MPLS Implementation and Configuration

Foreword

- In the mid-1990s, Internet traffic grew rapidly. Traditional IP packets were forwarded by routers based on routing tables. However, due to hardware technology limitations, the forwarding performance of routers is low. As a result, this mode becomes a bottleneck for network data forwarding.
- As such, the Multiprotocol Label Switching (MPLS) protocol is proposed. It is designed to speed up packet forwarding on routers. On an MPLS network, IP packet headers are analyzed on network edges only, and MPLS uses labels to guide packet forwarding inside the MPLS network. Label-based forwarding features high efficient, shortening the packet processing time.
- With the continuous improvement of devices' hardware performance, the advantage of MPLS in improving the data forwarding speed is gradually weakened. However, as MPLS supports multi-layer label nesting and forwarding-and-control separation inside a device, MPLS is applicable to many scenarios, such as virtual private network (VPN) and quality of service (QoS).
- This course describes the principles and label-based forwarding process of MPLS, as well as the method for configuring static label switched paths (LSPs).

Objectives

- On completion of this course, you will be able to:
  - Understand basic MPLS concepts and terms.
  - Understand the principles of MPLS.
  - Configure static LSPs.
  - Describe the MPLS forwarding process.

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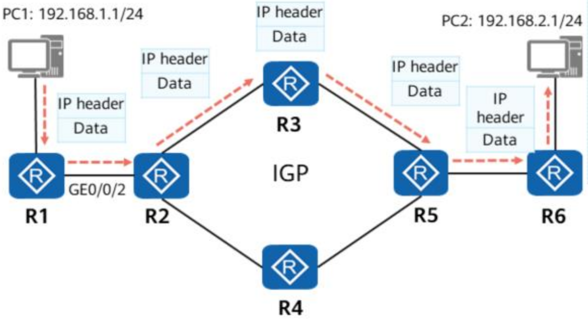
Traditional IP Routing and Forwarding

Traditional IP forwarding uses the hop-by-hop forwarding mode, in which a packet is decapsulated by all routers that receive the packet. Each router needs to obtain the network layer information and search its routing table for a route based on the longest match rule. The repeated processes of decapsulating packets, searching routing tables, and re-encapsulating the packets on routers result in low forwarding performance.



Characteristics of traditional IP routing and forwarding:

- All routers need to know the network-wide routes.
- The length of an IP header is not fixed, and the processing efficiency is low.
- Traditional IP forwarding is connectionless and cannot provide good end-to-end QoS guarantee.

R1 routing table

Destination/Mask	Protocol	Preference	Cost	Next Hop	Interface
192.168.1.0/24	Direct	0	0	192.168.1.254	GE0/0/0
192.168.0.0/16	Direct	0	0	192.168.12.1	GE0/0/2
0.0.0.0/0	Static	60	0	192.168.12.2	GE0/0/2

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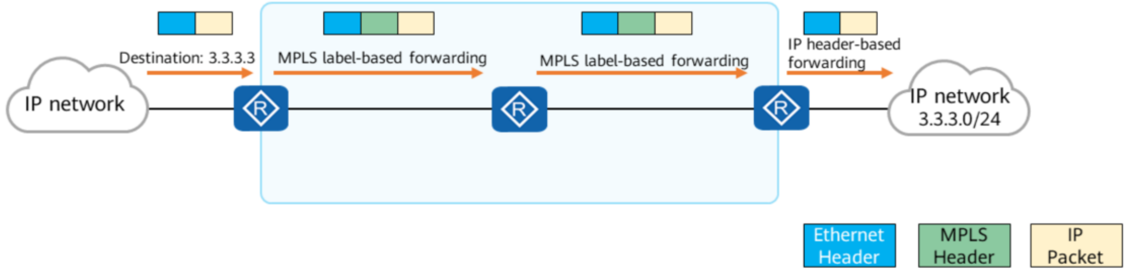
Basic MPLS Concepts

- MPLS is located between the data link layer and the network layer in the TCP/IP protocol stack and can provide services for all network layers.
- An MPLS header is added between a data-link-layer header and a network-layer header, and data can be forwarded quickly based on the Label field in the MPLS header.
- This course describes the application of MPLS on IP networks only.



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- MPLS is derived from the Internet Protocol version 4 (IPv4). Core MPLS technologies can be extended to support multiple network protocols, such as the Internet Protocol version 6 (IPv6), Internet Packet Exchange (IPX), Appletalk, DECnet, and Connectionless Network Protocol (CLNP). MPLS uses label-based forwarding to replace IP forwarding. A label is a short connection identifier of fixed length that is meaningful only to a local end.

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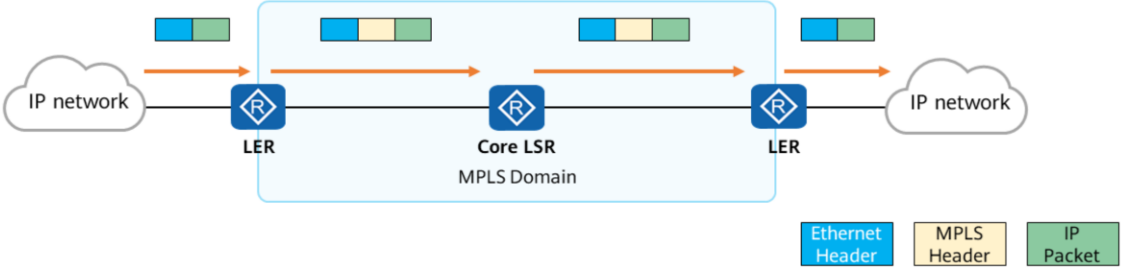
MPLS Terms - LSR and MPLS Domain

- MPLS domain: consists of a series of consecutive network devices that run MPLS.
- Label switching router (LSR): a routing device, such as a router or switch, that runs MPLS. An LSR that resides at the edge of an MPLS domain and connects to a non-MPLS network is called a label edge router (LER). An LSR that resides inside an MPLS domain is called a core LSR.



