IP Routing Basics

Contents

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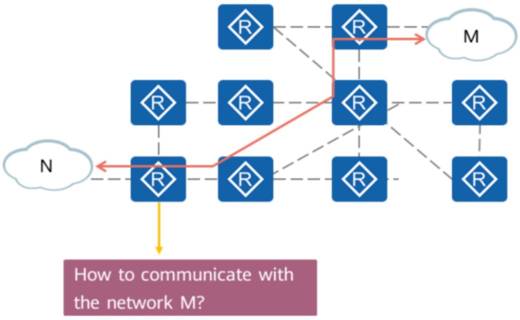
Background: Inter-Subnet Communication



- An IP address uniquely identifies a node on a network. Each IP address belongs to a unique subnet, and each subnet may belong to a different area of the network.
- To implement IP addressing, subnets in different areas need to communicate with each other.

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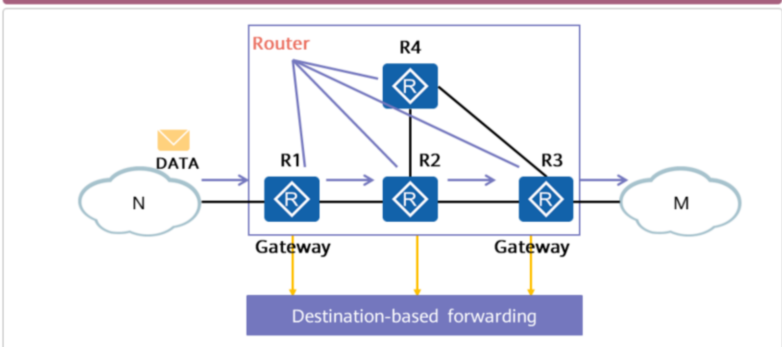
- A unique network node can be found based on a specific IP address. Each IP address belongs to a unique subnet. These subnets may be distributed around the world and constitute a global network.
- To implement communication between different subnets, network devices need to forward IP packets from different subnets to their destination IP subnets.

Routes

- Routes are the path information used to guide packet forwarding.
- A routing device is a network device that forwards packets to a destination subnet based on routes. The most common routing device is a router.
- A routing device maintains an IP routing table that stores routing information.

Route-based Packet Forwarding



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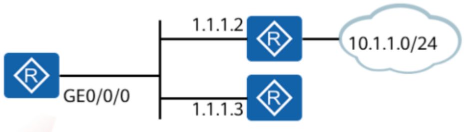
- A gateway and an intermediate node (a router) select a proper path according to the destination address of a received IP packet, and forward the packet to the next router. The last-hop router on the path performs Layer 2 addressing and forwards the packet to the destination host. This process is called route-based forwarding.
- The intermediate node selects the best path from its IP routing table to forward packets.
- A routing entry contains a specific outbound interface and next hop, which are used to forward IP packets to the corresponding next-hop device.

Routing Information



IP routing table

Destination/Mask	Outbound Interface	Next Hop
10.1.1.0/24	GE0/0/0	1.1.1.2

- A route contains the following information:
  - Destination: identifies a destination subnet.
  - Mask: identifies a subnet together with a destination IP address.
  - Outbound interface: indicates the interface through which a data packet is sent out of the local router.
  - Next hop: indicates the next-hop address used by the router to forward the data packet to the destination subnet.

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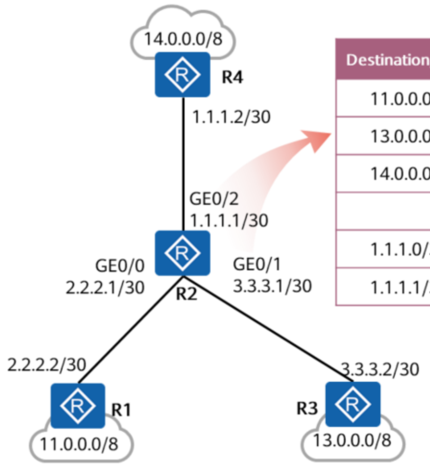
- Based on the information contained in a route, a router can forward IP packets to the destination along the required path.
- The destination address and mask identify the destination address of an IP packet. After an IP packet matches a specific route, the router determines the forwarding path according to the outbound interface and next hop of the route.
- The next-hop device for forwarding the IP packet cannot be determined based only on the outbound interface. Therefore, the next-hop device address must be specified.

IP Routing Table



Destination/Mask	Next Hop	Outbound Interface
11.0.0.0/8	2.2.2.2	GE0/0
13.0.0.0/8	3.3.3.2	GE0/1
14.0.0.0/8	1.1.1.2	GE0/2
....		
1.1.1.0/30	1.1.1.1	GE0/2
1.1.1.1/32	127.0.0.1	GE0/2

- Routers discover routes using multiple methods.
- A router selects the optimal route and installs it in its IP routing table.
- The router forwards IP packets based on routes in the IP routing table.
- Routers manage path information by managing their IP routing tables.

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- A router forwards packets based on its IP routing table.
- An IP routing table contains many routing entries.
- An IP routing table contains only optimal routes but not all routes.
- A router manages routing information by managing the routing entries in its IP routing table.

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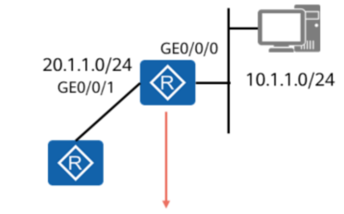
How to Obtain Routing Information

Direct Routes

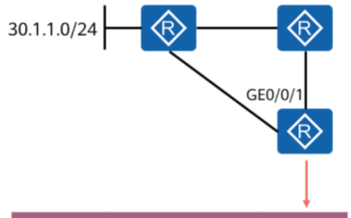
- Direct routes are automatically generated by devices and point to local directly connected networks.



Protocol	Destination/Mask	Outbound Interface
Direct	10.1.1.0/24	GE0/0/0
Direct	20.1.1.0/24	GE0/0/1

Static Routes

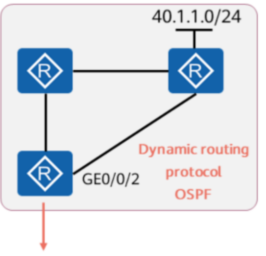
- Static routes are manually configured by network administrators.



