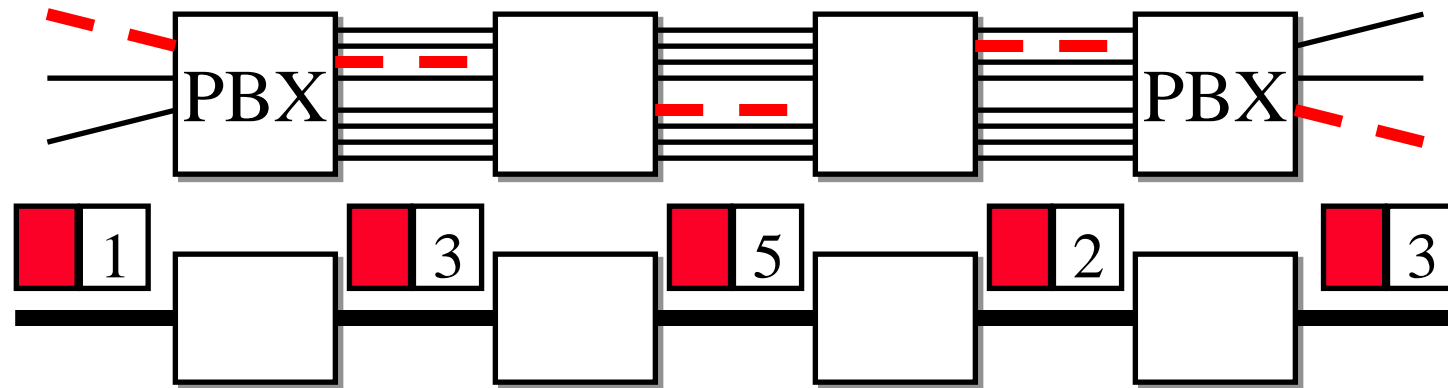


# Carrier IP Networks: MPLS



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These slides and audio/video recordings of this class lecture are at:

<http://www.cse.wustl.edu/~jain/cse570-23/>

Student Questions



1. Plesiochronous Digital Hierarchy
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

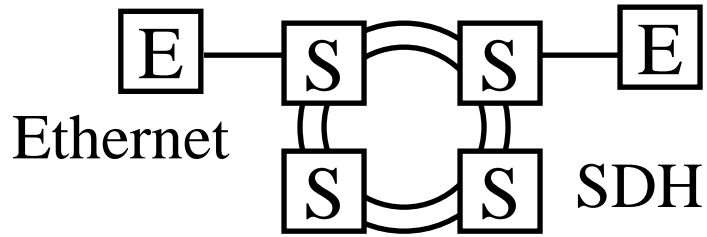


T1



## Student Questions

# SONET/SDH

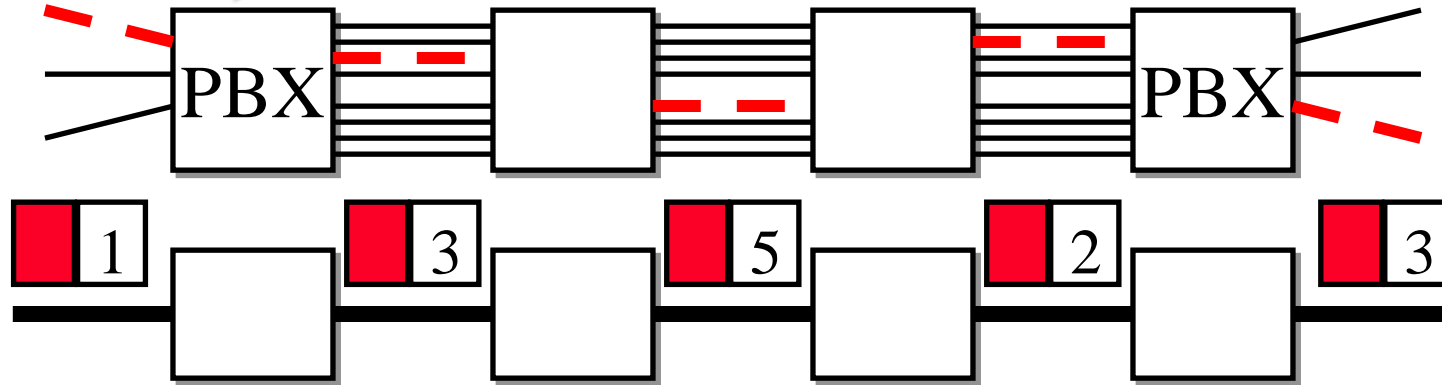


- ❑ SONET=Synchronous optical network
- ❑ Standard for digital optical transmission
- ❑ Standardized by ANSI and then by ITU  
⇒ Synchronous Digital Hierarchy (SDH)
- ❑ Protection: Allows redundant Lines or paths
- ❑ Fast Restoration: 50ms using rings
- ❑ Sophisticated management
- ❑ Ideal for Voice: 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

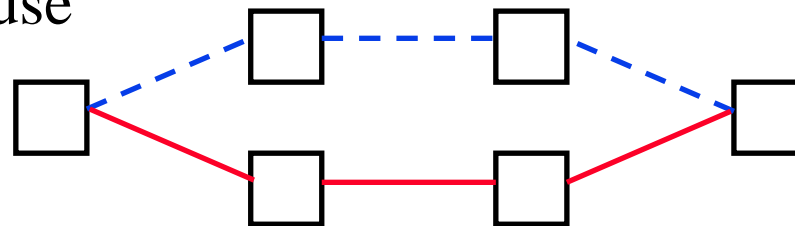
## Student Questions

- ❑ Is there any bad influence when PDH uses 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)
- ❑ LSPs have to be set up before use
- ❑ Allows traffic engineering



## Student Questions

- ❑ What is the advantage of MPLS compare to previous method?

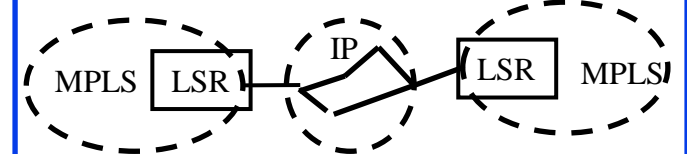
*MPLS allows "Traffic Engineering," fixed paths and reservations.*

- ❑ 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 an IP header to another LSR.*