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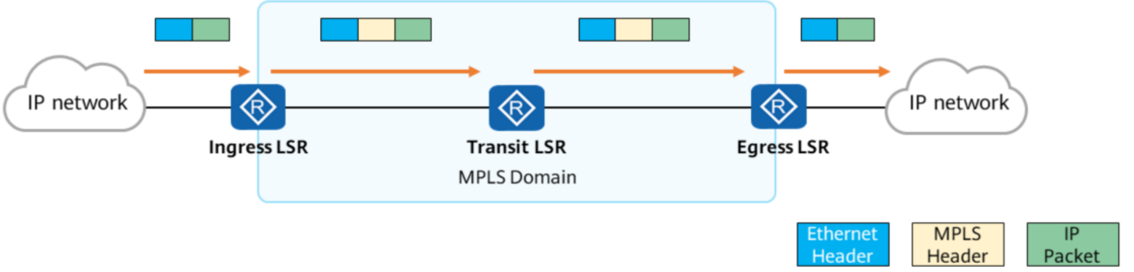
MPLS Terms - LSR Classification

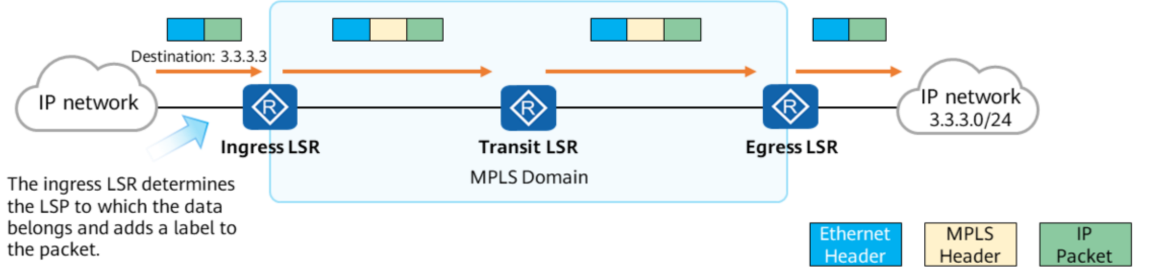
- In addition to location-based LSR classification, LSRs can also be classified according to data processing modes:
  - Ingress LSR: generally pushes an MPLS header into an IP packet and generates an MPLS packet.
  - Transit LSR: generally pushes a label, swaps a label, or pops out a label in a received MPLS packet, and then forwards the packet inside the MPLS domain.
  - Egress LSR: generally pops out an MPLS header to restore the IP packet.



- MPLS label operations will be introduced in following courses.

MPLS Terms - FEC

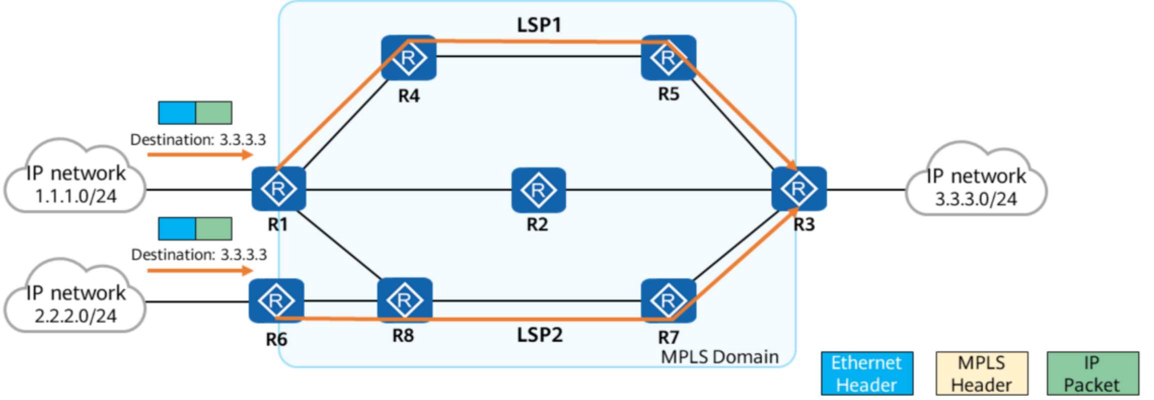
- Forwarding equivalence class (FEC): a set of packets with similar or identical characteristics and forwarded in the same way by LSRs.
  - On an MPLS network, FECs can be classified based on destination IP addresses, network masks, DSCP values, and so on.
  - When a packet enters an MPLS domain, the ingress LSR determines the LSP to which the packet belongs.
  - MPLS labels match FECs. A mechanism must be available for LSRs to obtain label information about FECs.



- In traditional IP forwarding that uses the longest match algorithm, all packets that match the same route belong to the same FEC.
- In MPLS, the most common example of FEC is: Packets whose destination IP addresses match the same IP route are considered to belong to the same FEC.

MPLS Terms - LSP

- Label switched path (LSP): a path through which a labeled packet traverses an MPLS domain to reach a destination.
- The packets of the same FEC usually traverse an MPLS domain through the same LSP. Therefore, an LSR always uses the same label to forward the packets of the same FEC.



- An LSP is composed of an ingress LSR, an egress LSR, and a variable number of transit LSRs. Therefore, an LSP can be considered as an ordered set of these LSRs.
- An LSP must be established before a packet is forwarded; otherwise, the packet fails to traverse an MPLS domain.
- LSPs can be established in static or dynamic mode.
- An LSP is a unidirectional path from the start point to the end point. If bidirectional data communication is required, an LSP for return traffic needs to be established between the two ends.

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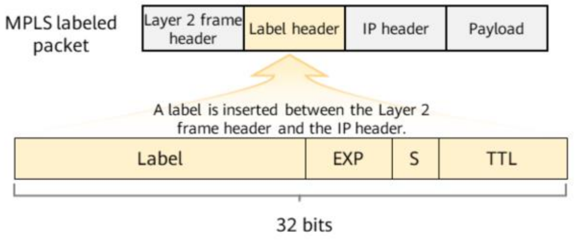
MPLS Labels

Before an IP packet enters an MPLS domain, the ingress LSR pushes an MPLS header (also called an MPLS label) into the packet to form an MPLS labeled packet. An MPLS labeled packet can contain one or more labels.

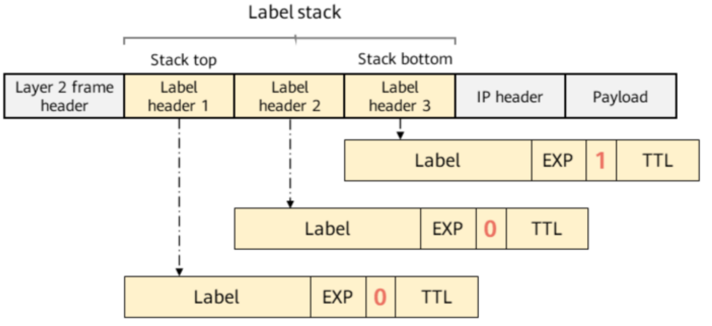


- Label: carries a label value and is 20 bits long.
- Experimental use (EXP): is mainly used for class of service (CoS) and is 3 bits long.
- Bottom of stack (S): indicates whether a label header is the last label and is 1 bit long. If its value is 1, the current label header is at the bottom of the label stack. If its value is 0, the current label header is not at the bottom and is followed by other label headers.
- Time to live (TTL): prevents a labeled packet from being infinitely forwarded when a loop occurs. It is 8 bits long and has the same meaning as the TTL field in an IP packet header.

