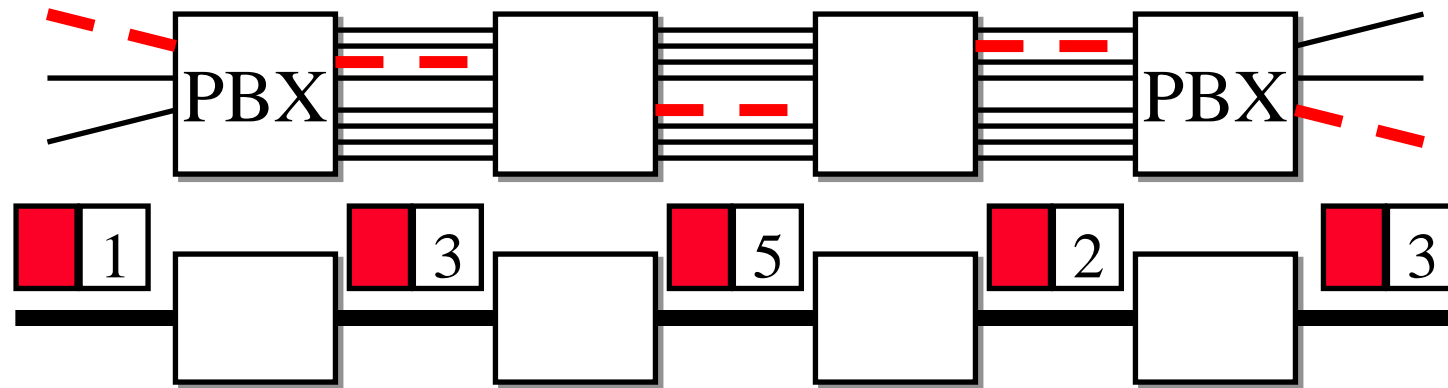# Carrier IP Networks: MPLS

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These slides and audio/video recordings of this class lecture are at:
http://www.cse.wustl.edu/~jain/cse570-21/

Student Questions

Overview

1. Plesiochronous Digital Hierarcy
2. Multiprotocol Label Switching (MPLS)
3. MPLS over Ethernet
4. Ethernet over MPLS

Student Questions

Plesiochronous Digital Hierarchy (PDH)

❑ Plesios + Synchronous = Near synchronous

❑ Phone Line = 64 kbps = 1 User channel

❑ North America

   ➢ T1 = 1.544 Mbps = 24 User channels

   ➢ T2 = 6.312 Mbps = 96 Channels

   ➢ T3 = 44.736 Mbps = 480 Channels

❑ Europe:

   ➢ E1 = 2.048 Mbps = 32 Channels

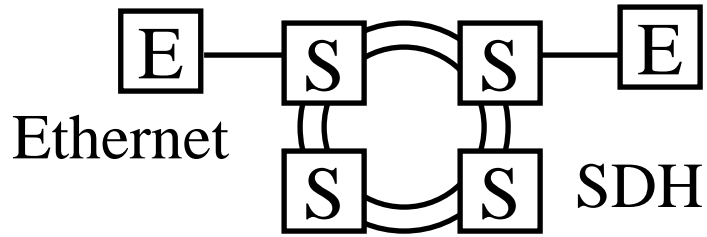   ➢ E2 = 8.448 Mbps = 128 Channels

   ➢ E3 = 139.264 Mbps = 2048 Channels

T1

Student Questions

SONET/SDH

Ethernet — SDH

- SONET=Synchronous optical network
- Standard for digital optical transmission
- Standardized by ANSI and then by ITU
  ⇒ Synchronous Digital Hierarchy (SDH)
- Protection: Allows redundant Line or paths
- Fast Restoration: 50ms using rings
- Sophisticated management
- Ideal for Voice: No queues. Guaranteed delay
- Fixed Payload Rates: OC1=51.84 Mbps, OC3=155M, OC12=622M, OC48=2.4G, OC192=9.5G
  Rates do not match data rates of 10M, 100M, 1G, 10G
- Static rates not suitable for bursty traffic
- One Payload per Stream ⇒ High Cost