Protocol	Destination/Mask	Outbound Interface
Static	30.1.1.0/24	GE0/0/1

Dynamic Routes

- Dynamic routes are learned by dynamic routing protocols running on routers.



Protocol	Destination/Mask	Outbound Interface
OSPF	40.1.1.0/24	GE0/0/2

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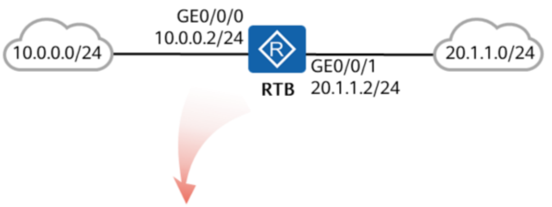
- Direct routes are the routes destined for the subnets to which directly connected interfaces belong. They are automatically generated by devices.
- Static routes are manually configured by network administrators.
- Dynamic routes are learned by dynamic routing protocols, such as OSPF, IS-IS, and BGP.

Direct Routes (1)

Direct Routes



Direct routes in the IP routing table of RTB

Destination/Mask	Protocol	Next Hop	Outbound Interface
10.0.0.0/24	Direct	10.0.0.2	GE0/0/0
20.1.1.0/24	Direct	20.1.1.2	GE0/0/1

- A direct route is automatically generated by a device and points to a local directly-connected network.
- When a router is the last hop router, IP packets to be forwarded will match a direct route and the router will directly forward the IP packet to the destination host.
- When a direct route is used for packet forwarding, the destination IP address of a packet to be forwarded and the IP address of the router's outbound interface are in the same subnet.

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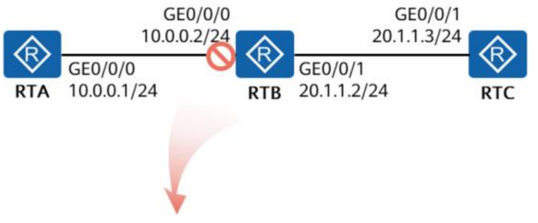
- When a packet matches a direct route, a router checks its ARP entries and forwards the packet to the destination address based on the ARP entry for this destination address. In this case, the router is the last hop router.
- The next-hop address of a direct route is not an interface address of another device. The destination subnet of the direct route is the subnet to which the local outbound interface belongs. The local outbound interface is the last hop interface and does not need to forward the packet to any other next hop. Therefore, the next-hop address of a direct route in the IP routing table is the address of the local outbound interface.
- When a router forwards packets using a direct route, it does not deliver packets to the next hop. Instead, the router checks its ARP entries and forwards packets to the destination IP address based on the required ARP entry.

Direct Routes (2)

Direct routes



Direct routes in the IP routing table of RTB

Destination/Mask	Protocol	Next Hop	Outbound Interface
20.1.1.0/24	Direct	20.1.1.2	G0/0/1

- When GE0/0/0 goes down, the direct route for this interface is not installed in the IP routing table.

- Not all the direct routes generated for interfaces are installed in the IP routing table. Only the direct routes of which the physical status and protocol status of interfaces are up are installed in the IP routing table.

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Examining the IP Routing Table

```
<Quidway> display ip routing-table
Route Flags: R - relay, D - download to fib
------------------------------------------------------------------------------
----------------
Routing Tables: Public
        Destinations : 6        Routes : 6

  Destination/Mask    Proto     Pre  Cost   Flags       NextHop      Interface

       1.1.1.1/32     Static    60    0      D          0.0.0.0      NULL0
       2.2.2.2/32     Static    60    0      D          100.0.0.2    Vlanif100
     100.0.0.0/24     Direct    0     0      D          100.0.0.1    Vlanif100
     100.0.0.1/32     Direct    0     0      D          127.0.0.1    Vlanif100
     127.0.0.0/8      Direct    0     0      D          127.0.0.1    InLoopBack0
     127.0.0.1/32     Direct    0     0      D          127.0.0.1    InLoopBack0
```

Destination/Mask
Protocol
Route preference
Cost (Metric)
Flag
Next-hop address
Outbound interface

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Fields in the IP Routing Table

- Destination/Mask: indicates the destination network address and mask of a specific route. The subnet address of a destination host or router is obtained through the AND operation on the destination address and mask. For example, if the destination address is 1.1.1.1 and the mask is 255.255.255.0, the IP address of the subnet to which the host or router belongs is 1.1.1.0.
- Proto (Protocol): indicates the protocol type of the route, that is, the protocol through which a router learns the route.
- Pre (Preference): indicates the routing protocol preference of the route. There may be multiple routes to the same destination, which have different next hops and outbound interfaces. These routes may be discovered by different routing protocols or be manually configured. A router selects the route with the highest preference (with the lowest preference value) as the optimal route.
- Cost: indicates the cost of the route. When multiple routes to the same destination have the same preference, the route with the lowest cost is selected as the optimal route.
- NextHop: indicates the local router's next-hop address of the route to the destination network. This field specifies the next-hop device to which packets are forwarded.
- Interface: indicates the outbound interface of the route. This field specifies the local interface through which the local router forwards packets.

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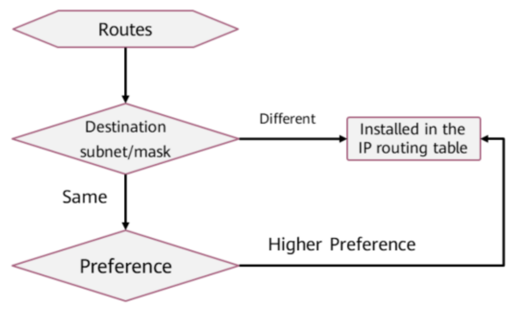
- The Preference field is used to compare routes from different routing protocols, while the Cost field is used to compare routes from the same routing protocol. In the industry, the cost is also known as the metric.

