

# **BROADBAND AND HIGH SPEED NETWORKS**

## **Multiprotocol Label Switching (MPLS)**

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# TOPICS TO BE COVERED

<b>Multiprotocol Label Switching (MPLS)</b>	<b>2</b>	<b>8</b>
MPLS Basics		
FECs and Label Imposition		
MPLS Architecture Example		
MPLS Data Structures		
Penultimate Hop Popping		
Label Encapsulation		

# WHAT IS MPLS?

- ❑ **Multi Protocol** – supports protocols even other than IP.
  - It supports IPv4, IPv6, IPX, and AppleTalk at the *network layer*.
  - It supports Ethernet, Token Ring, FDDI, ATM, Frame Relay, and PPP at the *data link layer*.
  
- ❑ **Label** – short fixed length identifier to determine a route.
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- ❑ **Switching** – forwarding a packet.
  - Packets are forwarded based on the label value.
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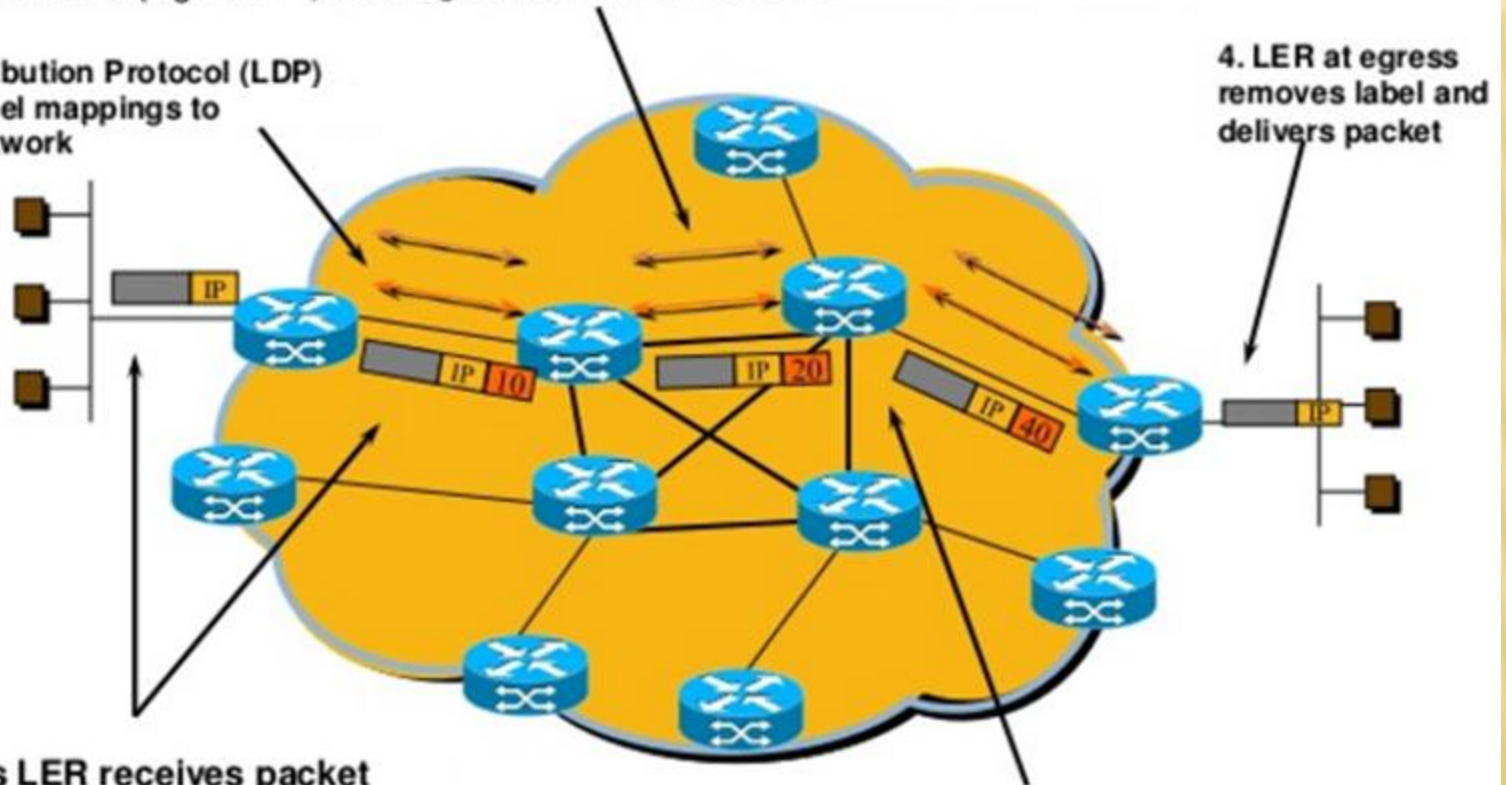
# TERMINOLOGY / COMPONENTS

- ❑ **LSR (Label Switched Router)**
  - ❑ High speed routers which switch data traffic within MPLS domain.
  - ❑ Swaps (Exchange) labels on packets in core of networks.
- ❑ **LSP (Label Switch Path)**
  - ❑ A unidirectional path to transport packets within MPLS domain
  - ❑ The path is setup before the data transmission similar to circuit switching
  - ❑ Path through network based on a FEC (Forwarding Equivalent Class).
- ❑ **LER (Label Edge Router)**
  - ❑ Attach labels to packets based on a FEC.
  - ❑ Operates at the edge of the access network & MPLS network.
  - ❑ Responsible for assignment and removal of labels.
  - ❑ Support Multiple Protocols connected to dissimilar networks (such as frame relay, ATM and Ethernet).
- ❑ **LIB (Label Information Base)**
  - ❑ Table maintained by the Routers.
  - ❑ MPLS equivalent to IP routing table, contains FEC-to-Label bindings.
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  - ❑ Group of packets sharing the same type of transport.
  - ❑ A path is a representation of a FEC.
- ❑ **LDP (Label Distribution Protocol)**
  - ❑ IETF defined protocol for explicit signaling and management.

# MPLS OPERATION

1a. Routing protocols (e.g. OSPF ) exchange to destination networks

1b. Label Distribution Protocol (LDP) establishes label mappings to destination network



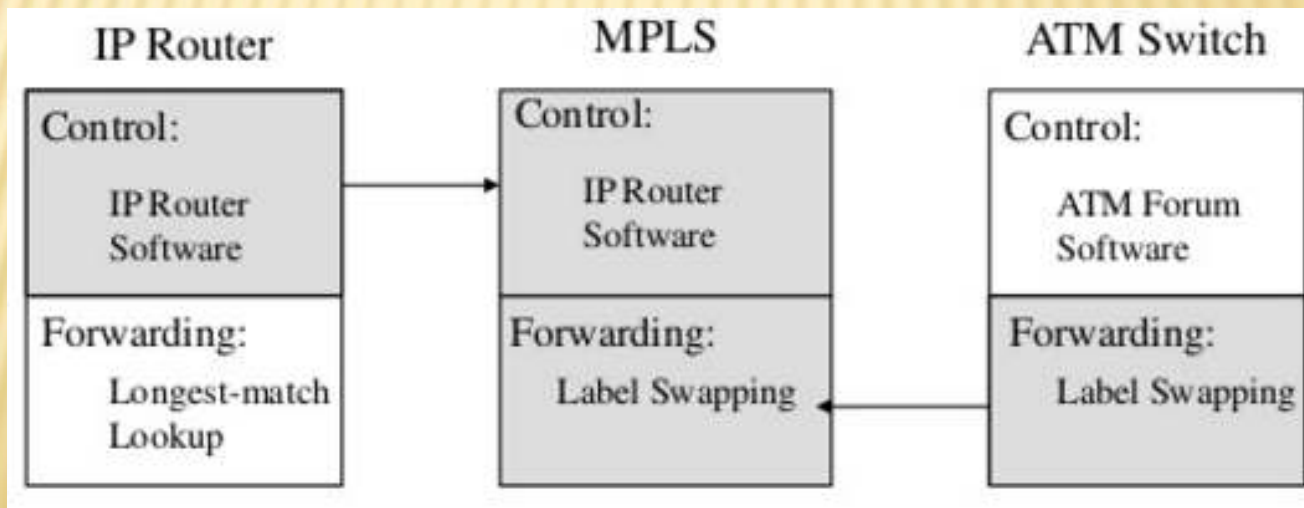
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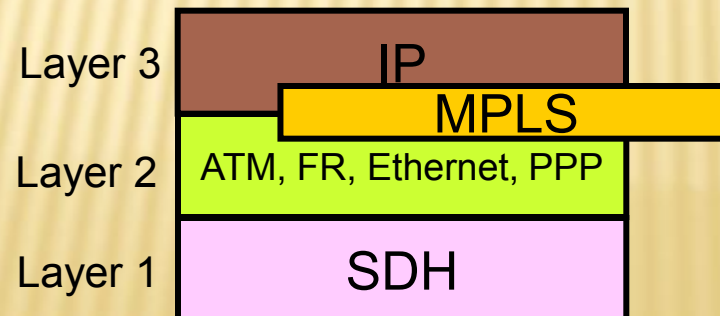
# MPLS

- ❑ A label is assigned for each IP flow
- ❑ LSP is created between ingress and egress
- ❑ Packet forwarding at each router by table lookup (based on label)
- ❑ MPLS supports a range of access technologies, including T1/E1, ATM, Frame Relay, and DSL
- ❑ MPLS is a mechanism in high performance networks that direct data from one network node to the next based on a short path labels rather than long network addresses, avoiding lookups in a routing table.

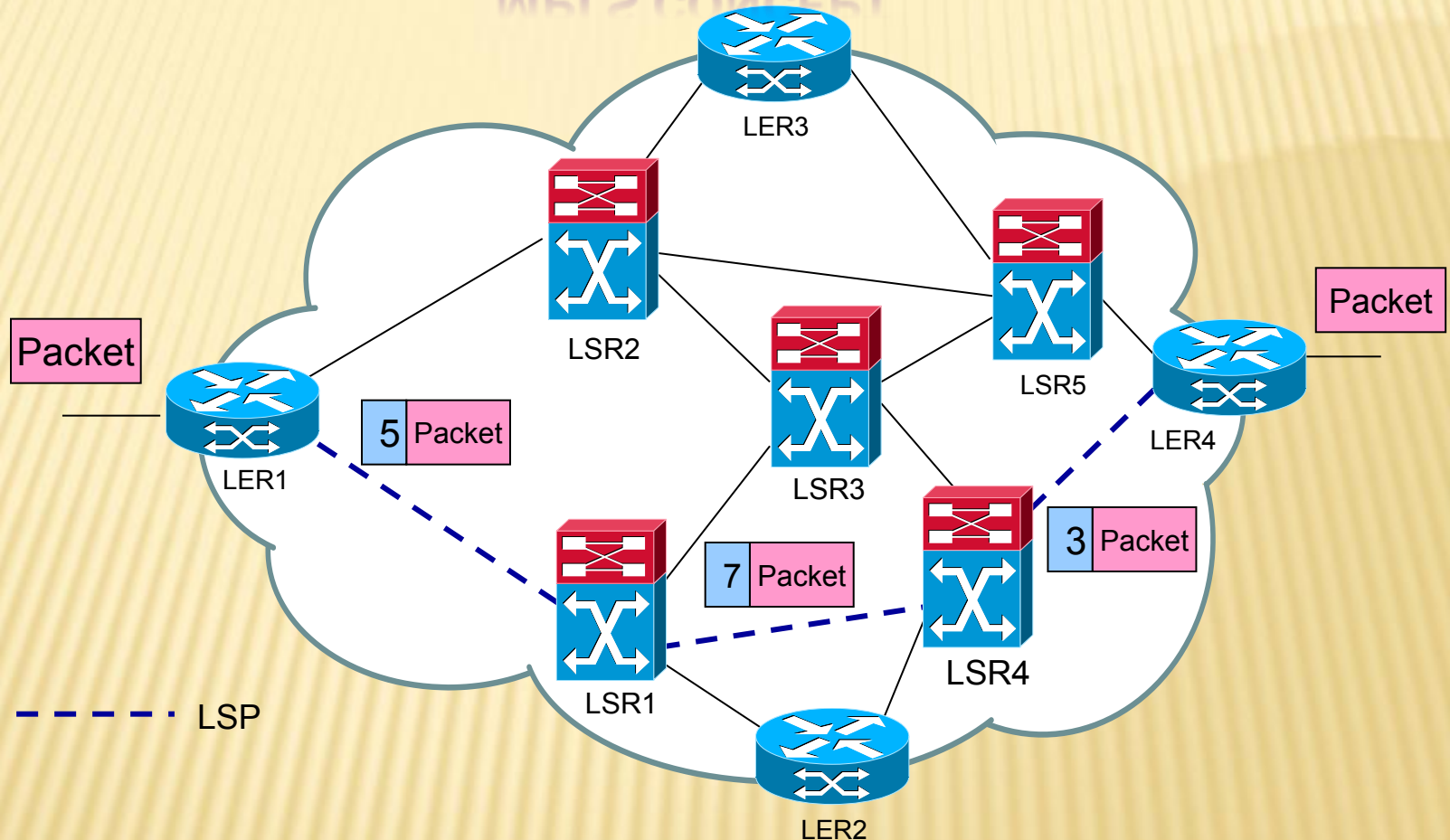


# WHAT IS MPLS?

- ❑ Standardized by *Internet Engineering Task Force (IETF)*.
- ❑ Integration of layer 2 and layer 3.
  - Simplified *connection-oriented forwarding of layer 2*.
  - Flexibility and scalability of *layer 3 routing*.
- ❑ MPLS does not replace IP; it supplements IP.
- ❑ Traffic can be marked, classified and routed.
- ❑ **QoS** can be achieved through MPLS.



# MPLS CONCEPT



In an MPLS network, all incoming packets before entering the MPLS network are **assigned to labels** by a **Label Edge Router (LER)**. Then, the Packets are traveled along a **Label Switched Path (LSP)** where each **Label-Switched Router (LSR)** performs the forwarding according to the numbered label. At each hop, **the LSR pops the existing label and applies a new label**, which is understood by the next LSR for performing the same procedure popping label and assigning another one. Finally, the **egress LER pops the label** and forwards the packet to its destination outside the MPLS network.

# MPLS COMPONENTS

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- ✦ **FEC**: Forwarding Equivalence Class.
- ✦ **LSR**: Label Switching Router.
- ✦ **LER**: Label Edge Router.
- ✦ **LSP**: Label Switched Path.
- ✦ **LDP**: Label Distribution Protocol.

