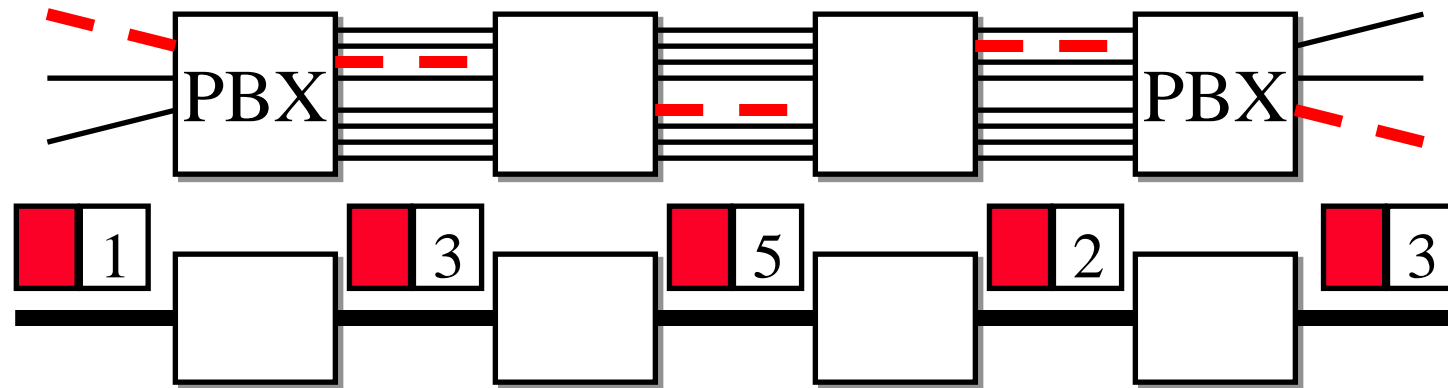


Carrier IP Networks: MPLS



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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

- ❑ Is a channel possibly having a higher bandwidth than the others? Say that in T1, a channel can use more bandwidth than the other 23 channels.

No. Channels are fixed size and static.

- ❖ Can you explain again what T1, T2, T3 is? what is the difference from E1, E2, E3?

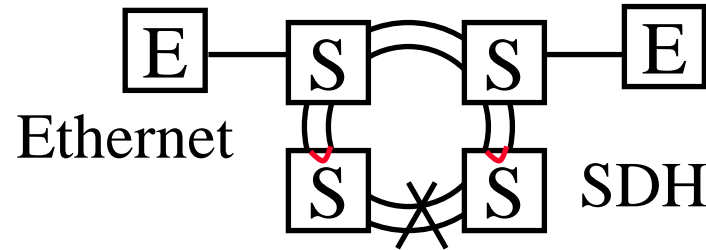
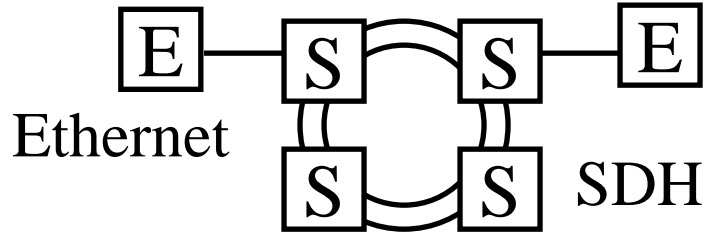
USA+Canada+Mexico:

