MPLS

A Tutorial

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Agenda

1. MPLS overview and LSP types
2. Label Distribution Protocol (LDP)
3. RSVP-TE
4. Questions

Introduction

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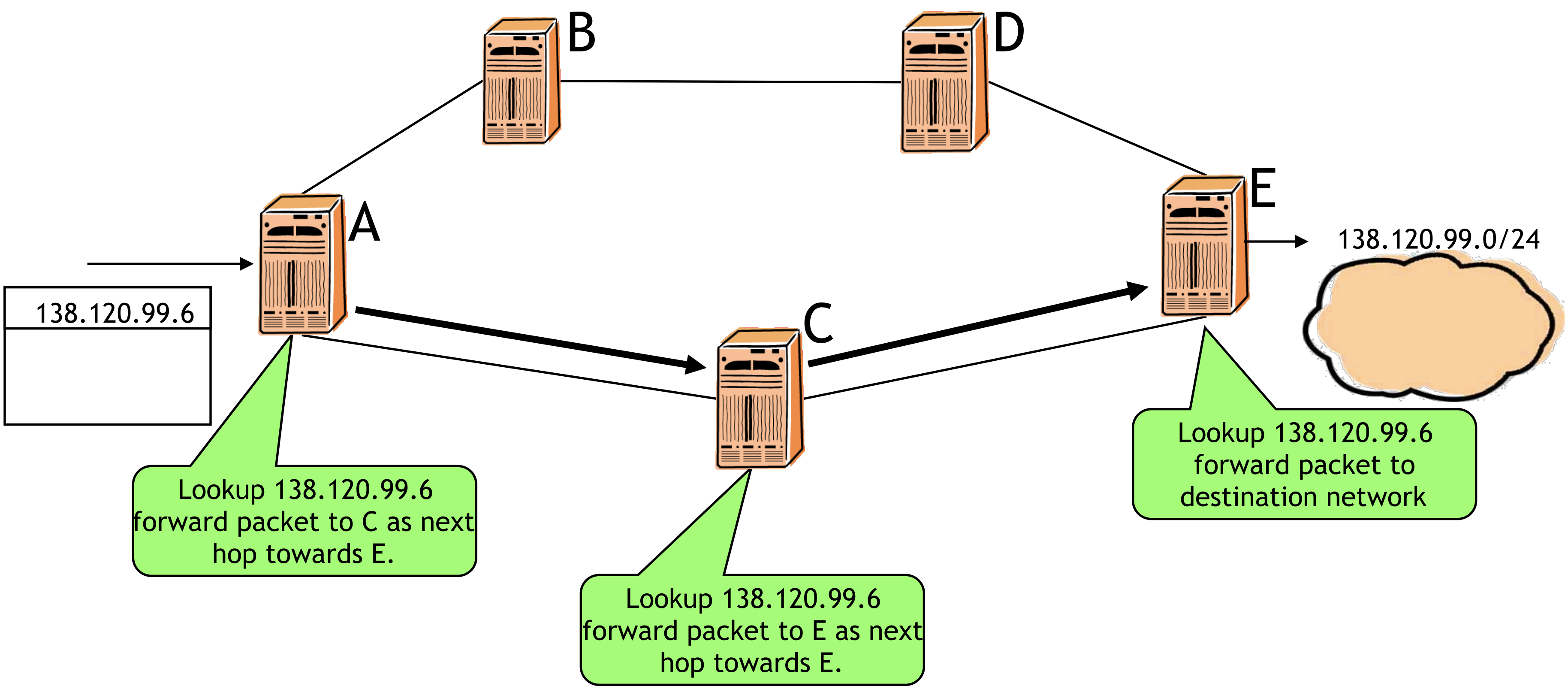
- Director, Platform Strategy – IP Routing and Transport Regional Business Centre APAC, Alcatel-Lucent
- Key focus areas:
  - Routing platform evolution, virtualisation and SDN
  - Large-scale IP/MPLS networks
  - L2/L3 VPNs
  - Carrier Ethernet
  - Next-generation mobile backhaul networks

1 MPLS overview and LSP types

Motivation: Classical Connectionless IP Networks

- Packets are forwarded hop-by-hop, with no ordering or delivery guarantees.
- An independent forwarding decision is made at each hop.



Motivation: Classical Connectionless IP Network

- <u>Definition:</u> Forwarding Equivalence Class (FEC) represents *“a group of packets which are forwarded in the same manner (e.g., over the same path, with the same forwarding treatment)”*
- An IP router considers two packets to be in the same FEC if an IP prefix in the routing table is the "longest match" for each packet's destination address
- As the packet traverses the network, each hop in turn *re-examines* the packet header and assigns it to a FEC.
- Choosing the next hop is a composition of two functions:
  - Partitioning the stream of packets into FECs
  - Assigning each FEC to a next hop
- Routing protocols are used to figure out:
  - what addresses are reachable in a network
  - the best path to use to reach an address
  - OSPF,ISIS,BGP are all well established and understood routing protocols used in IP networks

What is MPLS?

- MPLS stands for **M**ulti-**P**rotocol **L**abel **S**witching
- Assignment of a particular packet to a particular FEC is done just once, as the packet enters the network
- Packets are “labeled” before they are forwarded to the next hop
- All forwarding is driven by labels
- No further analysis of the packet’s network layer header at subsequent hops.
- Label is used as an index into a table which specifies the next hop and a new label. The old label is swapped with the new label and the packet is forwarded to its next hop

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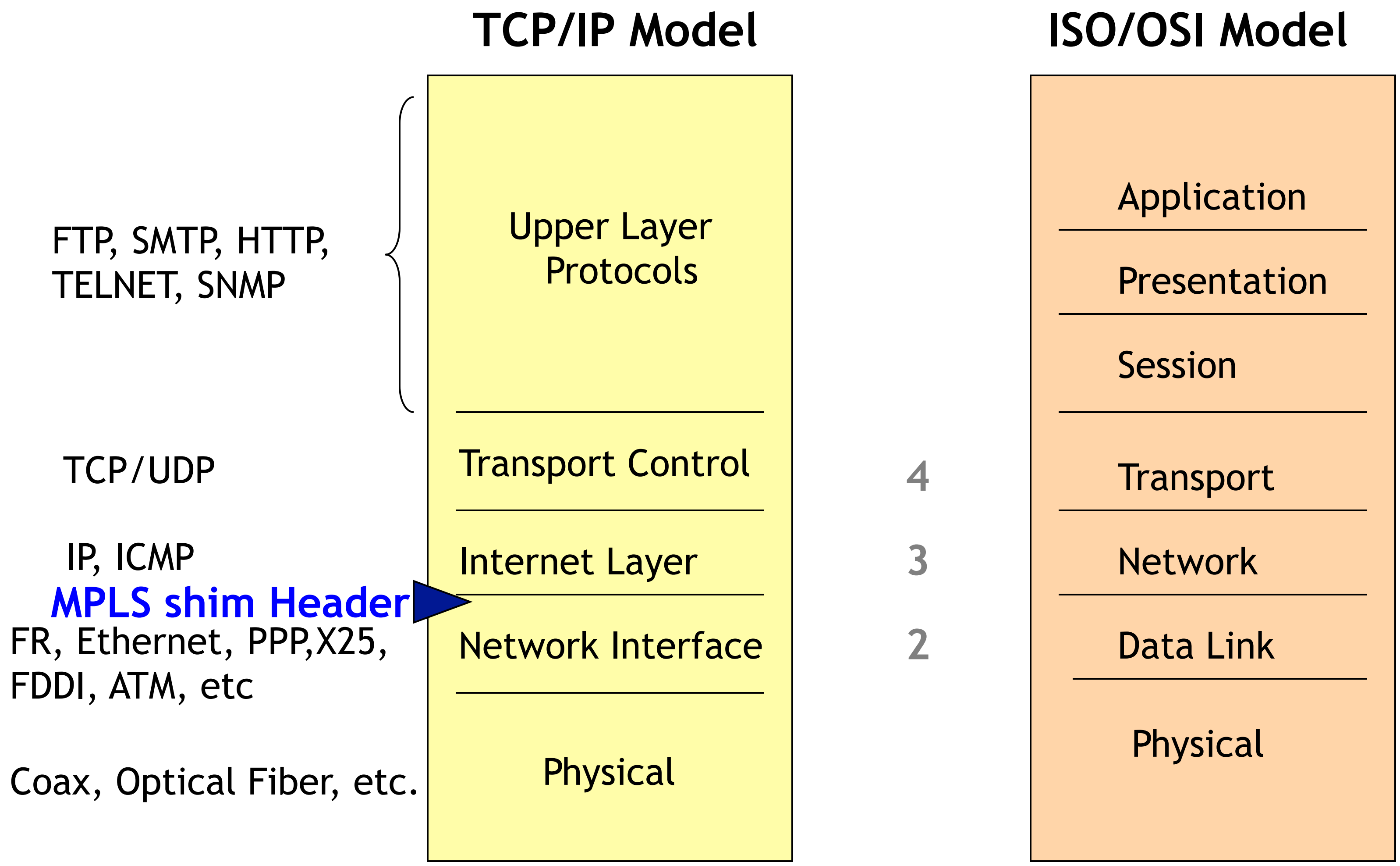
MPLS Benefits in Comparison to Traditional IP Routing

- FEC assignment is performed once at network ingress instead of at each hop
- Information not contained in packet headers can be used for FEC determination
  - Packets arriving on different ports may be assigned to different FECs
  - Same packet that enters a network via two different LSRs or LSR ports can be forwarded via two different paths
- MPLS offers improved network resiliency and recovery options compared to traditional IP networks
- MPLS is able to traffic-engineer packets to follow certain paths
- Allows for manual or dynamic path assignment across the MPLS domain

Layered Model: where does MPLS fit ?



MPLS Terminology

FEC - Forwarding Equivalence Class: “A subset of packets that are treated the same way by a router”

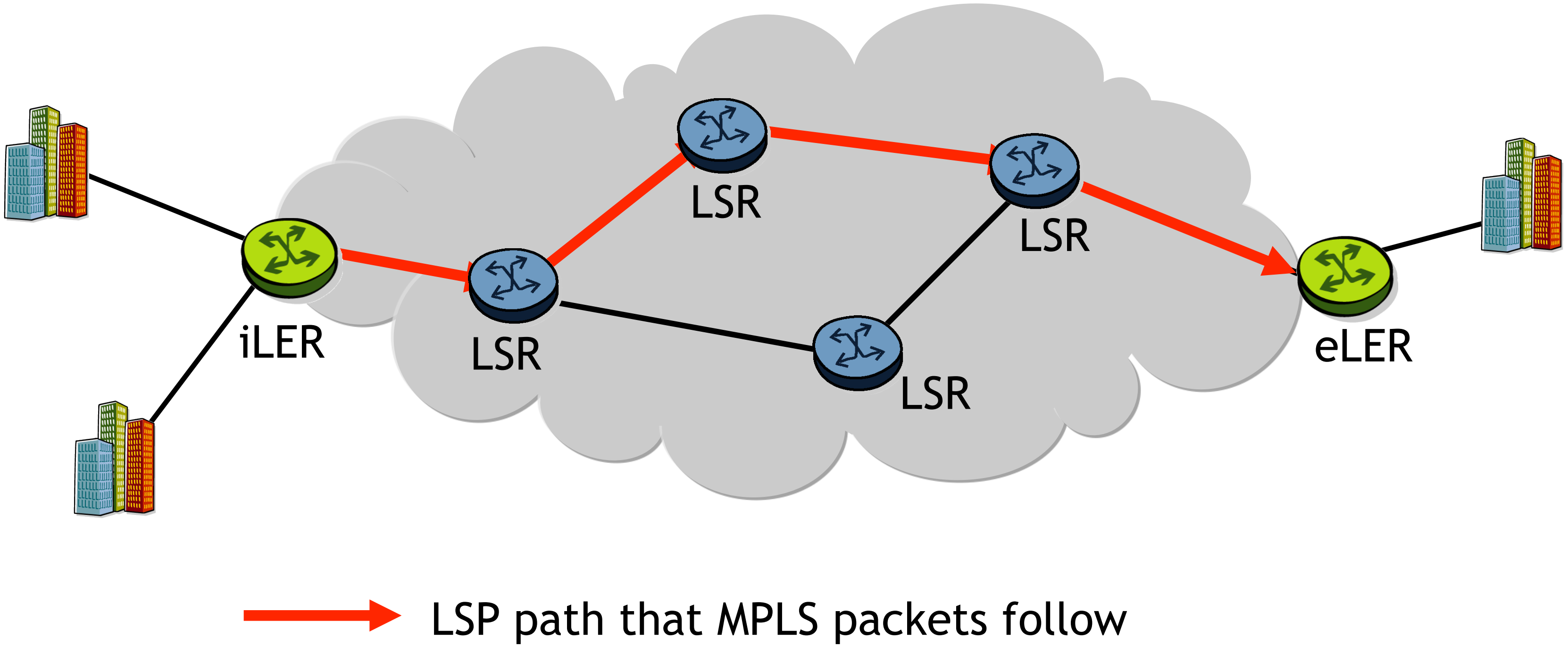
In IP routing, a packet is assigned to a FEC at each hop (i.e. L3 look-up).
In MPLS it is only done once at the network ingress.

iLER – ingress Label Edge Router that pushes MPLS label.