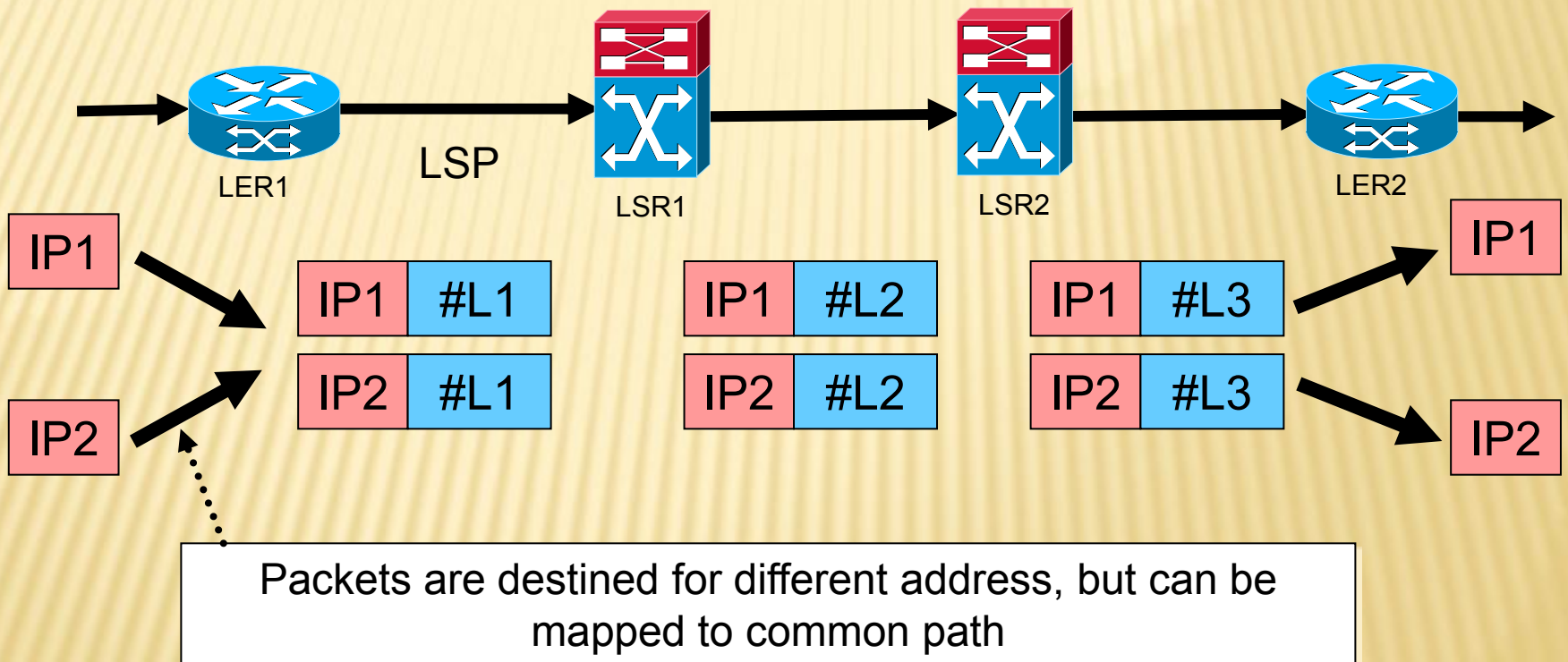
## FORWARDING EQUIVALENCE CLASS (FEC)

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- ❑ An **FEC** is *a group of packets share a common path through MPLS domain.*
- ❑ Packets mapping to FEC based many criteria:
  - ❑ **Destination IP address.**
  - ❑ **TCP/UDP port.**
  - ❑ **Quality of Services (QoS).**
  - ❑ **Services (VPN).**
  - ❑ **Combination of the above criteria.**

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- ❑ Once any packet in the same FEC enters the MPLS domain, it will have the same *initial label*. The result is that the packet will travel through the MPLS domain along the same *label-switched path* until its MPLS header removed at the same exit of the MPLS domain (*egress point*).
  - ❑ The *packet-to-FEC assignment* is done once, at the ingress point of the network. This procedure is called **label imposition**.
  - ❑ FEC means that a subset of packets that are all treated the same way by a router.
  - ❑ The concept of FECs provides for a great deal of flexibility and scalability.
  - ❑ In *conventional 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.

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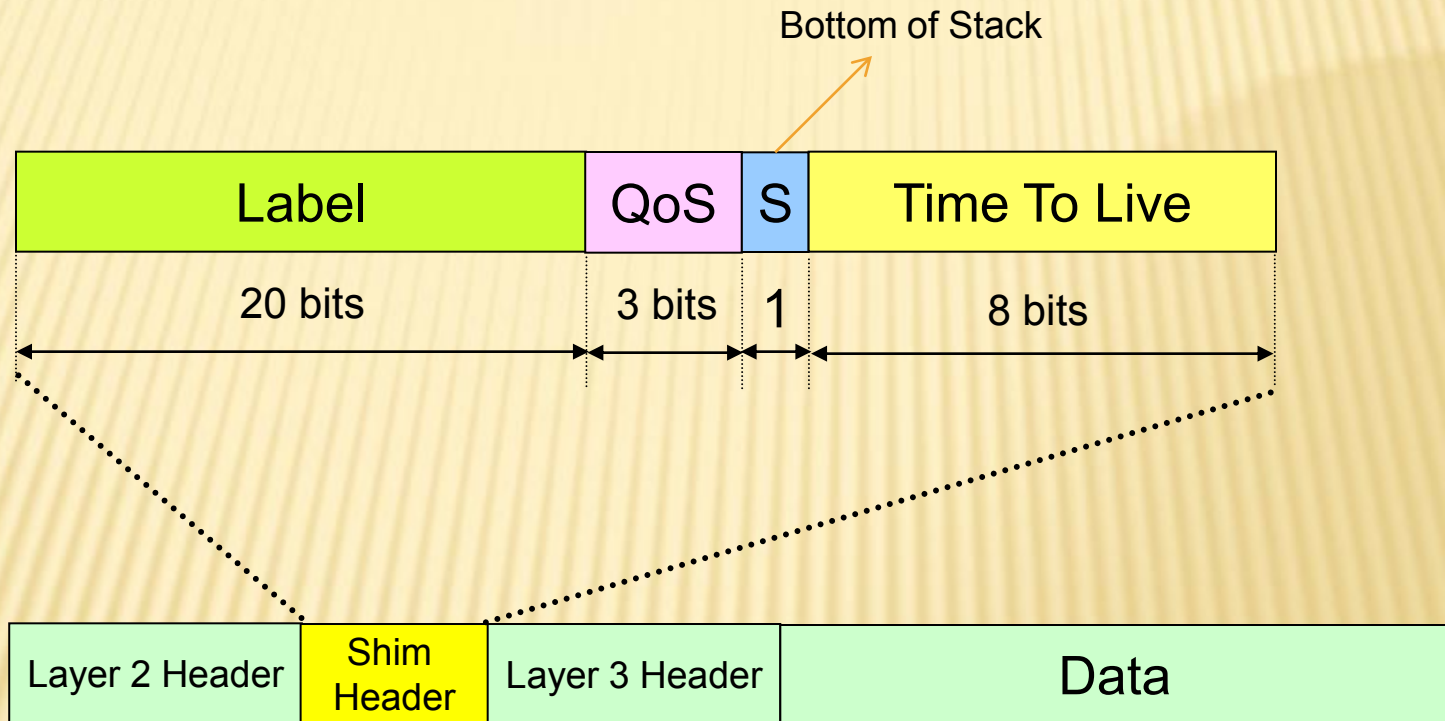


# LABEL

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- ❑ A *label* is a fixed-length information inside each packet header, used to identify a FEC.
- ❑ It can be represented in two ways:
  - ❑ In some layer 2 networks such as **ATM**, **Frame Relay**, etc., their own fields can be used for the **MPLS label**. For example, when ATM is used, the **VPI/VCI** field is used to carry a label.
  - ❑ In other layer 2 networks such as **Ethernet**, **shim header** is used. This header is placed between the layer 2 and layer 3 headers.

# SHIM HEADER



# LABEL EDGE ROUTER (LER)

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- ✘ LERs are located at the *boundaries* of a network.
- ✘ **Ingress LER** performing additional network layer services by **analyzing** the IP header packet and **applying labels to packets**.
- ✘ **Label popping** is the act of removing the last label from a packet at the **egress LER** before it is forwarded to a neighbor that is outside the MPLS domain.

# LABEL SWITCH ROUTER (LSR)

- ✘ The LSR is a device that implements the *MPLS forwarding*.
- ✘ The LSR forwards a packet based on the value of a *label* encapsulated in the packet.
- ✘ At each hop, the LSR pop the existing label and push the new label which tells the next hop how to forward the packet.
- ✘ High-speed switching of data is possible because the *fixed-length labels* are inserted at the very beginning of the packet or cell and can be used by hardware to switch packets quickly between links.

# LABEL SWITCH PATH (LSP)

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- ❑ In MPLS, data transmission occurs on LSPs.
- ❑ LSPs are a *sequence of labels* at every LSR along the path from the source to the destination.
- ❑ The LSP is set up prior to data transmission.
- ❑ The LSP setup for an FEC is *unidirectional* in nature.
  - ❑ The *return traffic* must take another LSP.

# LABEL SWITCH PATH (LSP)

- ❑ MPLS provides the following two options *to set up an LSP*:
  - ❑ **Hop-by-Hop Routing** : Each LSR independently selects the next hop for a given FEC. This methodology is similar to that currently used in IP networks. The LSR uses any available routing protocols, such as OSPF, ...etc.
  - ❑ **Explicit routing (ER)** : similar to *source routing*. The *ingress LER* specifies the list of nodes through which the **ER-LSP** traverses. The resources may be reserved to ensure QoS to the data traffic.

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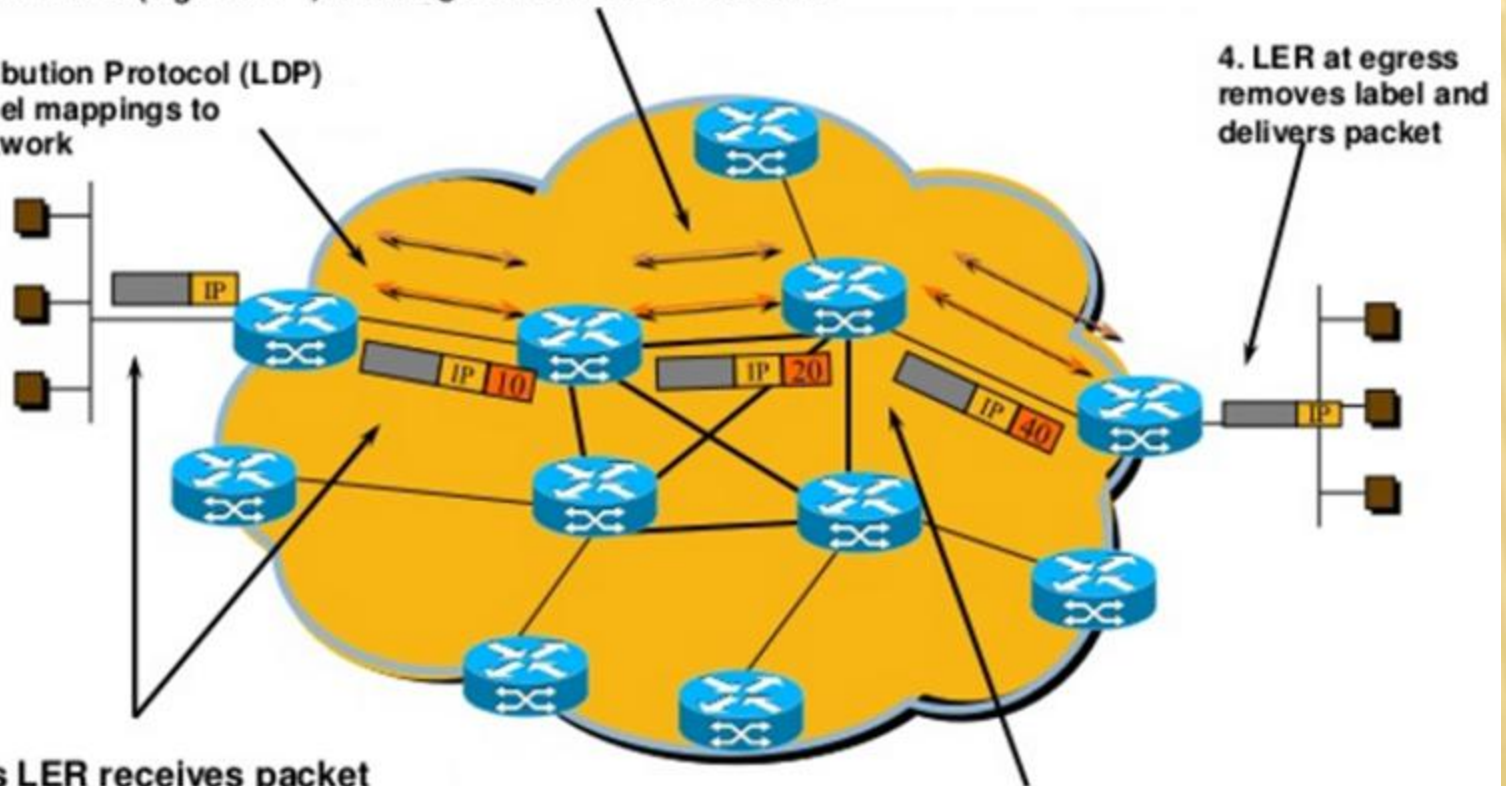
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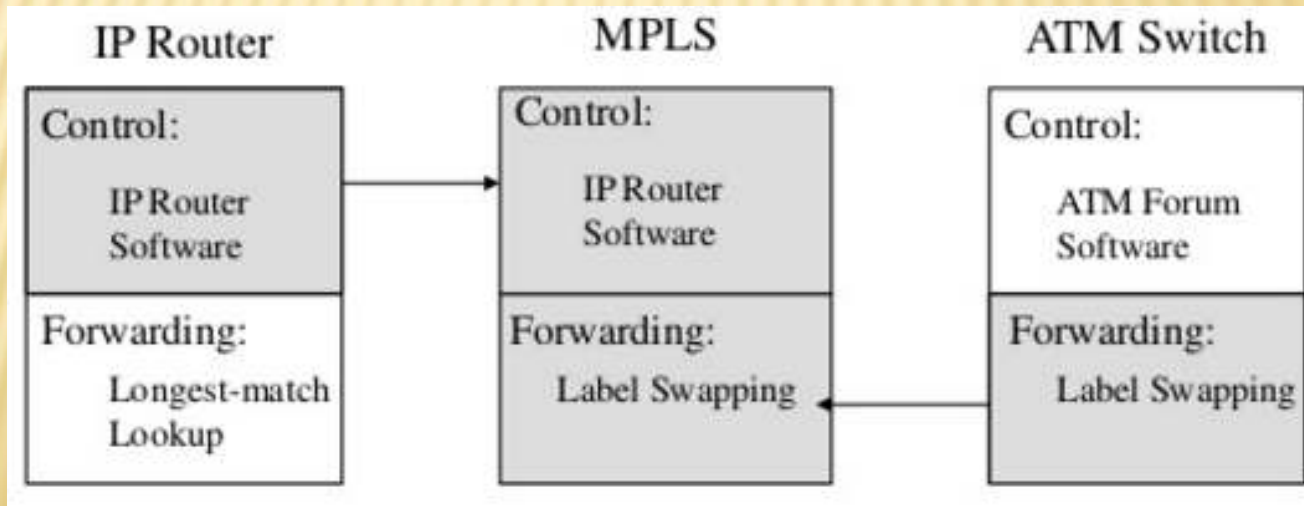
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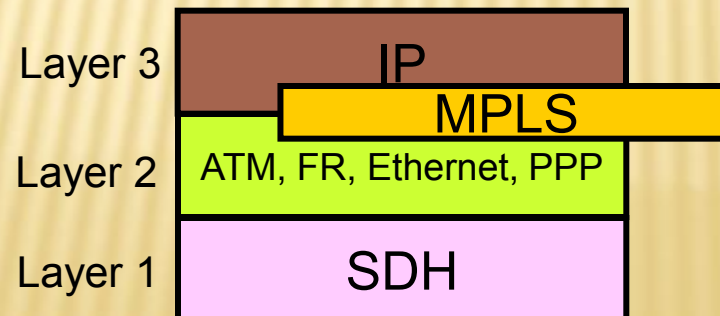
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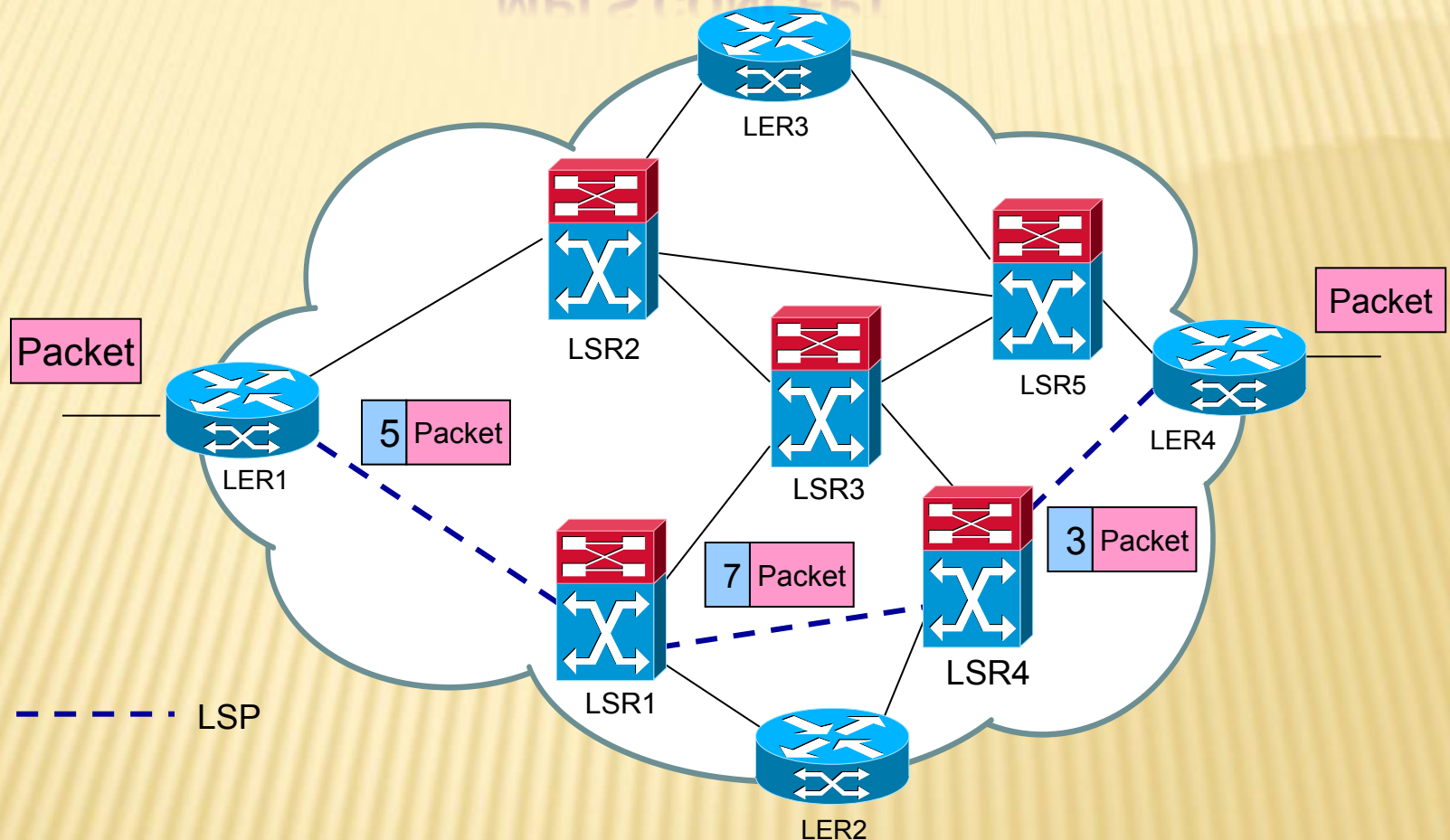


