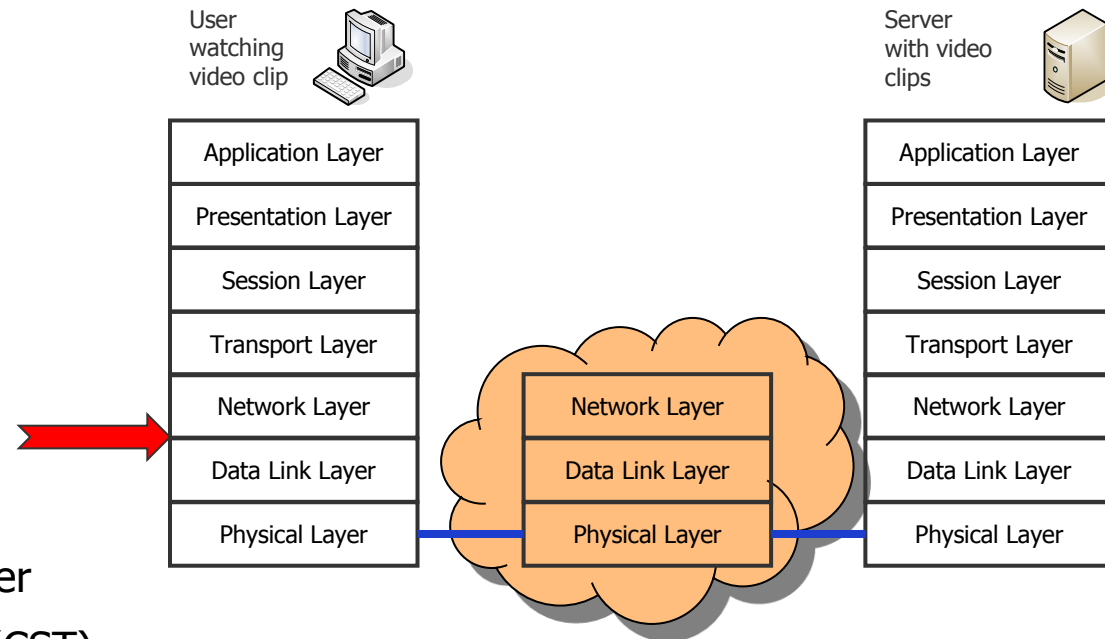


# Telematics

## Chapter 7: MPLS



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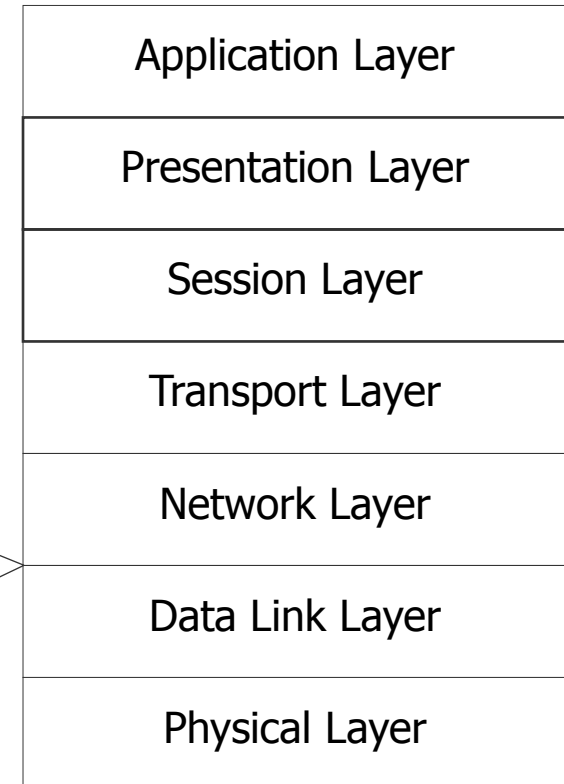


# Design Issues

# Design Issues

- Two different types of networks
  - Packet switched networks
  - Circuit switched networks
- Global network: Internet
  - The Internet is inherently connection-less on the network layer (packet switched)
  - Many applications require however QoS
  - Realize services of connection-oriented communication over a packet switched network
- MPLS is located between Layer 2 and Layer 3

## OSI Reference Model



# Motivation

- Convergence of IP and ATM
  - ATM supports traffic management
  - ATM-Switches provide high performance and scalability
  - IP is the protocol of the Internet
  - Nearly all data traffic is carried by IP
  - Plenty of Frame-Relay networks
- New requirements/challenges to IP
  - High bandwidth, differentiated services, security, management
  - Commercial usage as VPN
  - Routing has to consider new metrics, like costs, delay, and jitter
    - Not only shortest paths (SPF, shortest path first)
- How to use existing networks with QoS- and management functionality together with IP?

# MPLS

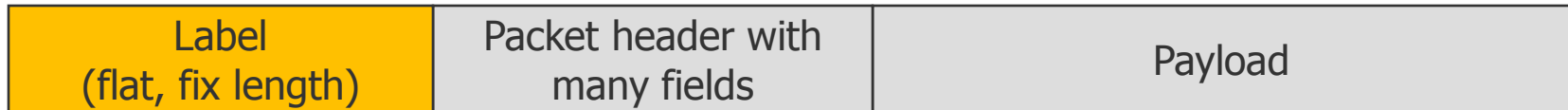
- Framework of the IETF for efficient routing, fast forwarding, and management of data flows
- Operations
  - Mechanisms for the management of data flows with different granularity
  - Independent of Layer 2 and Layer 3 protocols
  - Mechanism for **mapping** of **IP addresses** to simple (**flat**) **labels** with fix length
  - Interface to routing and signaling protocols like RSVP and OSPF
  - Supports PPP/Ethernet, ATM, Frame Relay, ...
- **Forwarding of data packets is based on labels**

# Traditional IP Routing vs. MPLS

- Router
  - Routing-Table
    - Mapping of address-prefix/net mask to the next router/interface
  - Routing-Algorithm
    - Method to determine the shortest/best/cheapest/... route
  - Routing-Protocol
    - Exchange of routing information, e.g., OSPF, BGP, ...
  - Forwarding
    - For each incoming data packet decide based on the destination IP address to which output/neighbor to forward
    - Optionally other header fields may be considered for the decision, e.g., prioritizing data packets
  
- Important: Each router has to make for each packet the forwarding decision

# Label

- Unique identification of packets for simple forwarding

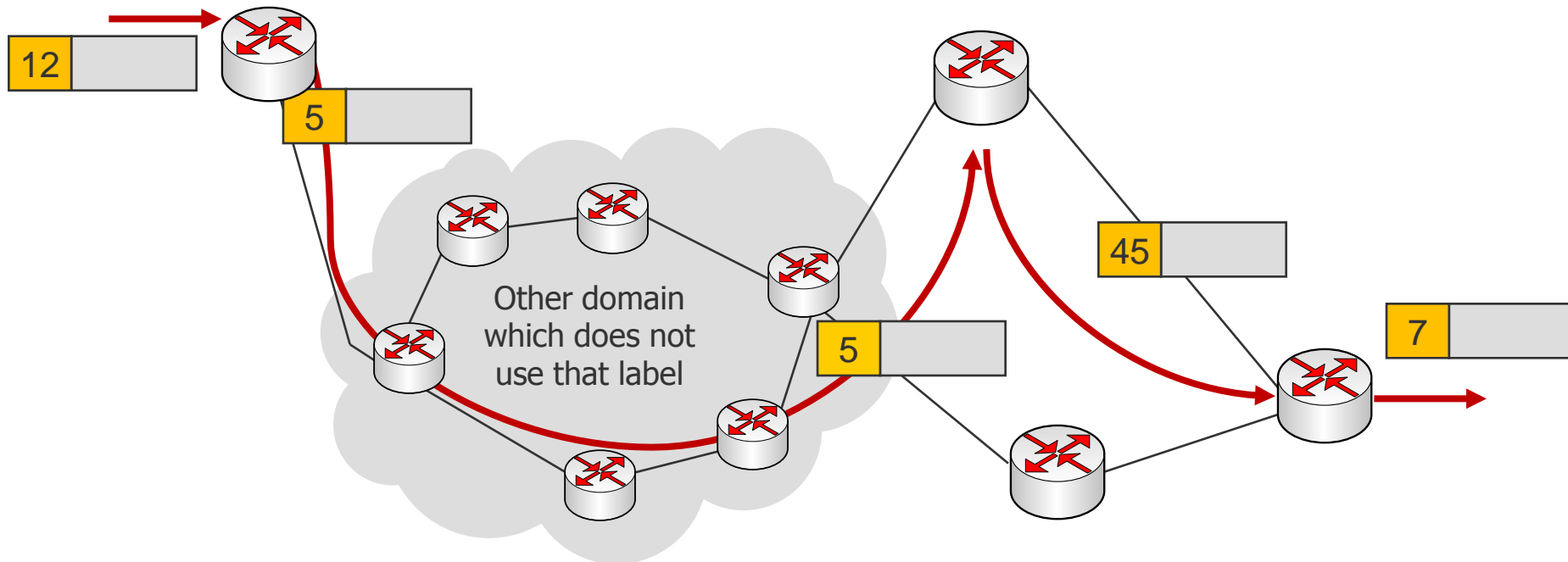


- New name for ...
  - ATM: VPI/VCI, in each cell
  - Frame Relay: DLCI – in each frame
  - STM: each time slot is implicitly a label
  - X.25: LCN is a label
  - Many proprietary protocols (Tag-Switching, ...)
  - Wave length in WDM may be interpreted as label
  - ...