LSR - Label Switching Router, swaps MPLS label.

eLER – egress Label Edge Router that pops MPLS Label.

LSP - Label Switched Path. Path that MPLS packets follow from iLER to eLER.



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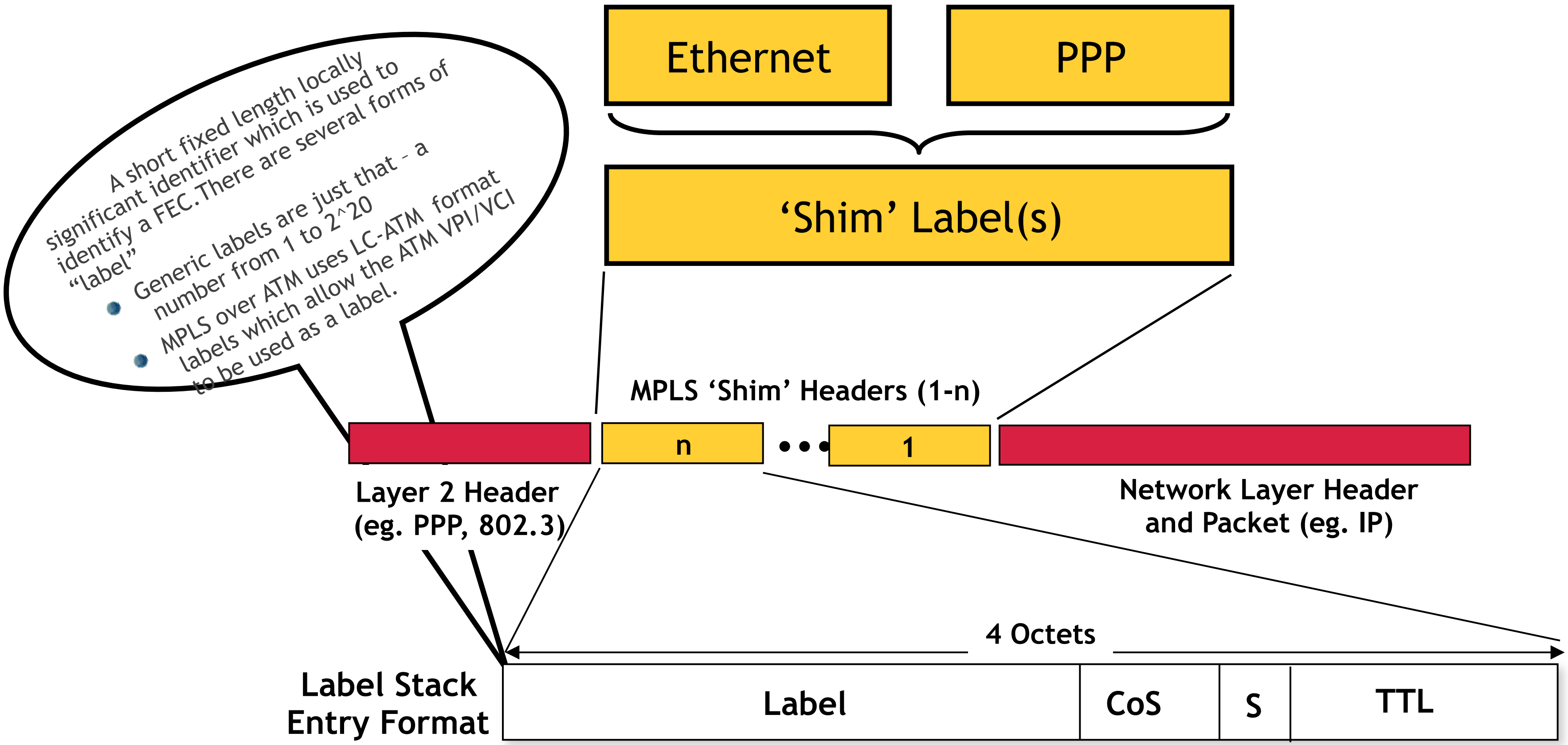
MPLS Packet Encapsulation & MPLS Header Fields



Packet-based encoding

Label:	Label Value, 20 bits (0-15 reserved)
CoS.:	Class of Service, 3 bits
S:	Bottom of Stack, 1 bit (1 = last entry in label stack)
TTL:	Time to Live, 8 bits

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Label Manipulation

Label PUSH

- The action to add a label to a packet
- A Label could already exist → add an extra label (Tunneling)
  - Initial label is called “Inner label”
  - New label is called “Outer label”

Label SWAP

- Change the value of the label by popping the top label and pushing a new label
- If multiple labels are present only the last introduced label (outer label) will be operated on
- This allows the local significance (on a link by link based) of a label
  - → Improves scalability : there is no unique label end to end for a path

Label POP

- The action to remove a label from a packet
- In a stacked label solution, the next label will be used to go further
- If it was the last label, local routing will take place using standard protocol behavior

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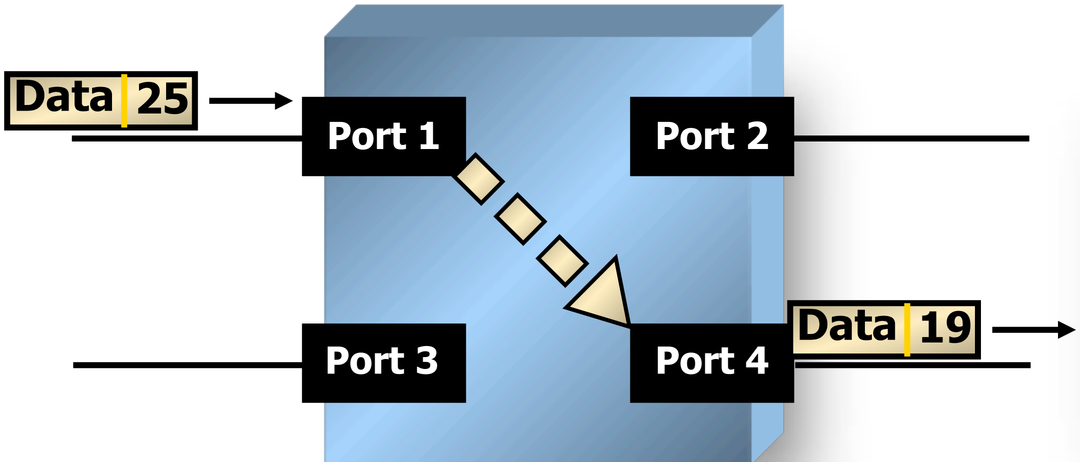
MPLS Terminology



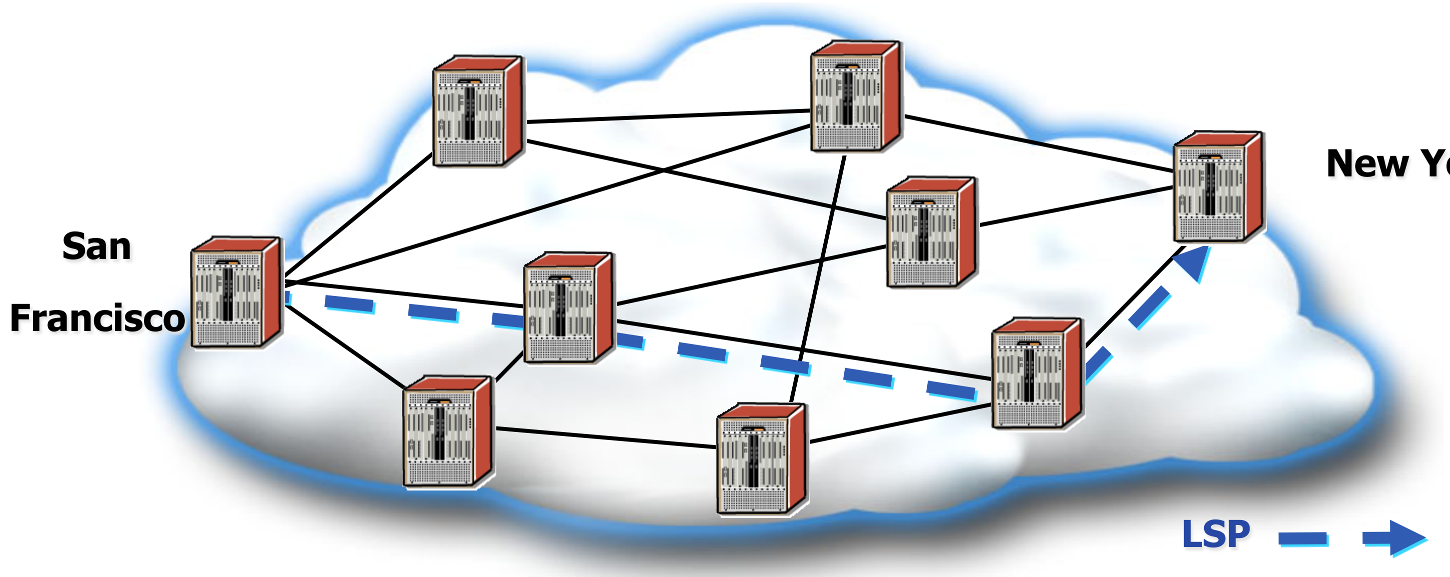
Connection Table

In (port, label)	Out (port, label)	Label Operation
(1, 22)	(2, 17)	Swap
(1, 24)	(3, 17)	Swap
(1, 25)	(4, 19)	Swap
(2, 23)	(3, 12)	Swap

Label Swapping

- Connection table maintains mappings
- Exact match lookup
- Input (port, label) determines:
  - Label operation
  - Output (port, label)
- Same forwarding algorithm used in Frame Relay and ATM

MPLS Terminology: Label-Switched Path



Label-Switched Path (LSP)

- Simplex L2 tunnel across a network
- Concatenation of one or more label switched hops
- Analogous to an ATM or Frame Relay PVC

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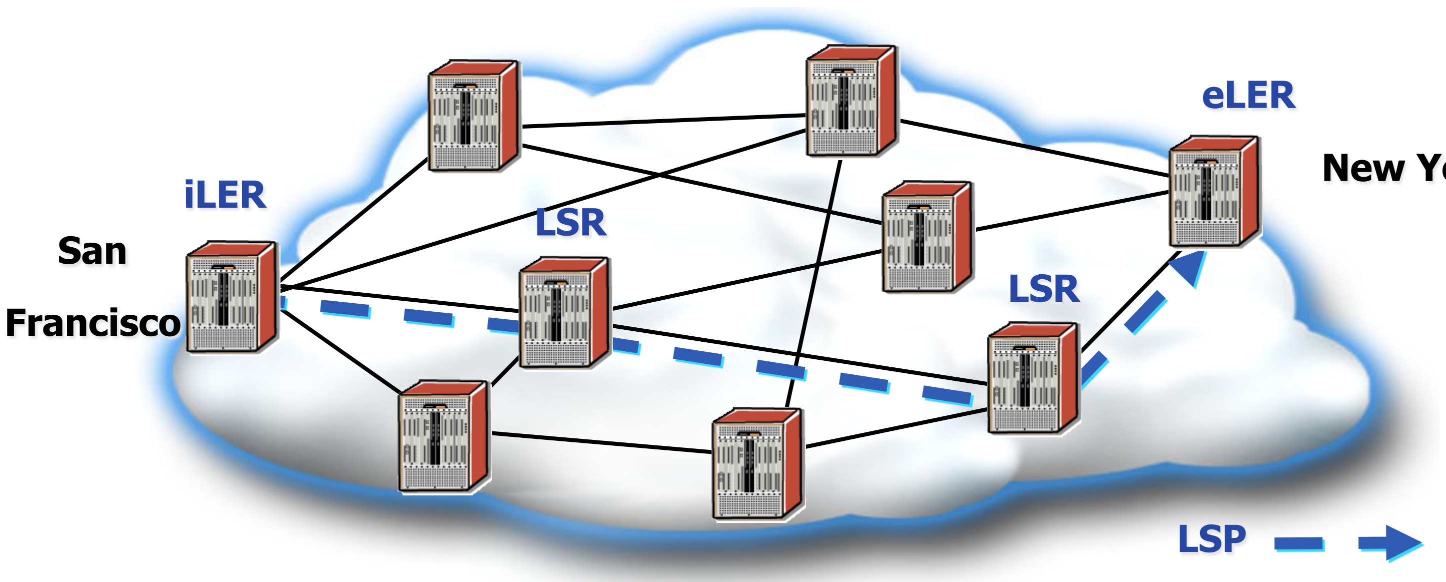
MPLS Terminology: Label-Switching Router



