Lecture 2: Internet Structure

COMP 332, Spring 2018
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Acknowledgements: materials adapted from Computer Networking: A Top Down Approach 7th edition: ©1996-2016, J.F Kurose and K.W. Ross, All Rights Reserved as well as from slides by Abraham Matta at Boston University and some material from Computer Networks by Tannenbaum and Wetherall.

Today

1. Announcements
   - help sessions now Tu (Exley 638) as well as Mo (Exley 618)
   - please do the reading!
   - to run Python 3: type python3
   - homework 1 posted: may want to wait for lecture 3 for problem 1

2. Recap
   - direct vs indirect connectivity
   - Internet protocol stack

3. Internet organization
   - edge
     - how you connect to Internet
   - core
     - how your packets get to their destination
     - circuit-switching vs. packet-switching
   - structure
     - network of networks: internetwork

Network

CONNECTIVITY

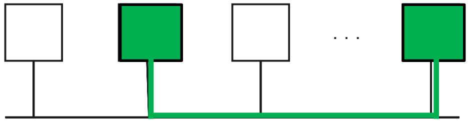
Connectivity

Direct links

- point-to-point

point-to-point network

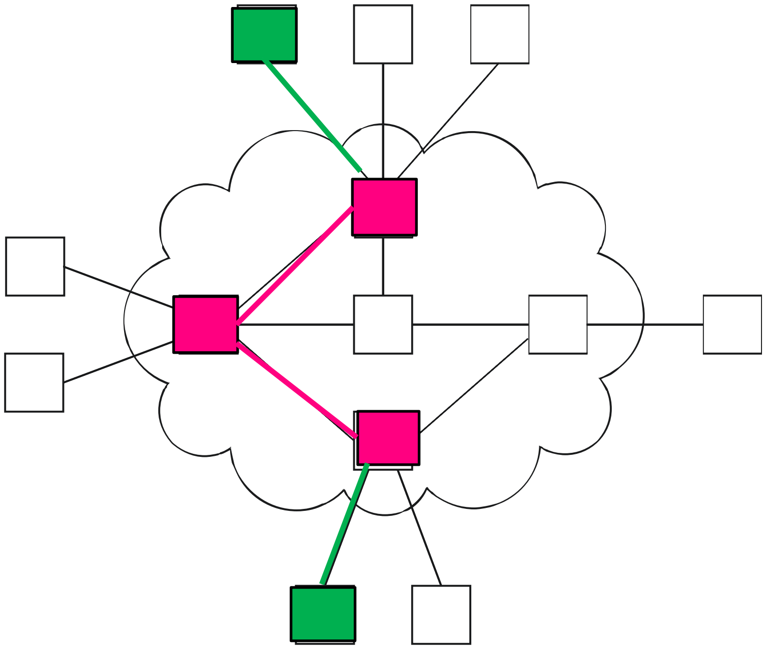
- multiple access



multiple access network

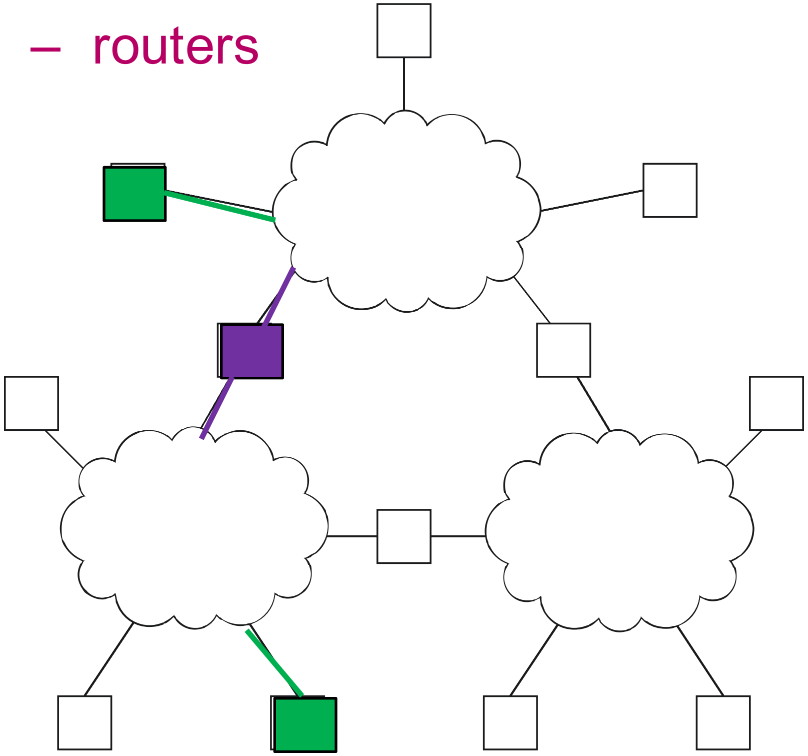
Indirect connectivity

- switched network



Internetwork

- routers

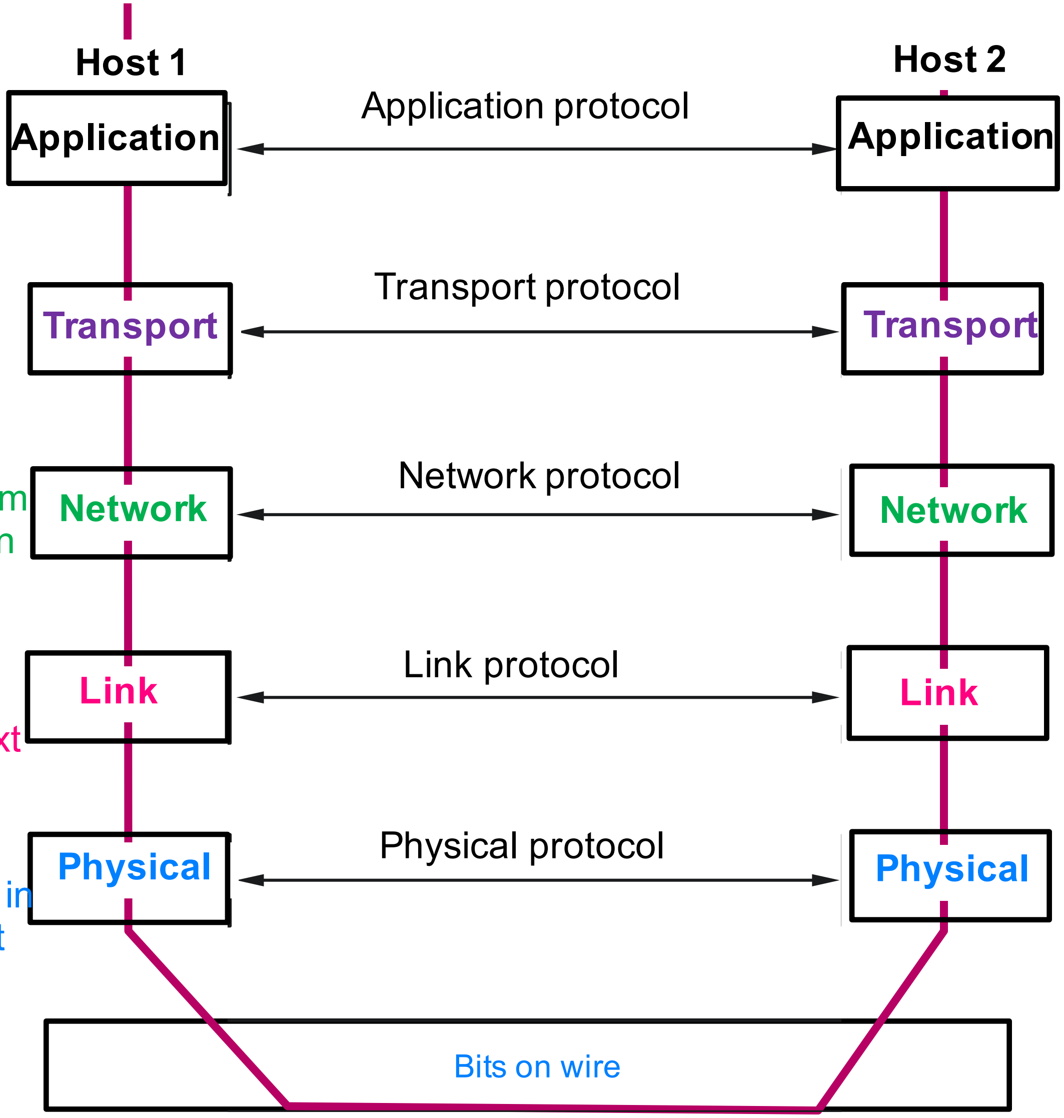


Internet

PROTOCOL STACK

Internet protocol stack

Mail service example	**Service provided**
Person reads letter	Support network applications
Letter delivered to person in house	Deliver msgs to app endpoints, flow control, reliability
Letter conveyed between sending house and receiving house	Route segments from source to destination host (indirect)
Letter conveyed from house to mailbox/P.O or from one P.O directly to another P.O.	Move pkt over link from one host to next host (direct)
The actual carrying of the letter across a "link"	Move individual bits in frame from one host to next



