Fundamentals
Multiprotocol Label Switching – MPLS I

Design of Telecommunication Infrastructures
2008-2009

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Goals of the section

- ☑ Explain the driving factors behind MPLS
- ☑ List the benefits of forwarding labeled packets instead of forwarding IP packets
- ☑ Explain the applications of MPLS that have received widespread acceptance

Evolution of MPLS

- Definition
- Benefits

- Review Questions

What is MPLS?

Networking technology that uses labels attached to packets to forward them through the network

- MPLS labels used to forward packets instead of IP address
- F/R and ATM were based on label switching
- MPLS helps integrating IP and ATM

Pre-MPLS Protocols

- ATM and F/R were the top WAN technologies
- IP extended everywhere → IP over VPNs
- Private networks
  - Use of L2 WAN technologies
  - Overlay Networks
- Migration from traditional VPNs to MPLS VPNs

Improved switching?

- Switching IP packets use to be time consuming:
  - Read IP header (32 bits)
  - Check unicast/multicast
  - Look up destination address (routing table)
- Switching Labels → hardware process
- These days IP switching is as fast as Label switching

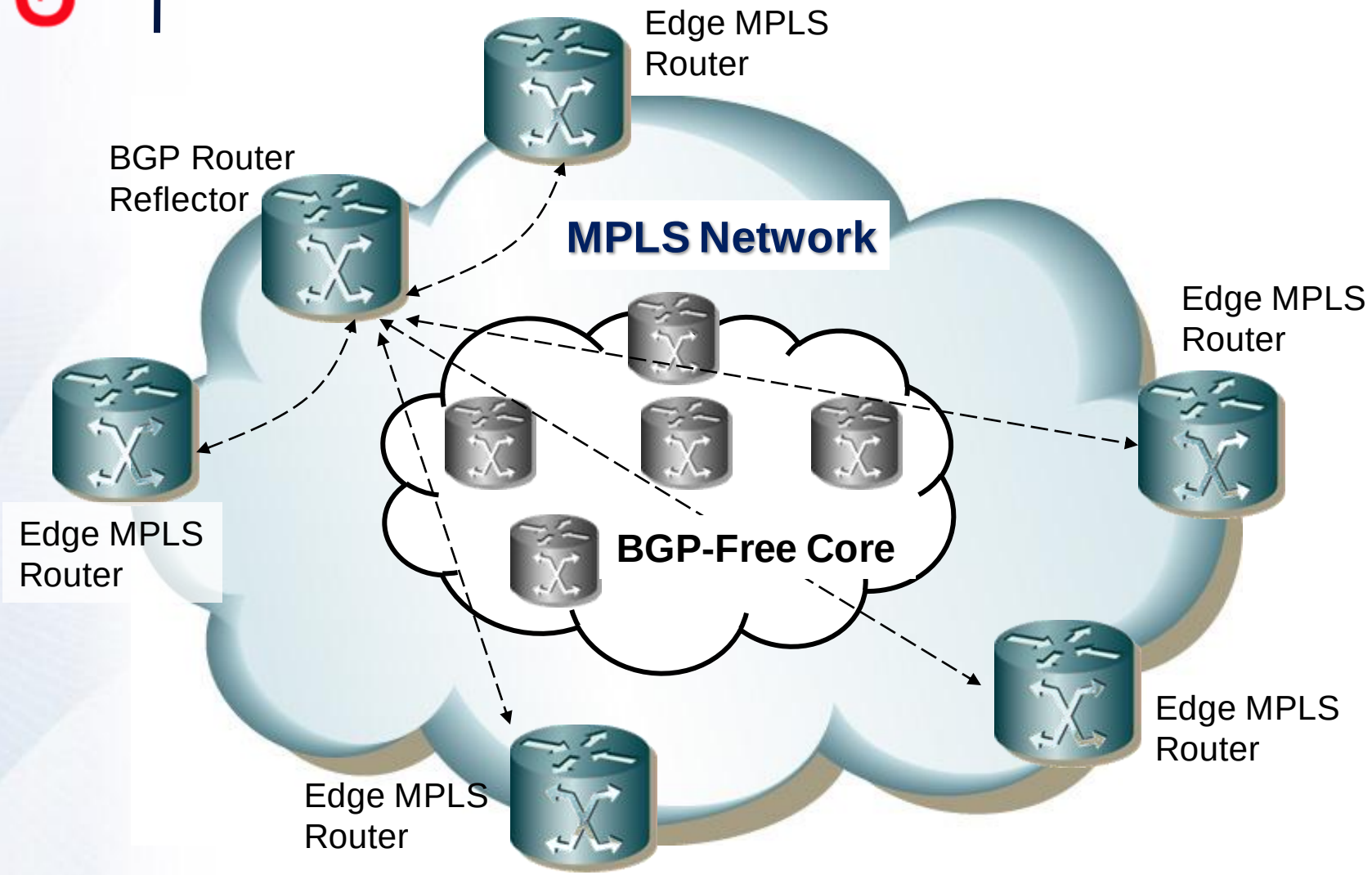
Unified Network Infrastructure

- MPLS Concept
  - Label Ingress packet based on destination address (or other criteria) and switch all the traffic
- MPLS + IP
  - Carry all the IP capable data (data, telephone,…)
- AToM (*Any Transport over MPLS*)
  - MPLS can transport IPv4, IPv6, Ethernet, HDLC, PPP and other Layer 2 technologies

IP over ATM Integration

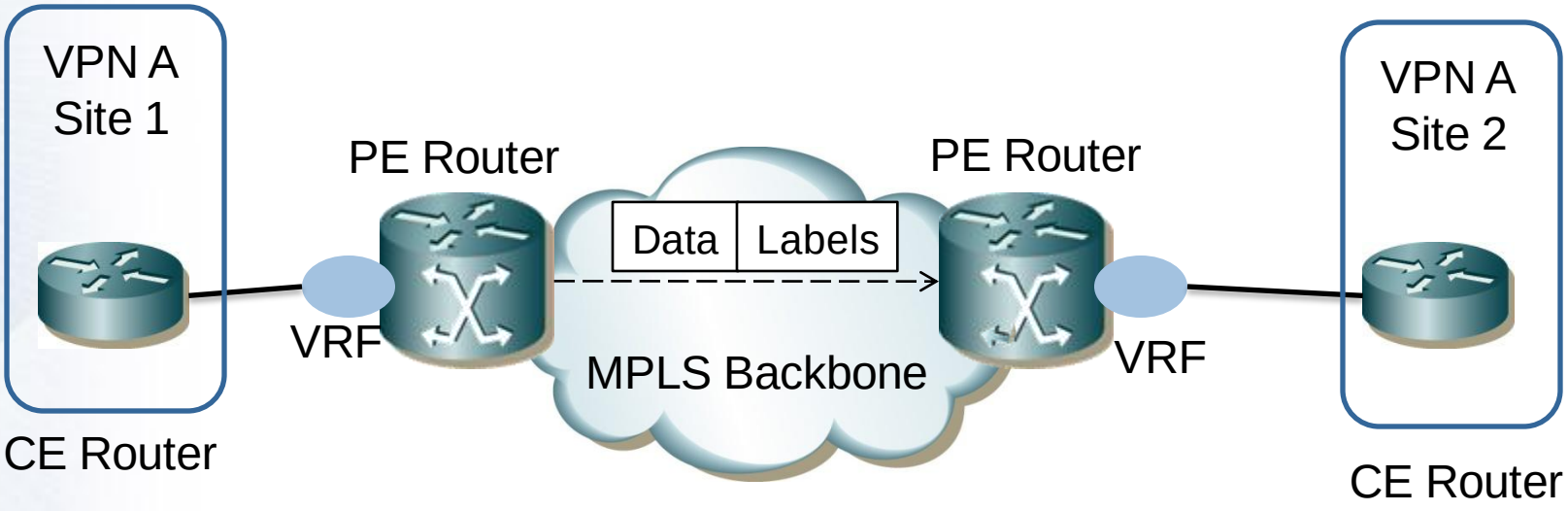
- IP won the Layer 3 battle & ATM the Layer 2
- IP over ATM was needed (WAN backbone)
  - RFC 1483, *Multiprotocol Encapsulation over ATM Adaptation Layer 5* → Management burden
  - LANE (*LAN Emulation*)
  - MPOA (*Multiprotocol over ATM*) → Complex
- Final Solution → MPLS
  - Intelligence on the ATM Networks