Label-Switching Router (LSR)

- Forwards MPLS packets using label-switching
- Capable of forwarding native IP packets
- Executes one or more IP routing protocols
- Participates in MPLS control protocols

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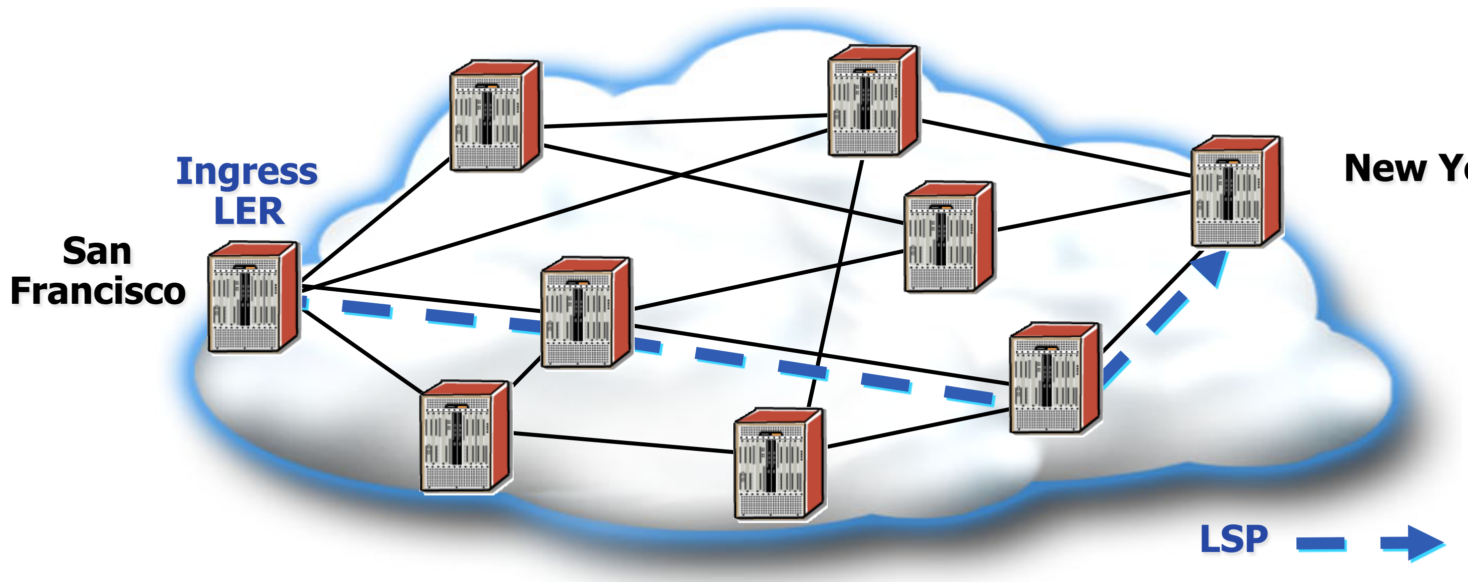
MPLS Terminology: Ingress LER



Ingress LER

- Processes traffic as it enters the MPLS domain
- Examines inbound IP packets
- Classifies IP packet to an FEC (Forwarding Equivalent Class)
- Generates MPLS header and assigns initial label
- Upstream from all other LSRs in the LSP
- "Head-end LSR"

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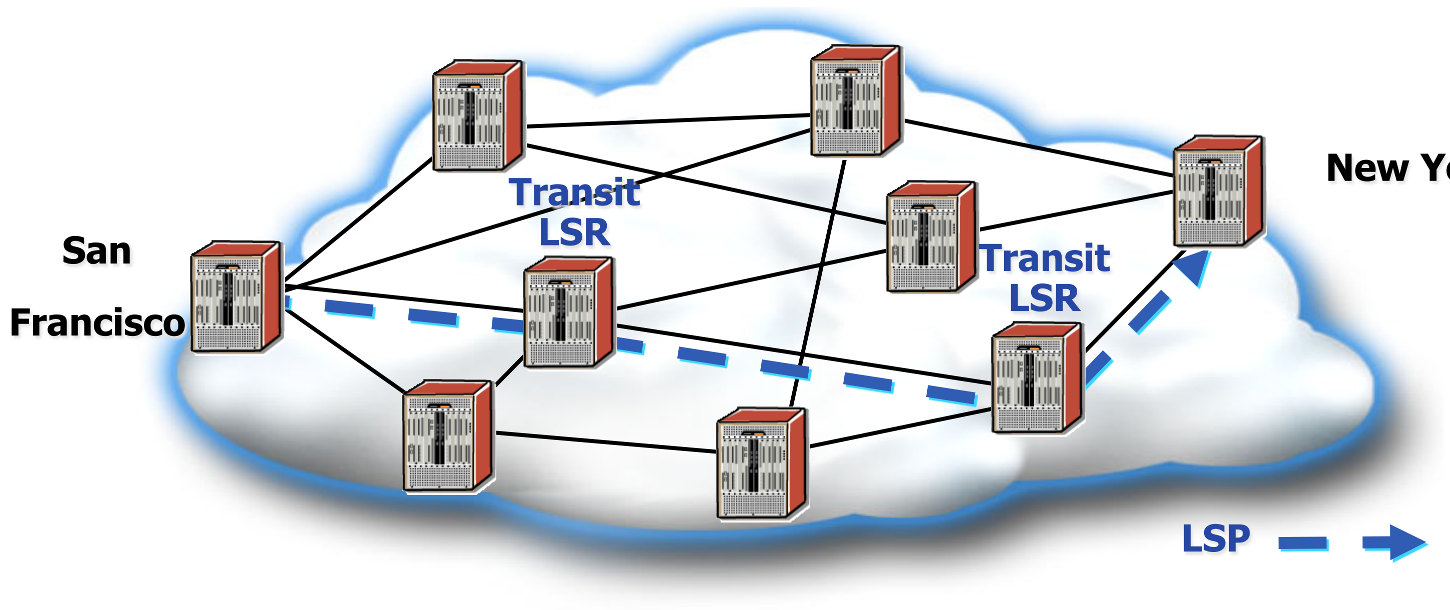
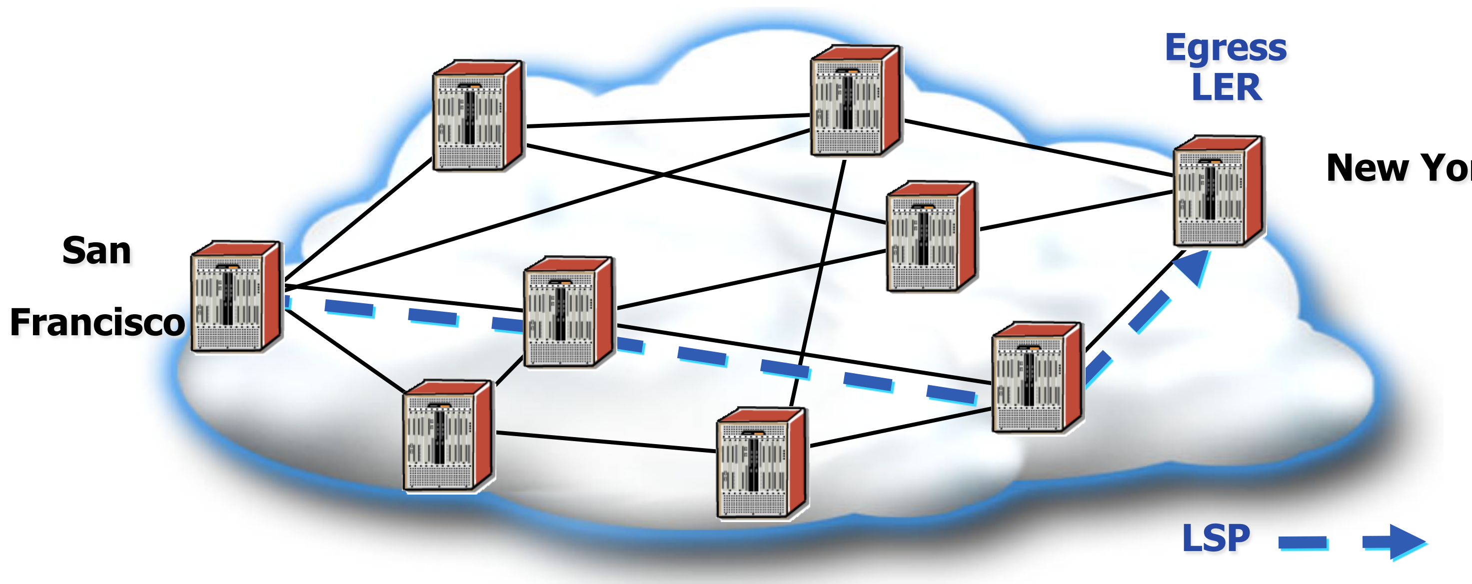
MPLS Terminology: Transit LSR



Transit LSR

- Processes traffic within the MPLS domain
- Zero or more transit routers
- Forwards MPLS packets using label swapping

MPLS Terminology: Egress LER



Egress LER

- Processes traffic as it leaves the MPLS domain
- Removes the MPLS header
- Downstream from all other LSRs in the LSP
- “Tail-end LSR”

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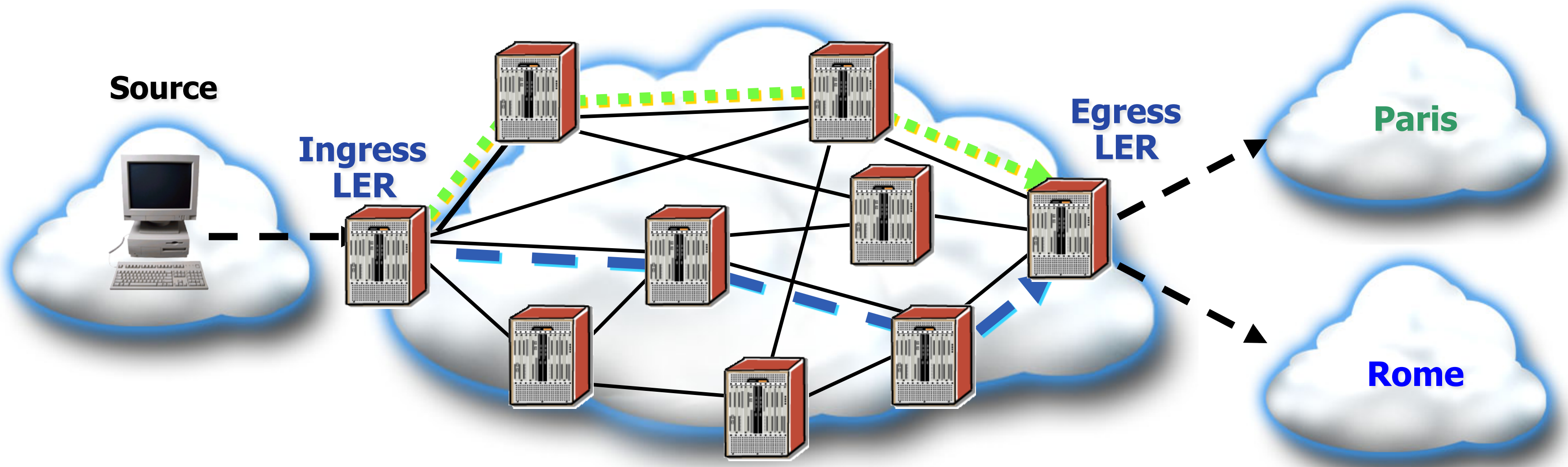
MPLS Forwarding Model



- Ingress LER determines FEC and assigns a label
  - Forwards Paris traffic on the Green LSP
  - Forwards Rome traffic on the Blue LSP
- Traffic is label swapped at each transit LSR
- Egress LER
  - Removes MPLS header
  - Forwards packet based on destination address

