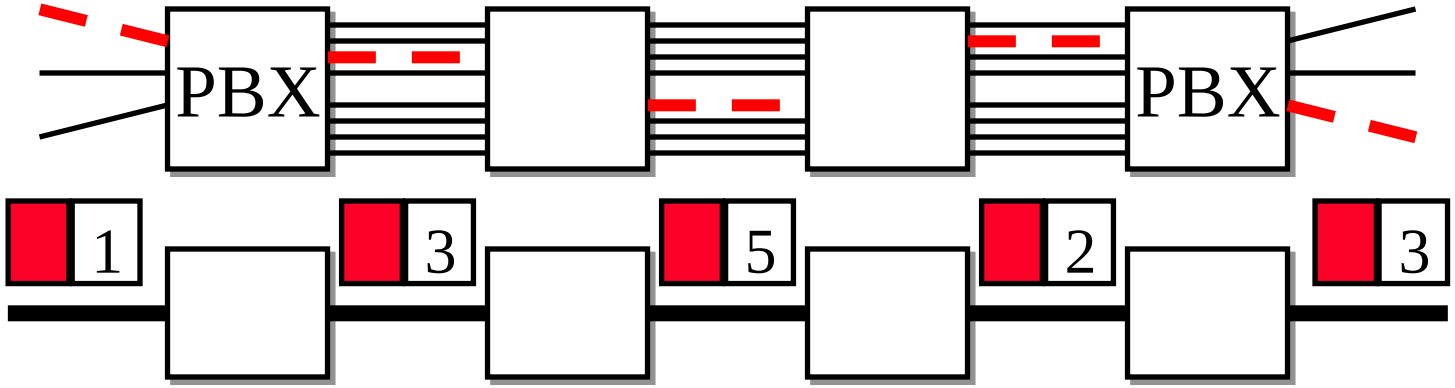
Carrier IP Networks: MPLS



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These slides and audio/video recordings of this class lecture are at:
http://www.cse.wustl.edu/~jain/cse5700-25/

Student Questions

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Overview

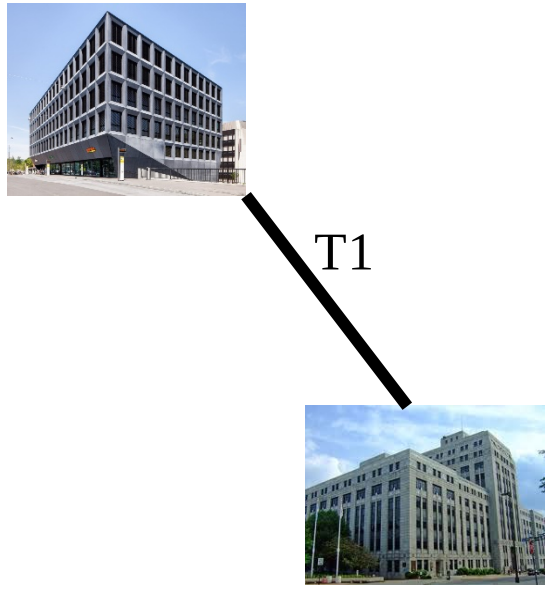
1. Plesiochronous Digital Hierarchy
2. Multiprotocol Label Switching (MPLS)
3. MPLS over Ethernet
4. Ethernet over MPLS

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Plesiochronous Digital Hierarchy (PDH)

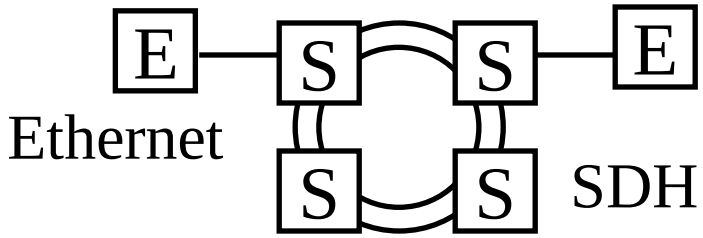
- Plesios + Synchronous = Near synchronous
- Phone Line = 64 kbps = 1 User channel
- North America
  - T1 = 1.544 Mbps = 24 User channels
  - T2 = 6.312 Mbps = 96 Channels
  - T3 = 44.736 Mbps = 480 Channels
- Europe:
  - E1 = 2.048 Mbps = 32 Channels
  - E2 = 8.448 Mbps = 128 Channels
  - E3 = 139.264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