T1=1.544 Mbps Link

T2=45 Mbps Link = 24x1.544 Mbps link

European System: E1

SONET/SDH

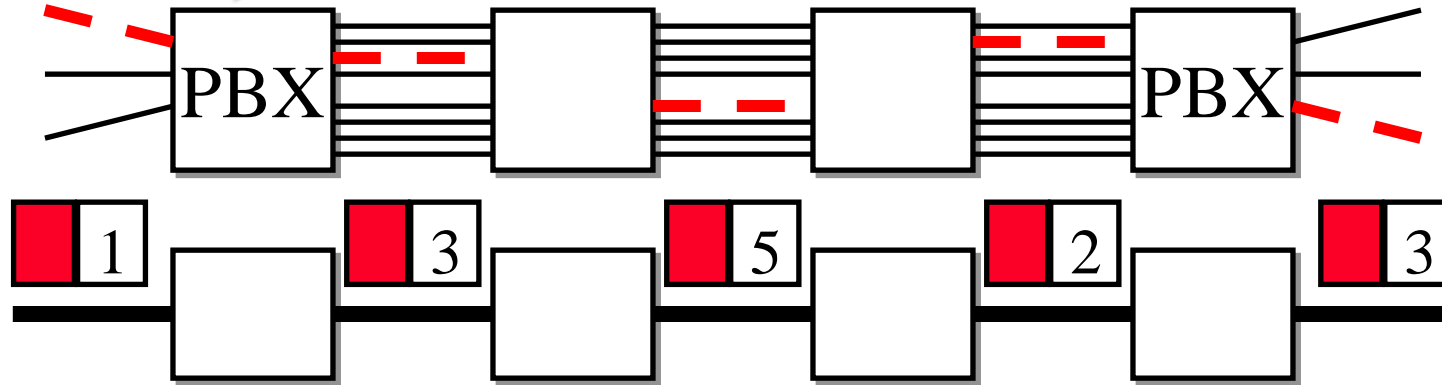


- ❑ SONET=Synchronous optical network
- ❑ Standard for digital optical transmission
- ❑ Standardized by ANSI and then by ITU
⇒ Synchronous Digital Hierarchy (SDH)
- ❑ Protection: Allows redundant Lines or paths
- ❑ Fast Restoration: 50ms using rings
- ❑ Sophisticated management
- ❑ Ideal for Voice: No 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

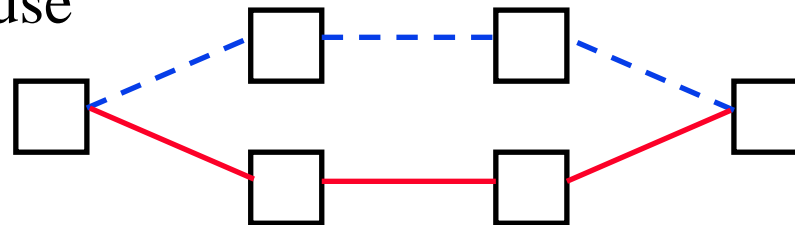
Student Questions

- ❑ Is there any bad influence when PDH uses extensive software?
When operating at high speed, hardware is faster and cheaper than software.
- ❑ Could you please draw again for the protection example?
See the picture on the right.
- ❖ Where in the fiber optic network would the SONET topology be used, like within the data centers or in global backbone connections?
Was quite common in city-wide carrier networks.

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?

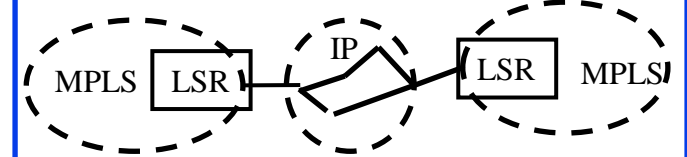
MPLS allows "Traffic Engineering," fixed paths and reservations.

- ❑ 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?

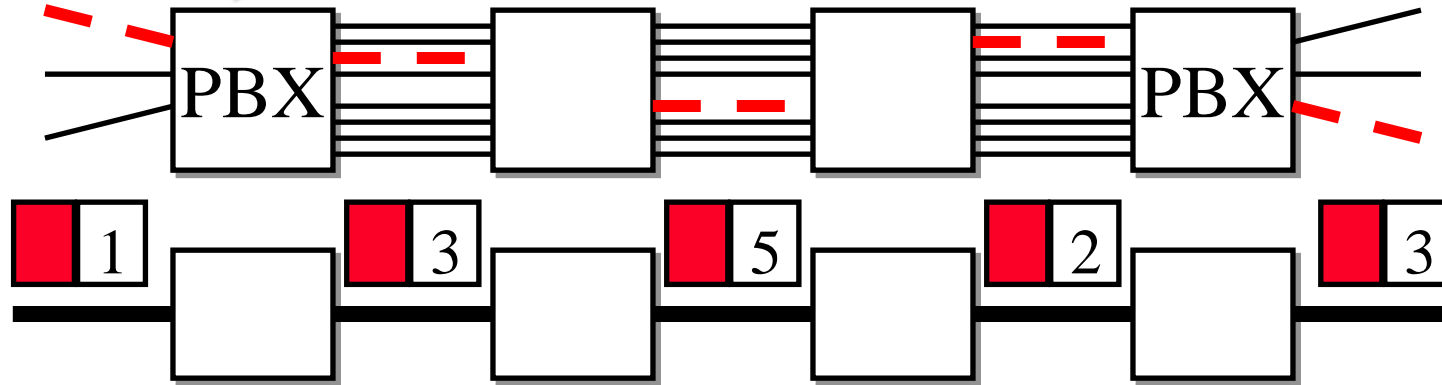
It is possible for an LSR to encapsulate an MPLS packet in an IP datagram so that the outer header is an IP header to another LSR.