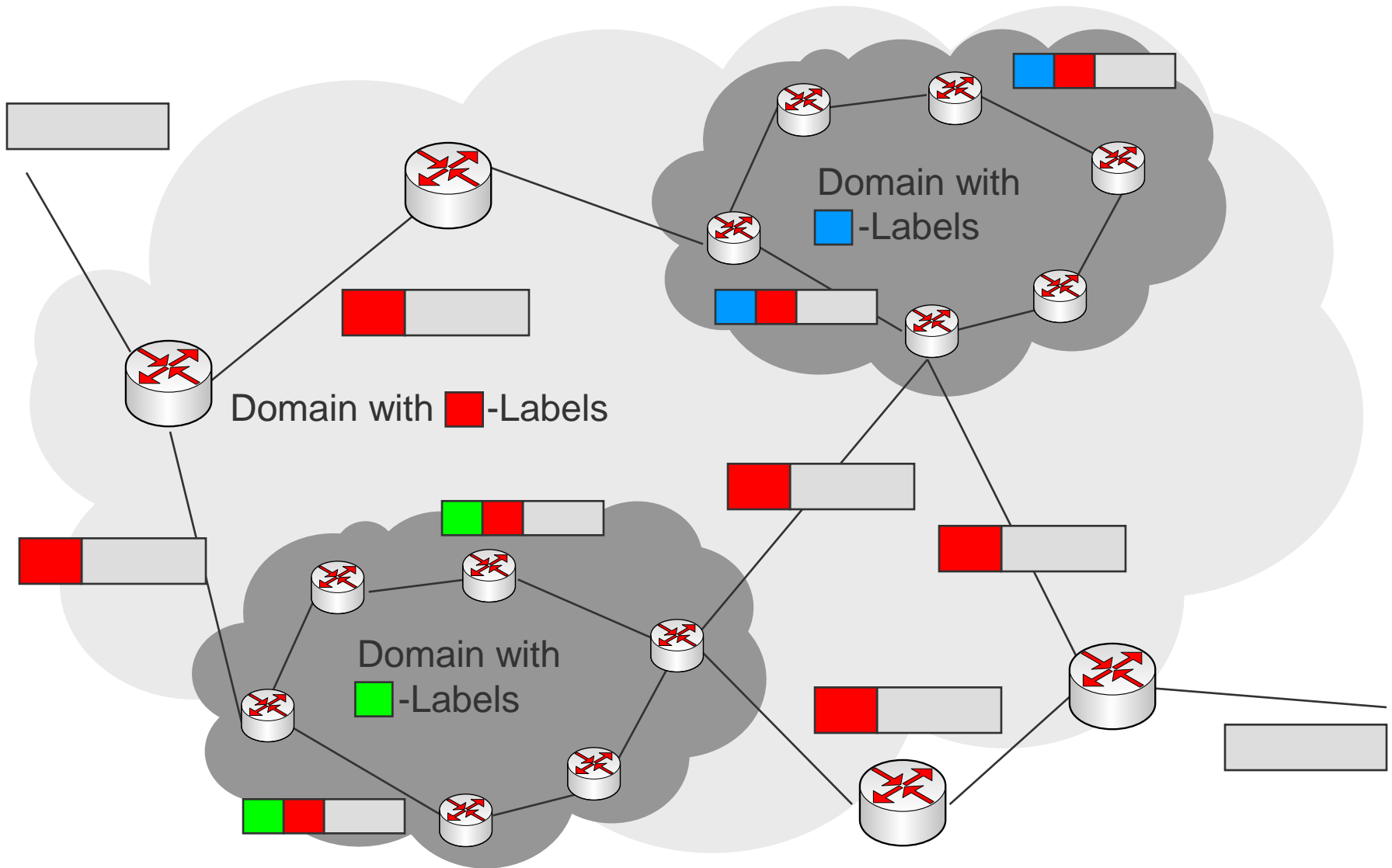
# Label

- A label is only locally valid
  - Local means two networks which communicate on the same level
  - Intermediate networks substitute labels (**label substitution**) and forward packets based on the label (**label switching**)





# Hierarchies of Labels





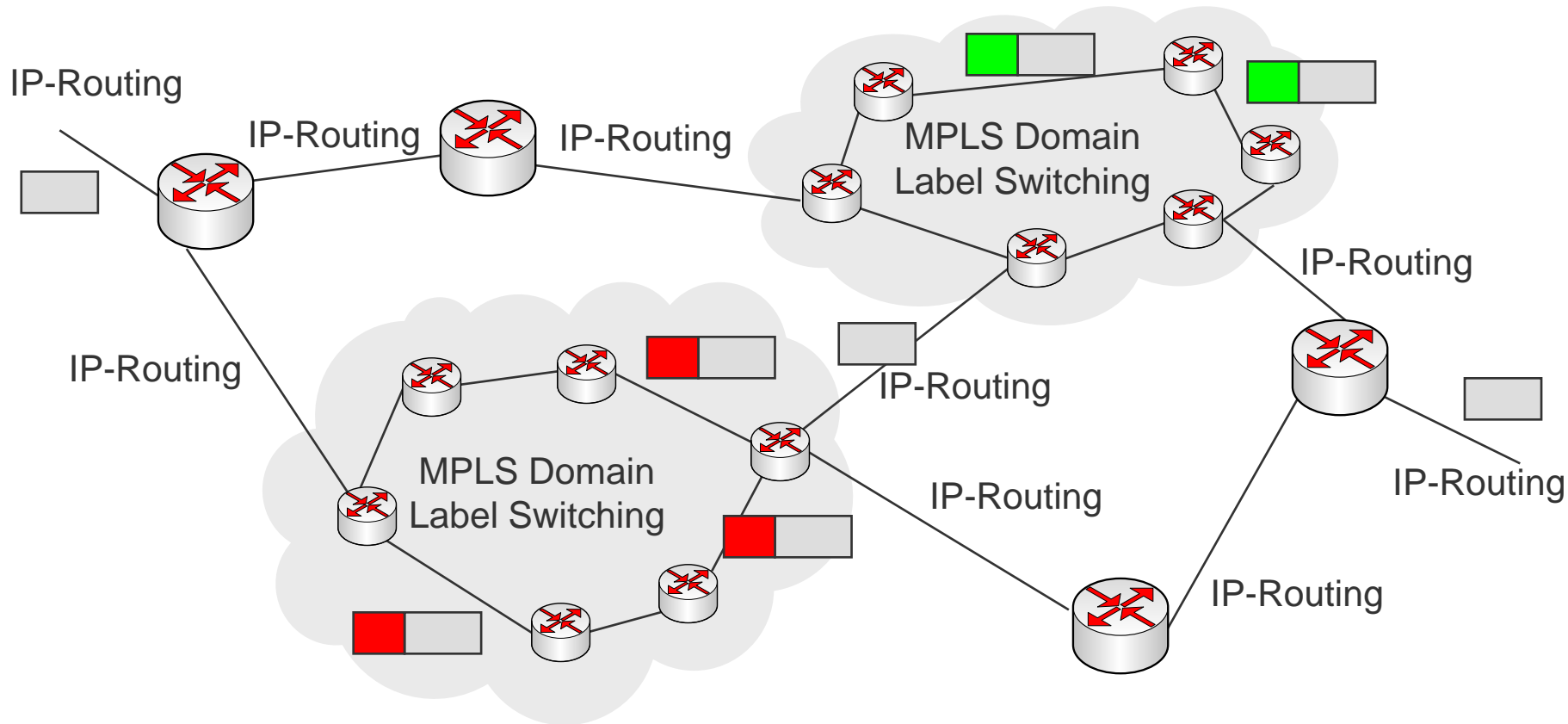
# MPLS Concepts

# MPLS: Concepts

- Packet forwarding is done based on labels
  - A packet is assigned a label as soon as it enters an MPLS domain
- Packet classification
  - When a packet enters an MPLS domain, it is classified according to
    - Destination address, destination network
    - Quality of Service (Security, Bandwidth, Delay, ...)
    - Application
    - Virtual Private Network (VPN)
    - Multicast-Group
  - Mapping to a **Forward Equivalence Class (FEC)**
    - Group of packets, which has to be handled in the same manner and over the same path
    - Classification is coded into the label and is done only at the entry into the MPLS domain

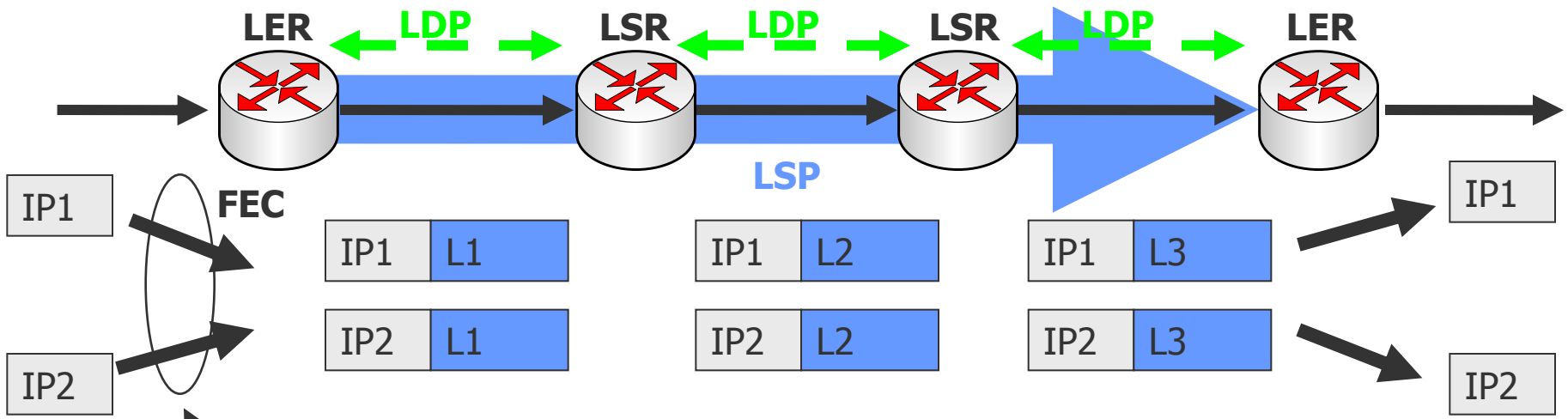
# MPLS: Concepts

- IP-Routing outside of the MPLS domain and Label-Switching inside
  - An MPLS network looks to the outside like a large IP router



