شبکه های کامپیوتری ۲

جلسه ۱۲ فصل ۶

MPLS

دانشگاه صنعتی اصفهان
دانشکده مهندسی برق و کامپیوتر
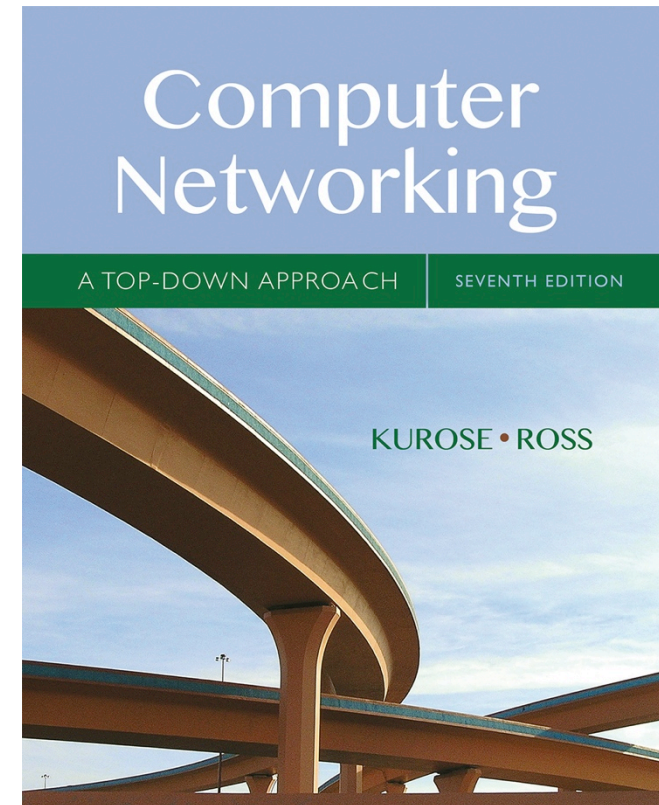
Chapter 1
Introduction