Internet protocol stack

	Layer	Service provided to upper layer	Protocols	Unit of information
5	Application	• Support network applications	FTP, DNS, SMTP, HTTP	Message 1 message may be split into multiple segments
4	Transport	• Deliver messages to app endpoints • Flow control • Reliability	TCP (reliable) UDP (best-effort)	Segment (TCP) Datagram (UDP) 1 segment may be split into multiple packets
3	Network	• Route segments from source to destination host	IP (best-effort) Routing protocols	Packet (TCP) Datagram (UDP)
2	Link	• Move packet over link from one host to next host	Ethernet, 802.11	Frame MTU is 1500 bytes
1	Physical	• Move individual bits in frame from one host to next • “bits on wire”	Ethernet phy 802.11 phy Bluetooth phy DSL	Bit

Internet protocol stack

Where to place functionality in Internet?

- Option 1:
  - inside network (switches/routers)

- Option 2:
  - at edges (hosts)

Illustrates “end-end” principle

- some network functionality can only be correctly implemented at end-hosts
- e.g., file transfer
  - should each link check or end hosts check?
  - what if a link on path fails?

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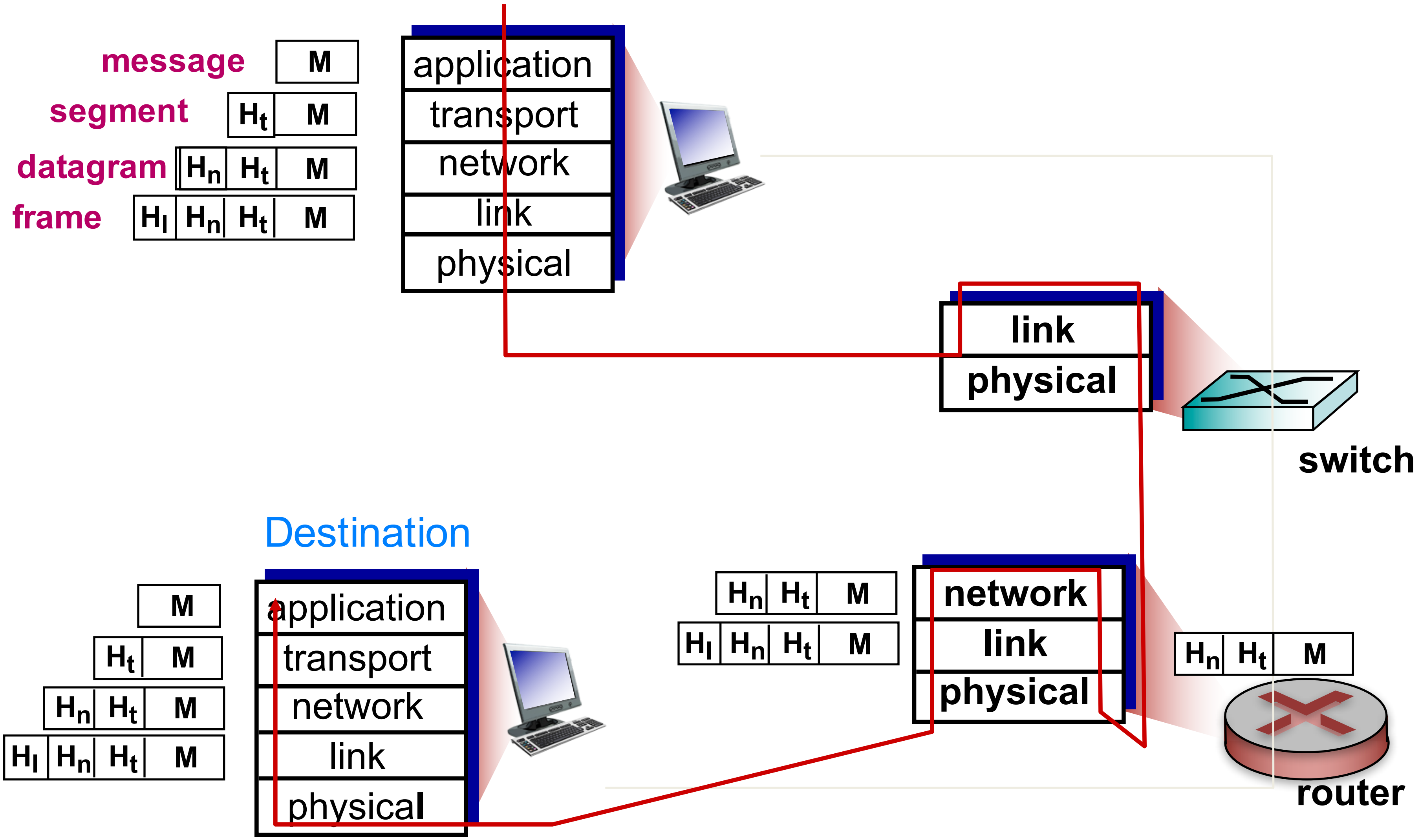
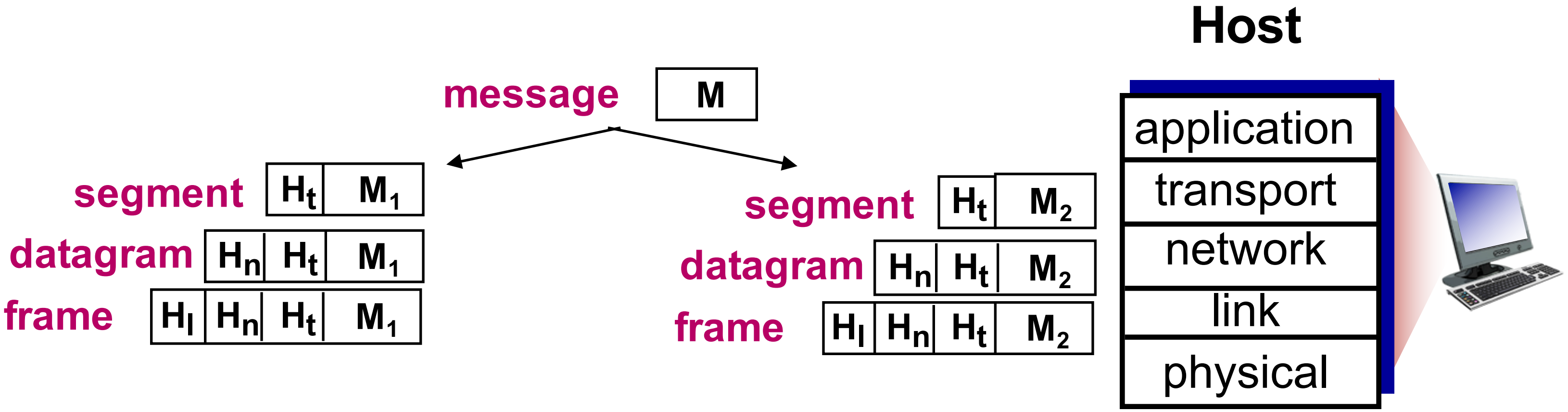
Encapsulation/Decapsulation



