



## Foreword

- Static routes are manually configured. If a network topology changes, static routes have to be manually adjusted, which restricts the large-scale application of static routes on the live network.
- Dynamic routing protocols are widely used on live networks because of their high flexibility, high reliability, and easy scalability. The Open Shortest Path First (OSPF) protocol is a widely used dynamic routing protocol.
- This course describes basic concepts, working mechanism, and basic configurations of OSPF.

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## Objectives

- On completion of this course, you will be able to:
  - Describe the advantages and classification of dynamic routing protocols.
  - Describe basic OSPF concepts and usage scenarios.
  - Describe the working mechanism of OSPF.
  - Implement basic OSPF configurations.

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## Contents

- OSPF Overview
- OSPF Working Mechanism
- Typical OSPF Configuration

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## Why Are Dynamic Routing Protocol Used?

- Static routes are manually configured and maintained, and the command lines are simple and clear. They apply to small-scale or stable networks. Static routes have the following disadvantages:
  - Unable to adapt to large-scale networks: As the number of devices increases, the configuration workload increases sharply.
  - Unable to dynamically respond to network changes: If the network topology changes, the network cannot automatically converge, and static routes must be manually modified.

The diagram shows two network states. On the left, three routers (R1, R2, R3) are connected in a triangle. A blue double-headed arrow connects R1 and R2, labeled "R1-to-R2 static route". On the right, the same topology is shown, but the link between R1 and R2 is broken, indicated by a red lightning bolt and a red "X". A blue arrow points from the left state to the right state, labeled "Link fault". Below the right state, the text "Manually configured static route R1-R3-R2" is displayed.

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## Classification of Dynamic Routing Protocols

By ASs

- Interior Gateway Protocols (IGPs)
  - RIP
  - OSPF
  - IS-IS
- Exterior Gateway Protocols (EGPs)
  - BGP

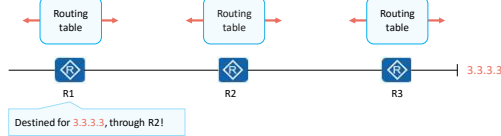
By working mechanisms and algorithms

- Distance Vector Routing Protocols
  - RIP
- Link-State Routing Protocols
  - OSPF
  - IS-IS

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## Distance-Vector Routing Protocol

- A router running a distance-vector routing protocol periodically floods routes. Through route exchange, each router learns routes from neighboring routers and installs the routes into its routing table.
- Each router on a network is clear only about where the destination is and how far the destination is, but unclear about the whole network topology. This is the essence of the distance-vector algorithm.

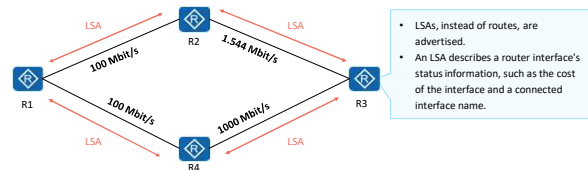


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## Link-State Routing Protocol - LSA Flooding

- Different from a distance-vector routing protocol, a link-state routing protocol advertises link status information rather than routes in the routing table. Routers that run a link-state routing protocol establish a neighbor relationship and then exchange Link State Advertisements (LSAs).

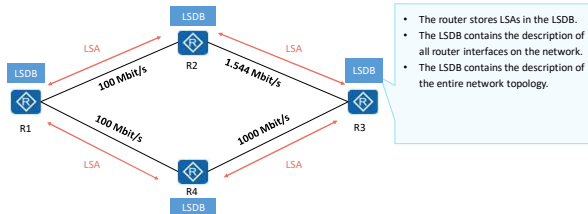


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## Link-State Routing Protocol - LSDB Creation

- Each router generates LSAs and adds the received LSAs to its own link state database (LSDB). Routers learn the whole network topology through the LSDB.