- The EXP field is defined in early MPLS standards and is an experimental field. Actually, this field is mainly used for CoS. To avoid ambiguity, this field is renamed Traffic Class in RFC 5462.

MPLS Label Stack

- MPLS allows one or more layers of label headers to be added in a packet. The ordered set of these label headers is called label stack.
- When there are multiple labels in the label stack:
  - The label closest to the Layer 2 header is the top label, and the S field in the label is 0.
  - The label closest to the IP header is the bottom label, and the S field in the label is 1.



- When the upper layer is the MPLS label stack, the Type field in the Ethernet header is 0x8847, and the Protocol field in the PPP header is 0x8281.

Label Space

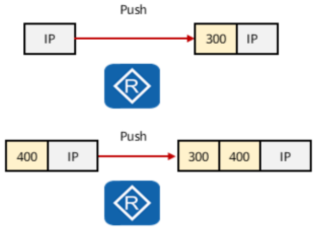
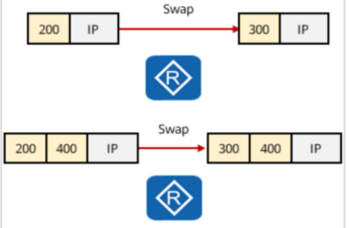
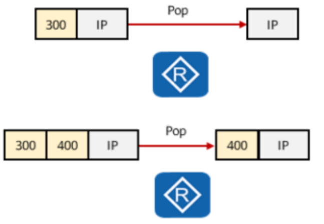
A label is a short and fixed-length identifier that has only local significance. A label space means a label value range. The label value range and planning are as follows:

Label Value	Description
0 to 15	Special label values. For example, 0 indicates an IPv4 explicit null label, and 3 indicates an implicit null label.
16 to 1023	Label space shared by static LSPs and static CR-LSPs.
1024 to 1048575	Label space for dynamic signaling protocols, such as Label Distribution Protocol (LDP), Resource Reservation Protocol-Traffic Engineering (RSVP-TE), and Multiprotocol Extensions for Border Gateway Protocol (MP-BGP). Each dynamic signaling protocol uses an independent and contiguous label space, which is not shared with other dynamic signaling protocols.

- The label spaces of different LSRs are independent of each other, indicating that each router can use the entire label space.

MPLS Label Processing

LSRs can perform the following operations on labels: push, swap, and pop.

Push	Swap	Pop
		
When an IP packet enters an MPLS domain, the ingress adds a label between the Layer 2 frame header and IP header of the packet. When the packet reaches a transit node, the transit node can also add a new label at the top of the label stack.	When the packet is forwarded inside the MPLS domain, a transit node searches the label forwarding table and replaces the top label with the label that is assigned by the next hop.	Before the packet leaves the MPLS domain, the egress removes the label of the MPLS packet.