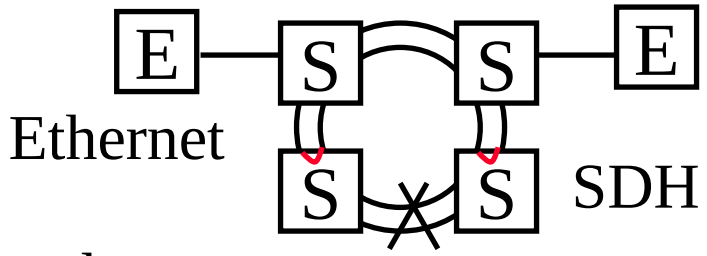


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SONET/SDH





- 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

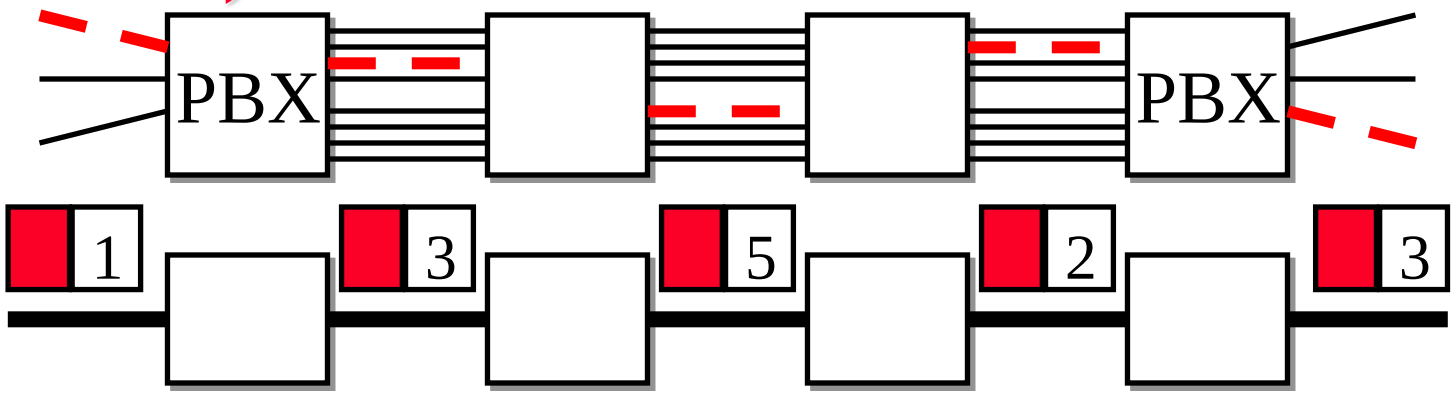
Student Questions

- What is the main difference between SONET and SDH? Why do we need both standards?

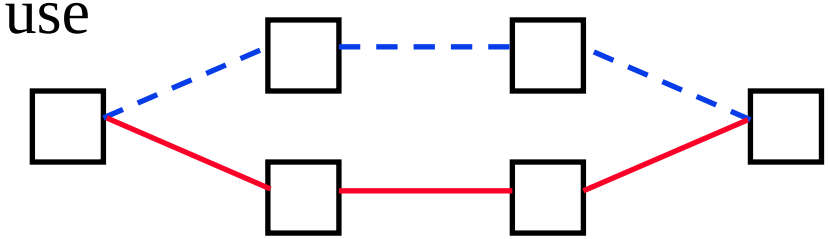
SONET is the original standard from North America. SDH is a European standard used in the rest of the world.

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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