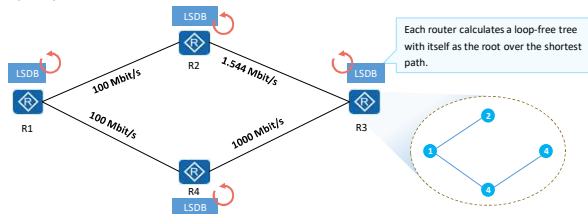


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## Link-State Routing Protocol - SPF Calculation

- Each router uses the Shortest Path First (SPF) algorithm and LSDB information to calculate routes. Each router calculates a loop-free tree with itself as the root and the shortest path. With this tree, a router determines the optimal path to each corner of a network.

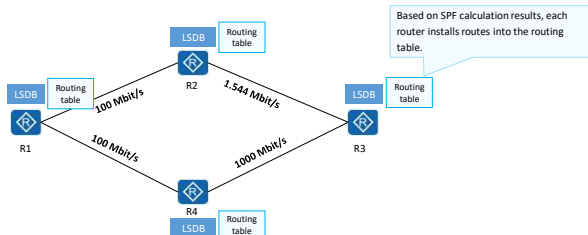


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## Link-State Routing Protocol - Routing Table Generation

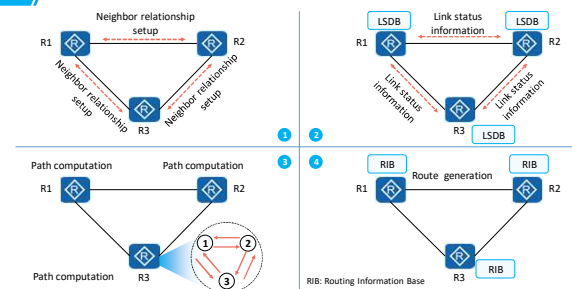
- Ultimately, the router installs routes for the calculated preferred paths into its routing table.



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## Summary of Link-State Routing Protocols



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## Introduction to OSPF

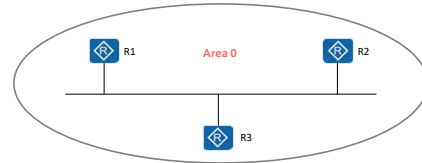
- OSPF is a typical link-state routing protocol and one of the widely used IGP's in the industry.
- OSPFv2, as defined in RFC 2328, is designed for IPv4. OSPFv3, as defined in RFC 2740, is designed for IPv6. Unless otherwise specified, OSPF in this presentation refers to OSPFv2.
- OSPF routers exchange link status information, but not routes. Link status information is key information for OSPF to perform topology and route calculation.
- An OSPF router collects link status information on a network and stores the information in the LSDB. Routers are aware of the intra-area network topology and are able to calculate loop-free paths.
- Each OSPF router uses the SPF algorithm to calculate the shortest path to a specific destination. Routers generate routes based on these paths and install the routes to the routing table.
- OSPF supports the variable length subnet mask (VLSM) mechanism and manual route summarization.
- The multi-area design enables OSPF to support a larger network.

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## Basic OSPF Concepts: Area

- The OSPF area keyword identifies an OSPF area.
- The area is considered as a logical group, and each group is identified by an area ID.

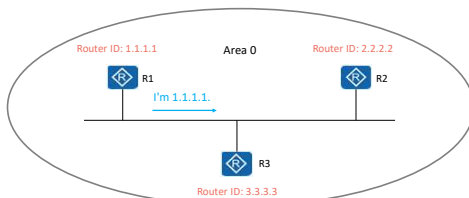


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## Basic OSPF Concepts: Router ID

- A router ID uniquely identifies a router in an OSPF area.
- The router ID can be manually specified or automatically assigned by the system.

