MPLS Basic Principle

Foreword

- The course introduces the MPLS architecture that contains two planes, MPLS encapsulation mode and label format. The process of MPLS data forwarding is the key point of the course.

Objectives

- Upon completion of this course, you will be able to:
  - Describe the background and typical applications of MPLS.
  - Describe the basic concepts and working principles of MPLS.
  - Describe the process of MPLS data forwarding.

Contents

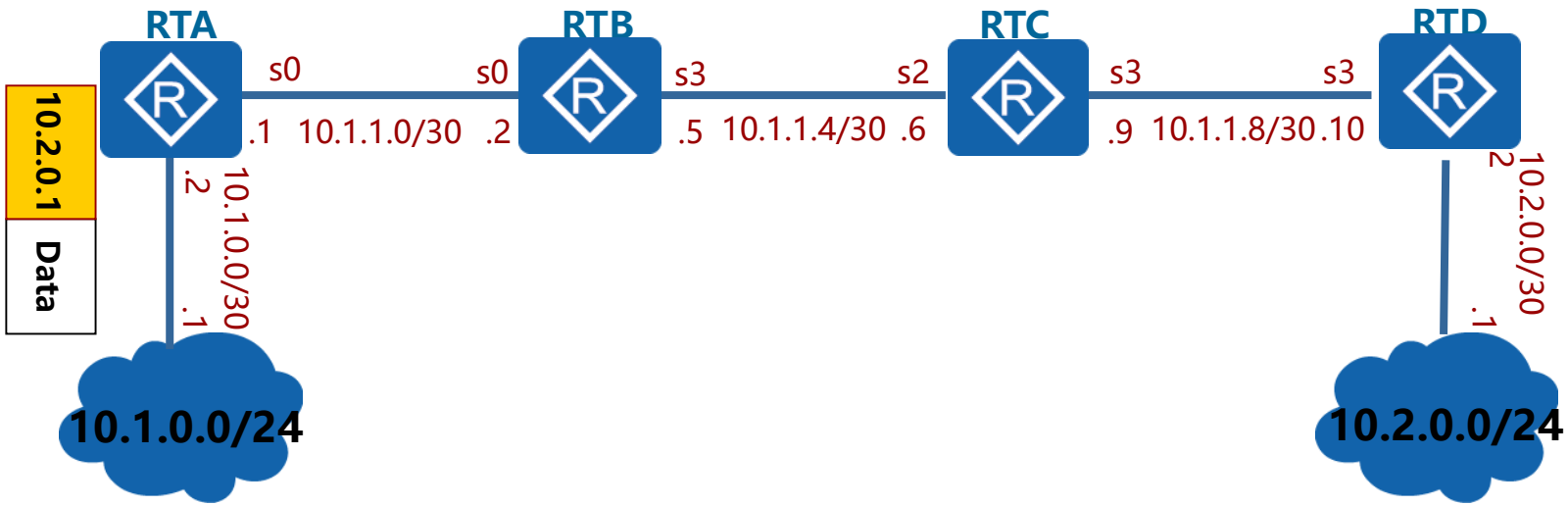
Traditional IP forwarding

Network	Nexthop
10.1.0.0/24	10.1.0.2
10.1.0.1/32	10.1.0.1
10.1.1.0/30	10.1.1.1
10.1.1.2/32	10.1.1.2
10.1.1.4/30	10.1.1.2
10.1.1.8/30	10.1.1.2
10.2.0.0/24	**10.1.1.2**

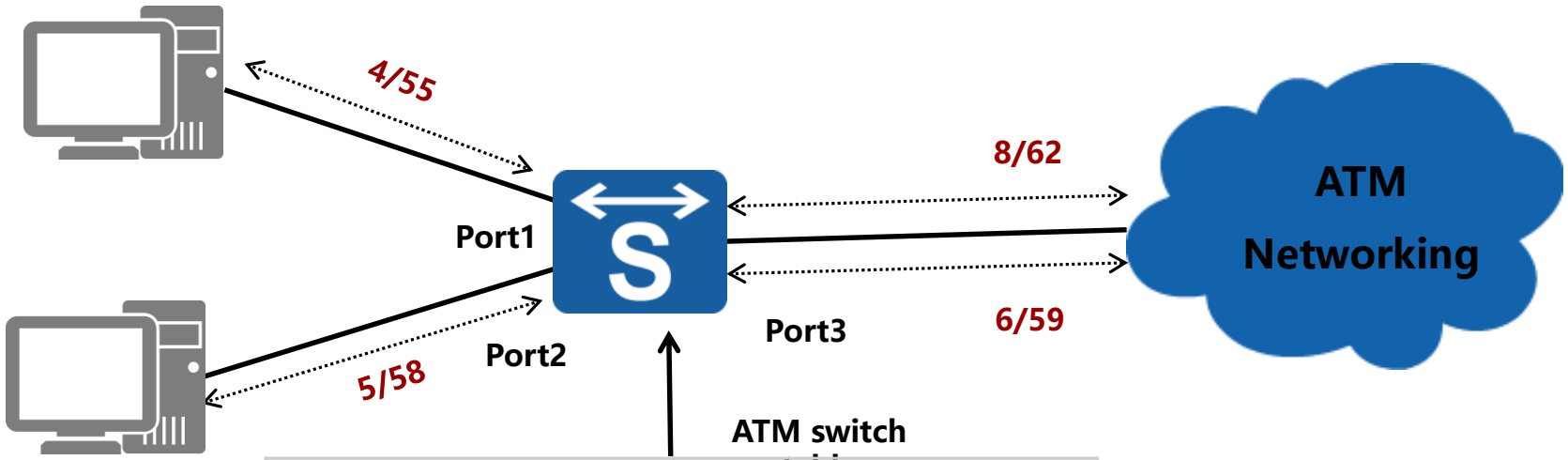
Network	Nexthop
10.1.0.0/24	10.1.1.1
10.1.1.0/30	10.1.1.2
10.1.1.1/32	10.1.1.1
10.1.1.4/30	10.1.1.5
10.1.1.6/32	10.1.1.6
10.1.1.8/30	10.1.1.6
10.2.0.0/24	**10.1.1.6**

Network	Nexthop
10.1.0.0/24	10.1.1.5
10.1.1.0/30	10.1.1.5
10.1.1.4/30	10.1.1.6
10.1.1.5/32	10.1.1.5
10.1.1.8/30	10.1.1.9
10.1.1.10/32	10.1.1.10
10.2.0.0/24	**10.1.1.10**

Network	Nexthop
10.1.0.0/24	10.1.1.9
10.1.1.0/30	10.1.1.9
10.1.1.4/30	10.1.1.9
10.1.1.8/30	10.1.1.10
10.1.1.9/32	10.1.1.9
10.2.0.0/24	**10.2.0.2**
10.2.0.1/32	10.2.0.1