Student Questions
- Are there any bad influence when PDH using extensive software?
When operating at high speed, hardware is faster and cheaper than software.
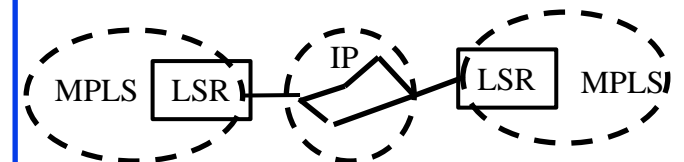
Multiprotocol Label Switching (MPLS)
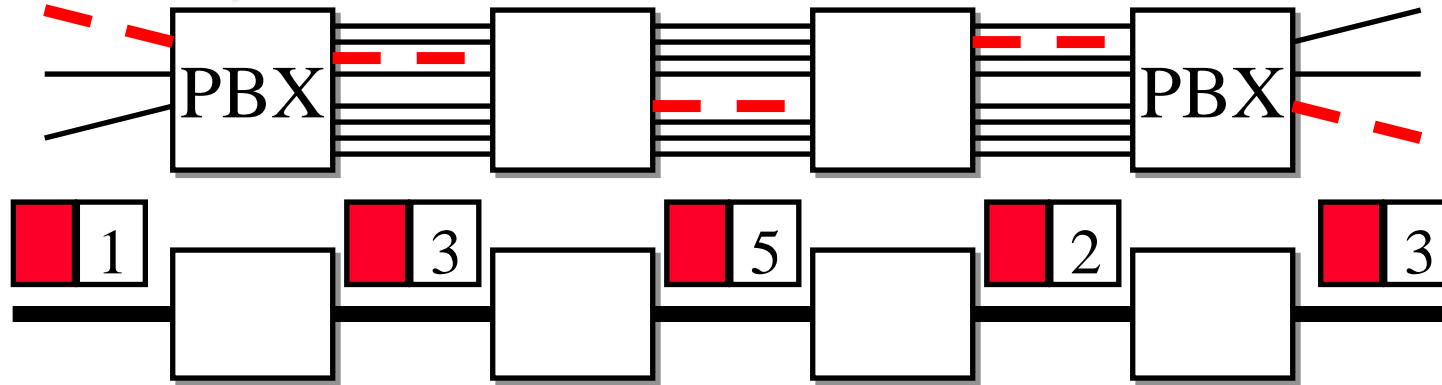
- Allows virtual circuits in IP Networks (May 1996)
- Each packet has a virtual circuit number called 'label'
- Label determines the packet's queuing and forwarding
- Circuits are called Label Switched Paths (LSPs)
- LSP's have to be set up before use
- Allows traffic engineering
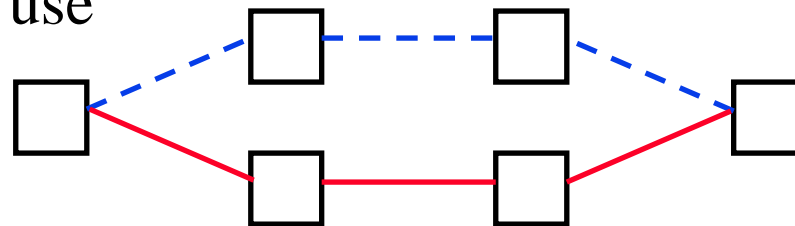
Student Questions

- What is the advantage of MLPS compare to previous method?

MPLS allows "Traffic Engineering," fixed paths and reservations.

- Is MPLS for private networks only or for all service provider networks?

For both, but mostly used in service provider networks.

- Do MPLS packets still go through ordinary L3 routers that know nothing about the label, but can use the IP address.

It is possible for an LSR to encapsulate an MPLS packet in an IP datagram so that the outer header is IP header to another LSR.
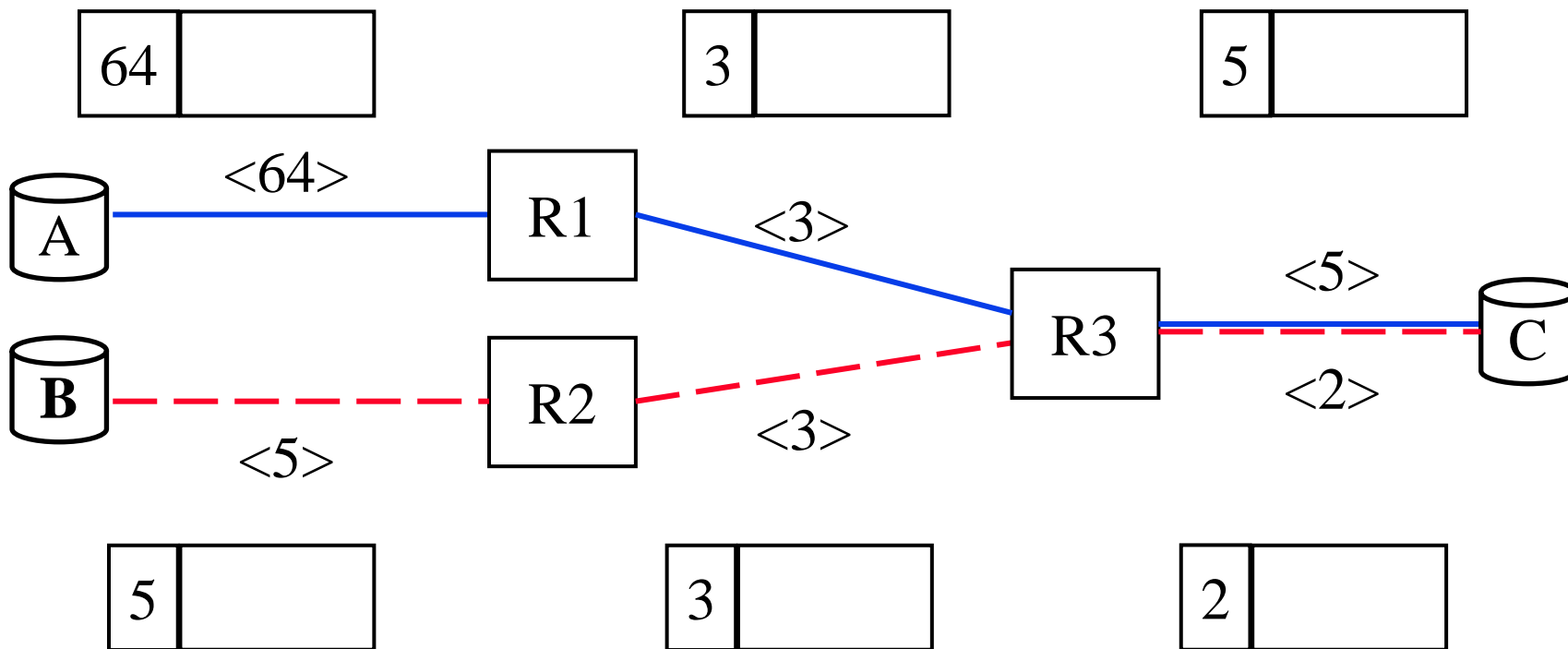
Label Switching Example

