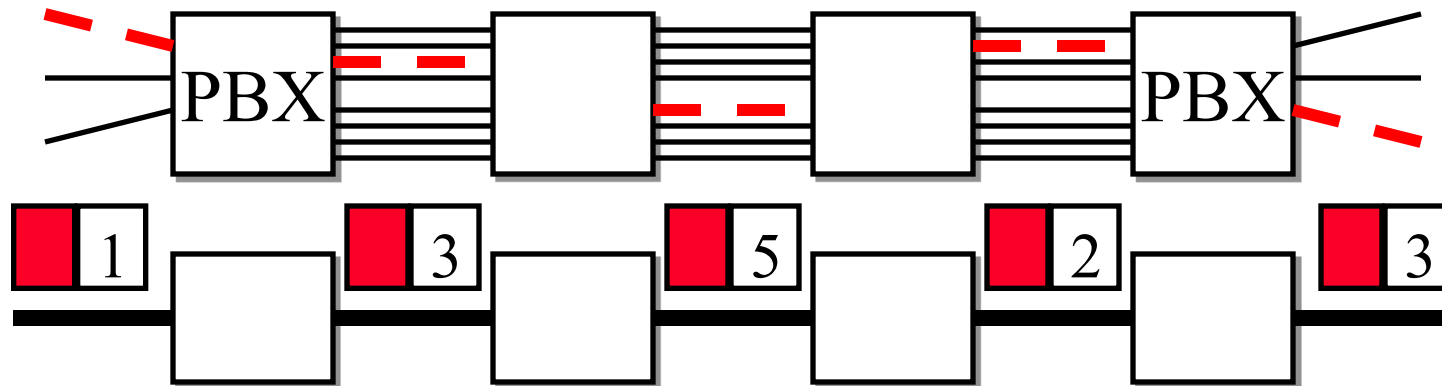


Carrier IP Networks: MPLS



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These slides and audio/video recordings of this class lecture are at:
<http://www.cse.wustl.edu/~jain/cse570-19/>



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

Plesiochronous Digital Hierarchy (PDH)

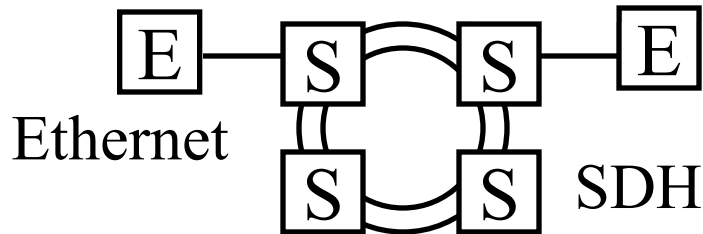
- ❑ Plesios + Synchronous = Near synchronous
- ❑ Phone Line = 64 kbps = 1 User channel
- ❑ North America
 - T1 = 1.544 Mbps = 24 User channels
 - T2 = 6.312 Mbps = 96 Channels
 - T3 = 44.736 Mbps = 480 Channels
- ❑ Europe:
 - E1 = 2.048 Mbps = 32 Channels
 - E2 = 8.448 Mbps = 128 Channels
 - E3 = 139.264 Mbps = 2048 Channels