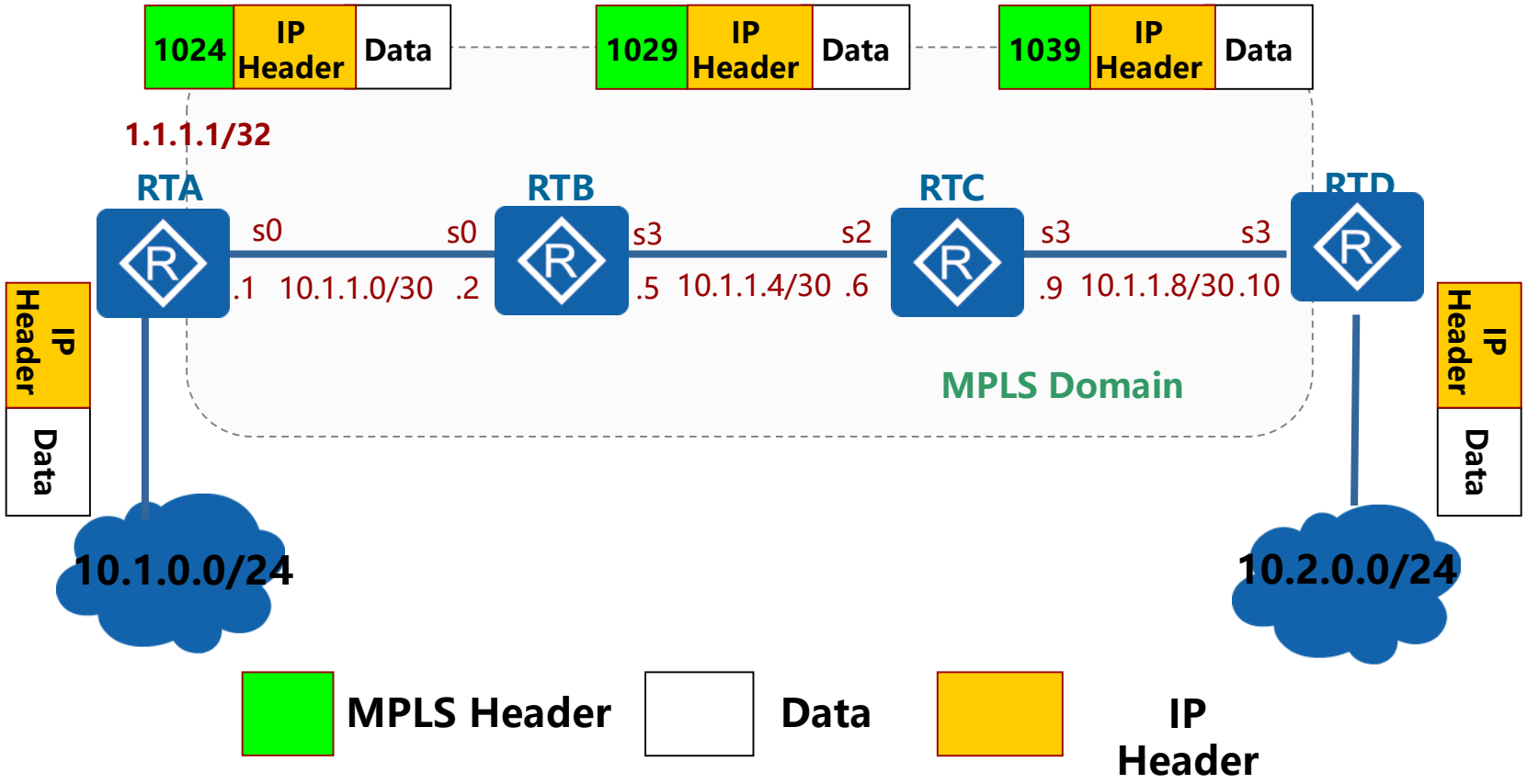


ATM cell forwarding

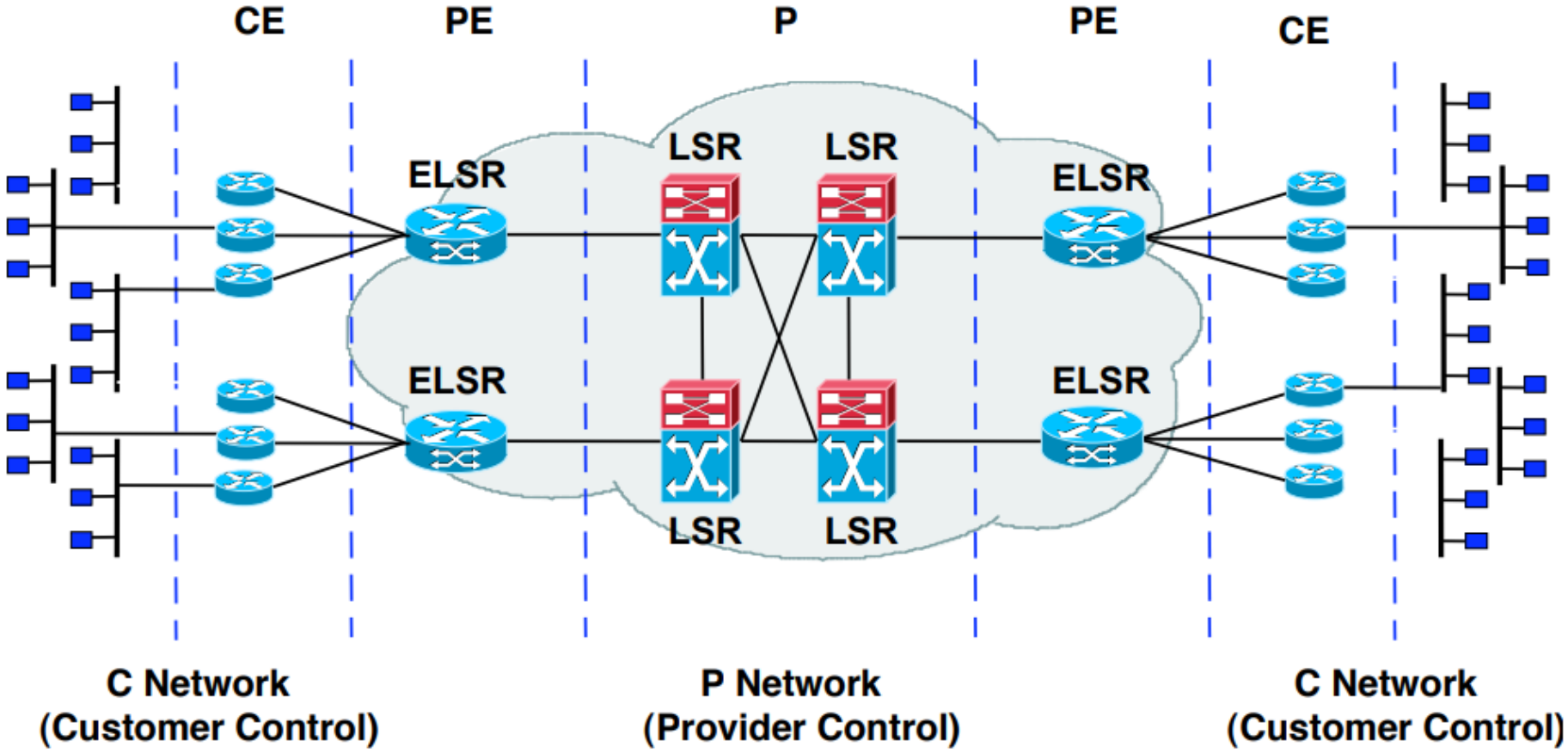


In		Out	
port	VPI/VCI	port	VPI/VCI
1	4/55	3	8/62
2	5/58	3	6/59
3	8/62	1	4/55
3	6/59	2	5/58

MPLS label forwarding



Componenti di una rete MPLS



Componenti di una rete MPLS

Edge Label Switching Router (ELSR o PE o LER)

- Aggiunge una label a pacchetti che ne sono sprovvisti all'inizio della Label Switching Path (LSP);
- Rimuove una label dai pacchetti alla fine della LSP;

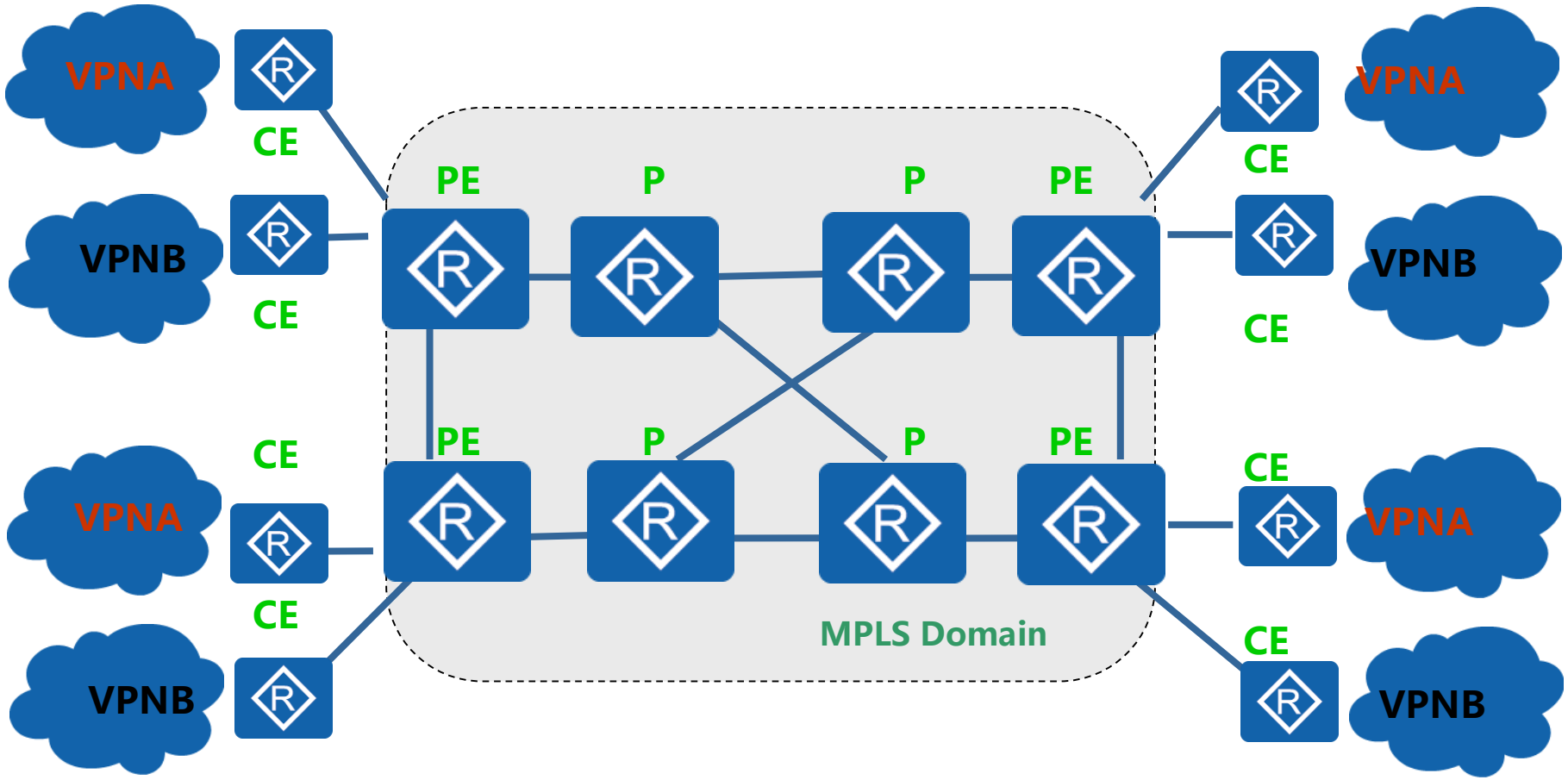
Label Switching Routers (LSR o LP)

- Inoltra i pacchetti sulla base delle informazioni contenute nelle label.

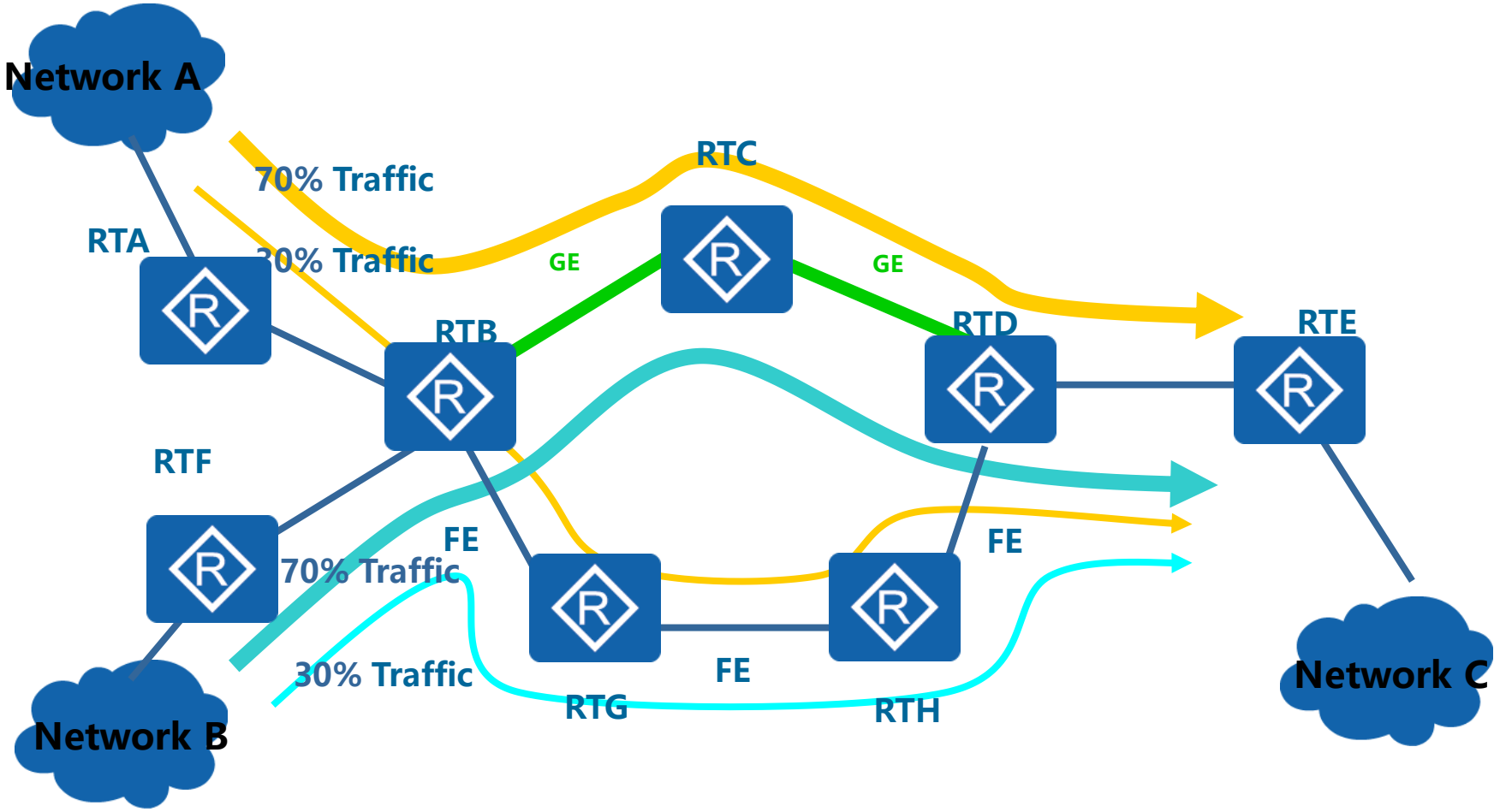
Customer Edge (CE)

- Il dispositivo del customer.