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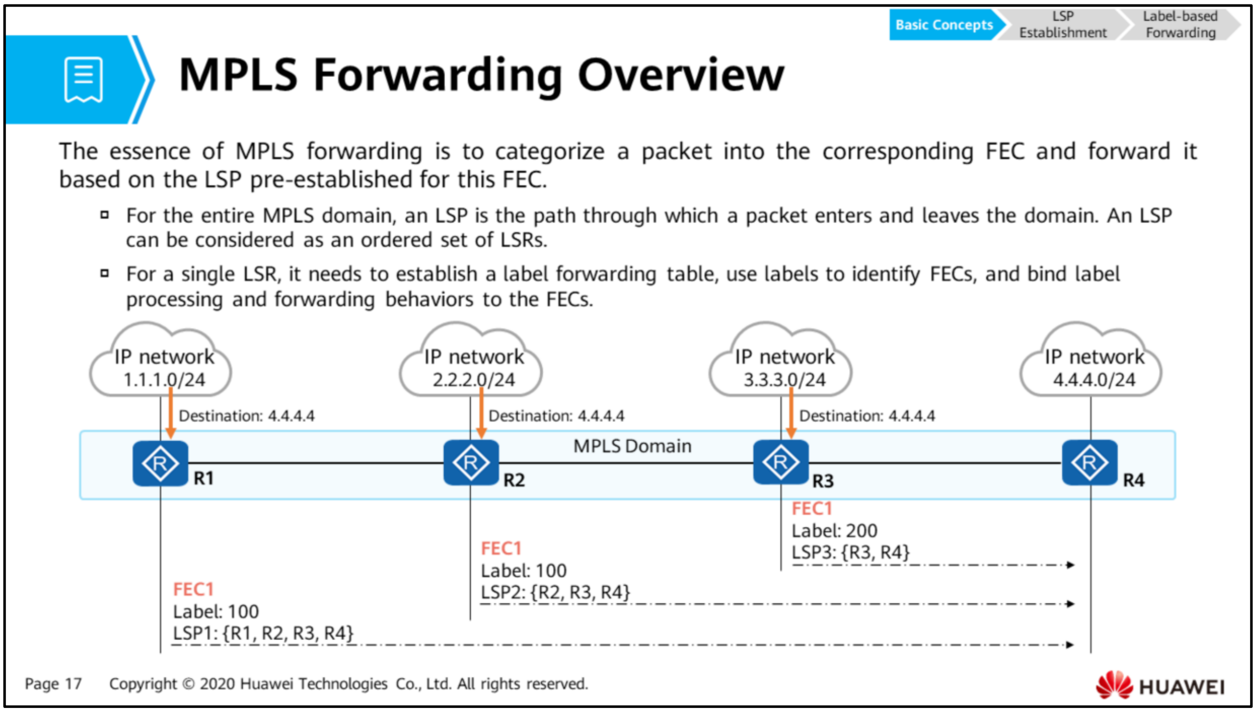
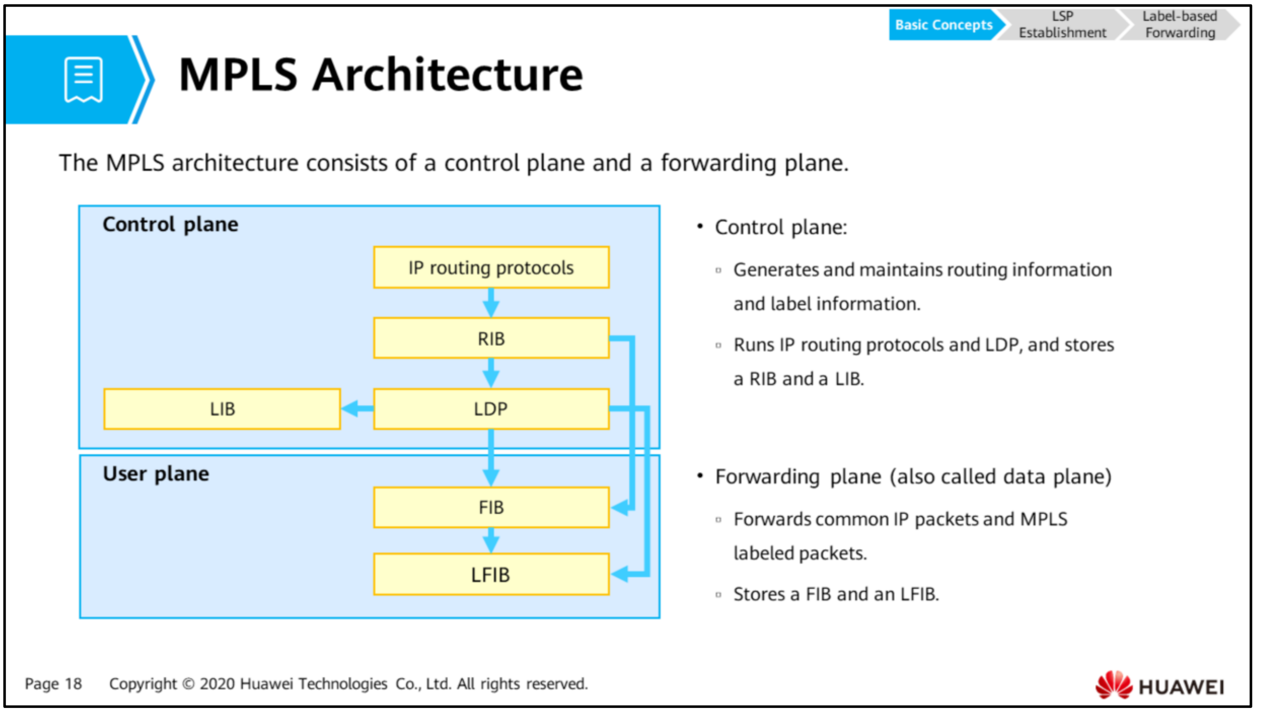
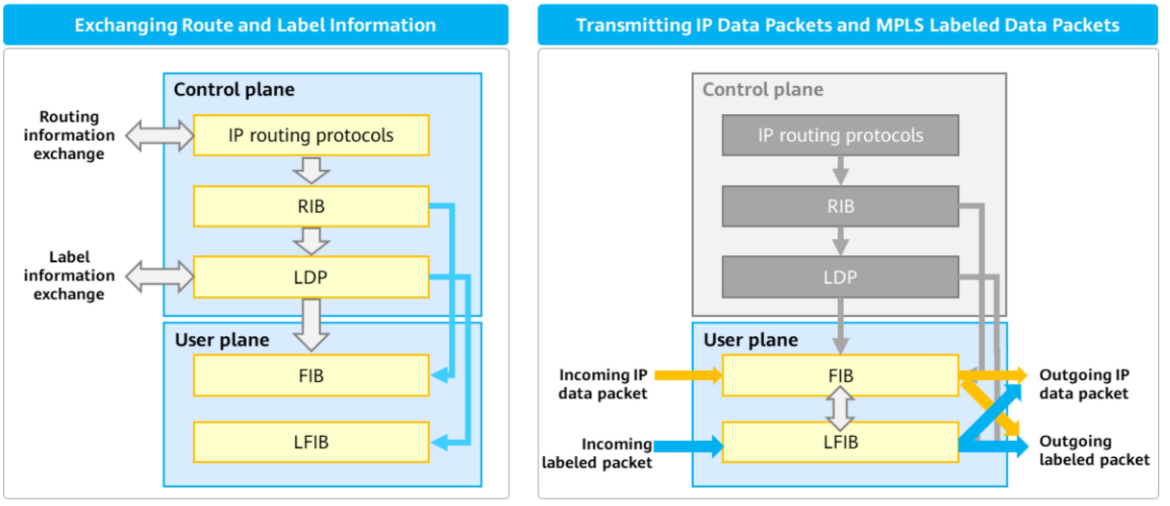


- If the ingress LSRs of packets belonging to the same FEC are different, the LSPs for forwarding the packets are different.
- An LSR uses the same way to process packets in the same FEC, regardless of where the packets' inbound interfaces are the same.
- An LSP is composed of the forwarding actions of LSRs, and the label forwarding table determines the forwarding action. Therefore, establishing a label forwarding table can also be considered as establishing an LSP.
- As shown in the figure, the three packets belong to the same FEC, FEC1, because they have the same destination. However, as their ingress LSRs are different, the packets are forwarded along different LSPs (LSP1, LSP2, and LSP3, respectively). The labels assigned by different LSRs to the same FEC can be the same or different, because labels are valid only on their local LSRs.



- Control plane:
    - The control plane is connectionless. It generates and maintains routing and label information.
    - The control plane includes:
        - Routing information base (RIB): stores static routes, direct routes, and routes generated by IP routing protocols. Routes can be selected from the RIB to guide packet forwarding.
        - Label information base (LIB): stores and manages labels statically configured and dynamically generated by label switching protocols (such as LDP and RSVP).
- Forwarding plane
    - The forwarding plane, also called the data plane, is connection-oriented. It forwards common IP packets and MPLS labeled packets.
    - The forwarding plane includes:
        - Forwarding information base (FIB): stores forwarding information that is generated based on the routing information extracted from the RIB. The forwarding information is used to guide common IP packet forwarding.
        - Label forwarding information base (LFIB): stores label-based forwarding information to guide MPLS labeled packet forwarding.

