Remote Network Entries

Route source
Administrative distance
Next-hop
Outgoing interface

Destination network
Metric
Route timestamp

R 172.16.4.0/28 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
Dynamically Learned IPv4 Routes
Routing Table Terms

Routes are discussed in terms of:
- Ultimate route
- Level 1 route
- Level 1 parent route
- Level 2 child routes
Dynamically Learned IPv4 Routes

Ultimate Route

An ultimate route is a routing table entry that contains either a next-hop IP address or an exit interface. Directly connected, dynamically learned are ultimate routes.
Dynamically Learned IPv4 Routes
Level 1 Route

Sources of Level 1 Routes

- Network: 192.168.1.0/24
- Supernet: 192.168.0.0/16
- Default: 0.0.0.0/0

Next-hop IP address and/or exit interface:
- Path/Interface
Dynamically Learned IPv4 Routes

Level 1 Parent Route

Level 1 Parent Routes of R1

```
R1# show ip route | begin Gateway
Gateway of last resort is 209.165.200.234 to network 0.0.0.0
S* 0.0.0.0/0 [1/0] via 209.165.200.234, Serial0/0/1
    is directly connected, Serial0/0/1
    172.16.0.0/16 is variably subnetted, 5 subnets, 3 masks
    C  172.16.1.0/24 is directly connected, GigabitEthernet0/0
    L  172.16.1.1/32 is directly connected, GigabitEthernet0/0
    R  172.16.2.0/24 [120/1] via 209.165.200.226, 00:00:12, Serial0/0/0
    R  172.16.3.0/24 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
    R  172.16.4.0/28 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
    R  192.168.0.0/16 [120/2] via 209.165.200.226, 00:00:03, Serial0/0/0
    209.165.200.0/24 is variably subnetted, 5 subnets, 2 masks
    C  209.165.200.224/30 is directly connected, Serial0/0/0
```
Dynamically Learned IPv4 Routes
Level 2 Child Route

Example of Level 2 Child Routes

```
R1#show ip route | begin Gateway
Gateway of last resort is 209.165.200.234 to network 0.0.0.0
S* 0.0.0.0/0 [1/0] via 209.165.200.234, Serial0/0/1
    is directly connected, Serial0/0/1
    172.16.0.0/16 is variably subnetted, 5 subnets, 3
    masks
C 172.16.1.0/24 is directly connected, GigabitEthernet0/0
L 172.16.1.1/32 is directly connected, GigabitEthernet0/0
R 172.16.2.0/24 [120/1] via 209.165.200.226, 00:00:12, Serial0/0/0
R 172.16.3.0/24 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
R 172.16.4.0/28 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
R 192.168.0.0/16 [120/2] via 209.165.200.226, 00:00:03, Serial0/0/0
    209.165.200.0/24 is variably subnetted, 5 subnets, 2
    masks
C 209.165.200.224/30 is directly connected, Serial0/0/0
```
The IPv4 Route Lookup Process

**Best Route = Longest Match**

Matches for Packet Destined to 172.16.0.10

<table>
<thead>
<tr>
<th>IP Packet Destination</th>
<th>172.16.0.10</th>
<th>10101100.00010000.00000000.00001010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route 1</td>
<td>172.16.0.0/12</td>
<td>10101100.00010000.00000000.00000000</td>
</tr>
<tr>
<td>Route 2</td>
<td>172.16.0.0/18</td>
<td>10101100.00010000.00000000.00000000</td>
</tr>
<tr>
<td>Route 3</td>
<td>172.16.0.0/26</td>
<td>10101100.00010000.00000000.00000000</td>
</tr>
</tbody>
</table>
Single-Area OSPF

Routing Protocols
## Open Shortest Path First

### Evolution of OSPF

**Interior Gateway Protocols**

<table>
<thead>
<tr>
<th>Interior Gateway Protocols</th>
<th>Distance Vector</th>
<th>Link-State</th>
<th>Exterior Gateway Protocols</th>
<th>Path Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPv4</td>
<td>RIPv2</td>
<td>EIGRP</td>
<td>OSPFv2</td>
<td>IS-IS</td>
</tr>
<tr>
<td>IPv6</td>
<td>RIPng</td>
<td>EIGRP for IPv6</td>
<td>OSPFv3</td>
<td>IS-IS for IPv6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BGP-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BGP-MP</td>
</tr>
</tbody>
</table>