MPLS VPN Application

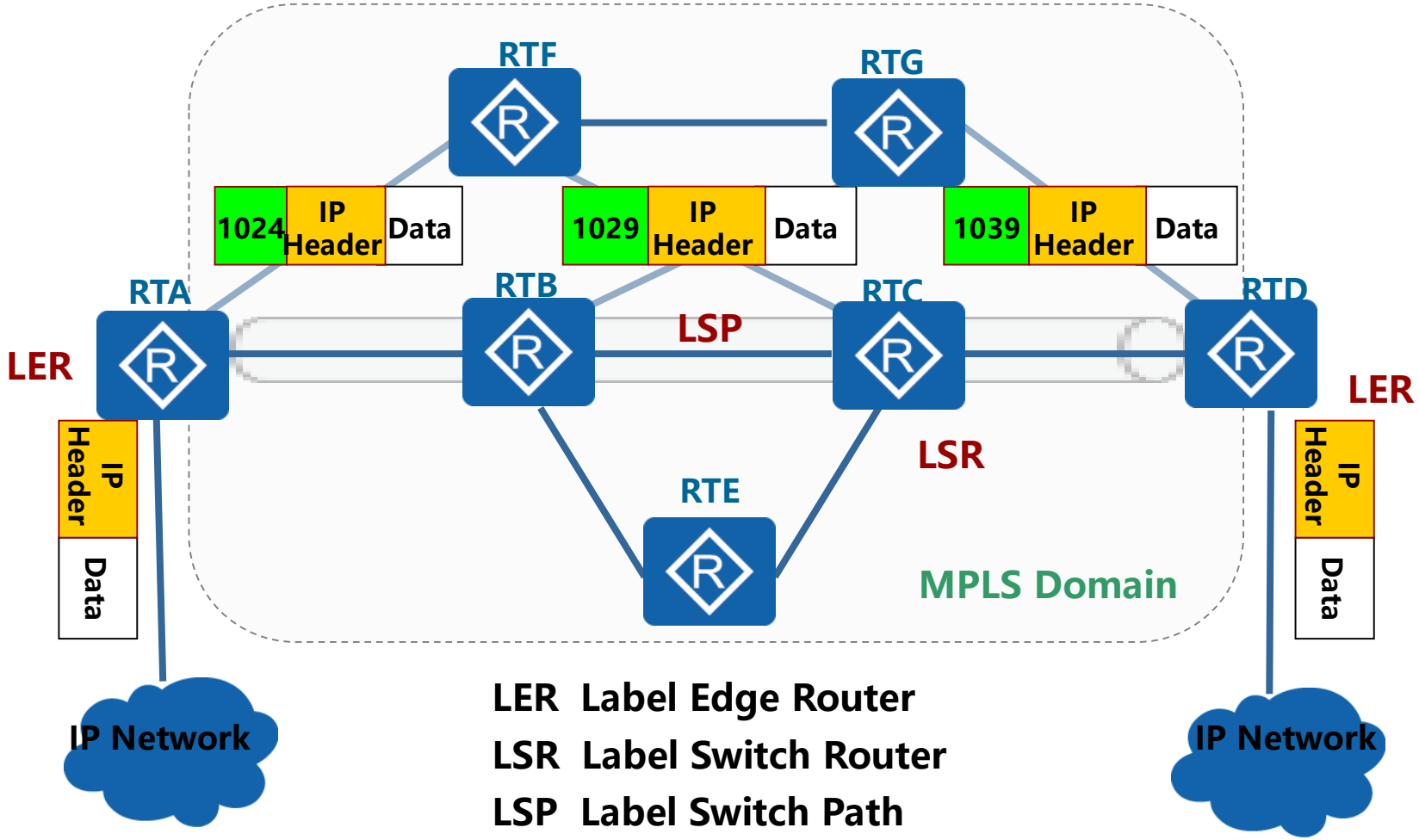


MPLS TE Application

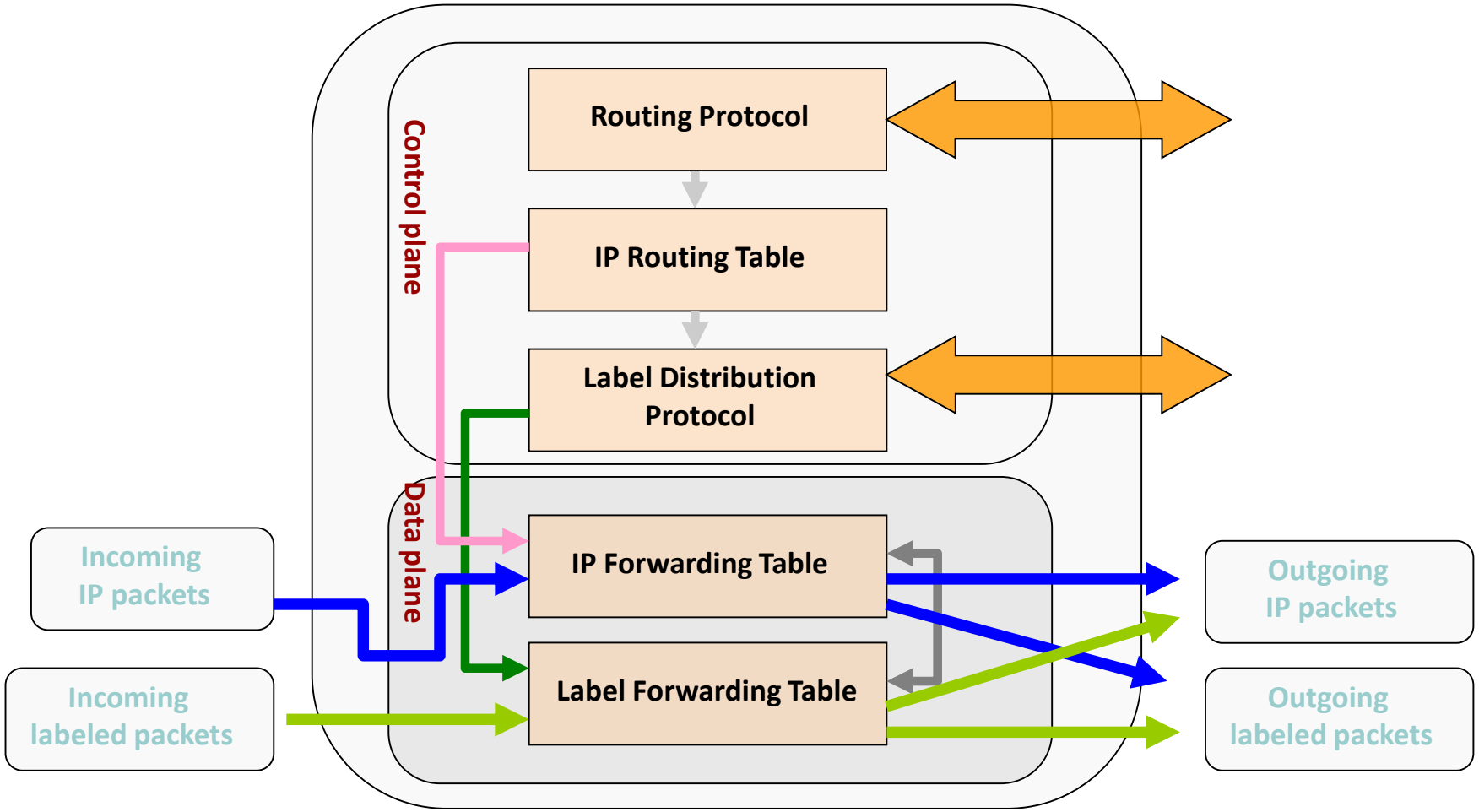


Contents

MPLS network model



MPLS control plane and forwarding plane



MPLS control plane and forwarding plane

- Control Plane: genera e mantiene le informazioni
  - Sul routing;
  - Sulle labels;
- Componenti:
  - LDP – Label Distribution Protocol:
    - Alloca le labels;
    - Crea il LIB (Label Information Base);
    - Stabilisce e rimuove i LSP (Label Switching Paths)

MPLS control plane and forwarding plane

- Forwarding Plane: inoltra pacchetti IP e pacchetti MPLS;
- FIB (Forward information Base):
  - Generato da RIB (Routing Information Base);
  - Usato per inoltrare i pacchetti IP;
- LFIB (Label Forwarding Information Base):
  - generato da LDP su un LSR;
  - Usato per inoltrare le label;

Contents

Frame mode MPLS

- MPLS has two encapsulation modes: Frame mode and cell mode (ATM uses the MPLS cell encapsulation mode, which is not involved in this course). In frame encapsulation mode, an MPLS label header is added between the Layer 2 header and Layer 3 header of a packet. Ethernet and PPP use this encapsulation mode.

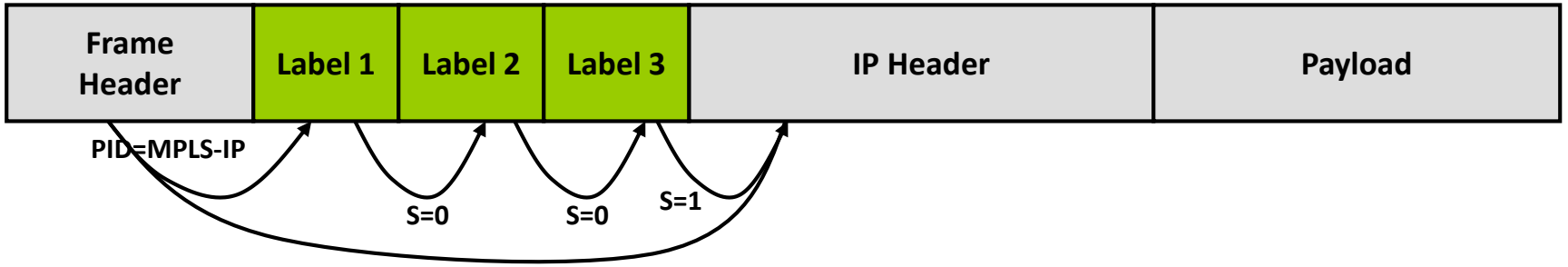
Layer 2 frame format

MPLS frame mode encapsulation

MPLS Header

- The total length of MPLS header is 4byte (32bit)
- The length of Label field is 20bit
- The length of EXP（Experimental Use）field is 3bit
- The length of S（Bottom of Stack）field is1bit
- The length of TTL field is 8bit

MPLS Label Nesting



- PID indicates the types of packet follows Frame Header
  - Ethernet: 0x0800=IPv4, 0x8847=Unicast MPLS packet, 0x8848=Multicast MPLS packet
  - PPP: 0x8021=IPCP, 0x8281=Unicast MPLS packet, 0x8283=Multicast MPLS packet
- S indicates whether it is the last label
- Applications of label nesting
  - MPLS VPN
  - MPLS TE

Contents

FEC and NHLFE

- FEC (Forwarding Equivalence Class) is a set of data flows with certain common characteristics. These data flows are processed by the LSR in the same way during the forwarding process.
- FEC can be classified based on the address, service type, and QoS. For example, in the traditional IP forwarding that uses the longest matching algorithm, all packets **to** the same route are an FEC.

FEC and NHLFE

- NHLFE (Next Hop Label Forwarding Entry): The NHLFE is used for label forwarding. It contains the following basic information:
  - Next hop of the packet
  - How to perform a tag operation (including pushing a new tag, popping a tag, and swapping the original tag with a new tag).
  - The NHLFE may also contain other information, such as the link layer encapsulation used for sending packets.

Example of FEC and NHLFE

- *FEC: Forwarding Equivalence Classes*
- **NHLFE: Next Hop Label Forwarding Entry**

```
<RTA>display  mpls lsp include 10.2.0.0 24 verbose
------------------------------------------------
                 LSP Information: LDP LSP
------------------------------------------------
  No                    :  1
  VrfIndex              :
  Fec                   :  10.2.0.0/24
  Nexthop               :  10.1.1.2
  In-Label              :  NULL
  Out-Label             :  1030
  In-Interface          :  ----------
  Out-Interface         :  Serial0
  LspIndex              :  10249
  Token                 :  0x22005
  LsrType               :  Ingress
  Outgoing token        :  0x0
  Label Operation       :  PUSH
  Mpls-Mtu              :  1500
  TimeStamp             :  822sec
```

Label Switching Path

- Before forwarding packets, MPLS must allocate labels to packets and establish an LSP.
- LSPs can be:
  - STATIC
  - DYNAMIC

Label Switching Path - Static

- You can manually allocate labels to set up static LSPs.
- A static LSP is valid for only the local node, and nodes on the LSP are unaware of the entire LSP.
- A static LSP is set up **without any label distribution protocols** or exchange of control packets.
- Static LSPs have low costs and are recommended for small-scale networks with simple and stable topologies.
- Static LSPs cannot adapt to network topology changes and must be configured by an administrator.

Label Switching Path - Dynamic

- Dynamic LSPs are established using **label distribution protocols**.
- A label distribution protocol defines FECs, distributes labels, and establishes and maintains LSPs.
- MPLS can use the following protocols for label distribution:
  - **LDP**

    The Label Distribution Protocol (LDP) is designed for distributing labels. It sets up an LSP hop by hop according to Interior Gateway Protocol (IGP) and Border Gateway Protocol (BGP) routing information.