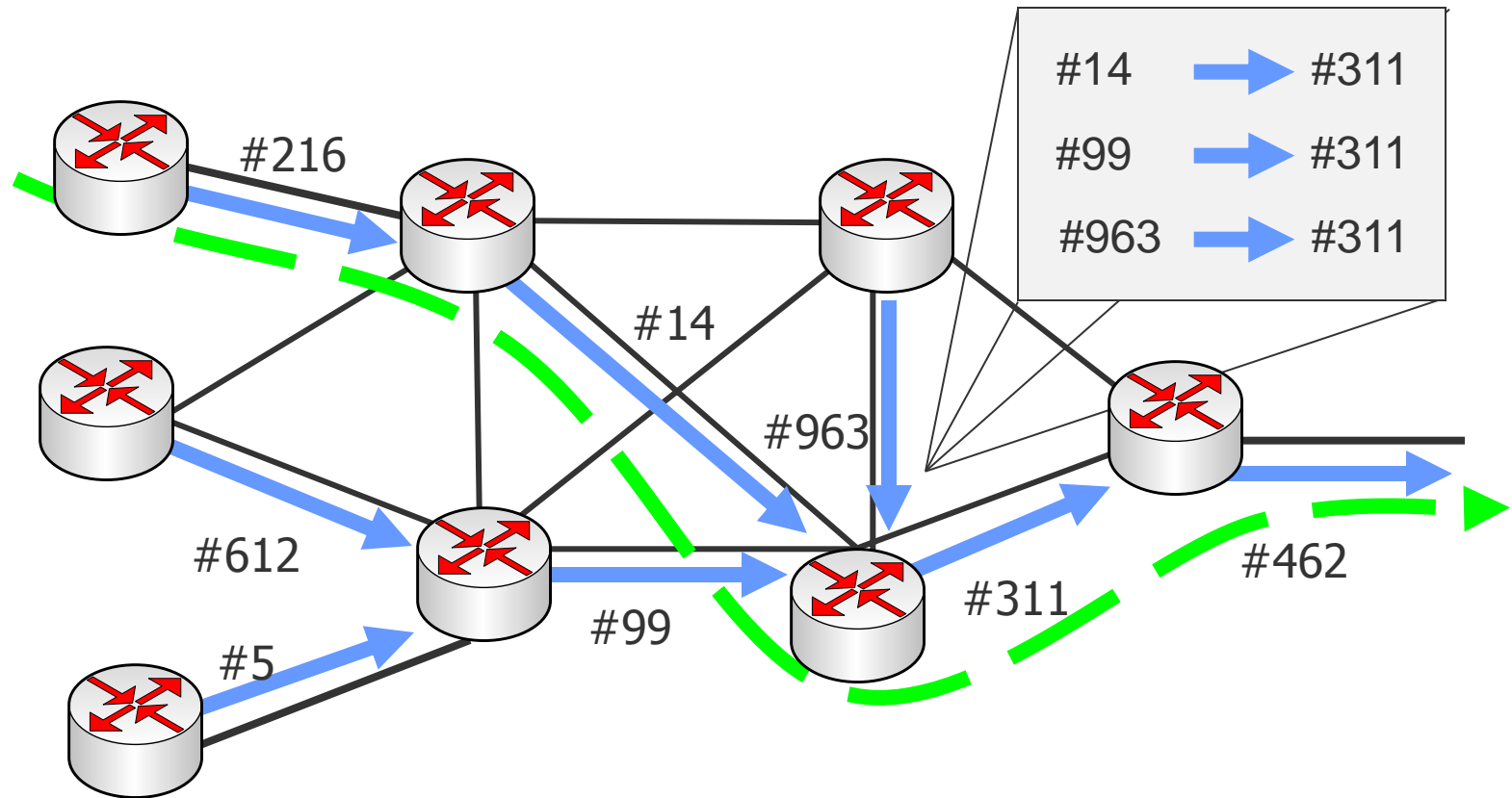
# MPLS: Components

- Components of MPLS
  - FEC: Forward Equivalence Class
  - LSR: Label Switching Router
  - LER: Label Edge Router
  - LSP: Label Switched Path
  - LDP: Label Distribution Protocol



Packets with different IP addresses are assigned to the same FEC group and thus handled in the same way.

# Label Switched Path (simple Variant)

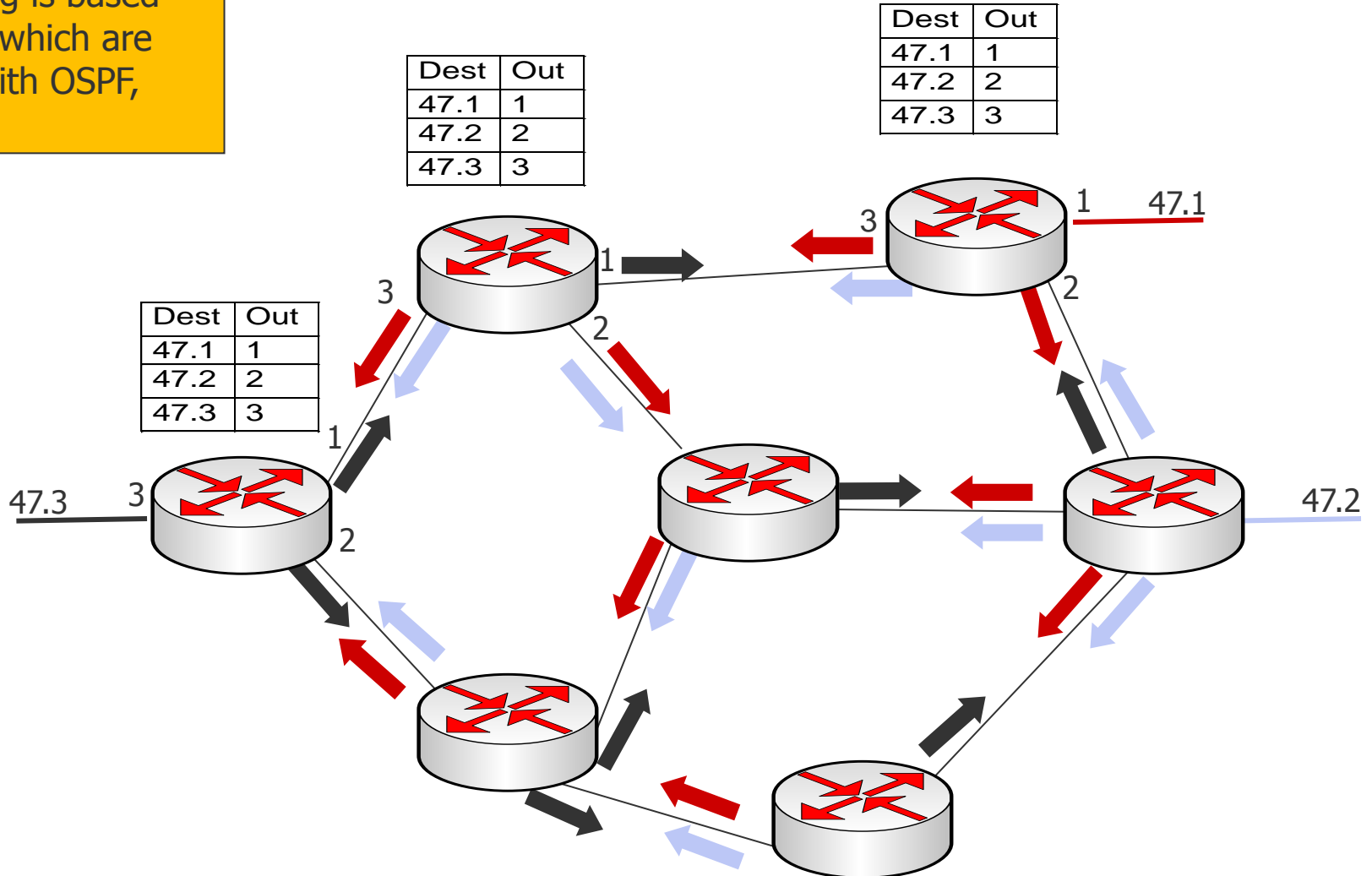


- An LSP is a part of a tree from the source to the destination
- An LDP generates that tree with the aid of existing IP routing tables



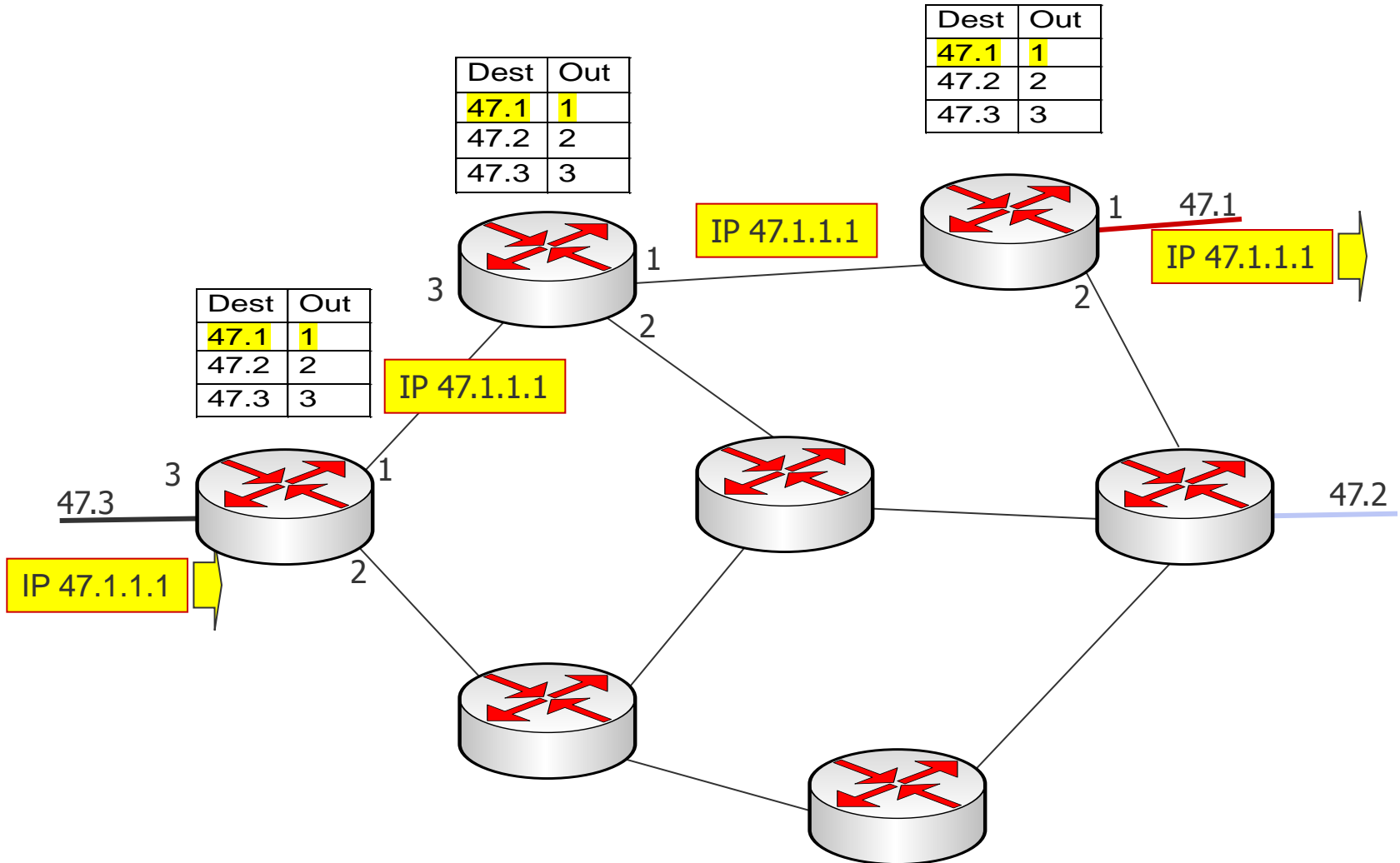
# MPLS uses IP

Forwarding is based on tables which are created with OSPF, RIP, ...





