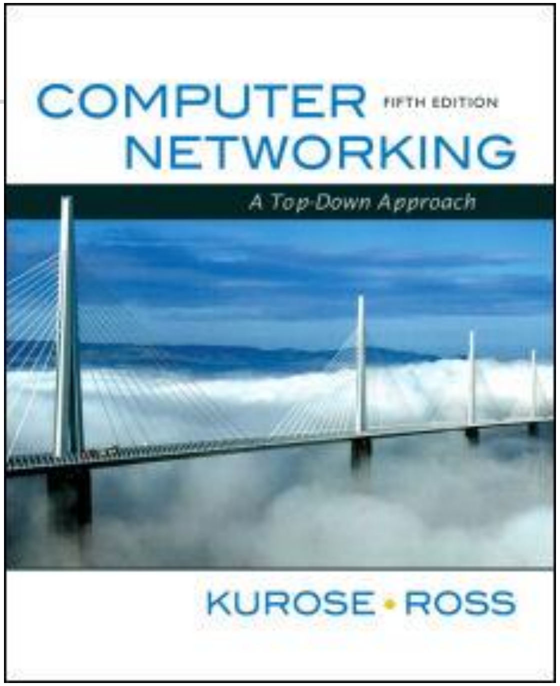
Chapter 1
Introduction



Computer Networking: A Top Down Approach Featuring the Internet, 5th edition.
Jim Kurose, Keith Ross
Pearson Addison-Wesley, 2009.

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Thanks and enjoy! JFK/KWR

Chapter 1: Roadmap

1.1 What *is* the Internet?

1.2 Network edge

1.3 Network core

1.4 Network access and physical media

1.5 Internet structure and ISPs

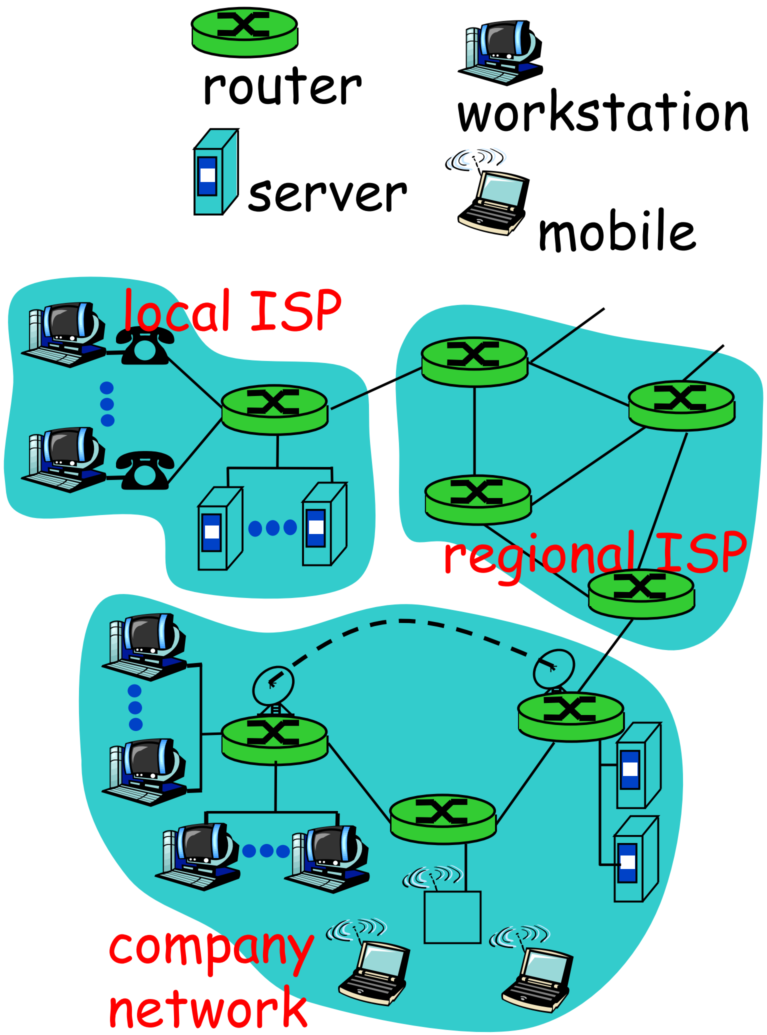
1.6 Delay & loss in packet-switched networks