Label Switching Path - Dynamic

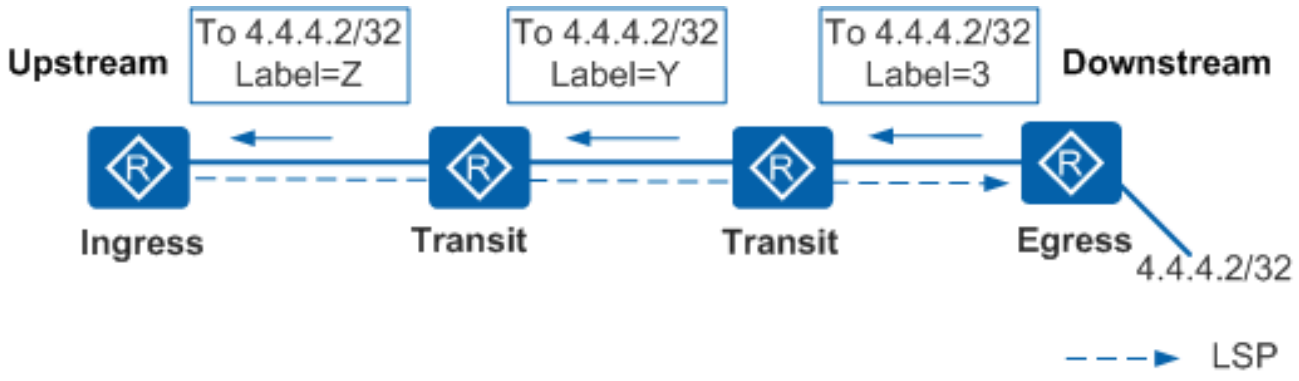
- MPLS can use the following protocols for label distribution:
  - **RSVP-TE**

    Resource Reservation Protocol Traffic Engineering (RSVP-TE) is an extension of RSVP and is used to set up a constraint-based routed LSP (CR-LSP). In contrast to LDP LSPs, RSVP-TE tunnels are characterized by bandwidth reservation requests, bandwidth constraints, link "colors" (designating administrative groups), and explicit paths.
  - **MP-BGP**

    MP-BGP is an extension to BGP and allocates labels to MPLS VPN routes and inter-AS VPN routes.

Label Switching Path - Dynamic

- MPLS labels are distributed **from downstream LSRs to upstream LSRs**.
- A downstream LSR identifies FECs based on the IP routing table, allocates a label to each FEC, and records the mapping between labels and FECs.
- The downstream LSR then encapsulates the mapping into a message and sends the message to the upstream LSR.
- As this process proceeds on all the LSRs, the LSRs create a label forwarding table and establish an LSP.



MPLS Forwarding

- **Label operations** involved in MPLS packet forwarding include **push**, **swap**, and **pop**:
  - Push

    When an IP packet enters an MPLS domain, **the ingress node adds a new label to the packet between the Layer 2 header and the IP header**. Alternatively, an LSR adds a new label to the top of the label stack.
  - Swap

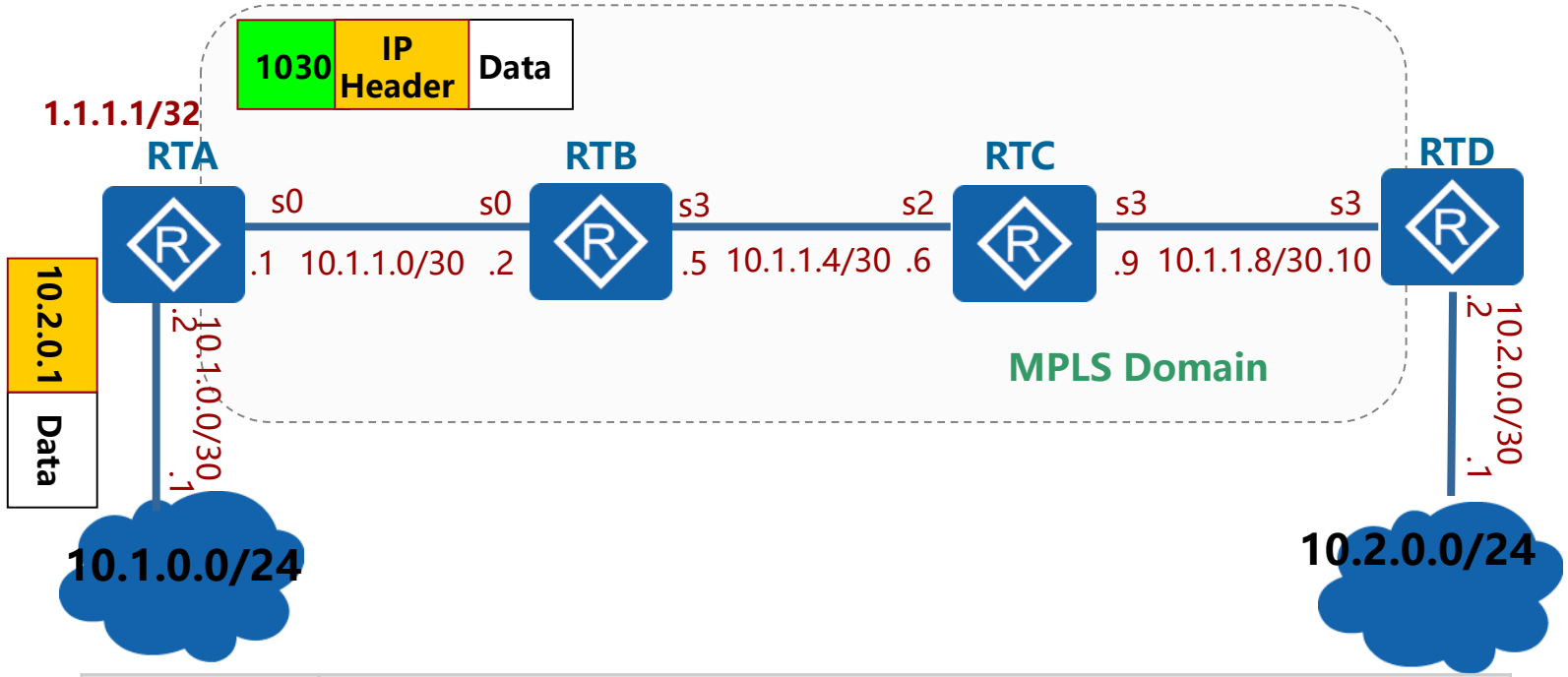
    When a packet is transferred within the MPLS domain, **a local node swaps the label at the top of the label stack in the MPLS packet for the label allocated by the next hop** according to the label forwarding table.
  - Pop

    When a packet leaves the MPLS domain**, the label is popped out** of (removed from) the MPLS packet.

MPLS Forwarding

- A label is **invalid at the last hop** of an MPLS domain.
- The **penultimate hop popping (PHP)** feature applies. On the penultimate node, the label is popped out of the packet to reduce the size of the packet that is forwarded to the last hop. Then, the last hop directly forwards the IP packet or forwards the packet by using the second label.
- By default, PHP is configured on the egress node. The egress node supporting PHP allocates the label with the value of 3 to the penultimate hop.

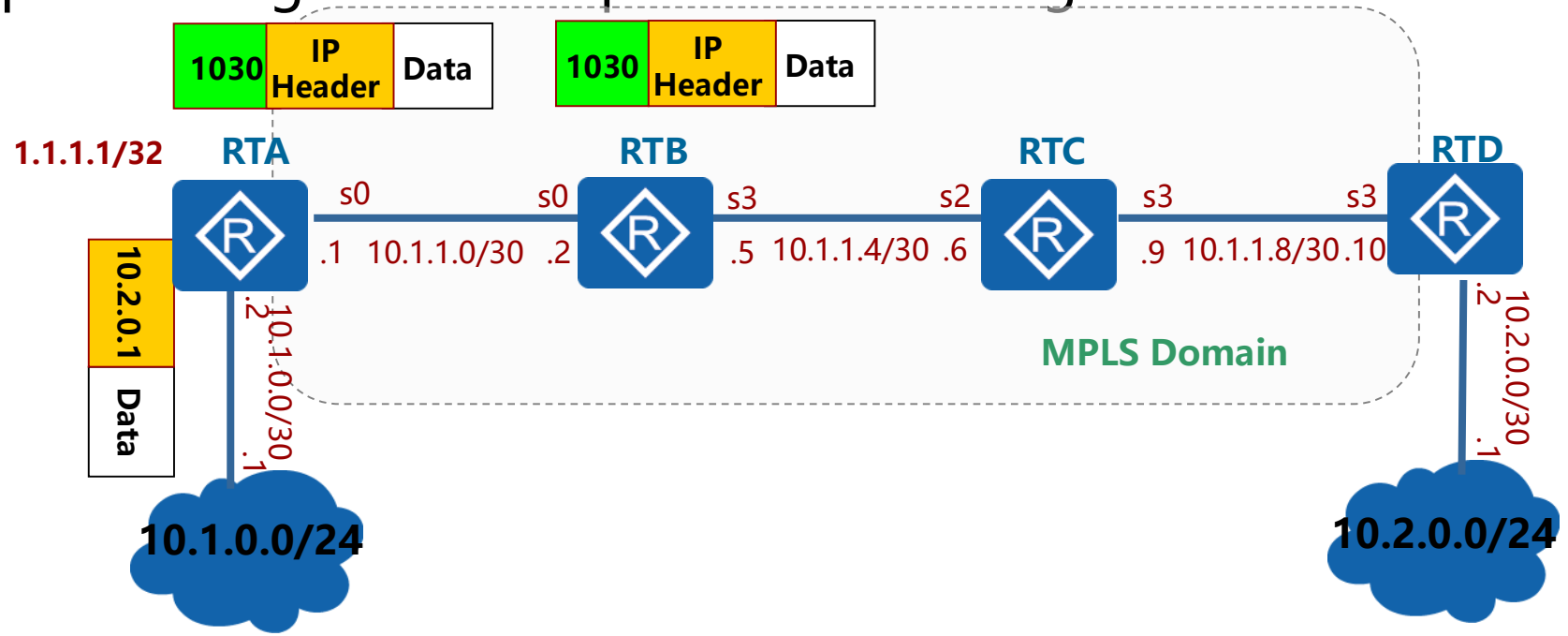
MPLS Forwarding - Ingress LER （RTA）



FEC	NHLFE			
	NextHop	Out Interface	Label Operation	Others
10.2.0.0	10.1.1.2	Serial0	Push	.....