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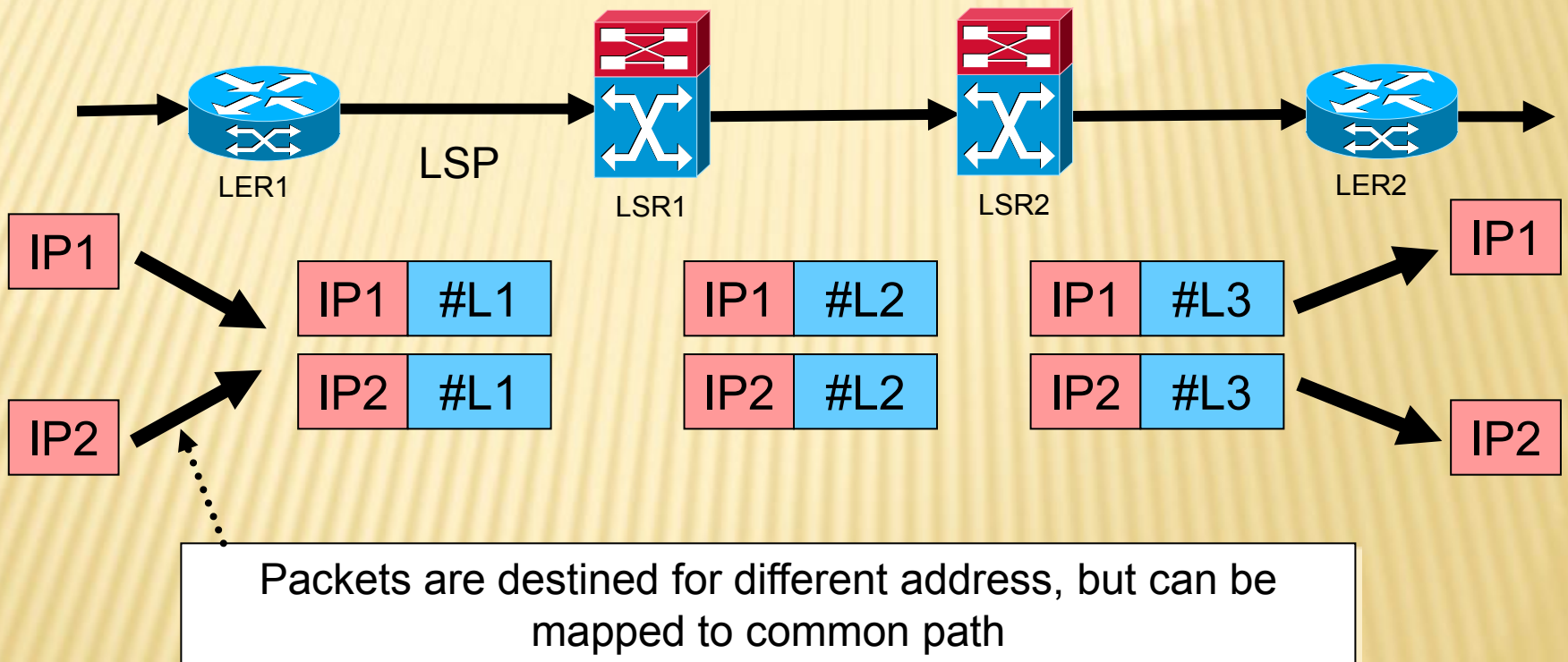
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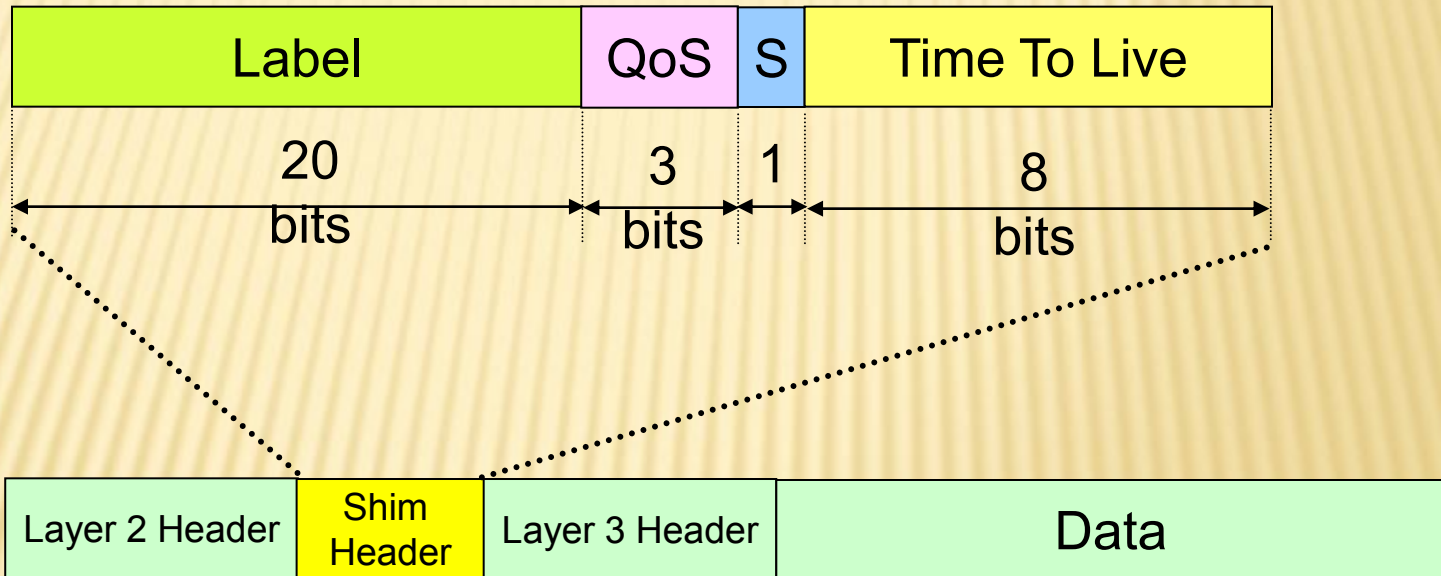


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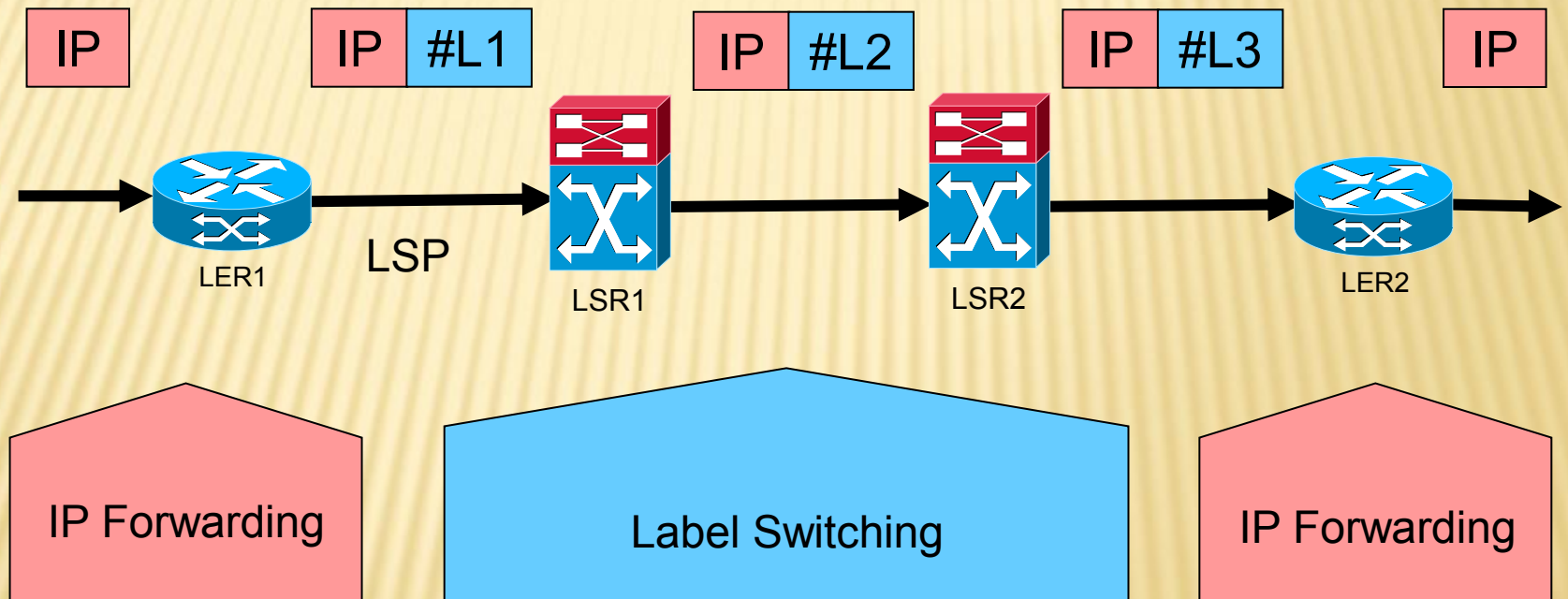
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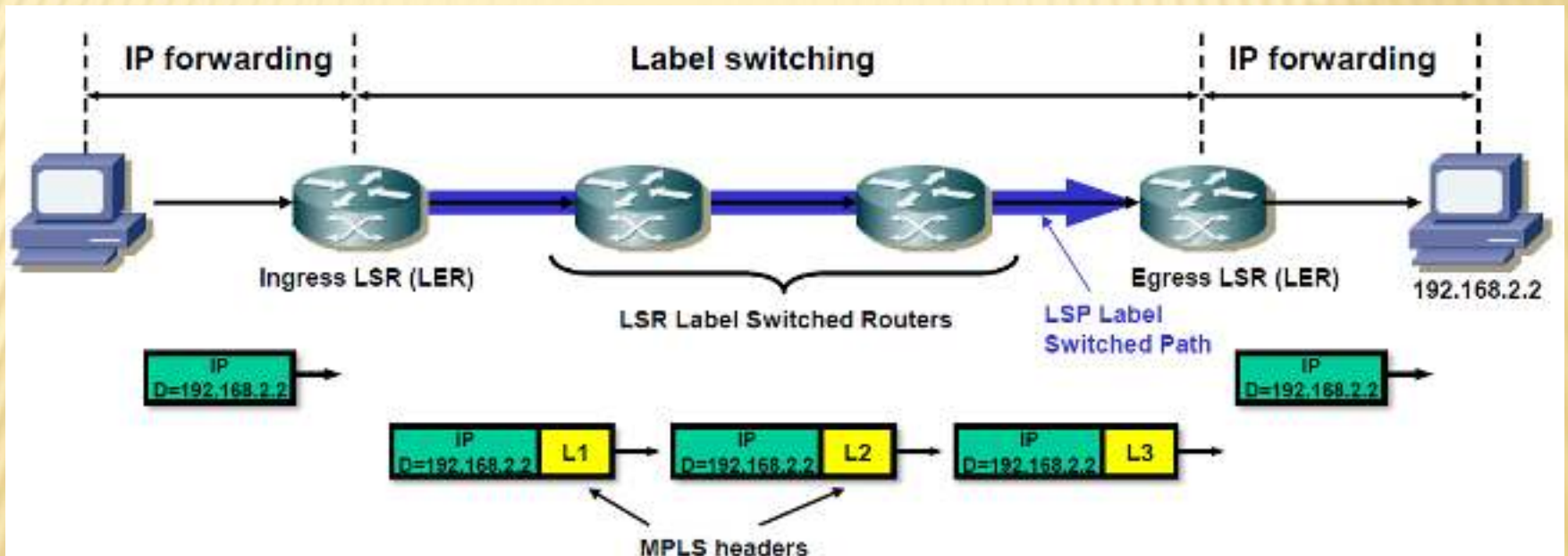
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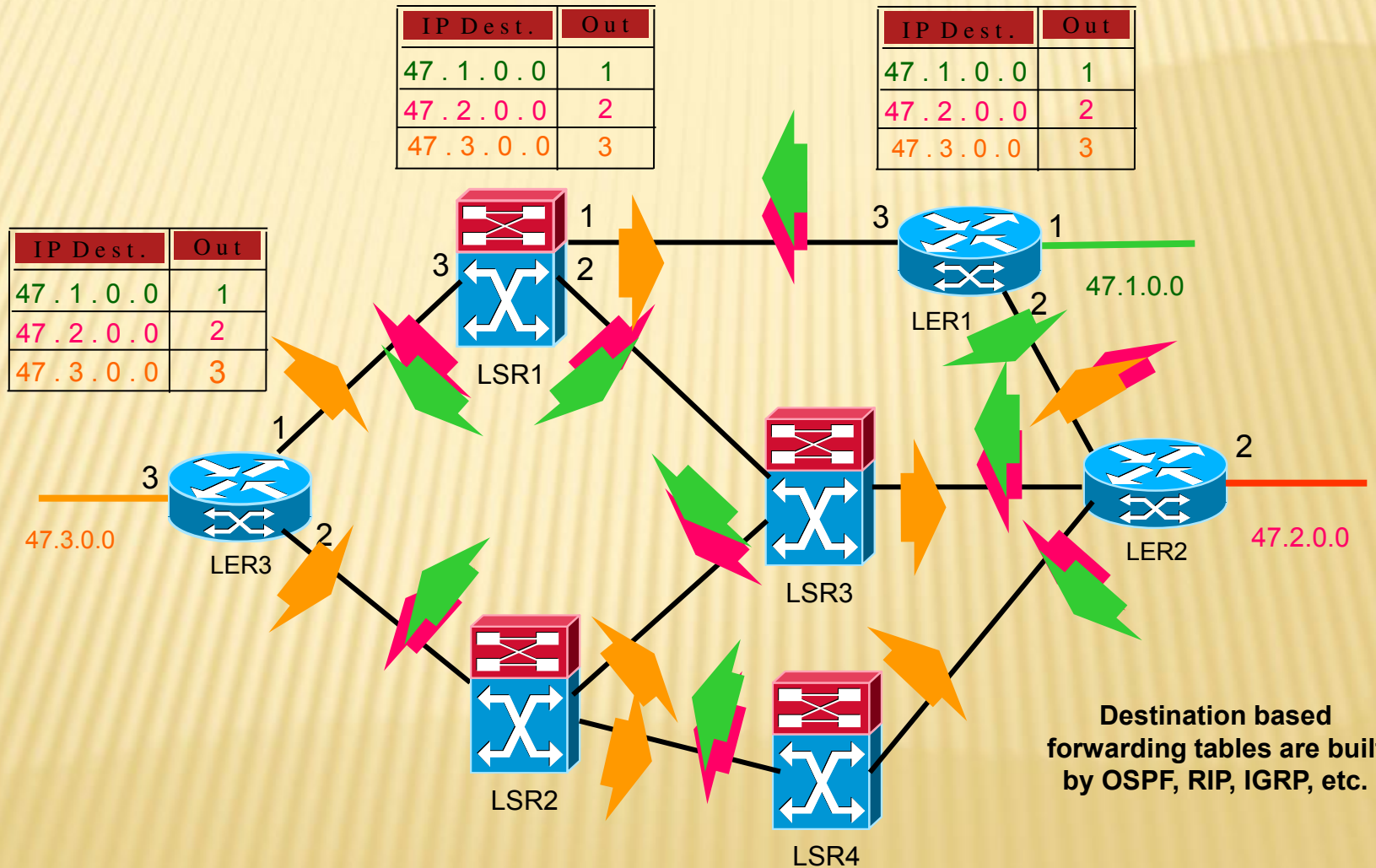