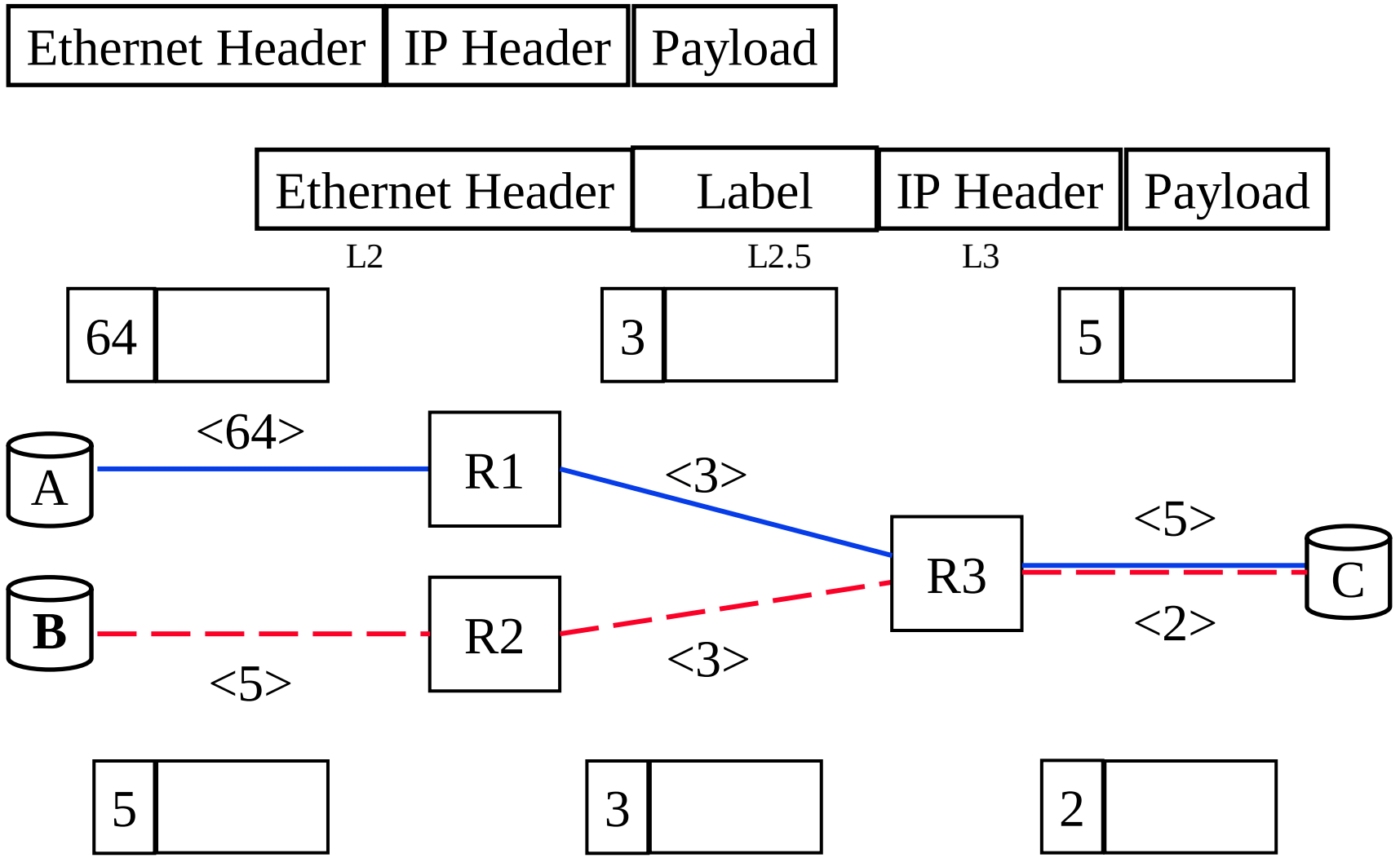
Student Questions

- As we know, each packet has a virtual circuit number called 'label.' Question: In large carrier networks or very big networks, where traffic can change very fast, doesn't this static label setup create problems? How do we / the companies look at them so that these MPLS adapt fast enough?

Generally, paths are set up for the long term. Flows are allocated to previously set up paths based on the QoS requested.

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Label Switching Example

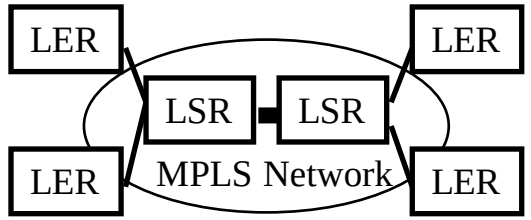


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MPLS Concepts

- **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

- Can you explain more on the roles of LER and LSR in Push/Pop?

LERs sit at the edge of the MPLS domain. They push/pop labels. LSRs are interior switches; they use the top label.

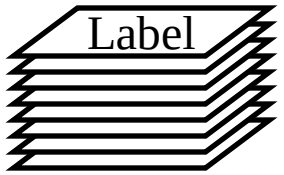
- Could you please explain this Slide again in more detail?

Sure.

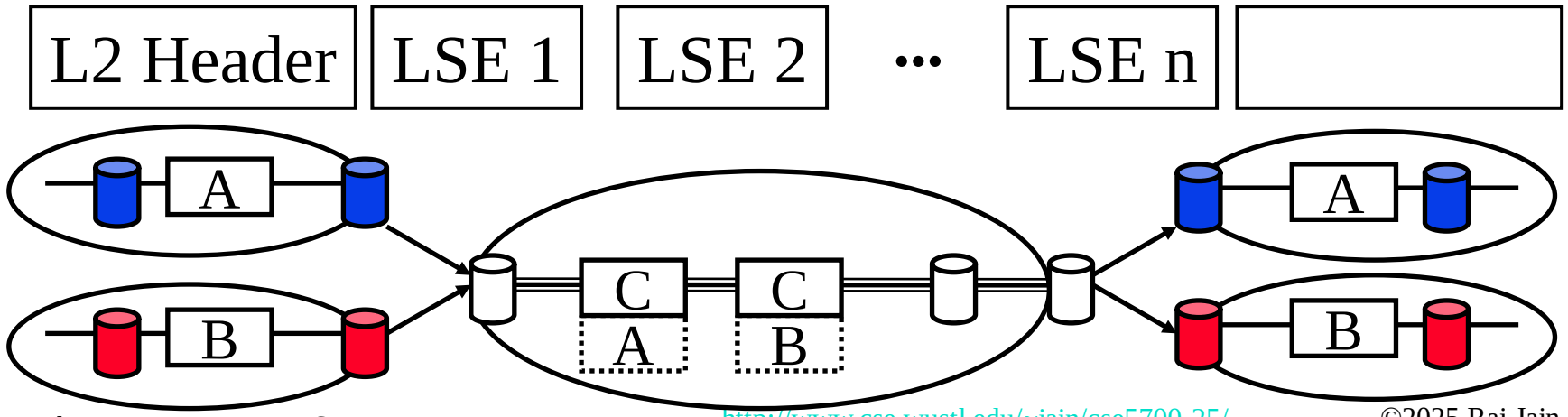
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Label Stacks