Route Preference - Basic Concepts

Comparing Route Preferences



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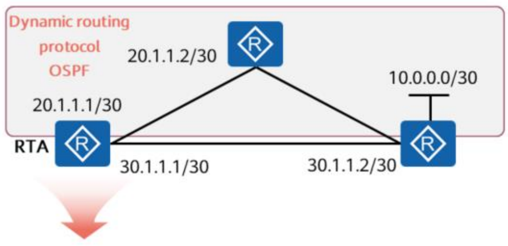
Route Preference - Comparison Process

Comparing Route Preferences



IP routing table of RTA

Destination/Mask	Protocol	Preference	Next Hop
10.0.0.0/30	Static	**60**	30.1.1.2
10.0.0.0/30	OSPF	**10**	20.1.1.2

Installed in the IP routing table

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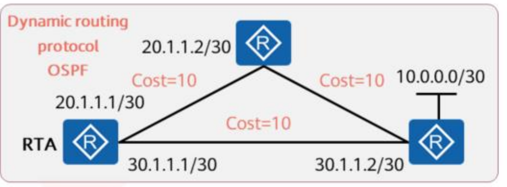
- RTA learns two routes to the same destination, one is a static route and the other an OSPF route. It then compares the preferences of the two routes, and prefers the OSPF route because this route has a higher preference. RTA installs the OSPF route in the IP routing table.

Metric - Comparison Process

Metric comparison



IP routing table of RTA

Destination/Mask	Protocol	Cost	Next Hop
10.0.0.0/30	OSPF	**20**	20.1.1.2
10.0.0.0/30	OSPF	**10**	30.1.1.2

Installed in the IP routing table

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Route Preference - Common Default Values

- The following table lists the default preference values of common route types:

Protocol	Route Type	Default Preference
Direct	Direct route	0
Static	Static route	60
Dynamic routing protocol	OSPF internal route	10
	OSPF external route	150

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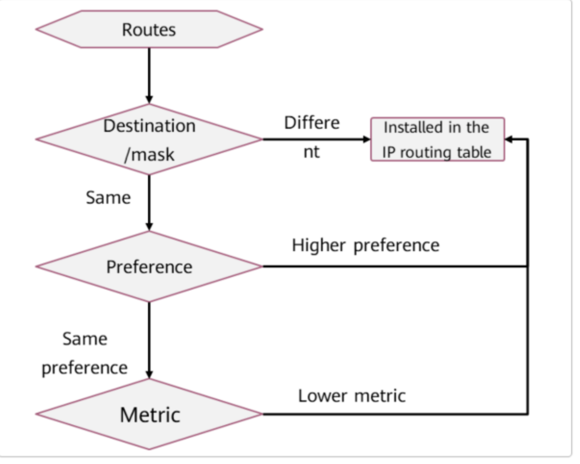
- The table lists the preferences of some common routing protocols. Actually, there are multiple types of dynamic routes. We will learn these routes in subsequent courses.

Metric - Basic Concepts

Comparing Metrics



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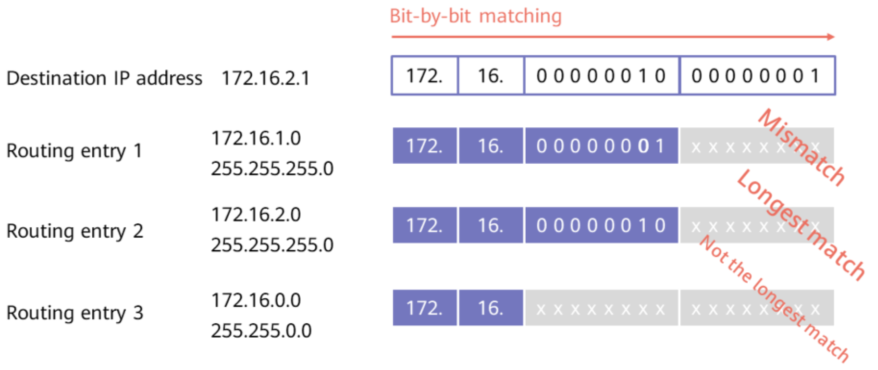
Longest Matching

- When a router receives an IP packet, it compares the destination IP address of the packet with all routing entries in the local routing table bit by bit until the longest matching entry is found. This is the longest matching mechanism.



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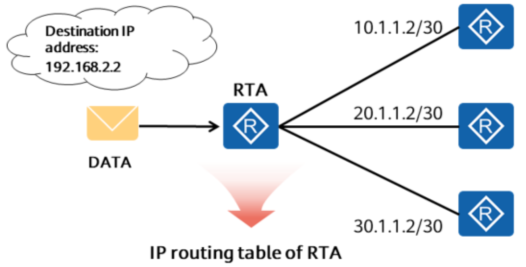
Example of Longest Matching (1)



Destination/Mask	Next Hop
192.168.0.0/16	10.1.1.2
192.168.2.0/24	20.1.1.2
192.168.3.0/24	30.1.1.2

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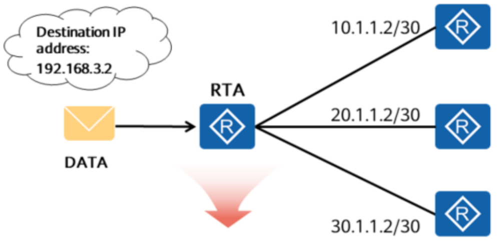
Example of Longest Matching (2)

Example of Longest Matching



IP routing table of RTA

Destination/Mask	Next Hop
192.168.0.0/16	10.1.1.2
192.168.2.0/24	20.1.1.2
192.168.3.0/24	30.1.1.2

Match

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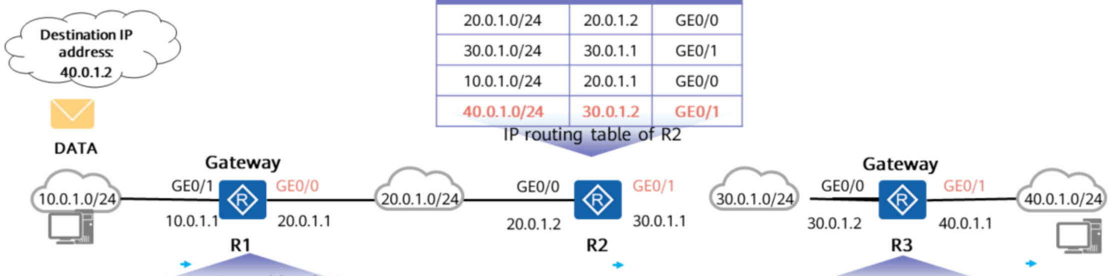
Route-based Forwarding Process