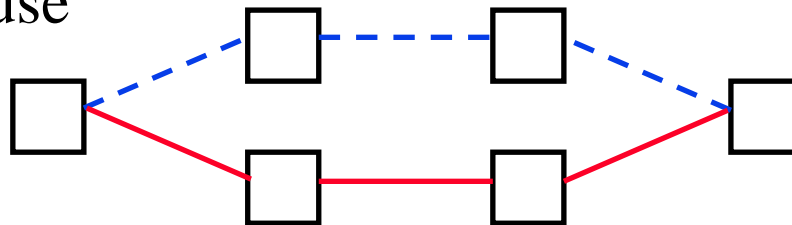
- ❑ Do virtual circuits in MPLS require setting up the circuit path before communicating?

Yes.

Multiprotocol Label Switching (MPLS)



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Student Questions

- ❑ Can packets from the same source take different LSPs? Can LSPs change over time on the same network?

You can set up two LSPs between the source and destination. If a link breaks, the LSP will be reset over a different path.

- ❖ Could you define traffic engineering?

Deciding how and where to direct various traffic classes.

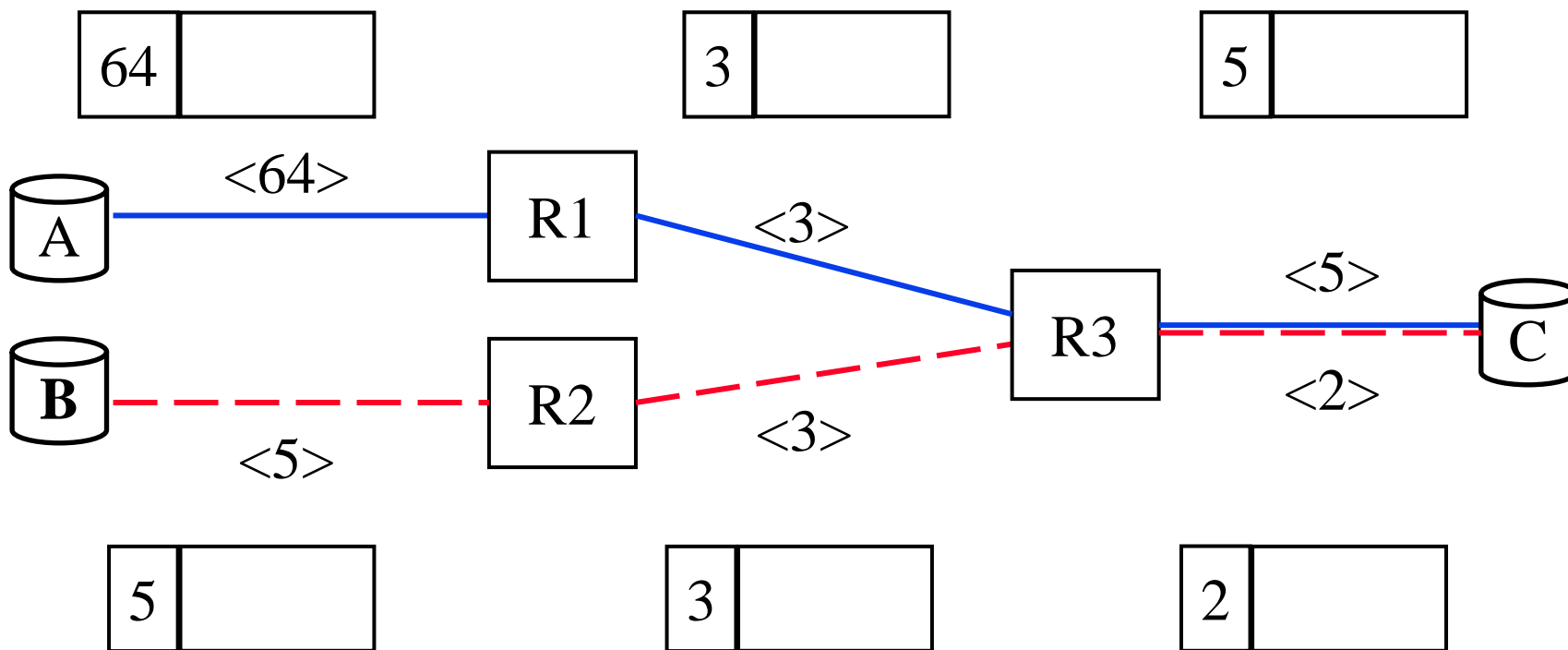
Label Switching Example



L2

L2.5

L3



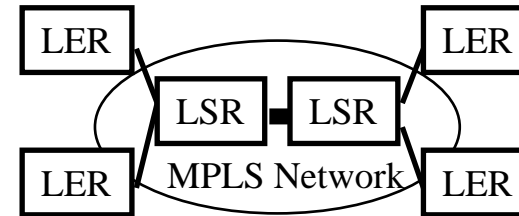
Student Questions

- 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.