- **1988**
- **Updated in 2008**
Open Shortest Path First

Features of OSPF

Classless

Efficient

Secure

Fast Convergence

Scalable
## Open Shortest Path First

### Components of OSPF

#### OSPF Data Structures

<table>
<thead>
<tr>
<th>Database</th>
<th>Table</th>
<th>Description</th>
</tr>
</thead>
</table>
| Adjacency Database        | Neighbor Table | • List of all neighbor routers to which a router has established bidirectional communication.  
                            |                | • This table is unique for each router.                                       
                            |                | • Can be viewed using the `show ip ospf neighbor` command.                   |
| Link-state Database (LSDB)| Topology Table | • Lists information about all other routers in the network.                 
                            |                | • The database shows the network topology.                                   
                            |                | • All routers within an area have identical LSDB.                           
                            |                | • Can be viewed using the `show ip ospf database` command.                  |
| Forwarding Database       | Routing Table  | • List of routes generated when an algorithm is run on the link-state database.  
                            |                | • Each router’s routing table is unique and contains information on how and where to send packets to other routers.  
                            |                | • Can be viewed using the `show ip route` command.                          |

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Open Shortest Path First

Components of OSPF

OSPF Routers Exchange Packets - These packets are used to discover neighboring routers and also to exchange routing information to maintain accurate information about the network.
If a neighbor is present, the OSPF-enabled router attempts to establish a neighbor adjacency with that neighbor.
Open Shortest Path First

Link-State Operation

- LSAs contain the state and cost of each directly connected link.
- Routers flood their LSAs to adjacent neighbors.
- Adjacent neighbors receiving the LSA immediately flood the LSA to other directly connected neighbors, until all routers in the area have all LSAs.
Open Shortest Path First
Link-State Operation

- Build the topology table based on the received LSAs.
- This database eventually holds all the information about the topology of the network.
- Execute the SPF Algorithm.
From the SPF tree, the best paths are inserted into the routing table.
Open Shortest Path First

Single-area and Multiarea OSPF

Single-Area OSPF

- Area 0 is also called the backbone area.
- Single-area OSPF is useful in smaller networks with few routers.

Multiarea OSPF

- Implemented using a two-layer area hierarchy as all areas must connect to the backbone area (area 0).
- Interconnecting routers are called Area Border Routers (ABR).
- Useful in larger network deployments to reduce processing and memory overhead.
Open Shortest Path First
Single-area and Multiarea OSPF

Link Change Impacts Local Area Only

- Link failure affects the local area only (area 51).
- The ABR (R2) isolates the fault to area 51 only.
- Routers in areas 0 and 1 do not need the run the SPF algorithm.
### OSPF Messages

#### Encapsulating OSPF Messages

<table>
<thead>
<tr>
<th>Data Link Frame Header</th>
<th>IP Packet Header</th>
<th>OSPF Packet Header</th>
<th>OSPF Packet Type-Specific Database</th>
</tr>
</thead>
</table>

**Data Link Frame (Ethernet Fields shown here)**
- MAC Destination Address = Multicast: 01-00-5E-00-00-05 or 01-00-5E-00-00-06
- MAC Source Address = Address of sending interface

**IP Packet**
- IP Source Address = Address of sending interface
- IP Destination Address = Multicast: 224.0.0.5 or 224.0.0.6
- Protocol field = 89 for OSPF

**OSPF Packet Header**
- Type code for OSPF Packet type
- Router ID and Area Id

**OSPF Packet types**
- 0x01 Hello
- 0x02 Database Description (DD)
- 0x03 Link State Request
- 0x04 Link State Update
- 0x05 Link State Acknowledgment
### OSPF Messages

#### Types of OSPF Packets

<table>
<thead>
<tr>
<th>Type</th>
<th>Packet Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hello</td>
<td>Discovers neighbors and builds adjacencies between them</td>
</tr>
<tr>
<td>2</td>
<td>Database Description (DBD)</td>
<td>Checks for database synchronization between routers</td>
</tr>
<tr>
<td>3</td>
<td>Link-State Request (LSR)</td>
<td>Requests specific link-state records from router to router</td>
</tr>
<tr>
<td>4</td>
<td>Link-State Update (LSU)</td>
<td>Sends specifically requested link-state records</td>
</tr>
<tr>
<td>5</td>
<td>Link-State Acknowledgment (LSAack)</td>
<td>Acknowledges the other packet types</td>
</tr>
</tbody>
</table>
OSPF Messages
Hello Packet

OSPF Type 1 packet = Hello packet

- Discover OSPF neighbors and establish neighbor adjacencies
- Advertise parameters on which two routers must agree to become neighbors
- Elect the Designated Router (DR) and Backup Designated Router (BDR) on multiaccess networks like Ethernet.
OSPF Messages

Hello Packet

[Diagram of OSPF Hello Packet Content]