MPLS Forwarding - LSR （RTB)

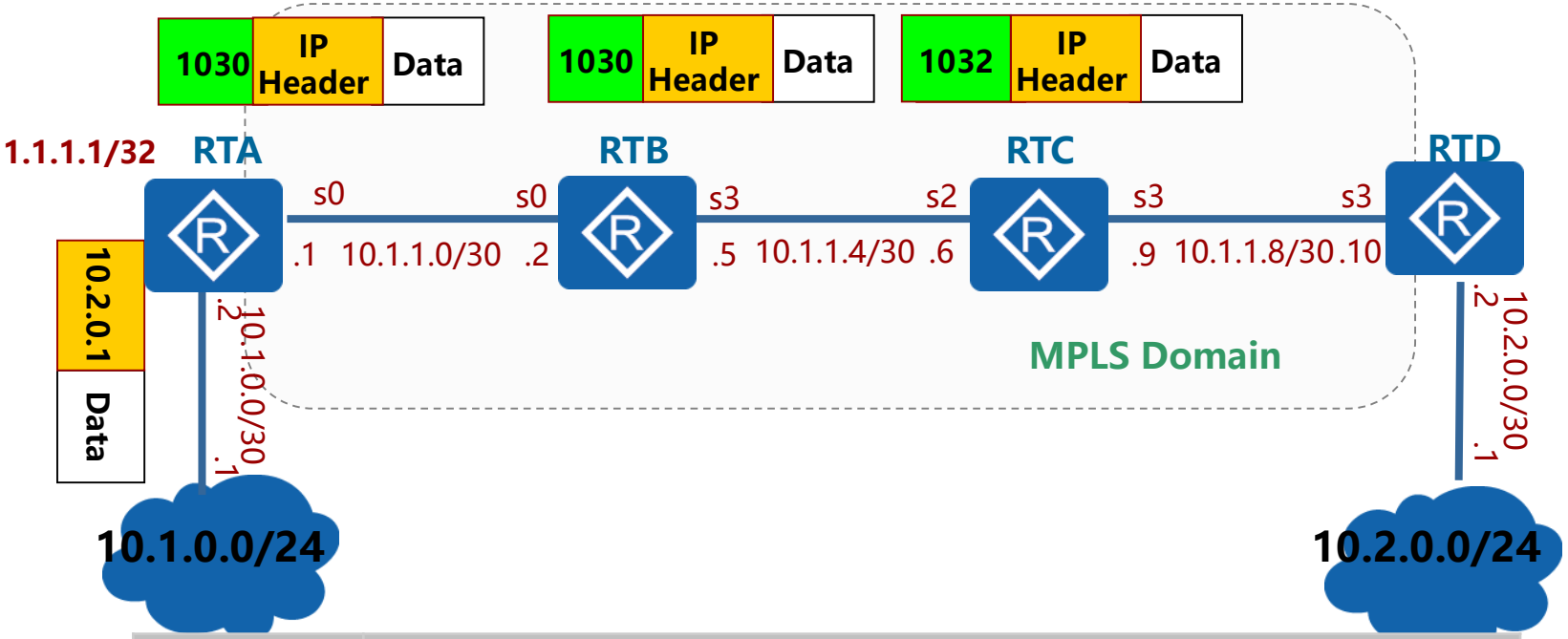
- On the transit node, the ILM(Incoming Label Map) table and NHLFE table are queried to guide MPLS packet forwarding.



InLabel	NHLFE			
	NextHop	Out Interface	Label Operation	Others
1030	10.1.1.6	Serial3	SWAP	.....

MPLS Forwarding - LSR （RTC)

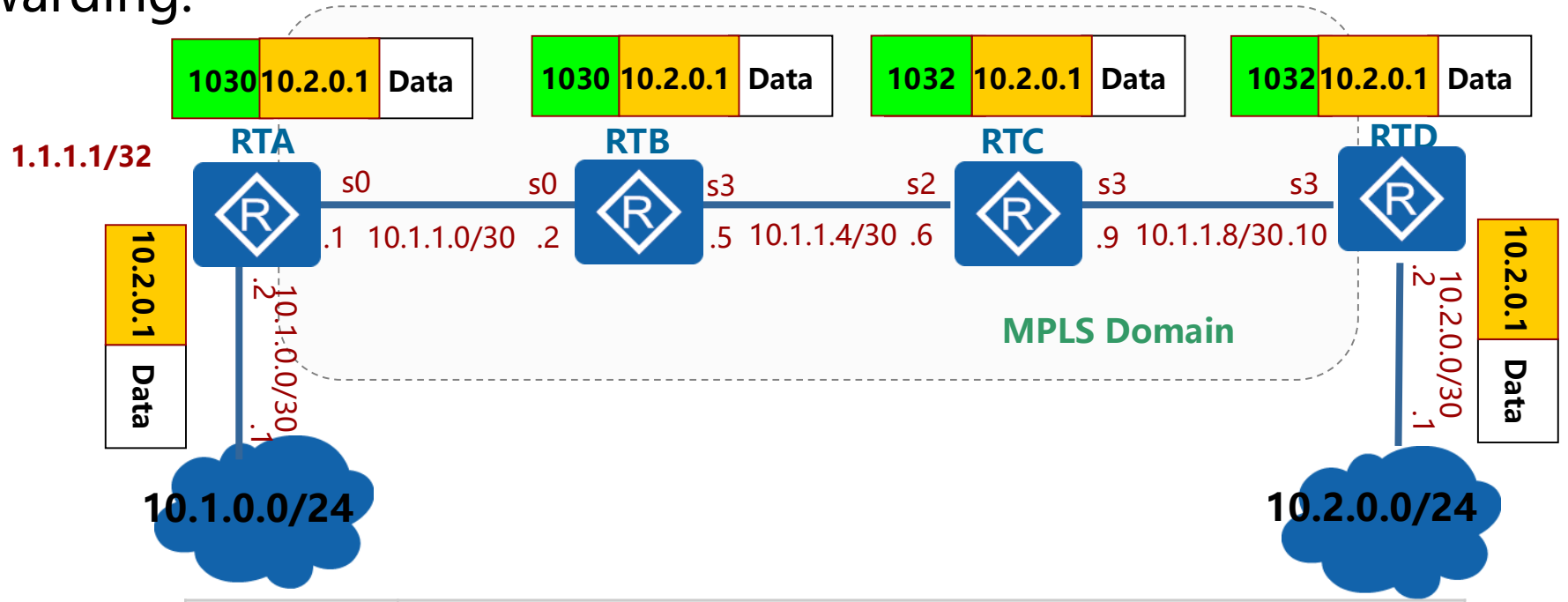
- On the transit node, the ILM(Incoming Label Map) table and NHLFE table are queried to guide MPLS packet forwarding.



InLabel	NHLFE			
	NextHop	Out Interface	Label Operation	Others
1030	10.1.1.10	Serial3	SWAP	.....

MPLS Forwarding - Egress LER (RTD)

- On the egress node, the ILM table is queried to guide MPLS packet forwarding.



InLabel	NHLFE			
	NextHop	Out Interface	Label Operation	Others
1032	10.2.0.2	--------	POP	.....

Quiz

1. Which field in the MPLS header is used to identify the stack bottom label ? ( )

   A. Label

   B. EXP

   C. S

   D. TTL

2. Which of the following actions can be performed when packets are forwarded based on MPLS labels? ( )

   A. Push

   B. Pop

   C. Swap

   D. Switch

Contents

Static LSP

Static LSPs are manually set up and applied to networks with simple and stable network topologies.

- **LSR-ID**

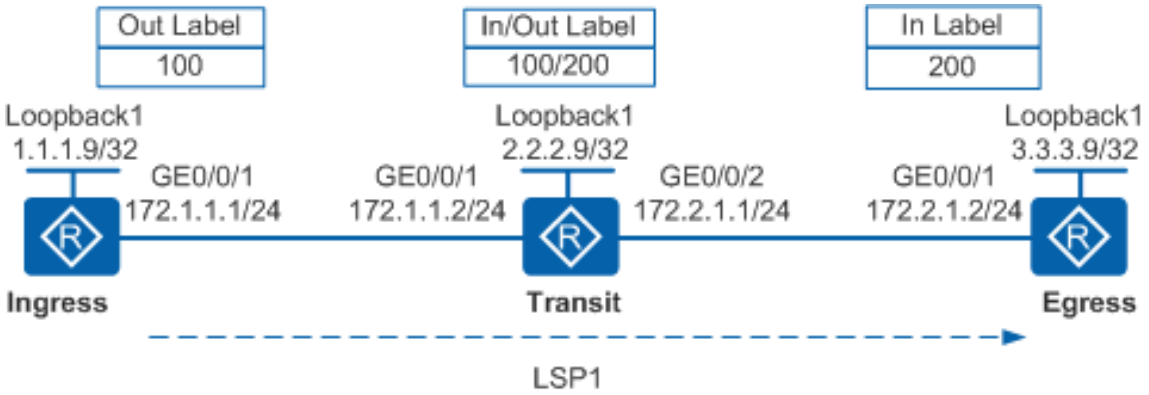
  LSR ID identifies an LSR on a network. To enhance network reliability, you are advised to use the IP address of a loopback interface on the LSR as the LSR ID.

  - system-view
    - mpls lsr-id <lsr-id>

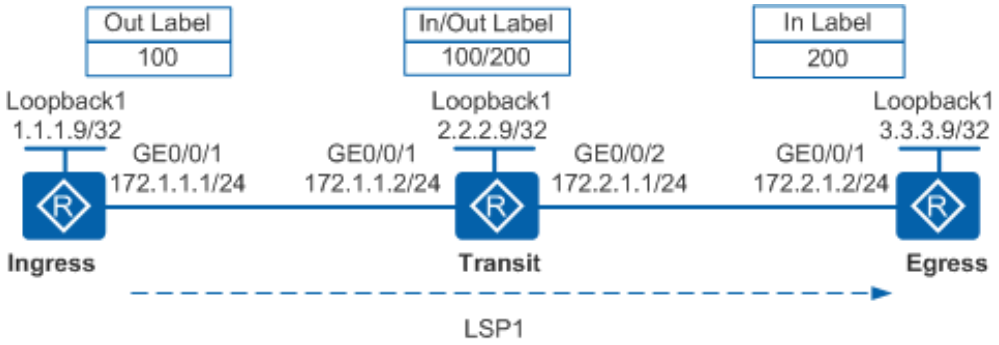
- **Enable MPLS**
  - system-view
    - mpls
  - interface <type> <number>
    - mpls

Static LSP

- Static LSPs and static Constraint-based Routed LSPs (CR-LSPs) share the same label space (16-1023).
- Note that the value of the outgoing label of the previous node is equal to the value of the incoming label of the next node.



Static LSP



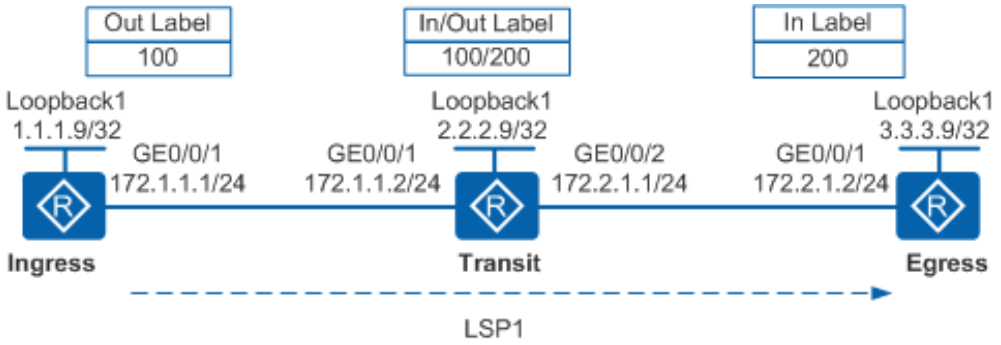
Ingress-node

- system-view
  - 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
  - static-lsp ingress LSP1 destination 3.3.3.9 32 nexthop 172.1.1.2 out-label 100

Transit-node

- system-view
  - 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
  - static-lsp transit LSP1 incoming-interface gigabitethernet 0/0/1 in-label 100 nexthop 172.2.1.2 out-label 200

Static LSP



Egress-node

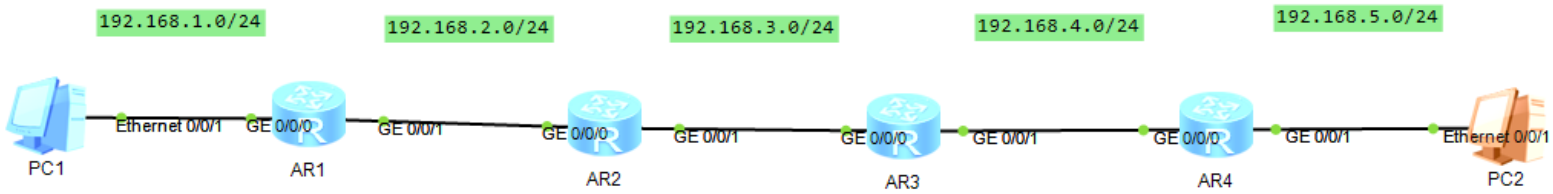
- system-view
  - static-lsp egress lsp-name incoming-interface interface-type interface-number in-label in-label [lsrid ingress-lsr-id tunnel-id tunnel-id]
  - static-lsp egress LSP1 incoming-interface gigabitethernet 0/0/1 in-label 200

Static LSP

Verifica del funzionamento:

- Run the **display default-parameter mpls management** command to check default configurations of the MPLS management module.
- Run the **display mpls static-lsp [lsp-name] [{ include | exclude } ip-address mask-length] [verbose]** command to check the static LSP.
- Run the **display mpls label static available [[label-from label-index] label-number label-number]** command to check information about labels available for transmitting static services.