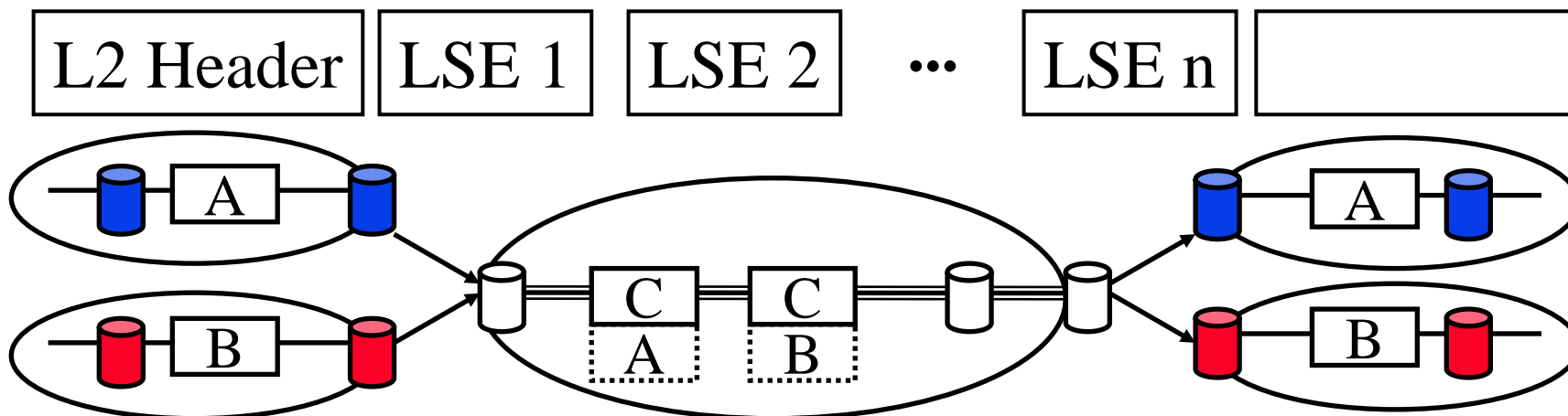
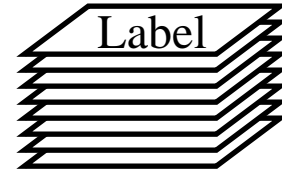
Student Questions

- ❑ Do LERs get to decide which LSP a packet takes?

Yes.

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.

- ❑ Are stacks here can be regarded as a kind of tunneling?

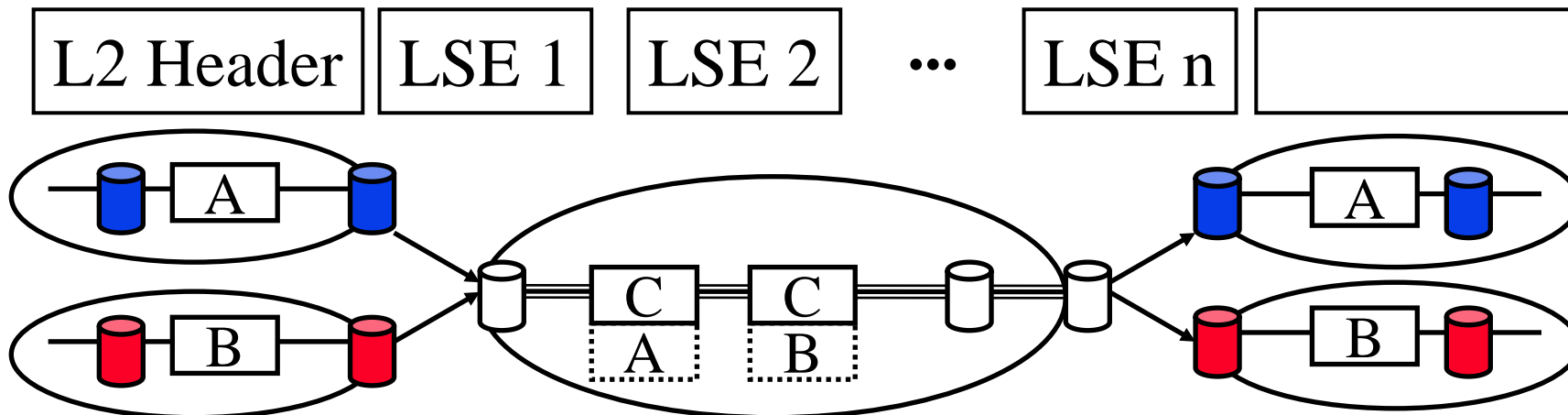
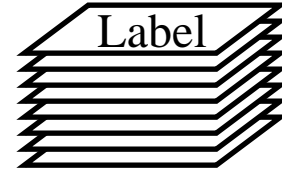
Yes.