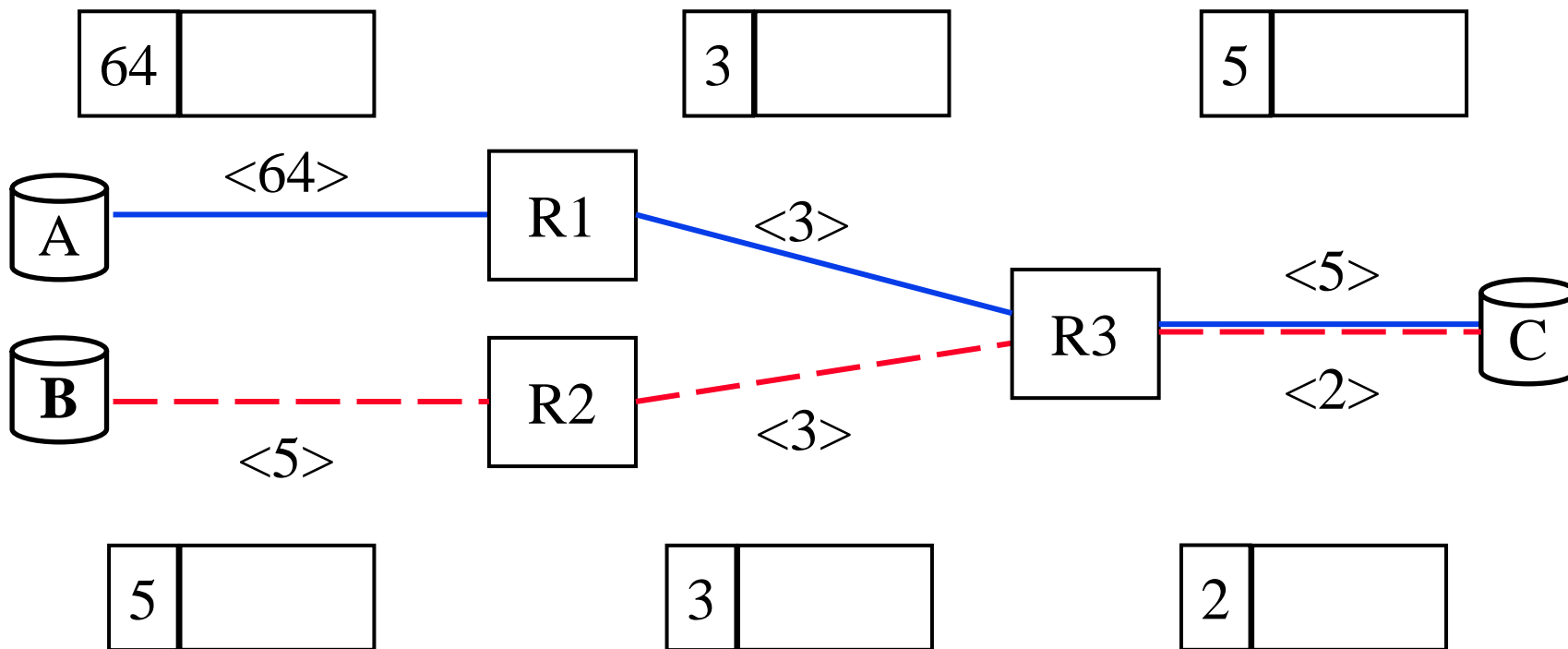
# Label Switching Example



L2

L2.5

L3



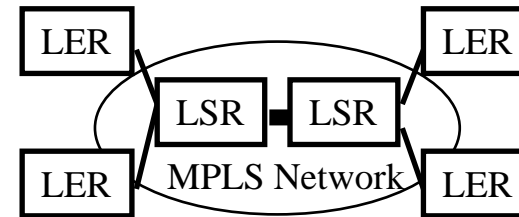
## Student Questions

- What does the label mean to the router, and which port to take? How does the packet know this ahead of time?

*A label is straight indexed into the routing table. It has to be set up before sending any packets on that LSP.*

# MPLS Concepts

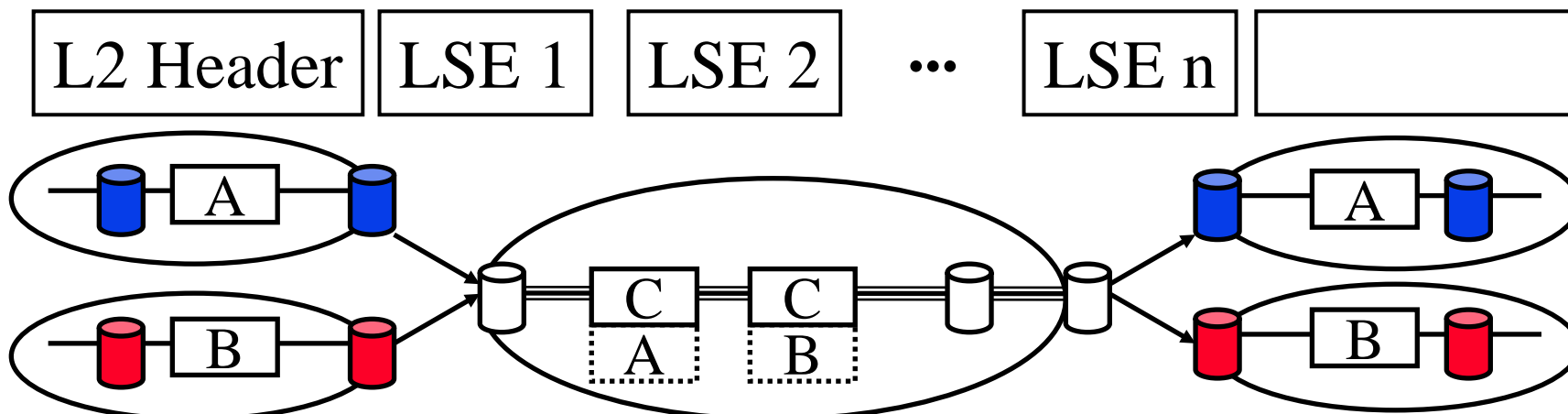
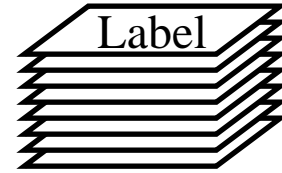
- ❑ **Forwarding Equivalence Class (FEC):** All packets with the same top label
- ❑ **Label Switched Path (LSP):** End-to-end path from label push to label pop
- ❑ **Label Edge Router (LER):** Routers that push labels at the beginning of LSP and pop at the end
- ❑ **Label Switch Router (LSR):** Core 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):** To discover other MPLS routers and set up LSPs.
- ❑ **Resource ReSerVation Protocol with Traffic Engineering (RSVP-TE):** OSPF and BGP are alternatives.