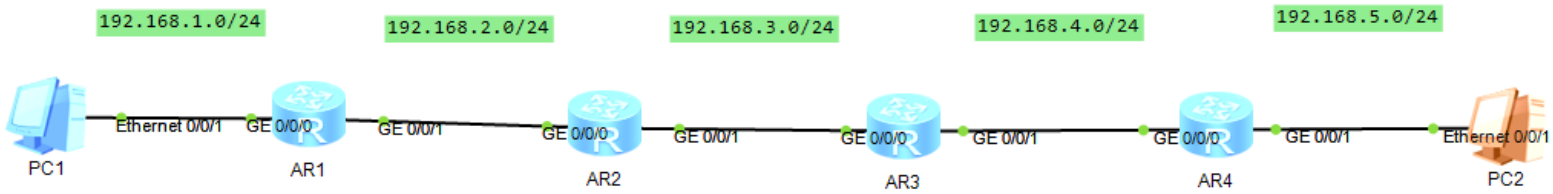
Static LSP



NB: la configurazione deve essere bidirezionale!

```
#R1
 system-view
 #
mpls lsr-id 1.1.1.1
mpls
#
#
interface GigabitEthernet0/0/0
 ip address 192.168.1.254 255.255.255.0
 ospf network-type p2p
 dhcp select interface
#

interface GigabitEthernet0/0/1
 ip address 192.168.2.1 255.255.255.0
 ospf network-type p2p
 mpls
#
#
static-lsp ingress R1R2 destination 192.168.5.0 24
nexthop 192.168.2.2 out-label 100

static-lsp egress R4R1 incoming-interface
GigabitEthernet0/0/1 in-label 240
#
```

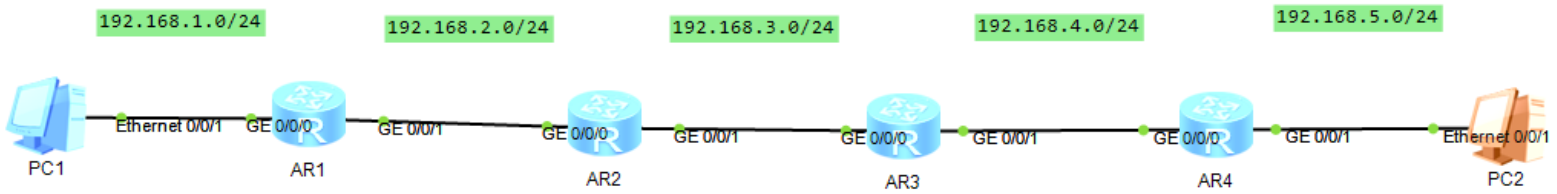
Static LSP




```
#R2
 #
mpls lsr-id 2.2.2.2
mpls
#
#
interface GigabitEthernet0/0/0
 ip address 192.168.2.2 255.255.255.0
 ospf network-type p2p
 mpls
#
interface GigabitEthernet0/0/1
 ip address 192.168.3.2 255.255.255.0
 ospf network-type p2p
 mpls
#
```

```
#
static-lsp transit R1R4 incoming-interface
GigabitEthernet0/0/0 in-label 100 nexthop 192.168.3.3
out-label 120

static-lsp transit R4R1 incoming-interface
GigabitEthernet0/0/1 in-label 230 nexthop 192.168.2.1
out-label 240
#
```

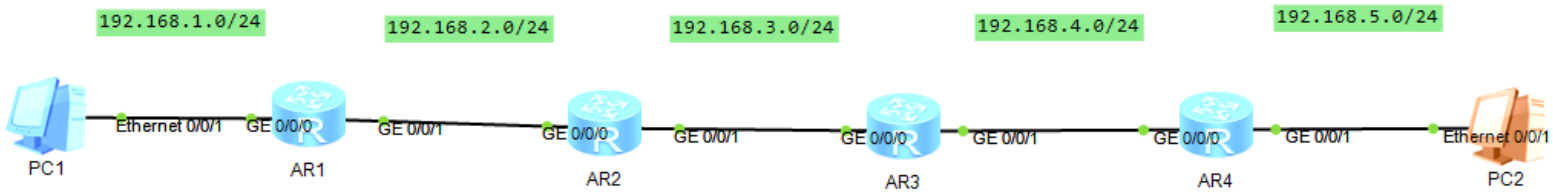
Static LSP




```
#R3
 #
mpls lsr-id 3.3.3.3
mpls
#
#
interface GigabitEthernet0/0/0
 ip address 192.168.3.3 255.255.255.0
 ospf network-type p2p
 mpls
#
interface GigabitEthernet0/0/1
 ip address 192.168.4.3 255.255.255.0
 ospf network-type p2p
 mpls
#
```

```
#
static-lsp transit R1R4 incoming-interface
GigabitEthernet0/0/0 in-label 120 nexthop 192.168.4.4
out-label 130

static-lsp transit R4R1 incoming-interface
GigabitEthernet0/0/1 in-label 200 nexthop 192.168.3.2
out-label 230
#
```

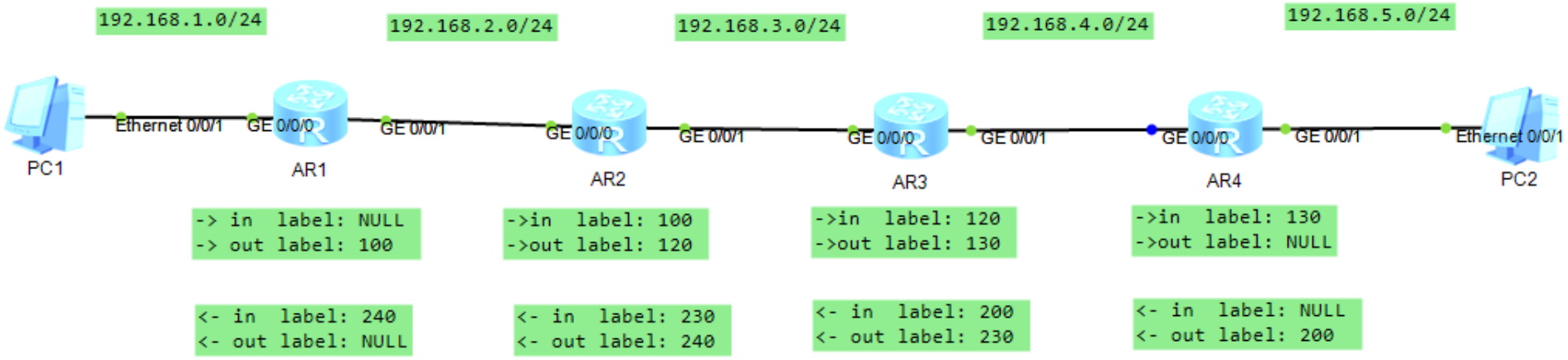
Static LSP




```
#R4
#
mpls lsr-id 4.4.4.4
mpls
#
#
interface GigabitEthernet0/0/0
 ip address 192.168.4.4 255.255.255.0
 ospf network-type p2p
 mpls
#
interface GigabitEthernet0/0/1
 ip address 192.168.5.254 255.255.255.0
 dhcp select interface
##
```

```
#
static-lsp egress R1R4 incoming-interface
GigabitEthernet0/0/0 in-label 130

static-lsp ingress R4R1 destination 192.168.1.0 24
nexthop 192.168.4.3 out-label 200
#
```

Static LSP



Static LSP

```
PC>ping 192.168.5.253 -c 1000

Ping 192.168.5.253: 32 data bytes, Press Ctrl_C to break
Request timeout!
From 192.168.5.253: bytes=32 seq=2 ttl=124 time=31 ms
From 192.168.5.253: bytes=32 seq=3 ttl=124 time=31 ms
From 192.168.5.253: bytes=32 seq=4 ttl=124 time=32 ms
From 192.168.5.253: bytes=32 seq=5 ttl=124 time=31 ms
From 192.168.5.253: bytes=32 seq=6 ttl=124 time=31 ms
From 192.168.5.253: bytes=32 seq=7 ttl=124 time=31 ms
From 192.168.5.253: bytes=32 seq=8 ttl=124 time=32 ms

--- 192.168.5.253 ping statistics ---
  8 packet(s) transmitted
  7 packet(s) received
  12.50% packet loss
  round-trip min/avg/max = 0/31/32 ms
```

```
PC>tracert 192.168.5.253

traceroute to 192.168.5.253, 8 hops max
(ICMP), press Ctrl+C to stop
 1   192.168.1.254    15 ms   16 ms   16 ms
 2   192.168.2.2      15 ms   16 ms   <1 ms
 3   192.168.3.3      47 ms   31 ms   31 ms
 4   192.168.4.4      31 ms   32 ms   31 ms
 5   192.168.5.253    31 ms   31 ms   32 ms

PC>
```

20	8.250000	192.168.5.253	192.168.1.253	ICMP	Echo (ping) reply	(id=0x6f93, seq(be/le)=52/13312, ttl=127)
21	9.265000	192.168.1.253	192.168.5.253	ICMP	Echo (ping) request	(id=0x7093, seq(be/le)=53/13568, ttl=127)
22	9.281000	192.168.5.253	192.168.1.253	ICMP	Echo (ping) reply	(id=0x7093, seq(be/le)=53/13568, ttl=127)

```
⊞ Frame 10: 78 bytes on wire (624 bits), 78 bytes captured (624 bits)
⊟ Ethernet II, Src: HuaweiTe_d0:7e:3f (00:e0:fc:d0:7e:3f), Dst: HuaweiTe_ae:7b:5f (00:e0:fc:ae:7b:5f)
  ⊞ Destination: HuaweiTe_ae:7b:5f (00:e0:fc:ae:7b:5f)
  ⊞ Source: HuaweiTe_d0:7e:3f (00:e0:fc:d0:7e:3f)
    Type: MPLS label switched packet (0x8847)
⊟ MultiProtocol Label Switching Header, Label: 200, Exp: 0, S: 1, TTL: 127
    MPLS Label: 200
    MPLS Experimental Bits: 0
    MPLS Bottom Of Label Stack: 1
    MPLS TTL: 127
⊞ Internet Protocol, Src: 192.168.5.253 (192.168.5.253), Dst: 192.168.1.253 (192.168.1.253)
⊞ Internet Control Message Protocol
```

Dynamic LSP

- The Label Distribution Protocol (LDP) is a control protocol of Multiprotocol Label Switching (MPLS) that functions like a signaling protocol on a traditional network.
- **LDP Peers**
  - Two LSRs that use LDP to set up an LDP session and exchange label messages are LDP peers.
  - LDP peers learn labels from each other over the LDP session between them.
- **LDP Adjacency**
  - When an LSR receives a Hello message from a peer, an LDP adjacency is set up between the two LSRs. Two types of LDP adjacencies are used:
  - Local adjacency: adjacency discovered by multicasting a Hello message (link Hello message)
  - Remote adjacency: adjacency discovered by unicasting a Hello message (targeted Hello message)

Dynamic LSP

- **LDP Session**
  - LSRs exchange messages over an LDP session that include label mapping and release messages. LDP sessions can be set up only between LDP peers:
    - Local LDP session: set up between two LSRs that are directly connected
    - Remote LDP session: set up between two LSRs that are directly or indirectly connected
  - An LSR can set up local and remote LDP sessions simultaneously.
- **LDP messages**:
  - Discovery message.
  - Session message.
  - Advertisement message.
  - Notification message.