- Date Link Frame Header
- IP Packet Header
- OSPF Packet Header
- OSPF Packet Type-Specific Data

<table>
<thead>
<tr>
<th>Bit(s):</th>
<th>0</th>
<th>7</th>
<th>8</th>
<th>15</th>
<th>16</th>
<th>23</th>
<th>24</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Version</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Type = 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packet Length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Router ID</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area ID</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Checksum</td>
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</tr>
<tr>
<td>AuType</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Authentication</td>
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<tr>
<td>Authentication</td>
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<td></td>
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</tr>
<tr>
<td>Network Mask</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hello Interval</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Option</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Router Priority</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dead Interval</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designated Router (DR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backup Designated Router (BDR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>List of Neighbor(s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
OSPF Messages

Hello Packet Intervals

OSPF Hello packets are transmitted
- To 224.0.0.5 in IPv4
- Every 10 seconds (default on multiaccess and point-to-point networks)
- Every 30 seconds (default on non-broadcast multiaccess [NBMA] networks)
- Dead interval is the period that the router waits to receive a Hello packet before declaring the neighbor down
- Router floods the LSDB with information about down neighbors out all OSPF enabled interfaces
- Cisco’s default is 4 times the Hello interval
OSPF Messages

Link-State Updates

**LSUs Contain LSAs**

<table>
<thead>
<tr>
<th>Type</th>
<th>Packet Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>5</td>
<td>LSAck</td>
<td>Acknowledges the other packet types</td>
</tr>
</tbody>
</table>

- An LSU contains one or more LSAs.
- LSAs contain route information for destination networks.

**LSA Type**

<table>
<thead>
<tr>
<th>LSA Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Router LSAs</td>
</tr>
<tr>
<td>2</td>
<td>Network LSAs</td>
</tr>
<tr>
<td>3 or 4</td>
<td>Summary LSAs</td>
</tr>
<tr>
<td>5</td>
<td>Autonomous System External LSAs</td>
</tr>
<tr>
<td>6</td>
<td>Multicast OSPF LSAs</td>
</tr>
<tr>
<td>7</td>
<td>Defined for Not-So-Stubby Areas</td>
</tr>
<tr>
<td>8</td>
<td>External Attributes LSA for Border Gateway Protocol (BGP)</td>
</tr>
<tr>
<td>9,10,11</td>
<td>Opaque LSAs</td>
</tr>
</tbody>
</table>
OSPF Operation

OSPF Operational States

When an OSPF router is initially connected to a network, it attempts to:
- Create adjacencies with neighbors
- Exchange routing information
- Calculate the best routes
- Reach convergence
- OSPF progresses through several states while attempting to reach convergence.
OSPF Operation

Establish Neighbor Adjacencies

Down State to Init State

Down State

Init State

Hello! My router ID is 172.16.5.1. Is there anyone else on this link?

Hello

The Init State

Hello! My router ID is 172.16.5.2 and here is my neighbor list.

Hello

R2 neighbor list: 172.16.5.1, int G0/1

Unicast to 172.16.5.1
OSPF Operation

Establish Neighbor Adjacencies

DR and BDR election only occurs on multi-access networks such as Ethernet LANs.
Creating Adjacencies With Every Neighbor

Number of Adjacencies = \( n(n-1)/2 \)

- \( n = \) number of routers

Example: 5 routers, \( (5-1)/2 = 10 \) adjacencies
OSPF Operation

Synchronizing OSPF Database

Decide Which Router Sends the First DBD

R2 has the highest router ID, becoming the master, and therefore it prepares to send a LSDB in a DBD packet.
OSPF Operation

Synchronizing OSPF Database

Exchange DBD Packets

Here is a summary of my link-state database.

Thanks for the information!

Here is a summary of my link-state database.

Thanks for the information!
8.2 Configuring Single-area OSPFv2
OSPF Router ID

OSPF Network Topology

Entering Router OSPF Configuration Mode on R1

```
R1(config)# router ospf 10
R1(config-router)# ?
Router configuration commands:
    auto-cost Calculate OSPF interface cost
        according to bandwidth
    network Enable routing on an IP network
    no Negate a command or set its defaults
    passive-interface Suppress routing updates on an
        interface
    priority OSPF topology priority
    router-id router-id for this OSPF process
```

**Note:** Output has been altered to display only the commands that will be used in this chapter.
OSPF Router ID

Router IDs

Router ID Order of Precedence

- **Router ID explicitly configured?**
  - Yes: Use that as the router ID.
  - No: Proceed to the next step.

- **Loopback interface configured?**
  - Yes: Proceed to the next step.
  - No: Use the highest active configured IP address.