T1

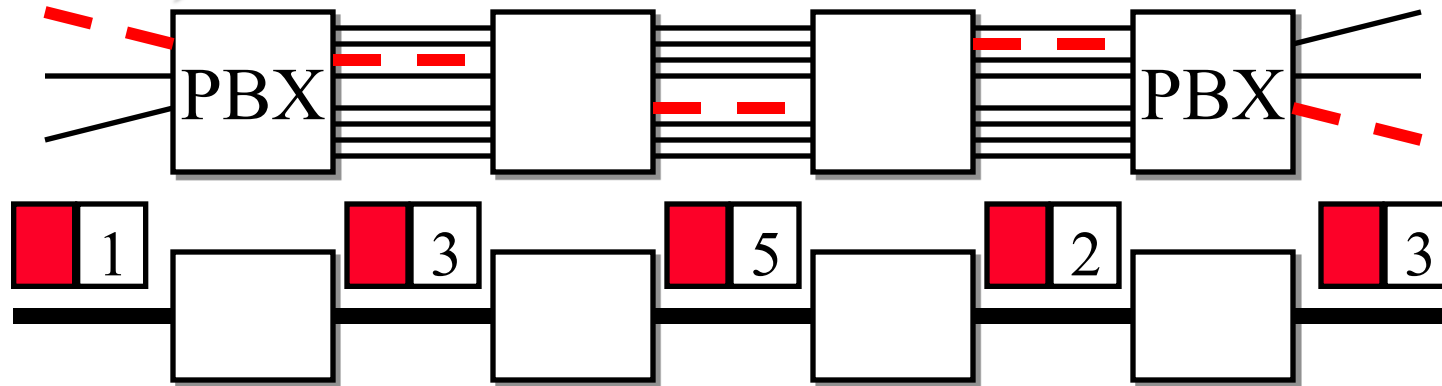


SONET/SDH

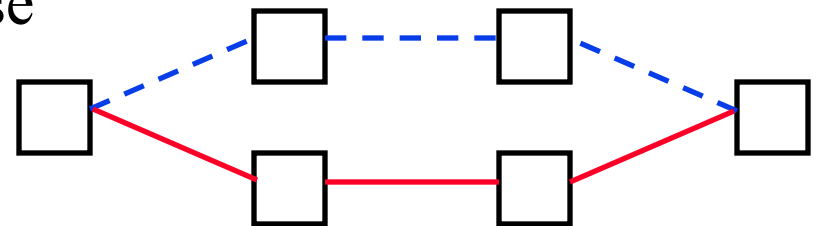


- ❑ SONET=Synchronous optical network
- ❑ Standard for digital optical transmission
- ❑ Standardized by ANSI and then by ITU
 - ⇒ Synchronous Digital Hierarchy (SDH)
- ❑ Protection: Allows redundant Line or paths
- ❑ Fast Restoration: 50ms using rings
- ❑ Sophisticated management
- ❑ Ideal for Voice: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

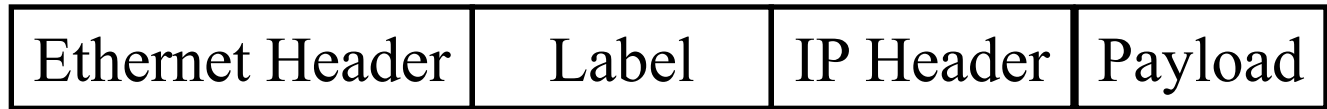
Multiprotocol Label Switching (MPLS)