- ❑ Does a packet have no more labels after it has left the MPLS network and all its labels are popped?

- ❑ *Yes.*

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.
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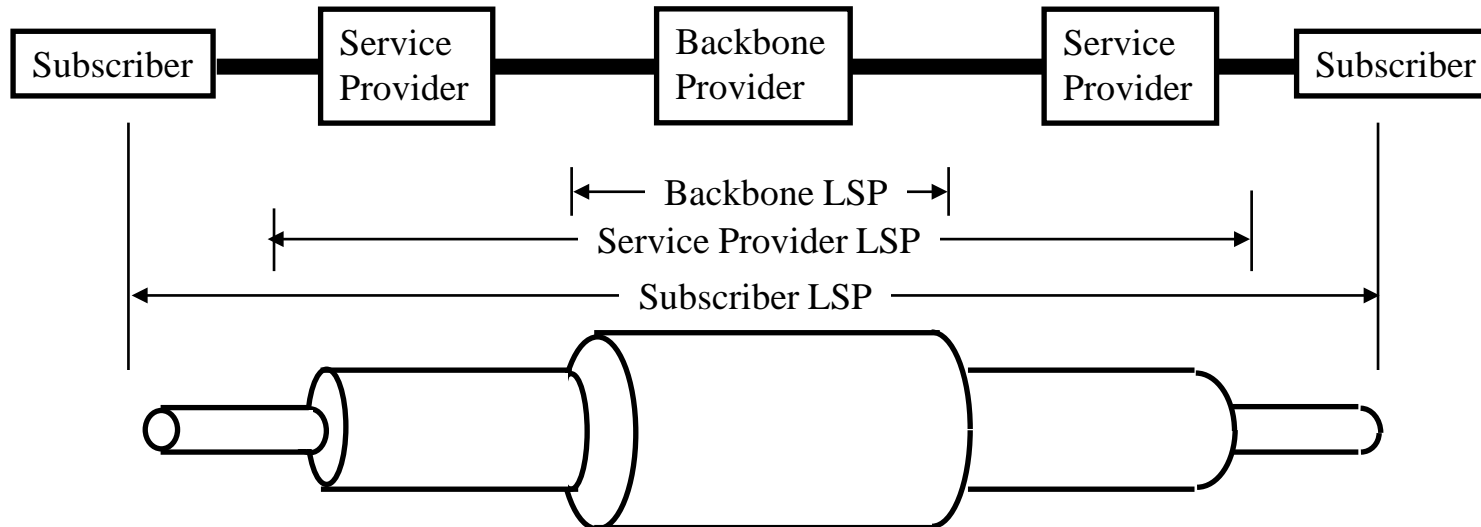
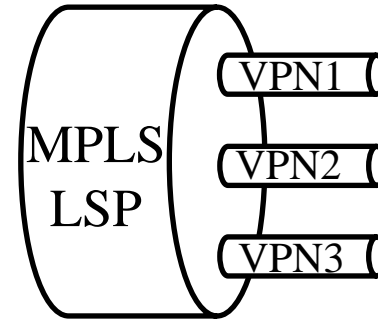
Student Questions

- ❑ If one label is missing, the transmission cannot hold.
Why would the label be missing? Of course, if the packet is corrupted, it will be detected and discarded.
- ❖ There is no limit to the number of labels that can be pushed onto the packet's stack. Is this because the LER maintains a memory of the previous label? And if so, how does the exiting LER know the former label?
The label is stored in the stack. Exit LERs pop the label on the top of the stack.

MPLS Label Stacking

Label stacking allows:

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



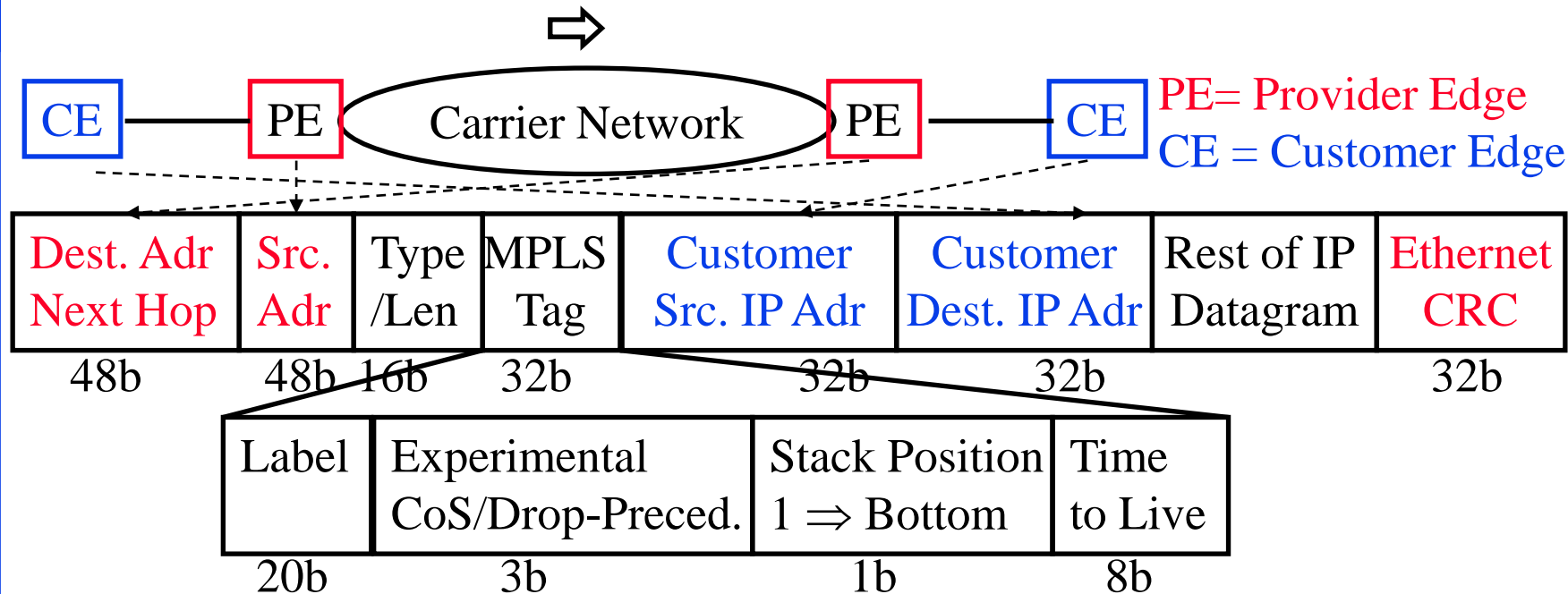
Student Questions

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

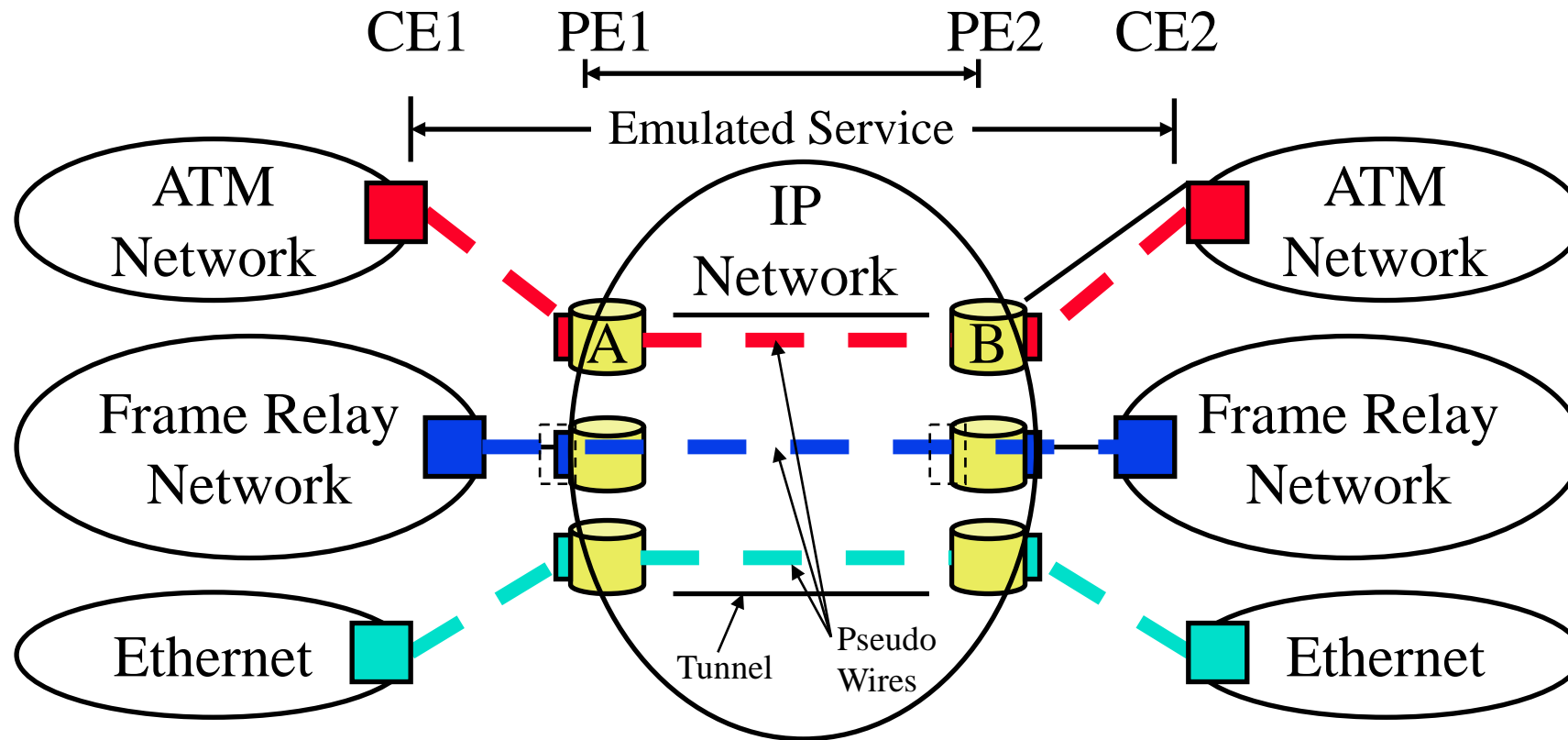


- ❑ Allows 2^{20} Label switched paths (LSP)
- ❑ Each path can have reserved capacity \Rightarrow Guaranteed **QoS**
- ❑ Explicit paths can be designed for specific traffic going to the same destination \Rightarrow **Traffic Engineering**
- ❑ Alternate paths are used if anything on the primary path fails \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 PE the same as LER mentioned in Slide 7?