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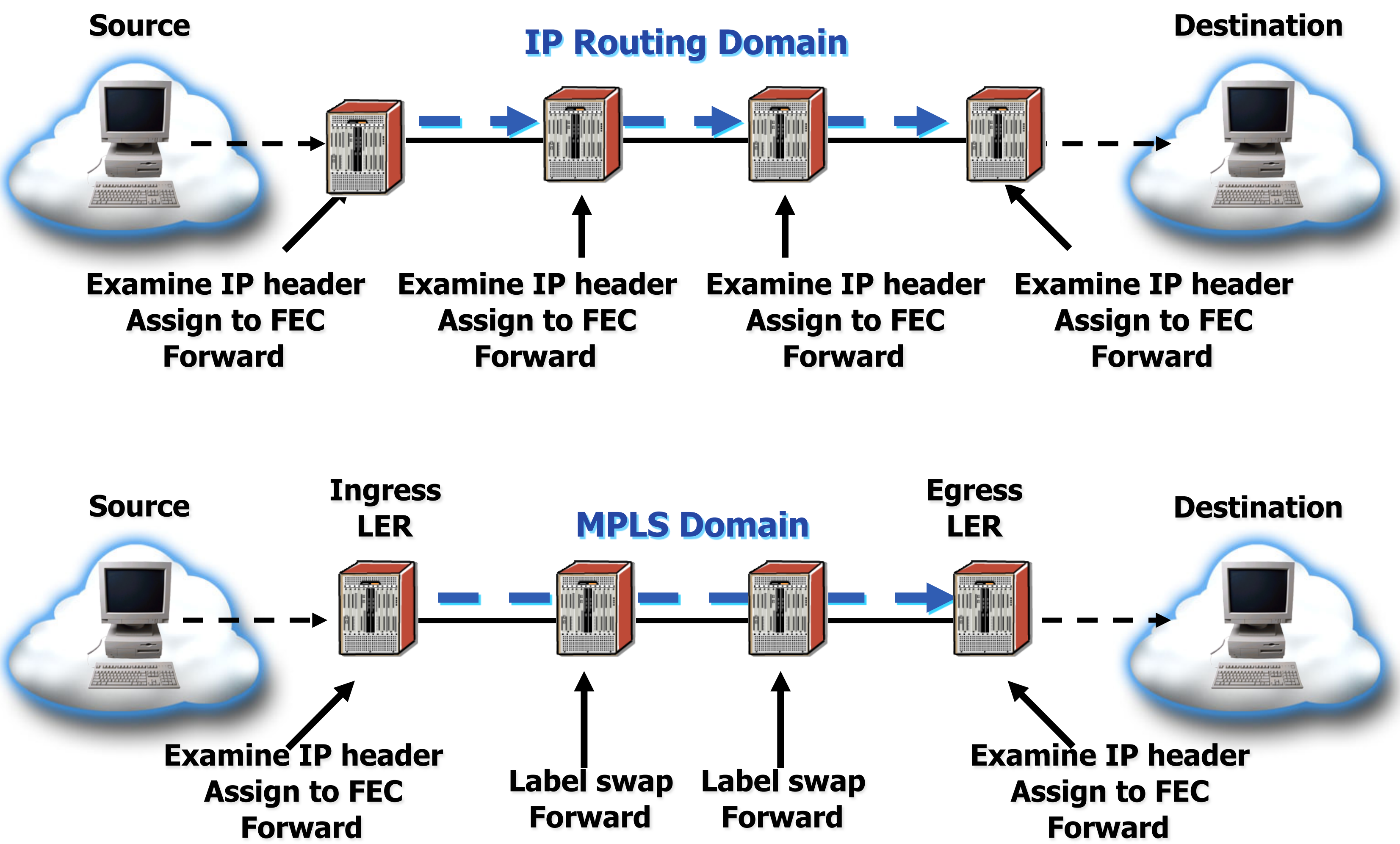
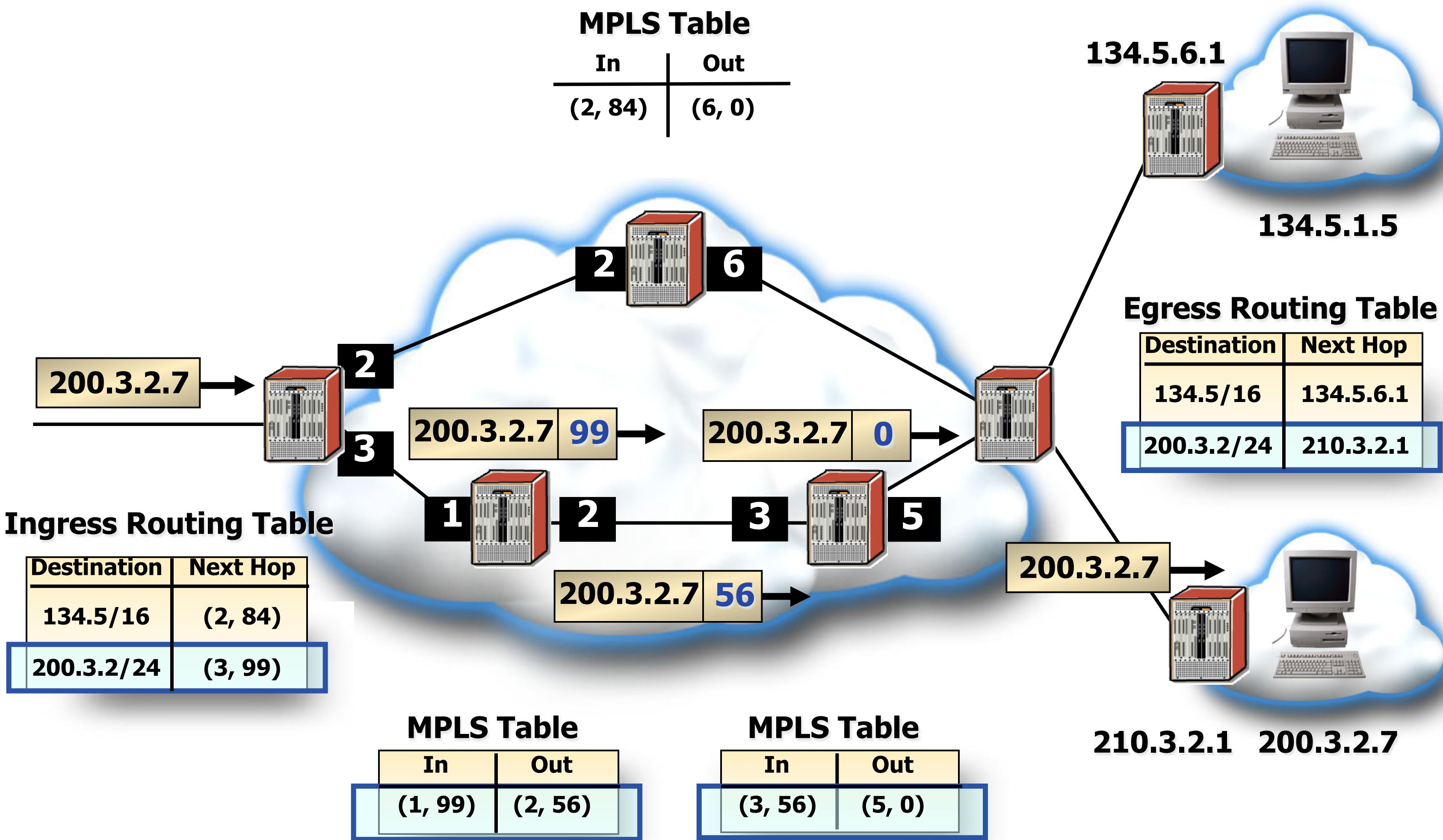
MPLS Forwarding vs. IP Routing



MPLS Forwarding Example



LSP Types

- **Static LSP:**
  - Specifies a static path i.e. no RSVP/LDP signaling is required.
  - Label are assigned manually by the operator.
  - Configured manually at each router (ingress, transit, egress).
  - No dependence on IGP or local forwarding table.
  - No failure detection and no re-routing capabilities.
- **Signaled LSP:**
  - Are setup using RSVP-TE or LDP signaling protocols.
  - Signaling allows labels to be assigned automatically from ingress router to egress router.
  - Configuration is required only on the ingress/egress routers.
  - Dependent on IGP and local forwarding table.
  - Various protection techniques & FRR.

LSP Types: Static LSP

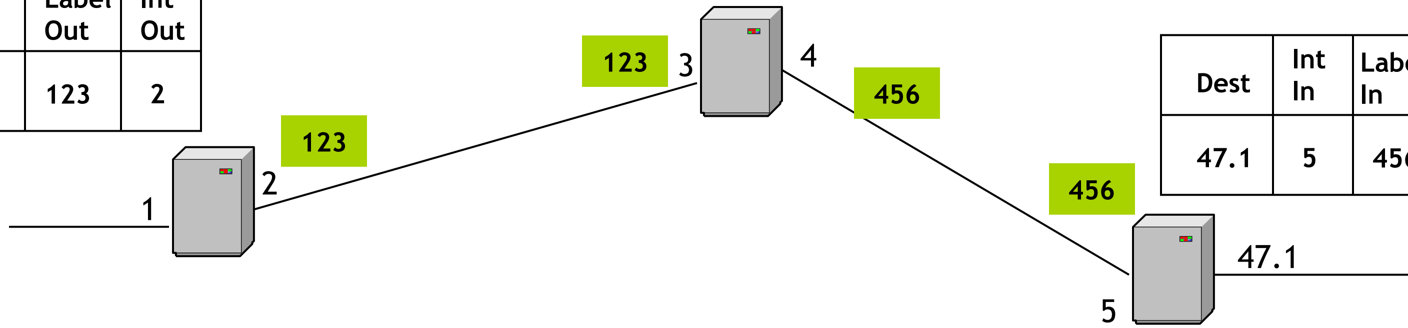
All Routers are configured manually with labels.

No signaling is required.

Dest	Int In	Label In	Int Out	Label Out
47.1	3	123	4	456

Dest	Int In	Label Out	Int Out
47.1	-	123	2

Dest	Int In	Label In	Int Out
47.1	5	456	-



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LSP Types: Signaled LSP

LSPs are setup using a signaling protocol: LDP or RSVP-TE

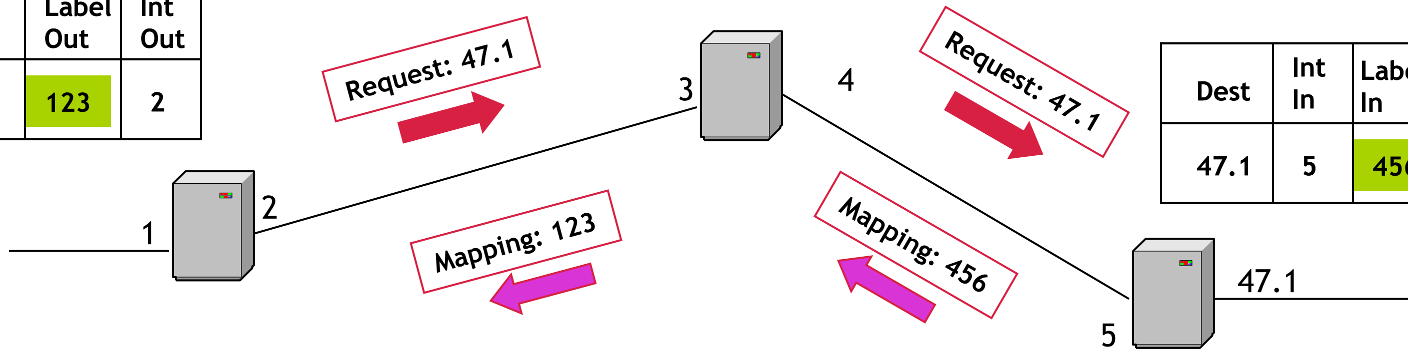
Signaling protocol facilitates:

- Assignment of labels from egress router to the ingress router.
- Signaling is triggered by the ingress/egress routers – no configuration is required on intermediate routers.
- Path Selection

Dest	Int In	Label Out	Int Out
47.1	-	123	2

Dest	Int In	Label In	Int Out	Label Out
47.1	3	123	4	456

Dest	Int In	Label In	Int Out
47.1	5	456	-



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Motivation: MPLS signaling and Label Distribution Protocols

A fundamental concept in MPLS is that two Label Switch Routers (LSR's) must agree on the labels used to forward traffic between and through them.

This common understanding is achieved by using a set of procedures, generically called a label distribution protocol, by which one LSR informs another of label bindings it has made

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MPLS Label Signaling & Label Distribution Protocols

- Signaling is a mechanism used to setup an LSP path through a network.
- Signaling involves the exchange of messages between LER/LSR routers.
- Exchanged messages include all the details required to setup and maintain LSP paths.
- Label distribution protocols define the procedures and messages by which MPLS LSR's inform each other of the label bindings it has made and their meaning.
- Example of MPLS signaling or label distribution protocols: LDP & RSVP.