Ethernet Header	IP Header	Payload

Ethernet Header	Label	IP Header	Payload
L2	L2.5	L3	

MPLS Concepts

- **Forwarding Equivalence Class (FEC)**: All packets with the same top label

- **Label Switched Path (LSP)**: End-to-end path from label push to label pop

- **Label Edge Router (LER)**: Routers that push labels at the beginning of LSP and pop at the end

- **Label Switch Router (LSR)**: Core routers that forward using the label

- **Label Forwarding Information Base (LFIB)**: Forwarding table created using routing protocols, e.g., OSPF, BGP

- **Label Distribution Protocol (LDP)**: Protocol to discover other MPLS routers and set up LSPs.

- **Resource ReSerVation Protocol with Traffic Engineering (RSVP-TE)**: OSPF and BGP are also alternatives.
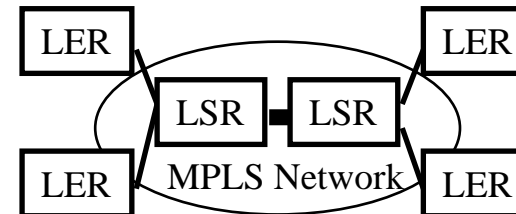
Student Questions

Label Stacks

□ Labels are pushed/popped
as they enter/leave MPLS domain

□ Routers in the interior will use Interior Gateway Protocol (IGP) labels. Border gateway protocol (BGP) labels outside.

□ Bottom label may indicate protocol (0=IPv4, 2=IPv6)
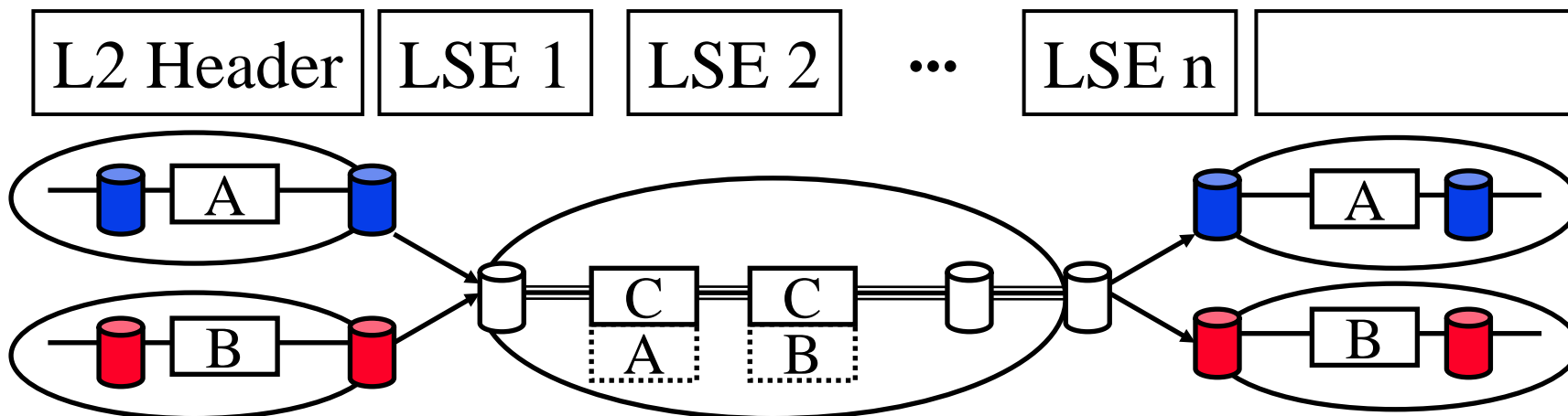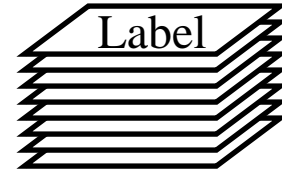
L2 Header	LSE 1	LSE 2	...	LSE n	