Fragmentation/Assembly

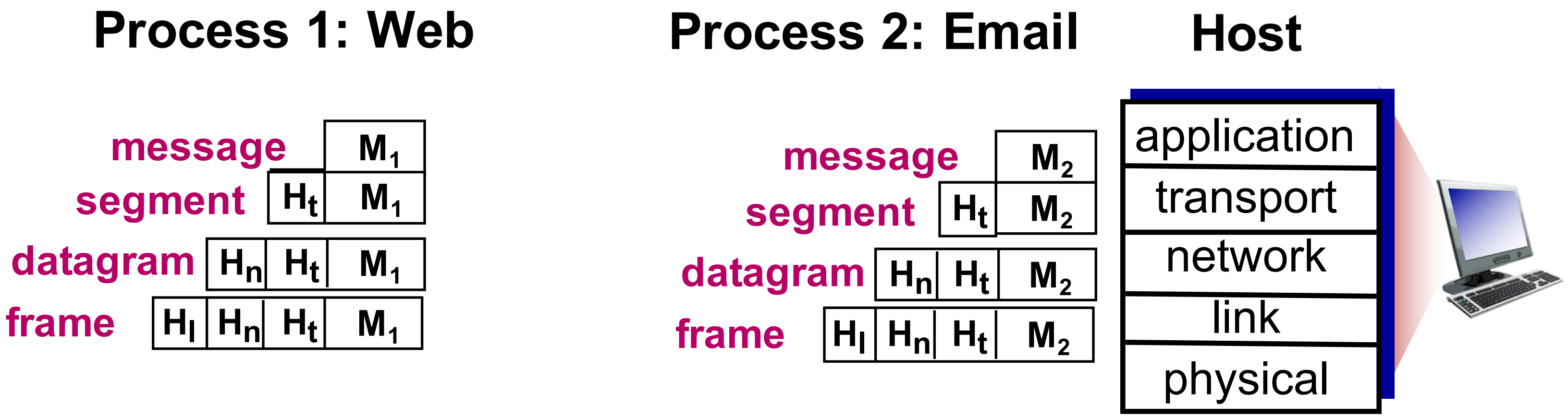
Why fragment? Max size of Ethernet frame is specified to be 1522 bytes



Now some additional book-keeping to keep track of which segments belong to which message

Multiplexing/Demultiplexing

Why multiplex? Many processes sending network traffic simultaneously on host, many hosts sharing network



Process 1: Web

message M_1
segment H_t M_1
datagram H_n H_t M_1
frame H_l H_n H_t M_1

Process 2: Email

message M_2
segment H_t M_2
datagram H_n H_t M_2
frame H_l H_n H_t M_2

Host

application
transport
network
link
physical

Now some additional book-keeping to keep track of which segments belong to which process on host

Internet

COMPONENTS

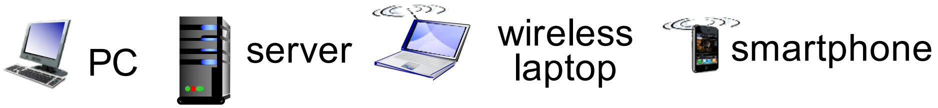
How is Internet organized physically?

A network of networks: internetwork

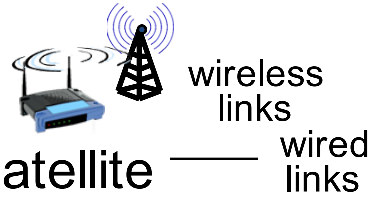
- every device implements IP (Internet Protocol) and has IP address

Billions of connected devices

- run network apps

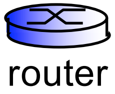


Communication links

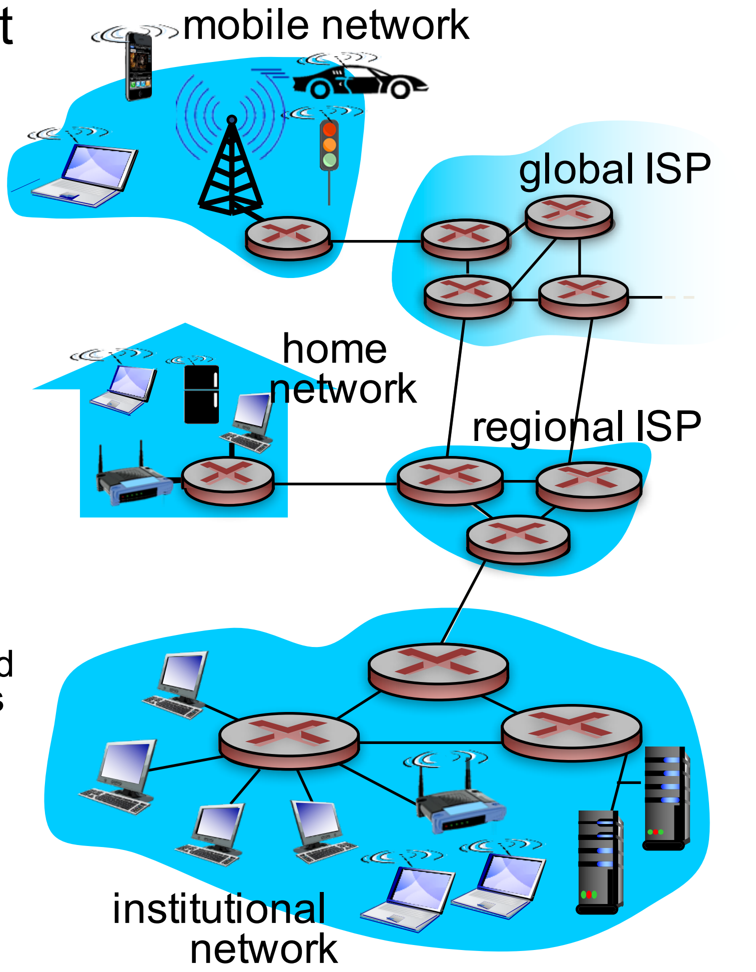


- fiber, copper, radio, satellite
- transmission rate: bandwidth

Routers (and switches)

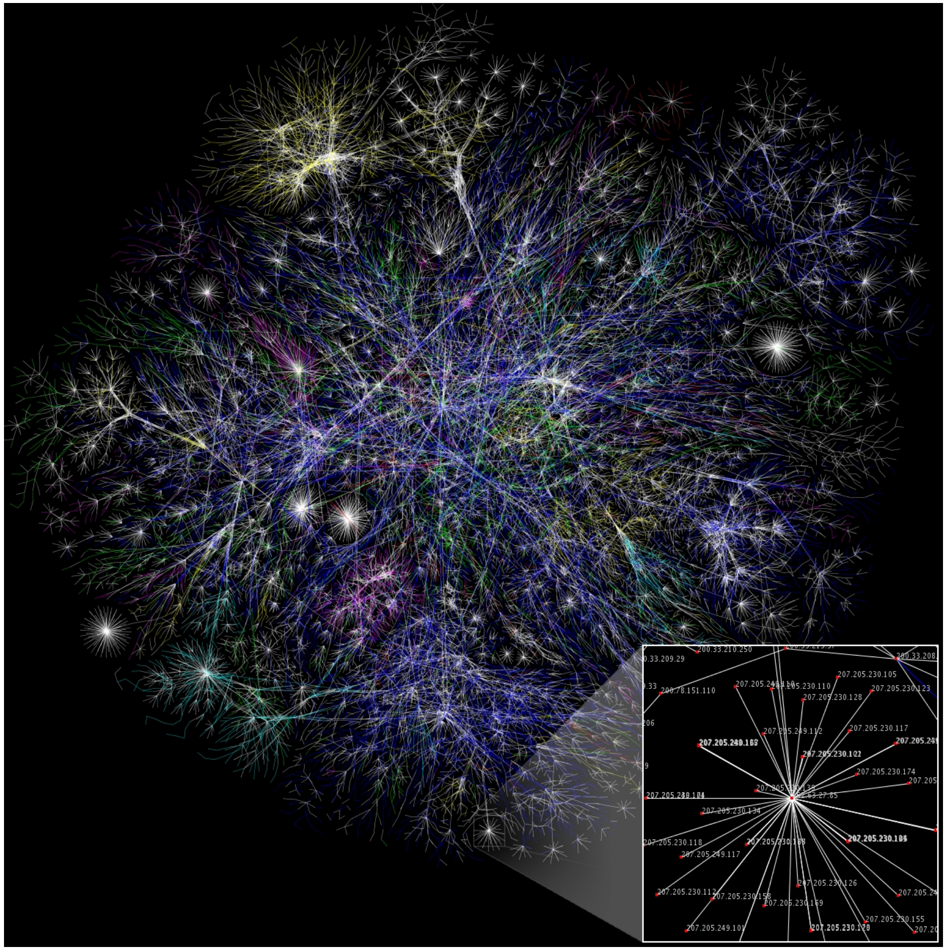


- forward packets (and frames)



ISP: Internet Service Provider

Map of the Internet



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Who is connected to whom?

Nodes

- IP addresses of devices

Edges

- lengths are delay between 2 devices

How is Internet structured?