IP Forwarding

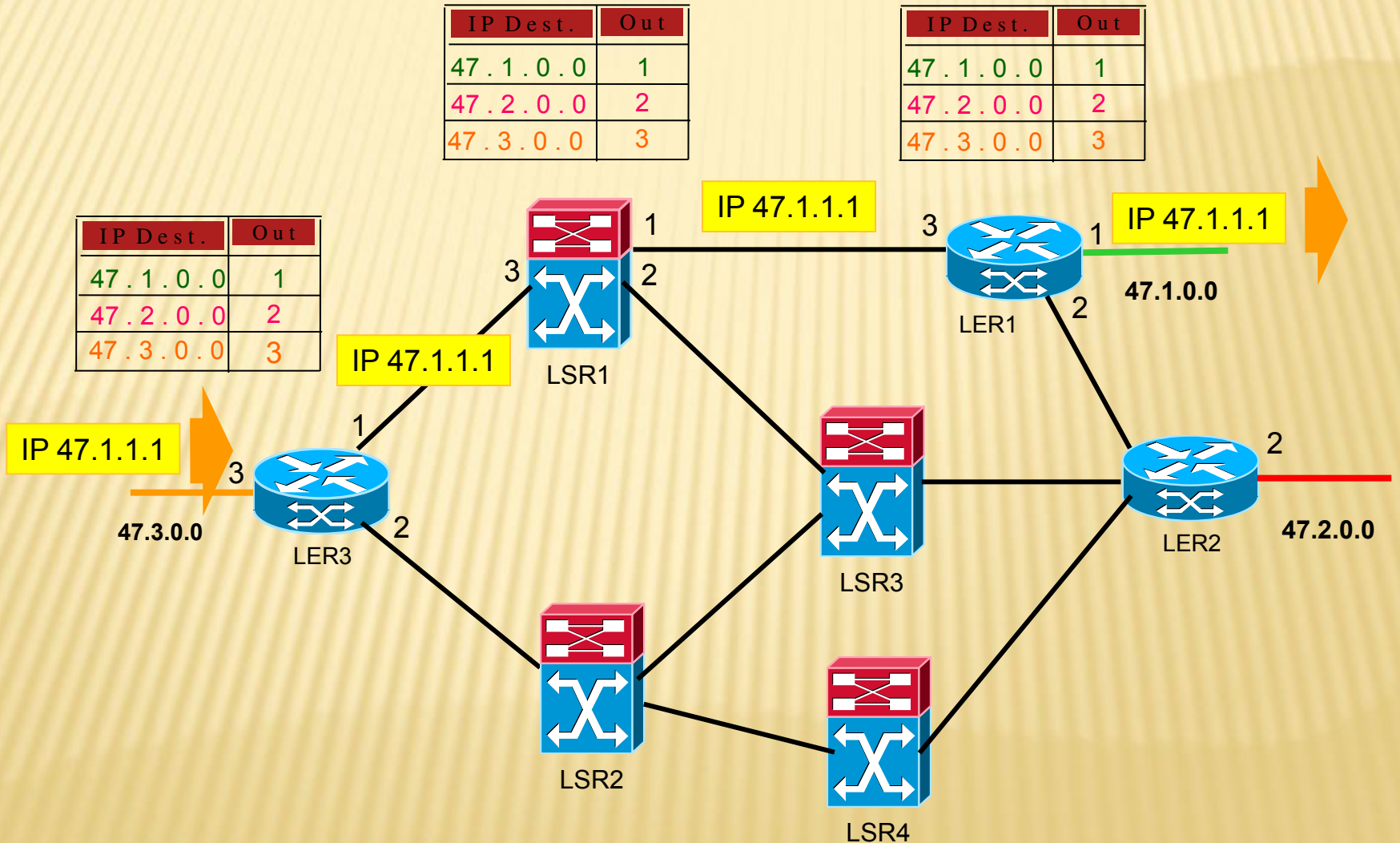
Label Switching

IP Forwarding

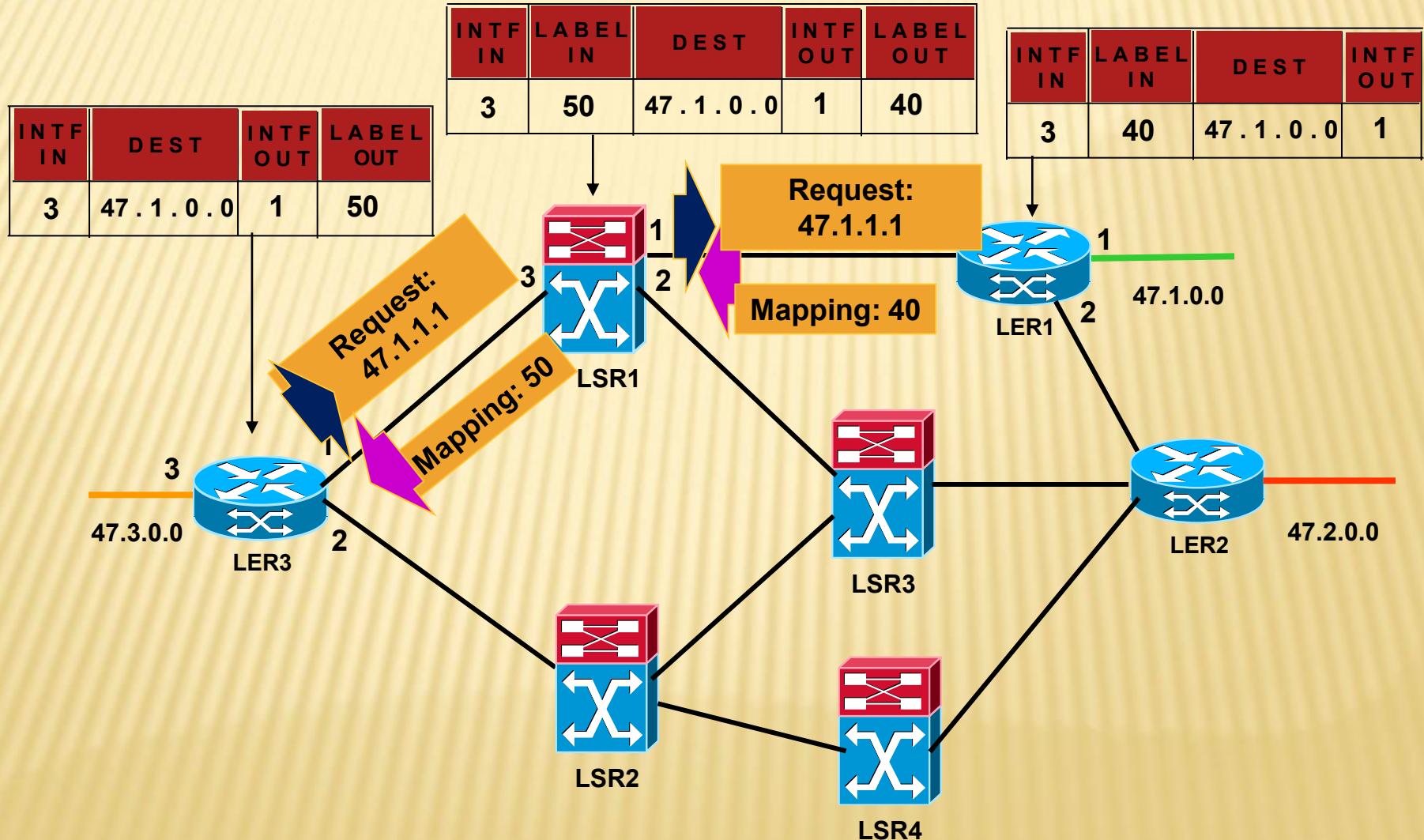
# TRADITIONAL IP



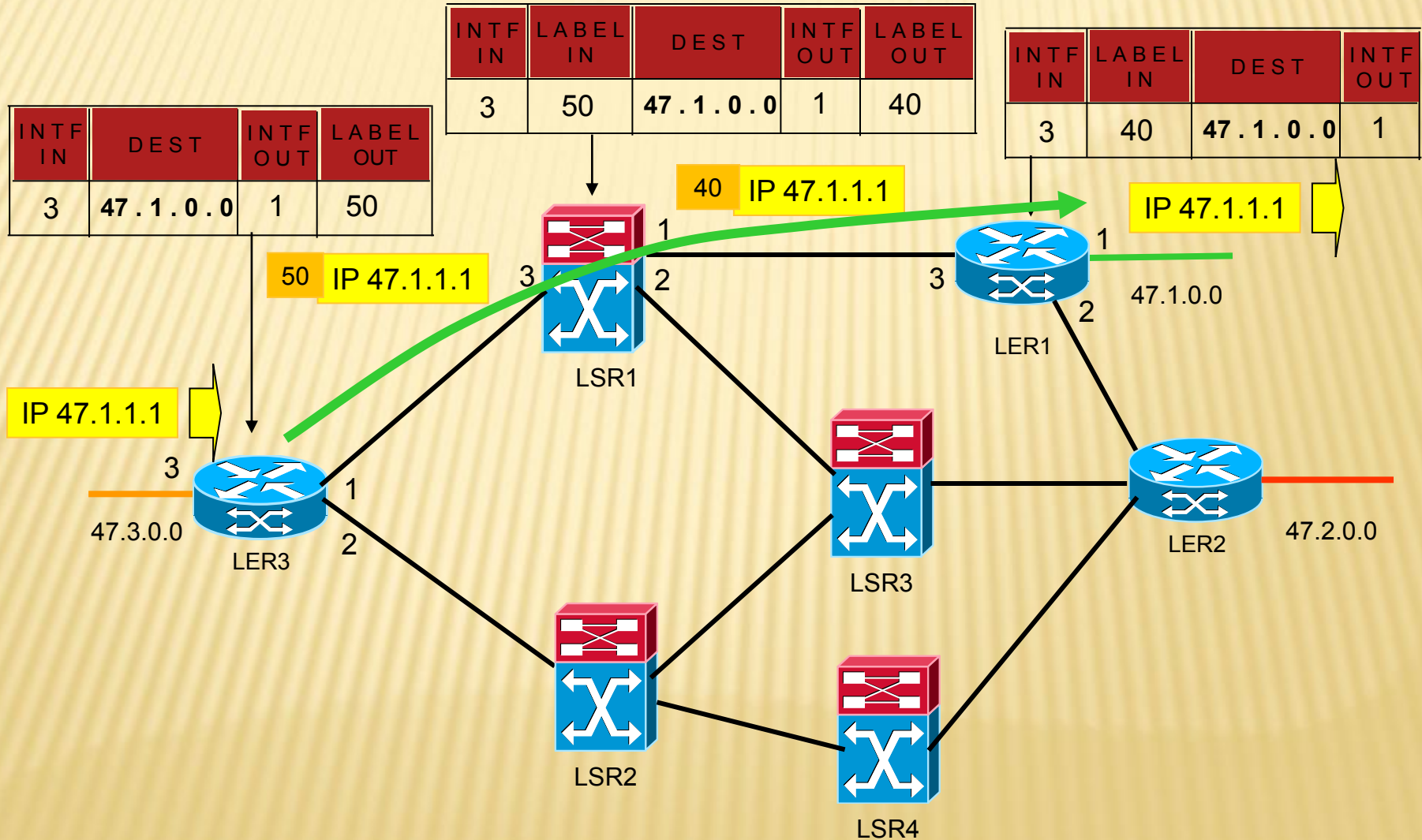
# IP FORWARDING USING HOP-BY-HOP CONTROL