MPLS Label Stacking

❑ Label stacking allows:
  ➢ Multiple levels of carriers.
  ➢ Multiple VPNs in a single LSP
  ➢ Multiple types of traffic in a single LSP
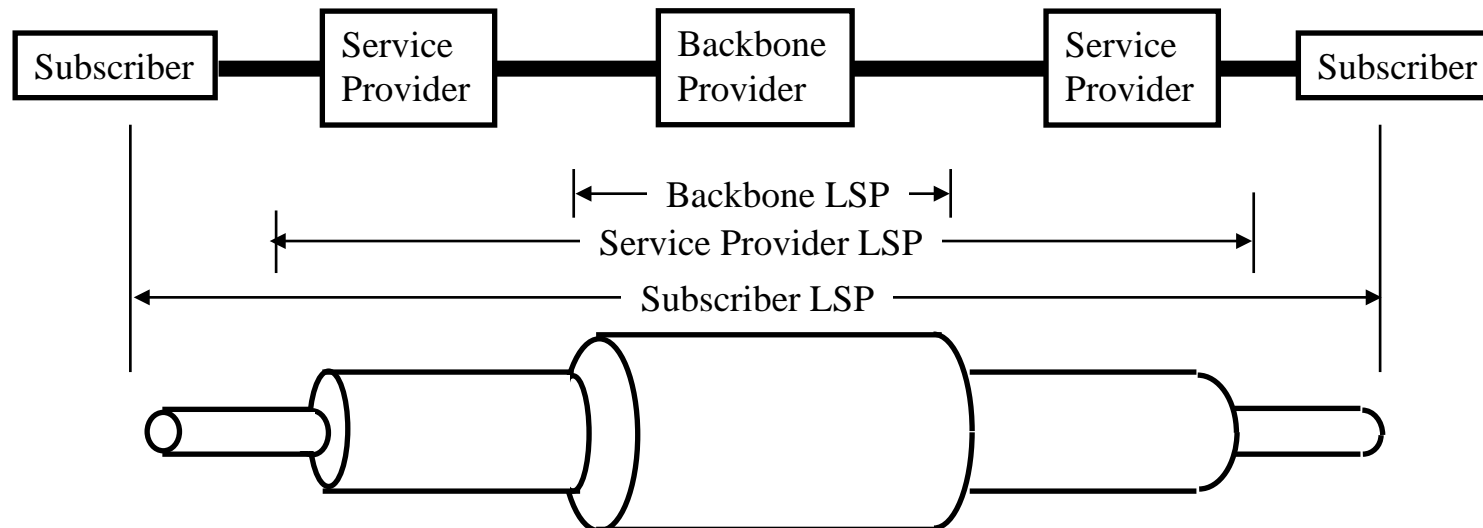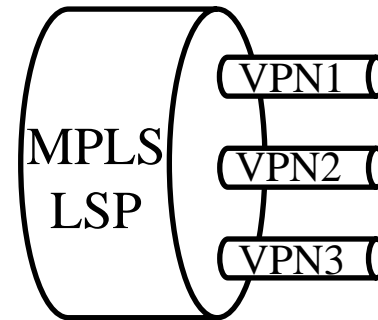
Student Questions

MPLS Traffic Engineering

❑ MPLS paths can be provisioned to follow a specific path (no need to use shortest path)

❑ Resources on the path can be reserved

❑ Multiple parallel LSPs can be established between the same pair of nodes

❑ Fault recovery via shifting traffic to standby LSPs

Student Questions

IP over MPLS over Ethernet

⇒

CE	—	PE	Carrier Network	PE	—	CE

PE= Provider Edge
CE = Customer Edge

Dest. Adr Next Hop	Src. Adr	Type /Len	MPLS Tag	Customer Src. IP Adr	Customer Dest. IP Adr	Rest of IP Datagram	Ethernet CRC
48b	48b	16b	32b	32b	32b		32b