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Thanks and enjoy! JFK/KWR

Computer Networking: A Top Down Approach

7th edition
Jim Kurose, Keith Ross
Pearson/Addison Wesley
April 2016

Chapter 1: roadmap

The network core

- mesh of interconnected routers

- packet-switching: hosts break application-layer messages into *packets*
  - forward packets from one router to the next, across links on path from source to destination
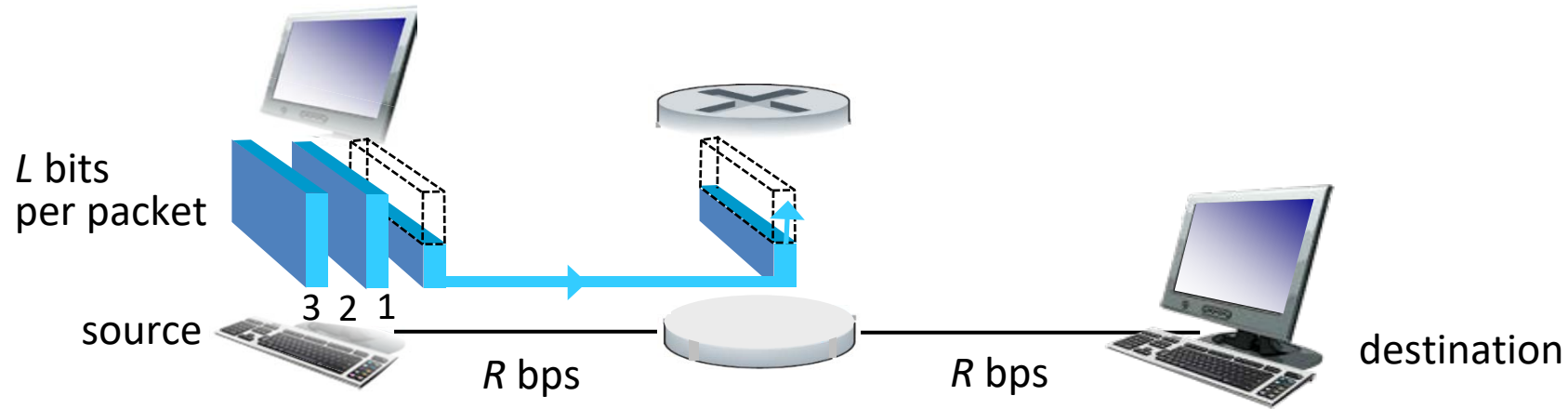 - each packet transmitted at full link capacity
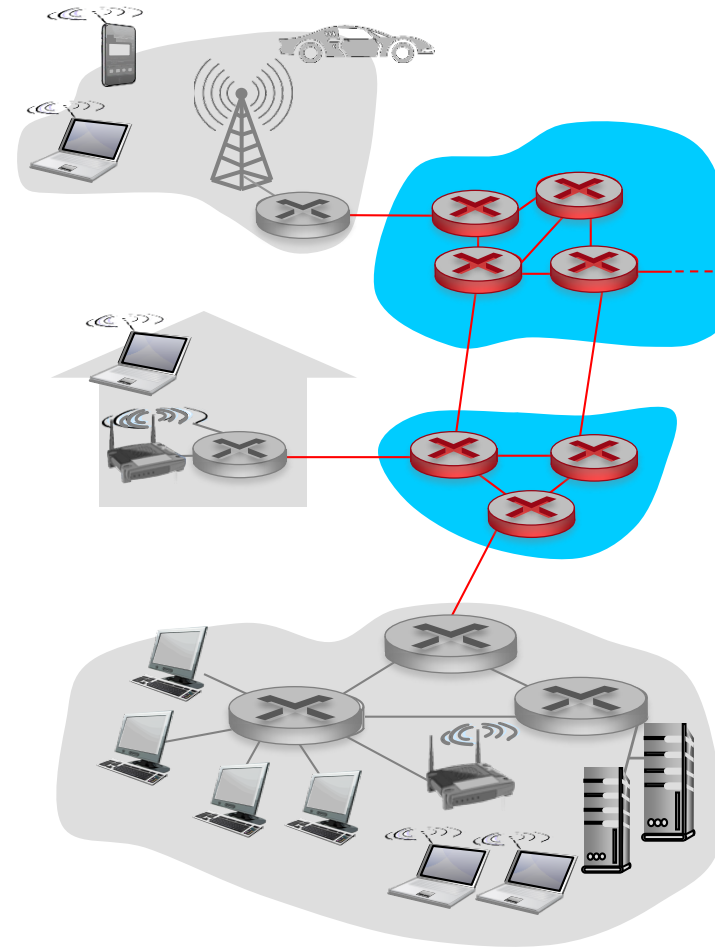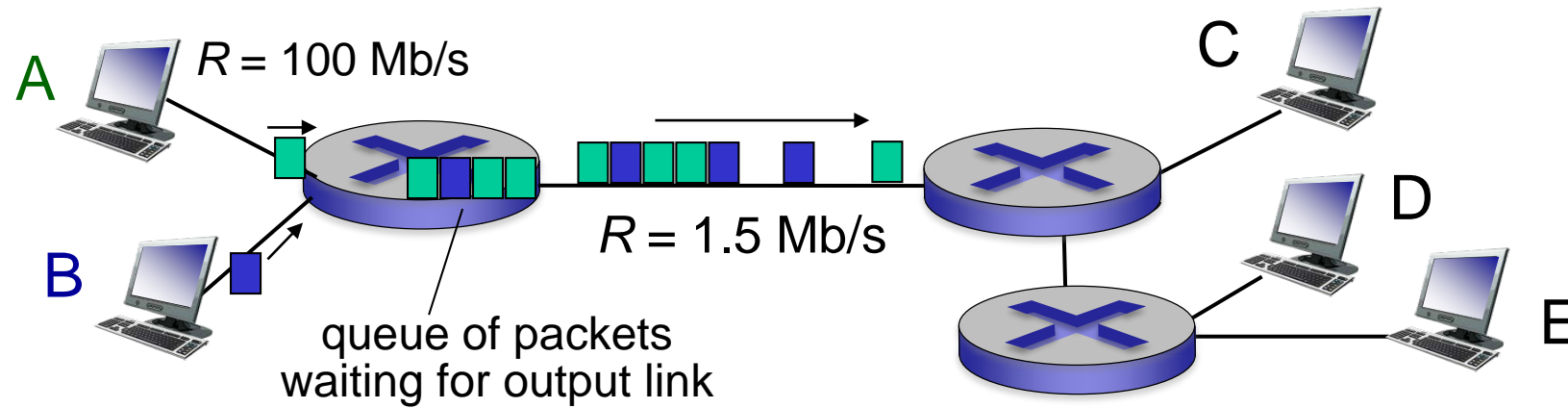
Packet-switching: store-and-forward