PE=Provider Edge. It can be Ethernet, MPLS, or IP for MPLS domains, PE=LER.
- ❑ Is there any benefit in determining the actual position of a label in the stack (i.e., how many are below)?
Generally, the carrier knows.

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.

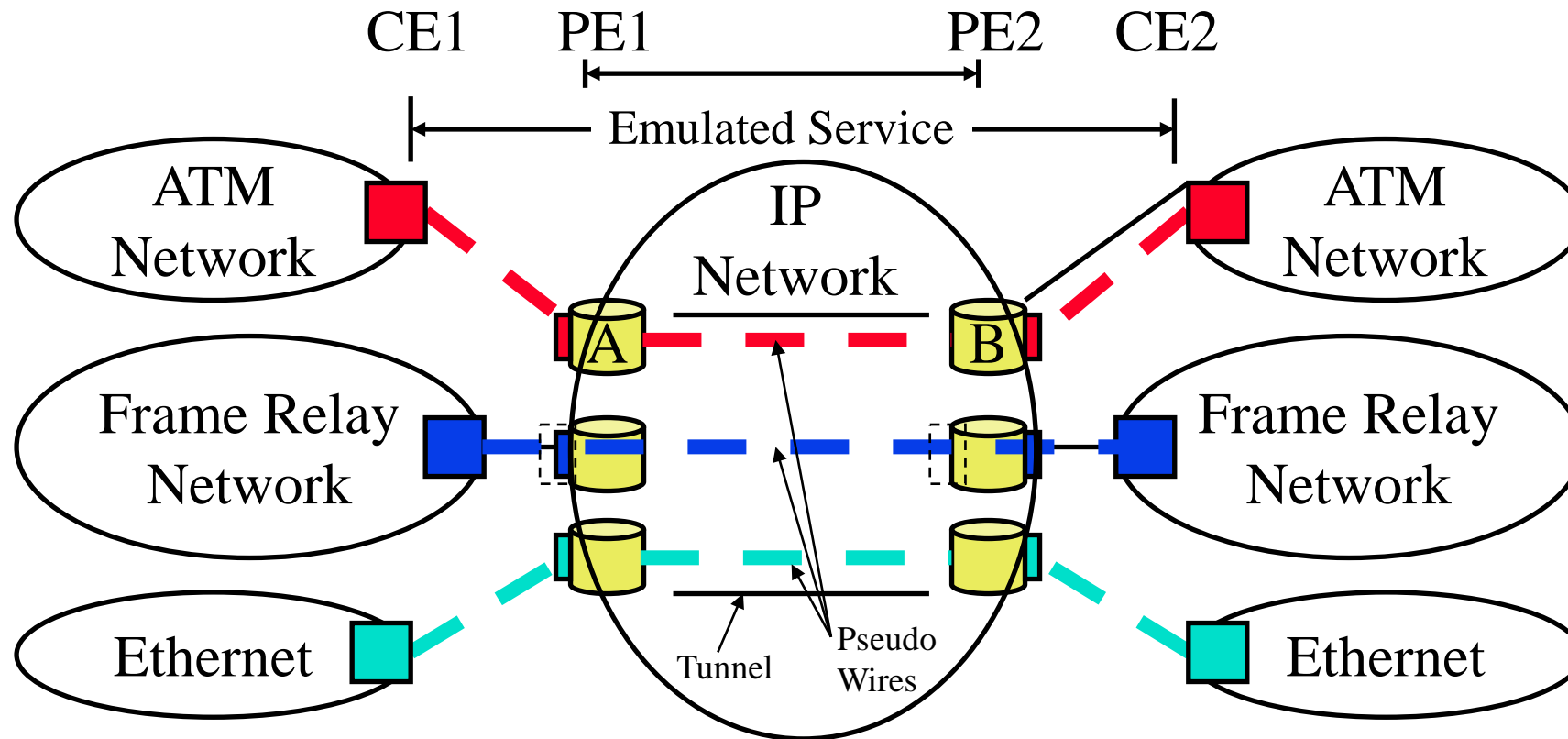
- ❑ So in the L2 Circuits over IP model, the customer edge routers do not care about IP address at all? It is up to the tunnel (e.g., MPLS) that establishes a pseudo-link in an IP network to figure out how to do forwarding over routers in the IP network to reach the destination.