BGP-Free Core

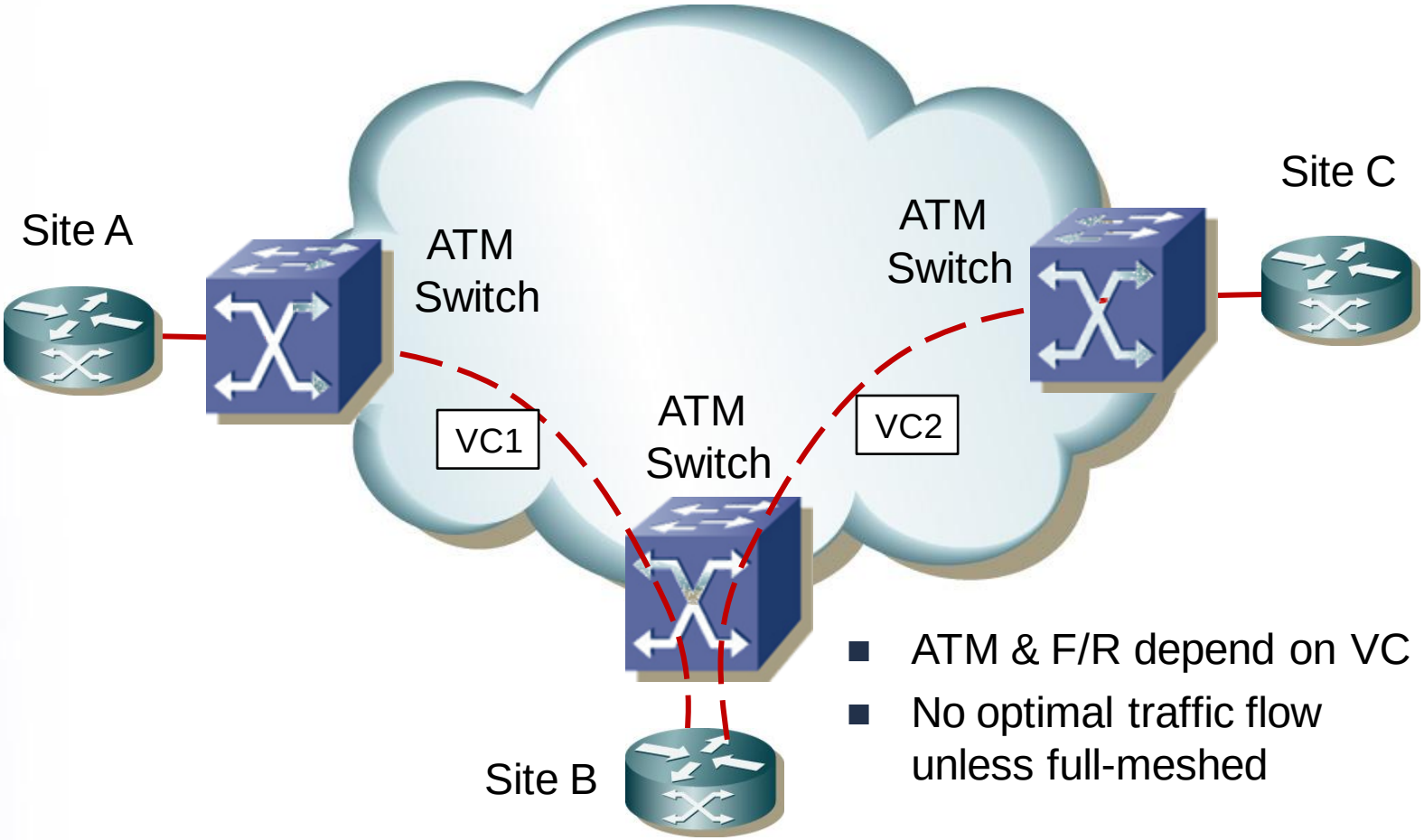


MPLS VPNs (peer-to-peer)

- Makes the peer-to-peer model easy to implement
- Privateness guaranteed through Virtual Routing Forwarding (VRF)



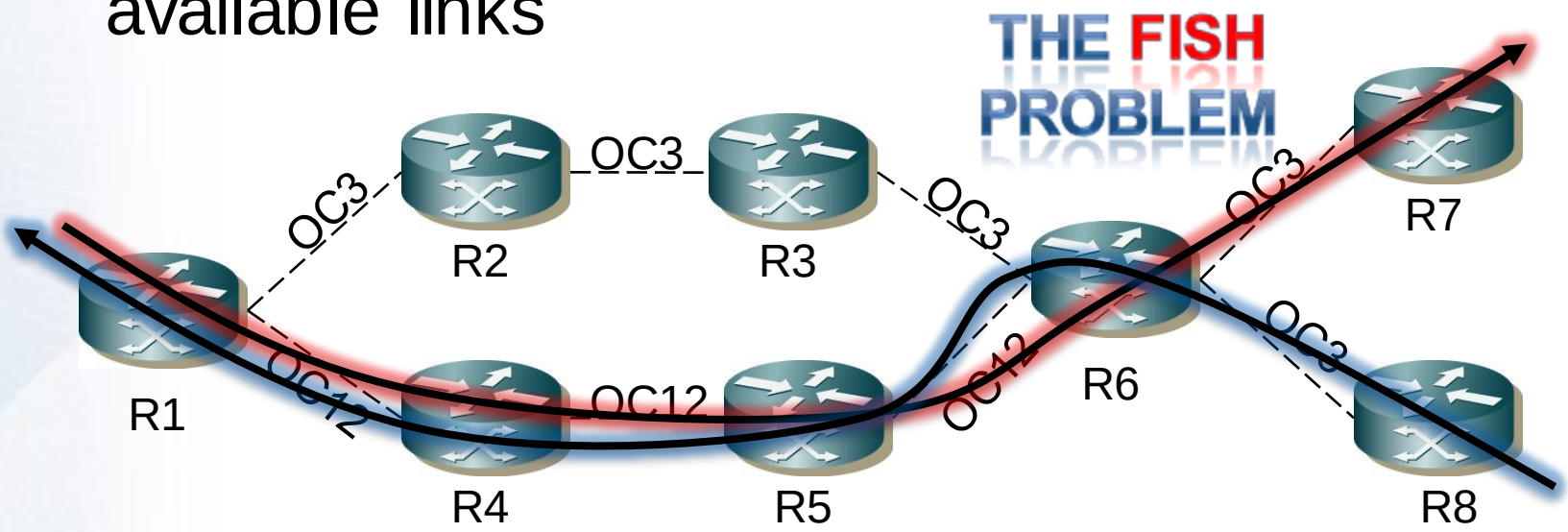
Optimal Traffic Flow



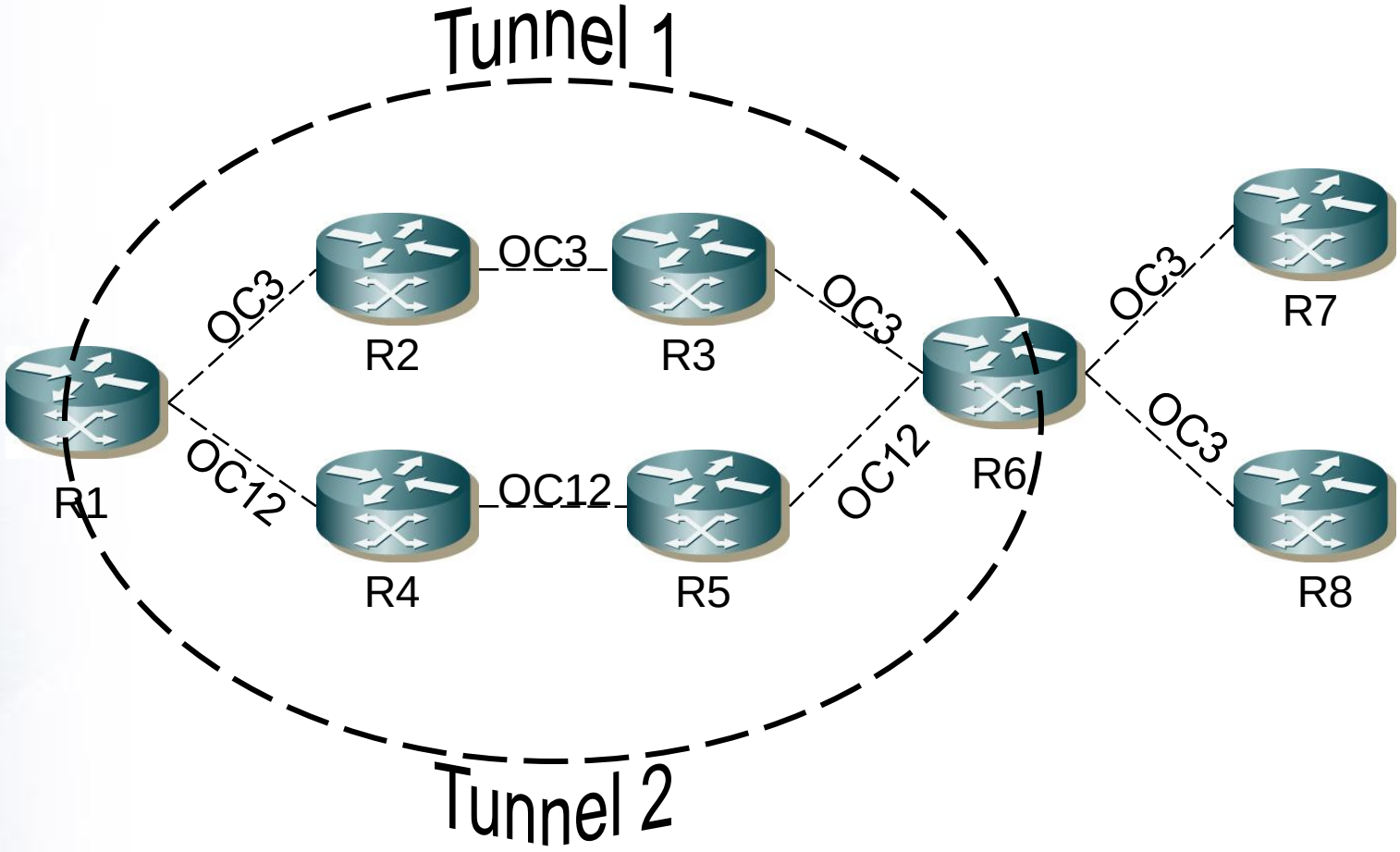
- ATM & F/R depend on VC
- No optimal traffic flow unless full-meshed

Traffic Engineering

- Optimal use of the network infrastructure
- Not all traffic through the least-cost path (dictated by IP routing protocol)
- Traffic is spread more evenly over the available links



MPLS-TE


Tunnel 1
OC3
OC3
OC3
OC3
OC3
R1
R2
R3
R6
R7
R8
OC12
OC12
OC12
R4
R5
Tunnel 2

Review Questions

1. What are the MPLS applications mentioned in this chapter?
2. Name three advantages of running MPLS in a service provider network.
3. What are the advantages of the MPLS VPN solution for the service provider over all the other VPN solutions?
4. Name the four technologies that can be used to carry IP over ATM.
5. Name two pre-MPLS protocols that use label switching.
6. What do the ATM switches need to run so that they can operate MPLS?
7. How do you ensure optimal traffic flow between all the customer sites in an ATM or Frame Relay overlay network?