- takes *L/R* seconds to transmit (push out) *L*-bit packet into link at *R* bps

- *store and forward:* entire packet must arrive at router before it can be transmitted on next link

Packet Switching: queueing delay, loss

A R = 100 Mb/s

C
D
E

R = 1.5 Mb/s

queue of packets
waiting for output link

queuing and loss:

- if arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

Alternative core: circuit switching

end-end resources allocated to, reserved for "call" between source & dest:

- in diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- commonly used in traditional telephone networks
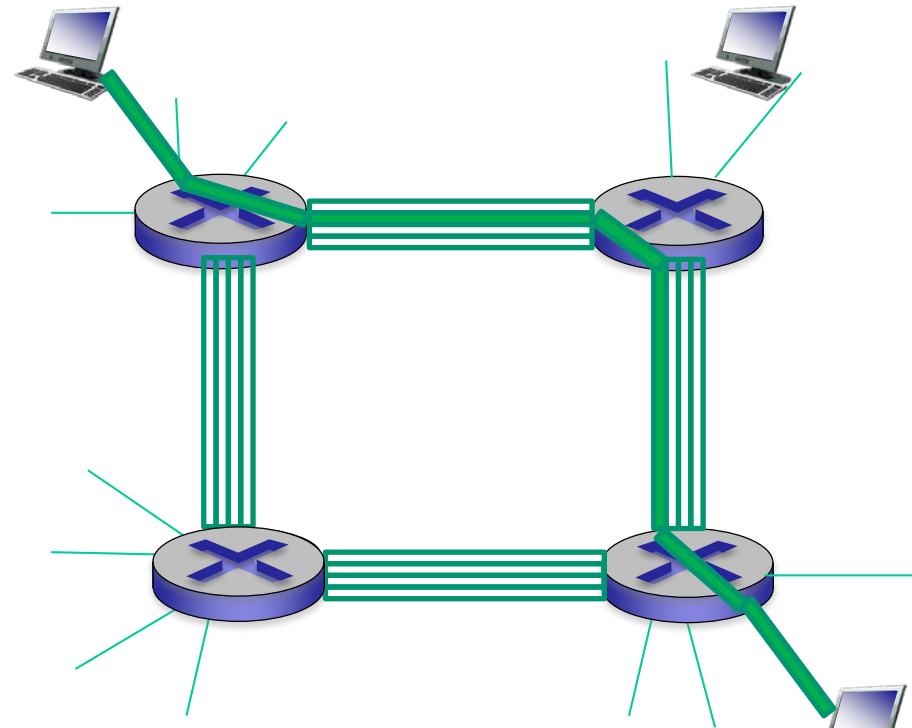
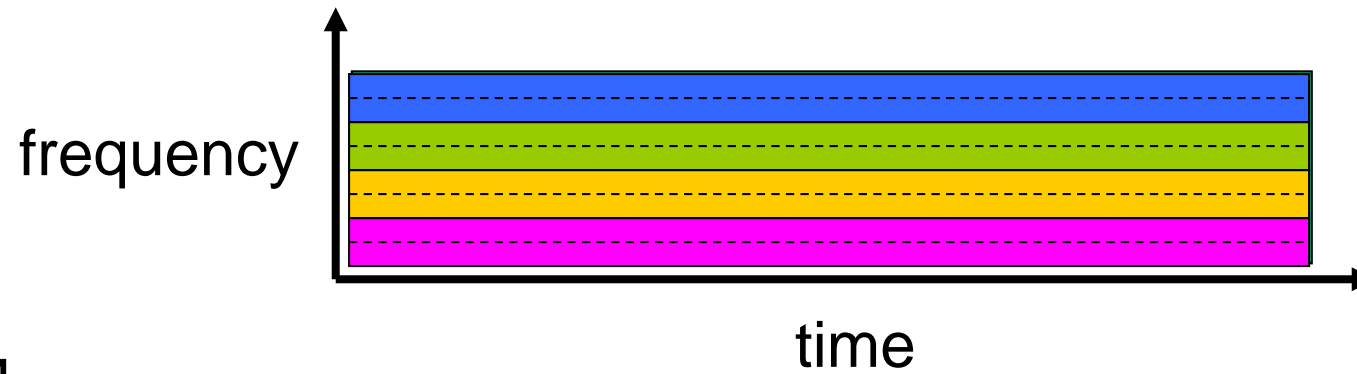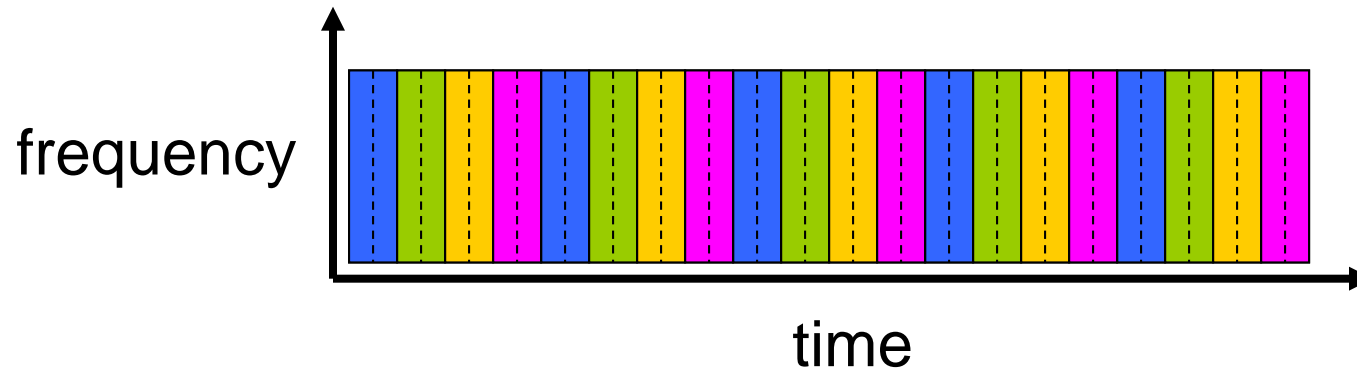# Circuit switching: FDM versus TDM