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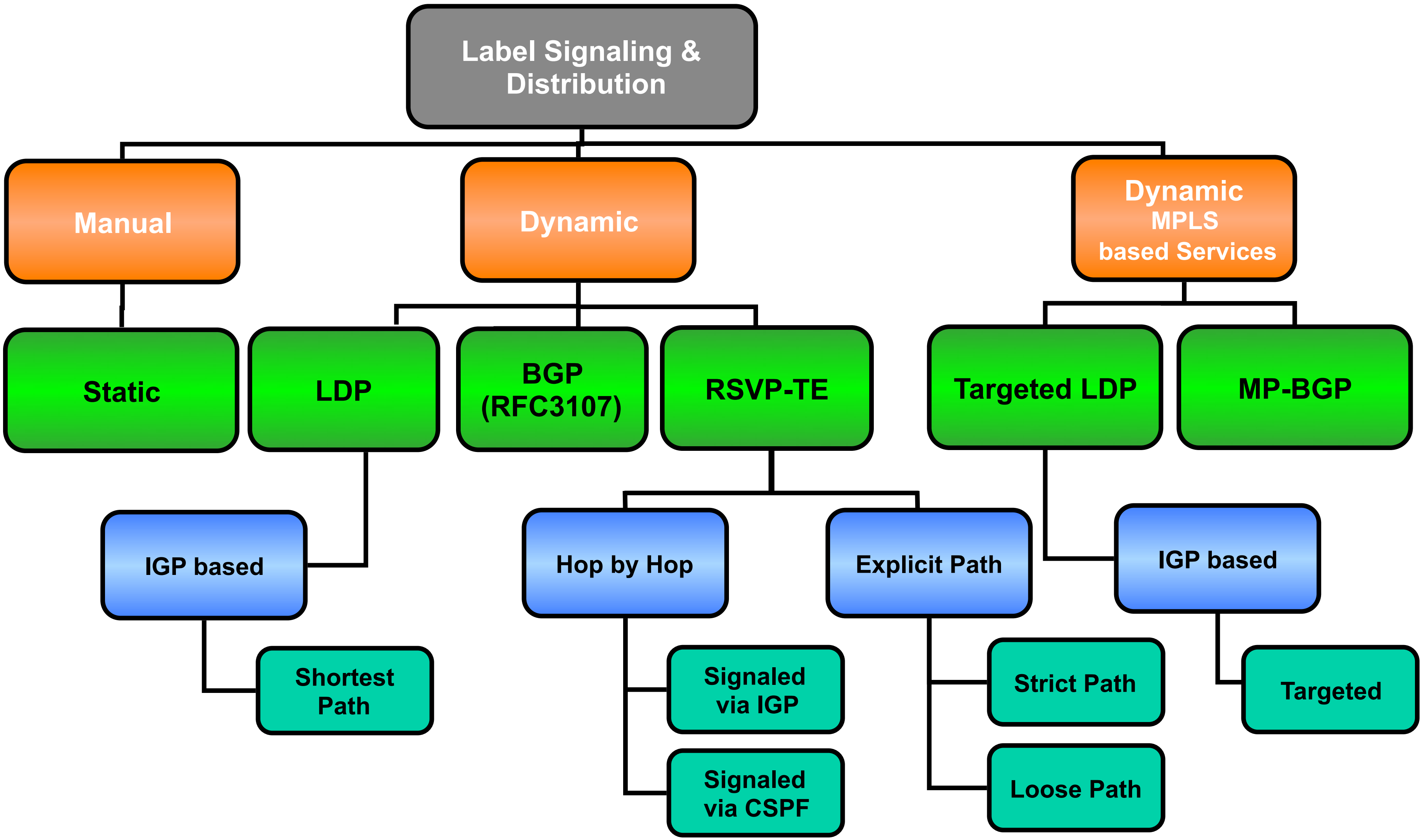
Label Signaling and Distribution Summary



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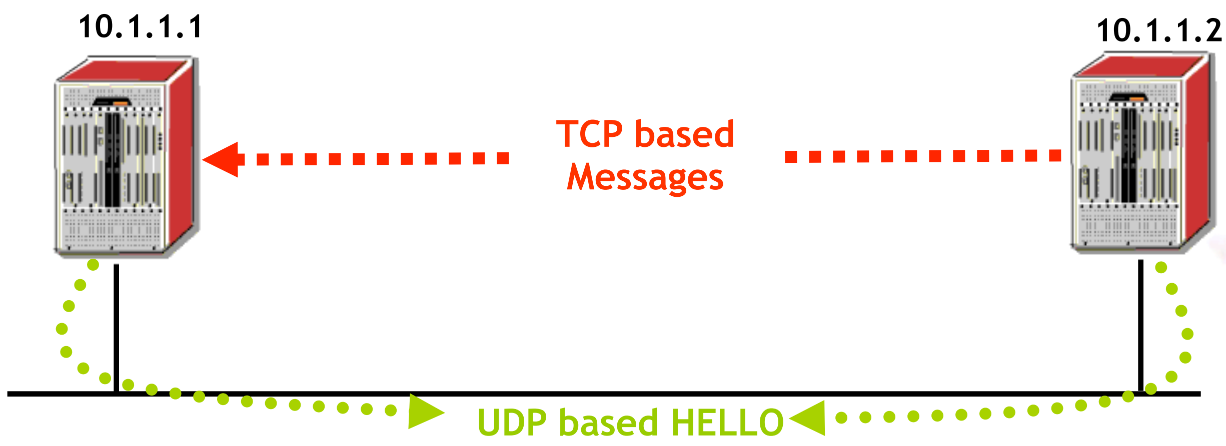
2 Label Distribution Protocol

LDP Overview

- LDP is a set of procedures and messages defined for distributing labels and establishing LSPs based on **RFC 5036**.
- Routers configured for the LDP protocol will establish an LDP session between them and become peers.
- The LDP sessions allow each LDP peer to exchange & learn the other's label/FEC binding (mapping).
- LDP message exchanges are carried in LDP PDUs over LDP session TCP connection.
- The LDP protocol is used for:
  1. Establishing Transport Tunnel LSP's
  2. Establishing Targeted LDP sessions between directly or non-directly connected routers.

LDP Transport Protocols

- LDP utilizes both UDP and TCP for transport services and uses port 646 for both.
- UDP is used as the transport protocol for the discovery mechanism
  - Discovery Hello messages periodically announce and maintain the presence of an LSR in a network
- TCP is used as the transport protocol for all messages except HELLO’s. TCP based messages are:
  - Session messages to establish, maintain and terminate sessions between LDP peers
  - Advertisement messages to create, change and delete label mappings for FEC’s
  - Notification messages to signal errors and other events



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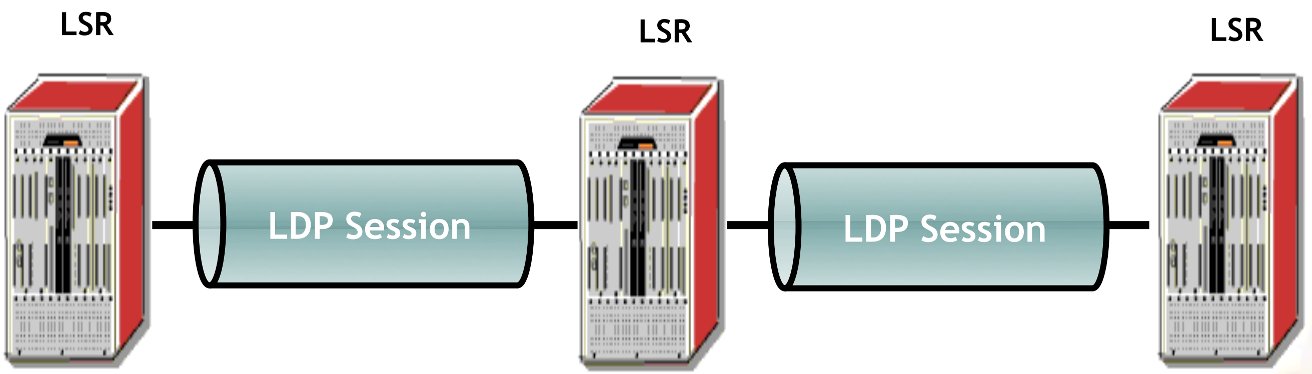
LDP Peers

- Routers configured for the LDP protocol will establish an LDP session between them and become peers.

- LDP peers are directly connected



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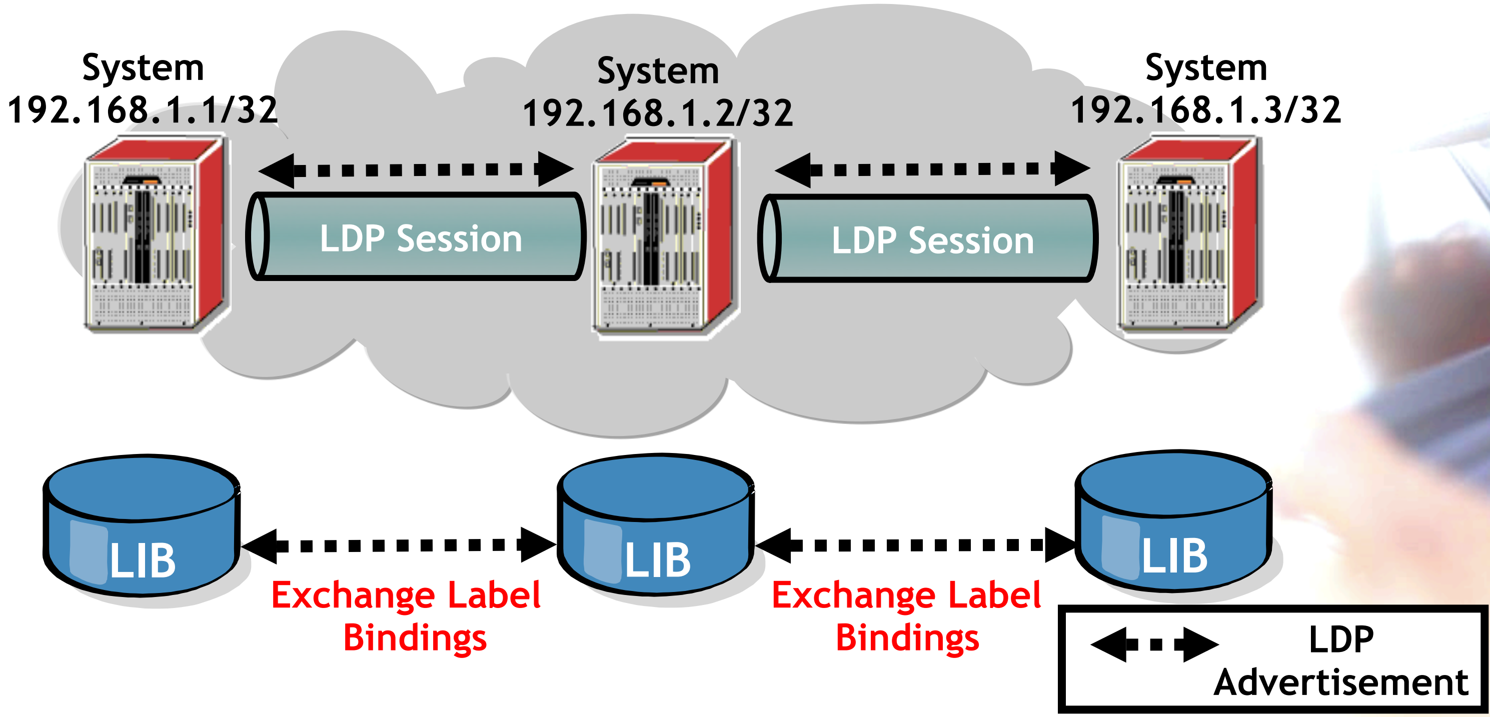
LDP Label Exchange

- There is a separate LDP session established per label space.
- An LDP session allows for the mutual exchange of FEC/label bindings using LDP label Mapping messages.



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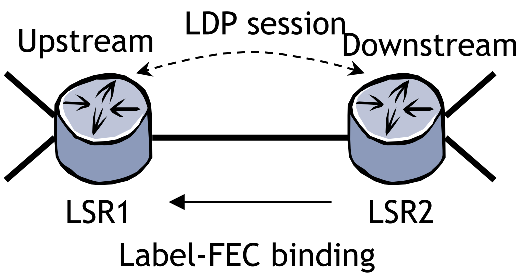
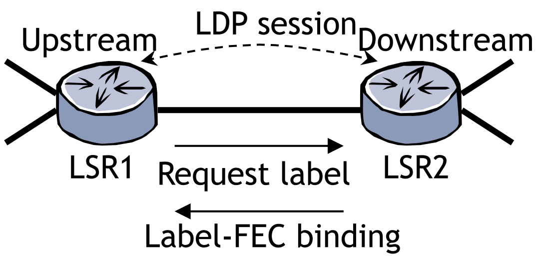
LDP - Label Advertisement Methods

Downstream Unsolicited



1. LSR2 discovers NH (IGP selected Next Hop) for a particular FEC
2. LSR2 sends label mapping message

Downstream-on-Demand



1. LSR1 recognizes LSR2 as NH for a FEC
2. LSR1 sends label request message
3. LSR2 responds with a label binding

LDP – Label Distribution Control

Independent Control

- Each LSR makes independent decision on when to advertise labels to upstream peers
- Label-FEC binding can be sent once NH has been recognized
- All LSRs may advertise labels (don't wait for downstream label binding)
- Faster convergence

Ordered Control

- Label-FEC binding is sent out if:
  - LSR is egress for FEC, or
  - Label binding has been received from downstream FEC-NH
- LSP is set up hop by hop from egress to ingress
- Only egress LSR can start LSP set up
- Setting up LSP takes longer

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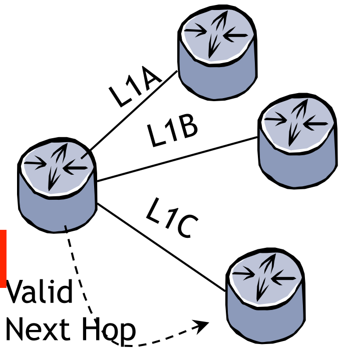
LDP - Label Retention Methods

Liberal Label Retention

LIB for FEC X

L1A - port A
L1B - port B
L1C - port C

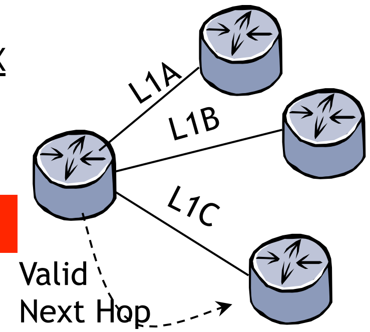


- LSR retains bindings received from LSR's other than the valid NH LSR.
- If NH changes, it may begin using these labels immediately.
- Allows rapid adaptation to routing changes.
- Requires LSR to retain more labels.