## Student Questions

# Label Stacks

- ❑ Labels are pushed/popped as they enter/leave the MPLS domain
- ❑ Routers in the interior will use Interior Gateway Protocol (IGP) labels. Border gateway protocol (BGP) labels outside.
- ❑ The bottom label may indicate protocol (0=IPv4, 2=IPv6)



## Student Questions

- ❑ What are the maximum times that the label stack can be used? I know it can change the label every time, but is there any limit for the label stack?

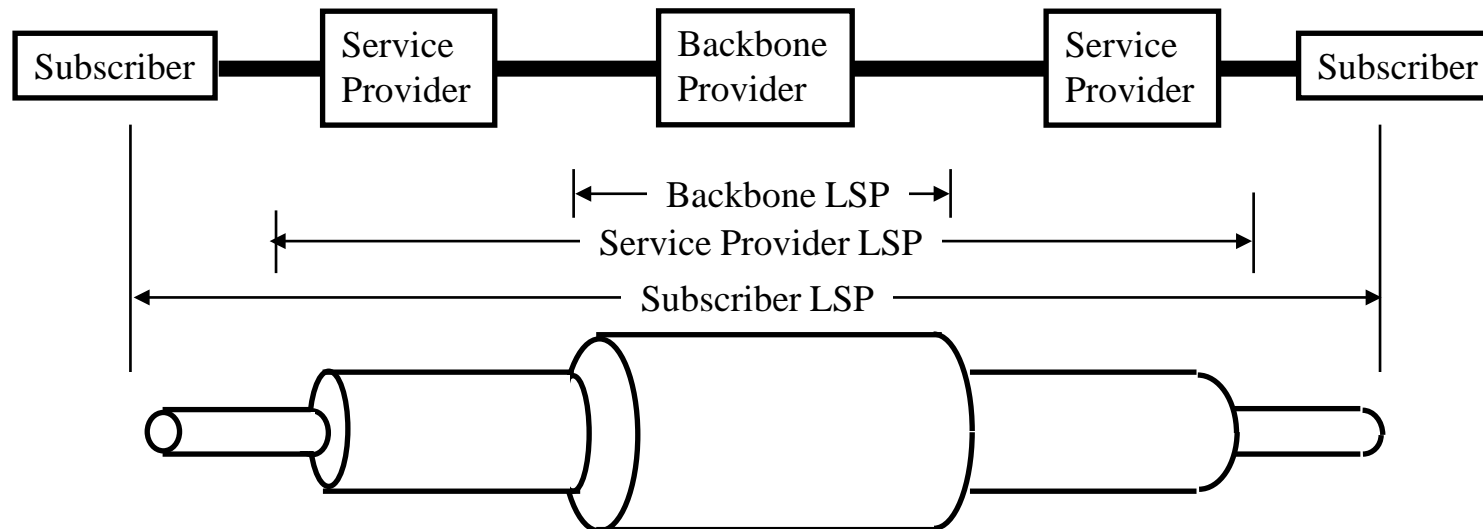
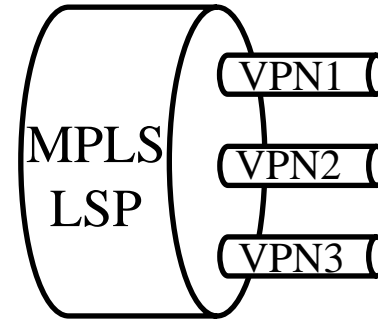
*There is no limit.*



# MPLS Label Stacking

Label stacking allows:

- Multiple levels of carriers.
- Multiple VPNs in a single LSP
- Multiple types of traffic in a single LSP