Example:

4 users

FDM

TDM

Packet switching versus circuit switching

packet switching allows more users to use network!

example:
- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time

- *circuit-switching:*
  - 10 users
- *packet switching:*
  - with 35 users, probability > 10 active at same time is less than .0004 *

N users

1 Mbps link
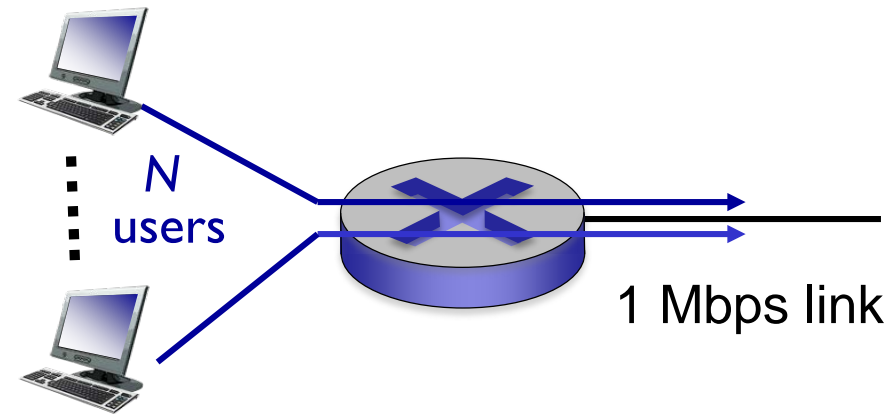
Packet switching versus circuit switching

is packet switching a "slam dunk winner?"

- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- *Q: How to provide circuit-like behavior?*
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 9)

Connection setup

- **3rd** important function in *some* network architectures:
  - ATM, frame relay, X.25
- before datagrams flow, two end hosts *and* intervening routers establish virtual connection
  - routers get involved
- network vs transport layer connection service:
  - *network:* between two hosts (may also involve intervening routers in case of VCs)
  - *transport:* between two processes

Network service model

Q: What *service model* for "channel" transporting datagrams from sender to receiver?

example services for individual datagrams:

❖ guaranteed delivery
❖ guaranteed delivery with less than 40 msec delay

example services for a flow of datagrams:

▪ in-order datagram delivery
▪ guaranteed minimum bandwidth to flow
▪ restrictions on changes in inter-packet spacing

Network layer service models:

Network Architecture	Service Model	Guarantees ?				Congestion feedback
		Bandwidth	Loss	Order	Timing	
Internet	best effort	none	no	no	no	no (inferred via loss)
ATM	CBR	constant rate	yes	yes	yes	no congestion
ATM	VBR	guaranteed rate	yes	yes	yes	no congestion
ATM	ABR	guaranteed minimum	no	yes	no	yes
ATM	UBR	none	no	yes	no	no

Chapter 4: outline

Connection, connection-less service

❖ *datagram* network provides network-layer *connectionless* service

❖ *virtual-circuit* network provides network-layer *connection* service

❖ analogous to TCP/UDP connecton-oriented / connectionless transport-layer services, but:

- *service:* host-to-host
- *no choice:* network provides one or the other
- *implementation:* in network core

Virtual circuits

"source-to-dest path behaves much like telephone circuit"

- performance-wise
- network actions along source-to-dest path

- call setup, teardown for each call *before* data can flow
- each packet carries VC identifier (not destination host address)
- *every* router on source-dest path maintains "state" for each passing connection
- link, router resources (bandwidth, buffers) may be *allocated* to VC (dedicated resources = predictable service)

VC implementation

a VC consists of:

1. *path* from source to destination
2. *VC numbers*, one number for each link along path
3. *entries in forwarding tables* in routers along path

❖ packet belonging to VC carries VC number (rather than dest address)

❖ VC number can be changed on each link.

▪ new VC number comes from forwarding table

VC forwarding table

VC number

interface number
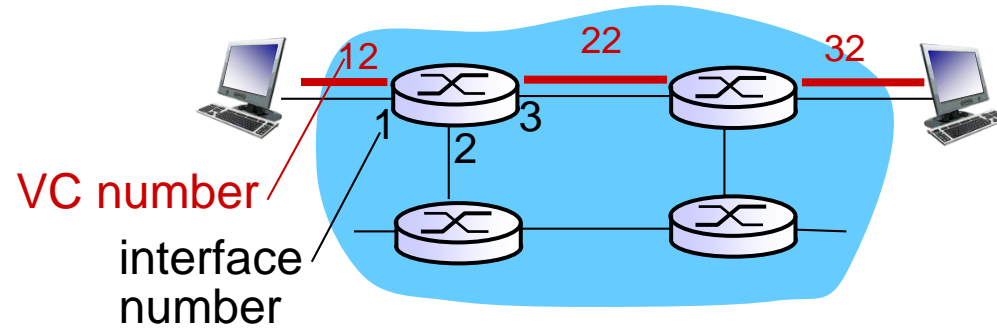
forwarding table in northwest router:

Incoming interface	Incoming VC #	Outgoing interface	Outgoing VC #
1	12	3	22
2	63	1	18
3	7	2	17
1	97	3	87
…	…	…	…

VC routers maintain connection state information!

Virtual circuits: signaling protocols

- used to setup, maintain teardown VC
- used in ATM, frame-relay, X.25
- not used in today's Internet
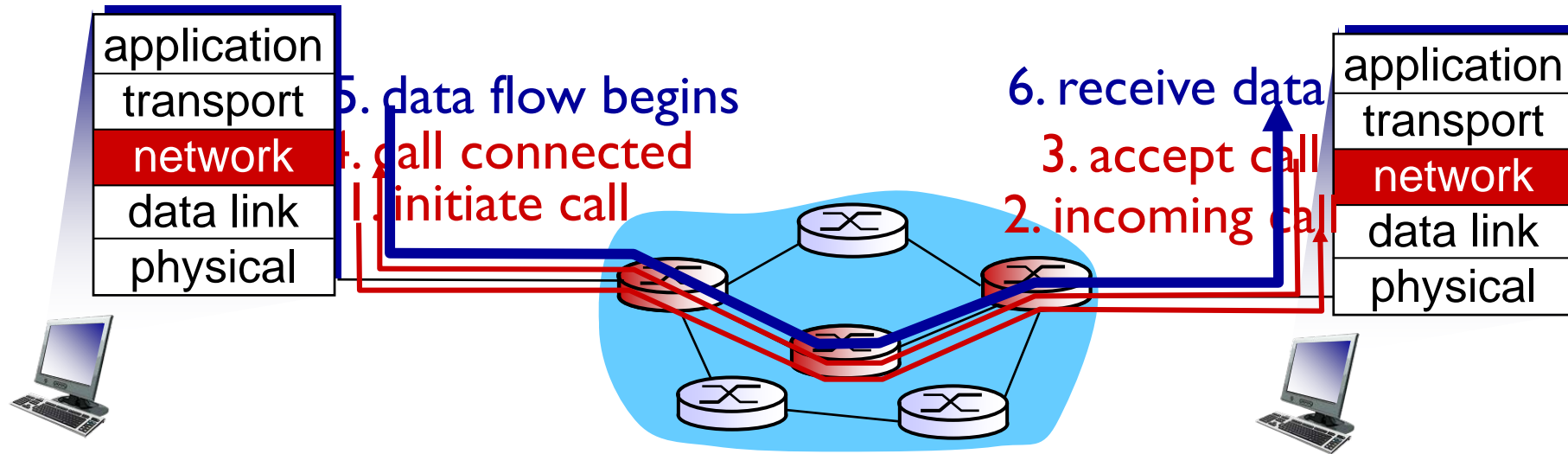
application
transport
network
data link
physical