Network edge

- hosts: clients and servers
- servers often in data centers

Access networks, physical media

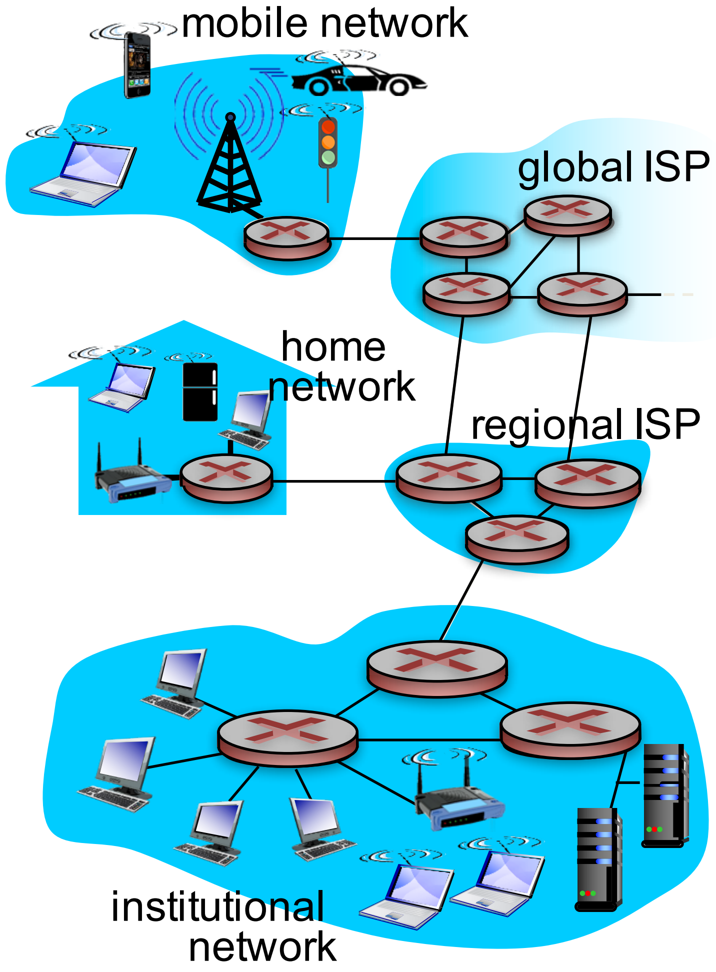
- wired, wireless communication links

Network core

- interconnected routers
- network of networks

Protocols

- control message sending, receiving



ISP: Internet Service Provider

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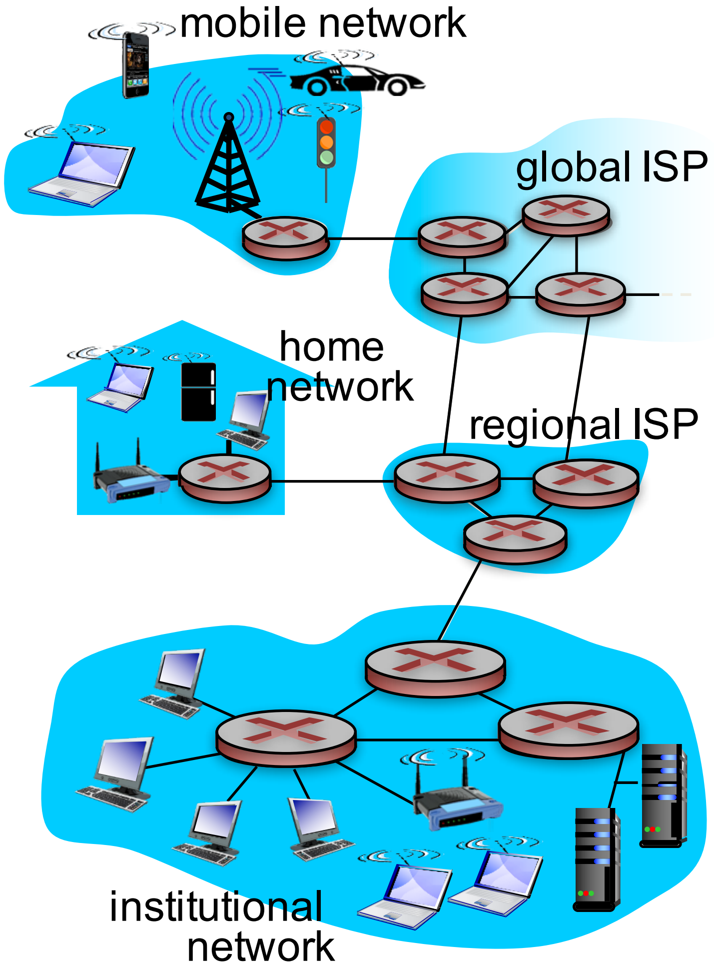
Internet provides services

Services to applications

- E.g., web, VoIP, email, games, ecommerce, social nets, …

Programming interface to apps

- hooks
  - for sending and receiving app programs to connect to Internet
- service options
  - analogous to postal service



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Internet

EDGE

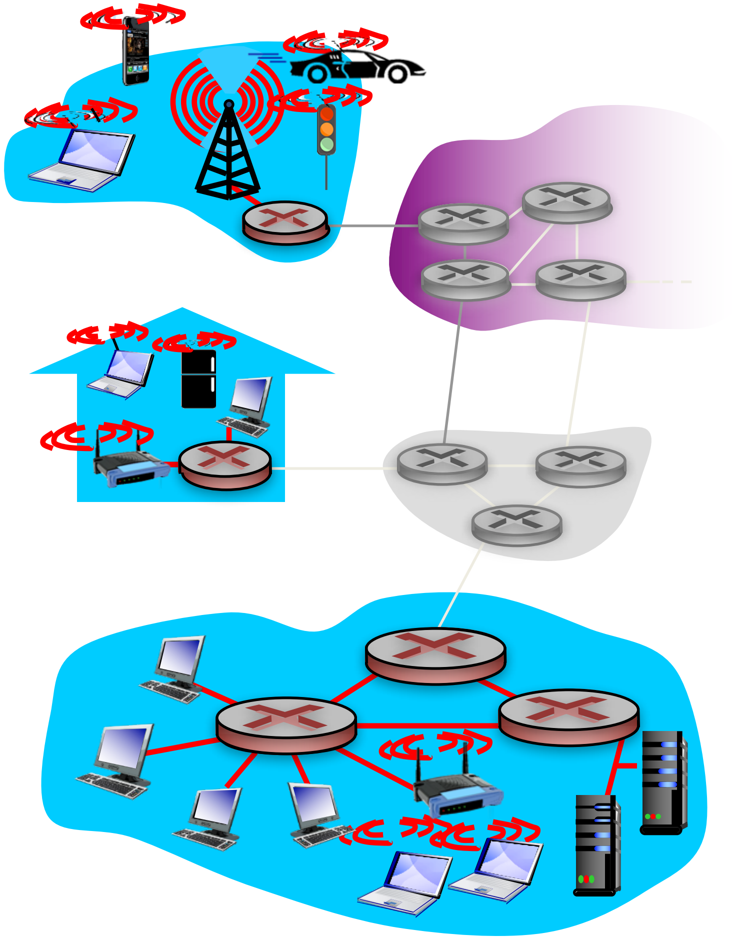
How do you connect to Internet?

Hosts connect to edge router

- access network/ISP

Access networks

- residential
  - DSL (telephone), cable,
- institutional
  - school, company
- mobile



Issues

- bandwidth (bps) of access network?
- shared or dedicated?