# IP-Forwarding is done "hop-by-hop"

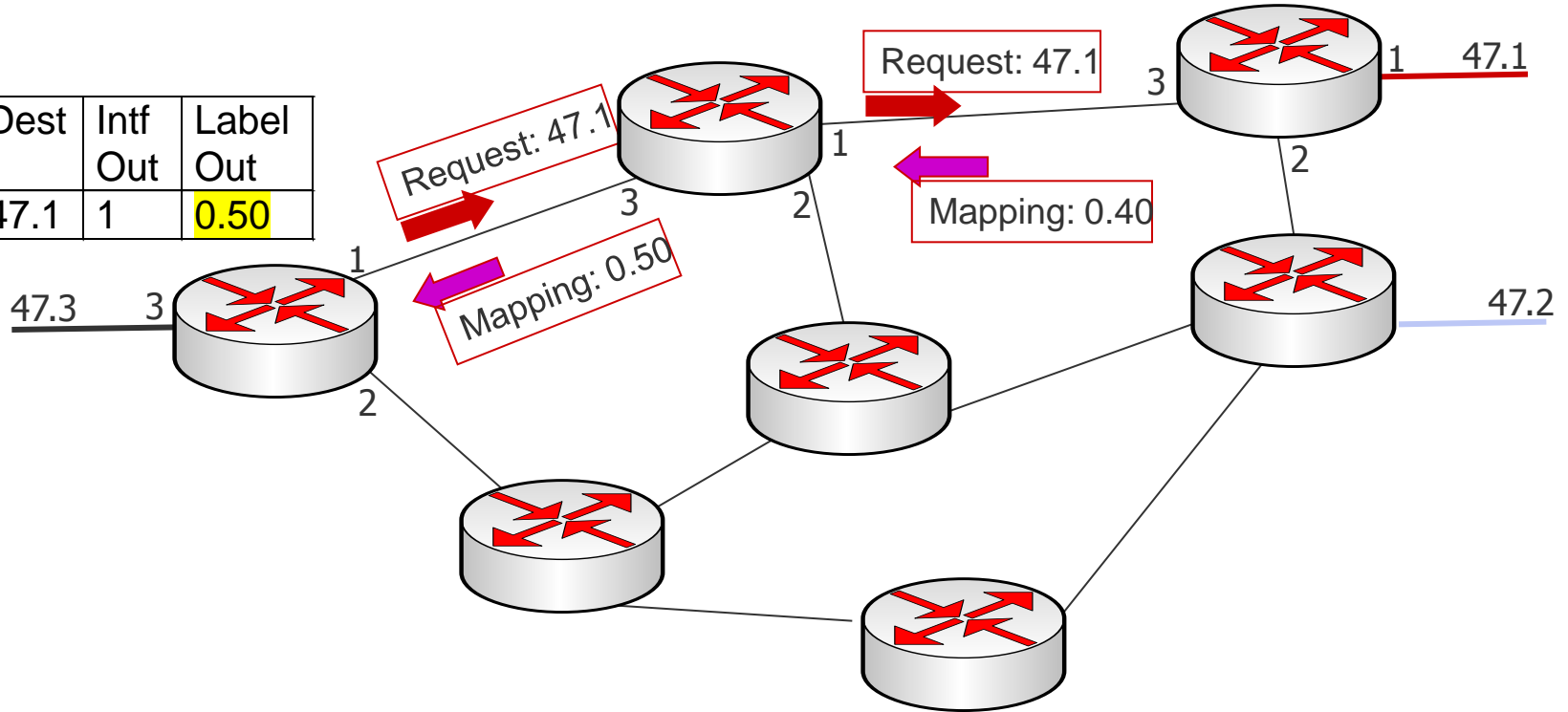


# MPLS-Label-Distribution (simple Variant)

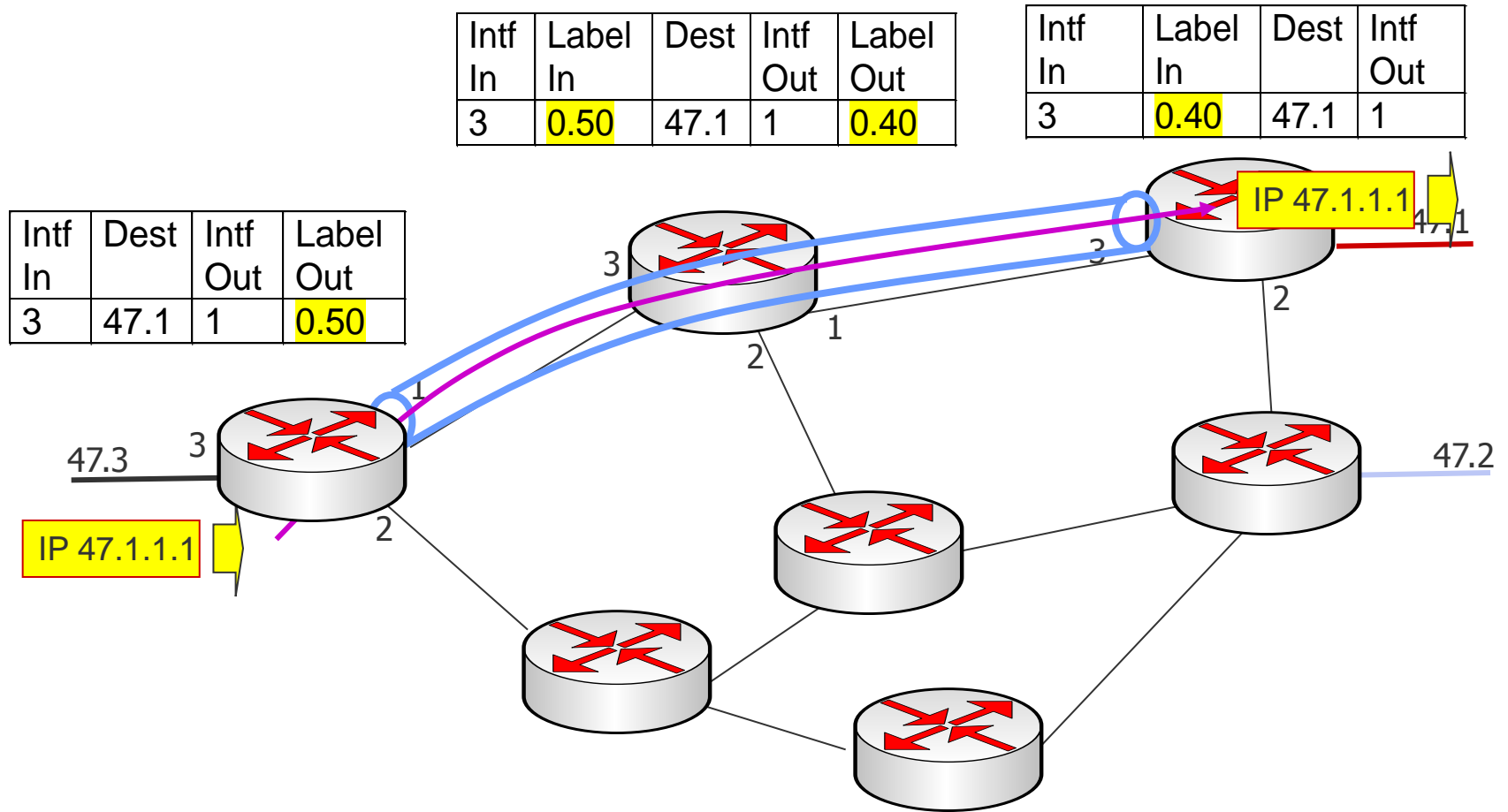
| Intf In | Label In | Dest | Intf Out | Label Out |
|---------|----------|------|----------|-----------|
| 3       | 0.50     | 47.1 | 1        | 0.40      |

| Intf In | Label In | Dest | Intf Out |
|---------|----------|------|----------|
| 3       | 0.40     | 47.1 | 1        |

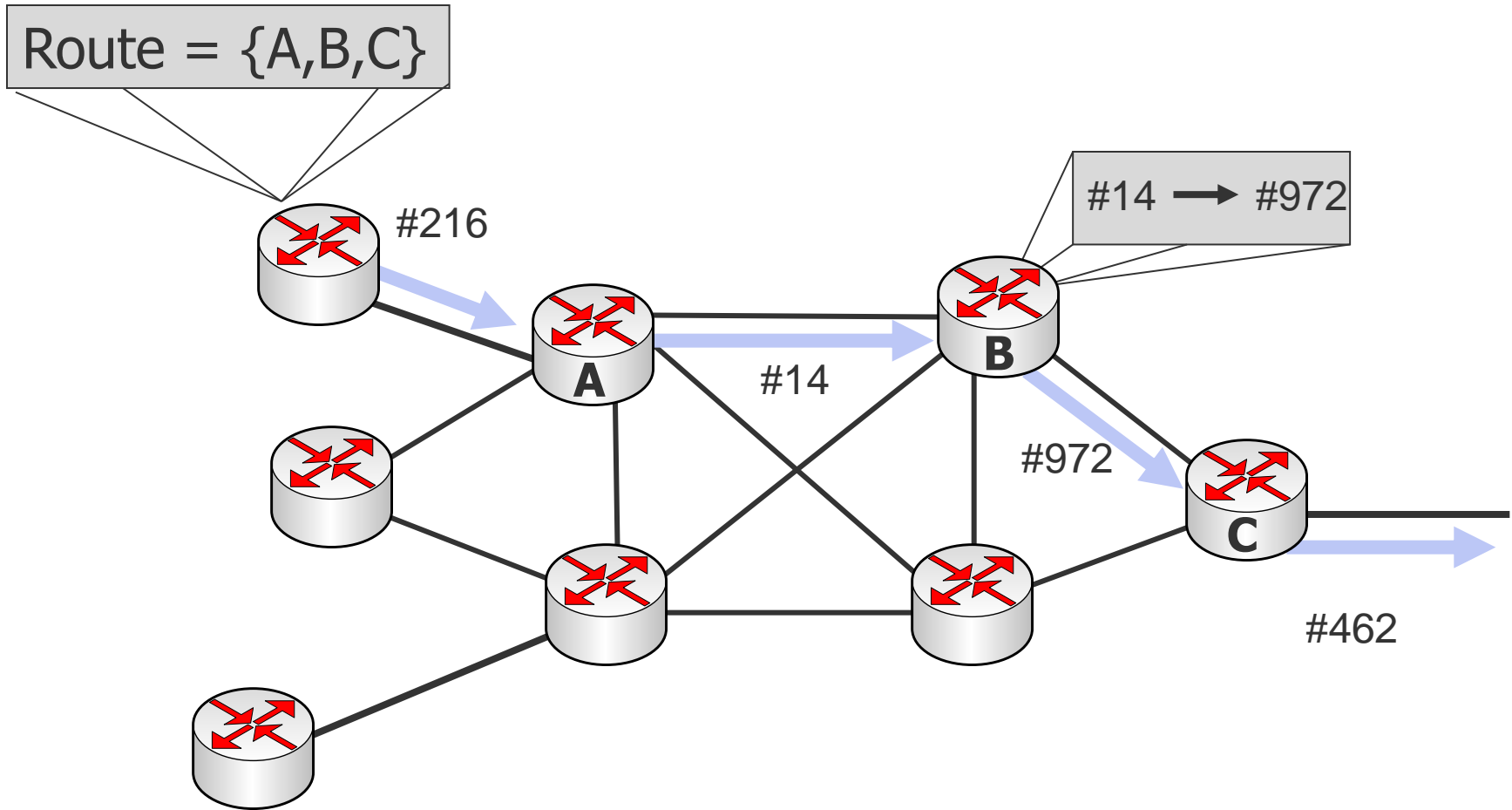
| Intf In | Dest | Intf Out | Label Out |
|---------|------|----------|-----------|
| 3       | 47.1 | 1        | 0.50      |