Dynamic LSP

LDP phases:

- LDP Session Setup
  - After LSRs send Hello messages to discover LDP peers, the LSRs establish an LDP session. LDP peers periodically send Hello and Keepalive messages to maintain the LDP session.
  - LDP peers periodically send Hello messages to maintain the adjacency
  - LDP peers periodically send Keepalive messages over the LDP session to maintain the LDP session.
- LDP LSP Setup
  - After a session is established, LDP peers advertise the mappings between FECs and labels and set up an LSP.

Dynamic LSP

Procedure di Advertisment e Management

- **Label Advertisment Modes**;

  An LSR assigns a label to a specified FEC and notifies its upstream LSR of the label. This means that labels are allocated by a downstream LSR and distributed from downstream to upstream.

  - Downstream Unsolicited (DU) mode

    An LSR distributes labels to a specified FEC without having to receive Label Request messages from its upstream LSR.

  - Downstream on Demand (DoD) mode

    An LSR distributes labels to a specified FEC only after receiving Label Request messages from its upstream LSR.

Dynamic LSP

Procedure di Advertisment e Management

- **Label Distribution Control Model**;
- The label distribution control mode refers to a label distribution method used on an LSR during LSP establishment.
  - Independent Mode
    A local LSR can distribute a label bound to an FEC and then inform the upstream LSR, without waiting for the label distributed by the downstream LSR
  - Ordered Mode
    An LSR advertises the mapping between a label and an FEC to its upstream LSR only when this LSR is the outgoing node of the FEC or receives the Label Mapping message of the next hop for the FEC

Dynamic LSP

Procedure di Advertisment e Management

- **Label Retention Model**;

  The label retention mode refers to the way an LSR processes the label mapping received but not immediately used.

  - Liberal mode

    Upon receiving a Label Mapping message from a neighbor LSR, an LSR retains the message regardless of whether the neighbor LSR is its next hop.

  - Conservative mode

    Upon receiving a Label Mapping message from a neighbor LSR, an LSR retains the message only when the neighbor LSR is its next hop.

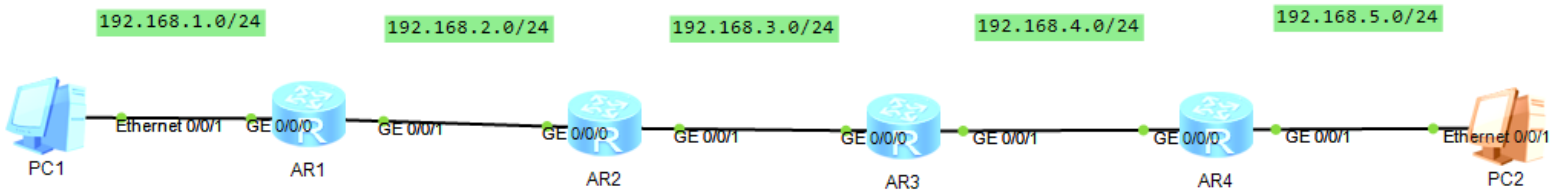
Dynamic LSP

Configurazione Base: (comandi in system-view)

- Configurazione lsr-id: mpls lsr-id lsr-id
- Abilitazione MPLS globale: mpls
- Abilitazione globale LDP: mpls ldp

- Configurazione della sessione LOCALE:
  - interface <type> <number>
  - mpls
  - mpls ldp
- Configurazione della sessione REMOTA:
  - mpls ldp remote-peer <remote peer name>
  - remote-ip <ip address>

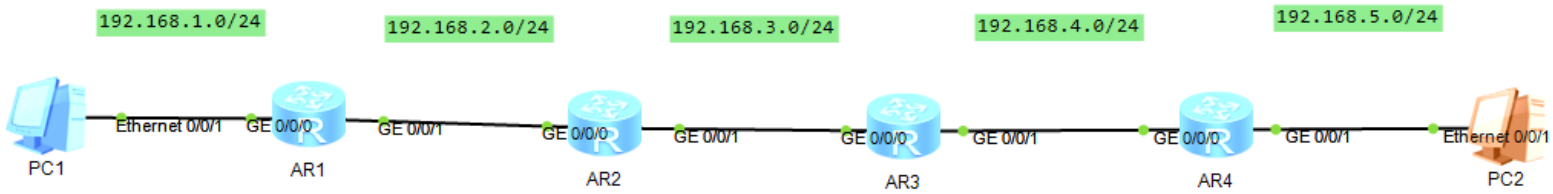
Dynamic LSP



#R1
 #
mpls lsr-id 172.16.31.1
mpls
#
mpls ldp
#
interface GigabitEthernet0/0/0
 ip address 192.168.1.254 255.255.255.0
 ospf network-type p2p
 dhcp select interface
#

#
interface GigabitEthernet0/0/1
 ip address 192.168.2.1 255.255.255.0
 ospf network-type p2p
 mpls
 mpls ldp
#

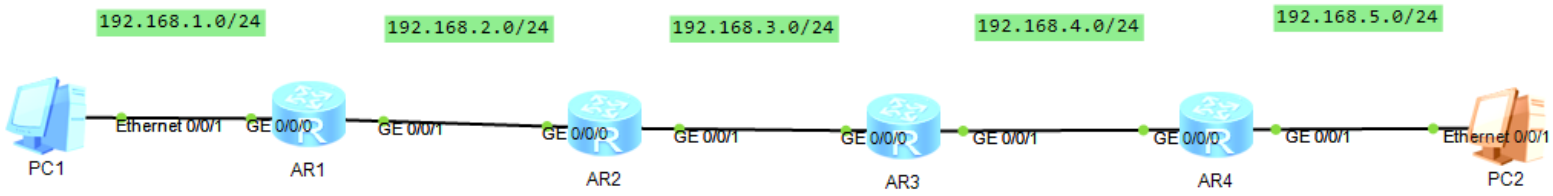
Dynamic LSP



#R2 – R3
#
mpls lsr-id 172.16.31.X
mpls
#
mpls ldp
#
interface GigabitEthernet0/0/0
 ip address 192.168.2.2 255.255.255.0
 ospf network-type p2p
 mpls
 mpls ldp
#

#
interface GigabitEthernet0/0/1
 ip address 192.168.3.2 255.255.255.0
 ospf network-type p2p
 mpls
 mpls ldp
#

Dynamic LSP

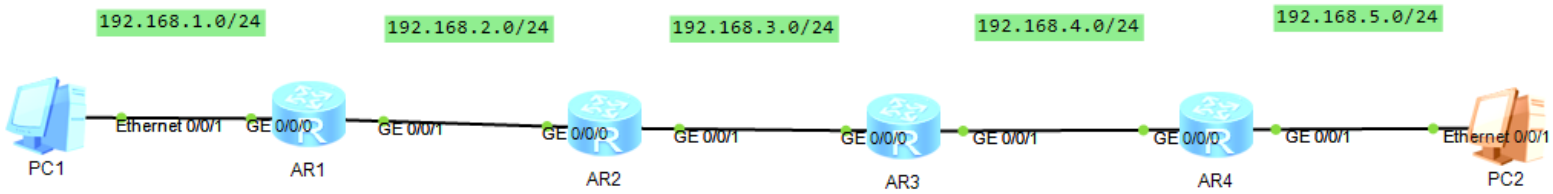


#R4
#
mpls lsr-id 172.16.31.4
mpls
 lsp-trigger all
#

#
interface GigabitEthernet0/0/0
 ip address 192.168.4.4 255.255.255.0
 ospf network-type p2p
 mpls
 mpls ldp
#

#
interface GigabitEthernet0/0/1
 ip address 192.168.5.254 255.255.255.0
 dhcp select interface
#

Dynamic LSP



Note alla configurazione:

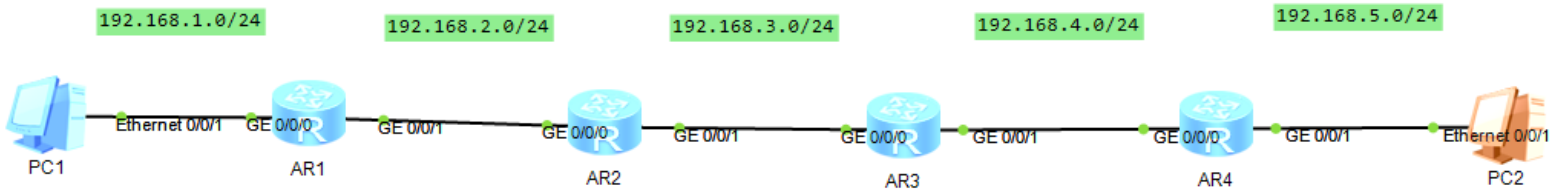
- mpls lsr-id mutuato dalla loopback;
- gli indirizzi delle loopback sono inseriti in OSPF;
- con questa configurazione il traffico tra PC1 e PC2 non transita in MPLS;

Dynamic LSP

```
<R1>dis mpls ldp lsp

 LDP LSP Information
 ------------------------------------------------------------------------------
 DestAddress/Mask   In/OutLabel    UpstreamPeer    NextHop
OutInterface
 ------------------------------------------------------------------------------

 172.16.31.1/32     3/NULL         172.16.31.2     127.0.0.1       InLoop0
*172.16.31.1/32     Liberal/1024                   DS/172.16.31.2
 172.16.31.2/32     NULL/3         -               192.168.2.2     GE0/0/1
 172.16.31.2/32     1024/3         172.16.31.2     192.168.2.2
GE0/0/1
 172.16.31.3/32     NULL/1025      -               192.168.2.2     GE0/0/1
 172.16.31.3/32     1025/1025      172.16.31.2     192.168.2.2
GE0/0/1
 172.16.31.4/32     NULL/1026      -               192.168.2.2     GE0/0/1
 172.16.31.4/32     1026/1026      172.16.31.2     192.168.2.2
GE0/0/1
 ------------------------------------------------------------------------------
 TOTAL: 7 Normal LSP(s) Found.
 TOTAL: 1 Liberal LSP(s) Found.
 TOTAL: 0 Frr LSP(s) Found.
 A '*' before an LSP means the LSP is not established
 A '*' before a Label means the USCB or DSCB is stale
 A '*' before a UpstreamPeer means the session is stale
 A '*' before a DS means the session is stale
 A '*' before a NextHop means the LSP is FRR LSP
```

Compaiono solo le rotte /32!

Dynamic LSP



Modifica della configurazione su tutti i router:

- system-view
  - mpls
    - lsp-trigger all

Con questa modifica tutte le entries della tabella di routing diventano un FEC e possono essere propagate.