Destination/Mask	Next Hop	Outbound Interface
20.0.1.0/24	20.0.1.2	GE0/0
30.0.1.0/24	30.0.1.1	GE0/1
10.0.1.0/24	20.0.1.1	GE0/0
40.0.1.0/24	30.0.1.2	GE0/1

IP routing table of R2



IP routing table of R1

Destination/Mask	Next Hop	Outbound Interface
10.0.1.0/24	10.0.1.1	GE0/1
20.0.1.0/24	20.0.1.1	GE0/0
30.0.1.0/24	20.0.1.2	GE0/0
40.0.1.0/24	20.0.1.2	GE0/0

IP routing table of R3

Destination/Mask	Next Hop	Outbound Interface
40.0.1.0/24	40.0.1.1	GE0/1
30.0.1.0/24	30.0.1.2	GE0/0
10.0.1.0/24	30.0.1.1	GE0/0
20.0.1.0/24	30.0.1.1	GE0/0

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- The IP packets from 10.0.1.0/24 need to reach 40.0.1.0/24. After receiving these packets, the gateway R1 searches its IP routing table for the next hop and outbound interface and forwards the packets to R2. After the packets reach R2, R2 forwards the packets to R3 by searching its IP routing table. Upon receipt of the packets, R3 searches its IP routing table, finding that the destination IP address of the packets belongs to the subnet where a local interface resides. Therefore, R3 directly forwards the packets to the destination subnet 40.0.1.0/24.

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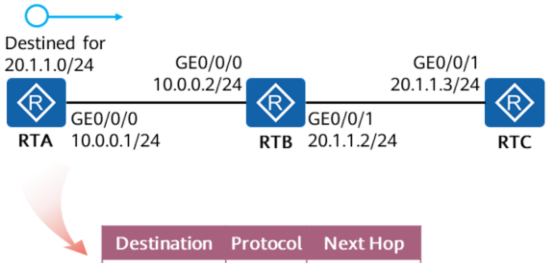
Application Scenarios of Static Routes

Static Routes



Destination	Protocol	Next Hop
20.1.1.0	Static	10.0.0.2
10.0.0.0	Direct	10.0.0.1

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Static Route Configuration

1. Specify a next-hop IP address for a static route.

   [Huawei] **ip route-static** *ip-address* { *mask* | *mask-length* } *nexthop-address*

2. Specify an outbound interface for a static route.

   [Huawei] **ip route-static** *ip-address* { *mask* | *mask-length* } *interface-type interface-number*

3. Specify both the outbound interface and next hop for a static route.

   [Huawei] **ip route-static** *ip-address { mask | mask-length } interface-type interface-number [nexthop-address]*

   When creating a static route, you can specify both the outbound interface and next hop. Alternatively, you can specify either the outbound interface or next hop, depending on the interface type:

   - For a point-to-point interface (such as a serial interface), you must specify the outbound interface.
   - For a broadcast interface (for example, an Ethernet interface) or a virtual template (VT) interface, you must specify the next hop.

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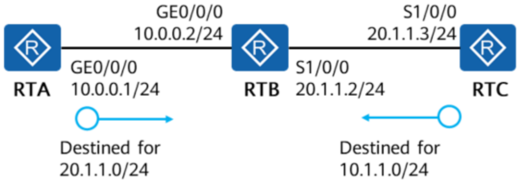
Configuration Example



- Configure static routes on RTA and RTC for communication between 10.0.0.0/24 and 20.1.1.0/24.
- Packets are forwarded hop by hop. Therefore, all the routers along the path from the source to the destination must have routes destined for the destination.
- Data communication is bidirectional. Therefore, both forward and backward routes must be available.

Configure RTA.

[RTA] **ip route-static 20.1.1.0 255.255.255.0 10.0.0.2**

Configure RTC.

[RTC] **ip route-static 10.0.0.0 255.255.255.0 S1/0/0**

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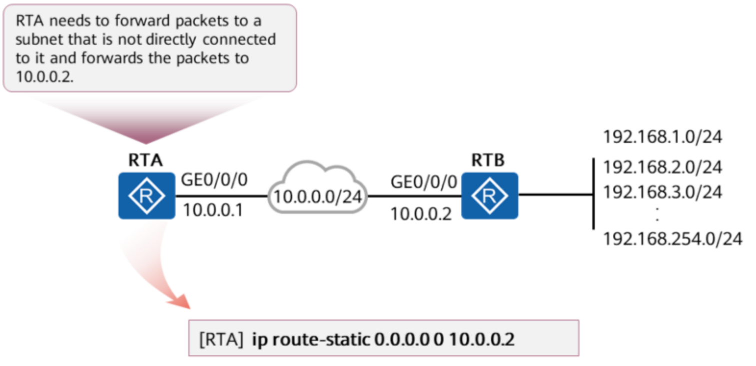
Default Routes

- Default routes are used only when packets to be forwarded do not match any routing entry in an IP routing table.
- In an IP routing table, a default route is the route to network 0.0.0.0 (with the mask 0.0.0.0), namely, 0.0.0.0/0.



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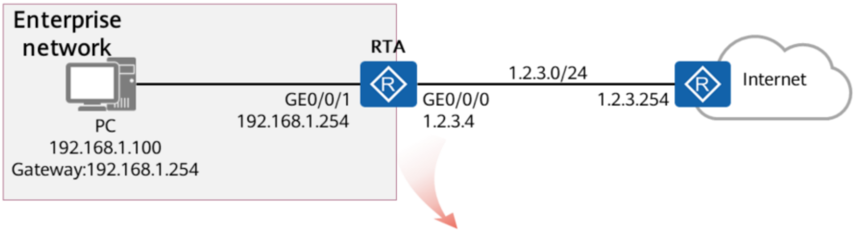
Application Scenarios of Default Routes

- Default routes are typically used at the egress of an enterprise network. For example, you can configure a default route on an egress device to enable the device to forward IP packets destined for any address on the Internet.