# Label Switched Path (LSP)

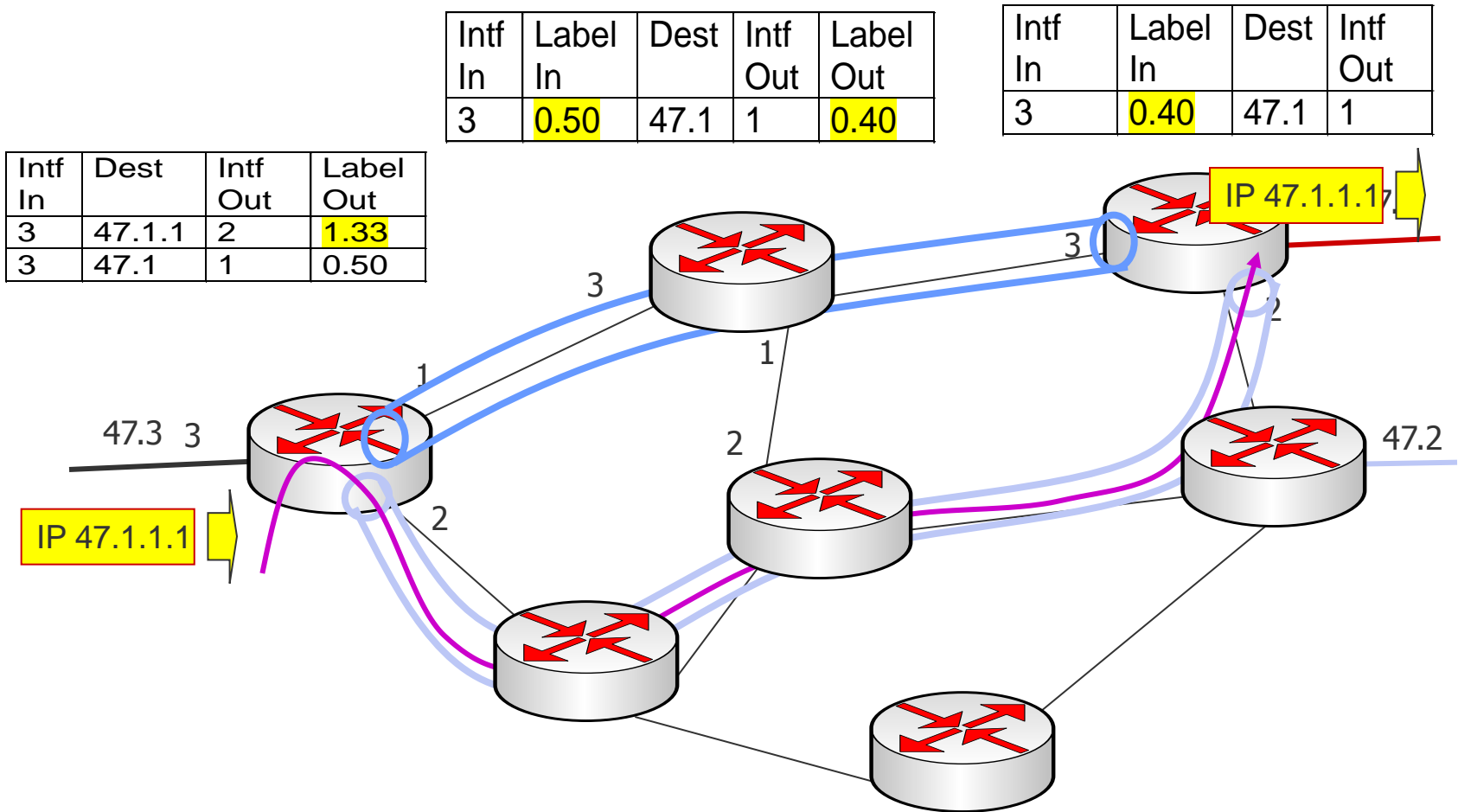


# Explicitly Routed LSP (ER-LSP)



A ER-LSP is selected by the source. A label request is send from the source (source routing).

# Explicitly Routed LSP (ER-LSP)



# Advantages of ER-LSP

- The network provider controls the route selection
  - Based on individual decisions
    - QoS, Costs, Load, Policy, ...
  - Thus, not only shortest path routes are taken
  - Support of Traffic Engineering
- Several protocols may be used
  - CR-LDP (Constraint Routing): LDP + ER-Extensions
  - RSVP ext: RSVP + Extensions for scalability + ER-Extensions
  - ...



# MPLS Labels

# MPLS Label

- MPLS labels can be contained in different headers
  - In the Layer 2 protocol, e.g., ATM and Frame Relay
  - In a **shim header**, i.e., between Layer 2 and Layer 3
  - In the Layer 2 protocol as well as in the shim header
- Labels may have various formats
  - Negotiated by the peers
  - Depends on the Layer 2 protocol
  - Specified for Frame Relay, ATM, PPP,...
- Labels can be stacked
  - Only the top label is considered
  - Bottom label is marked in particular way
- General format: 4 bytes
  - 20 bit label
  - 3 bit experimental
    - Used for Quality of Service (QoS)
  - 1 bit bottom label
  - 8 bit TTL







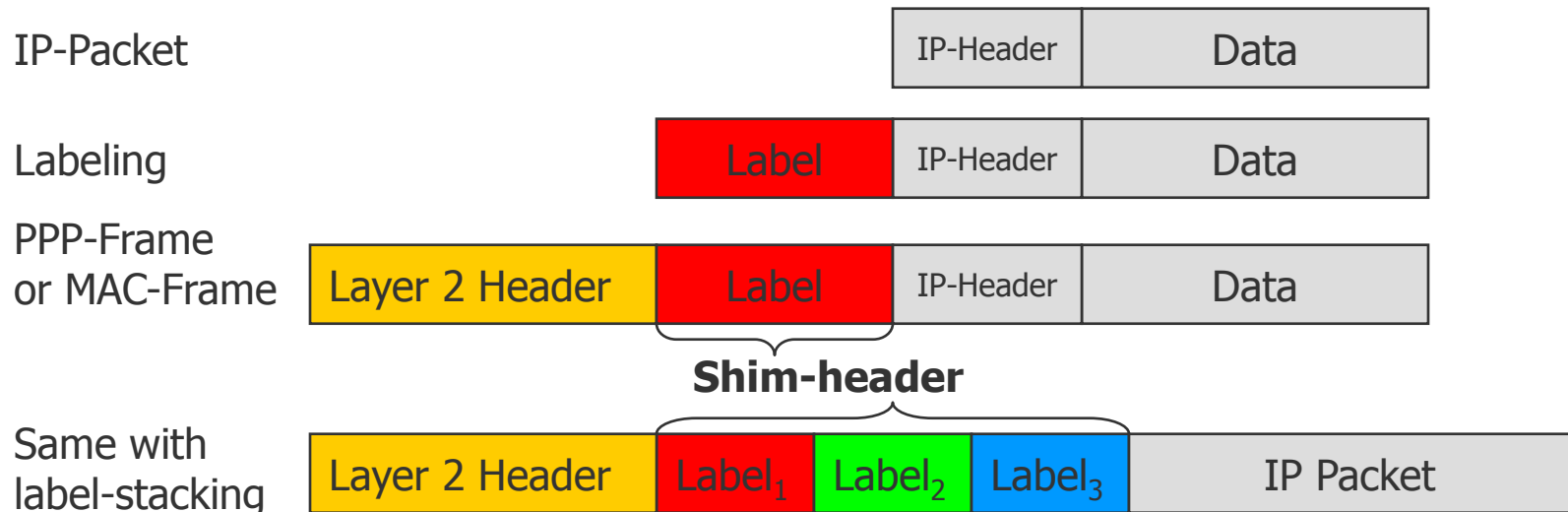
# MPLS Label

- Label stacking

|       |     |   |     |
|-------|-----|---|-----|
| Label | Exp | 0 | TTL |
| Label | Exp | 0 | TTL |
| ...   |     |   |     |
| Label |     | 1 | TTL |

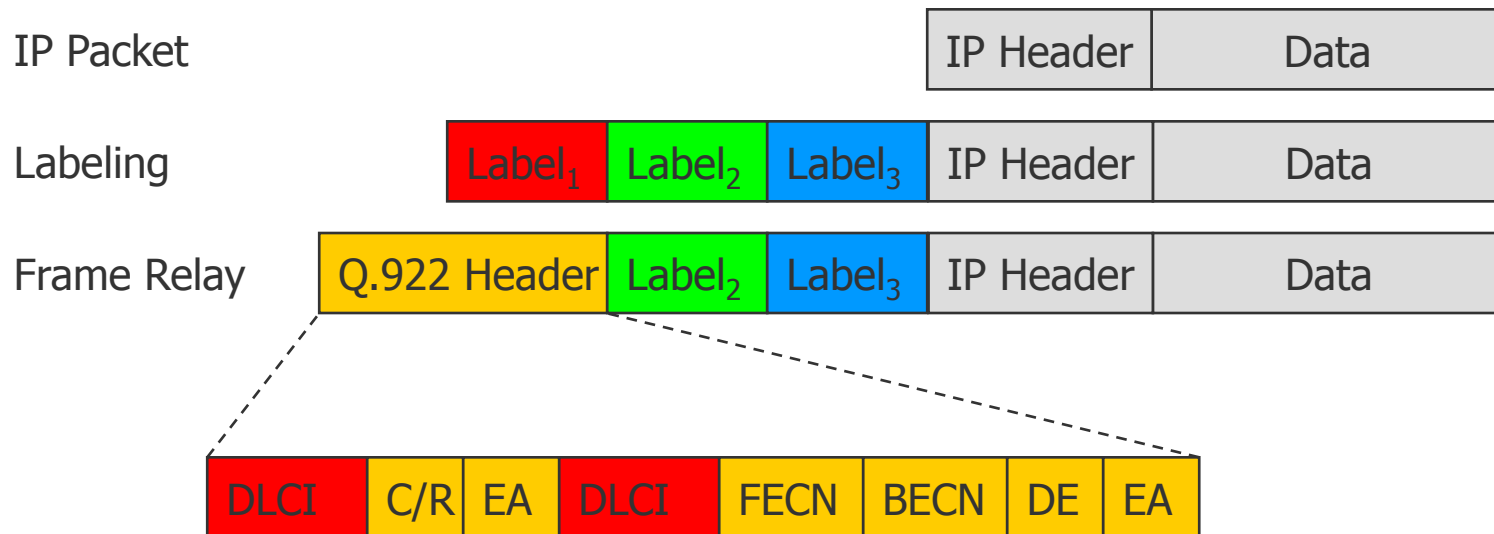
# MPLS Label with PPP/LAN-MAC

- Layer 3 protocol has to be defined at the bottom label
  - Similar to the type field in Ethernet, which may refer to IP
- Label TTL
  - At the first labeling the Label-TTL is set to IP-TTL
  - When the last label is removed the IP-TTL is set to Label-TTL
- Packet length
  - Due to multiple labeling the packet grows ➔ max. IP datagram size for labeling



# MPLS Label with Frame Relay

- Current Label
  - Is transported in the DLCI-Field of Frame Relay
  - May use 2 or 4 byte addresses according to Q.922
  - Other labels may be contained in the PPP/LAN format
  
- Example



# MPLS Label with ATM

- Two ATM header formats:
  - Communication between switches and endpoints: User-Network Interface (UNI)
  - Communication between two switches: Network-Network Interface (NNI)

## ● Header Fields

- Generic Flow Control (GFC)
  - Only with UNI, for local control of the transmission of data into the network. Typically unused.
  - With NNI these bits are used to increase the VPI field.