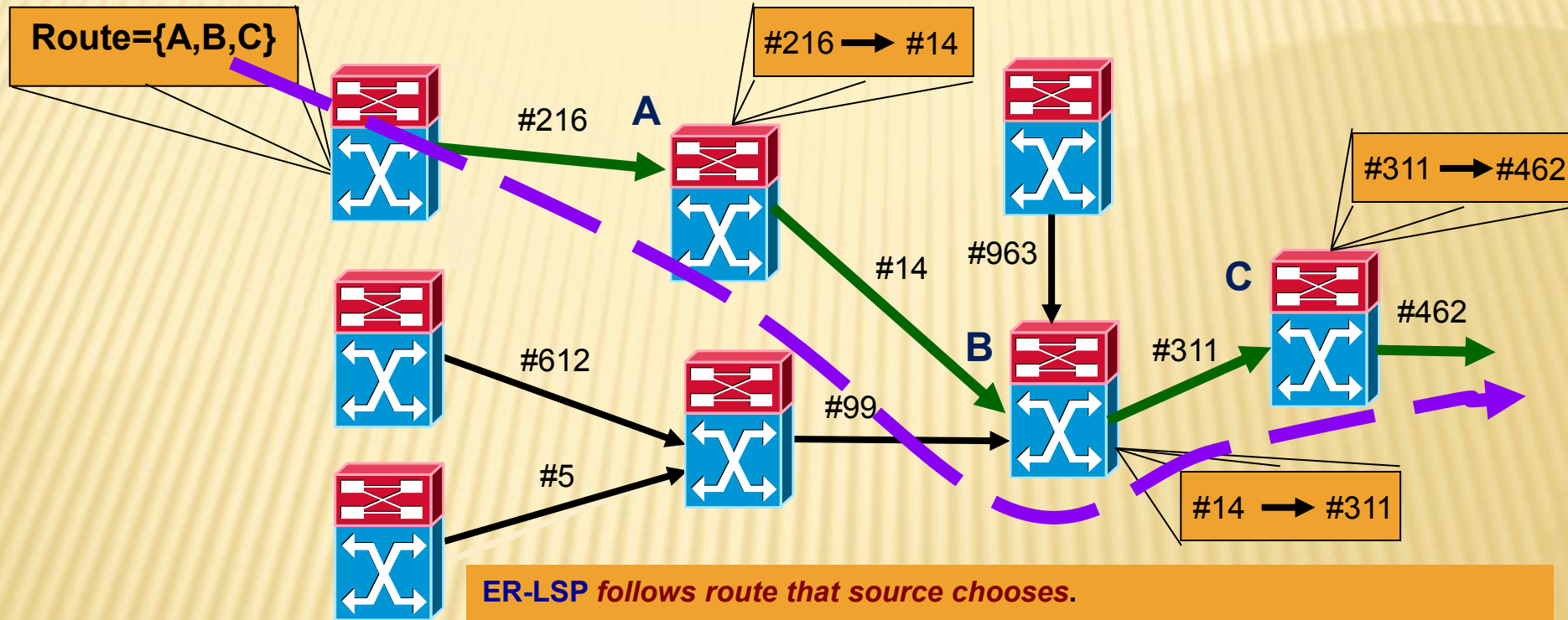
# MPLS LABEL DISTRIBUTION



# LABEL SWITCHED PATH (LSP)



# EXPLICITLY ROUTED LSP (ER-LSP)

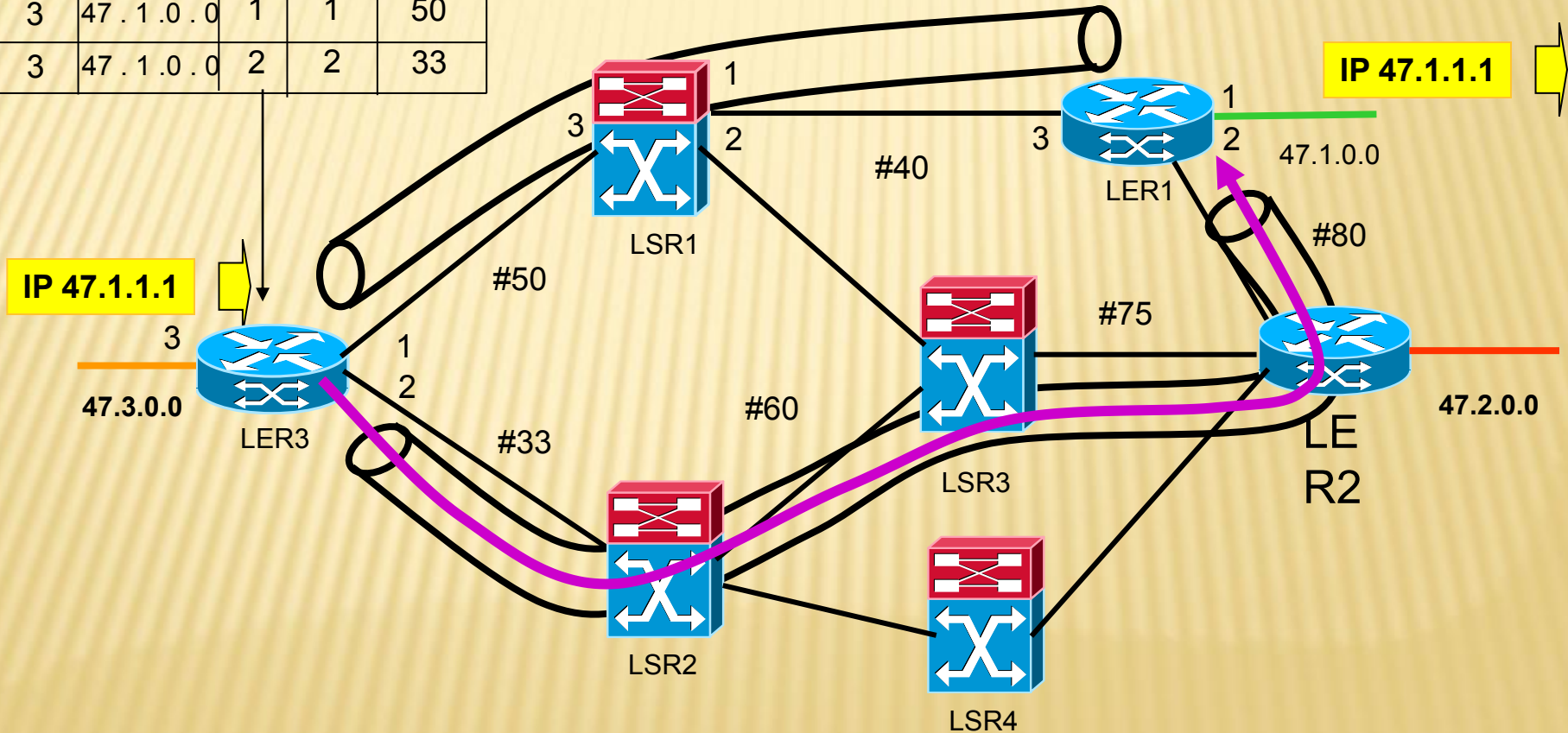


**ER-LSP follows route that source chooses.**

**The control message (*label request*) to establish the LSP is *source routed*.**

# EXPLICITLY ROUTED LSP (ER-LSP)

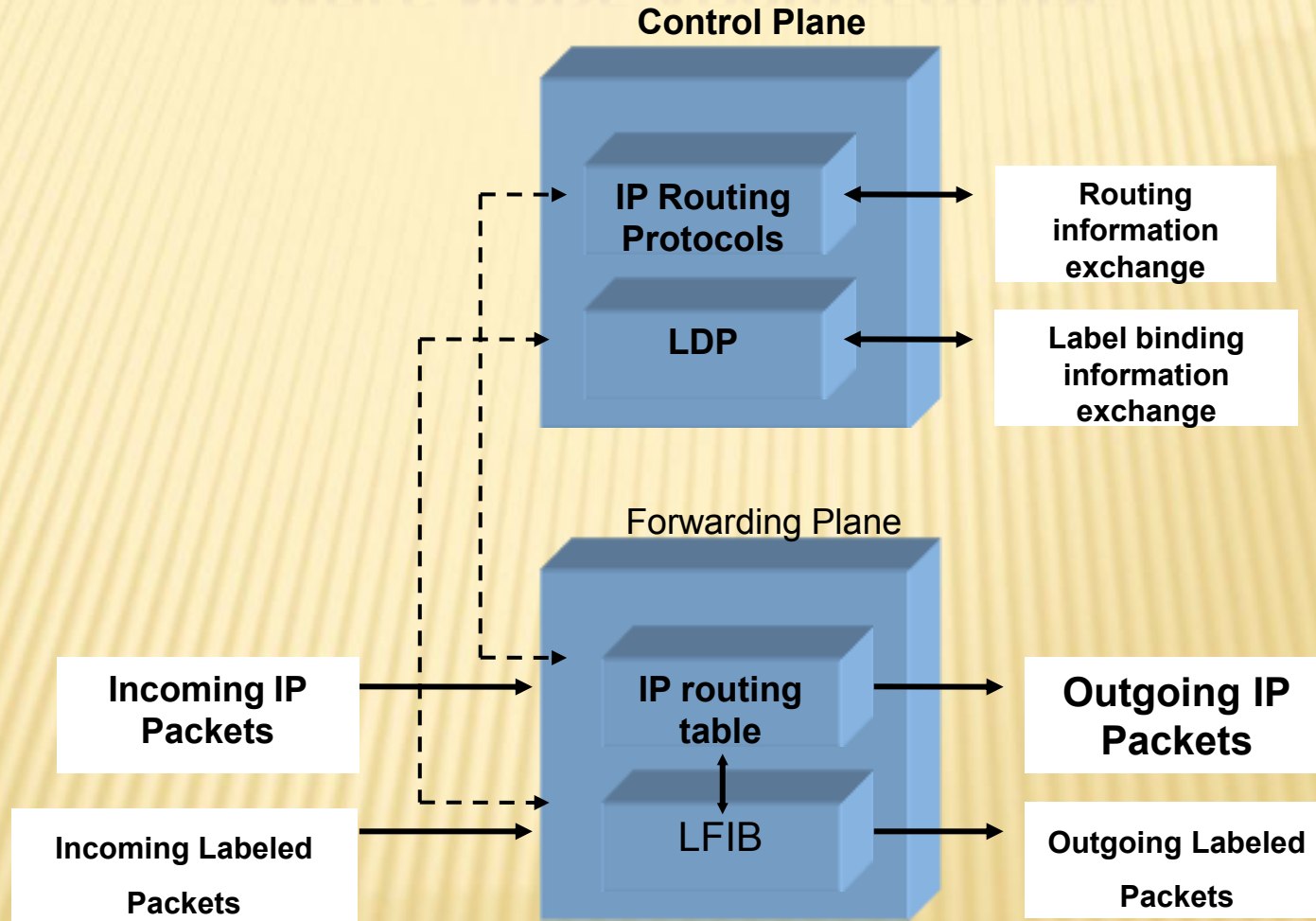
INTF IN	DEST	QoS	INTF OUT	LABEL IN
3	47.1.0.0	1	1	50
3	47.1.0.0	2	2	33



# ER LSP - ADVANTAGES

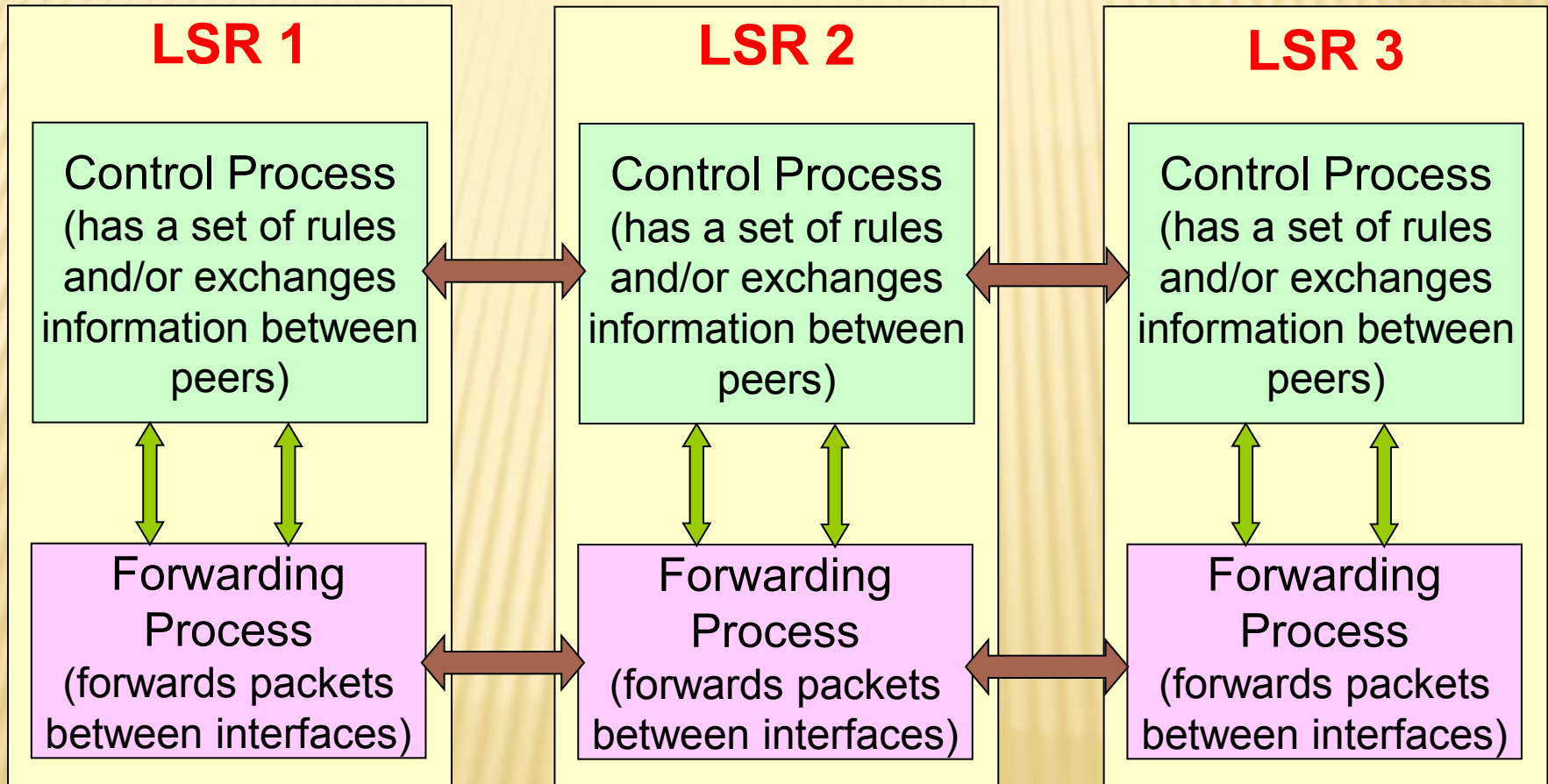
- ⊕ Operator has routing *flexibility* (policy-based, QoS-based)
- ⊕ Can use routes other than shortest path
- ⊕ Can compute routes based on constraints (traffic engineering)