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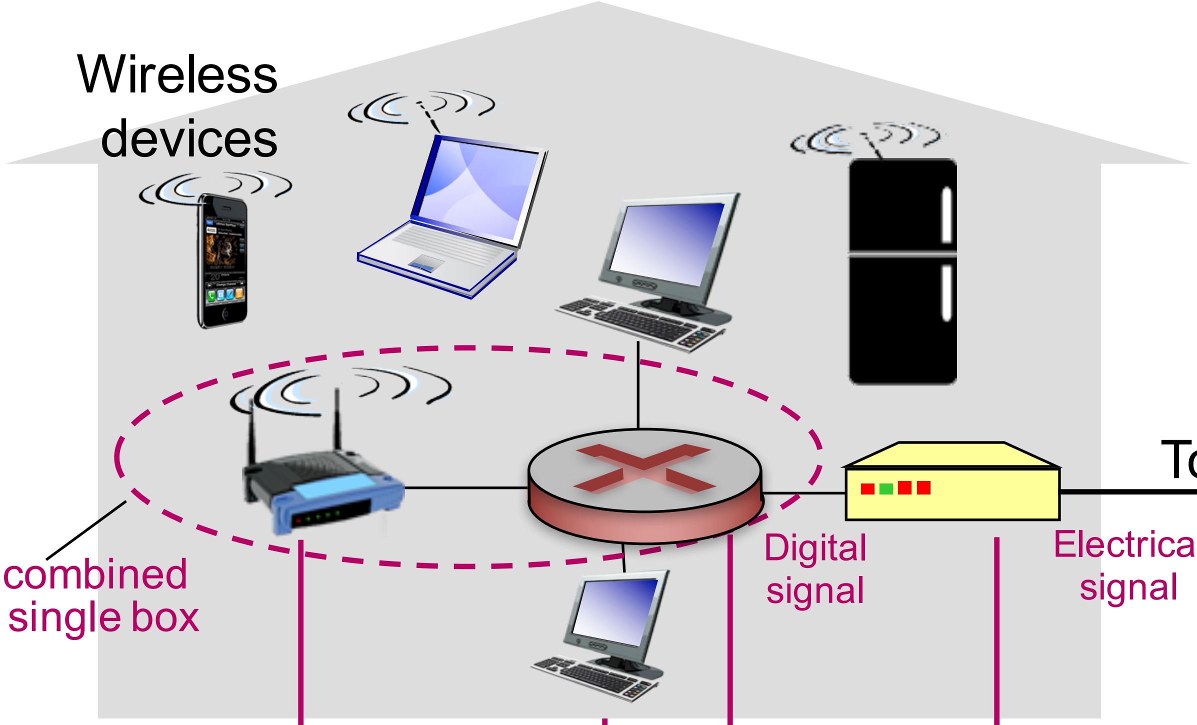
Access network: home network



Wireless devices

Often combined in single box

Digital signal

Electrical signal

To/from headend or central office

Cable or DSL modem

Router, firewall, NAT

Wireless access point (54 Mbps)

Wired Ethernet (1 Gbps)

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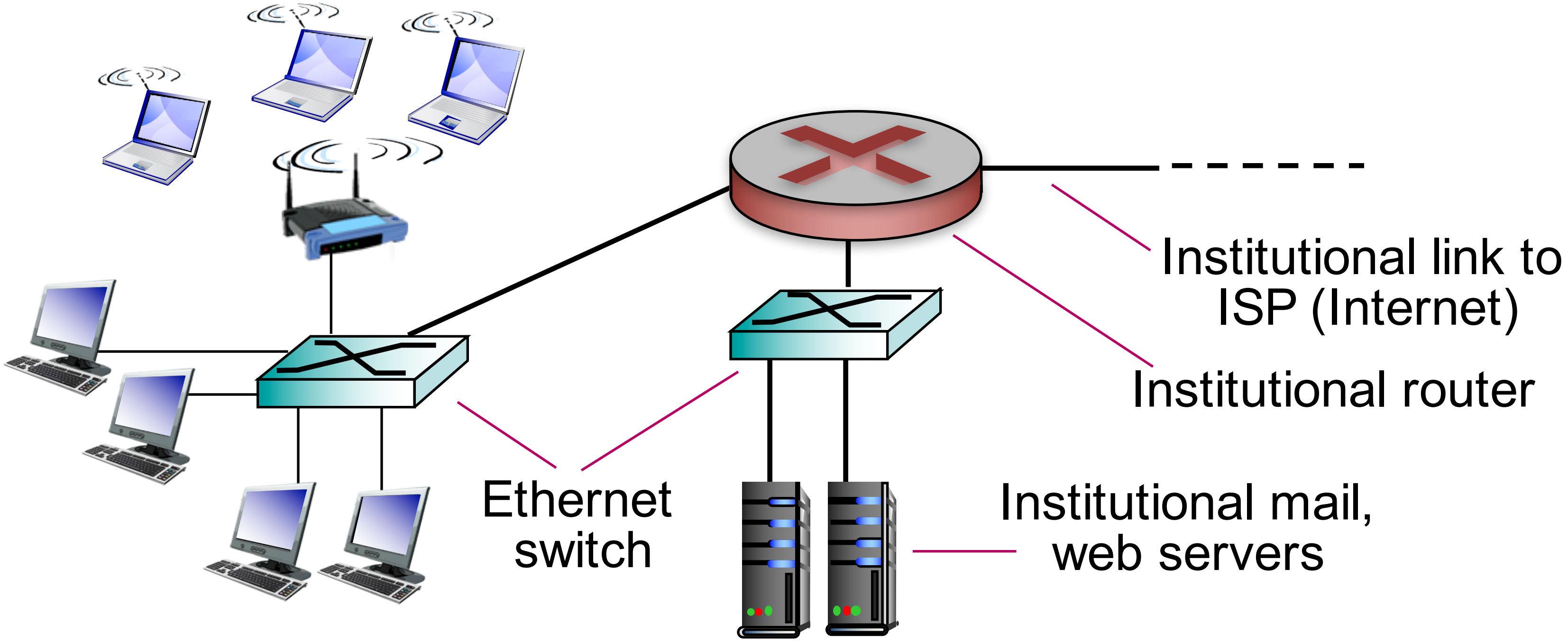
Access network: enterprise (Ethernet)

Typically used in companies, universities, etc.

- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch



Institutional link to ISP (Internet)

Institutional router

Ethernet switch

Institutional mail, web servers

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Access network: wireless

Shared wireless access network

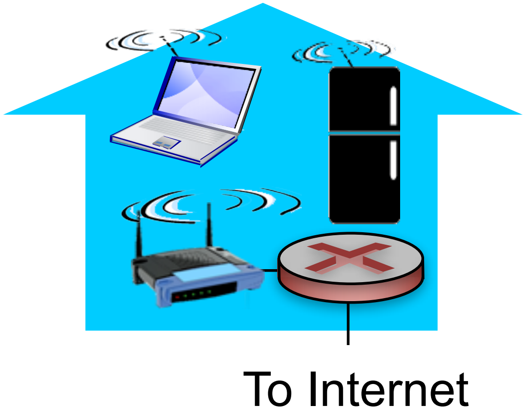
- connects end system to router via base station (aka "access point")

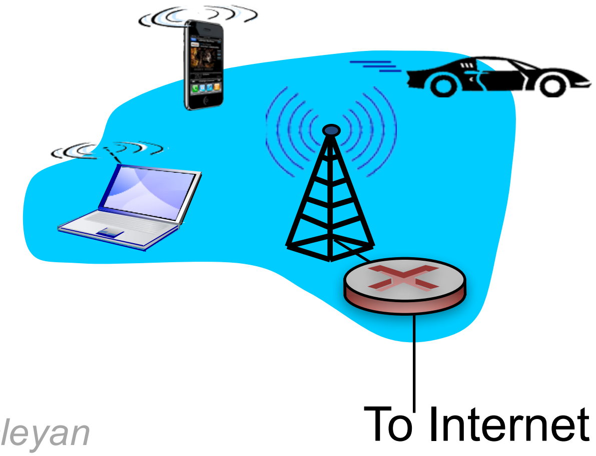
Wireless LANs

- within building (100 ft.)
- 802.11b/g/n (WiFi):
  - 11, 54, 450 Mbps

Wide-area wireless access

- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE





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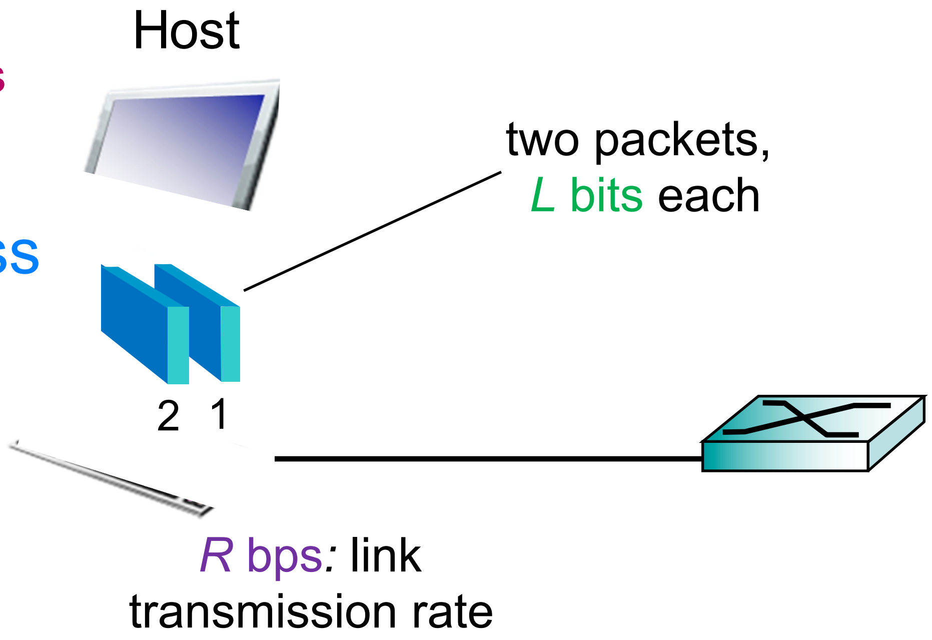
Host sends packets of data