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Goals of the section

- ☑ Explain the format of an MPLS label
- ☑ Describe a stack of MPLS labels and explain where it resides in the frame
- ☑ Tell what a LSR is and what its functions
- ☑ Describe what a LSP and a FEC are
- ☑ Explain the difference between LIB and LFIB
- ☑ Determine how labels are distributed in an MPLS network

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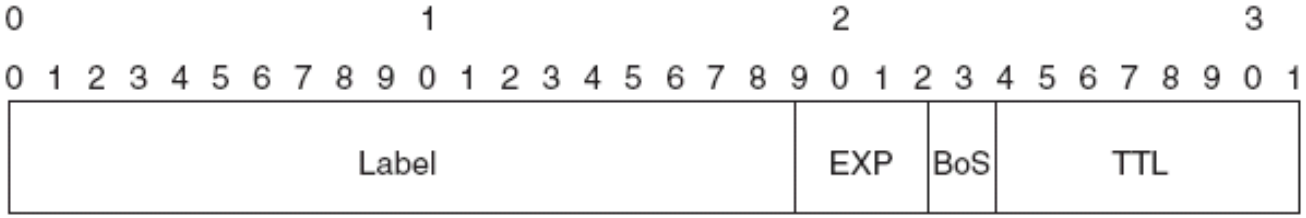
MPLS Architecture

- MPLS Labels
- Basic Components
- Label Distribution

- Review Questions

MPLS Labels

- MPLS Label is a field of 32 bits
- LABEL: 20 bits (max. 1,048,575 labels, 16 labels reserved)
- EXP: For QoS
- BoS: Set to 1 in the *Bottom Label* of the packet
- TTL: Time To Live

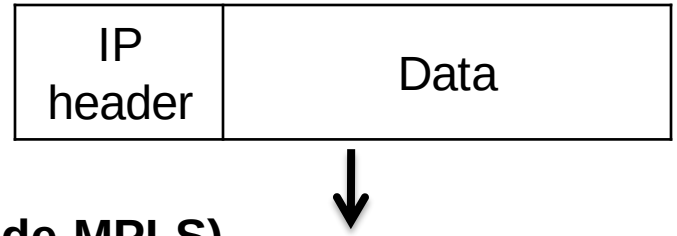


Label Stacking

- Several Label could be used to route the packet though the MPLS network
- The labels are stacked one on top of the next one

Label	EXP	0	TTL
Label	EXP	0	TTL
...			
Label	EXP	**1**	TTL

Label Location



Frame Formats (frame-mode MPLS)

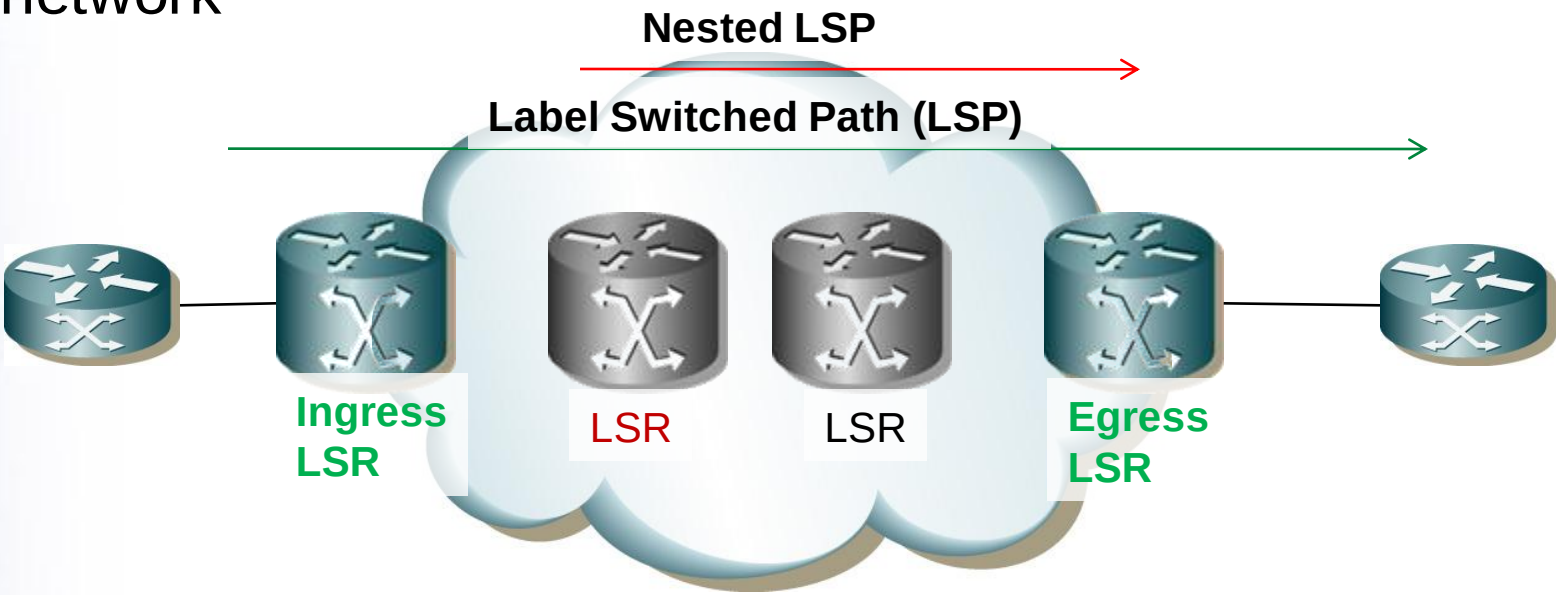
Ethernet Header	**MPLS Label**	IP header	Data	MAC trailer
PPP Header	**MPLS Label**	IP header	Data	MAC trailer
F/R Header	**MPLS Label**	IP header	Data	MAC trailer

OSI Layer 2.5

LSR & LSP –

Label Switched Router
Label Switched Path

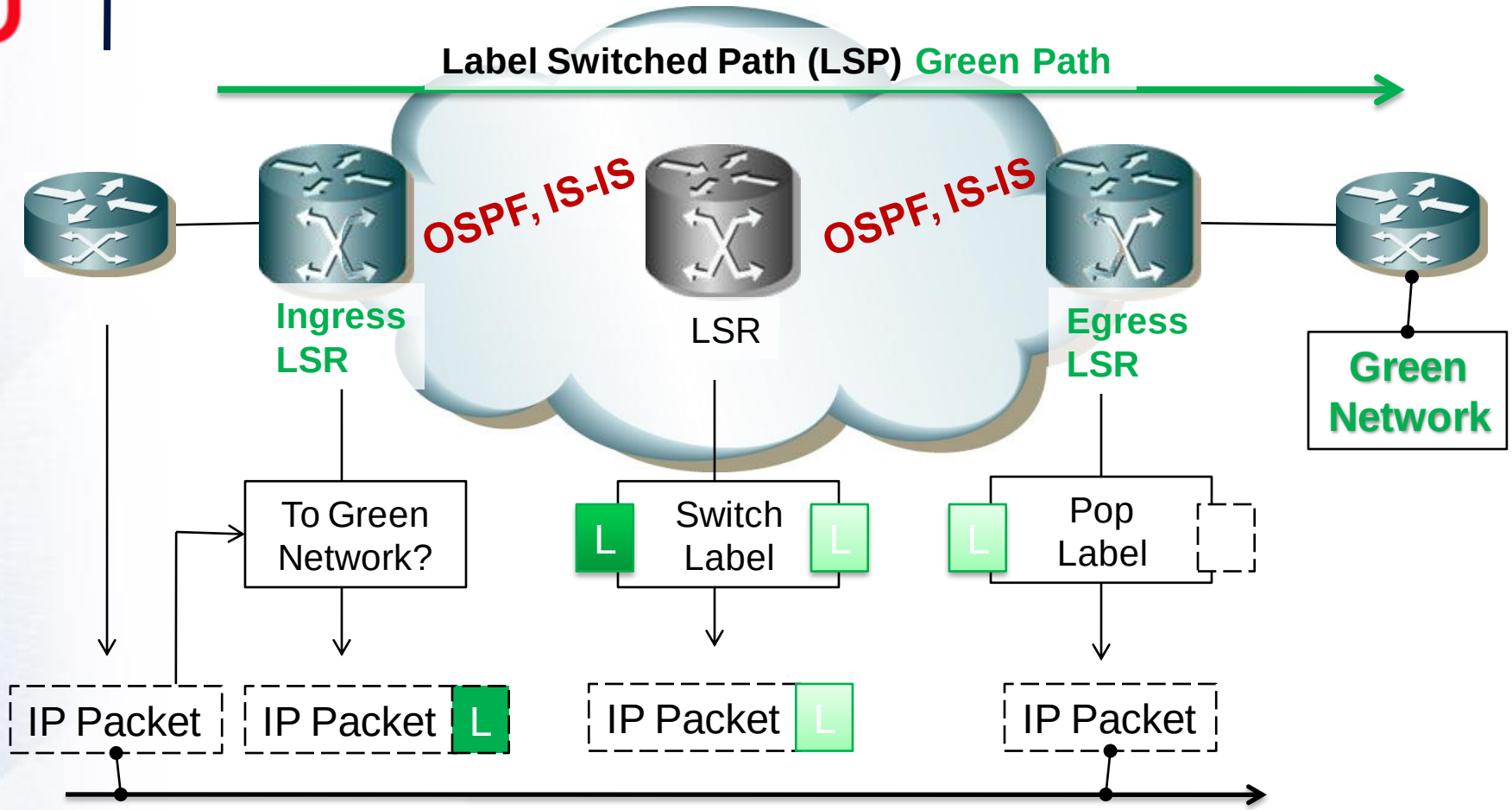
- LSR: Router that supports MPLS
- LSP: is a sequence of LSRs that switch a labeled packet through an MPLS network or part of an MPLS network



FEC
Forwarding Equivalent Class

- FEC: group of packets forwarded along the same path and treated in the same way
- Same FEC = same Label
- Same Label NOT ALLWAYS same FEC (ej. Because of different EXP)
- Ingress LSR classifies packets into FECs
  - Based on: IP source/destination, IP DiffServ Code Point, BGP prefix…

Label Distribution



A Label Distribution Protocol is needed!