# MPLS NODE ARCHITECTURE

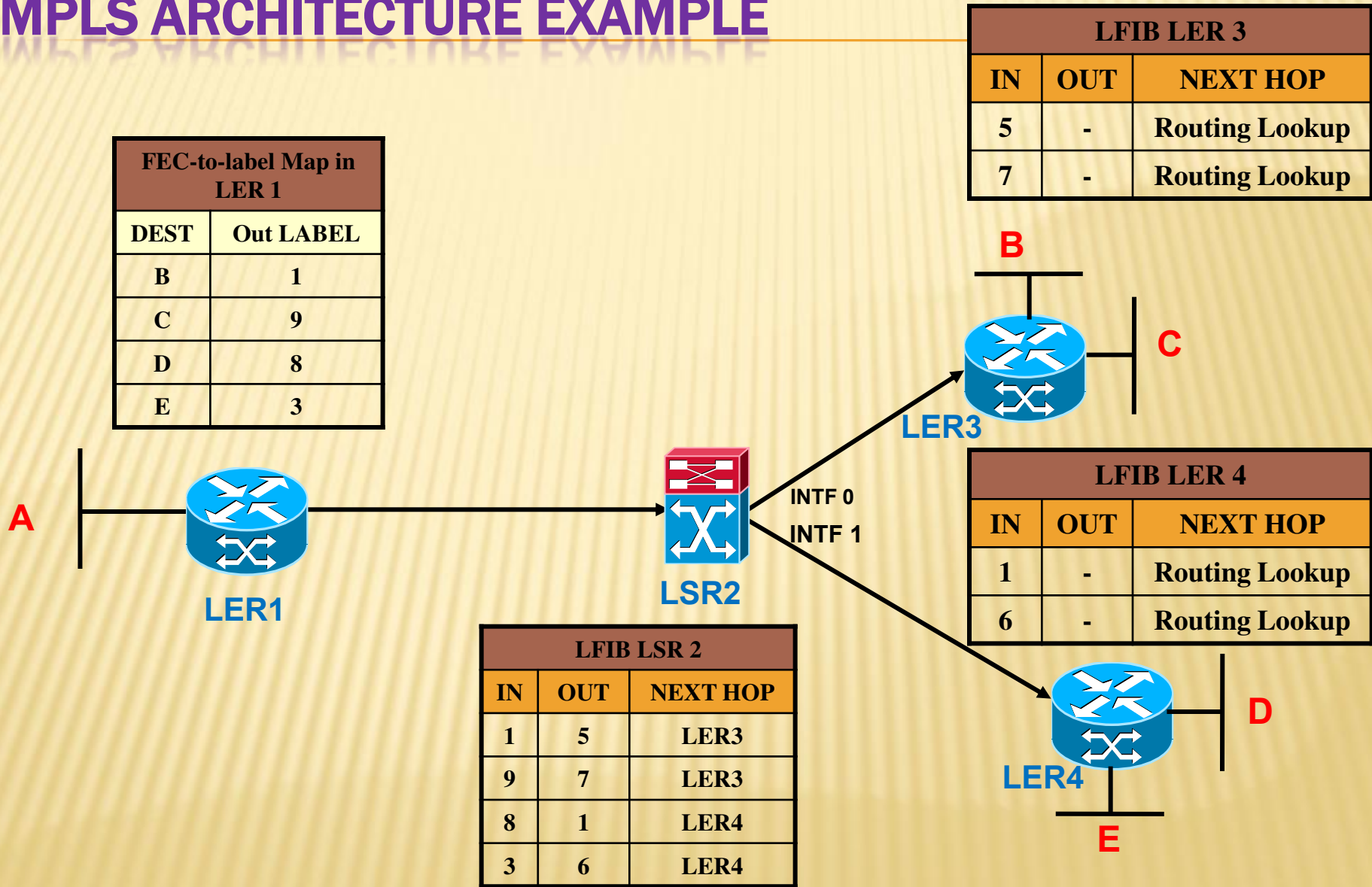


**Label Forwarding Information Base (LFIB)**  
**Label Distribution Protocol (LDP)**

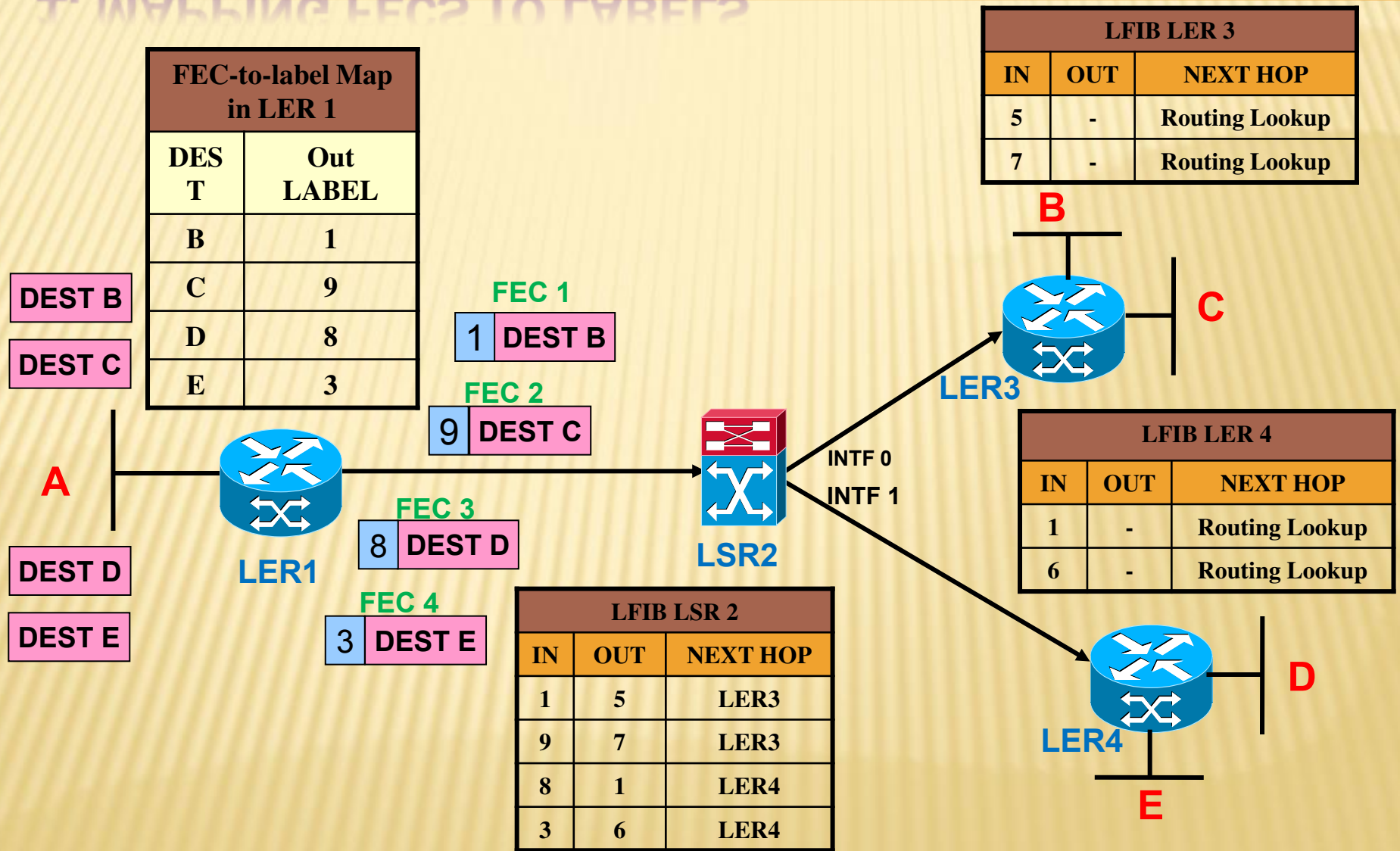
# DECOUPLING CONTROL AND FORWARDING PROCESSES