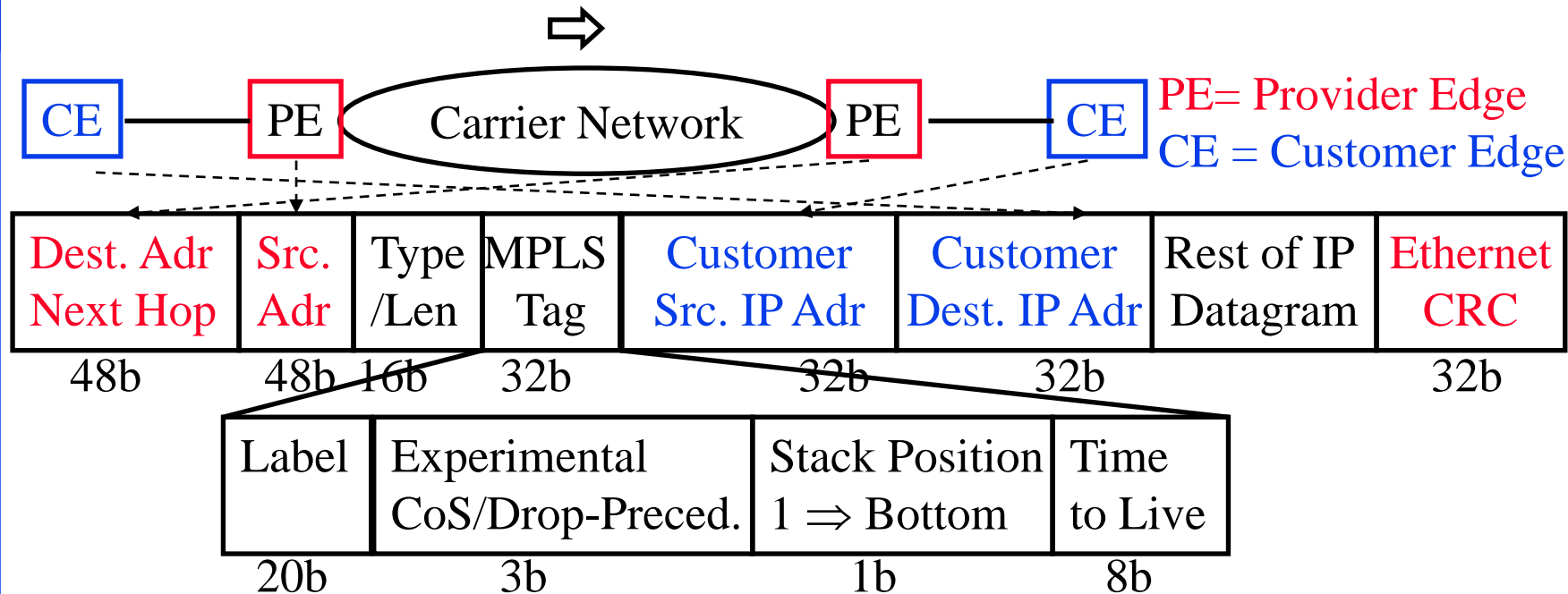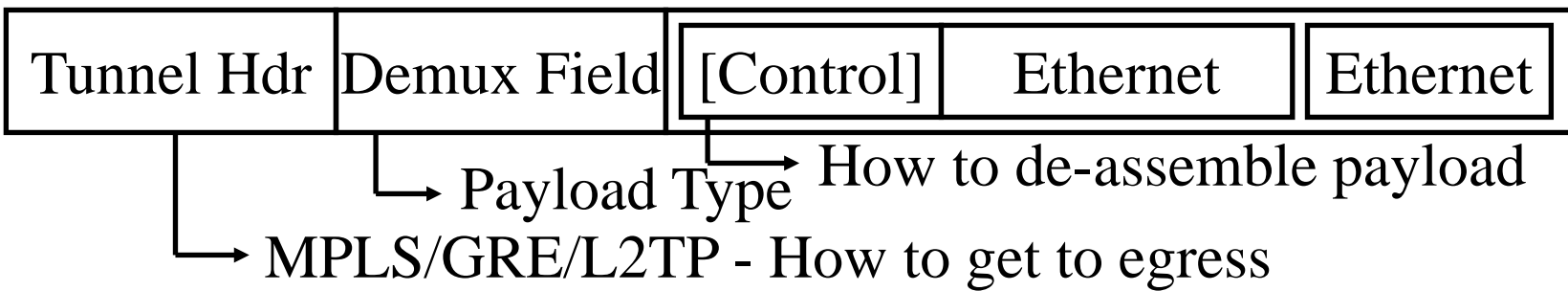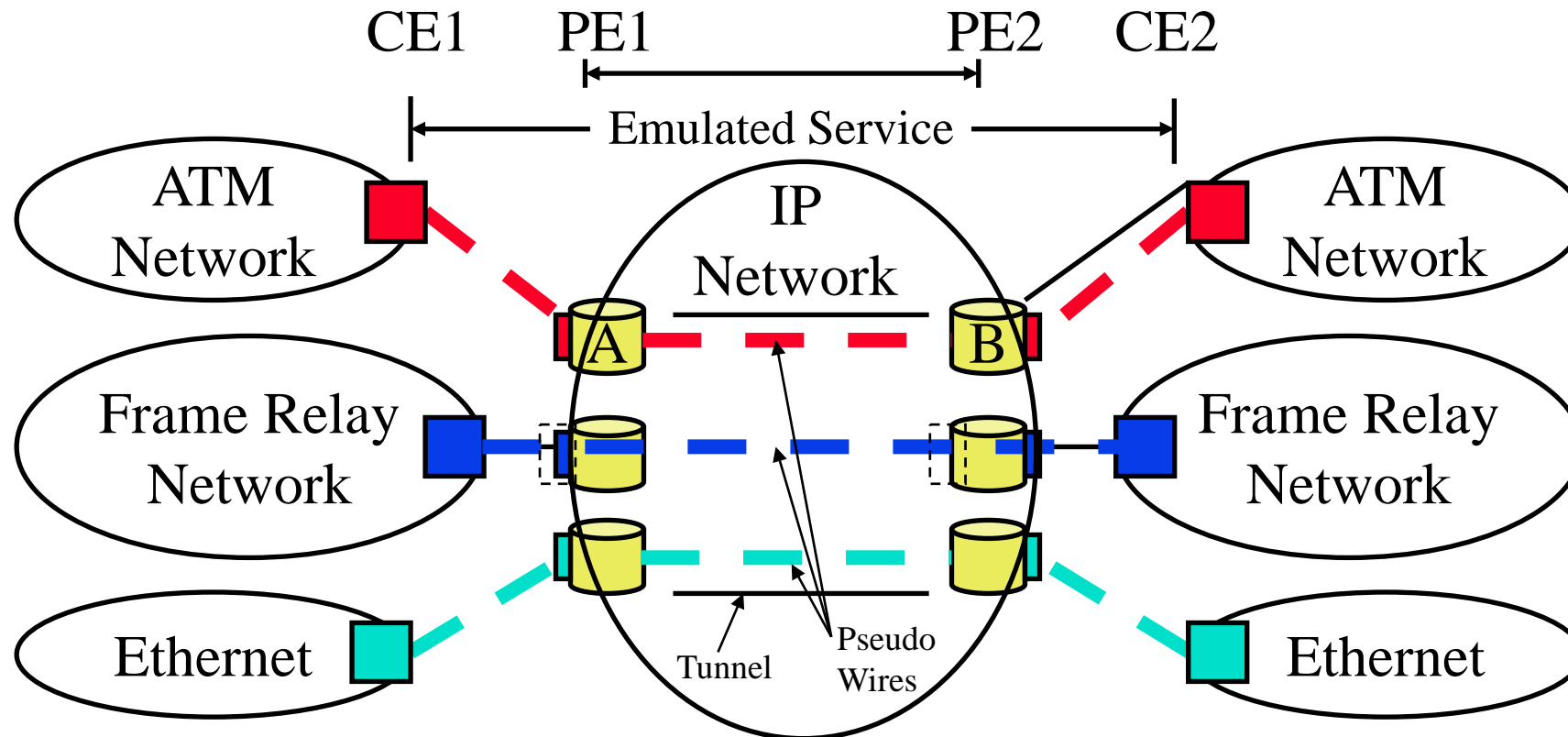| Label	Experimental CoS/Drop-Preced.	Stack Position 1 ⇒ Bottom	Time to Live
20b	3b	1b	8b