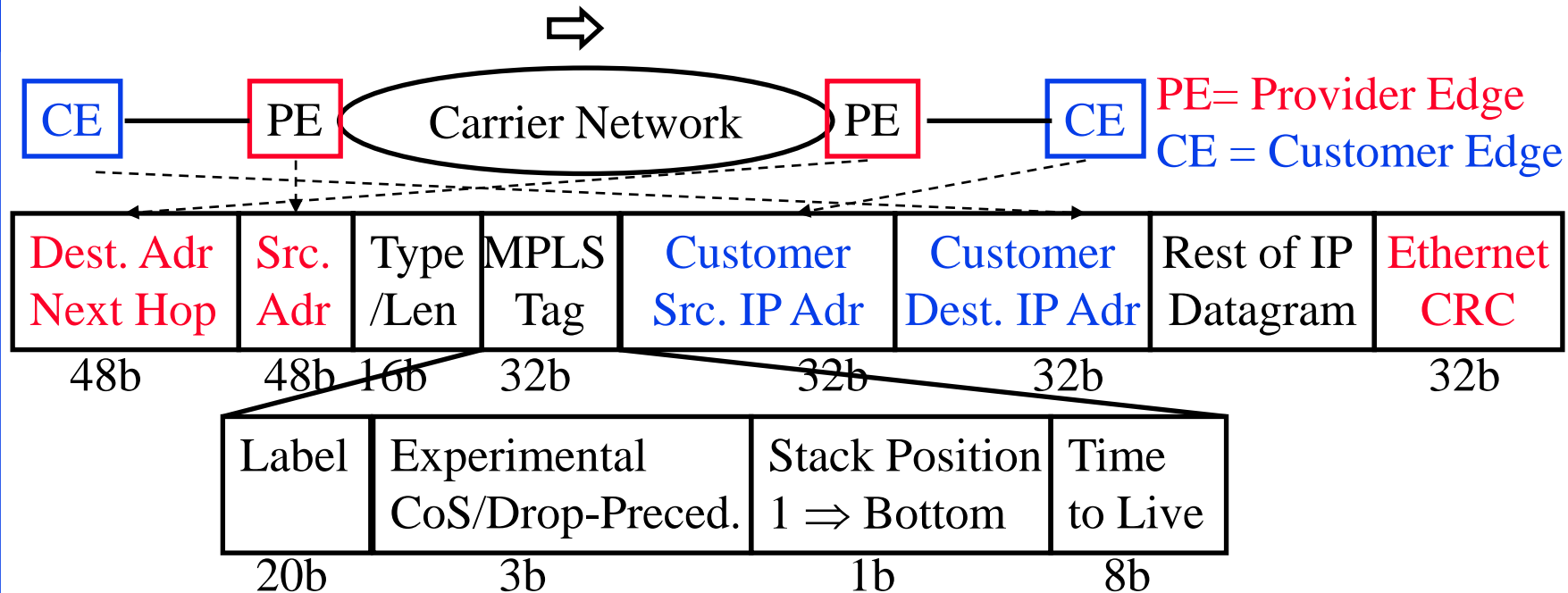
## Student Questions

# MPLS Traffic Engineering

- ❑ MPLS paths can be provisioned to follow a specific path (no need to use the 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