- ❑ 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



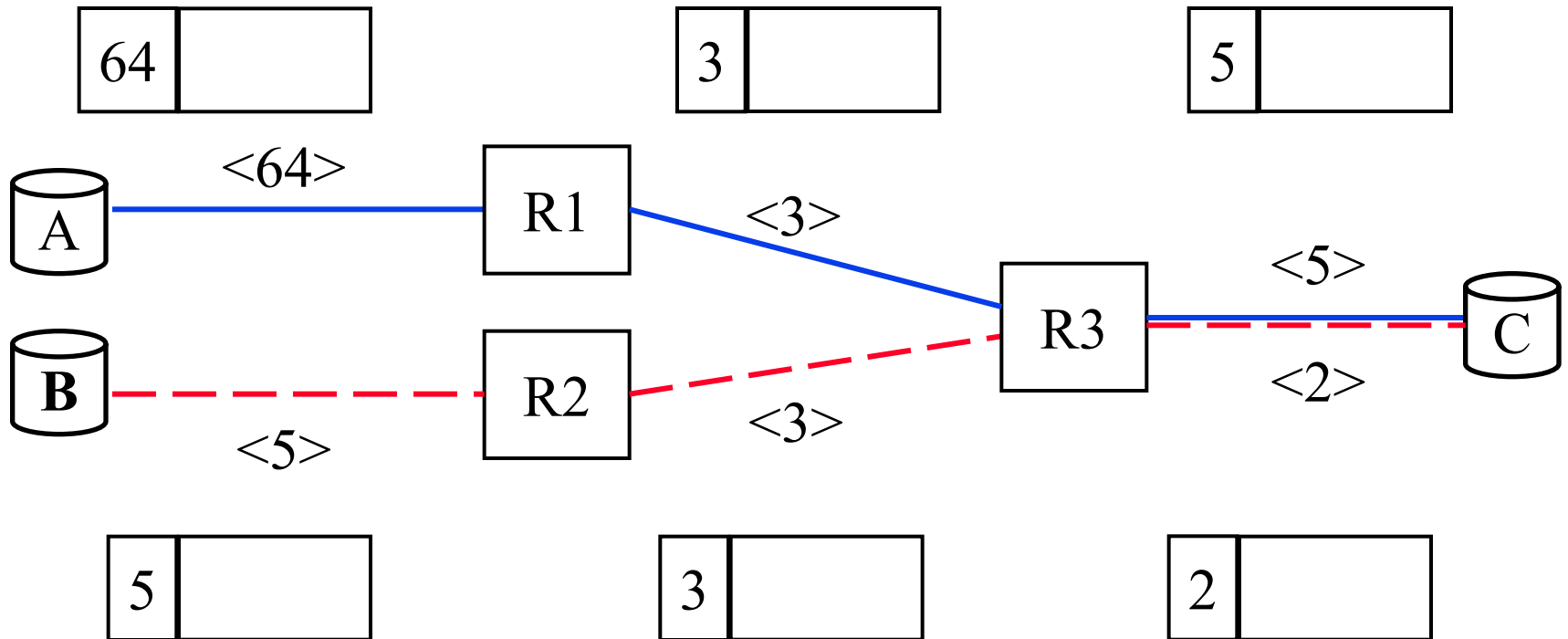
Label Switching Example



L2

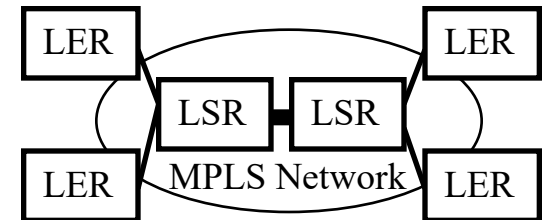
L2.5

L3



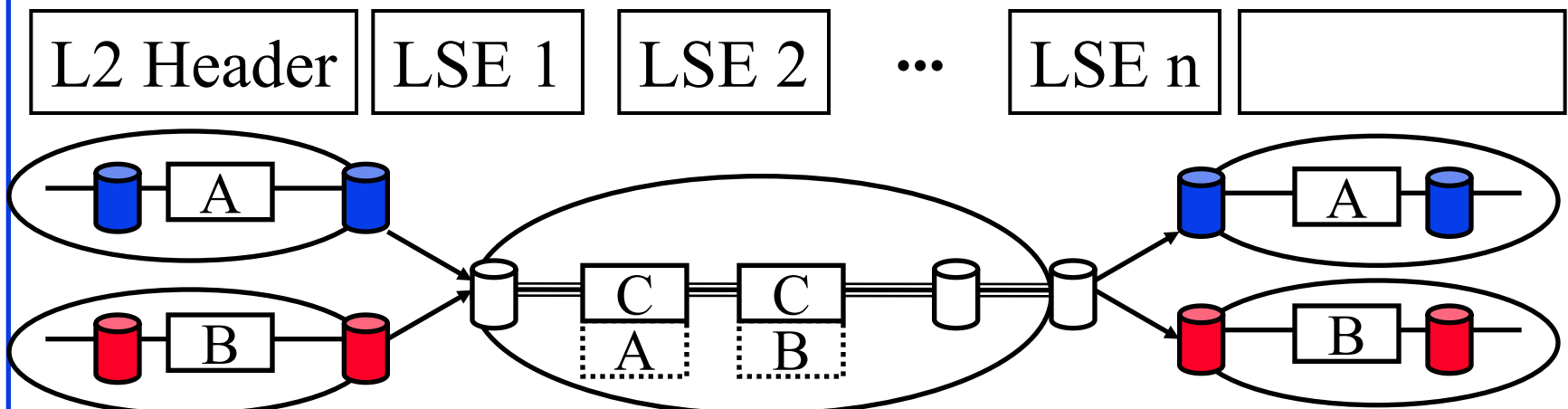
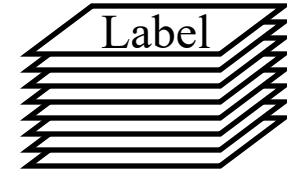
MPLS Concepts

- ❑ **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.