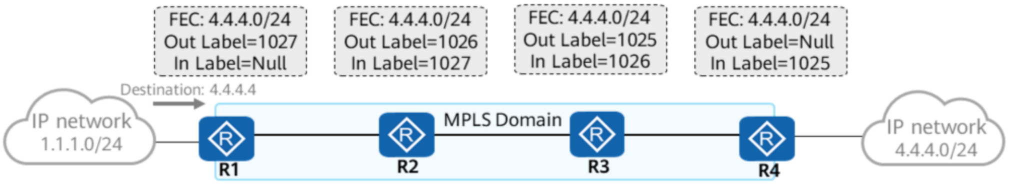
Control Plane and Forwarding Plane



Basic Concepts | **LSP Establishment** | Label-based Forwarding

LSP Establishment Principles

- When the network layer protocol is IP, the route for a FEC must exist in the IP routing table of an LSR. Otherwise, the label forwarding entry of the FEC does not take effect.
- An LSR uses labels to identify a FEC, and it can correctly process an incoming packet of a FEC only if the packet carries the correct label.



- A device provides an incoming label and an outgoing label for each FEC. The incoming label indicates the one that needs to be carried in a received packet. The outgoing label indicates the one that needs to be carried in a sent packet.
- Assume that a packet destined for 4.4.4.0/24 is sent from R1 to R2. R1 is the upstream LSR of R2, and R3 is the downstream LSR of R2. To ensure that a labeled packet is correctly processed and forwarded, the outgoing label carried in the packet sent from R1 to R2 must be the same as the incoming label on R2 for the FEC to 4.4.4.0/24. Similarly, the outgoing label on R2 for the FEC to 4.4.4.0/24 must be the same as the incoming label of R3.

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Basic Concepts > **LSP Establishment** > Label-based Forwarding

LSP Establishment Methods

MPLS needs to distribute labels to packets and establish LSPs before it can forward packets. LSPs can be either static or dynamic.

Static LSP	Dynamic LSP
• Basic concepts: ▫ A static LSP is established by manually configuring labels for a FEC. ▫ The establishment of static LSPs does not involve label distribution protocols or control packet exchanging. Therefore, this LSP establishment mode consumes less resources. ▫ Static LSPs cannot adapt to network topology changes, and require manual adjustment when the network topology changes. • Application scenarios: ▫ Stable and small-sized network with a simple topology • Label distribution principles: ▫ A packet's outgoing label value on the current node should be the same as the incoming label value on the next hop.	• Basic concepts: ▫ Dynamic LSPs are established automatically by a label distribution protocol. ▫ Label distribution protocols, also called signaling protocols, are MPLS control protocols used to identify FECs, distribute labels, and create and maintain LSPs. • Common label distribution protocol: LDP ▫ Full name: Label Distribution Protocol ▫ Definition: LDP is a control protocol for MPLS. It is responsible for FEC classification, label distribution, and LSP establishment and maintenance. LDP defines the messages used in label distribution and how to process these messages. ▫ Application scenario: LDP is widely in VPN scenarios as it features simple networking and configuration, supports dynamic establishment of LSPs based on routes, and supports a large number of LSPs.

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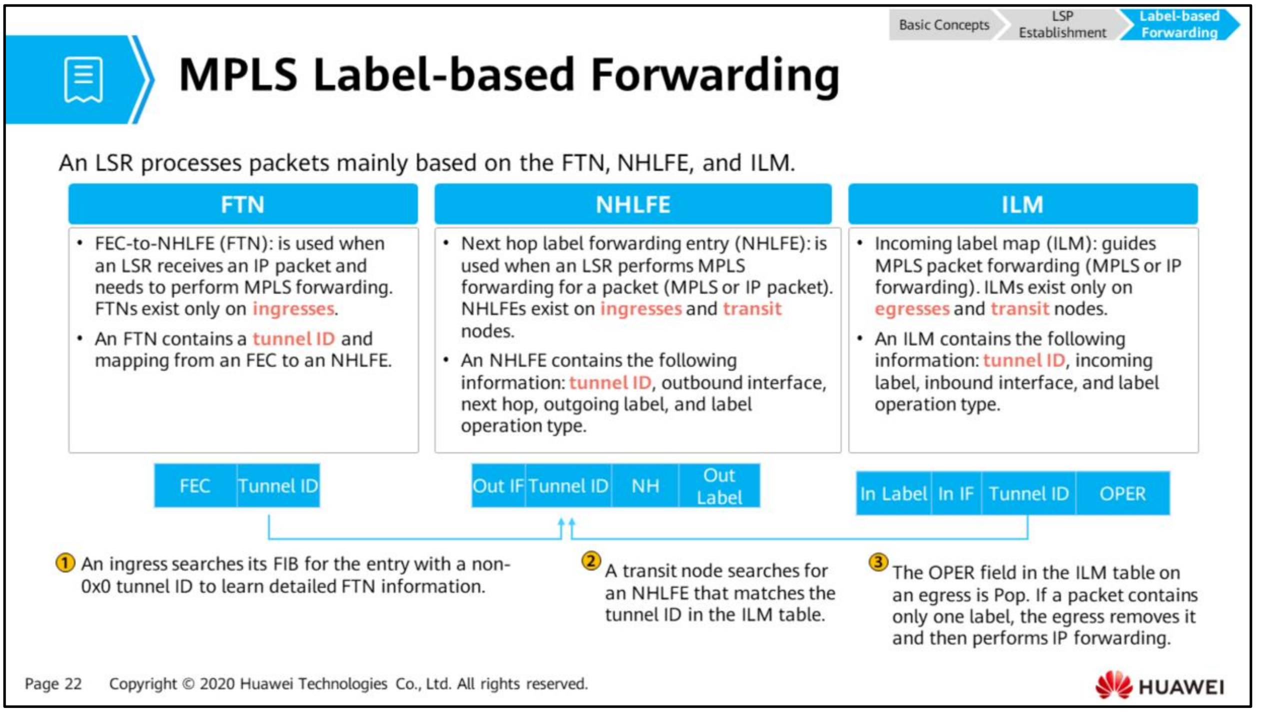
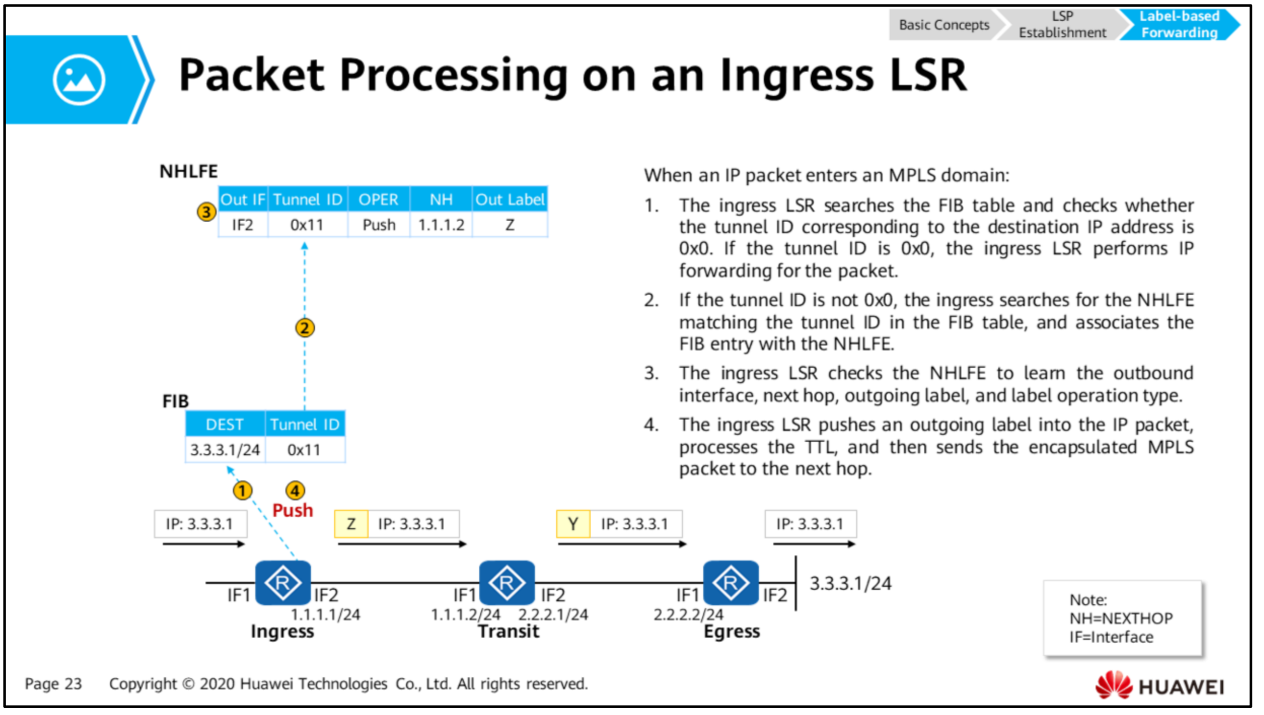
- Static LSP:
  - A static LSP is meaningful only to the local node, and the local node cannot be aware of the entire LSP.
- Dynamic LSP:
  - Other label distribution protocols:
    - Resource Reservation Protocol-Traffic Engineering (RSVP-TE): an extension based on RSVP. RSVP-TE is used to establish constraint-based routed LSPs (CR-LSPs). Unlike LDP LSPs, CR-LSPs support parameters, such as bandwidth reservation requests, bandwidth constraints, link colors, and explicit paths.
    - Multiprotocol Border Gateway Protocol (MP-BGP): an extension based on BGP. MP-BGP distributes labels to MPLS VPN routes and inter-AS VPN labeled routes.