- ❑ Allows 2^{20} Label switched paths (LSP)
- ❑ Each path can have reserved capacity ⇒ Guaranteed **QoS**
- ❑ Explicit paths can be designed for specific traffic going to the same destination ⇒ **Traffic Engineering**
- ❑ Alternate paths used if anything on the primary path fails ⇒ **Fast Reroute** ⇒ MPLS became a very popular

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Student Questions

- ❑ Why is Ethernet CRC added as the trailer rather than in the header?
HW knows CRC only when the entire packet is through. If you put it in the header, you have to hold the packet in the memory.
- ❑ We can't really stack the labels, so do they get placed in front of the old label when they're 'stacked'?
New label is placed in front of the old label.
- ❑ How MPLS route is determined?
By connection setup.
- ❑ Can a normal router can interpret MPLS label?
No.
- ❑ Is this PE same as LER mentioned in Slide 7?
PE=Provider Edge. It can be Ethernet, MPLS, or IP. For MPLS domains, PE=LER.
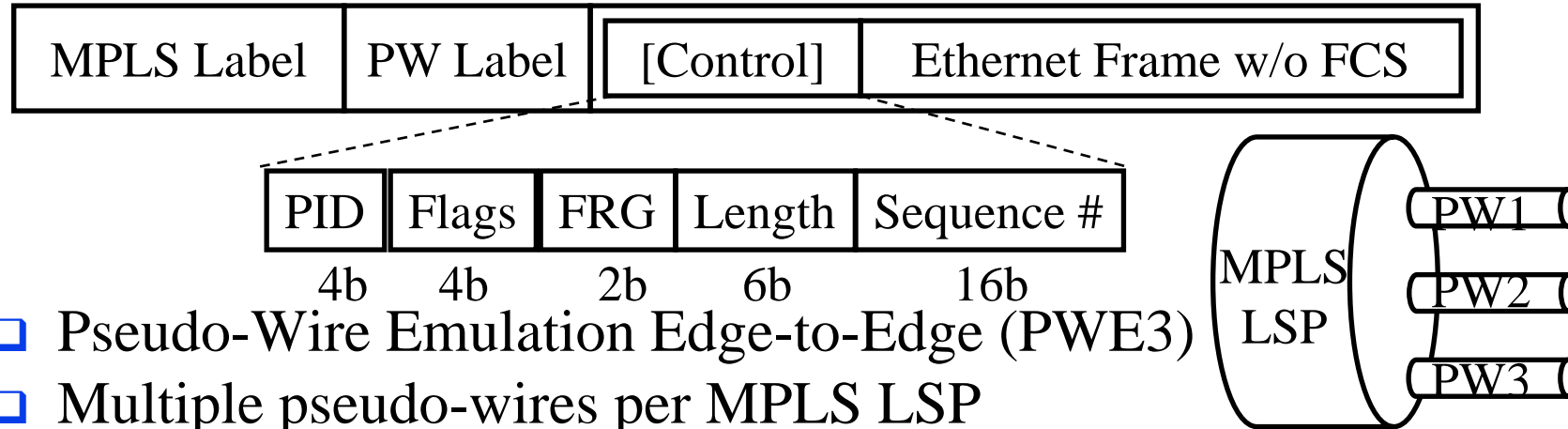
Pseudo Wire: L2 Circuits over IP

CE1   PE1   PE2   CE2

Emulated Service

IP Network

ATM Network

Frame Relay Network

Ethernet

ATM Network

Frame Relay Network

Ethernet

A   B

Tunnel

Pseudo Wires

Tunnel Hdr	Demux Field	[Control]	Ethernet	Ethernet

Payload Type

How to de-assemble payload

MPLS/GRE/L2TP - How to get to egress

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Student Questions

❑ So IP can understand MPLS without any destination or source addresses? Does IP not need look at any of this information when it sees MPLS since it will perform switching?

IP is a protocol. MPLS is another protocol. Protocol=Language. Only devices designed to understand a protocol can process it.

❑ So in the L2 Circuits over IP model, the customer edge routers do not care about IP address at all? It is up to the tunnel (e.g. MPLS) that establishes a pseudo-link in a IP network to figure out how to do forwarding over routers in the IP network to reach the destination?

LERs translate IP addresses to Labels with full IP packets inside.

❑ So many pseudo wires relay on one real channel?

Yes, pseudo=Virtual. Real=Physical.

Ethernet over PWE3 over MPLS

MPLS Label	PW Label	[Control]	Ethernet Frame w/o FCS

PID	Flags	FRG	Length	Sequence #
4b	4b	2b	6b	16b

MPLS LSP

PW1
PW2
PW3

- ❑ Pseudo-Wire Emulation Edge-to-Edge (PWE3)
- ❑ Multiple pseudo-wires per MPLS LSP
  ⇒ Core routers use outer "*path*" label and not inner "*VC*" label
- ❑ PW (VC) label format is same as MPLS label with End-of-Stack=1 and TTL=1. PW label is inserted/removed at the edge.
- ❑ Payload ID (PID): 5=Untagged Ethernet, 4=VLAN tagged, …
- ❑ 4⇒VLAN tag put by carrier and customers may or may not be relevant for forwarding. Determined administratively by PE.
- ❑ Flags: Payload specific. FRG: Used for fragmentation
- ❑ Pause frames are obeyed locally. Not transported.

Student Questions
- ❑ What is the meaning of LSP in MPLS protocol?

Label Switched Path is the "route" followed by the MPLS packets on that LSP.
- ❑ Why is the Ethernet w/o FCS?

MPLS will be sent over some L2 channel that will protect the packet. At the destination, a new Ethernet header will be needed and CRC computed.
- ❑ What's the different between MPLS over Ethernet and Ethernet over MPLS in terms of designs and applications?