5. data flow begins
4. call connected
1. initiate call

6. receive data
3. accept call
2. incoming call

application
transport
network
data link
physical

Link layer, LANs: outline

Multiprotocol label switching (MPLS)

- initial goal: high-speed IP forwarding using fixed length label (instead of IP address)
  - fast lookup using fixed length identifier (rather than shortest prefix matching)
  - borrowing ideas from Virtual Circuit (VC) approach
  - but IP datagram still keeps IP address!

PPP or Ethernet header	MPLS header	IP header	remainder of link-layer frame

label	Exp	S	TTL
20	3	1	5
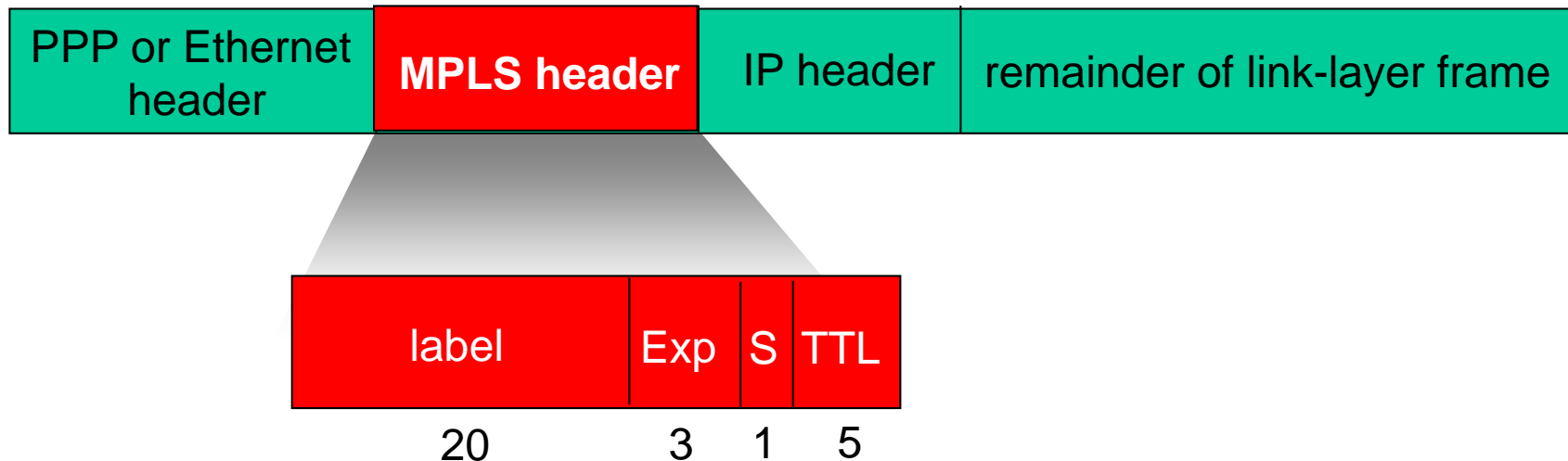
MPLS capable routers