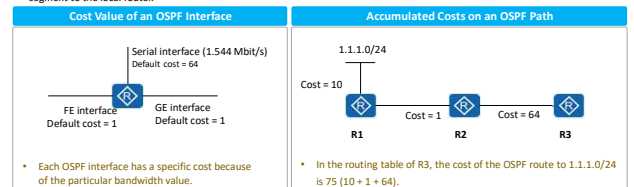


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## Basic OSPF Concepts: Cost Value

- OSPF uses costs as route metric values. Each OSPF-enabled interface maintains a cost value. Default cost value =  $\frac{100 \text{ Mbit/s}}{\text{interface bandwidth}}$ , where, 100 Mbit/s is the default reference value specified by OSPF and is configurable.
- Generally, the cost of an OSPF route is the sum of costs of all inbound interfaces along a path from the destination network segment to the local router.



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## OSPF Packet Types

- There are five types of OSPF protocol packets and implement different functions in interaction between OSPF routers.

Packet Name	Function
Hello	Is periodically sent to discover and maintain OSPF neighbor relationships.
Database Description	Describes the summary of the local LSDB, which is used to synchronize the LSDBs of two devices.
Link State Request	Requests a needed LSA from a neighbor. LSRs are sent only after DD packets have been successfully exchanged.
Link State Update	Is sent to advertise a requested LSA to a neighbor.
Link State ACK	Is used to acknowledge the receipt of an LSA.

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## Three Types of OSPF Entries - Entries in the Neighbor Table

- OSPF provides entries in three important tables: OSPF neighbor table, LSDB table, and OSPF routing table. For the OSPF neighbor table, you need to know:
  - Before OSPF transmits link status information, OSPF neighbor relationships must be established.
  - OSPF neighbor relationships are established by exchanging Hello packets.
  - The OSPF neighbor table describes the status of the neighbor relationship between OSPF routers. You can run the **display ospf peer** command to view status information.



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## Three Types OSPF Entries - Entries in the LSDB Table

- For the OSPF LSDB table, you need to know:
  - An LSDB stores LSAs generated by a router itself and received from neighbors. In this example, the LSDB of R1 contains three LSAs.
  - The **Type** field indicates an LSA type, and the **AdvRouter** field indicates the router that sends the LSA.
  - Run the **display ospf lsdb** command to query the LSDB.

```

<R1> display ospf lsdb
OSPF Process 1 with Router ID 1.1.1.1
Link State Database
Router ID: 0.0.0.0
Type LinkState ID AdvRouter Age Len Sequence Metric
Router 2.2.2.2 2.2.2.2 98 36 80000008 1
Router 1.1.1.1 1.1.1.1 92 36 80000005 1
Network 10.1.1.2 2.2.2.2 98 32 80000004 0
  
```

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## Three Types of OSPF Entries - Entries in the OSPF Routing Table

- For the OSPF routing table, you need to know:
  - The OSPF routing table and the router routing table are different. In this example, the OSPF routing table contains three routes.
  - An OSPF routing table contains information, such as the destination IP address, cost, and next-hop IP address, which guides packet forwarding.
  - Run the **display ospf routing** command to query the OSPF routing table.

```

<R1> display ospf routing
OSPF Process 1 with Router ID 1.1.1.1
Routing Tables
Routing for Network
Destination Cost Type NextHop AdvRouter Area
1.1.1.1/32 0 stub 1.1.1.1 1.1.1.1 0.0.0.0
10.1.1.0/20 1 Transit 10.1.1.1 1.1.1.1 0.0.0.0
2.2.2.2/32 1 stub 10.1.1.2 2.2.2.2 0.0.0.0
Total Nets: 3
Intra Area: 3 Inter Area: 0 ASE: 0 NSSA: 0
  
```

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## Contents

- OSPF Overview
- OSPF Working Mechanism**
- Typical OSPF Configuration

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## Relationships Between OSPF Routers

- There are two important concepts about the relationship between OSPF routers: neighbor relationship and adjacency.
- On a simple network, two routers are directly connected. OSPF is enabled on interconnected interfaces. The routers start to send and listen to Hello packets. After the two routers discover each other through Hello packets, they establish a neighbor relationship.
- The establishment of a neighbor relationship is just the beginning. A series of packets, such as DD, LSR, LSU, and LSack packets, will be exchanged later. When LSDB synchronization between two routers is complete and the two routers start to calculate routes independently, the two routers establish an adjacency.