- 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)

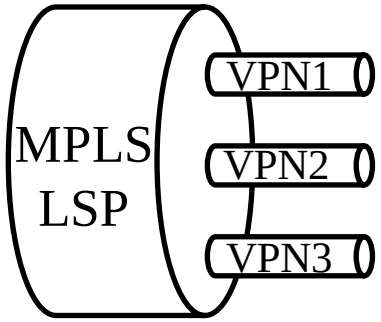


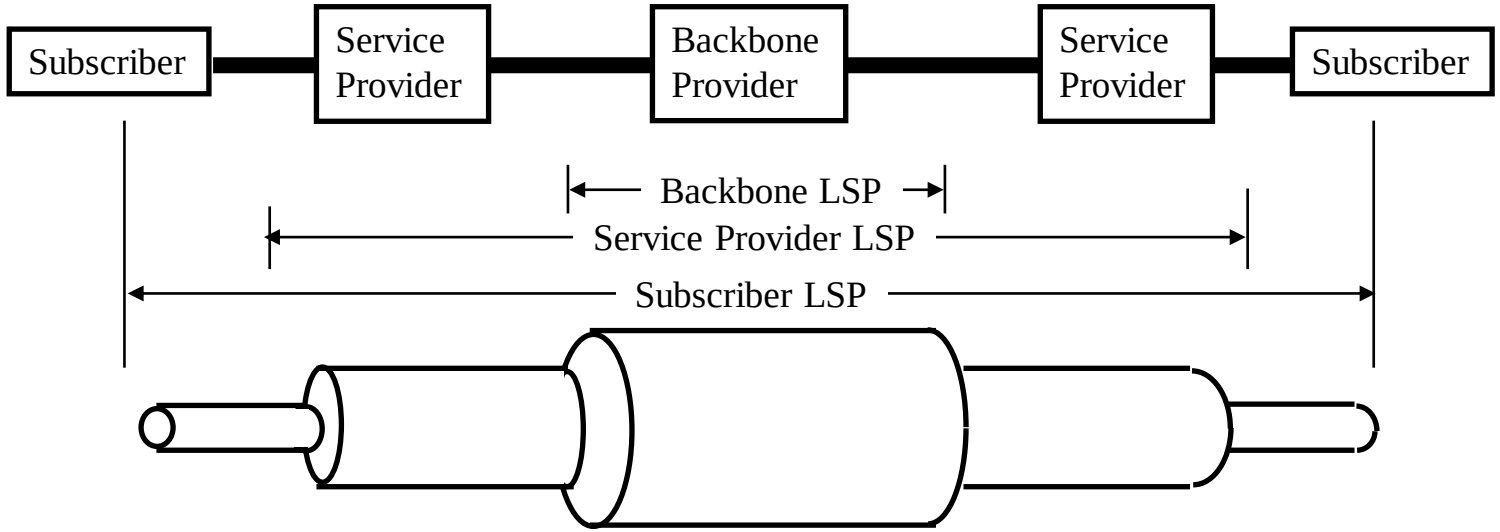
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MPLS Label Stacking

- Label stacking allows:
  - Multiple levels of carriers.
  - Multiple VPNs in a single LSP
  - Multiple types of traffic in a single LSP





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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

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End of Part 1

MPLS Forwarding Tables

- Interface numbers are in circles. Label IDs are in rectangles.