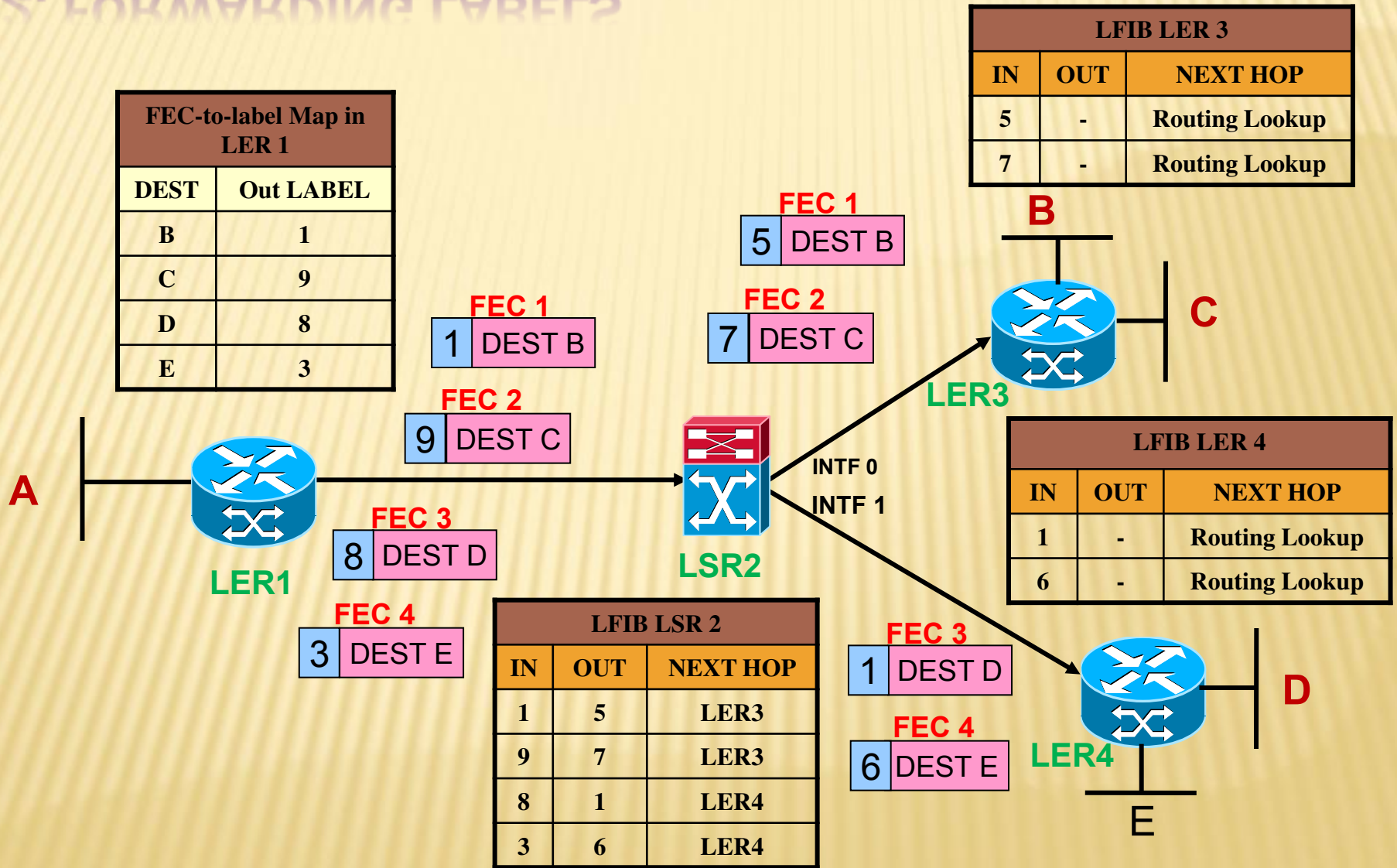
# MPLS ARCHITECTURE EXAMPLE



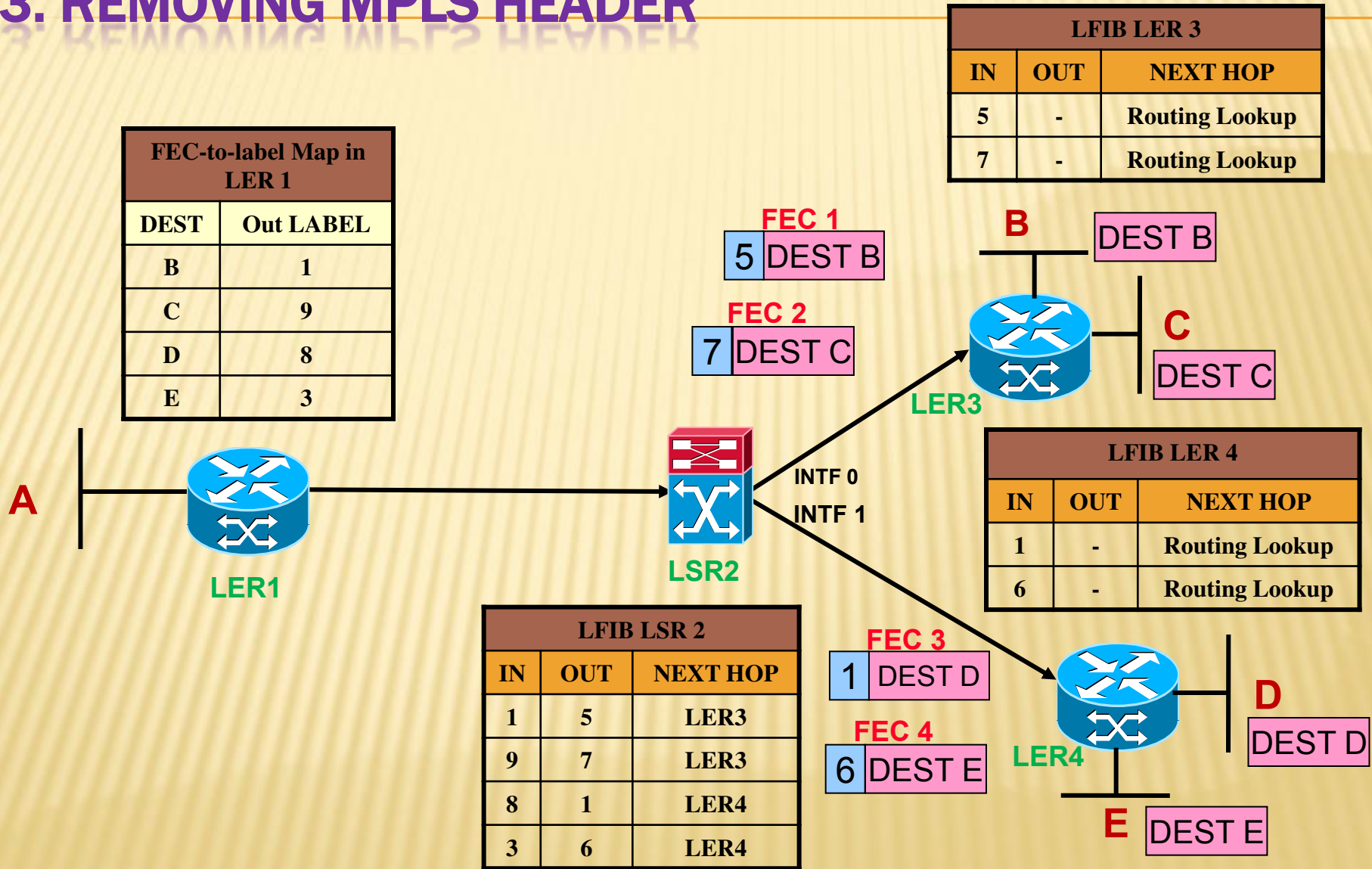
# 1. MAPPING FECs TO LABELS



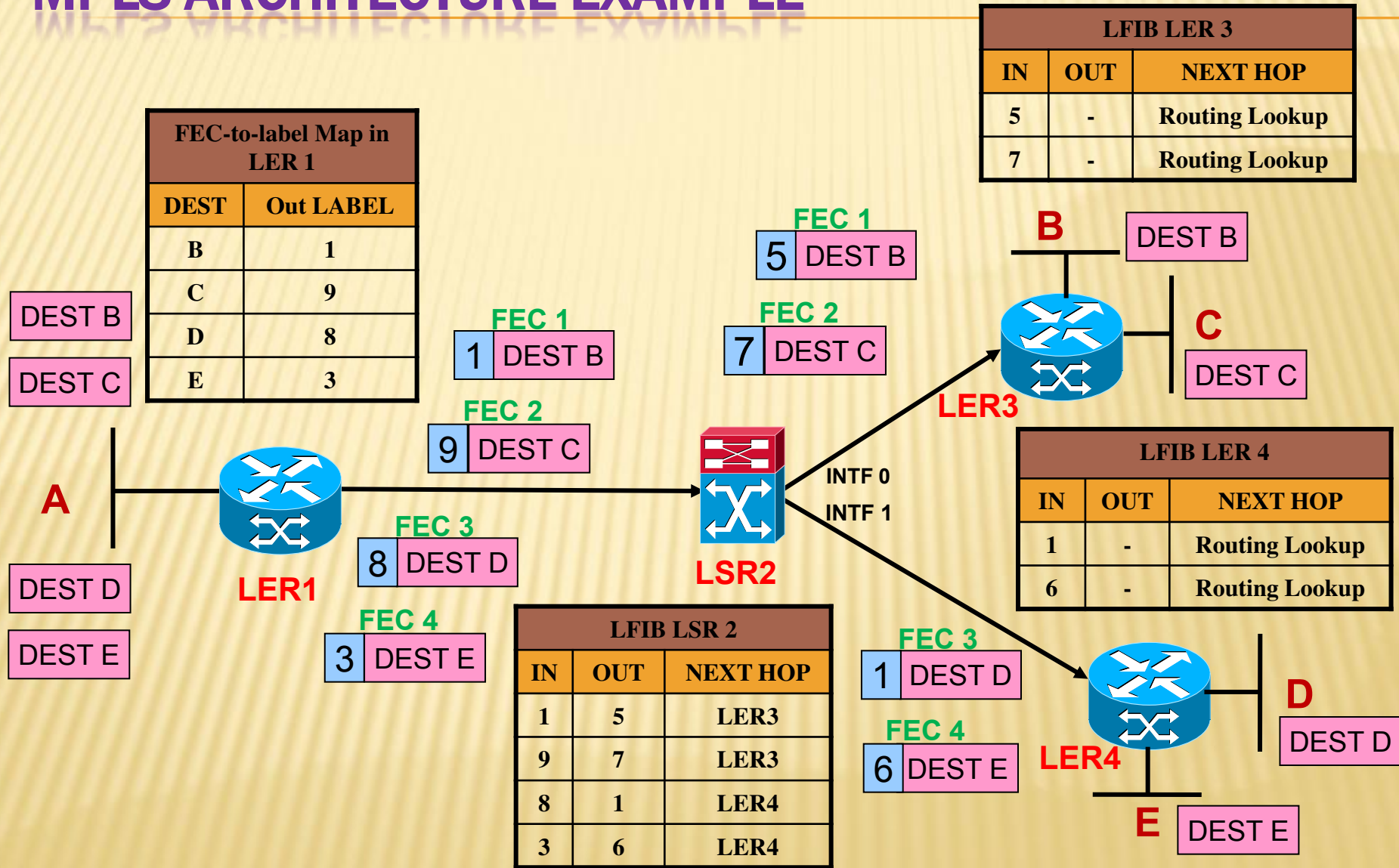
# 2. FORWARDING LABELS



# 3. REMOVING MPLS HEADER



# MPLS ARCHITECTURE EXAMPLE



# MPLS DATA STRUCTURES

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- An MPLS LSR maintains three important data structures:
  1. IP Routing Table.
  2. Label Information Base (LIB).
  3. Label Forwarding Information Base (LFIB).

# 1. IP ROUTING TABLE

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- ❑ To determine the next-hop forwarding information for the LFIB.
- ❑ The content of the **IP routing table** caused by exchanging information among all routing protocol peers within the network via a *routing algorithm* such as OSPF.
- ❑ The result computed by the *routing algorithm* is then stored in the **IP routing table**.
- ❑ The routing table will reflect the layer 3 topology of the network, as well as, the shortest path to reach any given network node.

## 2. LABEL INFORMATION BASE (LIB)

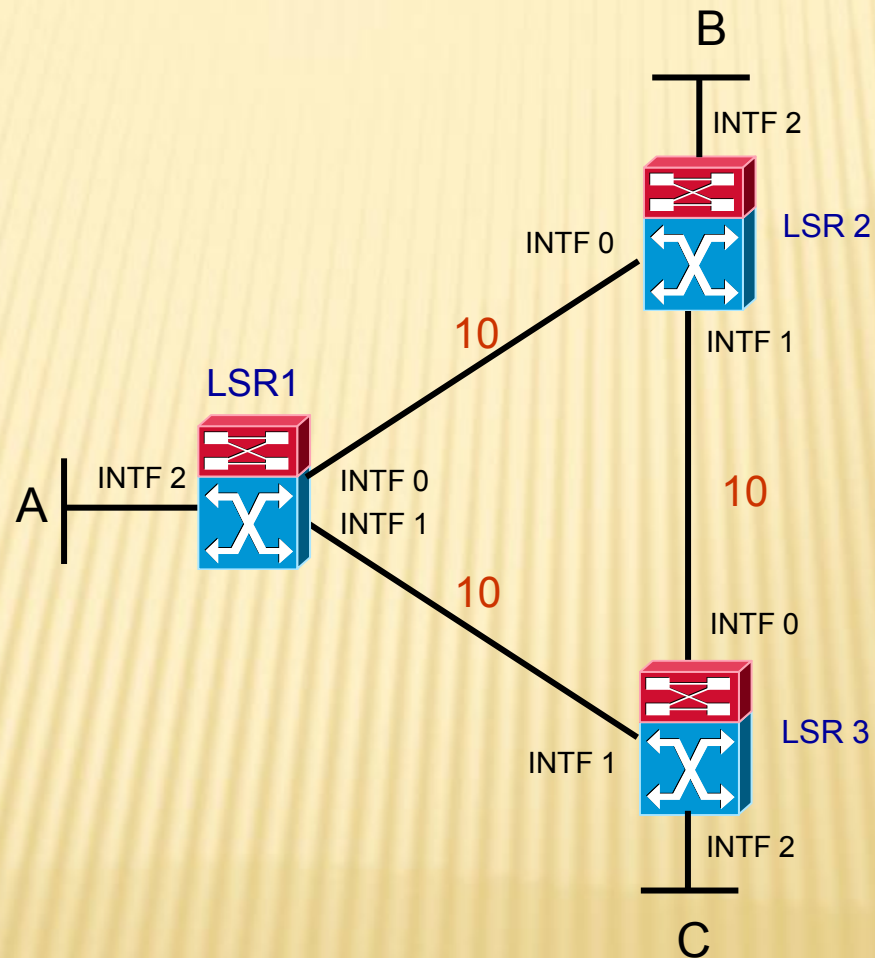
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- LIB stores all labels that have been advertised by other LSRs in the MPLS network.
- LSRs exchange the mapping of labels to their associated FECs.
- This is done using a variety of *label distribution protocols* such as:
  - Label Distribution Protocol (LDP).
  - Resource Reservation Protocol (RSVP).
  - Multiprotocol BGP (MP-BGP).

### 3. LABEL FORWARDING INFORMATION BASE (LFIB)

- ✦ Used by the actual packet forwarding process.
- ✦ MPLS LSR that wants to forward a packet will consult **LFIB** to determine *which label to swap on the packet* as well as *which next-hop interface it must forward the packet on to*.
- ✦ The information in the LFIB is the result of examining the IP routing table and the contents of the LIB and determining which IP destinations can be mapped to which MPLS labels.

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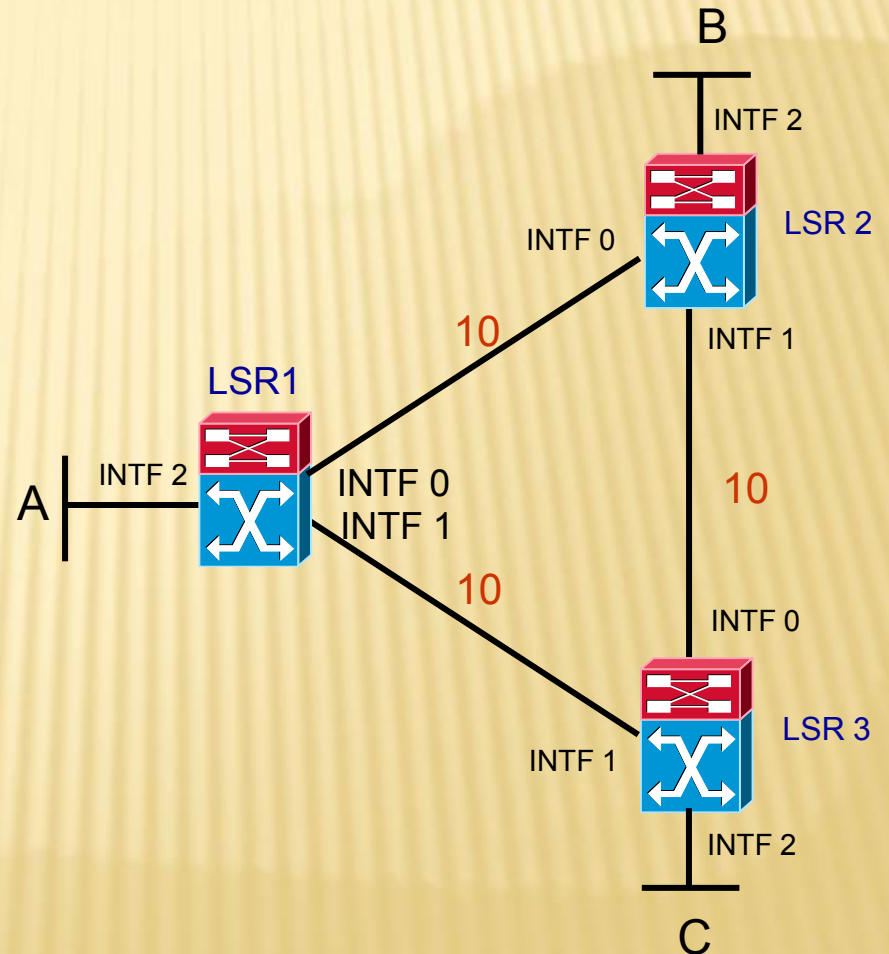


# MPLS DATA STRUCTURES - EXAMPLE

Routing Table LSR 1

DEST	METRIC	NEXT HOP	INTERFACE
A	0	Connected	2
B*	10	LSR 2	0
B	20	LSR 3	1
C*	10	LSR 3	1
C	20	LSR 2	0

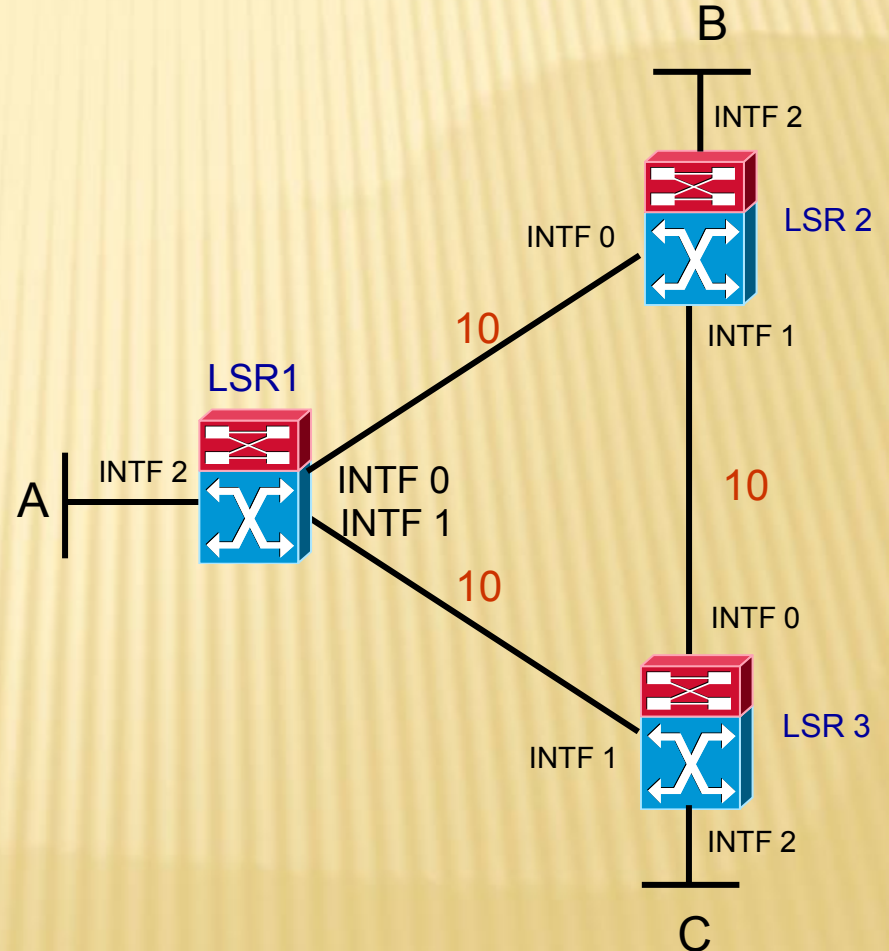
\* Optimum route to destination



# MPLS DATA STRUCTURES - EXAMPLE

## LIB LSR 1

DEST	LABEL	ADV. LSR	BINDING
A	13	LSR 1	Local
B	7	LSR 2	Remote
B	8	LSR 3	Remote
B	6	LSR 1	Local
C	9	LSR 2	Remote
C	2	LSR 3	Remote
C	11	LSR 1	Local