- Payload Type Identifier (PTI)

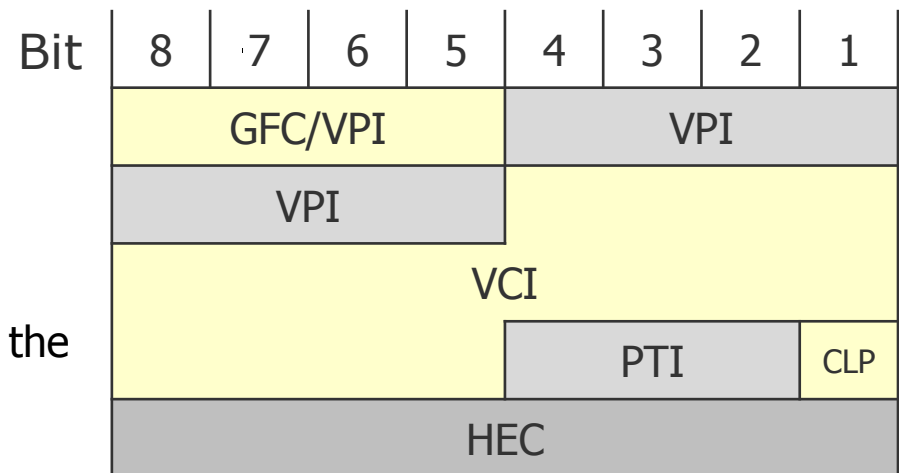
- Describes content of the data part, e.g. user data or different control data

- Cell Loss Priority (CLP)

- If the bit is 1, the cell can be discarded within overload situations.

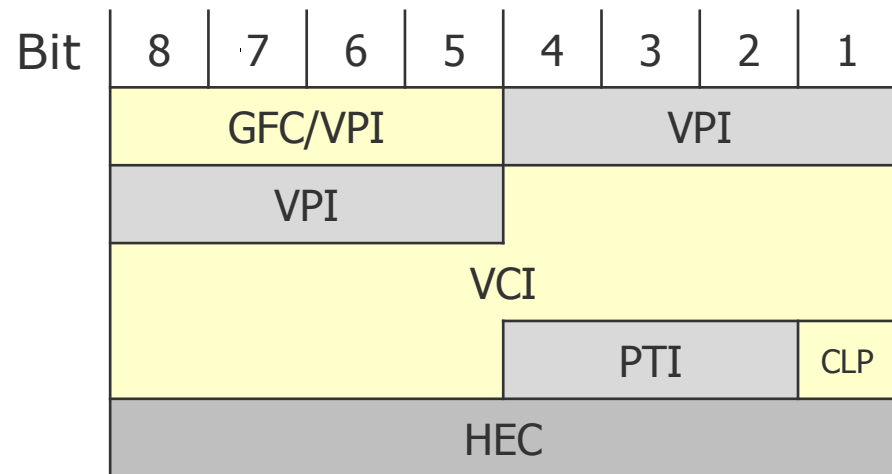
- Header Error Control (HEC)

- CRC for the first 4 bytes; single bit errors can be corrected.



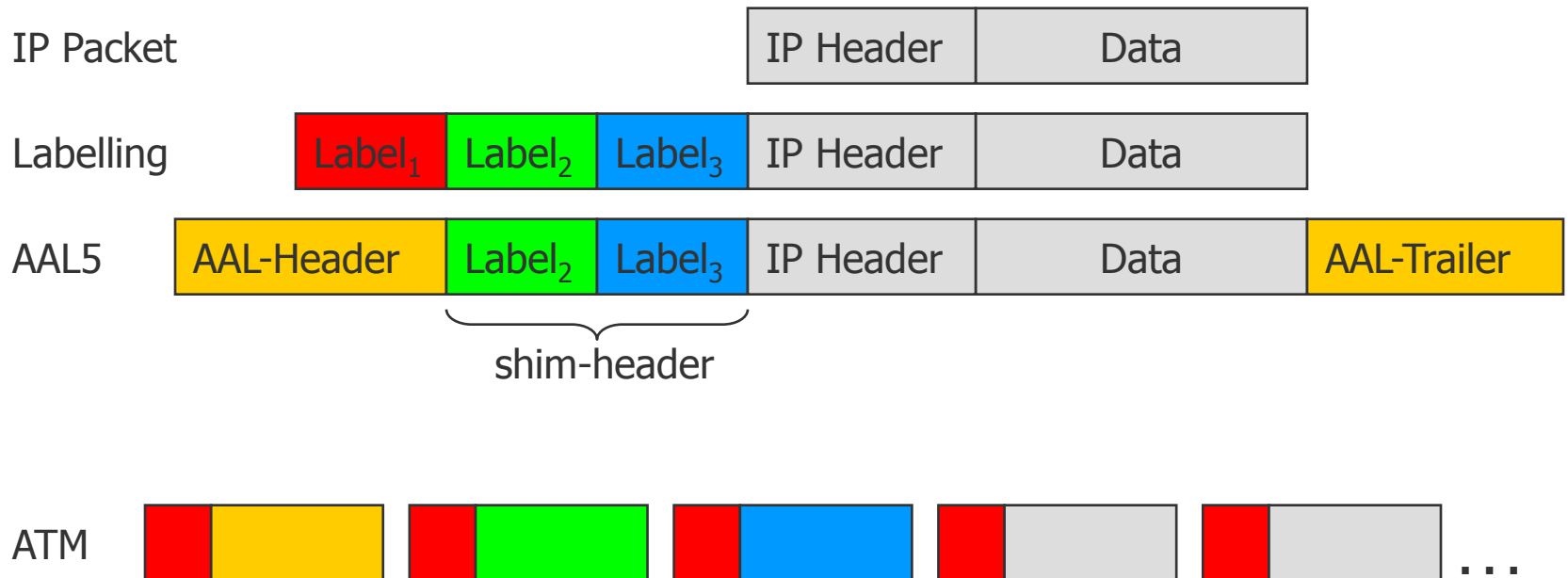
# MPLS Label with ATM

- Option 1: SVC Encoding (Switched Virtual Circuits, SVC)
  - (Top) Label is stored in VPI/VCI field
    - Works with all networks
    - Only one label in the ATM header
- Option 2: SVP Encoding (Switched Virtual Paths, SVP)
  - Top label in VPI field, second label in VCI field
    - Supporting of "VP switching"
- Option 3: SVP Multipoint Encoding
  - Top label in VPI field, second label as part of the VCI field. Remainder of the VCI field represents the LSP ingress LSR (aids for label merging)



# MPLS Label with ATM

- Label Stacking (multiple hierarchical labels) with ATM?
  - Other labels and fields which do not fit in VPI/VCI have to be stored in the shim header in the PPP/LAN format
- Example



# MPLS Label Distribution

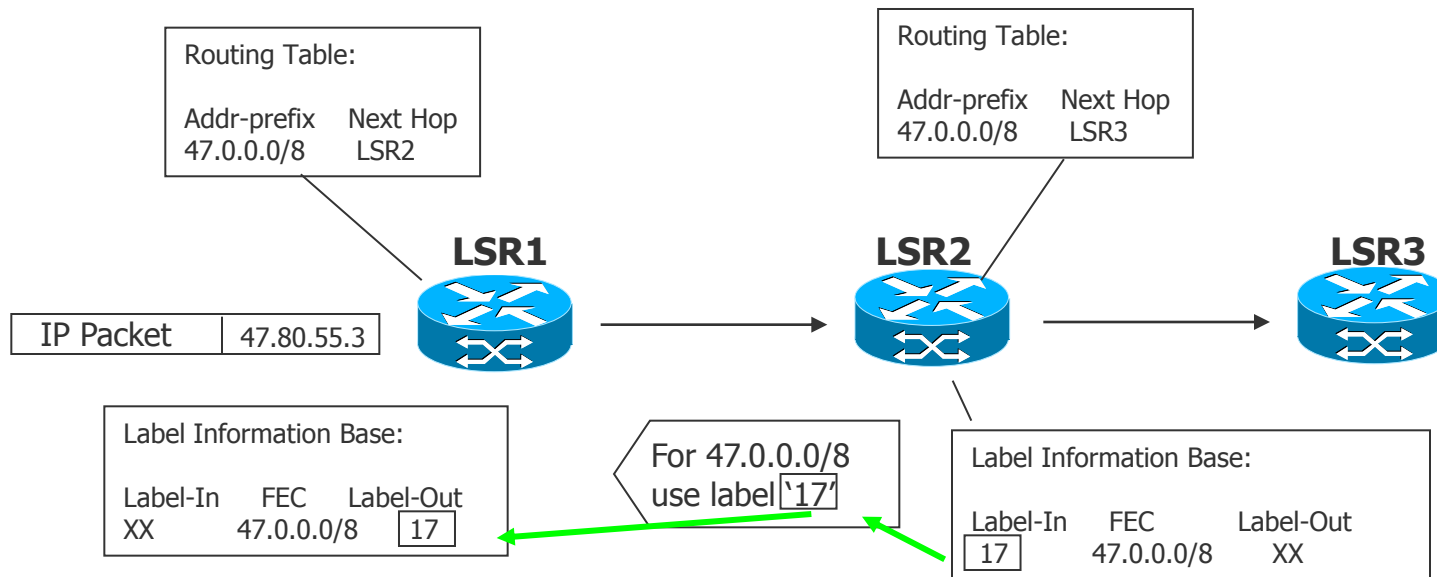
# Label Distribution

- MPLS do not specify a particular way of label distribution
  - Piggyback on existing IP routing protocol
  - Separate protocol to distribute labels
- Piggyback on existing IP routing protocol
  - Extension of protocols for particular deployment of resources
    - Constraint Route Label Distribution Protocol (CR-LDP)
    - Resource Reservation Protocol (RSVP-TE)
  - Protocol Independent Multicast (PIM)
  - BGP: Forwarding of external labels, e.g., for VPNs
- Label Distribution Protocol (LDP)
  - New protocol of the IETF developed with MPLS for the distribution and maintenance of labels



# Label Distribution Protocol (LDP)

The distribution of labels guarantees that neighbored LSRs have the same set of FECs



**Step 3:** LSR1 inserts the label into its forwarding table

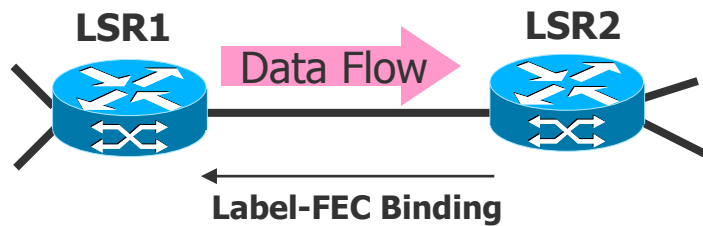
**Step 2:** LSR2 sends the mapping to neighbored LSRs

**Step 1:** LSR2 creates a mapping from FEC to a Label

The label distribution is done either via “piggybacking” on existing routing protocols or with a particular **Label Distribution Protocol (LDP)**