MPLS over Ethernet:
⇒ Outer header = Ethernet
Ethernet over MPLS:
⇒ Outer header is MPLS

Chinese over English

漢字
汉字

To: Jain
Hotel X

Summary
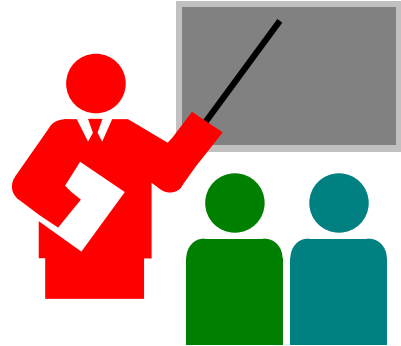
Student Questions

1. SONET, SDH, and PDH networks were designed for voice traffic

2. MPLS is used carriers to provide reliability and throughput guarantees similar to their previous networks

3. MPLS-TP is designed with OAM required for carriers

Reading List

❑ Karthik Ramasamy, Deep Medhi, "Network Routing," 2nd Edition, Morgan Kaufmann, September 2017, ISBN: 9780128008294 (Safari Book), Chapter 22: MPLS.

Student Questions

References

❑ Krzysztof Grzegorz Szarkowicz, Antonio Sanchez Monge, "MPLS in the SDN Era," O'Reilly Media, Inc., December 2015, 920 pp., ISBN:978-1-4919-0545-6 (Safari Book).

Student Questions

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Wikipedia Links

- http://en.wikipedia.org/wiki/Label-switched_path
- http://en.wikipedia.org/wiki/Link_protection
- http://en.wikipedia.org/wiki/MPLS-TP
- http://en.wikipedia.org/wiki/Multiprotocol_Label_Switching
- http://en.wikipedia.org/wiki/Operations,_administration_and_management
- http://en.wikipedia.org/wiki/Optical_Carrier_transmission_rates
- http://en.wikipedia.org/wiki/Optical_Transport_Network
- http://en.wikipedia.org/wiki/Path_protection
- http://en.wikipedia.org/wiki/Plesiochronous_digital_hierarchy
- http://en.wikipedia.org/wiki/Provider_Backbone_Bridge_Traffic_Engineering
- http://en.wikipedia.org/wiki/Pseudo-wire
- http://en.wikipedia.org/wiki/Synchronous_optical_networking
- http://en.wikipedia.org/wiki/Traffic_policing

Student Questions

Acronyms

- ANSI   American National Standards Institute
- BGP   Border Gateway Protocol
- CE   Customer Edge
- FCS   Frame Check Sequence
- FEC   Frame Equivalence Class
- FRG   Fragment Bit
- GMPLS   Generalized Multi-Protocol Label Switching
- GRE   Generic Routing Encapsulation
- ID   Identifier
- IGP   Interior Gateway Protocol
- IP   Internet Protocols
- ITU   International Telecommunications Union
- LDP   Label Distribution Protocol
- LER   Label Edge Router

Student Questions

Acronyms (Cont)

- LFIB   Label Forwarding Information Base
- LSE   Label Stack Entry
- LSP   Label Switched Paths
- LSR   Label Switching Router
- MPLS   Multi-Protocol Label Switching
- OAM   Operation, Administration and Maintenance
- OC   Optical Carrier
- OSPF   Open Shortest Path First
- PDH   Plesiochronous Digital Hierarchy
- PE   Provider Edge
- PID   Protocol ID
- PW   Pseudo-Wire
- PWE3   Pseudo-Wire Emulation Edge-to-Edge

Student Questions

Acronyms (Cont)

- QoS   Quality of Service
- SDH   Synchronous Digital Hierarchy
- SDN   Software Defined Networking
- SONET   Synchronous optical network
- TE   Traffic Engineering
- TP   Transport Profile
- TTL   Time to Live
- VC   Virtual Circuit
- VLAN   Virtual Local Area Network
- VPN   Virtual Private Network

Student Questions

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Student Questions

❑ Does SD-WAN replace MPLS?

SD-WAN = Software Defined Wide Area Network
No, we can discuss this after SDN (software defined network) module.

Related Modules

CSE567M: Computer Systems Analysis (Spring 2013),

https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),

https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw

Wireless and Mobile Networking (Spring 2016),

https://www.youtube.com/playlist?list=PLjGG94etKypKeb0nzyN9tSs_HCd5c4wXF

CSE571S: Network Security (Fall 2011),

https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u

Video Podcasts of Prof. Raj Jain's Lectures,

https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw

Student Questions

Video Quiz Part 1

- Part 1: 36 minutes
- 15 Min Slide 5
- Slide 4: OC3 is 100 Mbps
- False
- 27 Min Slide 10
- Slide 7: A LER pushes a label on the stack or pops it
- True
- Part 2: 24 min
- Slide 12
- Slide 11: MPLS allows packets going to the same destination take different paths
- True
- Slide 13: An MPLS circuit is able to carry only one pseudo wire
- False

Student Questions