Conservative Label Retention

LIB for FEC X

~~L1A - port A~~
~~L1B - port B~~
L1C - port C



- LSR will only retain label bindings received from FEC-NH.
- If NH changes, new binding must be requested from new next hop.
- Restricts adaptation to changes in routing.
- Fewer labels to be maintained in LSR.

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Contents of the LIB and LFIB

- The LIB is populated based on label exchange with neighbors.
- The LFIB is built from the LIB and the FIB

Table Name	Meaning	Contents	Populated By
RIB	Routing Information Base	Routing updates received	Routing Protocol Exchange - Each routing protocol has a separate RIB
FIB	Forwarding Information Base	Active routes	RTM selects the active routes from all protocol "Best" routes
LIB	Label Information Base	Locally generated and received MPLS labels	MPLS Label Exchange
LFIB	Label Forwarding Information Base	Labels used by the LSR	The labels assigned to the active routes (for each next-hop)

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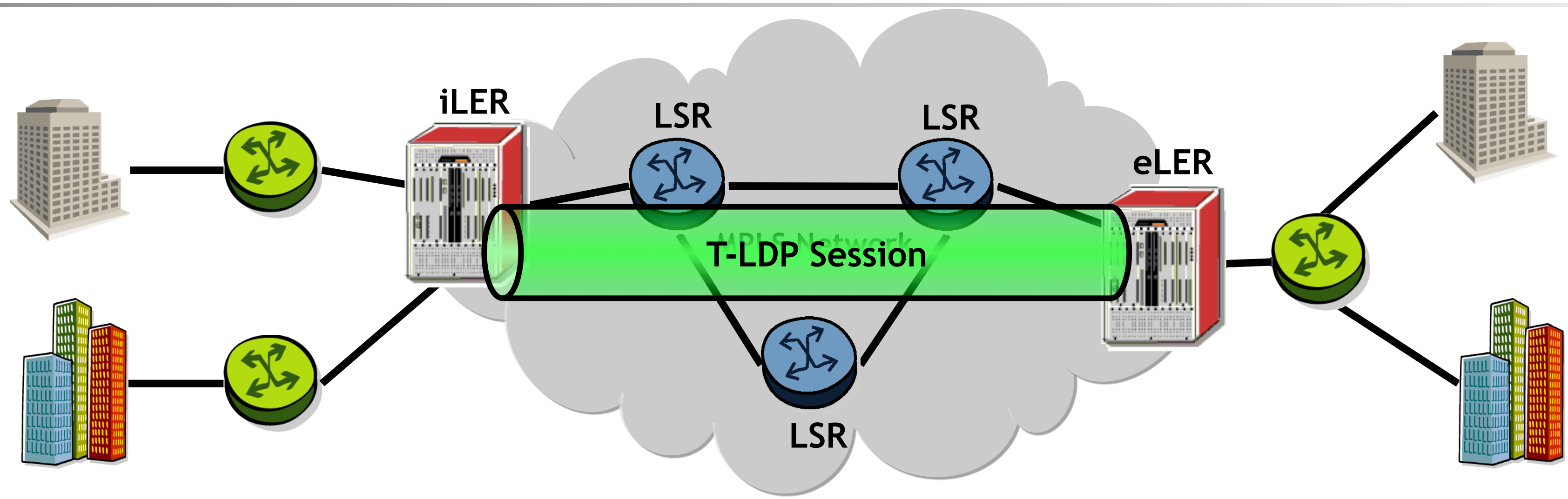
Summary of LDP Characteristics

Features	LDP
UDP/TCP Based	Yes
Dependency on the IGP	Yes
Traffic Engineering or BW reservation	No
Signaled LSP's via the IGP	Yes
Signaled LSP's via CSPF	No
Explicit Path LSP's	No
Protection Mechanism	No
MPLS Convergence	Failure Detection + IGP /LDP Convergence
Scalable	Yes
Administrative Control	Medium
Configuration Complexity	Low

Targeted LDP Sessions



- Targeted LDP would be configured in the case of a service implementation such as PWE3 Services: aPipe, cPipe, etc..
- Targeted LDP sessions can be established between peers that are not directly connected
  - Provides a tunnel between ingress and egress LERs
- Link based sessions may still remain between the directly connected LSRs
  - Provides the hop by hop tunnel across the core

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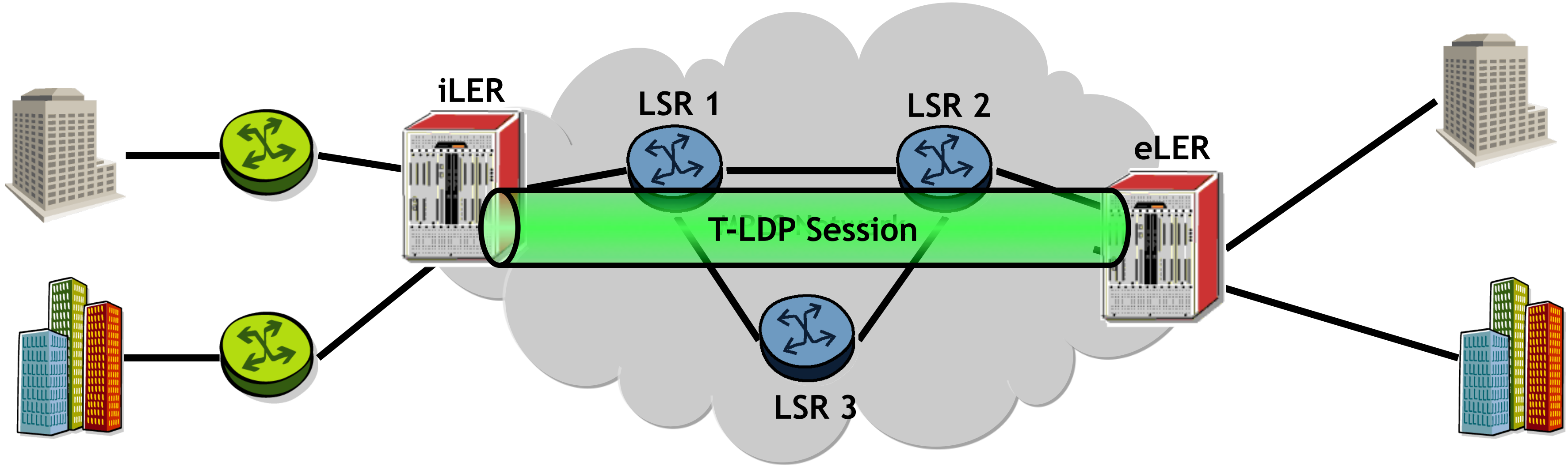
MPLS Label Stack

- An MPLS frame may have one or more labels applied to it
- The outer label is the Tunnel label and is used to switch the frame across the provider MPLS backbone
- The inner label is the Service label and is used by the egress LER to determine the egress interface or service

Data Link Header	Tunnel Label	Service Label	IP Packet	FCS



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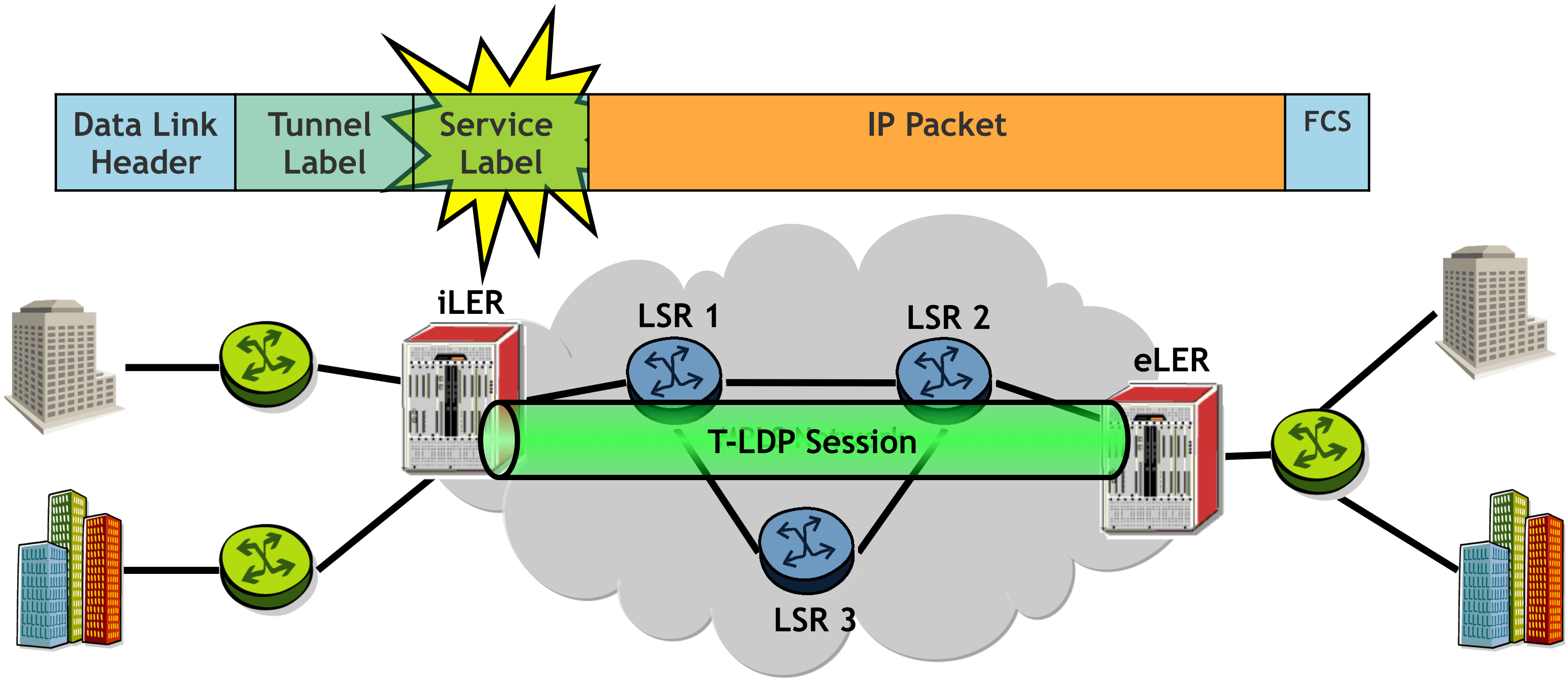
Service (Inner) Label

- The service labels, advertised by T-LDP, are used to identify to which service a packet belongs
  - It is PUSHed at the iLER and POPped at the eLER
  - Creates a per service tunnel that isolates traffic from other services.
- The Service labels are distributed via Targeted LDP (T-LDP)
- Labels are exchanged in Downstream Unsolicited (DU) mode



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3 RSVP-TE

RSVP-TE Overview

- RSVP is a protocol that defines procedures for signaling requirements and reserving the necessary resources for a router to provide a requested service through all nodes along a data path.
- RSVP is not a routing protocol. It works in conjunction with routing protocols.
- LSPs with traffic engineering
- RSVP requests resources for simplex flows. It requests resources only in one direction (unidirectional), duplex flows = 2 LSPs

RSVP-TE Overview

RSVP-TE is used for establishing LSPs in MPLS networks

RSVP-TE operates in ***downstream-on-demand (DOD)*** label advertisement mode with ***ordered LSP control***.