Label Stacks

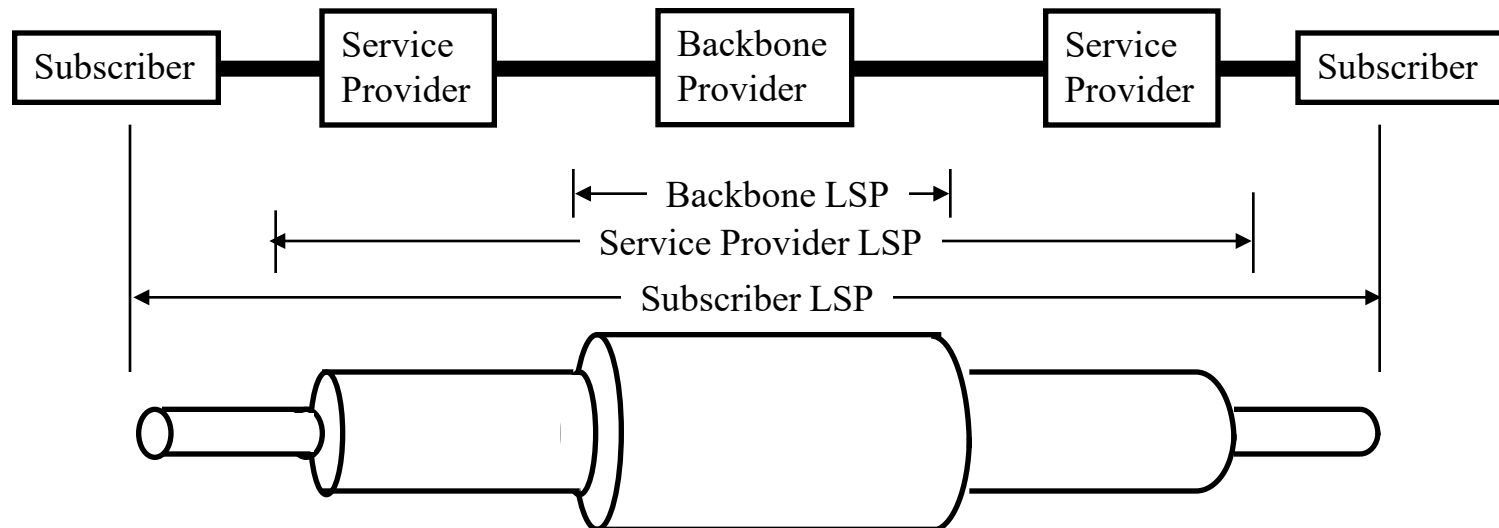
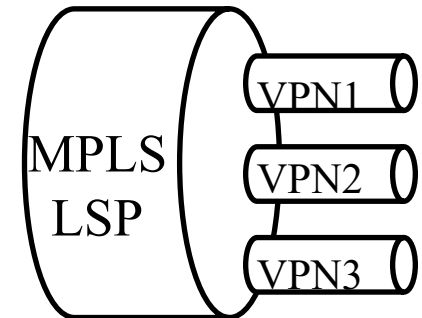
- ❑ Labels are pushed/popped as they enter/leave MPLS domain
- ❑ Routers in the interior will use Interior Gateway Protocol (IGP) labels. Border gateway protocol (BGP) labels outside.
- ❑ Bottom label may indicate protocol (0=IPv4, 2=IPv6)



MPLS Label Stacking

Label stacking allows:

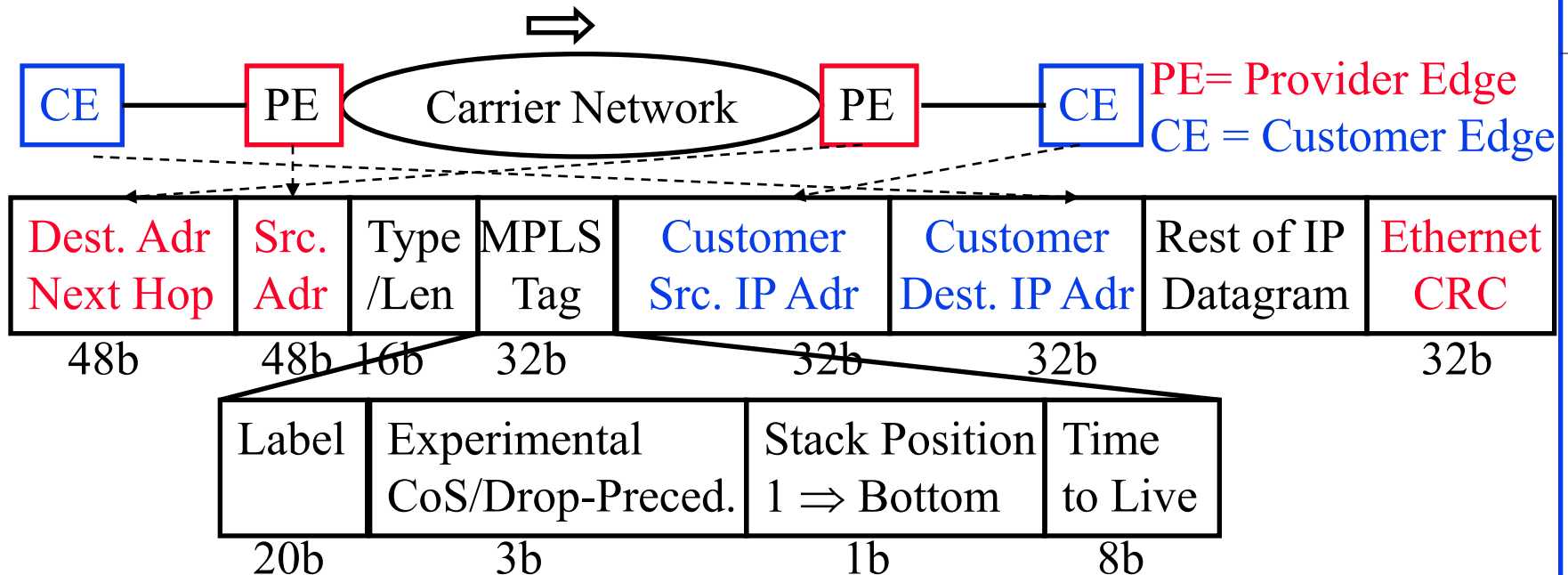
- Multiple levels of carriers.
- Multiple VPNs in a single LSP
- Multiple types of traffic in a single LSP