[RTA] **ip route-static 0.0.0.0 0 1.2.3.254**

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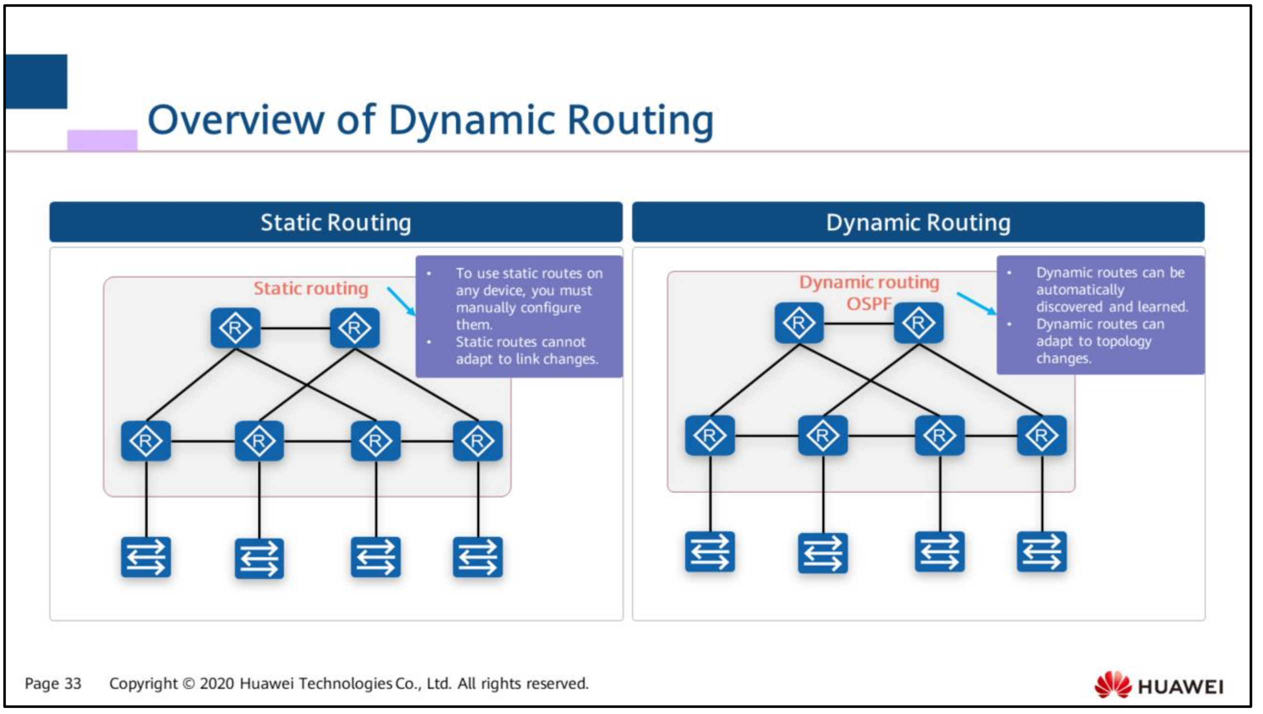
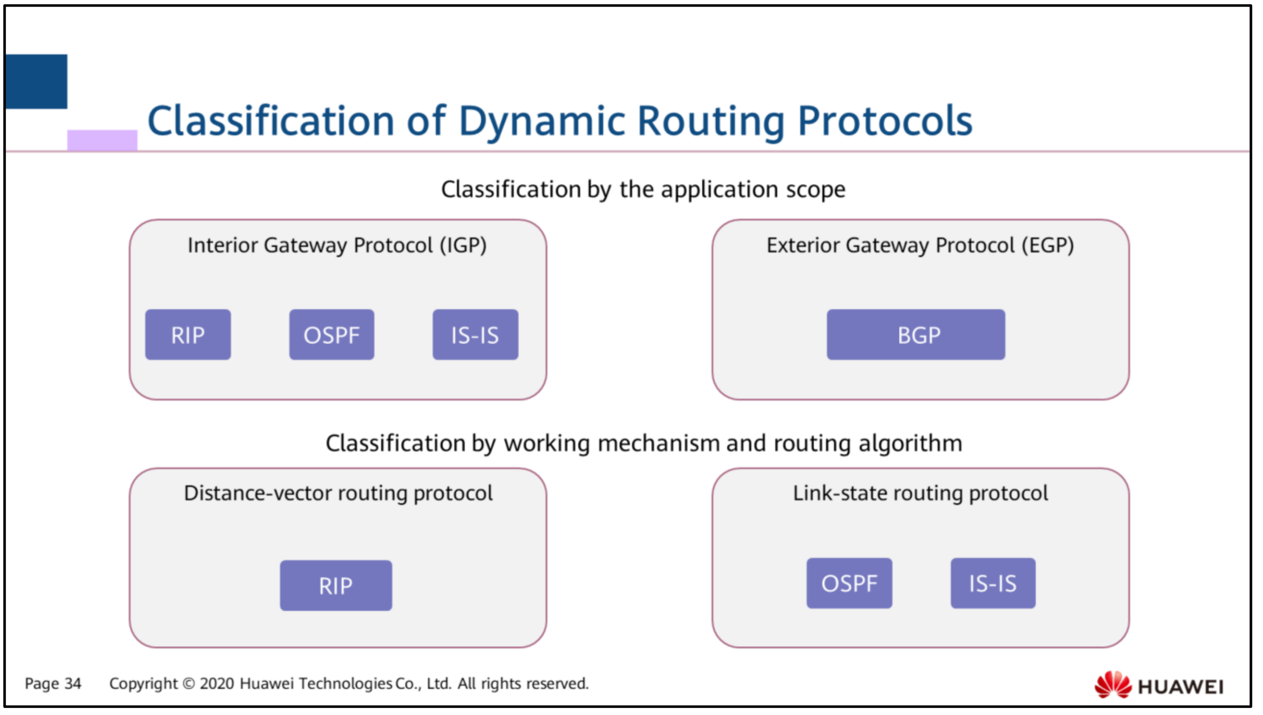


- The disadvantage of static routes is that they cannot automatically adapt to network topology changes and so require manual intervention.
- Dynamic routing protocols provide different routing algorithms to adapt to network topology changes. Therefore, they are applicable to networks on which many Layer 3 devices are deployed.