R6

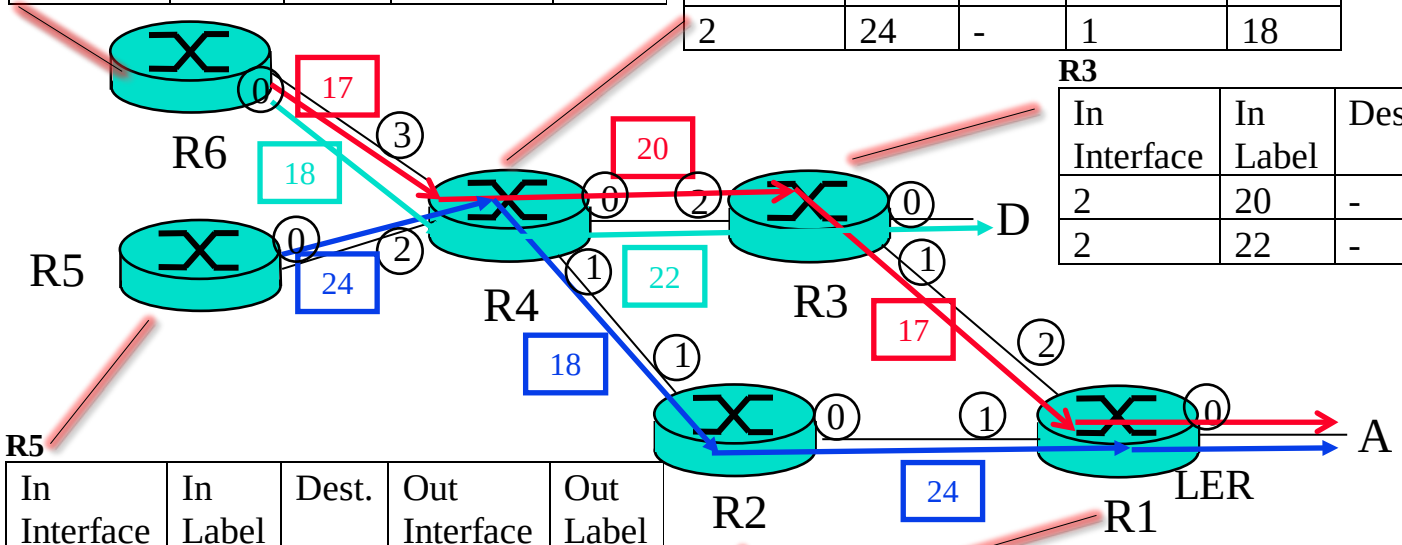
In Interface	In Label	Dest.	Out Interface	Out Label
-	None	A	0	17
-	None	D	0	18

R4

In Interface	In Label	Dest.	Out Interface	Out Label
3	17	-	0	20
3	18	-	0	22
2	24	-	1	18

R3

In Interface	In Label	Dest.	Out Interface	Out Label
2	20	-	1	17
2	22	-	0	None



R5

In Interface	In Label	Dest.	Out Interface	Out Label
-	None	A	0	24

R2

In Interface	In Label	Dest.	Out Interface	Out Label
1	18	-	0	24

R1

In Interface	In Label	Dest.	Out Interface	Out Label
2	17	-	0	None
1	24	-	0	None

Student Questions

- In the MPLS forwarding tables, why is the Destination shown only in the first table? Would repeating the Destination in every table improve clarity by making the final endpoint explicit?

It is not used after the first point.

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MPLS Forwarding Tables (Cont)

- The tables are per interface, not per router.
- The same label #s can be used in different interfaces of the same router. For example, See Router R3 in the "Label Switching Example" slide.
- Only one direction of circuits is shown for clarity.
  - There is an equal number of reverse circuits that have their own labels unrelated to forward labels.
- Out Label=None ⇒ MPLS Tag is removed.
  In Label=None ⇒ Packet arrives with no MPLS tag.

Student Questions

- You note that tables are per interface and that reverse circuits use independent labels unrelated to the forward direction. In a carrier network that advertises symmetric SLAs (bandwidth + FRR), how are the forward and reverse LSPs coordinated so that they share the same fate (same protection domain/restoration timing), even if they take different paths?

Each direction has its own protection and guarantees.