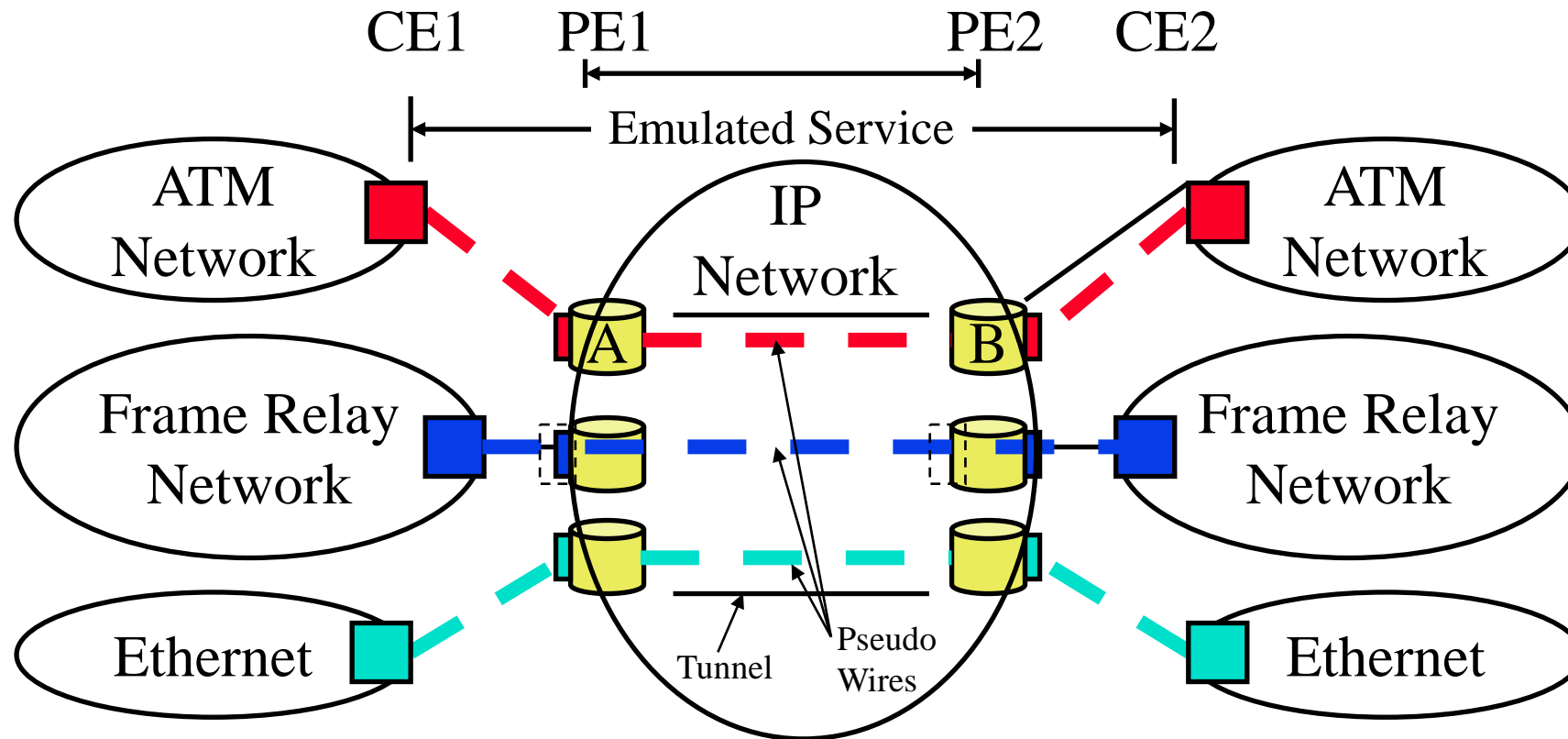


- ❑ Allows  $2^{20}$  Label switched paths (LSP)
- ❑ Each path can have reserved capacity  $\Rightarrow$  Guaranteed **QoS**
- ❑ Explicit paths can be designed for specific traffic going to the same destination  $\Rightarrow$  **Traffic Engineering**
- ❑ Alternate paths are used if anything on the primary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

## 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 must hold the packet in the memory.*
- ❑ We can't stack the labels, so do they get placed in front of the old label when they're 'stacked'?  
*The new label is placed in front of the old label.*
- ❑ How is the MPLS route determined?  
*By connection setup.*
- ❑ Can a normal router interpret the MPLS label?  
*No.*
- ❑ Is this PE the 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



→ Payload Type → How to de-assemble payload  
 → MPLS/GRE/L2TP - How to get to egress

## Student Questions

- ❑ So can IP understand MPLS without any destination or source addresses? Does IP not need to 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.*

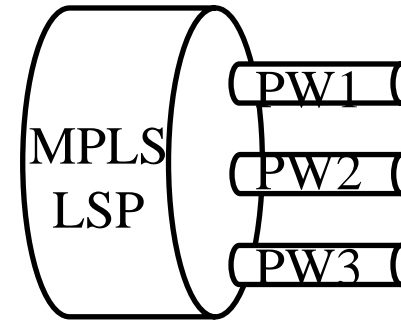
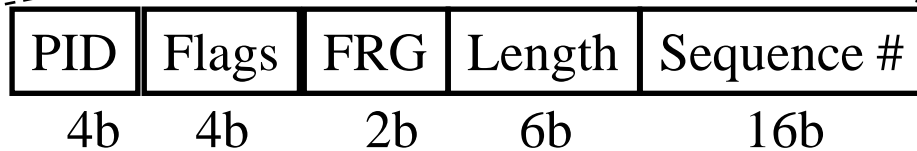
- ❑ So in the L2 Circuits over IP model, the customer edge routers do not care about IP address at all? It is up to the tunnel (e.g., MPLS) that establishes a pseudo-link in an IP network to figure out how to do forwarding over routers in the IP network to reach the destination.