- Dynamic routing protocols are classified into two types based on the routing algorithm:
  - Distance-vector routing protocol
    - RIP
  - Link-state routing protocol
    - OSPF
    - IS-IS
  - BGP uses a path vector algorithm, which is modified based on the distance-vector algorithm. Therefore, BGP is also called a path-vector routing protocol in some scenarios.
- Dynamic routing protocols are classified into the following types by their application scope:
  - IGPs run within an autonomous system (AS), including RIP, OSPF, and IS-IS.
  - EGP runs between different ASs, among which BGP is the most frequently used.

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Route Recursion (1)

[RTA] **ip route-static 30.1.2.0 24 20.1.1.3**

The next hop of the route to 30.1.2.0/24 is 20.1.1.3, which is not on a directly connected network of RTA. If the IP routing table does not have a route to 20.1.1.3, this static route does not take effect and cannot be installed in the IP routing table.

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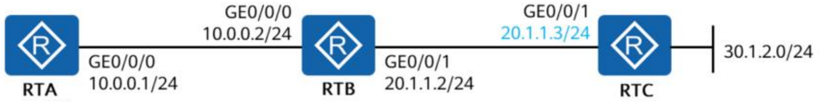
Route Recursion (2)



[RTA] **ip route-static 30.1.2.0 24 20.1.1.3**

Recursion

[RTA] **ip route-static 20.1.1.0 24 10.0.0.2**

Destination /Mask	Next Hop	Outbound Interface
30.1.2.0/24	20.1.1.3	GE0/0/0
20.1.1.0/24	10.0.0.2	GE0/0/0

Configure a route to 20.1.1.3, with the next hop pointing to 10.0.0.2 on the directly connected network. In this way, RTA can recurse the route with the destination 30.1.2.0/24 to the route with the destination 10.0.0.2.

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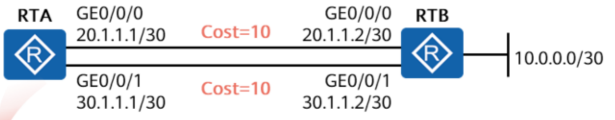
Equal-Cost Route

Equal-Cost Route



RTA's IP routing table

Destination/Mask	Next Hop
10.0.0.0/30	20.1.1.2
	30.1.1.2

If there are multiple routes to the same destination from the same source, with the same cost, but pointing to different next hops, the routes are installed in the IP routing table as equal-cost routes. Traffic to be sent to the destination will be distributed to these equal-cost routes.

- When there are equal-cost routes in the IP routing table, a router forwards IP packets to be sent to the destination subnet through all valid outbound interfaces and next hops in the equal-cost routes, achieving load balancing.

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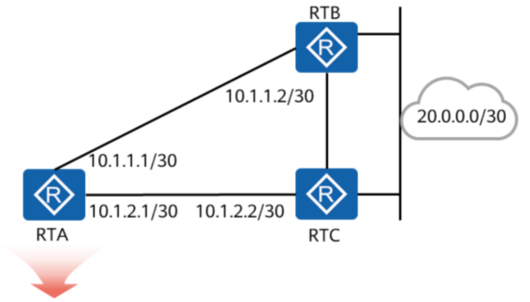
Floating Route - Basic Concepts

Floating Route



Configure a floating route on RTA.

```
[RTA] ip route-static 20.0.0.0 30 10.1.1.2
[RTA] ip route-static 20.0.0.0 30 10.1.2.2 preference 70
```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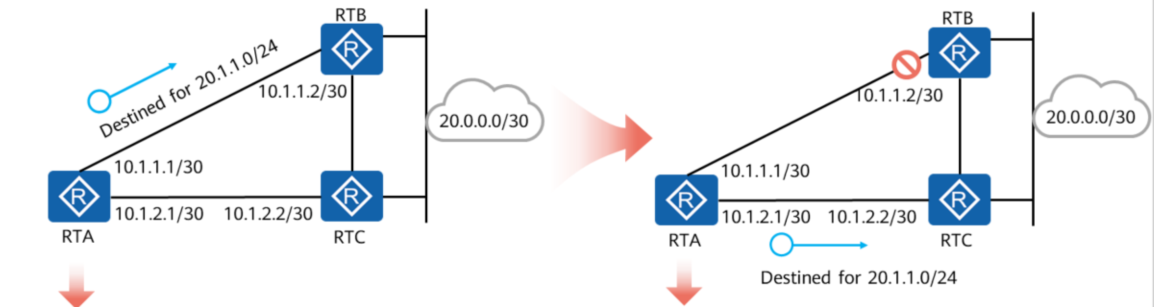
Floating Route - Example

Floating Route Switching



RTA's IP routing table when the primary link is available

Destination	Next Hop	Preference
20.0.0.0	10.1.1.2	60

RTA's IP routing table when the primary link fails

Destination	Next Hop	Preference
20.0.0.0	10.1.2.2	70

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- When the link between RTA and RTB is normal, the two routes to 20.0.0.0/30 are both valid. In this case, RTA compares the preferences of the two routes, which are 60 and 70 respectively. Therefore, the route with the preference value 60 is installed in the IP routing table, and RTA forwards traffic to the next hop 10.1.1.2.
- If the link between RTA and RTB is faulty, the next hop 10.1.1.2 is unreachable, which causes the corresponding route invalid. In this case, the backup route to 20.0.0.0/30 is installed in the IP routing table. RTA forwards traffic destined for 20.0.0.1 to the next hop 10.1.2.2.