1. Given application message
   - breaks into packets
     - smaller chunks of length *L* bits
2. Transmit packets into access network
   - at transmission rate *R*
     - aka link capacity
     - aka link bandwidth


Host

two packets,
L bits each

2 1

R bps: link
transmission rate

$$\text{Packet transmission delay} = \text{Time to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

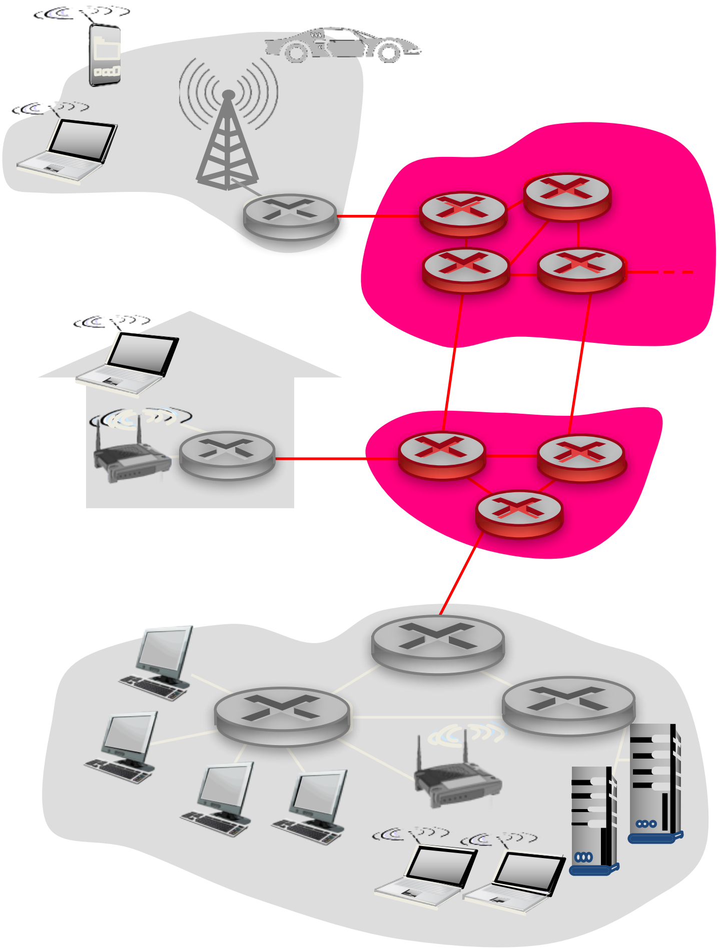
Internet

CORE

How to move data through Internet core?

Internet core

- mesh of interconnected routers



Option 1: Packet-switching

- on-demand resource allocation
- best effort service
- good bandwidth use

Option 2: Circuit-switching

- reserved resources
- guaranteed service
- may waste bandwidth

Let's see why packet-switching is used in core

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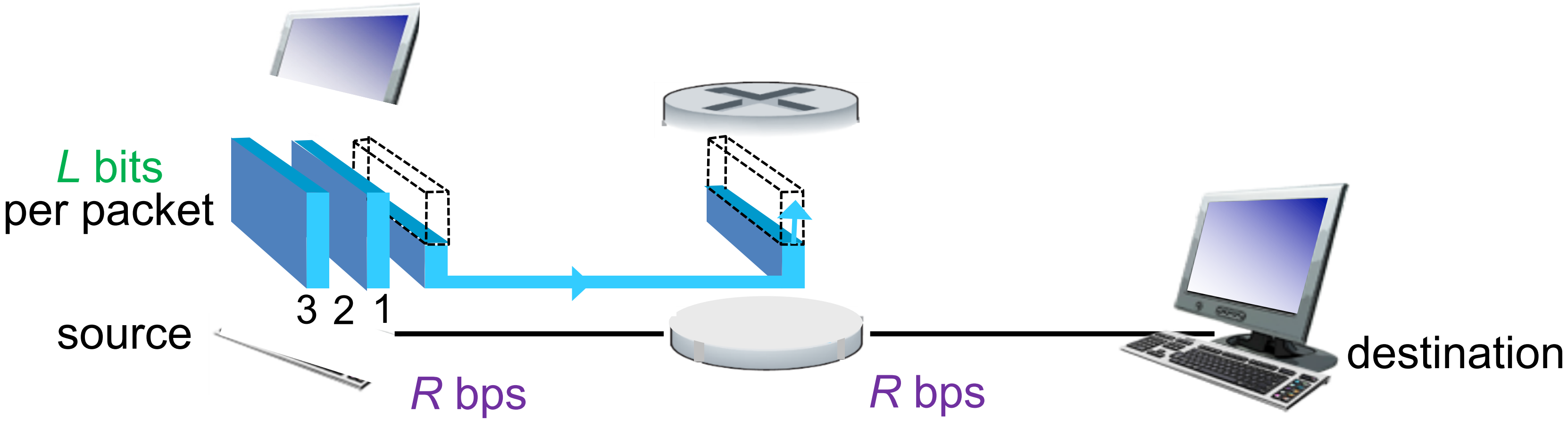
Packet-switching: store-and-forward