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## Process of Establishing an OSPF Adjacency Relationship

- OSPF adjacency relationship establishment involves four steps: establishing a neighbor relationship, negotiating the master/slave status, exchanging LSDB information, and synchronizing LSDBs.

Steps 1 to 4 involve interaction between both ends, and Step 5 is performed separately on each device.

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## Review of the OSPF Neighbor Table

```

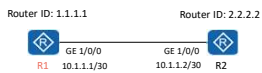
<R1> display ospf peer
OSPF Process 1 with Router ID 1.1.1.1
Neighbors
Area 0.0.0.0 Interface 10.1.1.1[GigabitEthernet1/0/0]'s neighbors
Area 2.2.2.2 Address: 10.1.1.2 GR State: Normal
State: Full Mode:Nbr is Master Priority: 1
DR: 10.1.1.1 BDR: 10.1.1.2 MTU: 0
Dead timer due in 35 sec
Retrans timer interval: 5
Neighbor is up for 00:00:05
Authentication Sequence: [ 0 ]
  
```

Quiz: What is the DR/BDR in the neighbor table?

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## OSPF Network Types

- Before learning concepts of the DR and BDR, understand OSPF network types.
- The OSPF network type is a very important interface variable. This variable affects OSPF operations on interfaces. For example, it determines how to send OSPF packets and whether to elect a DR or BDR.
- The default OSPF network type of an interface depends on the data link layer encapsulation used by the interface.
- As shown in the figure, OSPF has four network types: broadcast, NBMA, P2MP, and P2P.



[R1-GigabitEthernet1/0/0] ospf network-type ?

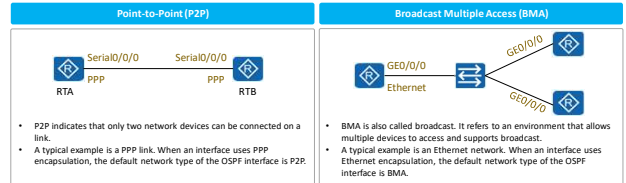
- broadcast** Specify OSPF broadcast network
- nbma** Specify OSPF NBMA network
- p2mp** Specify OSPF point-to-multipoint network
- p2p** Specify OSPF point-to-point network

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## OSPF Network Types (1)

- Generally, the network types of OSPF interfaces at both ends of a link must be the same. Otherwise, the two interfaces cannot establish a neighbor relationship.
- An OSPF network type can be manually changed on an interface to adapt to different network scenarios. For example, you can change the BMA network type to P2P.



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## OSPF Network Types (2)

### Non-Broadcast Multiple Access (NBMA)



- NBMA refers to an environment that allows multiple network devices to access but does not support broadcast.
- A typical example is a Frame Relay (FR) network.

### Point-to-Multipoint (P2MP)



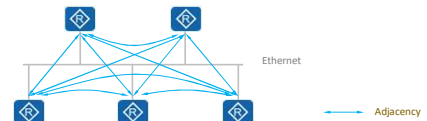
- A P2MP network is formed by bundling endpoints of multiple P2P links.
- No link layer protocol is considered as a P2MP network by default. This type must be manually changed from another network type.
- For example, a non-full-mesh NBMA network can be changed to a P2MP network.

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## Background of DR and BDR

- Multi-access (MA) networks are classified into BMA and NBMA networks. Ethernet is a typical broadcast multi-access network.
- On an MA network, if each OSPF router establishes OSPF adjacencies with all the other routers, excessive OSPF adjacencies exist on the network, which increases the load on the devices and the number of OSPF packets flooded on the network.
- Once the network topology changes, LSA flooding on the network may waste bandwidth and device resources.