Contents

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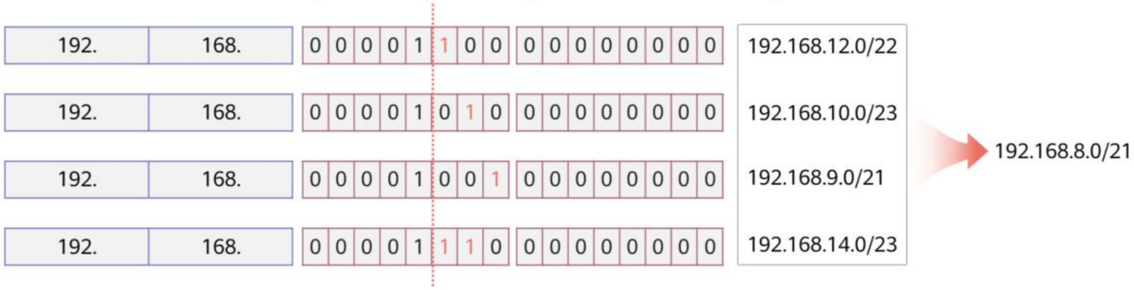
CIDR

- Classless Inter-Domain Routing (CIDR) uses IP addresses and masks to identify networks and subnets. CIDR replaces the previous addressing architecture of classful network design (such as classes A, B, and C addresses).
- CIDR is based on variable length subnet mask (VLSM). CIDR uses prefixes of any lengths to divide the address space with continuous IP addresses. Multiple address segments with continuous prefixes can be summarized into a network, effectively reducing the number of routing entries.



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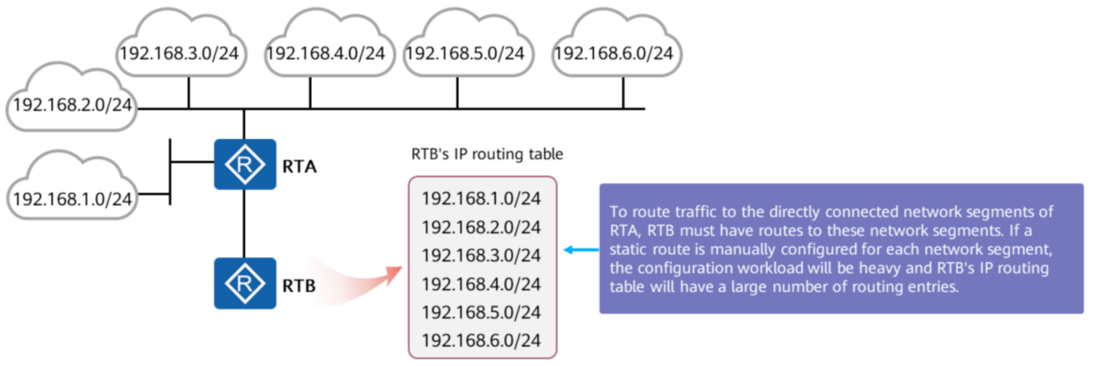
Background of Route Summarization

- Subnet division and VLSM resolve the problem of address space waste, but also bring a new challenge: increasing routing entries in the IP routing table.
- Route summarization can minimize routing entries.



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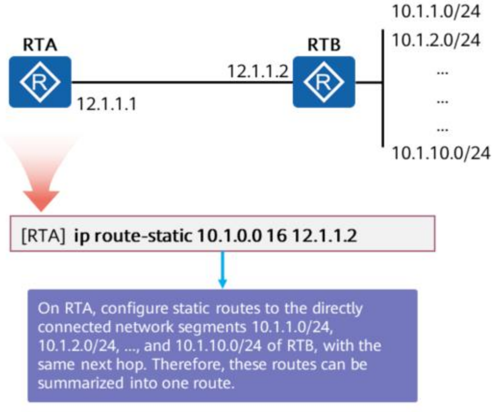
- On a large-scale network, routers or other routing-capable devices need to maintain a large number of routing entries, which will consume a large amount of device resources. In addition, the IP routing table size is increasing, resulting in a low efficiency of routing entry lookup. Therefore, we need to minimize the size of IP routing tables on routers while ensuring IP reachability between the routers and different network segments. If a network has scientific IP addressing and proper planning, we can achieve this goal by using different methods. A common and effective method is route summarization, which is also known as route aggregation.

Overview of Route Summarization



- Route summarization is an approach of summarizing routes with the same prefix into one summary route to minimize the IP routing table size and improve device resource usage.
- Route summarization uses CIDR to summarize network segments with the same prefix into a single one.
- The routes before being summarized are known as specific routes, and the routes created after summarization are known as summarized routes or summary routes.

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- To enable RTA to reach remote network segments, we need to configure a specific route to each network segment. In this example, the routes to 10.1.1.0/24, 10.1.2.0/24, and 10.1.3.0/24 have the same next hop, that is, 12.1.1.2. Therefore, we can summarize these routes into a single one.
- This effectively reduces the size of RTA's IP routing table.

Summarization and Calculation

	192	168	X	0
192.168.1.0/24	1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 0 0 0 0 0 1	0 0 0 0 0 0 0 0
192.168.2.0/24	1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 0 0 0 0 1 0	0 0 0 0 0 0 0 0
192.168.3.0/24	1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 0 0 0 0 1 1	0 0 0 0 0 0 0 0
	Network address			Host address
192.168.0.0/22	1 1 0 0 0 0 0 0	1 0 1 0 1 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0

- To summarize routes to multiple continuous network segments into one summary route that just includes these network segments, ensure that the mask length of the summary route is as long as possible.

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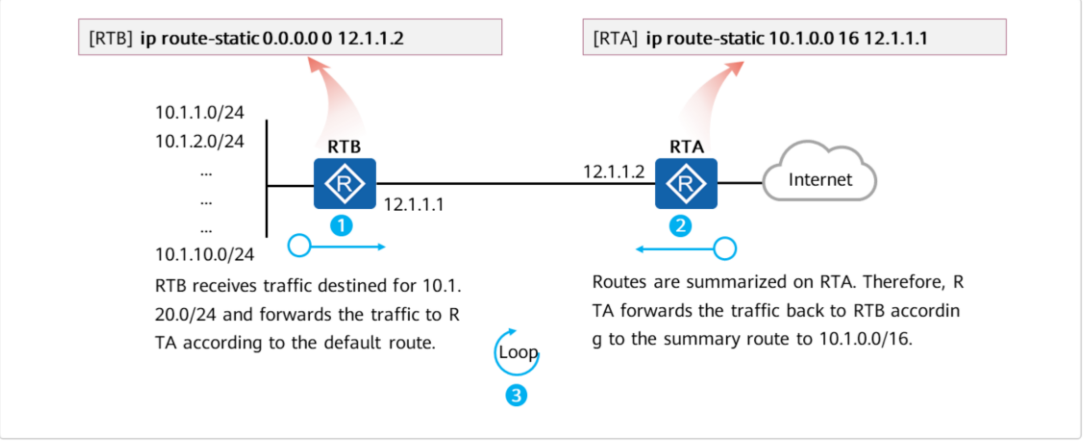
Problems Caused by Route Summarization (1)