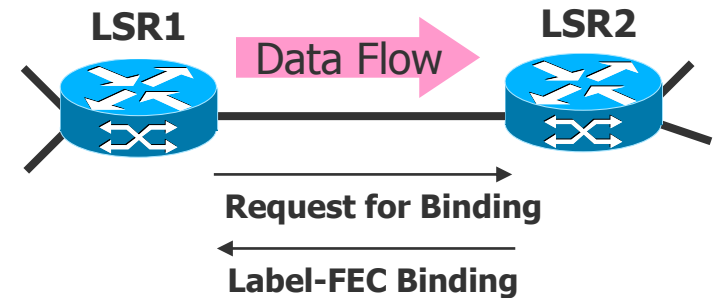
# Alternatives for Label Distribution

- Downstream “unsolicited” Label Distribution



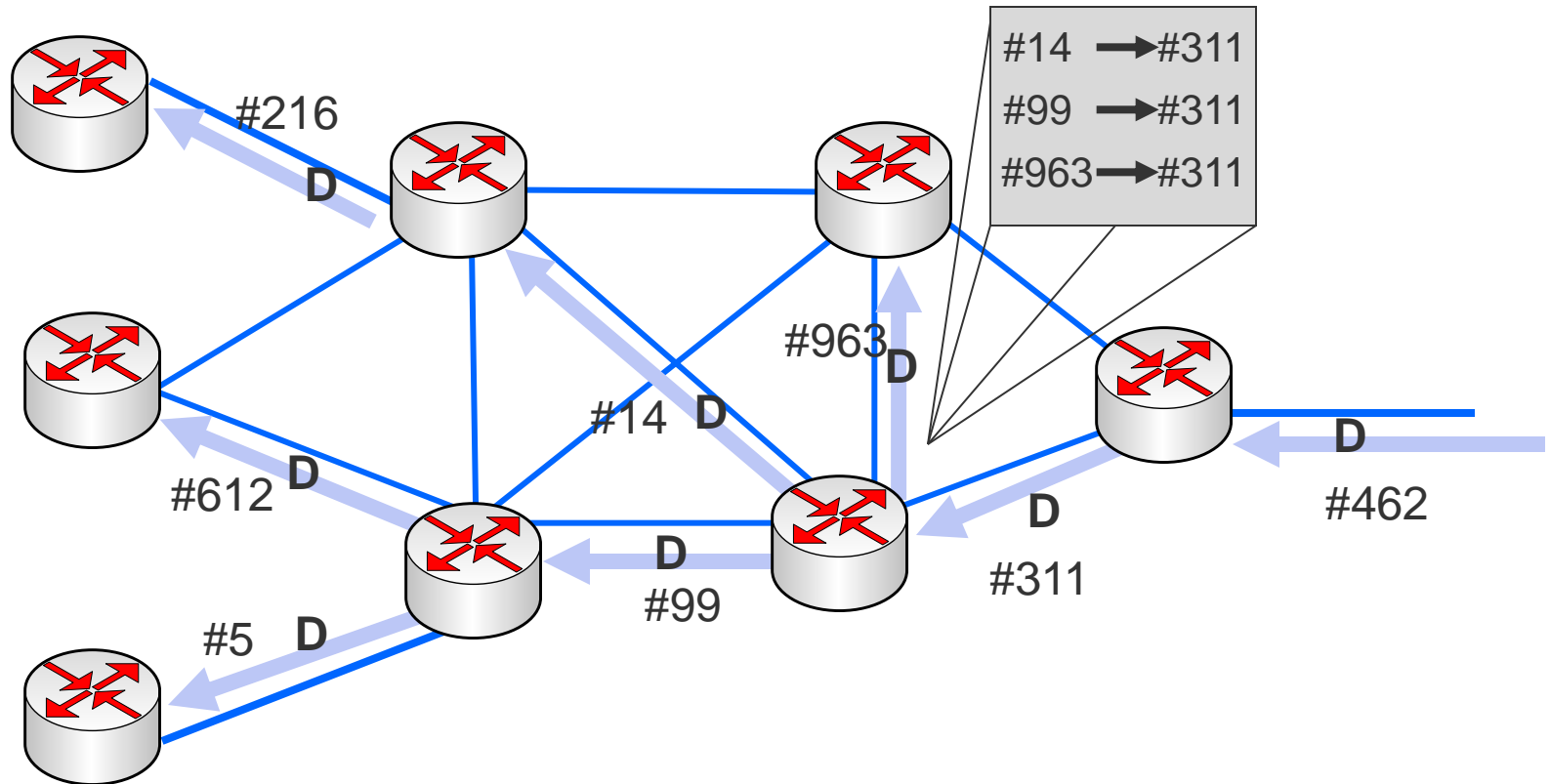
- LSR2 is the “downstream” LSR for LSR1
- LSR2 detects a “next hop” for a FEC
- LSR2 creates a label for the FEC and sends the mapping to LSR1
- LSR1 inserts the mapping into its table
- Is LSR2 the “next hop” for a FEC, then LSR1 can use the label

- Downstream-on-Demand Label Distribution



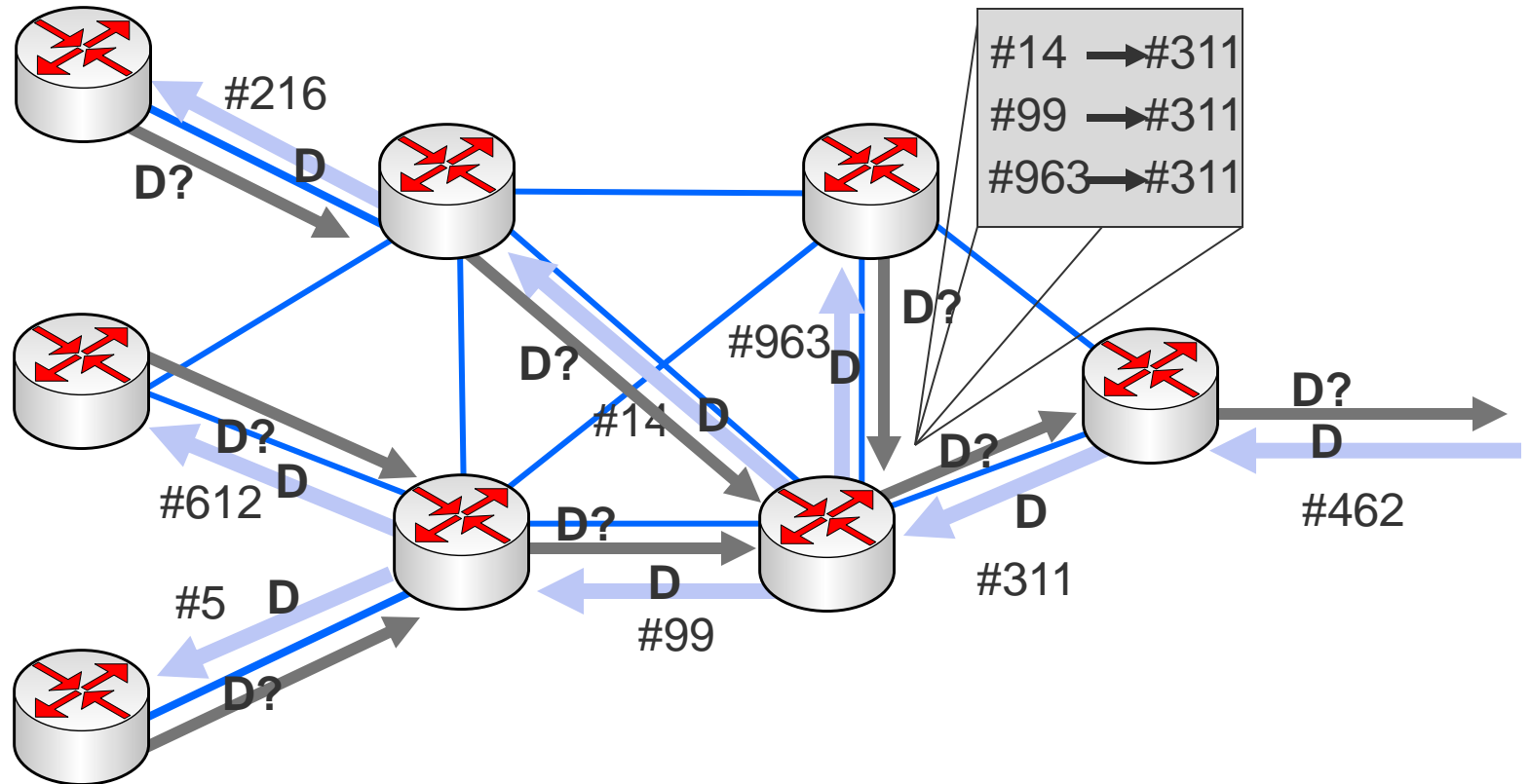
- LSR1 detects LSR2 as one “next hop” for a FEC
- Request to LSR2 for a mapping from FEC to a label
- When LSR 2 recognizes the FEC and has a “next hop”, then it creates a mapping and sends it to LSR1
- Both LSRs have the same mapping for the FEC

# Downstream-Mode generates a Shortest-Path-First Tree





# In Analogous with Downstream-on-Demand



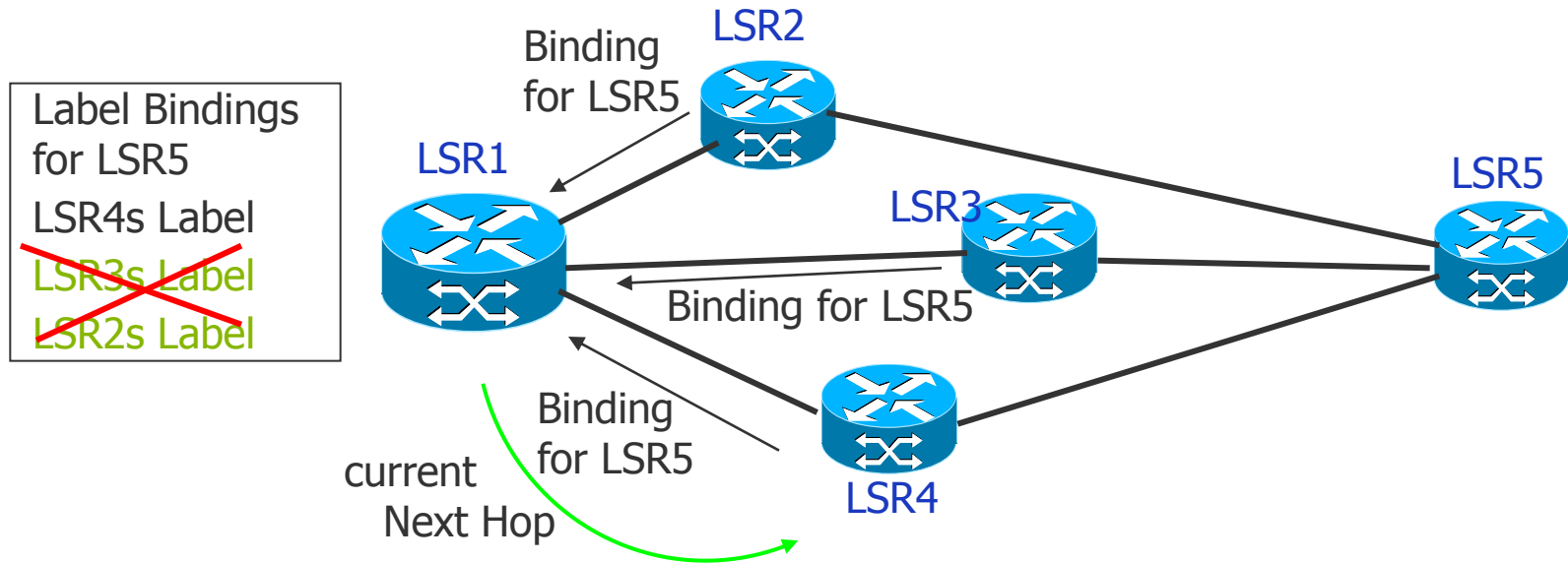
# Control of Label Distribution

- Independent LSP-Control
  - Each LSR creates independent mappings of FEC-to-Label
  - Forwarding as soon as “next hop” determined
  - LSP is created by connecting in/out label
- Advantages
  - Label-Generation and exchange faster
  - Independent of availability of Egress-LSRs
- Disadvantages
  - Inconsistent availability of labels
  - Loop prevention required