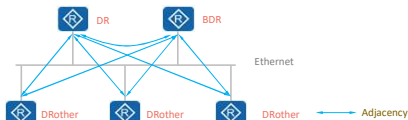


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## DR and BDR

- To optimize OSPF neighbor relationships on an MA network, the OSPF protocol specifies three types of OSPF routers: DR, BDR, and DRother.
- Only the DR and BDR can establish adjacencies with other OSPF routers. DRothers do not establish OSPF adjacencies with one another, and their relationship is in the 2-way state.
- The BDR monitors the status of the DR and takes over the role of the DR if the existing DR fails.



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## OSPF Domain and Single Area

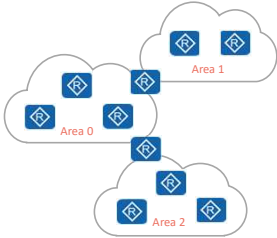
- An OSPF domain is a network that consists of a series of contiguous OSPF network devices that use the same policy.
- An OSPF router floods LSAs in the same area. To ensure that all routers have the same understanding of the network topology, LSDBs need to be synchronized within an area.
- If there is only one OSPF area, the number of OSPF routers increases with the network scale. This causes the following problems:
  - The LSDB becomes larger and larger, and the size of the OSPF routing table increases. A large number of router resources are consumed, device performance deteriorates, and data forwarding is affected.
  - It is difficult to calculate routes based on a large LSDB.
  - When the network topology changes, LSA flooding and SPF recalculation on the entire network bring heavy loads.



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## Multi-Area OSPF

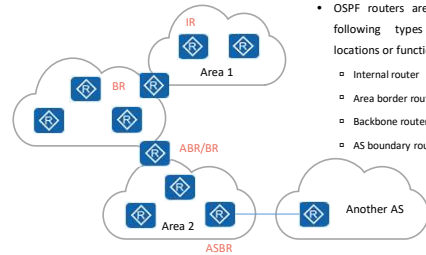


- OSPF introduces the concept of area. An OSPF domain is divided into multiple areas to support larger-scale networking.
- The OSPF multi-area design reduces the flooding scope of LSAs and effectively controls the impact of topology changes within an area, optimizing the network.
- Routes can be summarized at the area border to reduce the size of the routing table.
- Multi-area improves network scalability and facilitates large-scale network construction.

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## Types of OSPF Routers

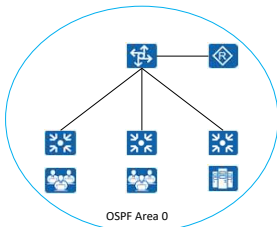


- OSPF routers are classified into the following types based on their locations or functions:
  - Internal router
  - Area border router (ABR)
  - Backbone router
  - AS boundary router (ASBR)

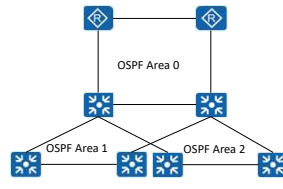
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## Typical OSPF Single-Area and Multi-Area Networking



Small- and medium-sized enterprise network (single area)



Large enterprise network (multiple areas)

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## Contents

1. OSPF Overview
2. OSPF Working Mechanism
3. Typical OSPF Configuration

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## Basic OSPF Configuration Commands (1)

1. [System view] Create and run an OSPF process.

```
[Huawei] ospf [ process-id ] router-id router-id
```

The **process-id** parameter specifies an OSPF process. The default process ID is 1. OSPF supports multiple processes. Multiple OSPF processes can separately run on the same device. The **router-id** command is used to manually specify the ID of a device. If no ID is specified, the system automatically selects the IP address of an interface as the device ID.

2. [OSPF view] Create an OSPF area and enter the OSPF area view.

```
[Huawei] area area-id
```

The **area** command creates an OSPF area and displays the OSPF area view. The **area-id** value can be a decimal integer or in dotted decimal notation. If the value is an integer, it ranges from 0 to 4294967295.