Clearing the OSPF Process

- **R1# clear ip ospf process**
  - Reset ALL OSPF processes?
    - [no]: y
  - Yes: Clear the OSPF process.
  - No: Continue with the current process.

Example Configuration:

```
R1(config)# router ospf 10
R1(config-router)# router-id 1.1.1.1
% OSPF: Reload or use "clear ip ospf process" command, for this to take effect.
R1(config-router)# end

R1(config)# interface loopback 0
R1(config-if)# ip address 1.1.1.1 255.255.255.255
R1(config-if)# end
R1# *Mar 25 19:46:22.423: %OSPF-5-ADJCHG: Process 10, Nbr 1.1.1.3 on Serial0/0/1 from FULL to DOWN, Neighbor Down: Interface down or detached
*Mar 25 19:46:22.423: %OSPF-5-ADJCHG: Process 10, Nbr 2.2.2.2 on Serial0/0/0 from FULL to DOWN, Neighbor Down: Interface down or detached
```
Configure Single-area OSPFv2

The network Command

Assigning Interfaces to an OSPF Area

```
R1(config)# router ospf 10
R1(config-router)# network 172.16.1.0 0.0.0.255 area 0
R1(config-router)# network 172.16.3.0 0.0.0.3 area 0
R1(config-router)# network 192.168.10.4 0.0.0.3 area 0
R1(config-router)#
R1#
```

Assigning Interfaces to an OSPF Area with a Quad Zero

```
R1(config)# router ospf 10
R1(config-router)# network 172.16.1.1 0.0.0.0 area 0
R1(config-router)# network 172.16.3.1 0.0.0.0 area 0
R1(config-router)# network 192.168.10.5 0.0.0.0 area 0
R1(config-router)#
R1#```
Configure Single-area OSPFv2

Configuring Passive Interfaces

Use the `passive-interface` router configuration mode command to prevent the transmission of routing messages through a router interface, but still allow that network to be advertised to other routers.
OSPF Cost

OSPF Metric = Cost

Cost = \textit{reference bandwidth} / \textit{interface bandwidth}
(default reference bandwidth is $10^8$)

Cost = 100,000,000 bps / \textit{interface bandwidth in bps}

Default Cisco OSPF Cost Values

<table>
<thead>
<tr>
<th>Interface Type</th>
<th>Reference Bandwidth in bps</th>
<th>Default Bandwidth in bps</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gigabit Ethernet 10 Gbps</td>
<td>100,000,000</td>
<td>10,000,000,000</td>
<td>1</td>
</tr>
<tr>
<td>Gigabit Ethernet 1 Gbps</td>
<td>100,000,000</td>
<td>1,000,000,000</td>
<td>1</td>
</tr>
<tr>
<td>Fast Ethernet 100 Mbps</td>
<td>100,000,000</td>
<td>100,000,000</td>
<td>1</td>
</tr>
<tr>
<td>Ethernet 10 Mbps</td>
<td>100,000,000</td>
<td>10,000,000</td>
<td>10</td>
</tr>
<tr>
<td>Serial 1.544 Mbps</td>
<td>100,000,000</td>
<td>1,544,000</td>
<td>64</td>
</tr>
<tr>
<td>Serial 128 kbps</td>
<td>100,000,000</td>
<td>128,000</td>
<td>781</td>
</tr>
<tr>
<td>Serial 64 kbps</td>
<td>100,000,000</td>
<td>64,000</td>
<td>1562</td>
</tr>
</tbody>
</table>
OSPF Cost

OSPF Accumulates Costs

Cost of an OSPF route is the accumulated value from one router to the destination network.
OSPF Cost

Adjusting the Reference Bandwidth

- Use the command `- auto-cost reference-bandwidth`
- Must be configured on every router in the OSPF domain
- Notice that the value is expressed in Mb/s:
  - Gigabit Ethernet - auto-cost reference-bandwidth 1000
  - 10 Gigabit Ethernet - auto-cost reference-bandwidth 10000

Verifying the S0/0/0 Link Cost

```bash
RI$ show ip ospf interface serial 0/0/0
Serial0/0/0 is up, line protocol is up
Internet Address 172.16.3.1/30, Area 0, Attached via Network Statement
Process ID 10, Router ID 1.1.1.1, Network Type POINT_TO_POINT, Cost:647
Topology-NTID Cost Disabled Shutdown Topol 0 647 no no
Transmit Delay is 1 sec, State POINT_TO_POINT
Timer intervals configured, Hello 10, Dead 40, Wait 40,
oob-resync timeout 40
Hello due in 00:00:01
Supports Link-local Signaling (LLS)
Cisco NSF helper support enabled
IETF NSF helper support enabled
Index 3/3, flood queue length 0
Next Ox0(0)/0x0(0)
Last flood scan length is 1, maximum is 1
Last flood scan time is 0 msec, maximum is 0 msec
Neighbor Count is 1, Adjacent neighbor count is 1
  Adjacent with neighbor 2.2.2.2
  Suppress hello for 0 neighbor(s)
RI$
```

Verifying the Metric to the R2 LAN