1. Hosts break app-layer messages into packets



2. Time to transmit (push out) *L*-bit packet into *R* bps link: *L / R seconds*

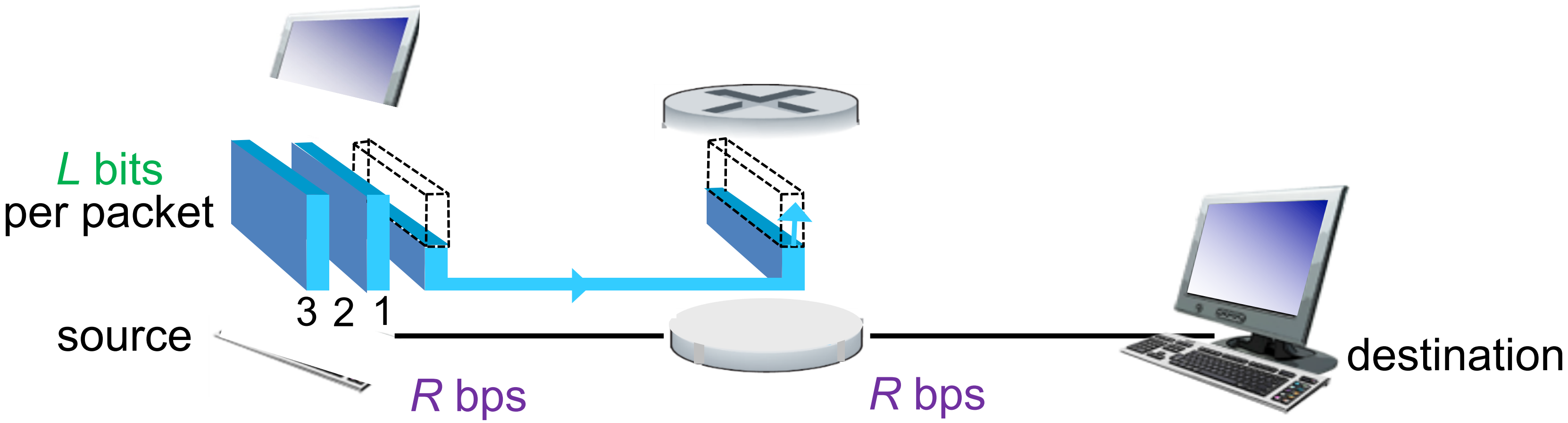
1-hop example

- L = 7.5 Mbits
- R = 1.5 Mbps
- 1-hop transmission delay = 5 sec

Packet-switching: store-and-forward

1. Hosts break app-layer messages into packets

3. Store-and-forward: entire packet must arrive at router before it can be transmitted on next link

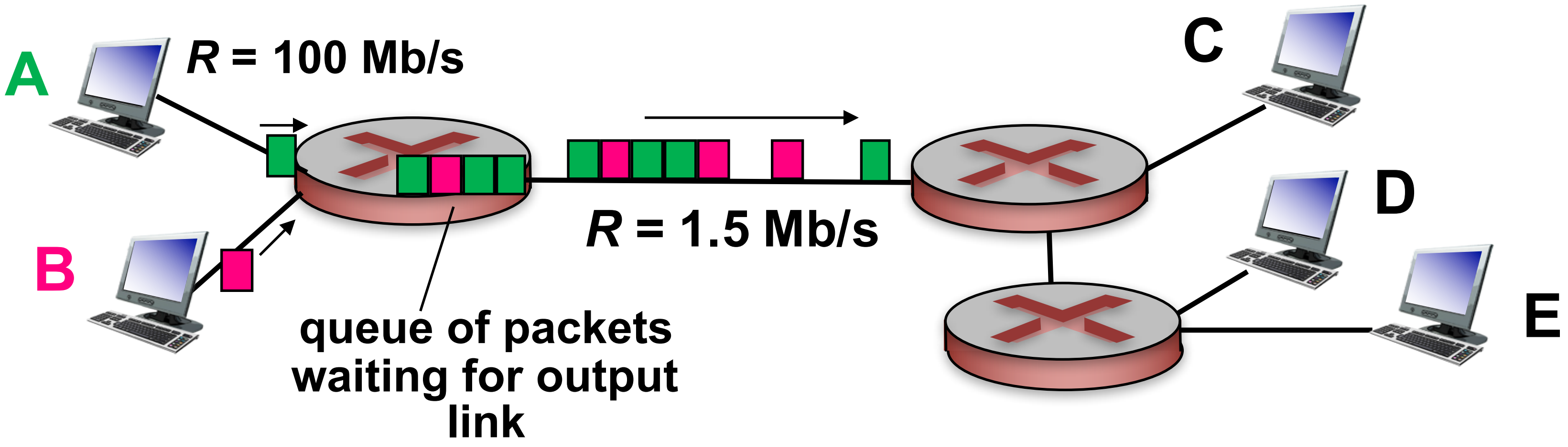


2. Time to transmit (push out) L-bit packet into R bps link: L/R seconds

4. L/R seconds

End-end transmission delay = $2L/R$
(assuming zero propagation delay)

Packet-switching: queueing delay, loss



If link arrival rate (in bits) > transmission rate link for some time

- packets will queue, wait to be transmitted on link
- packets can be dropped (lost) if memory (buffer) fills up

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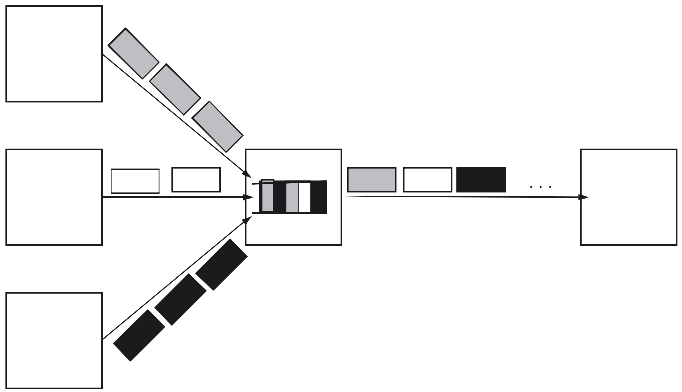
Packet-switching: multiplexing users



Multiplexing

- share links and network resources among multiple users

Statistical Multiplexing

- time-division, but on demand rather than fixed (no waste)
- reschedule link on a per-packet basis
- packets from different sources interleaved on link
- buffer packets that are contending for link
- packet queue may be processed FIFO, but not necessarily
- buffer overflow, causing packet drop (loss), is called congestion

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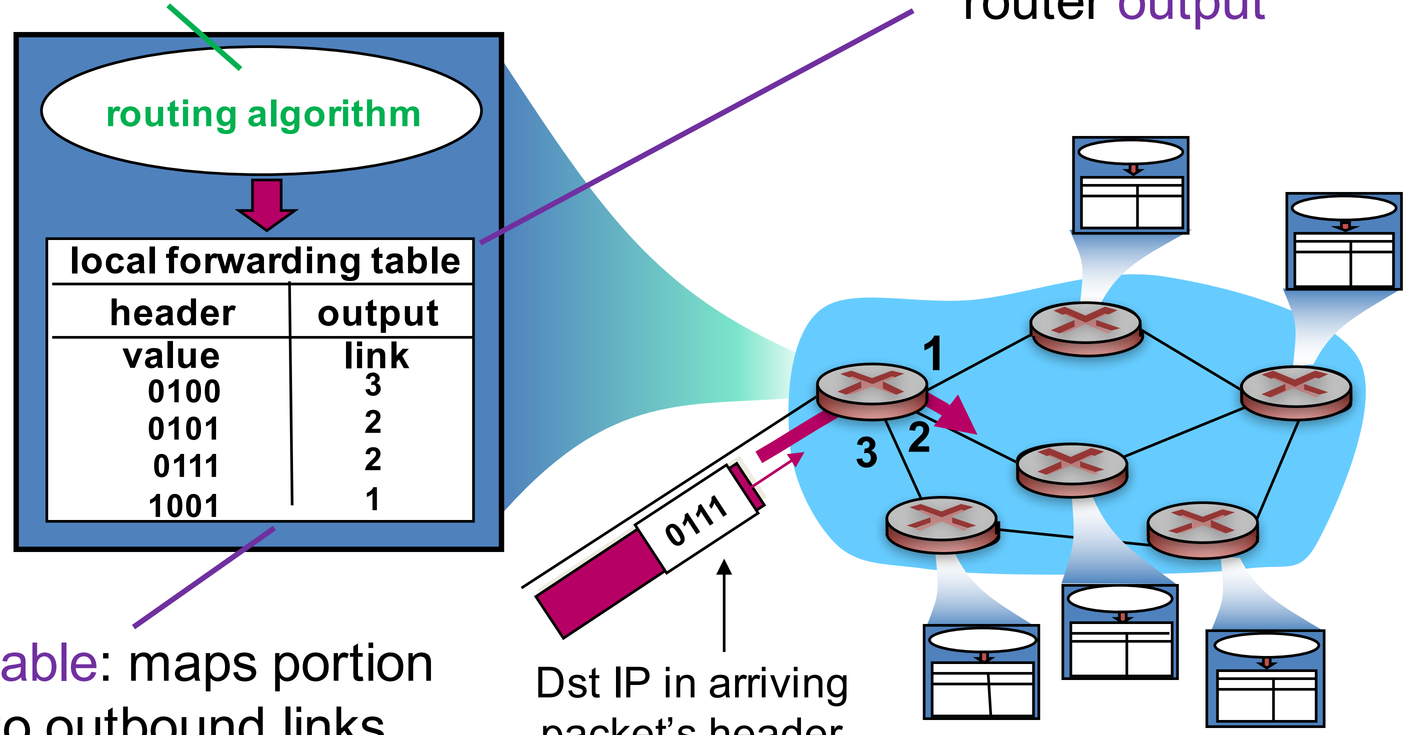
Packet-switching: 2 key functions of Internet core

How does Internet router determine outgoing link for packet?