- a.k.a. label-switched router
- forward packets to outgoing interface based only on label value (*don't inspect IP address*)
  - MPLS forwarding table distinct from IP forwarding tables
- *flexibility:* MPLS forwarding decisions can *differ* from those of IP
  - use destination *and* source addresses to route flows to same destination differently (traffic engineering)
  - re-route flows quickly if link fails: pre-computed backup paths (useful for VoIP)
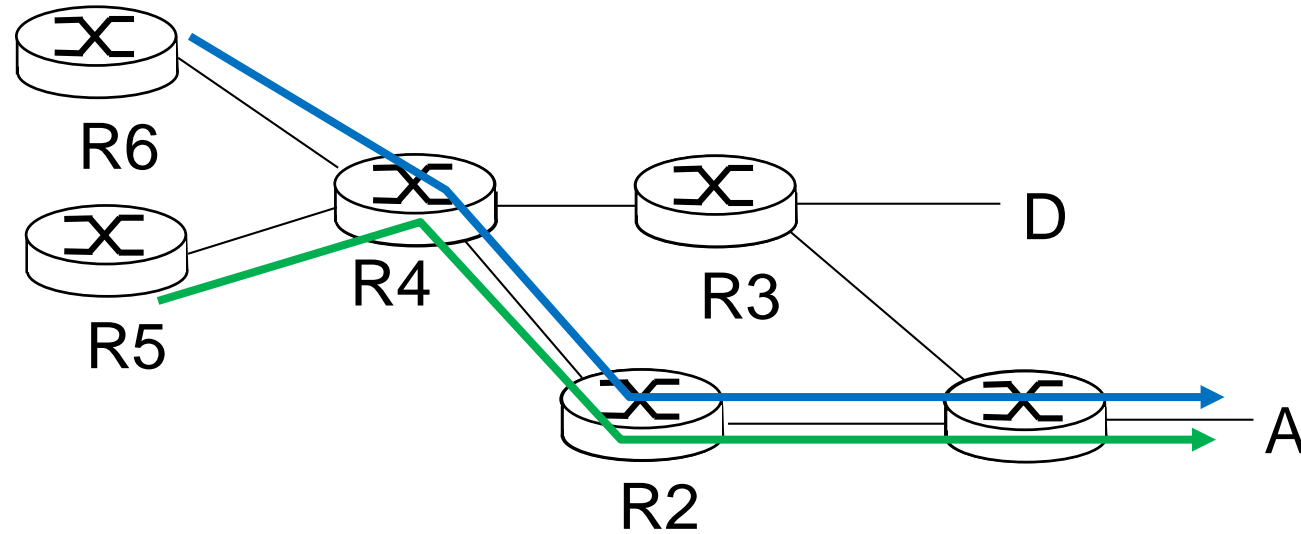
MPLS versus IP paths

- *IP routing: path to destination determined by destination address alone*

IP router

MPLS versus IP paths

entry router (R4) can use *different* MPLS routes to A based, e.g., on source address