3. [OSPF area view] Specify the interface that runs OSPF.

```
[Huawei-ospf-1-area-0.0.0.0] network network-address wildcard-mask
```

The **network** command specifies the interface that runs OSPF and the area to which the interface belongs. The **network-address** parameter specifies the network segment address of the interface. The **wildcard-mask** parameter is the wildcard of an IP address, which is equivalent to the reverse mask of the IP address (0 is converted to 1, and 1 to 0). For example, 0.0.0.255 indicates that the mask length is 24 bits.

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## Basic OSPF Configuration Commands (2)

4. [Interface view] Set an OSPF interface cost.

```
[Huawei-GE1/0/1] ospf cost cost
```

The **ospf cost** command sets a cost for an OSPF interface. By default, OSPF automatically calculates the cost of an interface based on the interface bandwidth. The cost value is an integer ranging from 1 to 65535.

5. [OSPF view] Set an OSPF bandwidth reference value.

```
[Huawei-ospf-1] bandwidth-reference value
```

The **bandwidth-reference** command sets a bandwidth reference value that is used to calculate interface costs. The value ranges from 1 to 2147483648, in Mbit/s. The default value is 100 Mbit/s.

6. [Interface view] Set the priority of an interface for DR election.

```
[Huawei-GigabitEthernet0/0/0] ospf dr-priority priority
```

The **ospf dr-priority** command sets a priority for an interface that participates in DR election. A larger value indicates a higher priority. The value ranges from 0 to 255.

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## OSPF Configuration Example

Description:

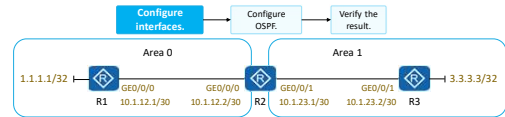
- There are three routers, R1, R2, and R3. R1 and R3 are connected to networks 1.1.1.1/32 and 3.3.3.3/32 (simulated by Loopback 0), respectively. OSPF needs to be used to implement interworking between the two networks. Detailed topology was as follows:



Configure interfaces. → Configure OSPF. → Verify the result.

- The configuration process consists of three steps: configuring device interfaces, configuring OSPF, and verifying the result.

## OSPF Configuration Example - Configuring Interfaces



- Set IP addresses for R1's, R2's, and R3's interfaces according to the plan.

# Configure interfaces of R1.

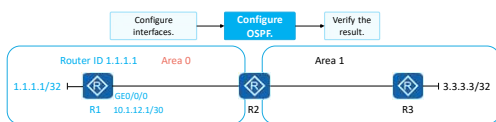
```
[R1] interface LoopBack 0
[R1-LoopBack0] ip address 1.1.1.1 32
[R1-LoopBack0] interface GigabitEthernet 0/0/0
[R1-GigabitEthernet0/0/0] ip address 10.1.12.1 30
```

# Configure interfaces of R3.

```
[R3] interface LoopBack 0
[R3-LoopBack0] ip address 3.3.3.3 32
[R3-LoopBack0] interface GigabitEthernet 0/0/1
[R3-GigabitEthernet0/0/1] ip address 10.1.23.2 30
```

Assign IP addresses for GE0/0/0 and GE0/0/1 on R2. For details, see comment in this slide.

## OSPF Configuration Example - Configuring OSPF (1)



- Planned OSPF parameters: The OSPF process ID is 1. Router IDs of R1, R2, and R3 are 1.1.1.1, 2.2.2.2, and 3.3.3.3 respectively.

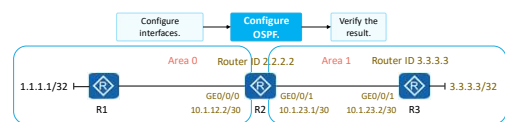
Procedure:

- Create and run an OSPF process.
- Create an OSPF area and enter the OSPF area view.
- Specify the interface that runs OSPF.

```
# Configure OSPF on R1.
[R1] ospf 1 router-id 1.1.1.1
[R1-ospf-1] area 0
[R1-ospf-1-area-0.0.0.0] network 1.1.1.1 0.0.0.0
[R1-ospf-1-area-0.0.0.0] network 10.1.12.0 0.0.0.3
```

An inverse mask is specified here.