How to distribute labels? (I)

- Piggyback the labels on an existing IP routing protocol
  - ☺ No new protocol is needed on LSR
  - ☺ Routing and label protocol are sync
  - ☺ Implementation in distance vector routing protocol is straightforward (EIGRP)
  - ☹ Extension of IP protocol required
  - ☹ Link state routing protocol have problems

How to distribute labels? (II)

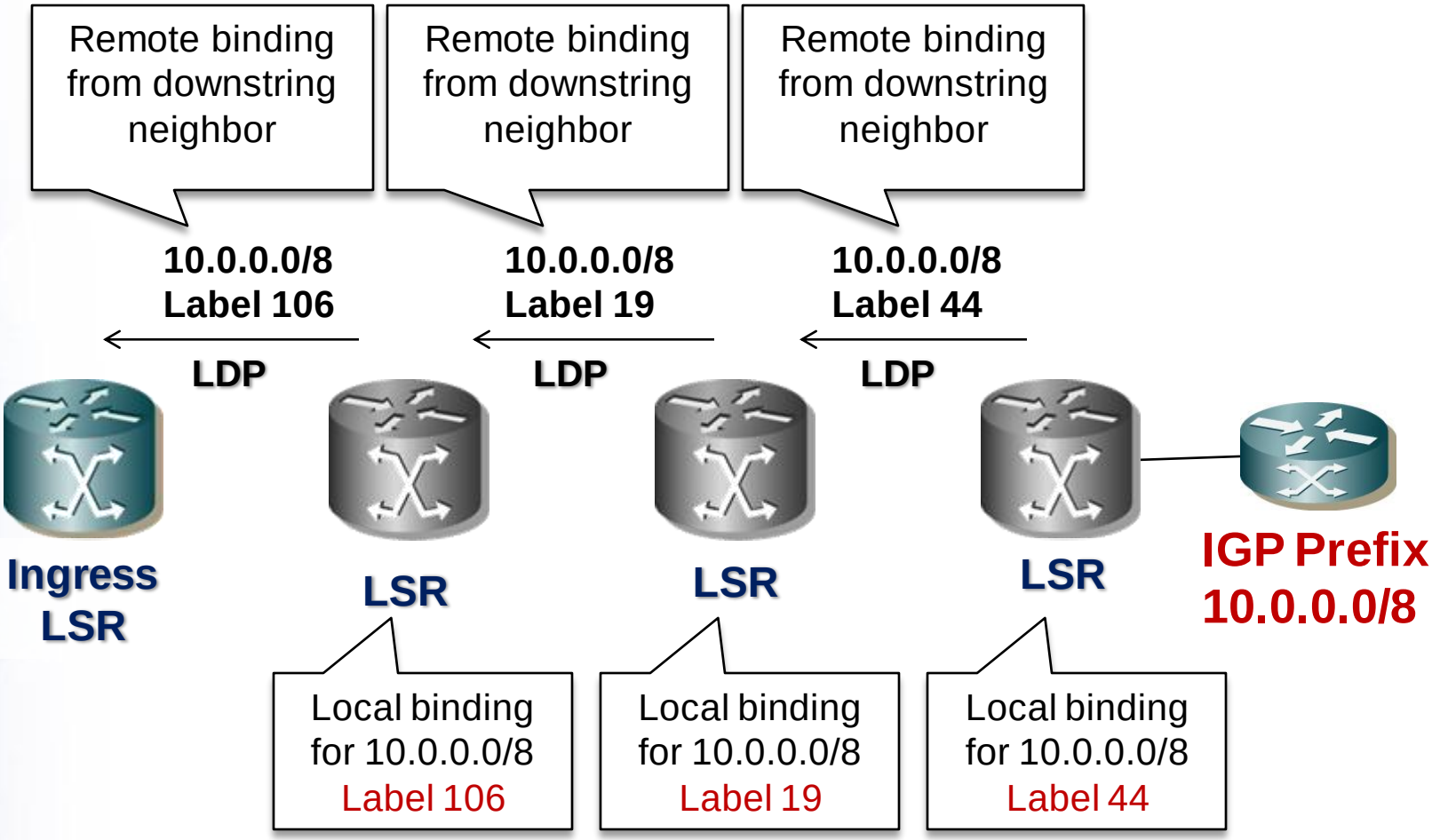
- Running a Separate Protocol for Label Distribution
  - ☺ Routing protocol independent
  - ☹ A new protocol needed in the LSRs
  - Several varieties
    - Tag Distribution Protocol (TDP) [Cisco/deprecated]
    - Label Distribution Protocol (LDP)
    - Resource Reservation Protocol (RSVP)

Label Distribution Protocol - LDP

- LSR
  1. Define a *Label* (binding) for each IGP IP Prefix
  2. Redistribute this binding to all LDP neighbors
  3. Receive the remote bindings and add them to *LIB*
- Label space can be *per-platform* or *per-interface*
  Each LSR has only one local binding
- Several remote bindings can be received for the same prefix → One needs to be picked
- Set-up *Label Forwarding Information Base* (LFIB)
  - Swapping incoming for outgoing label

LIB: Label Information Base

Label Distribution Protocol - LDP



Label Forwarding Information Base - LFIB

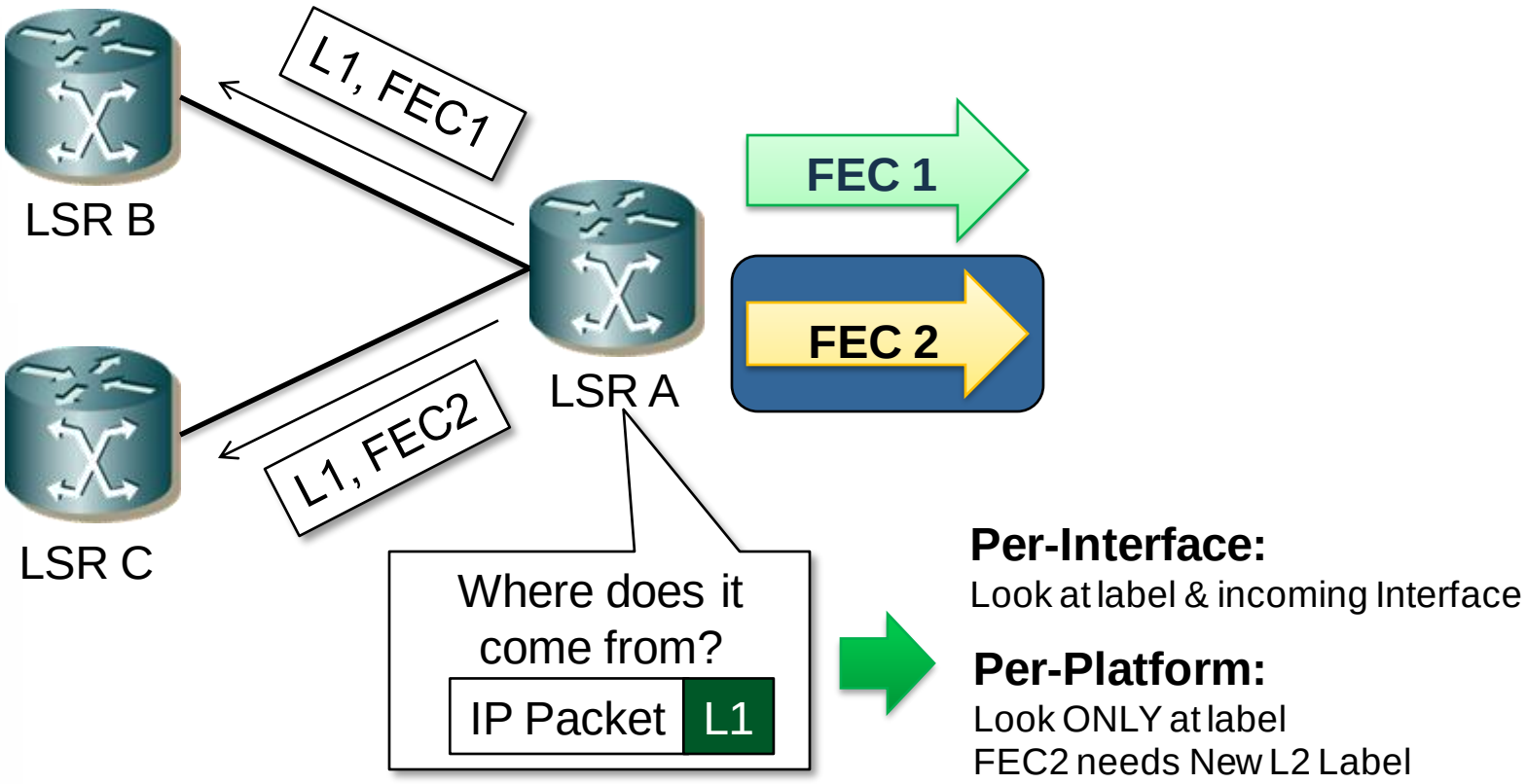
- The LFIB is the table used to forward labeled packets
  - Incoming label → from the local binding
  - Outgoing label → chosen from remote binding from all the possibilities (based on best path)
- LFIB populated by
  - LDP
  - RSVP: For MPLS-TE
  - BGP: For MPLS VPNs

MPLS Payload?

- MPLS has no *Network Level Protocol (NLP)* identifier field
- LSR do not need to know about payload, only the top MPLS label is important
- LSR only needs to have a binding for the top level label
- Egress LSR removes all labels and assign NLP

MPLS Label Spaces

Per-Interface vs. Per-Platform



MPLS Modes

- Modes when distributing Labels
  - Label *distribution* mode
    - Downstream-on-Demand (DoD) label distribution
    - Unsolicited Downstream (UD) label distribution
  - Label *retention* mode
    - Liberal Label Retention (LLR) mode
    - Conservative Label Retention (CLR) mode
  - LSP *control* mode
    - Independent LSP Control mode
    - Ordered LSP Control mode

Review Questions

1. Name the four fields that are part of a label.
2. How many labels can reside in a label stack?
3. In which layer does MPLS fit in the OSI reference model?
4. Which table does an LSR use to forward labeled packets?
5. What type of interfaces use the Downstream-on-Demand label distribution mode and the per-interface label space?
6. Why does the MPLS label have a Time To Live (TTL) field?