*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



- ❑ Pseudo-Wire Emulation Edge-to-Edge (PWE3)
- ❑ Multiple pseudo-wires per MPLS LSP  
⇒ Core routers use the outer “*path*” label and not the inner “*VC*” label
- ❑ PW (VC) label format is the same as the 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 tags by carriers 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. A new Ethernet header will be needed at the destination, and CRC will be computed.*
- ❑ What’s the difference between MPLS over Ethernet and Ethernet over MPLS regarding designs and applications?

*MPLS over Ethernet:*

⇒ *Outer header = Ethernet*

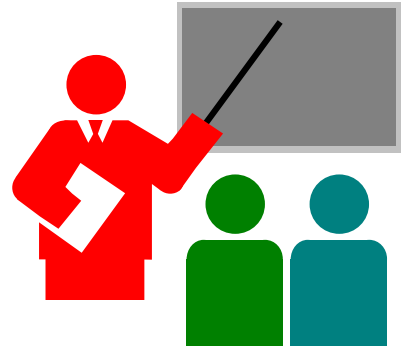
*Ethernet over MPLS:*

*The outer header is MPLS*



Chinese  
over English

# Summary



1. SONET, SDH, and PDH networks were designed for voice traffic
2. Carriers use MPLS to provide reliability and throughput guarantees similar to their previous networks
3. MPLS-TP is designed with OAM required for carriers

## Student Questions

# 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



# Wikipedia Links

- ❑ [http://en.wikipedia.org/wiki/Label-switched\\_path](http://en.wikipedia.org/wiki/Label-switched_path)
- ❑ [http://en.wikipedia.org/wiki/Link\\_protection](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/Multiprotocol_Label_Switching)
- ❑ [http://en.wikipedia.org/wiki/Operations,\\_administration\\_and\\_management](http://en.wikipedia.org/wiki/Operations,_administration_and_management)
- ❑ [http://en.wikipedia.org/wiki/Optical\\_Carrier\\_transmission\\_rates](http://en.wikipedia.org/wiki/Optical_Carrier_transmission_rates)
- ❑ [http://en.wikipedia.org/wiki/Optical\\_Transport\\_Network](http://en.wikipedia.org/wiki/Optical_Transport_Network)
- ❑ [http://en.wikipedia.org/wiki/Path\\_protection](http://en.wikipedia.org/wiki/Path_protection)
- ❑ [http://en.wikipedia.org/wiki/Plesiochronous\\_digital\\_hierarchy](http://en.wikipedia.org/wiki/Plesiochronous_digital_hierarchy)
- ❑ [http://en.wikipedia.org/wiki/Provider\\_Backbone\\_Bridge\\_Traffic\\_Engineering](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/Synchronous_optical_networking)
- ❑ [http://en.wikipedia.org/wiki/Traffic\\_policing](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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[http://www.cse.wustl.edu/~jain/cse570-23/m\\_05cip.htm](http://www.cse.wustl.edu/~jain/cse570-23/m_05cip.htm)

## Student Questions

- Does SD-WAN replace MPLS?  
*SD-WAN = Software Defined Wide Area Network*  
*We can discuss this after the SDN (software-defined network) module.*
-

# Related Modules



CSE567M: Computer Systems Analysis (Spring 2013),

[https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n\\_1X0bWWNyZcof](https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof)

CSE473S: Introduction to Computer Networks (Fall 2011),

[https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e\\_10TiDw](https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e_10TiDw)



Wireless and Mobile Networking (Spring 2016),

[https://www.youtube.com/playlist?list=PLjGG94etKypKeb0nzyN9tSs\\_HCd5c4wXF](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