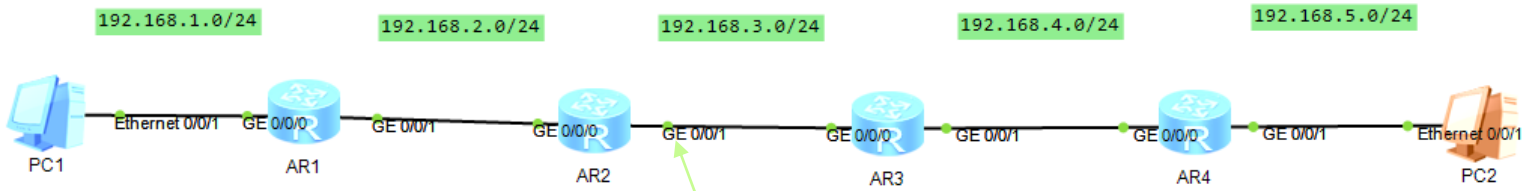
Dynamic LSP

```
<R1>dis mpls ldp lsp

 LDP LSP Information
 ------------------------------------------------------------------------------
 DestAddress/Mask   In/OutLabel    UpstreamPeer    NextHop         OutInterface
 ------------------------------------------------------------------------------

 172.16.31.0/24     3/NULL         172.16.31.2     172.16.31.1     Loop0
*172.16.31.0/24     Liberal/3                      DS/172.16.31.2
 172.16.31.1/32     3/NULL         172.16.31.2     127.0.0.1       InLoop0
*172.16.31.1/32     Liberal/1024                   DS/172.16.31.2
 172.16.31.2/32     NULL/3         -               192.168.2.2     GE0/0/1
 172.16.31.2/32     1024/3         172.16.31.2     192.168.2.2     GE0/0/1
 172.16.31.3/32     NULL/1025      -               192.168.2.2     GE0/0/1
 172.16.31.3/32     1025/1025      172.16.31.2     192.168.2.2     GE0/0/1
 172.16.31.4/32     NULL/1026      -               192.168.2.2     GE0/0/1
 172.16.31.4/32     1026/1026      172.16.31.2     192.168.2.2     GE0/0/1
 192.168.1.0/24     3/NULL         172.16.31.2     192.168.1.254   GE0/0/0
*192.168.1.0/24     Liberal/1027                   DS/172.16.31.2
 192.168.2.0/24     3/NULL         172.16.31.2     192.168.2.1     GE0/0/1
*192.168.2.0/24     Liberal/3                      DS/172.16.31.2
 192.168.3.0/24     NULL/3         -               192.168.2.2     GE0/0/1
 192.168.3.0/24     1027/3         172.16.31.2     192.168.2.2     GE0/0/1
 192.168.4.0/24     NULL/1028      -               192.168.2.2     GE0/0/1
 192.168.4.0/24     1028/1028      172.16.31.2     192.168.2.2     GE0/0/1
 192.168.5.0/24     NULL/1029      -               192.168.2.2     GE0/0/1
 192.168.5.0/24     1029/1029      172.16.31.2     192.168.2.2     GE0/0/1
 ------------------------------------------------------------------------------
 TOTAL: 16 Normal LSP(s) Found.
 TOTAL: 4 Liberal LSP(s) Found.
 TOTAL: 0 Frr LSP(s) Found.
 A '*' before an LSP means the LSP is not established
 A '*' before a Label means the USCB or DSCB is stale
 A '*' before a UpstreamPeer means the session is stale
 A '*' before a DS means the session is stale
 A '*' before a NextHop means the LSP is FRR LSP
```

Dynamic LSP

```
<R1>dis mpls lsp
------------------------------------------------------------------------------
                LSP Information: LDP LSP
------------------------------------------------------------------------------
FEC                 In/Out Label  In/Out IF                      Vrf Name
172.16.31.1/32      3/NULL        -/-
172.16.31.2/32      NULL/3        -/GE0/0/1
172.16.31.2/32      1024/3        -/GE0/0/1
172.16.31.3/32      NULL/1025     -/GE0/0/1
172.16.31.3/32      1025/1025     -/GE0/0/1
172.16.31.4/32      NULL/1026     -/GE0/0/1
172.16.31.4/32      1026/1026     -/GE0/0/1
192.168.2.0/24      3/NULL        -/-
172.16.31.0/24      3/NULL        -/-
192.168.1.0/24      3/NULL        -/-
192.168.3.0/24      NULL/3        -/GE0/0/1
192.168.3.0/24      1027/3        -/GE0/0/1
192.168.4.0/24      NULL/1028     -/GE0/0/1
192.168.4.0/24      1028/1028     -/GE0/0/1
192.168.5.0/24      NULL/1029     -/GE0/0/1
192.168.5.0/24      1029/1029     -/GE0/0/1
<R1>
```

Dynamic LSP



11 6.891000	192.168.1.253	192.168.5.253	ICMP	Echo (ping) reply	(id=0xffc6, seq(be/le)=3/768, ttl=127)
12 7.906000	192.168.5.253	192.168.1.253	ICMP	Echo (ping) request	(id=0x00c7, seq(be/le)=4/1024, ttl=127)
13 7.937000	192.168.1.253	192.168.5.253	ICMP	Echo (ping) reply	(id=0x00c7, seq(be/le)=4/1024, ttl=127)
14 8.953000	192.168.5.253	192.168.1.253	ICMP	Echo (ping) request	(id=0x01c7, seq(be/le)=5/1280, ttl=127)
15 8.969000	192.168.1.253	192.168.5.253	ICMP	Echo (ping) reply	(id=0x01c7, seq(be/le)=5/1280, ttl=127)

```
⊞ Frame 11: 78 bytes on wire (624 bits), 78 bytes captured (624 bits)
⊞ Ethernet II, Src: HuaweiTe_f0:58:b8 (00:e0:fc:f0:58:b8), Dst: HuaweiTe_ae:7b:5e (00:e0:fc:ae:7b:5e)
⊟ MultiProtocol Label Switching Header, Label: 1029, Exp: 0, S: 1, TTL: 126
    MPLS Label: 1029
    MPLS Experimental Bits: 0
    MPLS Bottom Of Label Stack: 1
    MPLS TTL: 126
⊞ Internet Protocol, Src: 192.168.1.253 (192.168.1.253), Dst: 192.168.5.253 (192.168.5.253)
⊞ Internet Control Message Protocol
```

MPLS - TE

- **LSP**

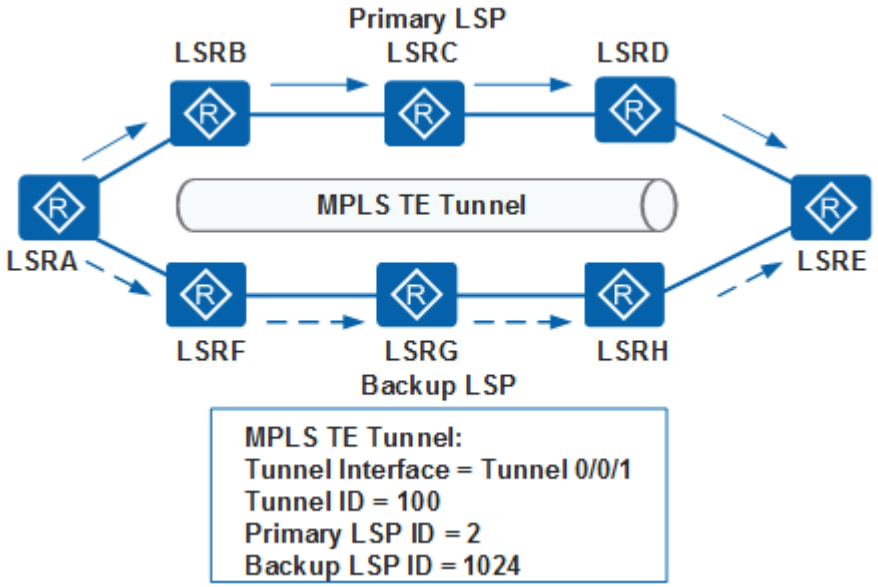
  On a label switched path (LSP), traffic forwarding is determined by the labels added to packets by the ingress node of the LSP. An LSP can be considered as a tunnel because traffic is transparently transmitted on intermediate nodes along the LSP.

- **MPLS TE Tunnel**

  MPLS TE usually associates multiple LSPs with a virtual tunnel interface to form an MPLS TE tunnel. An MPLS TE tunnel involves the following terms:

  - Tunnel interface: a point-to-point virtual interface used to encapsulate packets. Similar to a loopback interface, a tunnel interface is a logical interface.
  - Tunnel ID: a decimal number that uniquely identifies an MPLS TE tunnel to facilitate tunnel planning and management.
  - LSP ID: a decimal number that uniquely identifies an LSP to facilitate LSP planning and management.

MPLS - TE



- Two LSPs are available on the network.
- The path LSRA->LSRB->LSRC->LSRD->LSRE is the primary LSP with an LSP ID of 2.
- The path LSRA->LSRF->LSRG->LSRH->LSRE is the backup LSP with an LSP ID of 1024.
- The two LSPs form an MPLS TE tunnel with a tunnel ID of 100, and the tunnel interface is Tunnel0/0/1.

MPLS - TE

Comandi in system-view

- mpls
- mpls te
- quit
- interface <type> <number>
  - mpls
  - mpls te

MPLS - TE

Configurazione del tunnel (in system-view)

- interface tunnel <number>
  - ip address <ip_add>
  - tunnel-protocol mpls te
  - destination <ip_add>

    The destination address of the tunnel is configured, which is usually the LSR ID of the egress node.
  - mpls te tunnel-id <tunnel-id>
  - mpls te signaling-protocol cr-static
  - mpls te commit

MPLS - TE

Configurazione del cr-lsp su router (system-view)

- Ingress
  - static-cr-lsp ingress { tunnel-interface tunnel interface-number | tunnel-name } destination destination-address { nexthop next-hop-address | outgoing-interface interface-type interface-number } * out-label out-label
    es: static-cr-lsp ingress Tunnel0/0/1 destination 10.1.3.1 nexthop 10.1.1.2 out-label 237
- Transit
  - static-cr-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 [description description]
    es: static-cr-lsp transit tunnel39 incoming-interface gigabitethernet 1/0/0 in-label 123 outgoing-interface gigabitethernet 2/0/0 out-label 253 bandwidth ct0 20

MPLS - TE

Configurazione del cr-lsp su router (system-view)

- Egress
  - static-cr-lsp egress lsp-name [incoming-interface interface-type interface-number] in-label in-label [lsrid ingress-lsr-id tunnel-id tunnel-id]

    es: static-cr-lsp egress tunnel34 incoming-interface gigabitethernet 1/0/0 in-label 233

MPLS - TE

Dynamic MPLS TE tunnels are set up using RSVP-TE signaling and are changed according to network changes. On a large-scale network, dynamic MPLS TE tunnels reduce the burden of per-hop configuration. Configuring a dynamic MPLS TE tunnel is the basis for configuring advanced features of MPLS TE.

- Configure an IGP to ensure reachable routes between nodes.
- Configure an LSR ID for each node.
- Enable MPLS globally on each node.
- Enable MPLS on each interface of each node.

MPLS - TE

Enabling MPLS TE and RSVP-TE (system-view)

- mpls
- mpls te
- mpls rsvp-te
- quit
- interface <type> <number>
- mpls
- mpls te
- mpls rsvp-te

MPLS - TE

Configuring an MPLS TE Tunnel Interface (system-view)

- interface tunnel <number>
- ip address <ip_address>
- tunnel-protocol mpls te
- destination <dest_ip_address>

  A tunnel destination address is configured, which is usually the LSR ID of the egress.
- mpls te tunnel-id <id>
- mpls te signal-protocol rsvp-te
- mpls te commit

MPLS - TE

Advertising TE Link Information (system-view)

- Nodes on an MPLS network use OSPF TE to exchange TE link attributes such as bandwidth and colors to generate TEDBs.
- TEDB information is used by CSPF to calculate paths for MPLS TE tunnels. Current, the device can use two methods to advertise TE information to generate TEDBs.
  - OSPF TE

    OSPF extension used on an MPLS TE network. OSPF areas do not support TE by default.
  - IS-IS TE

    IS-IS extension used on an MPLS TE network.

MPLS - TE

Advertising TE Link Information con OSPF (system-view)

- ospf <process_id>
- opaque-capability enable
- area <area_id>
- mpls-te enable

MPLS - TE

Configuring Path Calculation (system-view)

- To calculate a tunnel path meeting specified constraints, CSPF should be configured on the ingress.
- CSPF extends the shortest path first (SPF) algorithm and is able to calculate the shortest path meeting MPLS TE requirements.
- CSPF calculates paths using the following information:
  - Link state information sent by IGP-TE and saved in TEDBs;
  - Network resource attributes, such as the maximum available bandwidth, maximum reservable bandwidth, and affinity property, sent by IGP-TE and saved in TEDBs;
  - Configured constraints such as explicit paths

MPLS - TE

Configuring Path Calculation (system-view)

- mpls
- mpls te cspf
- mpls te cspf preferred-igp { isis [isis-process-id [level-1 | level-2]] | ospf [ospf-process-id [area { area-id-1 | area-id-2 }]] }

  A preferred IGP is specified. By default, OSPF is preferred for CSPF path calculation.

Summary

- Background of MPLS
- Basic Concepts of MPLS
- MPLS packet format
- MPLS Forwarding Principle


Thank You
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