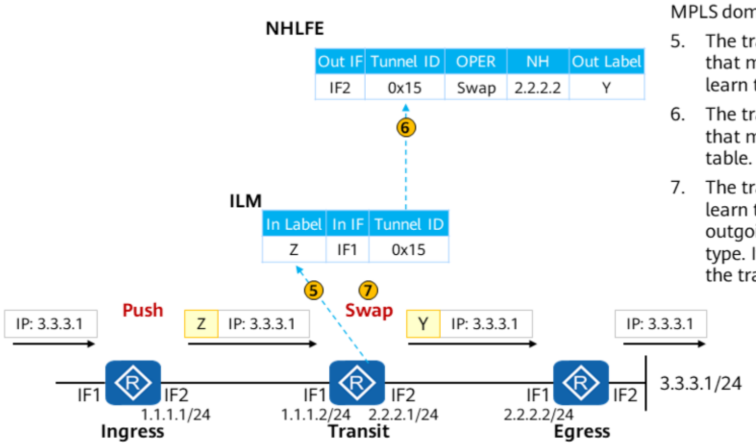


- Tunnel ID: an ID automatically allocated to a tunnel, providing a unified interface for upper-layer applications (such as VPN and route management) that use the tunnel. A tunnel ID is 32 bits long and is valid only on the local device. During MPLS forwarding, LSRs find matching FIB entries, ILMs, and NHLFEs based on tunnel IDs.



- An ingress LSR searches the FIB table (to learn FTN information) and NHLFE table to guide packet forwarding.
- When an IP packet enters an MPLS domain, the ingress searches the FIB to check whether the tunnel ID corresponding to the destination IP address is 0x0.
    - If the tunnel ID is 0x0, the ingress LSR performs IP forwarding for the packet.
    - If the tunnel ID is not 0x0, the ingress LSR performs MPLS forwarding for the packet.

Packet Processing on a Transit LSR



When an MPLS packet is forwarded in an MPLS domain:

5. The transit LSR searches for the ILM that matches the MPLS label value to learn the tunnel ID.
6. The transit LSR searches for the NHLFE that matches the tunnel ID in the ILM table.
7. The transit LSR checks the NHLFE to learn the outbound interface, next hop, outgoing label, and label operation type. If the label operation type is Swap, the transit LSR performs label swapping.

Note:
NH=NEXTHOP
IF=Interface

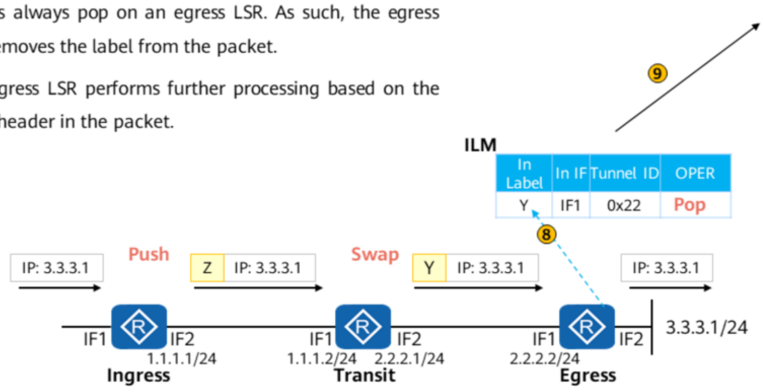
- A transit LSR searches for ILMs and NHLFEs to guide MPLS packet forwarding.

Packet Processing on an Egress LSR

When an MPLS packet leaves an MPLS domain:

8. An egress LSR searches the ILM table for the operation type that matches the FEC of the packet. The operation type is always pop on an egress LSR. As such, the egress LSR removes the label from the packet.
9. The egress LSR performs further processing based on the inner header in the packet.