# MPLS DATA STRUCTURES - EXAMPLE

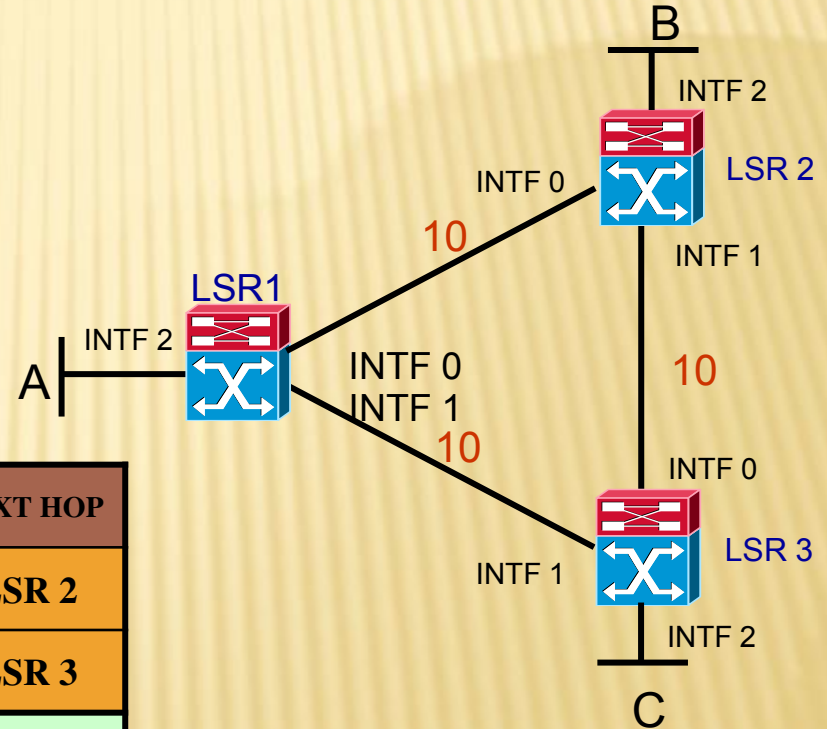
LFIB LSR 1

IN	OUT	FEC	INTERFACE	NEXT HOP
-	7	B	0	LSR 2
-	2	C	1	LSR 3
6	7	B	0	LSR 2
11	2	C	1	LSR 3
13	-	A	-	Routing Process

Mapping of incoming unlabeled packets to labels

Labeled packets exchanged between LSR3 and LSR2

Labeled packets destined for network A will be passed on to the IP routing process



# MPLS DATA STRUCTURES - EXAMPLE

ROUTING TABLE LSR 1

DEST	METRIC	NEXT HOP	INTF
A	0	connected	2
B*	10	LSR2	0
B	20	LSR3	1
C*	10	LSR3	1
C	20	LSR2	0

\* Optimum route to destination

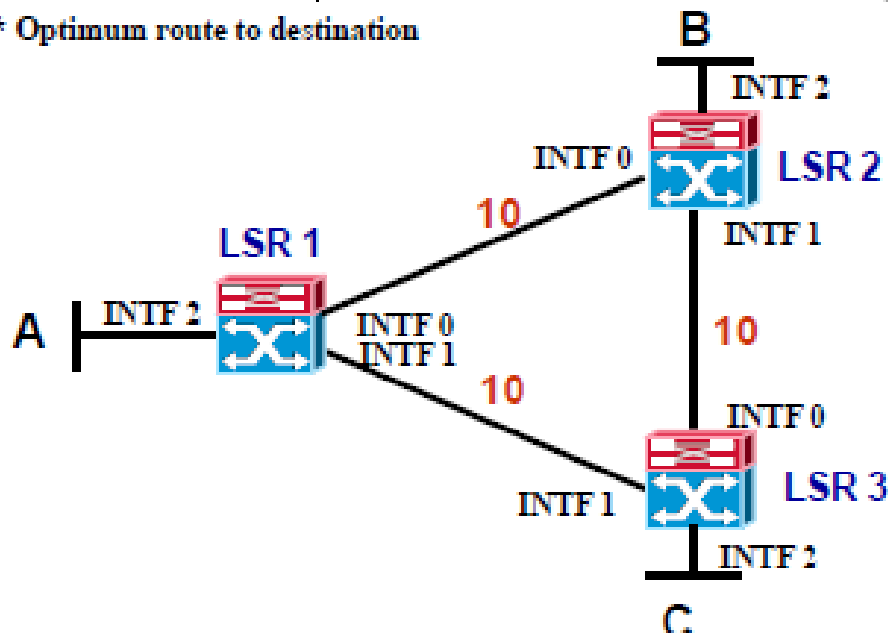
LIB LSR 1

DEST	LABEL	ADV. LSR	BINDING
A	13	LSR 1	Local
B	7	LSR 2	Remote
B	8	LSR 3	Remote
B	6	LSR 1	Local
C	9	LSR 2	Remote
C	2	LSR 3	Remote
C	11	LSR 1	Local



LFIB LSR 1

IN	OUT	FEC	INTF	NEXT HOP
-	7	B	0	LSR 2
-	2	C	1	LSR 3
6	7	B	0	LSR 2
11	2	C	1	LSR 3
13	-	A	2	Routing Process

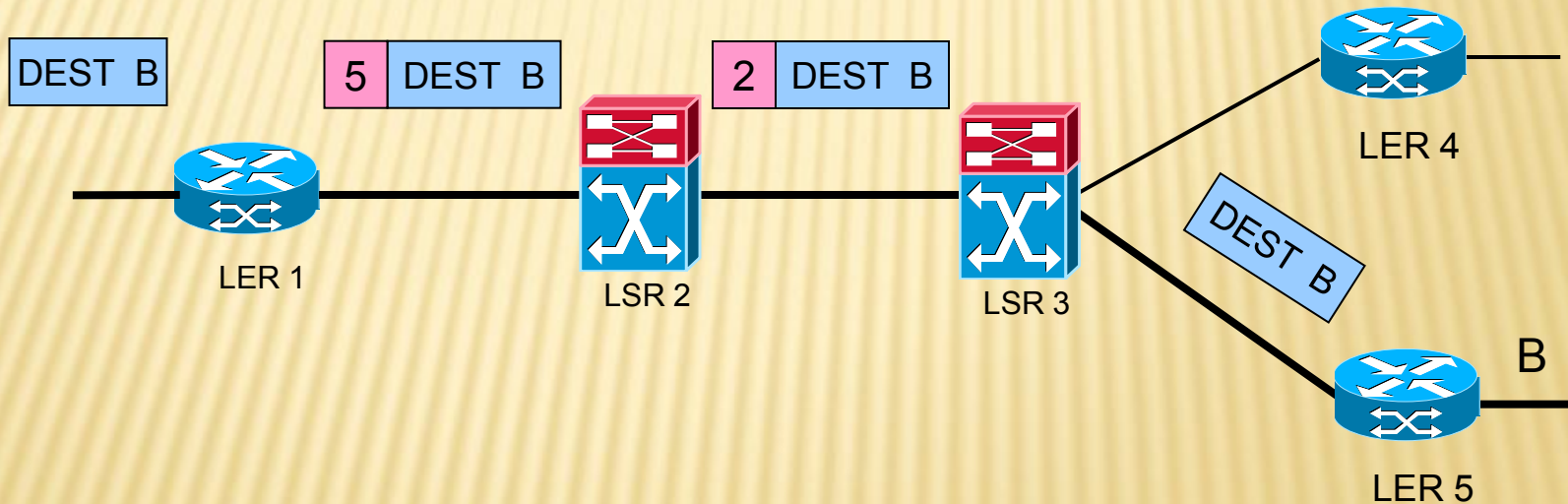


# MPLS DATA STRUCTURES – EXAMPLE NOTES

- LSR 1 has a route to network B via LSR 2. This path has a metric of 10.
- Also, LSR 1 has a route to network B via LSR 3. This path has a metric of 20, and therefore less preferable.
- LSR1 will always choose LSR 2 as the next hop to network B.
- After the routing process has *converged*, the LDP will build a session between all LDP neighbors (LDP Peers) that are reachable by that LSR.
- Each LDP session is established using **TCP port 646**, and label mapping information is exchanged with the LSR and all of the appropriate LDP peers.
- The downstream LSR must then define which label is mapped to a particular FEC. The label distribution process is called *downstream-on-demand* label allocation.
- “If LSR 1 sends packets destined for network B to LSR 2, use label 7.”
- “If LSR 1 sends packets destined for network B to LSR 3, use label 8.”

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- ✿ The LIB will eventually be populated with all possible destinations.
  - ✿ However, LIB does not yet contain any information about the next-hop address a packet classified with a particular FEC-to-label mapping should take.
  - ✿ The next-hop can only be found in the IP routing table.
  - ✿ The next-hop information and related label information are then put in the LFIB.
  - ✿ The LFIB is used by the forwarding process.
  - ✿ In LFIB of LSR 1, the *first two entries* are without an incoming label. This indicates that the packets arrived from outside MPLS domain and will have label imposed on them by LSR 1.
  - ✿ *The last entry* of the LFIB indicates that if a packet arrives with label 13, the label should be removed and the IP packet should be passed on to the routing process in LSR 1.

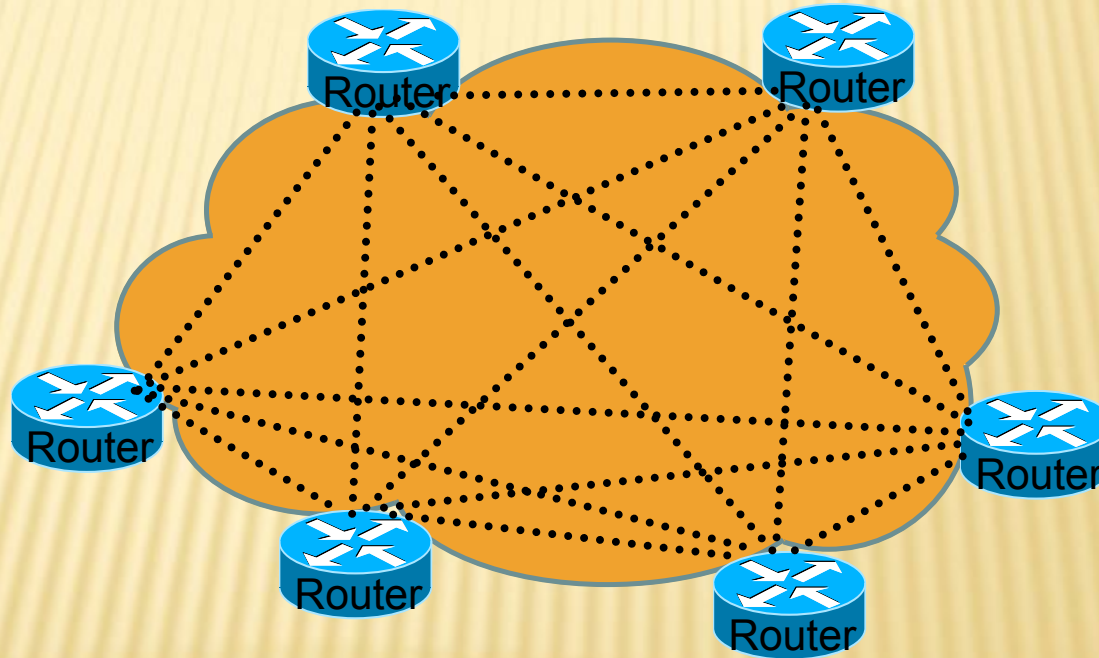
# PENULTIMATE HOP POPPING



Penultimate Hop Popping (PHP) is a function performed by certain routers in an MPLS enabled network. It refers to the process whereby the outermost label of an MPLS tagged packet is removed by a Label Switch Router (LSR) before the packet is passed to an adjacent Label Edge Router (LER).

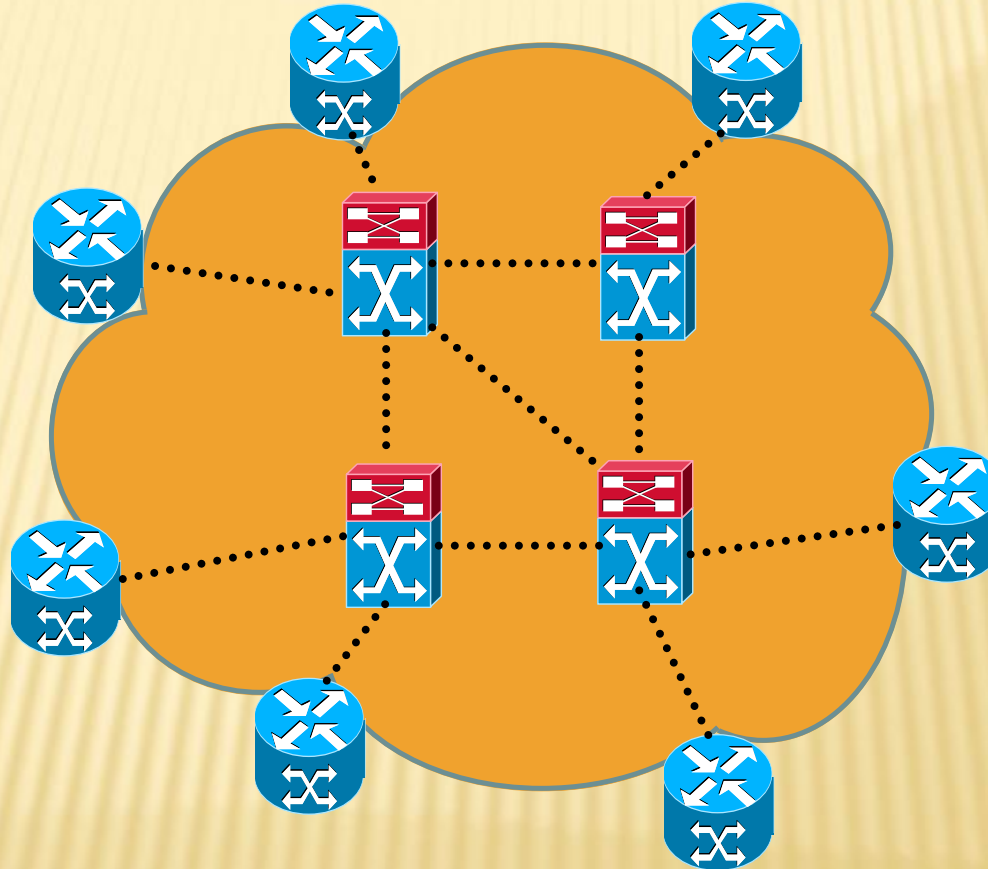
# MPLS ADVANTAGES OVER ATM

## Full Mesh Problem:



Overlay Model

# MPLS ADVANTAGES OVER ATM



Peer Model

# LABEL DISTRIBUTION PROTOCOL

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- ❑ LDP uses many messages to create LSPs, classified in the following four types:
  - ❑ **Discovery**—To identify other LSRs
  - ❑ **Adjacency**—To create, maintain, and end sessions between LSRs
  - ❑ **Label advertisement**—To request, map, withdraw, and release labels
  - ❑ **Notification**—To provide advisory and error information

- 
- ❖ Unlike the other LDP messages, the **discovery process** runs over UDP.
  - ❖ Each LSR periodically broadcasts a **link hello message** to the well-known **UDP port, 646**.
  - ❖ Each LSR listens on this port for **link hello messages** from other LSRs. In this manner, **each LSR learns about all other LSRs to which it is directly connected, creating link hello adjacencies**.
  - ❖ When an LSR learns about another LSR, it establishes a TCP connection to the peer on well-known TCP port 646 and creates an LDP session on top of the TCP connection.