Test Questions

1. **How many octets are there in the MPLS label stack header?**
   - A. 1
   - B. 2
   - C. 3
   - D. 4
2. **In frame-mode MPLS, the MPLS label stack resides _____ and _____.** (Choose two.)
   - A. Before the Layer 2 header
   - B. After the Layer 2 header
   - C. Before the Layer 3 payload
   - D. After the Layer 3 payload
3. **How many bits make up the label portion of the MPLS label stack?**
   - A. 3
   - B. 16
   - C. 20
   - D. 32

Test Questions

4. **An MPLS-capable router/switch is called a(n) _____?**
   - A. LSA
   - B. LSR
   - C. LRR
   - D. TSR

5. **Which device in the network only connects to service provider equipment?**
   - A. P
   - B. PE
   - C. CE
   - D. C

6. **Which network device typically imposes the labels?**
   - A. P
   - B. PE
   - C. CE
   - D. C

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Goals of the section

- ☑ Explain how labeled packets are forwarded
- ☑ Name the reserved MPLS labels and know what they are used for
- ☑ Determine the importance of MPLS MTU
- ☑ Explain what happens to labeled packets that have TTL expiring
- ☑ Explain what happens with labeled packets that need to be fragmented

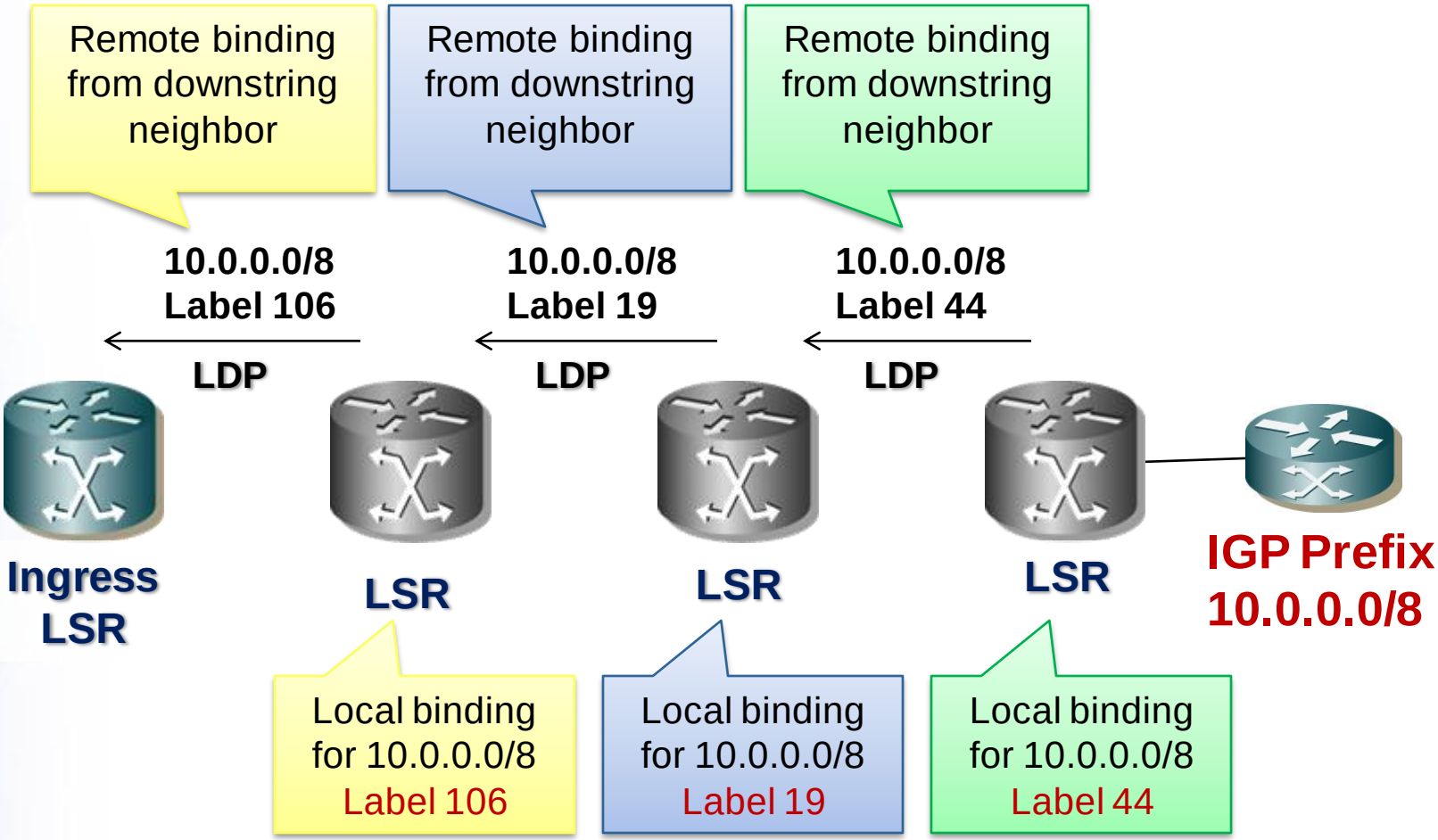
Forwarding Labeled Packets

- Forwarding Labeled packets
- Label Numbers
- TTL Behavior of Labeled Packets
- MPLS MTU

- Review Questions

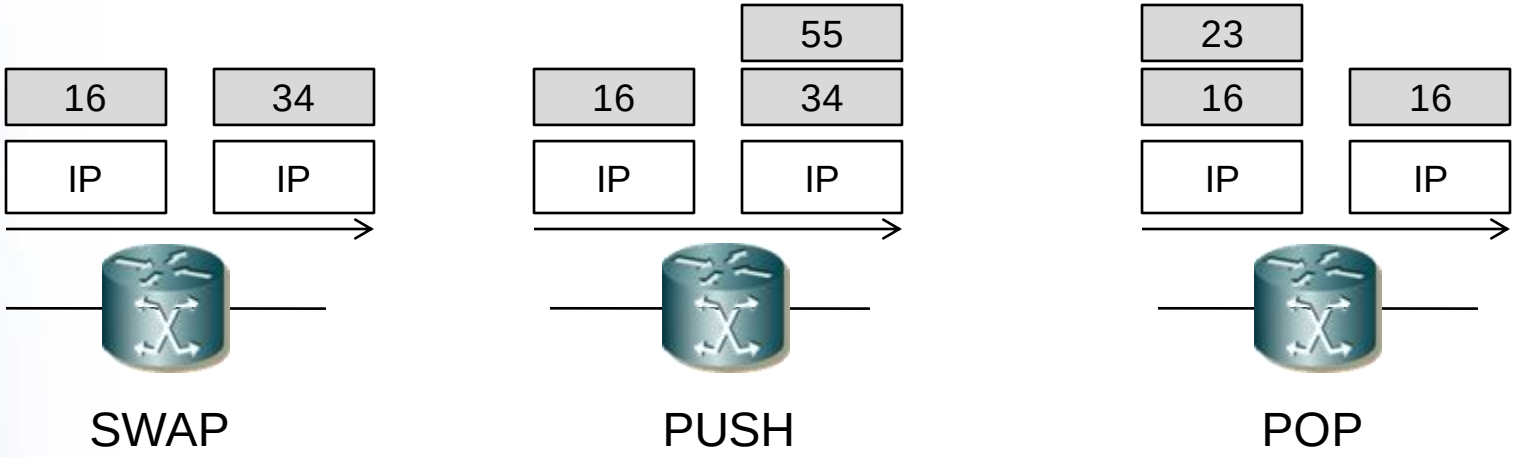
Summary MPLS

Review



Label Operation

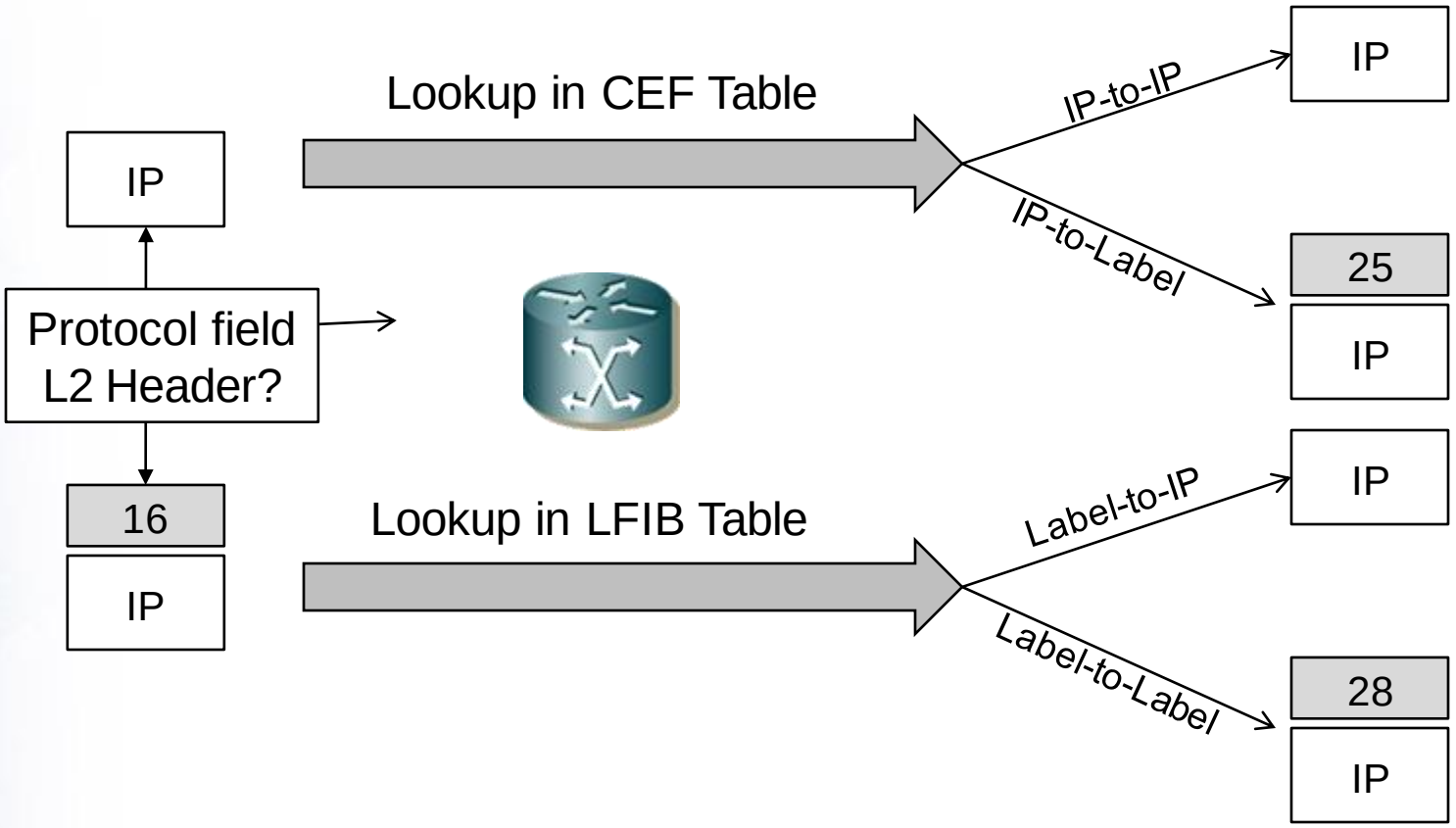
- Possible label operations: swap, push, and pop.