- S = 1: The current label is the bottom label, and IP forwarding is performed for the packet.
- S = 0: The current label is not the bottom label, and a lower-layer label exists. In this case, the packet is performed based on the lower-layer label.



Note:
NH=NEXTHOP
IF=Interface

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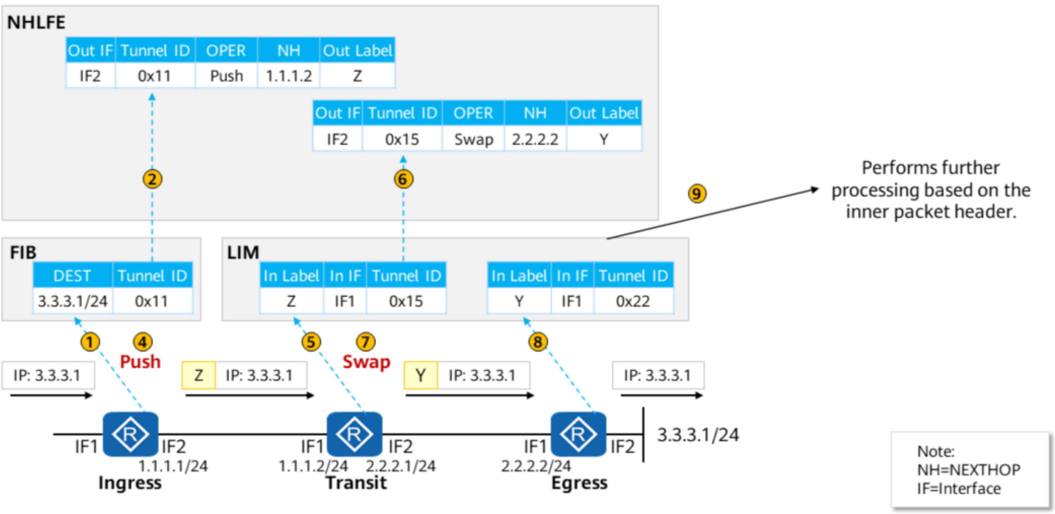
- The egress LSR searches the ILM table to guide MPLS packet forwarding.

Detailed MPLS Packet Forwarding Process



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Basic MPLS Configuration Commands

1. Set an LSR ID.

    [Huawei] **mpls lsr-id** *lsr-id*

    The **mpls lsr-id** command sets an LSR ID. An LSR ID uniquely identifies an LSR on a network. By default, no LSR ID is set for an LSR, and an LSR ID can only be manually set. To improve network reliability, you are advised to use the IP address of a loopback interface on an LSR as the LSR ID and plan the LSR IDs of all LSRs on the network in a unified manner before configuration.

2. Enable MPLS.

    [Huawei] **mpls**

    The **mpls** command enables MPLS on the current node and displays the MPLS view.

    [Huawei-GigabitEthernet0/0/0] **mpls**

    Enable MPLS on an interface. Before running this command, enable MPLS globally.

Static LSP Configuration Commands (1)

1. Configure a static LSP on an ingress LSR.

[Huawei] **static-lsp ingress** *lsp-name* **destination** *ip-address* { *mask-length* | *mask* } { **nexthop** *next-hop-address* | **outgoing-interface** *interface-type interface-number* }* **out-label** *out-label*

The **static-lsp ingress** command configures a static LSP on an ingress.

- You are advised to specify the **next-hop** parameter to configure a static LSP. This ensures that the local routing table contains the routing entry that exactly matches the specified destination IP address and next-hop IP address. If the outbound interface of the LSP is an Ethernet interface, you must specify **nexthop** *next-hop-address* to ensure normal forwarding along the LSP.
- The value of *out-label* ranges from 16 to 1048575.

2. Configure a static LSP on a transit LSR.

[Huawei] **static-lsp transit** *lsp-name* [**incoming-interface** *interface-type interface-number*] **in-label** *in-label* { **nexthop** *next-hop-address* | **outgoing-interface** *interface-type interface-number* }* **out-label** *out-label*

The **static-lsp transit** command configures a static LSP on a transit node.

- The configuration rules of the next hop and outbound interface are the same as those for an ingress LSR.
- The value of *in-label* ranges from 16 to 1023.
- The value of *out-label* ranges from 16 to 1048575.

- An outgoing label occupies the label space of the downstream LSR, but the label distribution mode used by the downstream space is uncertain. As such, the value of an outgoing label ranges from 16 to 1048575.
- An incoming label occupies the label space of the current LSR. When a static LSP is used, the value of an incoming label ranges from 16 to 1023.

Static LSP Configuration Commands (2)

3. Configure a static LSP on an egress LSR.

[Huawei] **static-lsp egress** *lsp-name* [**incoming-interface** *interface-type interface-number*] **in-label** *in-label*

The **static-lsp egress** command configures a static LSP on an egress LSR.

- The value of *in-label* ranges from 16 to 1023.

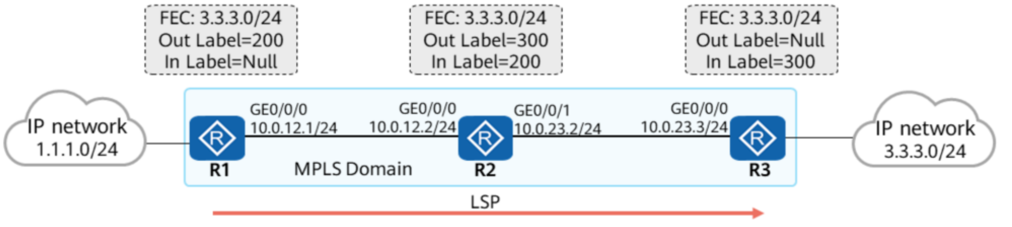
4. Check information about static LSPs.

[Huawei] **display mpls static-lsp** [*lsp-name*] [{ **include** | **exclude** } *ip-address mask-length*] [**verbose**]

The **display mpls static-lsp** command displays information about static LSPs.