- A request to bind labels to a specific LSP tunnel is initiated by an ingress node through the RSVP PATH message
- Labels are allocated downstream and distributed (propagated upstream) by means of the RSVP RESV message

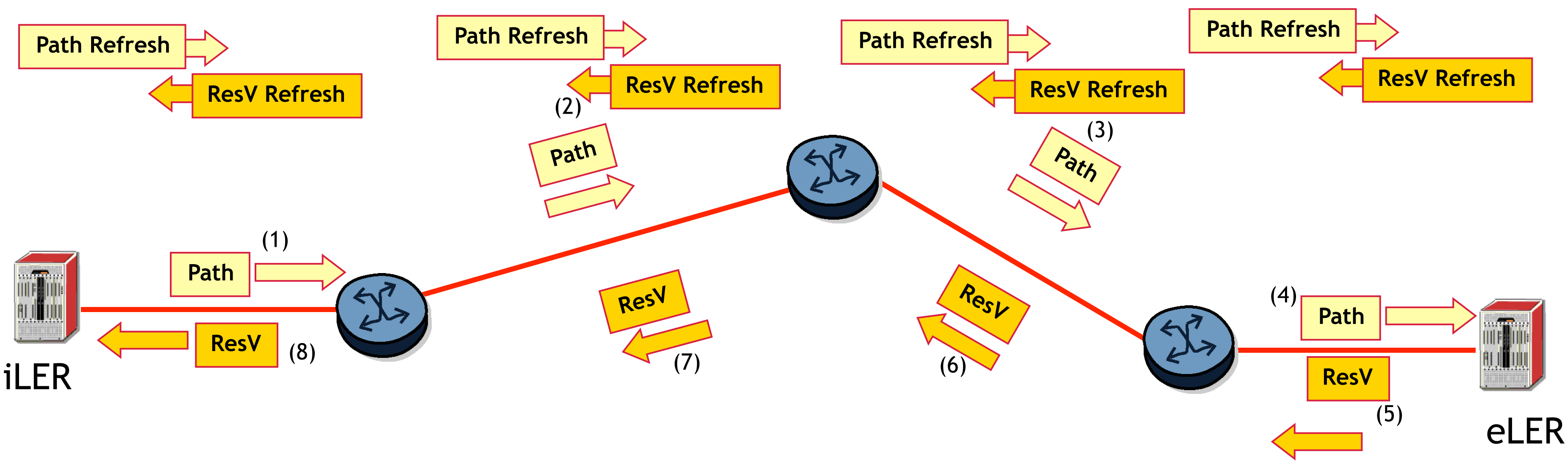
Advantage of using RSVP to establish LSP tunnels is that it enables the allocation of resources along the path.

- For example, bandwidth can be allocated to an LSP tunnel using standard RSVP reservations and Integrated Services service classes or strict/loose paths
- A RSVP message contains a lot of so-called OBJECTS

RSVP Message Types

RSVP uses two message types for resource reservation

- Sender sends PATH message towards receiver indicating characteristics of the traffic
  - Each Router along the path makes note of the traffic type
- Receiver sends RESV message back towards sender
  - Each Router reserves the resources requested (if available) for the micro-flow
- Path Refresh and RESV Refresh messages are sent periodically



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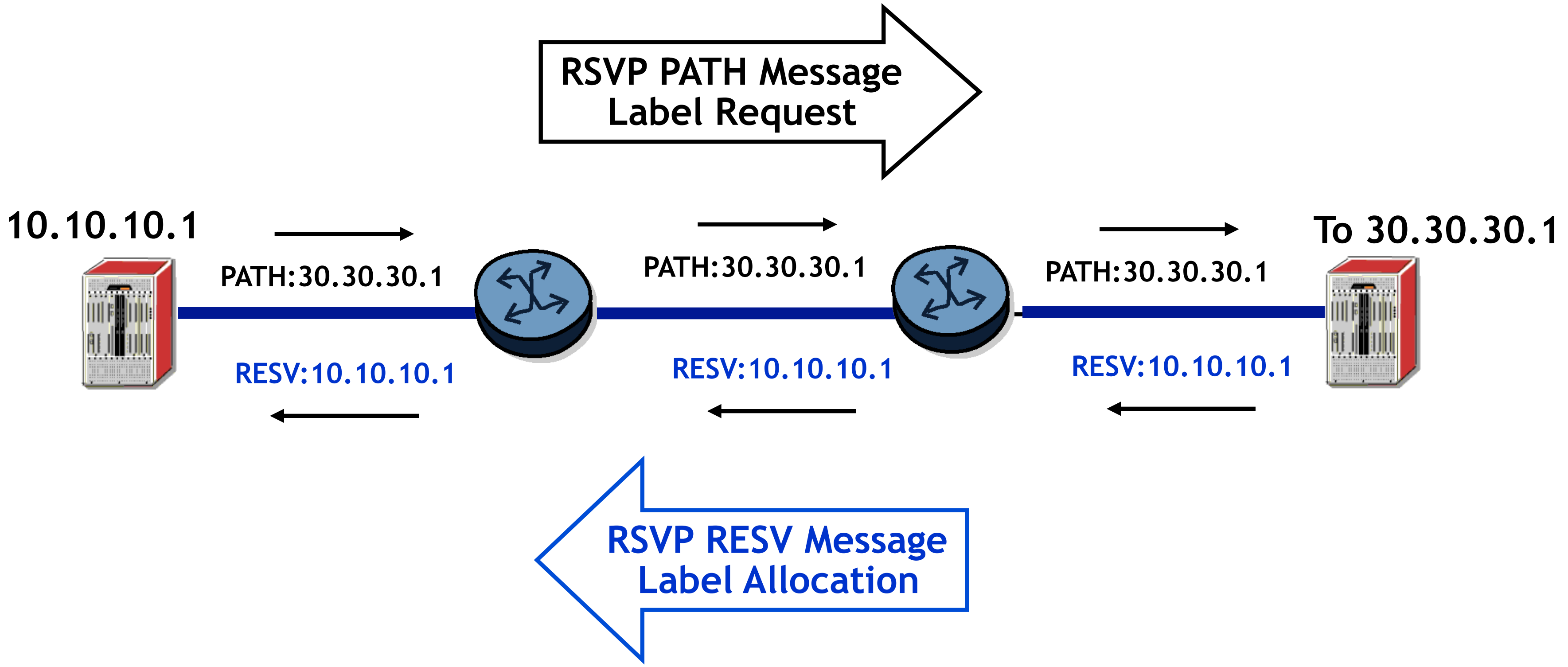
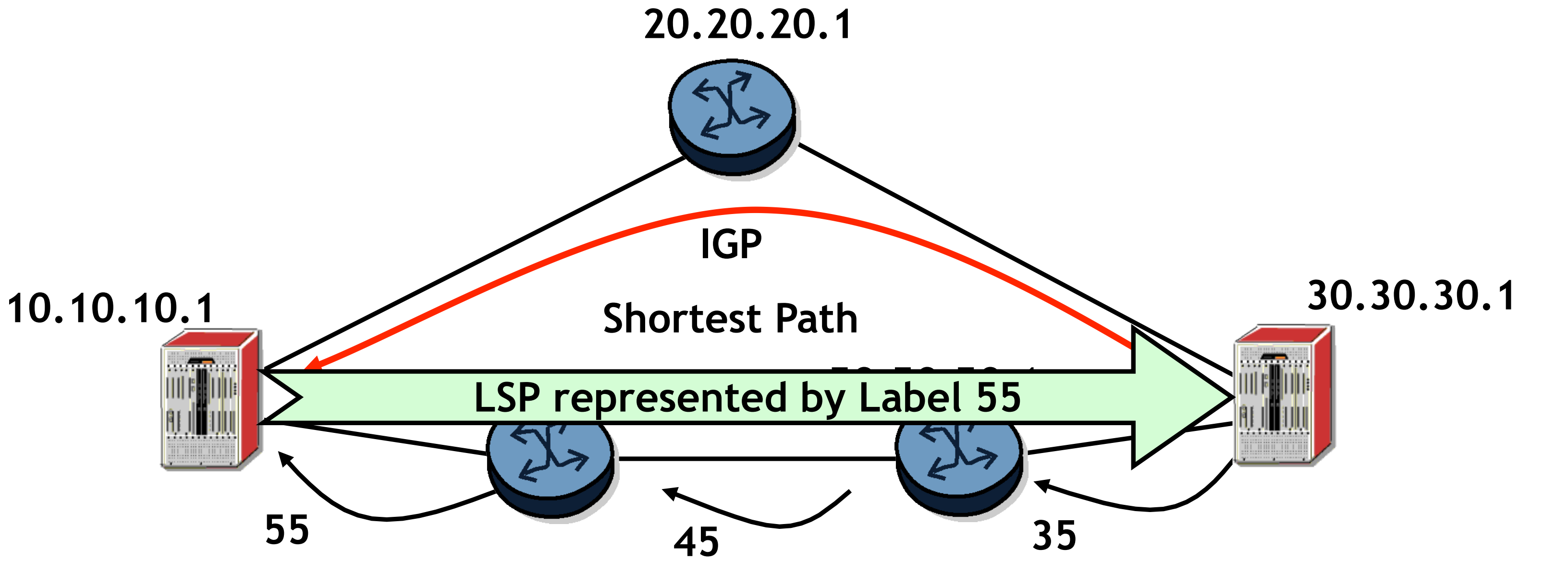
PATH vs. RESV Messages



RSVP Label Allocation



iLabel	eLabel	Action
---	55	Push

iLabel	eLabel	Action
55	45	Swap

iLabel	eLabel	Action
45	35	Swap

iLabel	eLabel	Action
35	---	Pop

iLabel - Ingress Label
eLabel - Egress Label

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RSVP Explicit Route Object (ERO)

- ERO provides specific path information for the RSVP Path message to follow
- If ERO is not present then IGP is used to follow the path
- ERO can be manually provided or computed based on RSVP requirements .

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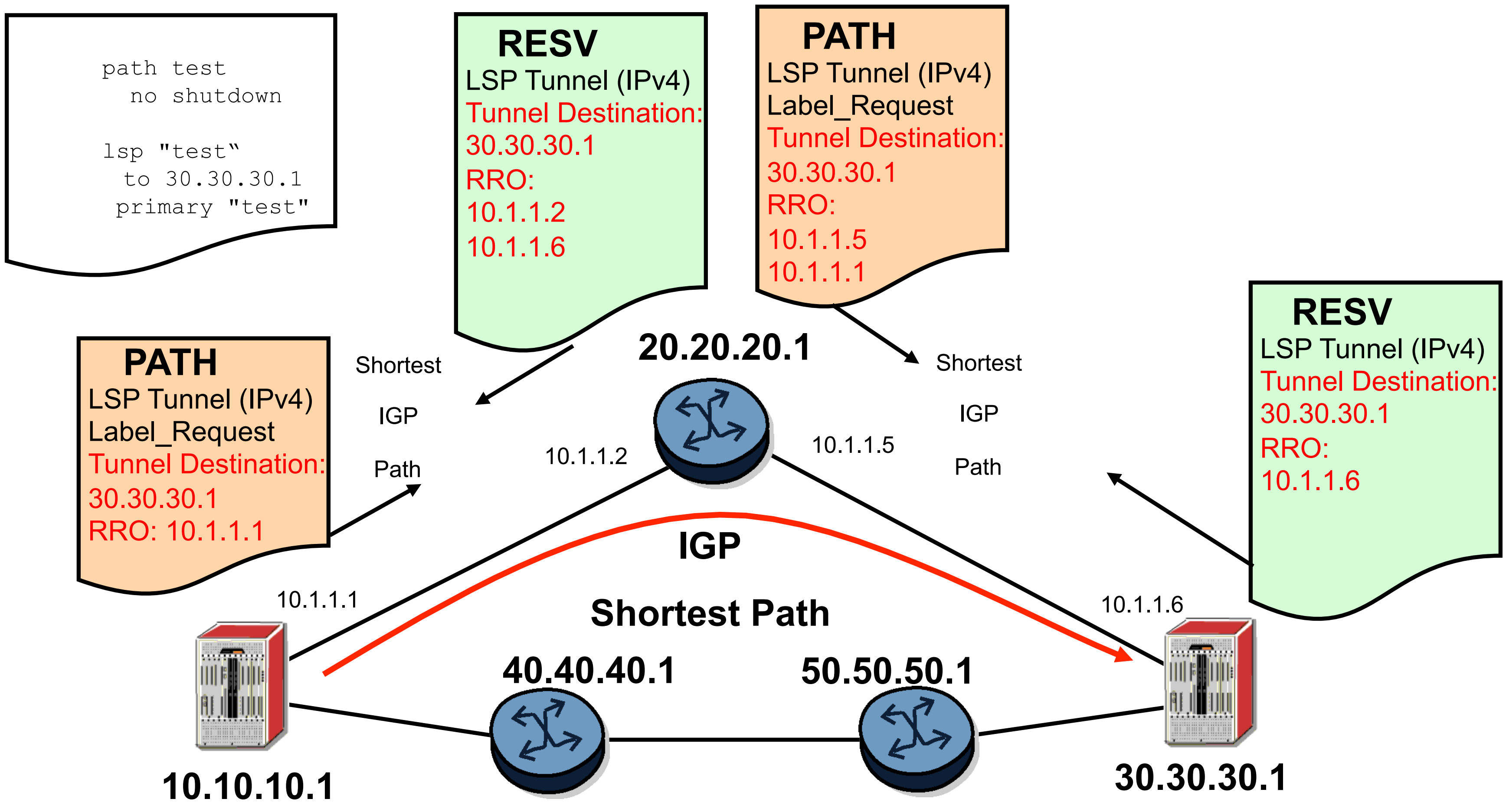
RSVP-TE Operation – No ERO Specified (IGP) / SPF