```bash
RI$ show ip route | include 172.16.2.0
0 172.16.2.0/24 [110/648] via 172.16.3.2, 00:06:03, Serial0/0/0
RI$
RI$ show ip route 172.16.2.0
Routing entry for 172.16.2.0/24
  Known via "ospf 10", distance 110, metric 648, type intra area
  Last update from 172.16.3.2 on Serial0/0/0, 00:06:17 ago
  Routing Descriptor Blocks:
    * 172.16.3.2, from 2.2.2.2, 00:06:17 ago, via Serial0/0/0
  Route metric is 648, traffic share count is 1
RI$
RI$
```
OSPF Cost

Default Interface Bandwidths

On Cisco routers, the default bandwidth on most serial interfaces is set to 1.544 Mb/s.
OSPФ Cost

Adjusting the Interface Bandwidths

Adjusting the R1 Serial 0/0/1 Interface

R1(config)# int s0/0/1
R1(config-if)# bandwidth 64
R1(config-if)# end
R1#  
*Mar 27 10:10:07.735: %SYS-5-CONFIG_I: Configured from console by c
R1#  
R1# show interfaces serial 0/0/1 | include BW
   MTU 1500 bytes, BW 64 Kbit/sec, DLY 20000 usec,
R1#  
R1# show ip ospf interface serial 0/0/1 | include Cost:
   Process ID 10, Router ID 1.1.1.1, Network Type
   POINT_TO_POINT, Cost: 15625
R1#
OSPF Cost

Manually Setting the OSPF Cost

Both the **bandwidth** interface command and the **ip ospf cost** interface command achieve the same result, which is to provide an accurate value for use by OSPF in determining the best route.

```
R1(config)# int s0/0/1
R1(config-if)# no bandwidth 64
R1(config-if)# ip ospf cost 15625
R1(config-if)# end
R1#
R1# show interface serial 0/0/1 | include BW
MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,

R1#
R1# show ip ospf interface serial 0/0/1 | include Cost:
Process ID 10, Router ID 1.1.1.1, Network Type POINT_TO_POINT,
Cost: 15625
R1#
```
Verify OSPF Neighbors

Verify that the router has formed an adjacency with its neighboring routers

```
R1# show ip ospf neighbor

+------------+-----+--------+-------------+---------------+----------+
<table>
<thead>
<tr>
<th>Neighbor ID</th>
<th>Pri</th>
<th>State</th>
<th>Dead Time</th>
<th>Address</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3.3.3</td>
<td>0</td>
<td>FULL/-</td>
<td>00:00:37</td>
<td>192.168.10.6</td>
<td>Serial0/0/1</td>
</tr>
<tr>
<td>2.2.2.2</td>
<td>0</td>
<td>FULL/-</td>
<td>00:00:30</td>
<td>172.16.3.2</td>
<td>Serial0/0/0</td>
</tr>
<tr>
<td>R1#</td>
<td></td>
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</tr>
</tbody>
</table>
```
Verify OSPF

Verify OSPF Protocol Settings

Verifying R1’s OSPF Neighbors

R1# `show ip protocols`
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 10"
Outgoing update filter list for all interfaces is not set
Incoming update filter list for all interfaces is not set
Router ID 1.1.1.1
Number of areas in this router is 1, 1 normal 0 stub 0 nssa
Maximum path: 4
Routing for Networks:
  172.16.1.0 0.0.0.255 area 0
  172.16.3.0 0.0.0.3 area 0
  192.168.10.4 0.0.0.3 area 0
Routing Information Sources:
  Gateway     Distance     Last Update
  2.2.2.2      110         00:17:18
  3.3.3.3      110         00:14:49
Distance: (default is 110)

R1#
Verify OSPF
Verify OSPF Interface Settings

Verifying R1’s OSPF Interfaces

```
R1# show ip ospf interface brief
  Interface  PID  Area  IP Address/Mask    Cost  State  Nbrs F/C
  Se0/0/1    10    0     192.168.10.5/30  15625  P2P    1/1
  Se0/0/0    10    0     172.16.3.1/30   647    P2P    1/1
  G10/0      10    0     172.16.1.1/24   1      DR     0/0
R1#
```