MPLS Traffic Engineering

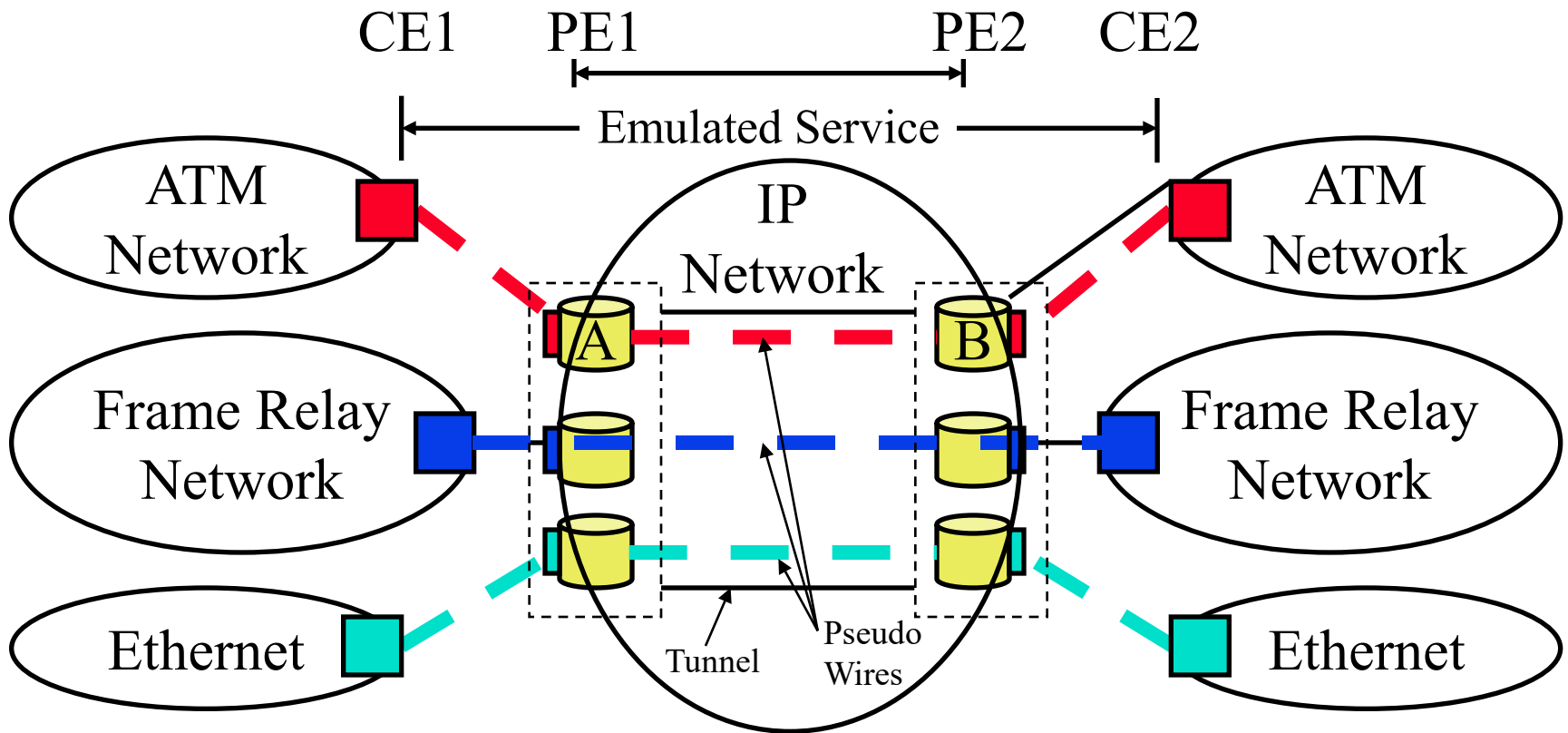
- ❑ MPLS paths can be provisioned to follow a specific path (no need to use shortest path)
- ❑ Resources on the path can be reserved
- ❑ Multiple parallel LSPs can be established between the same pair of nodes
- ❑ Fault recovery via shifting traffic to standby LSPs

IP over MPLS over Ethernet



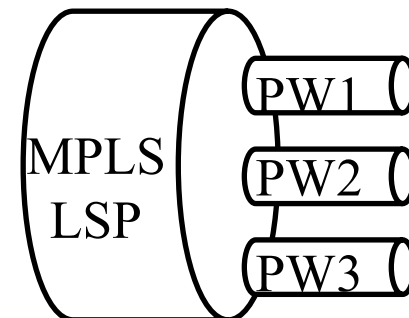
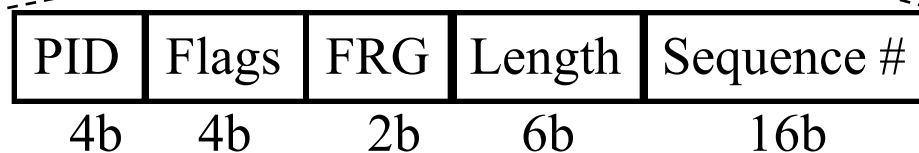
- ❑ Allows 2^{20} Label switched paths (LSP)
- ❑ Each path can have reserved capacity ⇒ Guaranteed **QoS**
- ❑ Explicit paths can be designed for specific traffic going to the same destination ⇒ **Traffic Engineering**
- ❑ Alternate paths used if anything on the primary path fails ⇒ **Fast Reroute**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

Pseudo Wire: L2 Circuits over IP



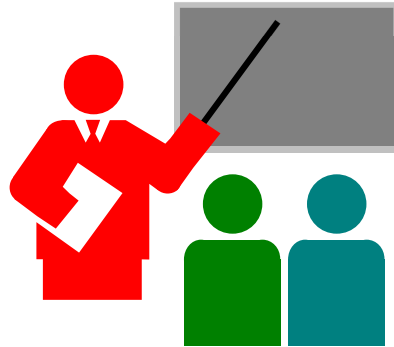
→ Payload Type → How to de-assemble payload
 → MPLS/GRE/L2TP - How to get to egress

Ethernet over PWE3 over MPLS



- ❑ 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.

Summary



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.

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).

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

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

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

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

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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>