## OSPF Configuration Example - Configuring OSPF (2)



- When configuring OSPF multi-area, be sure to advertise the route destined for a network segment that responds to a specified area.

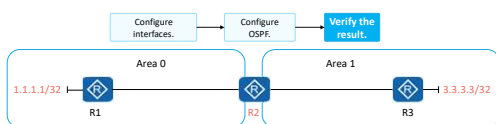
# Configure OSPF on R2.

```
[R2] ospf 1 router-id 2.2.2.2
[R2-ospf-1] area 0
[R2-ospf-1-area-0.0.0.0] network 10.1.12.0 0.0.0.3
[R2-ospf-1-area-0.0.0.0] area 1
[R2-ospf-1-area-0.0.0.1] network 10.1.23.0 0.0.0.3
```

# Configure OSPF on R3.

```
[R3] ospf 1 router-id 3.3.3.3
[R3-ospf-1] area 1
[R3-ospf-1-area-0.0.0.1] network 3.3.3.3 0.0.0.0
[R3-ospf-1-area-0.0.0.1] network 10.1.23.0 0.0.0.3
```

## OSPF Configuration Example - Verification (1)



- Check the OSPF neighbor table on R2.

```
<R2> display ospf peer brief
OSPF Process 1 with Router ID 2.2.2.2
Peer Statistic Information
+-----+-----+-----+-----+
Area Id Interface Neighbor Id State
+-----+-----+-----+-----+
0.0.0.0 GigabitEthernet0/0/0 1.1.1.1 Full
0.0.0.1 GigabitEthernet0/0/1 3.3.3.3 Full
```

Neighbor status  
Verify that the neighbor status is Full, indicating that the adjacency has been established successfully.

## OSPF Configuration Example - Verification (2)

- Check the routing table on R1 and ping 3.3.3.3 from 1.1.1.1.

```
<R1> display ip routing-table
Route Flags: R - relay, D - download to fib
-----
Routing tables: Public
Destinations : 10 Routes : 10

Destination/Mask Proto Pre Cost Flags NextHop Interface
1.1.1.1/32 Direct 0 0 D 127.0.0.1 LoopBack0
3.3.3.3/32 OSPF 10 2 D 10.1.12.2 GigabitEthernet 0/0/0
10.1.12.0/30 Direct 0 0 D 10.1.12.1 GigabitEthernet 0/0/0
...

Set the source IP address to 1.1.1.1 and ping 3.3.3.3.
<R1> ping -a 1.1.1.1 3.3.3.3
PING 3.3.3.3: 56 data bytes, press CTRL_C to break
Reply from 3.3.3.3: bytes = 56 Sequence = 1 ttl = 254 time = 50 ms
...
```



## Quiz

1. (Multiple) In the process of establishing OSPF neighbor relationships and adjacencies, which of the following states are stable? ( )  
 A. Exstart  
 B. Two-way  
 C. Exchange  
 D. Full
2. (Multiple) In which of the following situation will the establishment of adjacencies between routers be triggered? ( )  
 A. Two routers on a point-to-point link  
 B. DR and BDR on a broadcast network  
 C. DRoother and DRoother on an NBMA network  
 D. BDR and DRoother on a broadcast network



## Summary

- OSPF is a widely used routing protocol on the live network. This presentation describes basic concepts, application scenarios, and basic configurations of OSPF.
- The router ID, area, OSPF neighbor table, LSDB table, and OSPF routing table are basic OSPF concepts. Describe the establishment of OSPF neighbor relationships and adjacencies, which helps you better understand the link-state routing protocol.
- OSPF has more interesting details, such as LSA types, the SPF calculation process, and the OSPF special area. For more OSPF information, please continue your Huawei HCIP-Datacom certification courses.