Static LSP Configuration Example (1)

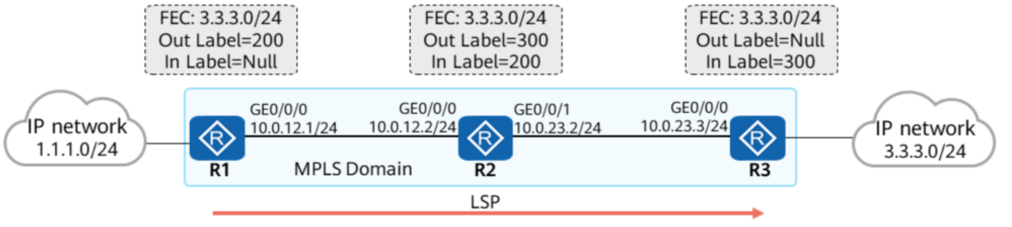
- Use case: An IGP has been deployed on R1, R2, and R3. The networks 1.1.1.0/24 and 3.3.3.0/24 can communicate with each other. In this scenario, configure static LSPs to allow the two networks to communicate through MPLS. The following figure shows the distributed labels.
- Configuration roadmap:
  1. Enable MPLS on the devices and interfaces.
  2. Configure static LSPs as planned.



Static LSP Configuration Example (2)

1. The LSR IDs of the three routers are 10.1.1.1, 10.1.1.2, and 10.1.1.3, respectively. The following example uses R1 to describe the configuration. Enable MPLS globally and on interfaces on R1.

```
[R1]mpls lsr-id 10.1.1.1
[R1]mpls
Info: Mpls starting, please wait... OK!
[R1-mpls]quit
[R1]interface GigabitEthernet 0/0/0
[R1-GigabitEthernet0/0/0]mpls
[R1-GigabitEthernet0/0/0]quit]
```



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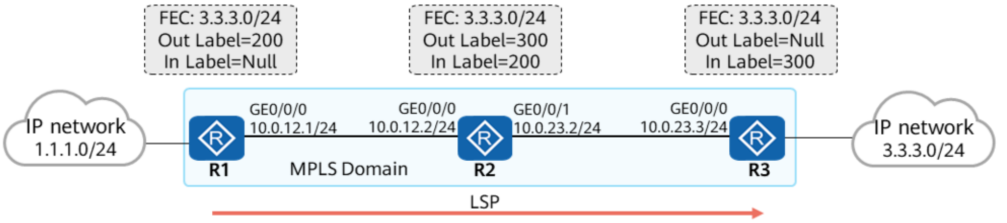
Static LSP Configuration Example (3)

2. Configure a static LSP from R1 to R3.

```
[R1] static-lsp ingress 1to3 destination 3.3.3.0 24 nexthop 10.0.12.2 out-label 200
```

```
[R2] static-lsp transit 1to3 incoming-interface GigabitEthernet 0/0/0 in-label 200 nexthop 10.0.23.3 out-label 300
```

```
[R3] static-lsp egress 1to3 incoming-interface GigabitEthernet 0/0/0 in-label 300
```



Static LSP Configuration Example - Checking the Configuration

```
[R1]display mpls lsp
----------------------------------------------------------------------
              LSP Information: STATIC LSP
----------------------------------------------------------------------
FEC            In/Out Label   In/Out IF      Vrf Name
3.3.3.0/24     NULL/200       -/GE0/0/0
```

```
[R2]display mpls lsp
----------------------------------------------------------------------
              LSP Information: STATIC LSP
----------------------------------------------------------------------
FEC            In/Out Label   In/Out IF      Vrf Name
3.3.3.0/24     200/300      GE0/0/0/GE0/0/1
```

```
[R3]display mpls lsp
----------------------------------------------------------------------
              LSP Information: STATIC LSP
----------------------------------------------------------------------
FEC            In/Out Label   In/Out IF      Vrf Name
3.3.3.0/24     300/NULL       GE0/0/0/-
```

The ping test from the host on the 1.1.1.0/24 network segment to the host on the 3.3.3.0/24 network segment is successful.

Why can bidirectional communication be implemented when only a unidirectional static LSP from 1.1.1.0/24 to 3.3.3.0/24 is configured?

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Static LSP Configuration Example - Packet Header Obtaining Analysis

No.	Time	Source	Destination	Protocol	Length	Info
5	12.109000	1.1.1.1	3.3.3.3	ICMP	102	Echo (ping) request

Frame 5: 102 bytes on wire (816 bits), 102 bytes captured (816 bits) on interface 0
Ethernet II, Src: HuaweiTe_b1:15:3e (00:e0:fc:b1:15:3e), Dst: HuaweiTe_49:20:bb (00:e0:fc:49:20:bb)
MultiProtocol Label Switching Header, Label: 300, Exp: 0, S: 1, TTL: 254
Internet Protocol Version 4, Src: 1.1.1.1, Dst: 3.3.3.3
Internet Control Message Protocol

No.	Time	Source	Destination	Protocol	Length	Info
6	12.141000	3.3.3.3	1.1.1.1	ICMP	98	Echo (ping) reply

Frame 6: 98 bytes on wire (784 bits), 98 bytes captured (784 bits) on interface 0
Ethernet II, Src: HuaweiTe_49:20:bb (00:e0:fc:49:20:bb), Dst: HuaweiTe_b1:15:3e (00:e0:fc:b1:15:3e)
Internet Protocol Version 4, Src: 3.3.3.3, Dst: 1.1.1.1
Internet Control Message Protocol

According to the obtained packet information, the packets from the host on the 1.1.1.0/24 network segment to the host on the 3.3.3.0/24 network segment are forwarded based on MPLS labels.
The packets from the host on the 3.3.3.0/24 network segment to the host on the 1.1.1.0/24 network segment are forwarded based on IP packet headers.

Quiz

1. (Multi-Answer) Which of the following statements about an MPLS header are correct?
   A. An MPLS header is 32 bits long.
   B. The value of the Label field in an MPLS header ranges from 0 to 65535.
   C. MPLS can implement multi-layer MPLS header nesting.
   D. The max_hop field in an MPLS header can be used to prevent labeled packets from being infinitely forwarded.
2. (Single-Answer) The values of the incoming and the outgoing label both range from 16 to 1023 for a static LSP to be configured on a transit LSR.
   A. True
   B. False

1. AC
2. B

Summary

- MPLS was originally proposed to solve the problem of low forwarding speed of traditional IP routers. MPLS implements fast forwarding through label headers.
- An MPLS label is a short and fixed-length identifier that has only local significance. It is used to uniquely identify the FEC to which a packet belongs. Label operations on an LSR include push, swap, and pop.
- MPLS consists of the control plane and data plane. The control plane transmits routing information and distributes labels, and the data plane forwards data.
- With the development of technologies, the advantage of MPLS in the data forwarding speed is weakened gradually, but MPLS is widely used in the VPN area due to its pros.


Thank You
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