- Ordered LSP-Control
  - One router is responsible for distributing labels
    - Typically the egress LSR
- Advantages
  - Consistent and loop free
  - Deployment for explicit route selection and multicast
- Disadvantages
  - Higher delay for LSP creation
  - Depends on egress LSR (bottleneck)

# Retention of Labels

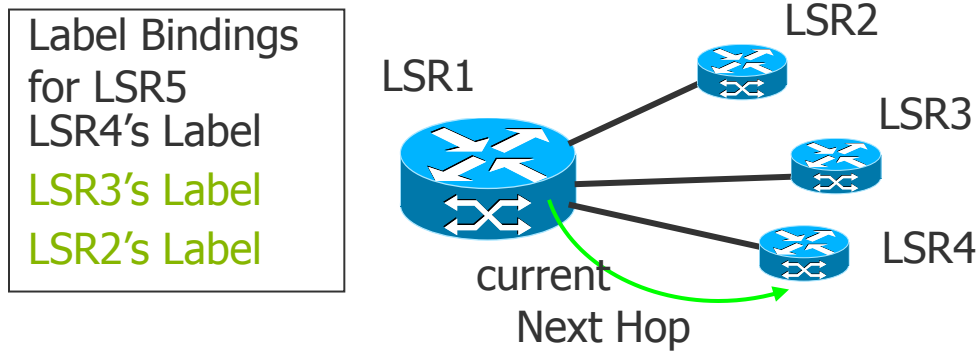
An LSR can receive mappings from several LSRs



## ● Functions

- An LSR keeps only the mapping which it receives from the valid "next hop"
- When the "next hop" changes, then a new mapping from the new "next hop" has to be requested
- Restricted adaption to changes
- An LSR has to maintain less mappings

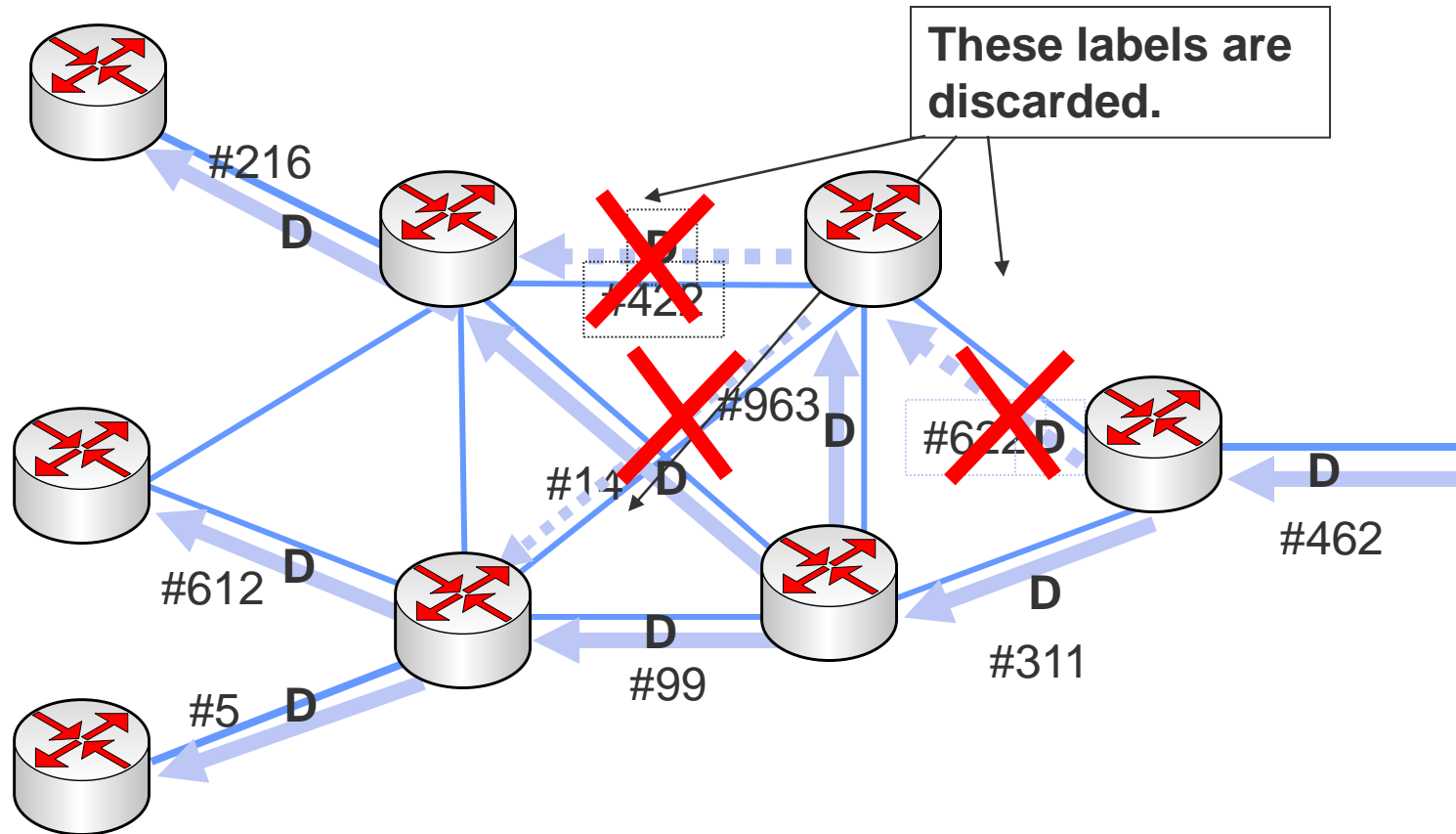
# Liberal Retention of Labels



- Function
  - An LSR maintains also mappings which are received from others than the "next hop" neighbor
  - When the "next hop" changes, the stored mappings can be used directly
    - Fast adaptation to changes
  - Requires the maintenance of many labels
- The selection of the retention mode is a trade-off between adaptability and memory.



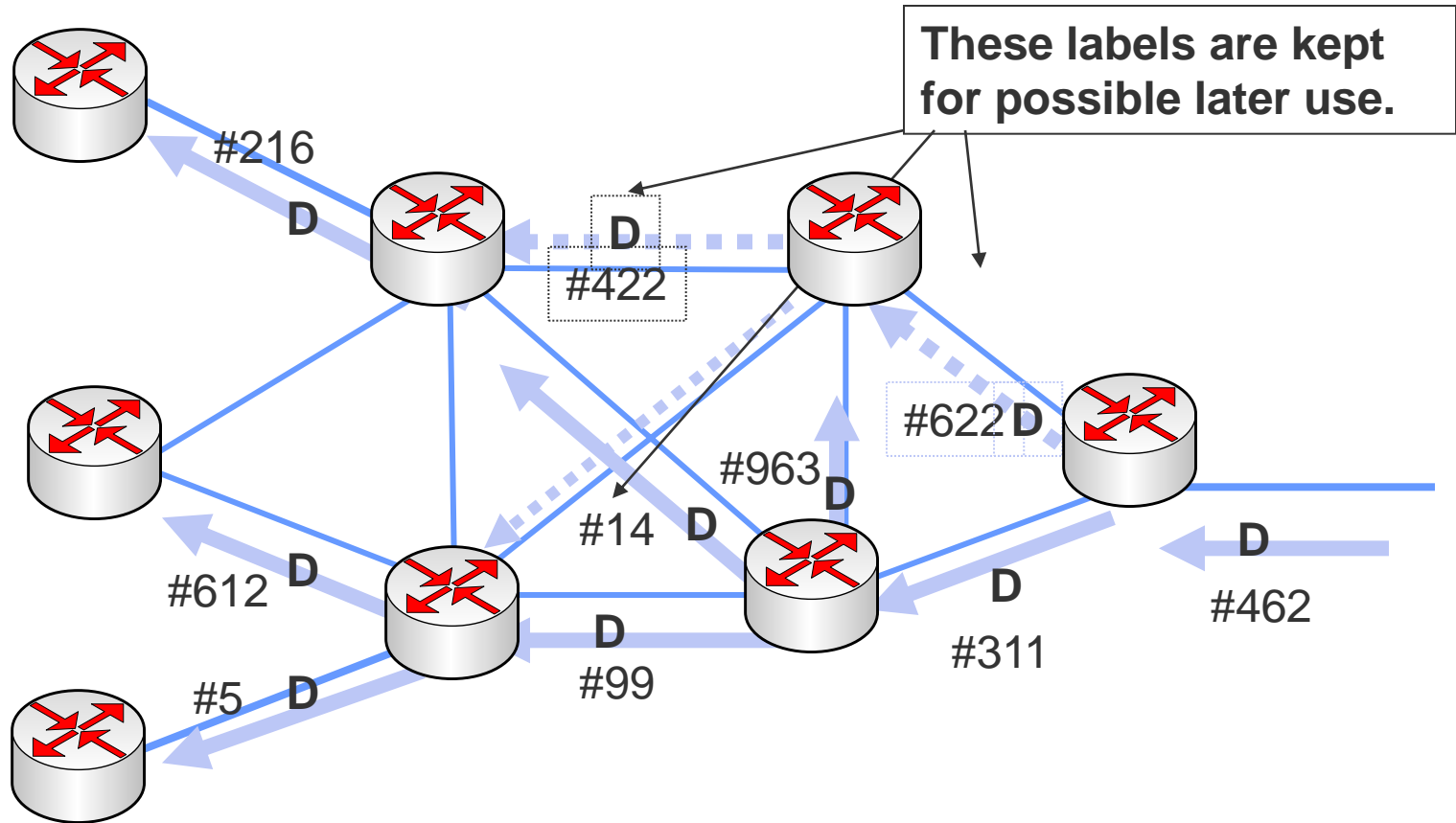
# Conservative Retention of Labels



Keep only the labels which are used for forwarding and discard others.



# Liberal Retention of Labels



# Summary

- Key advantages
  - Leverage growth of MPLS deployment in core and edge networks
  - Removes primary bottleneck of TCP termination
  - Realization in standard off-the-shelf switch hardware
  - Implements sophisticated request routing functions
- Requirements
  - Assign some request-routing functionality to proxies
  - MPLS-aware proxies at the network edges
  - Implementation of control protocol for label distribution