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Homework 5: MPLS

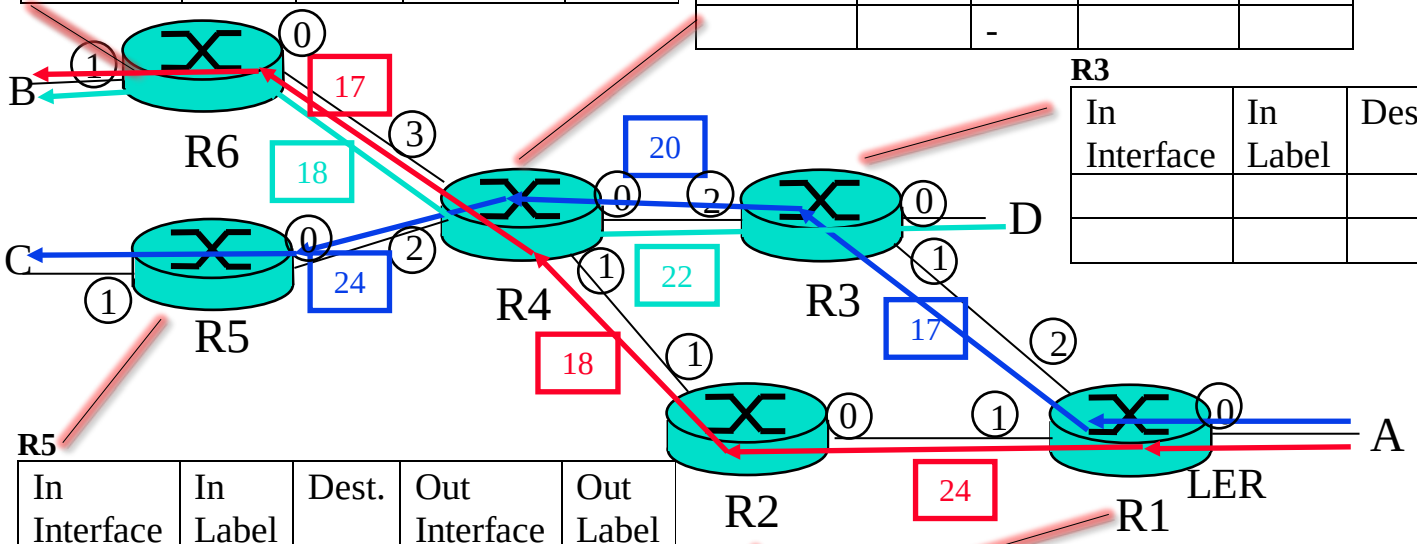
- [20 points] The next figure shows the flows on an MPLS network with the reverse direction flows. Using the Labels shown, fill in all the tables.

Student Questions

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Homework 5 (Cont)

- Interface numbers are in circles. Label IDs are in rectangles.



R6

In Interface	In Label	Dest.	Out Interface	Out Label

R4

In Interface	In Label	Dest.	Out Interface	Out Label
		-		

R3

In Interface	In Label	Dest.	Out Interface	Out Label

R5

In Interface	In Label	Dest.	Out Interface	Out Label

R2

In Interface	In Label	Dest.	Out Interface	Out Label

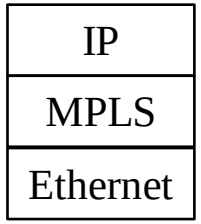
R1

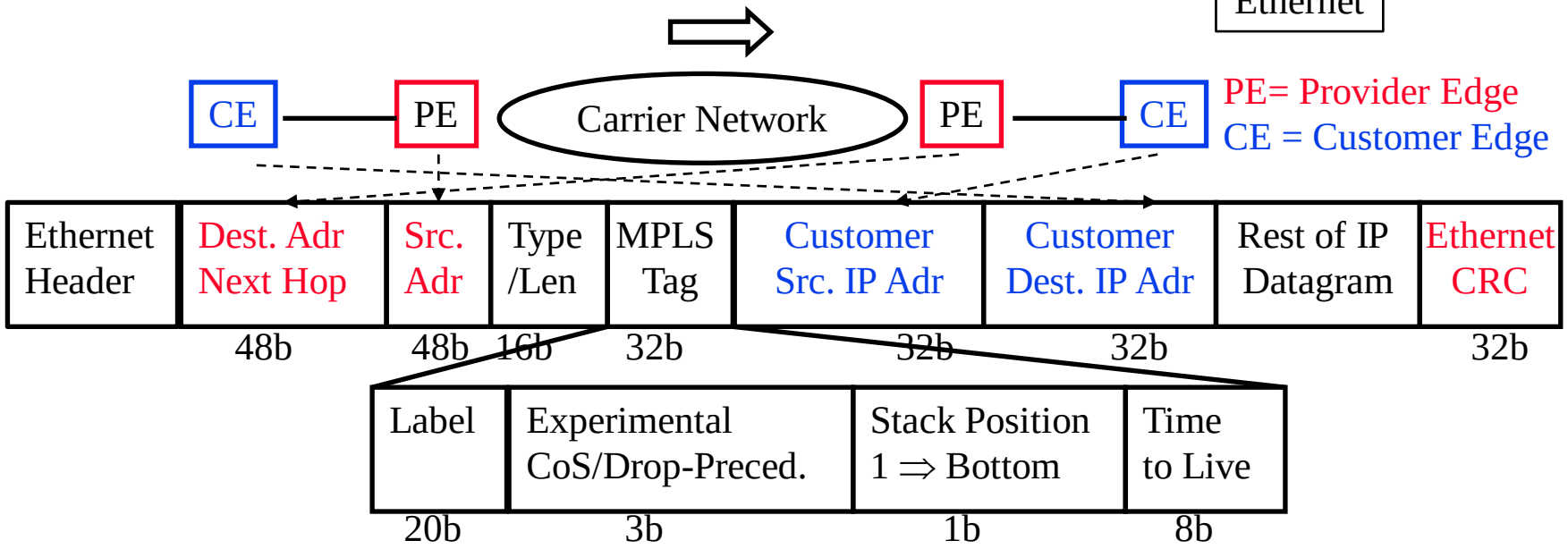
In Interface	In Label	Dest.	Out Interface	Out Label