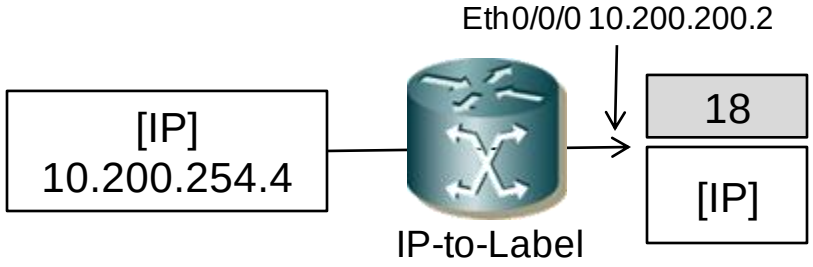
- The LSR sees the 20-bit field in the top label
  - looks up this value in the LFIB,
  - tries to match it with a value in the local labels list.

IP vs Label Lookup

- CEF (IP) or LFIB (Label) lookup



Example case



CEF Table

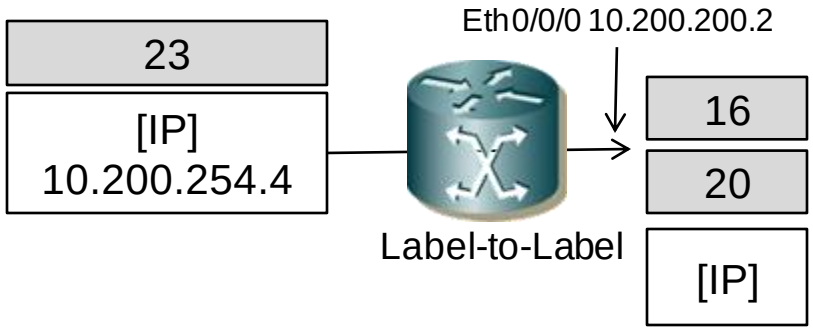
router# show ip cef 10.200.254.4
10.200.254.4/32, version 44, epoch 0, cached adjacency 10.200.200.2 0 packets, 0 bytes
tag information set, all rewrites owned
local tag: **20**
fast tag rewrite with **Et0/0/0**, **10.200.200.2**, tags imposed {**18**}
via 10.200.200.2, Ethernet0/0/0, 0 dependencies
next hop 10.200.200.2, Ethernet0/0/0
valid cached adjacency
tag rewrite with Et0/0/0, 10.200.200.2, tags imposed {18}

Extract of LFIB

router# show mpls forwarding-table

Local tag	Outgoing tag or VC	Prefix or Tunnel Id	Bytes tag switched	Outgoing interface	Next Hop
16	Untagged	10.1.1.0/24	0	Et0/0/0	10.200.200.2
17	16	10.200.202.0/24	0	Et0/0/0	10.200.200.2
18	Pop tag	10.200.203.0/24	0	Et0/0/0	10.200.200.2
19	Pop tag	10.200.201.0/24	0	Et0/0/0	10.200.200.2
20	**18**	**10.200.254.4/32**	**0**	**Et0/0/0**	**10.200.200.2**
21	Pop tag	10.200.254.2/32	0	Et0/0/0	10.200.200.2
22	17	10.200.254.3/32	0	Et0/0/0	10.200.200.2

Example case



- MPLS Forwarding table

router#show mpls forwarding-table 10.200.254.4

Local tag	Outgoing tag or VC	Prefix or Tunnel Id	Bytes tag switched	Outgoing interface	Next Hop
23	16	[T] 10.200.254.4/32	0	Tu1	point2point

[T] Forwarding through a TSP tunnel.

---

router#show mpls forwarding-table 10.200.254.4 detail

Local tag	Outgoing tag or VC	Prefix or Tunnel Id	Bytes tag switched	Outgoing interface	Next Hop
23	16	10.200.254.4/32	0	Tu1	point2point

MAC/Encaps=14/22, MRU=1496, **Tag Stack{20 16},** via Et0/0/0
00604700881D00024A4008008847 0001400000010000
No output feature configured

---

router#show mpls forwarding-tablevrf cust-one

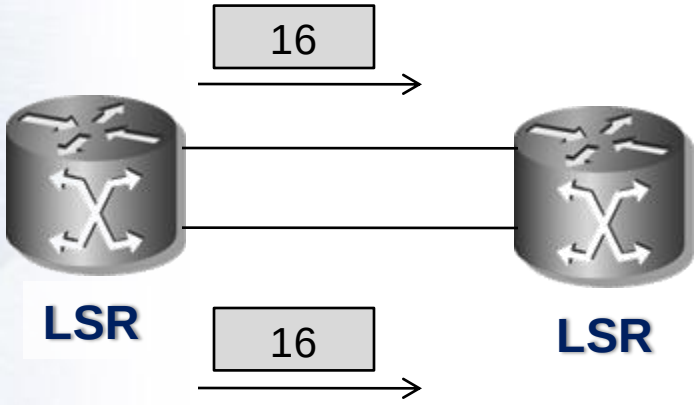
Local tag	Outgoing tag or VC	Prefix or Tunnel Id	Bytes tag switched	Outgoing interface	Next Hop
23	**Aggregate**	10.10.1.0/24[V]	0		

Load Balancing

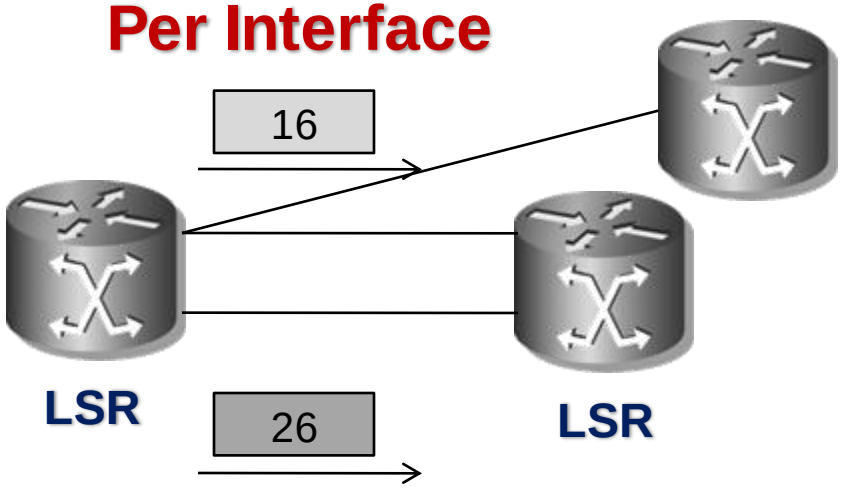
router#show mpls forwarding-table

Local tag	Outgoing tag or VC	Prefix or Tunnel Id	Bytes tag switched	Outgoing interface	Next Hop
17	Pop tag	10.200.254.3/32	252	Et1/3	10.200.203.2
	Pop tag	10.200.254.3/32	0	Et1/2	10.200.201.2
18	16	10.200.254.4/32	10431273	Et1/2	10.200.201.2
	16	10.200.254.4/32	238	Et1/3	10.200.203.2