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.

Pseudo Wire: L2 Circuits over IP

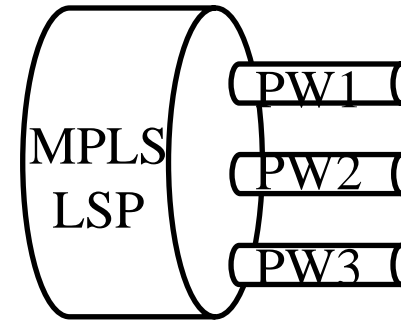
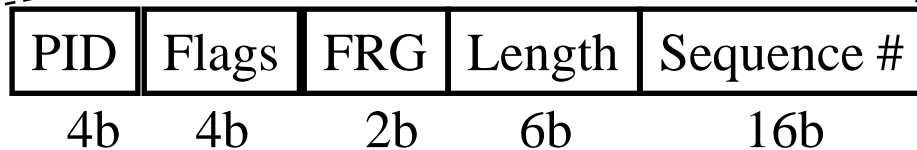


→ Payload Type → How to de-assemble payload
 → MPLS/GRE/L2TP - How to get to egress

Student Questions

- ❑ Could you explain more about the difference between L2TP and MPLS?
L2TP is a protocol that uses MPLS like TCP uses IP.
- ❑ Is it correct that VPNs are using this pseudo-wire technology?
Yes, VPNs can use pseudowire. However, VPNs can only be done with this technology.
- ❖ Is the CE the IP that "goes over" the PE MPLS, all done over ethernet connections?
*CE=Customer Edge
PE=Provider Edge
Each CE uses a different protocol.
PEs convert these to MPLS.*

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:

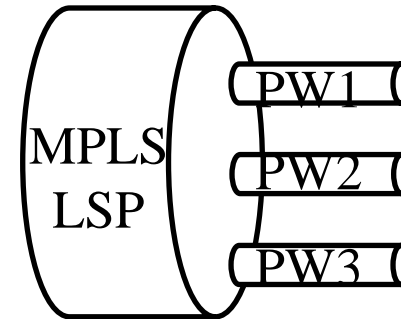
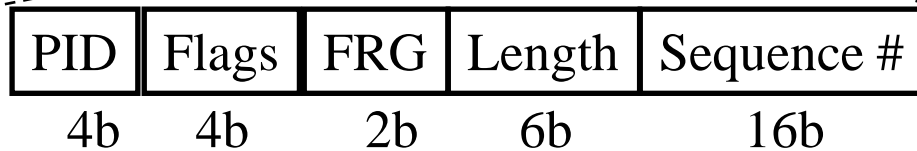
The outer header is MPLS



Chinese
over English

- ❑ What are the limitations associated with implementing Ethernet over PWE3 over MPLS?
Overhead

Ethernet over PWE3 over MPLS



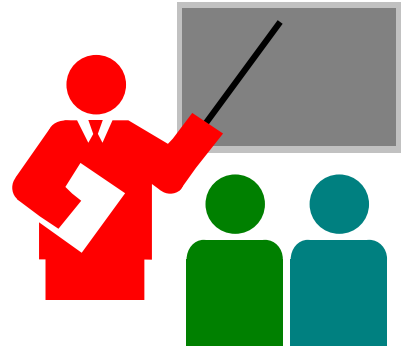
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- ❑ Flags: Payload specific. FRG: Used for fragmentation
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Student Questions

- ❑ So, is it correct to say that when protocol A "goes over" another protocol B, A is typically encapsulated into data that can be sent within the B frame/packet?

Yes.

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/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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Raj Jain

<http://rajjain.com>

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

CSE473S: Introduction to Computer Networks (Fall 2011),

https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e_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