Student Questions

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IP over MPLS over Ethernet



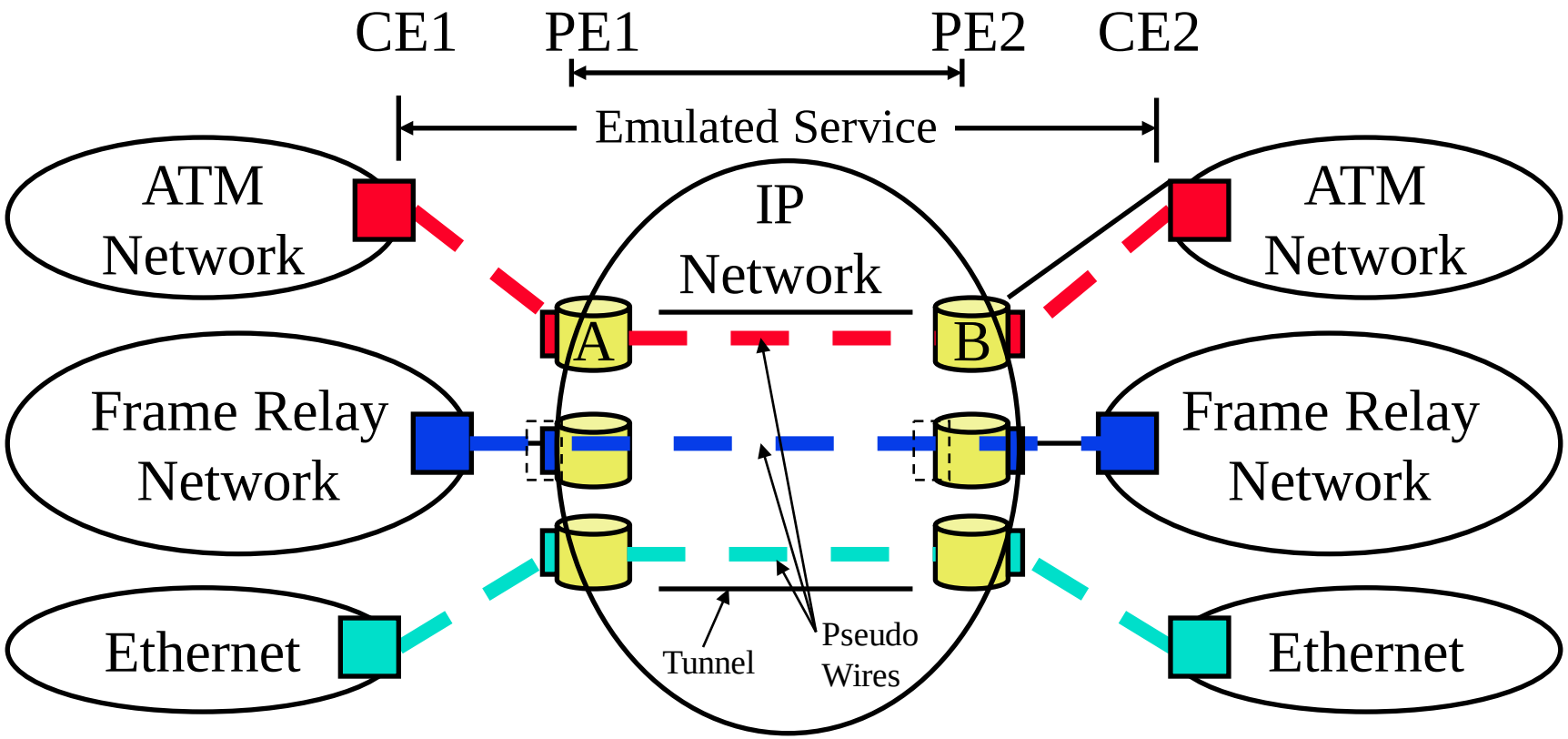


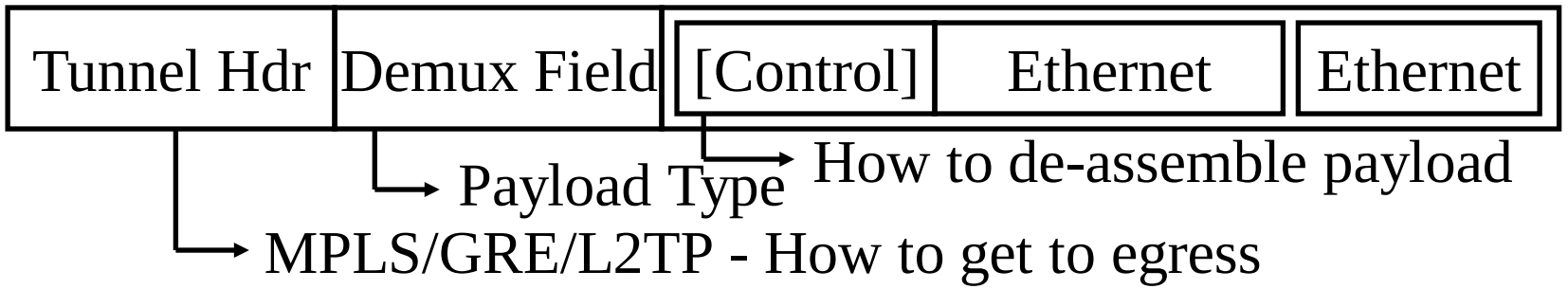
- Allows 2^{20} Label switched paths (LSP)
- Each path can have reserved capacity ⇒ Guaranteed **QoS**
- Explicit paths can be designed for specific traffic going to the same destination ⇒ **Traffic Engineering**
- Alternate paths are used if anything on the primary path fails ⇒ **Fast Reroute** ⇒ MPLS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

Student Questions

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Pseudo Wire: L2 Circuits over IP





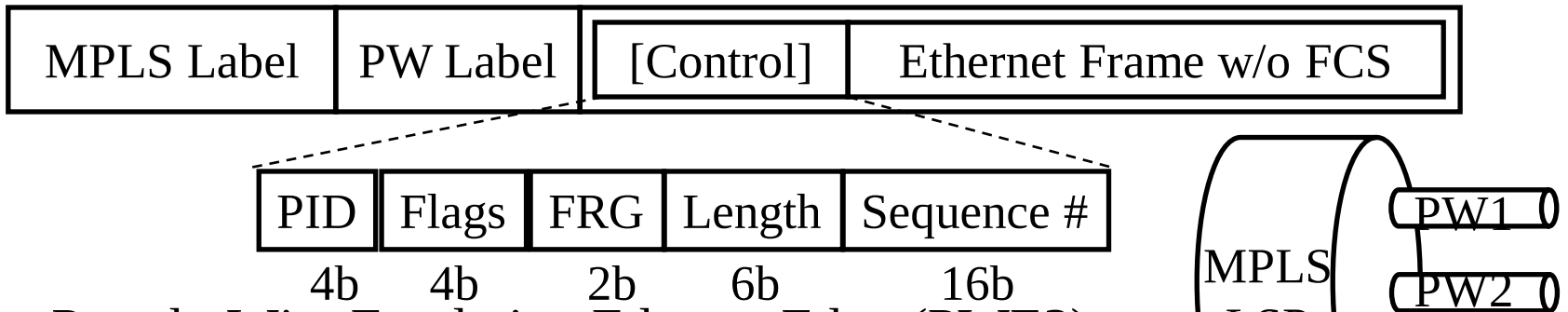
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- Why do we need both an MPLS label and a PW label?

PW indicates the payload type: Ethernet, Frame Relay, etc.

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Ethernet over PWE3 over MPLS

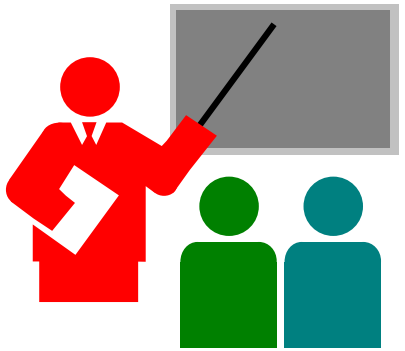


- Pseudo-Wire Emulation Edge-to-Edge (PWE3)
- Multiple pseudo-wires per MPLS LSP
  ⇒ Core routers use the outer "*path*" label and not the inner "*VC*" label
- PW (VC) label format is the same as the MPLS label with End-of-Stack=1 and TTL=1. PW label is inserted/removed at the edge.
- Payload ID (PID): 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

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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

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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).

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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

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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

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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

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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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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

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