Routing Loop



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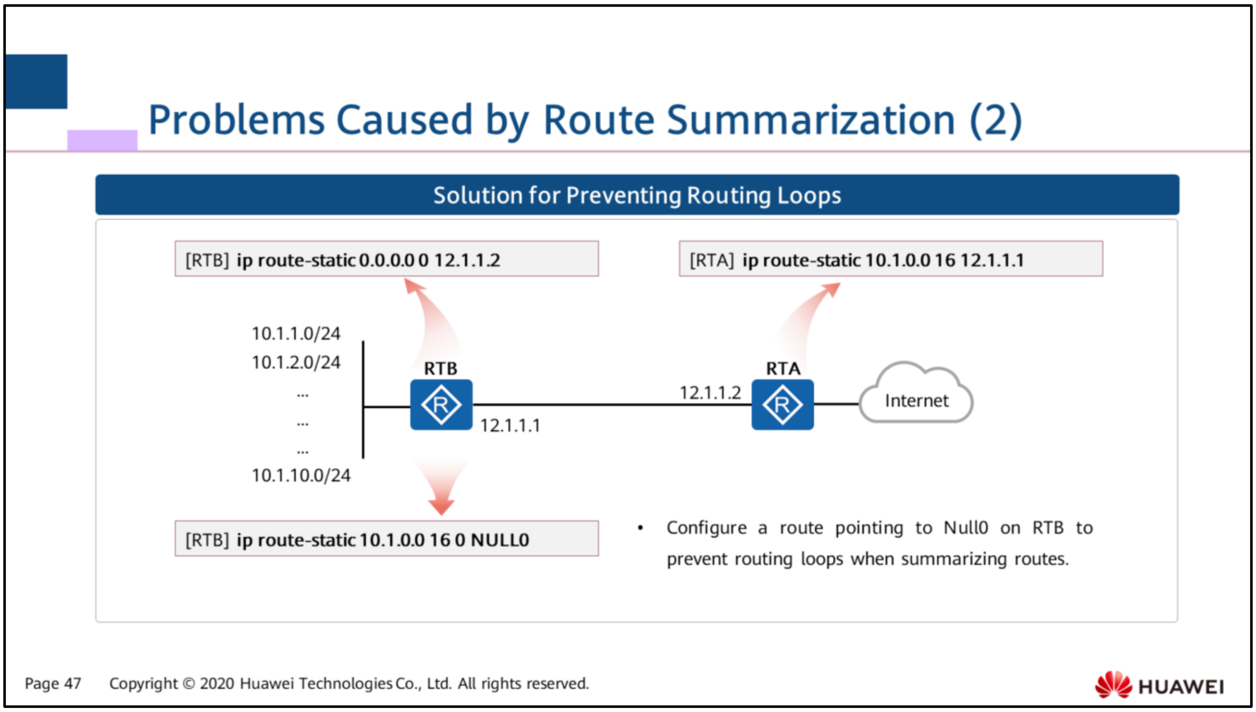
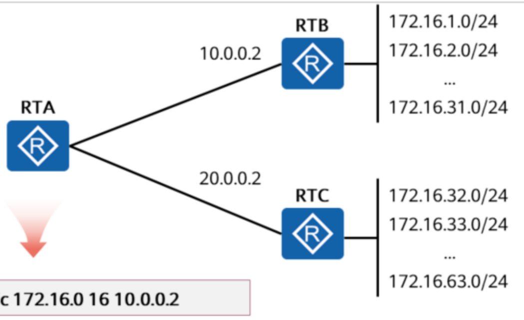


- In most cases, both static and dynamic routes need to be associated with an outbound interface. This interface is the egress through which the device is connected to a destination network. The outbound interface in a route can be a physical interface such as a 100M or GE interface, or a logical interface such as a VLANIF or tunnel interface. There is a special interface, that is, Null interface. It has only one interface number, that is, 0. Null0 is a logical interface and is always up. When Null0 is used as the outbound interface in a route, data packets matching this route are discarded, like being dumped into a black-hole. Therefore, such a route is called a black-hole route.

Accurate Route Summarization (1)

Accurate Route Summarization



[RTA] **ip route-static 172.16.0 16 10.0.0.2**

- To simplify the configuration, an administrator may configure a static summary route on RTA to allow RTA to reach network segments 172.16.1.0/24 to 172.16.31.0/24 of RTB. However, this summary route also includes the network segments of RTC. As a result, RTA forwards the traffic destined for network segments of RTC to RTB, causing data packet loss. This problem is caused by inaccurate route summarization. To resolve this problem, the summary route must be as accurate as possible; that is, it just covers all specific routes that are to be summarized, with no extra route included.

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Accurate Route Summarization (2)

Accurate Route Summarization

	10	1	0	0
10.1.1.0/24	0 0 0 0 1 0 1 0	0 0 0 0 0 0 0 1	0 0 0 0 0 0 0 1	0 0 0 0 0 0 0 0
10.1.2.0/24	0 0 0 0 1 0 1 0	0 0 0 0 0 0 0 1	0 0 0 0 0 0 1 0	0 0 0 0 0 0 0 0
10.1.3.0/24	0 0 0 0 1 0 1 0	0 0 0 0 0 0 0 1	0 0 0 0 0 0 1 1	0 0 0 0 0 0 0 0

/22

```
ip route-static 10.1.1.0 24 12.1.1.2
ip route-static 10.1.2.0 24 12.1.1.2
ip route-static 10.1.3.0 24 12.1.1.2
```

```
ip route-static 10.1.1.0 22 12.1.1.2
```

Accurately calculate the summarized network address and mask to ensure accurate route summarization.

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Summary

- This section presents the basic concepts of routes, how routes instruct routers to forward IP packets, common route attributes, and default routes (special static routes).
- In addition, this section describes advanced routing features including route recursion, floating routes, and equal-cost routes, which are widely used on live networks.

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