- uses destination IP address in packet

1. Routing: determines src-dst route taken by packets, used to set forwarding table

2. Forwarding: move pkts from router's input to appropriate router output



local forwarding table

header value	output link
0100	3
0101	2
0111	2
1001	1

Forwarding table: maps portion of dst IPs to outbound links

Dst IP in arriving packet's header

Alternative core: circuit switching

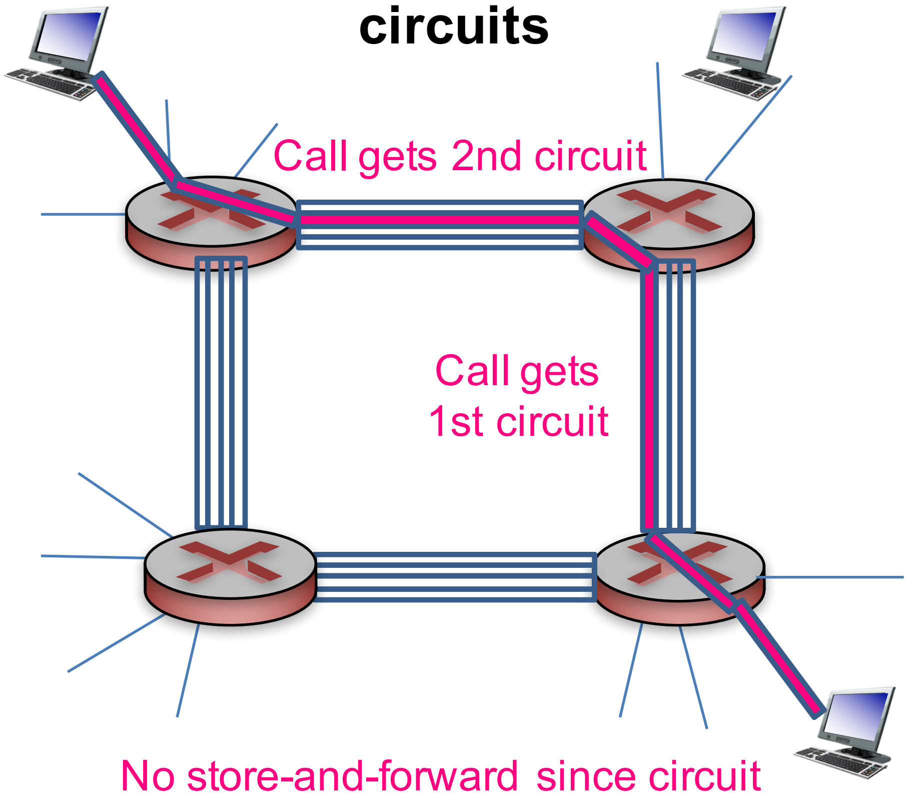
End-end resources allocated

- reserved for "call" between source & dest

Dedicated resources

- no sharing
- circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)

Commonly used in traditional telephone networks



Each link has four circuits

Call gets 2nd circuit

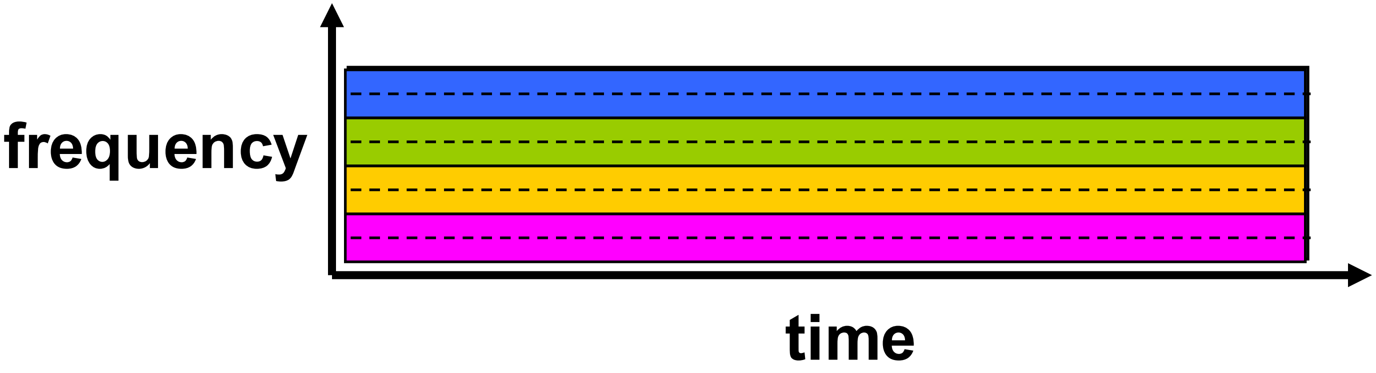
Call gets 1st circuit

No store-and-forward since circuit reserved in advance: already know where to forward data next

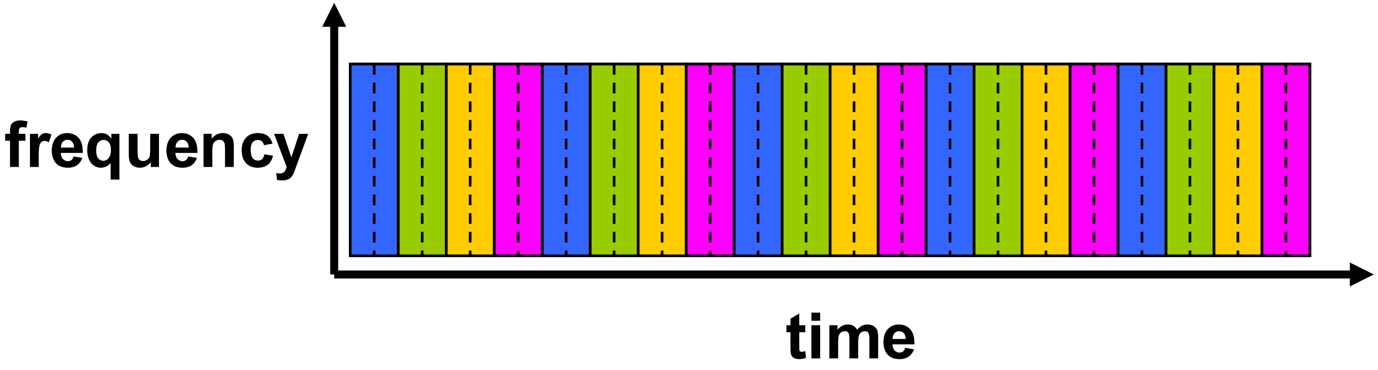
Q: what happens if there is a lull in conversation?

Circuit switching: multiplexing users

Frequency Division Multiplexing



Time Division Multiplexing

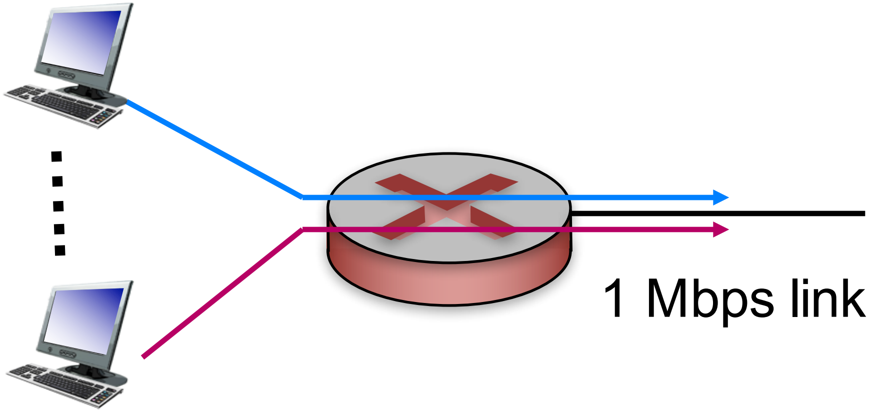


4 users 🟦 🟩 🟨 🟪

Packet switching versus circuit switching

N users

- each user is active 10% of time
- 100 Kbps when active



How many users can be supported?

Circuit switching

- 1 Mbps / 10 = 100 Kbps
- N = 10 users

Packet switching

- N = 35 users
- prob > 10 users active at same time is < .0004

Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

Packet switching allows more users to use network!

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Binomial random variable (homework)

Suppose we do n independent experiments, each of which succeeds with probability p and fails with probability 1-p

X = R.V. indicating # of successes that occur in n trials

$$P(X = i) = \underbrace{\binom{n}{i}}_{\substack{\text{n choose i} \\ \text{different ways to} \\ \text{get i successful} \\ \text{experiments}}} \overset{\text{successes}}{p^{i}} \underbrace{(1-p)^{n-i}}_{\text{failures}}$$

Independent experiments: knowledge about one experiment occurring does not affect probability of other experiment occurring: e.g., coin toss.

$$P(A \text{ and } B) = P(A) \times P(B)$$
$$P(A \text{ or } B) = P(A) + P(B)$$

$$P(X=4 \text{ and } X=5) = P(X=4) \times P(X=5)$$
$$P(X=4 \text{ or } X=5) = P(X=4) + P(X=5)$$

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Is packet switching always better?

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

How to provide circuit-like behavior?

- bandwidth guarantees needed for audio/video apps
- still an unsolved problem (chapter 7)

Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?