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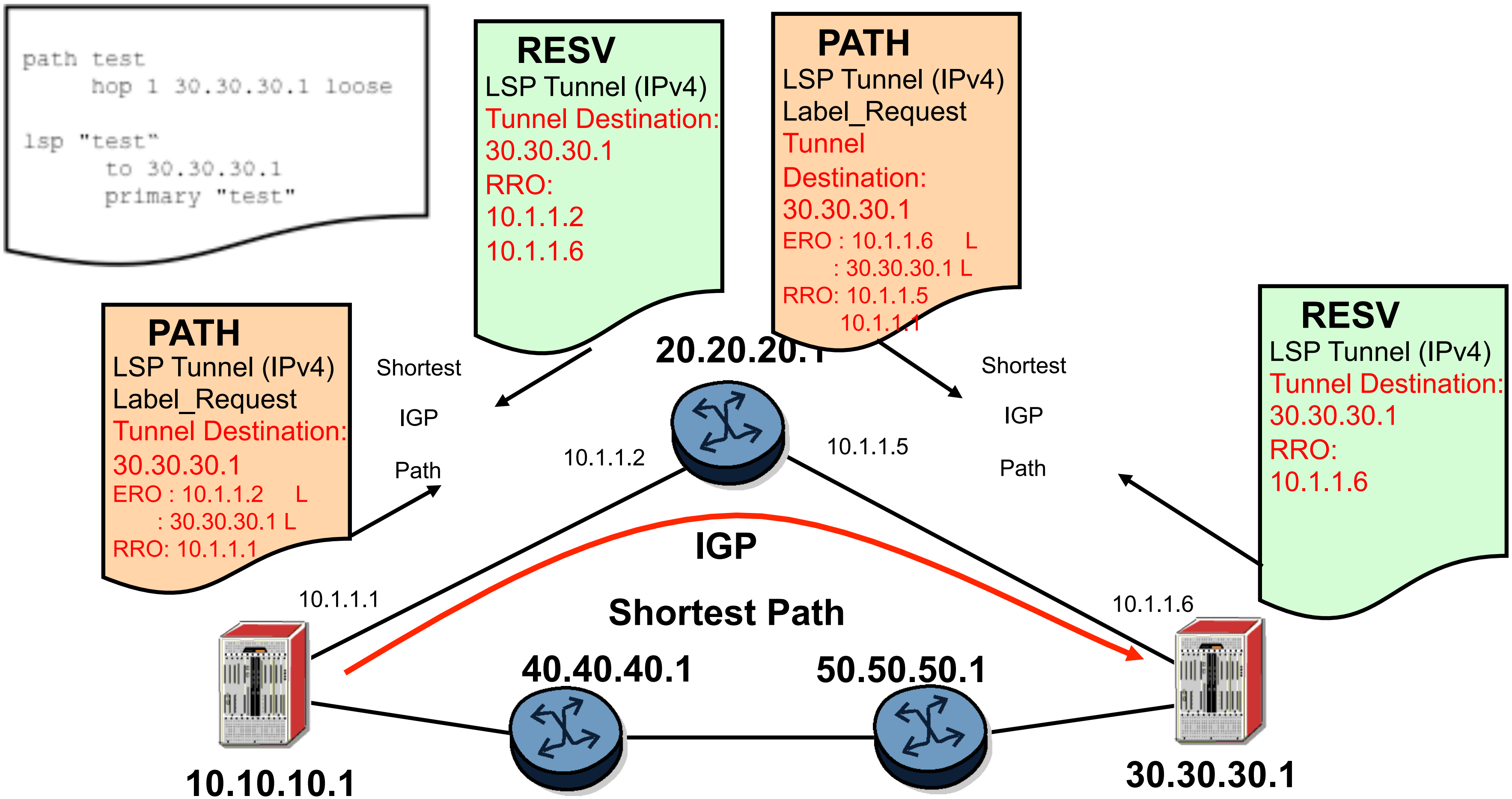
RSVP-TE Operation – ERO Specified loose / SPF



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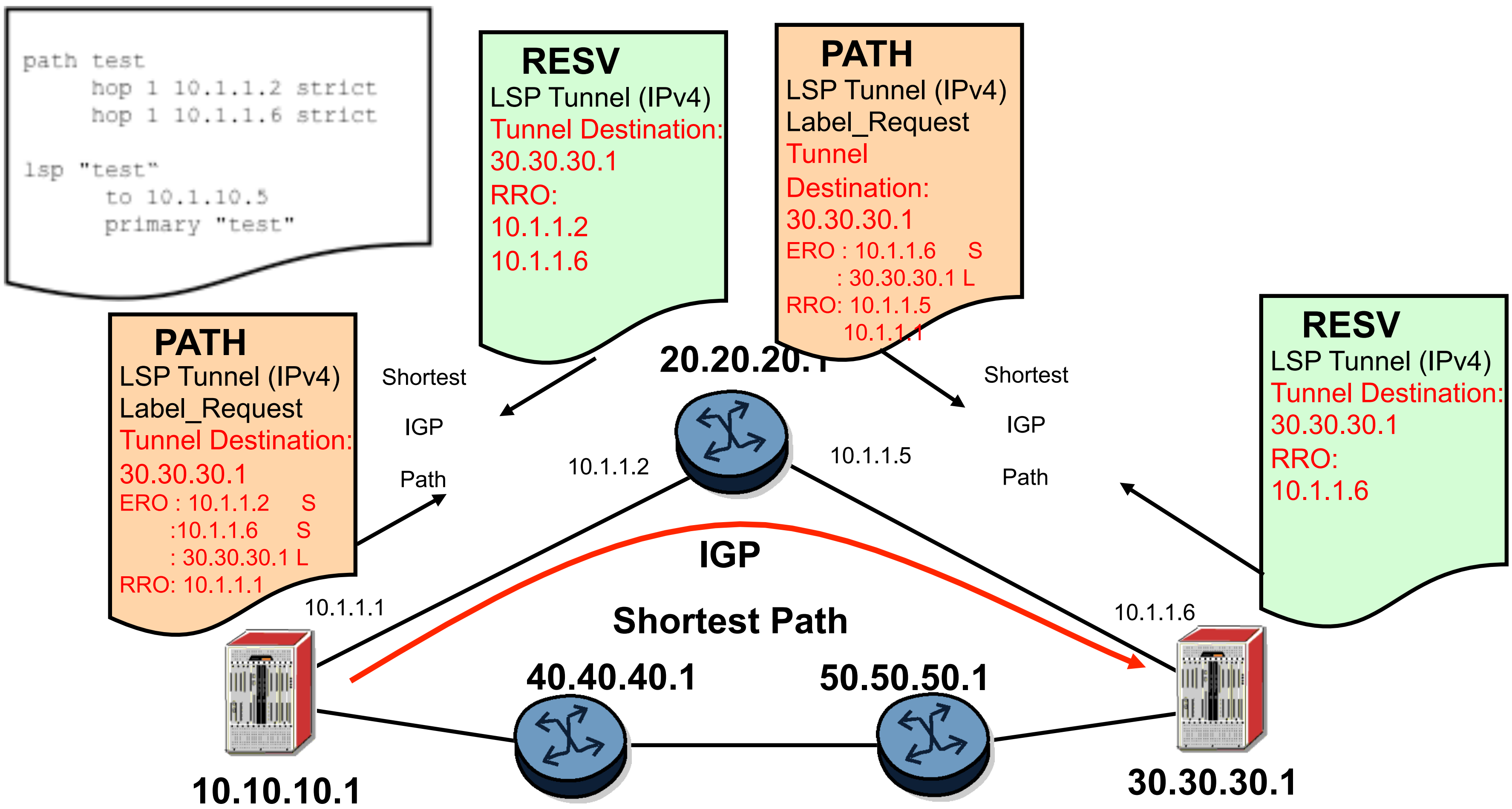
RSVP-TE Operation – ERO Specified strict / SPF



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RSVP-TE : How Traffic Engineering Works

- Traffic Engineering requires dynamic and detailed knowledge of the network topology.
- The control plane is implemented by defining IGP extensions so that link attributes are included in each routing update (LSAs for OSPF and TLV for ISIS).
- Best route selection will be computed via a modified SPF algorithm based on information contained in the TED. (traffic engineering database)

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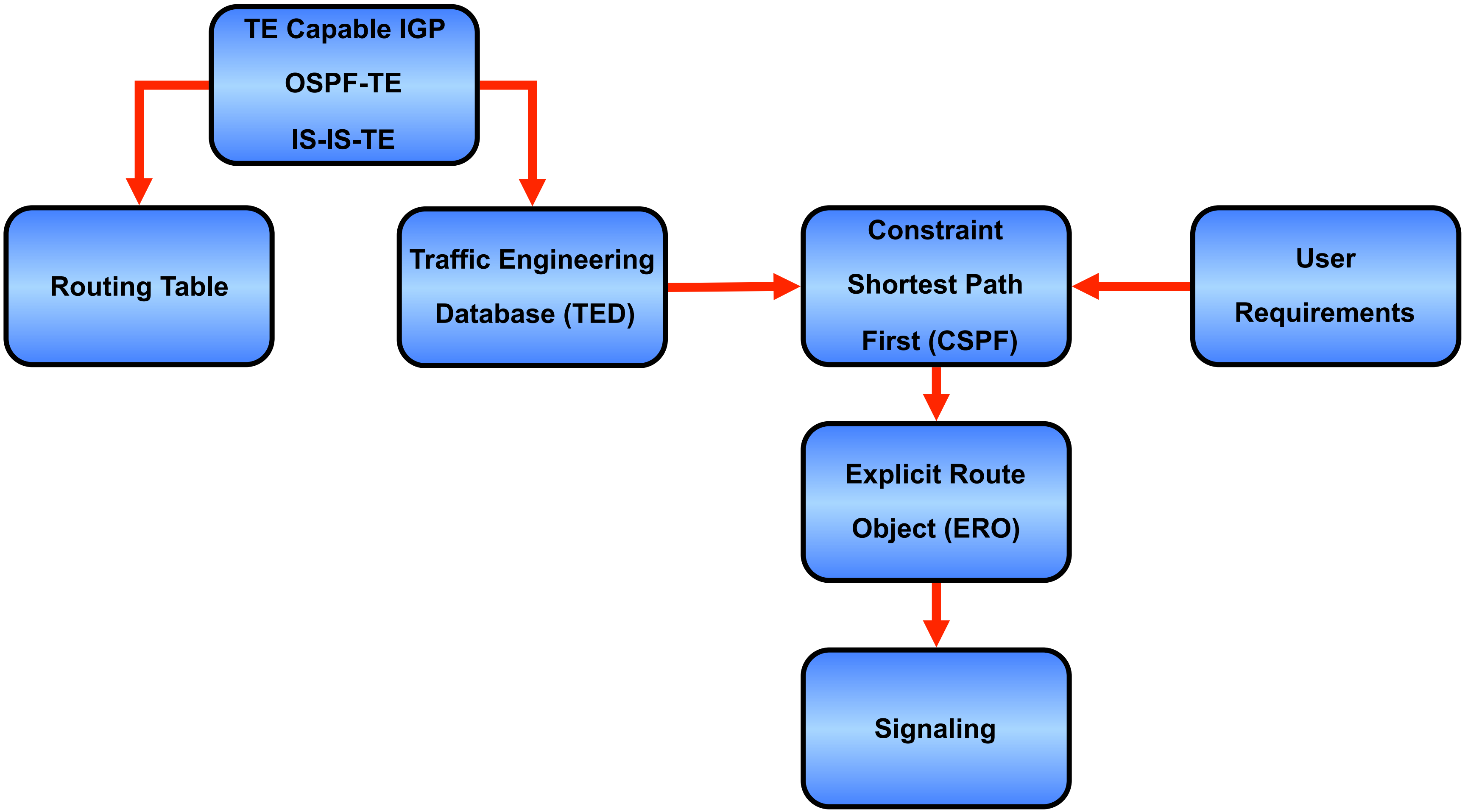
Signaled LSPs with CSPF



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The Constraint Shortest Path First (CSPF) Algorithm

- CSPF relies on input from multiple sources to perform its calculations
  - The Traffic Engineering Database (TED)
  - User configuration
- CSPF calculates a path based on the constraints provided and puts the computed path in an explicit route object (ERO)
- Each ingress router uses the TED to calculate the paths for its own set of LSPs across the routing domain
- The ERO consists of a sequence of routers providing the shortest path through the network within the defined constraints
- The ERO is then passed to the signaling protocol (typically RSVP-TE Path Message) to establish the forwarding state in the routers along the LSP

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Questions ???

Thank You

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