Per platform

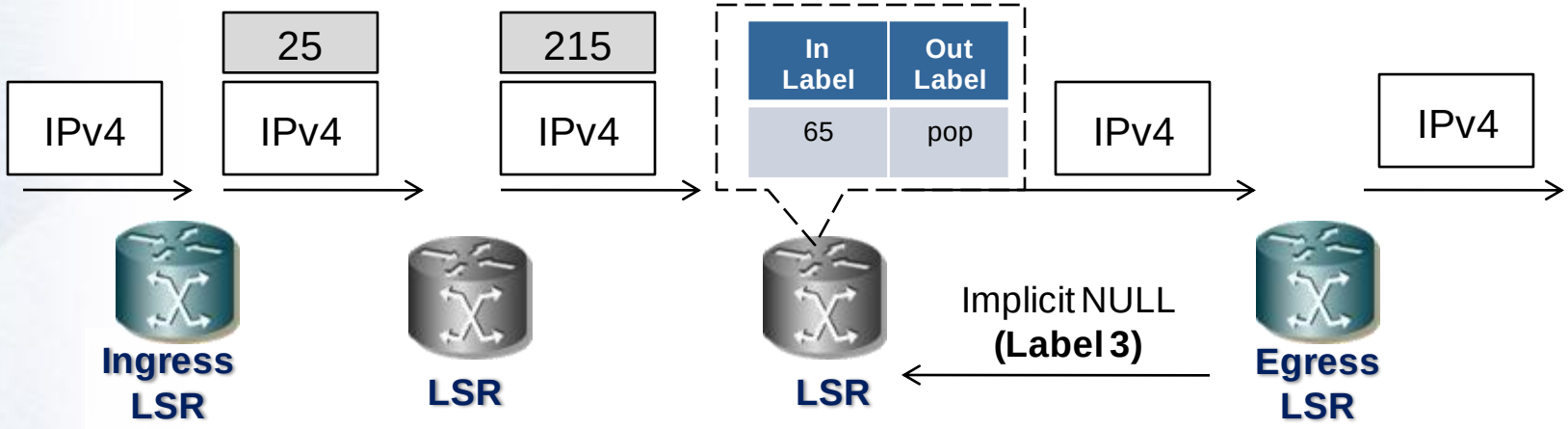


Per Interface



Implicit Null Label (penultimate hop popping (PHP))

- Labels 0 to 15 reserved,
  - Implicit null label: value “3”
- Used by LSR that does not want to assign a label to a FEC
- In egress routers it avoids a lookup



Explicit Null Label

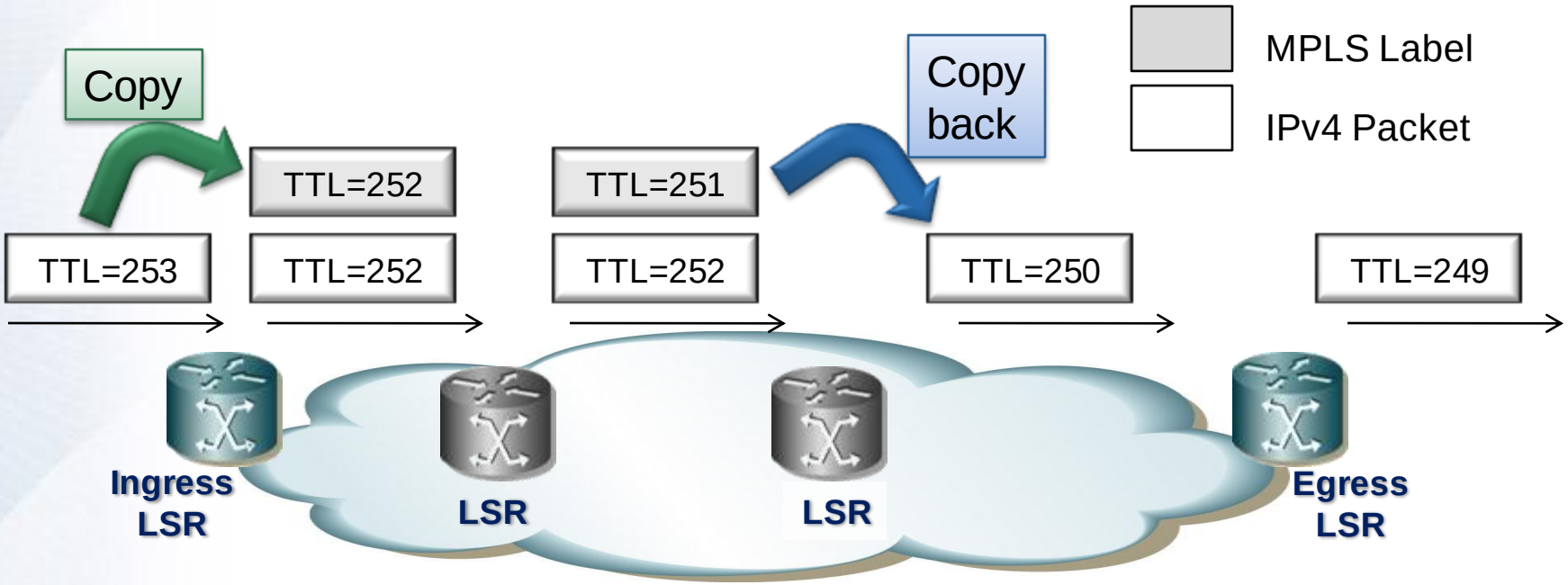
- Using Implicit null label
  - MPLS header is removed one hop before
  - EXP bits (QoS) are removed
- Explicit null label (label value “0”)
  - Packet are still label
  - Label 0 is removed without lookup
  - EXP bits are kept

Unreserved Labels

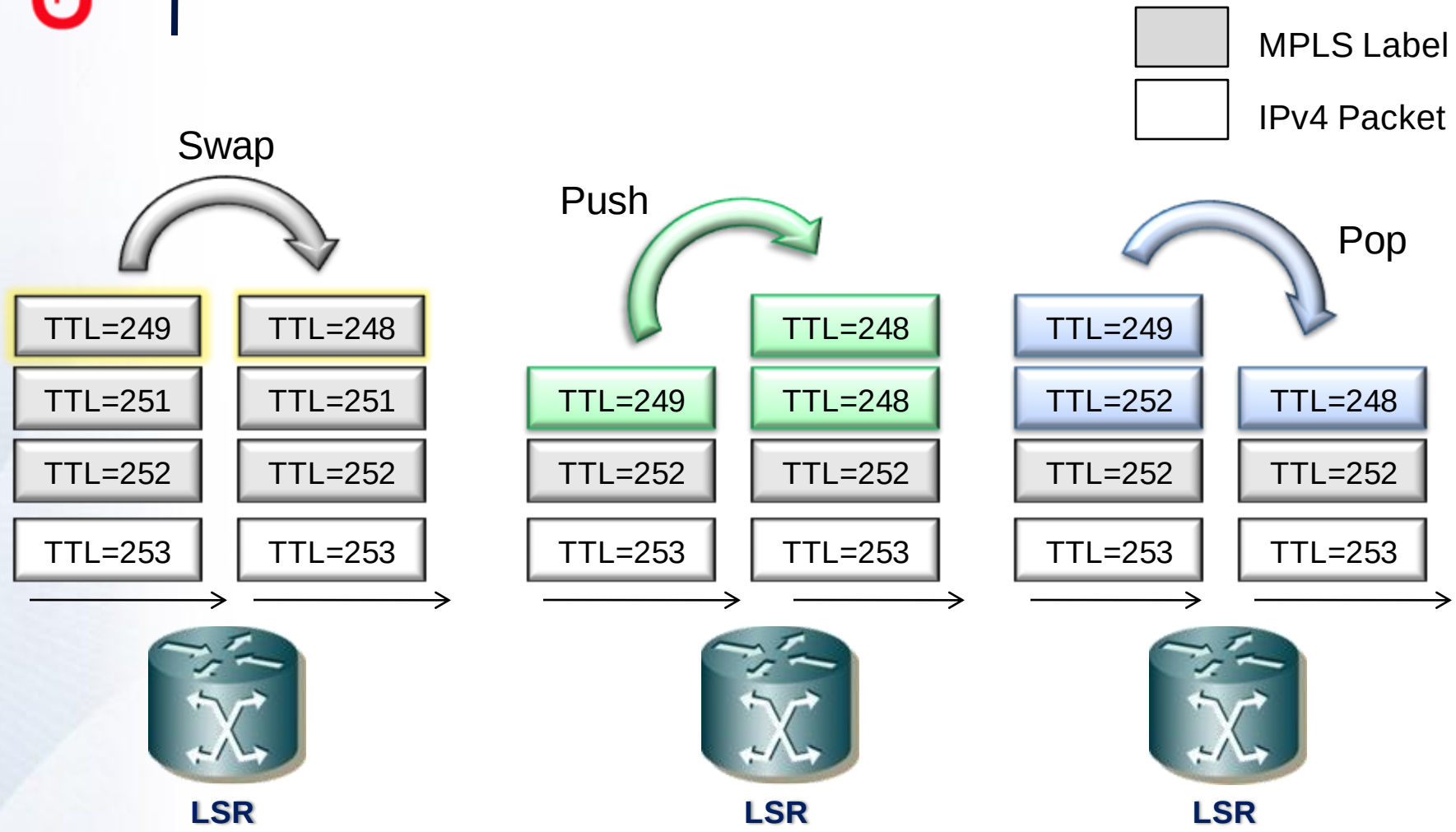
- Labels have 20 bits [16,1.048.575]
- Some routers (e.g. Cisco) uses 16-100.000
  - Enough for labelling all IGP prefixes
  - For BGP prefixes additional labels might be needed