R6

R5

R4

R3
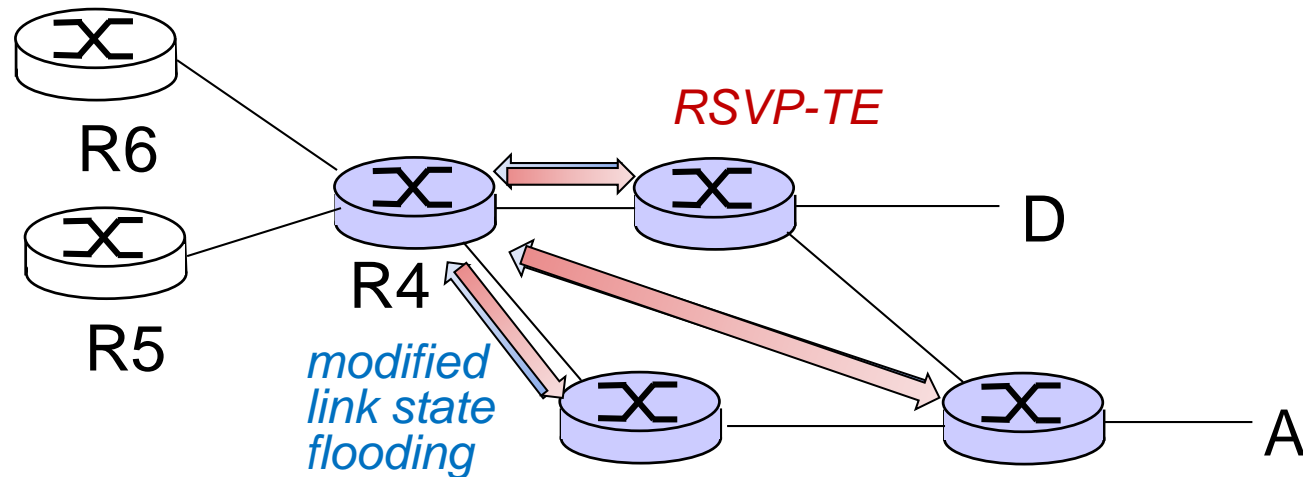
R2

D

A

- *IP routing:* *path to destination determined by destination address alone*

  IP-only router
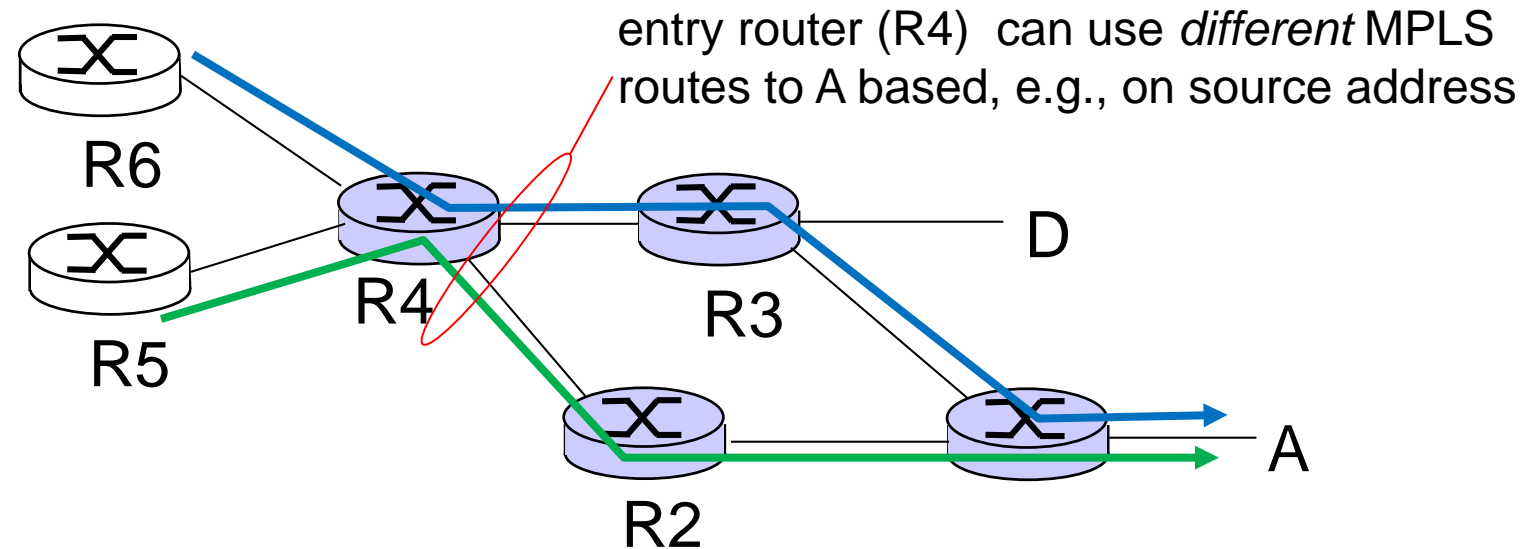
- *MPLS routing:* path to destination can be based on source *and* destination address

  MPLS and IP router

  - *fast reroute:* precompute backup routes in case of link failure

MPLS signaling

- modify OSPF, IS-IS link-state flooding protocols to carry info used by MPLS routing,
  - e.g., link bandwidth, amount of "reserved" link bandwidth
- *entry MPLS router uses RSVP-TE signaling protocol to set up MPLS forwarding at downstream routers*

RSVP-TE

modified link state flooding

R6

R5

R4

D

A

MPLS forwarding tables

in label	out label	dest	out interface
	10	A	0
	12	D	0
	8	A	1

in interface	in label	out label	dest	out interface
2	10	6	A	1
2	12	9	D	0

R6

R5

R4   0   2   R3   0   D

1

1   1

R2   0   2   A   0

1   1

in interface	in label	out label	dest	out interface
I	8	6	A	0

in interface	in label	out label	dest	out interface
2	6	-	A	0
I	6	-	A	0