IP-to-Label & Label-to-IP

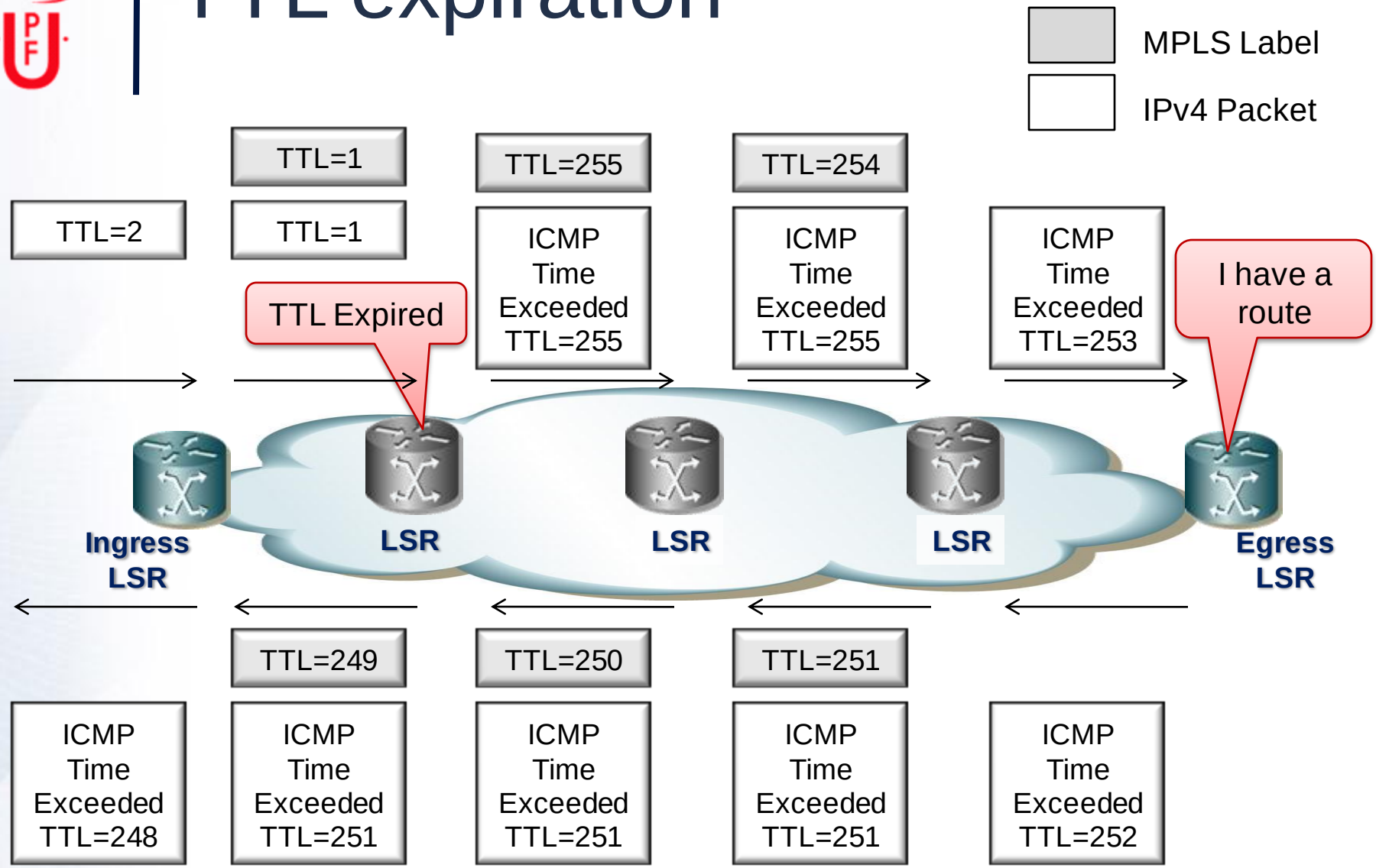
- TTL: Time to Live
  - 8 bits field (max.255 hops)
  - If TTL = 0 packet is dropped & ICMP to sender



TTL Label-to-Label



TTL expiration



MPLS MTU

- Maximum transfer unit (MTU)
  - Maximum frame size that can be sent on a data link without fragmentation
- MPLS frames are bigger than IP
  - IP packet + (4 bytes * #labels)
- MPLS Maximum Receive Unit
  - Used in the LFIB to keep track of how big labeled packets can be

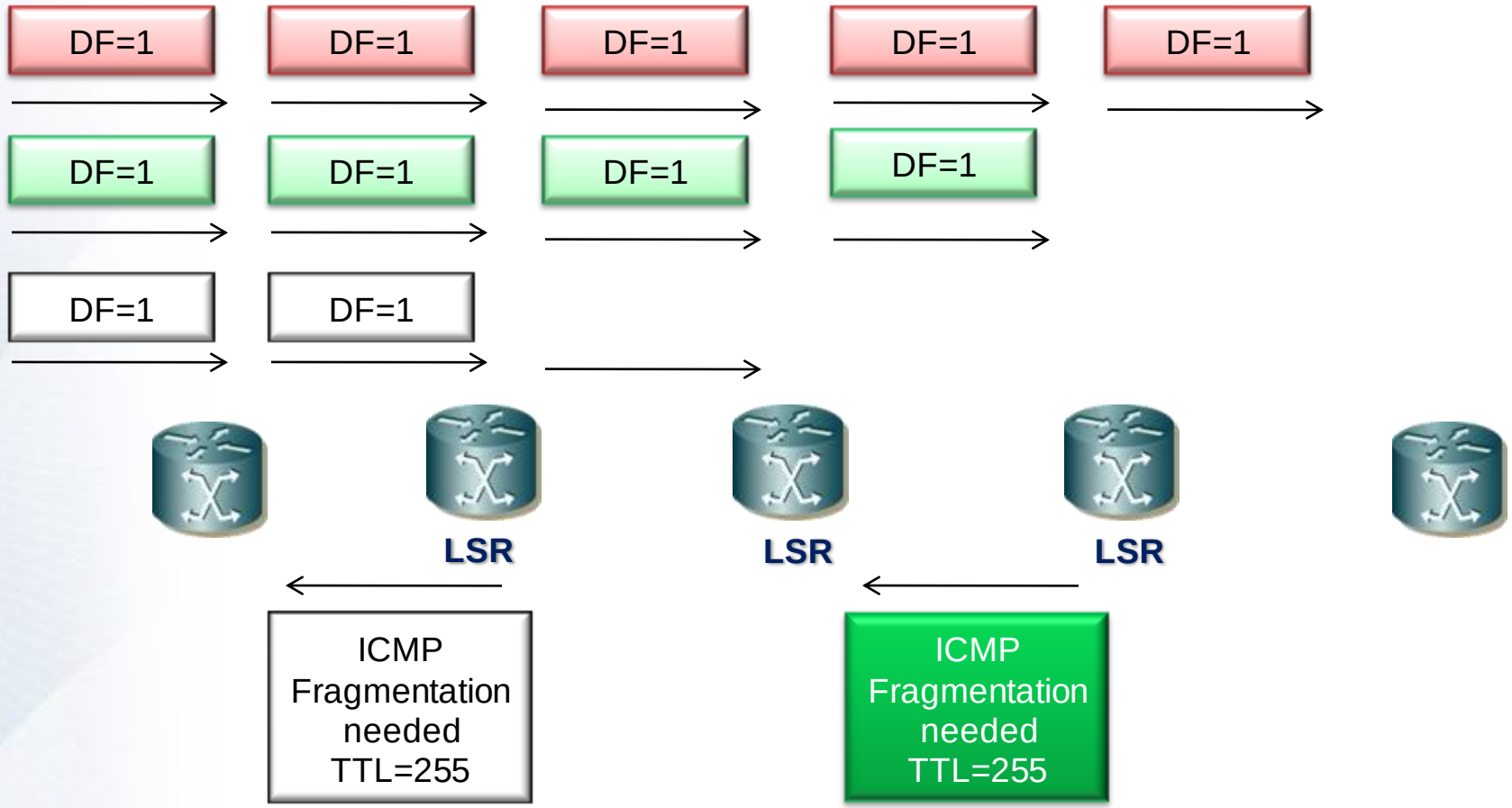
Giant and Baby Giant frames

- Baby Giant frames
  - Frames slightly bigger than expected by a certain data link (e.g. Ethernet frame (1500 bytes) + 1 Label (4 bytes)
  - If hardware is capable we can choose to send this kind of frames
- MTU discovery
  - To discover maximum MTU allowed over a path
  - To avoid fragmentation and increase performance

Fragmentation in MPLS

- Frames larger than MTU → fragmented
- Fragmentation
  - Remove all the MPLS stack
  - Fragment the IP packet
  - Perform operations over the stack
  - Add the stack to the fragmented packets
- If DF = 1 in IP Header
  - Packet drop and ICMP message sent

Path MTU Discovery



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- Evolution of MPLS
- MPLS Architecture
- Forwarding Labeled Packets

- **Review Test**

Review Questions

1. What does the push operation do on a labeled packet?
2. What does the outgoing label entry of “Aggregate” in the LFIB LSR mean?
3. What label value signals the penultimate LSR to use penultimate hop popping (PHP)?
4. Why does an LSR forward the ICMP message “time exceeded” along the LSP of the original packet with the TTL expiring instead of returning it directly?
5. Is using Path MTU Discovery a guarantee that there will be no MTU problems in the MPLS network?
6. Why is MTU such an important parameter in MPLS networks?

Test Questions

7. **What is the process of removing a label by the next-to-last router called?**

   A. Popping
   B. Fast switch popping
   C. Penultimate hop popping
   D. Label disposition

8. **Which field of the MPLS label stack is used for Quality of Service (QoS)?**

   A. Label C. S
   B. B. Experimental D. TTL

9. **Which of the following is *not a suitable application for MPLS?***

   A. Quality of Service
   B. Virtual private networks
   C. Routing protocol replacement
   D. Traffic engineering

Test Questions

10. **In MPLS, VPNs and traffic engineering are made possible by _____.** (Choose the most appropriate answer.)
    - A. Label stacking
    - B. Label popping
    - C. Label imposition
    - D. Label switching

11. **Cisco's proprietary version of MPLS is called _____.**
    - A. Multi-protocol tag switching
    - B. Multi-Protocol Label Switching
    - C. Tag forwarding
    - D. Tag switching

12. **Which protocol does MPLS use to exchange labels with neighbors?**
    - A. LDP
    - B. LIB
    - C. TDP
    - D. FIB

Test Questions

13. **For MPLS or tag switching to work, _____ must be enabled.**
    - A. LFIB
    - B. LIB
    - C. FIB
    - D. CEF
14. **To indicate the bottom of a stack, the S bit is set to _____.**
    - A. 0
    - B. 1
    - C. 2
    - D. None of the above
15. **An IP prefix is analogous to a(n) _____.**
    - A. FIB
    - B. LFIB
    - C. FEC
    - D. CEF

Test Questions

16. **LSPs are _____.**

A. Unidirectional
B. Bi-directional
C. None of the above

17. **An ATM switch that is MPLS-enabled is called a(n) _____.**

A. ATM-LSR
B. Edge-LSR
C. ATMF-LSR
D. Core-LSR