1.7 Protocol layers, service models

1.8 History

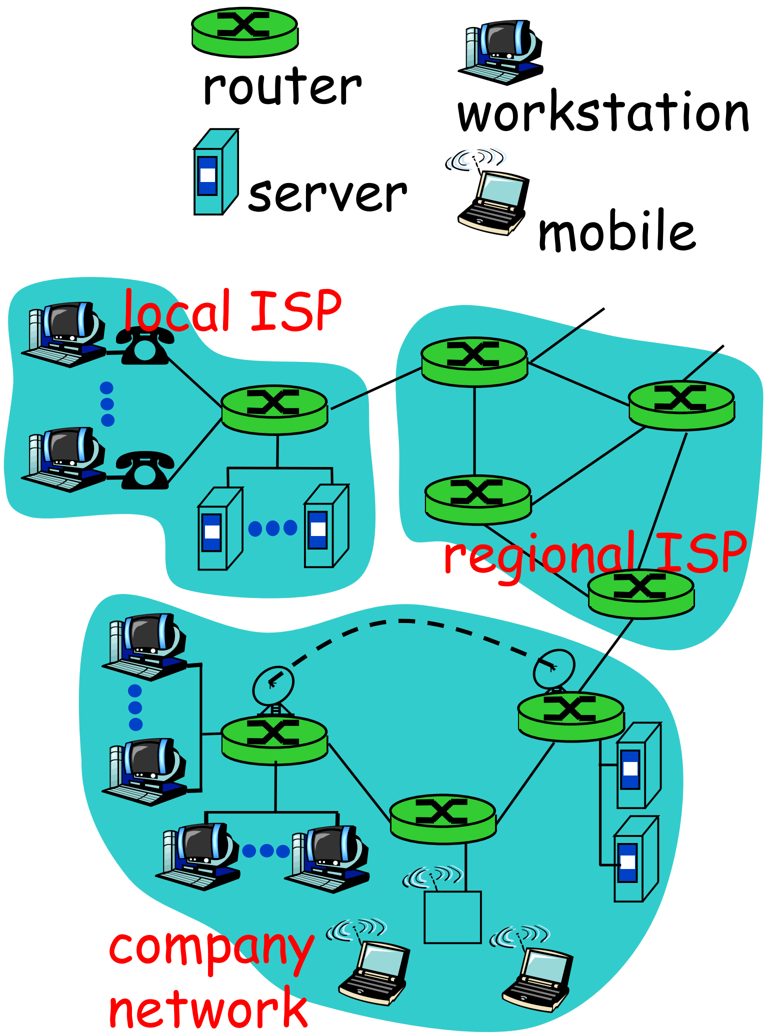
What's the Internet: "Nuts and bolts" view

- Millions of connected computing devices
  - *hosts = end systems*
- Running *network apps*
- *Communication links*
  - fiber, copper, radio, satellite
  - transmission rate = ***bandwidth***
- *Routers*
  - forward packets (chunks of data)



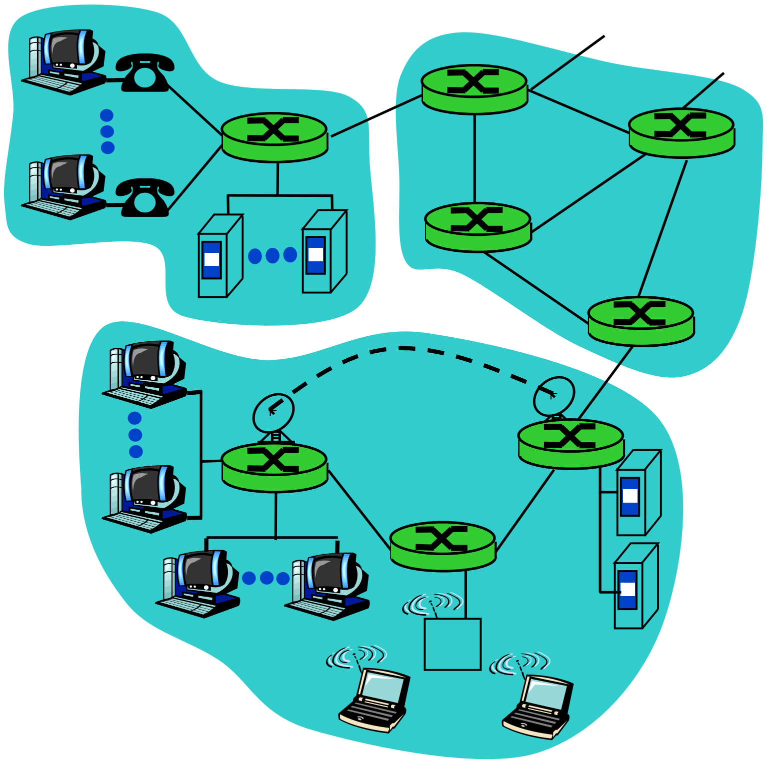
What's the Internet: "Nuts and bolts" view

- *Protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, FTP, PPP
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet: A service view

- Communication *infrastructure* enables distributed applications
  - web, email, games, e-commerce, file sharing
- Communication services provided to apps
  - connectionless unreliable
  - connection-oriented reliable



What's a protocol?

Human protocols

- "What's the time?"
- "I have a question"
- Introductions

… specific msgs sent

… specific actions taken when msgs received, or other events

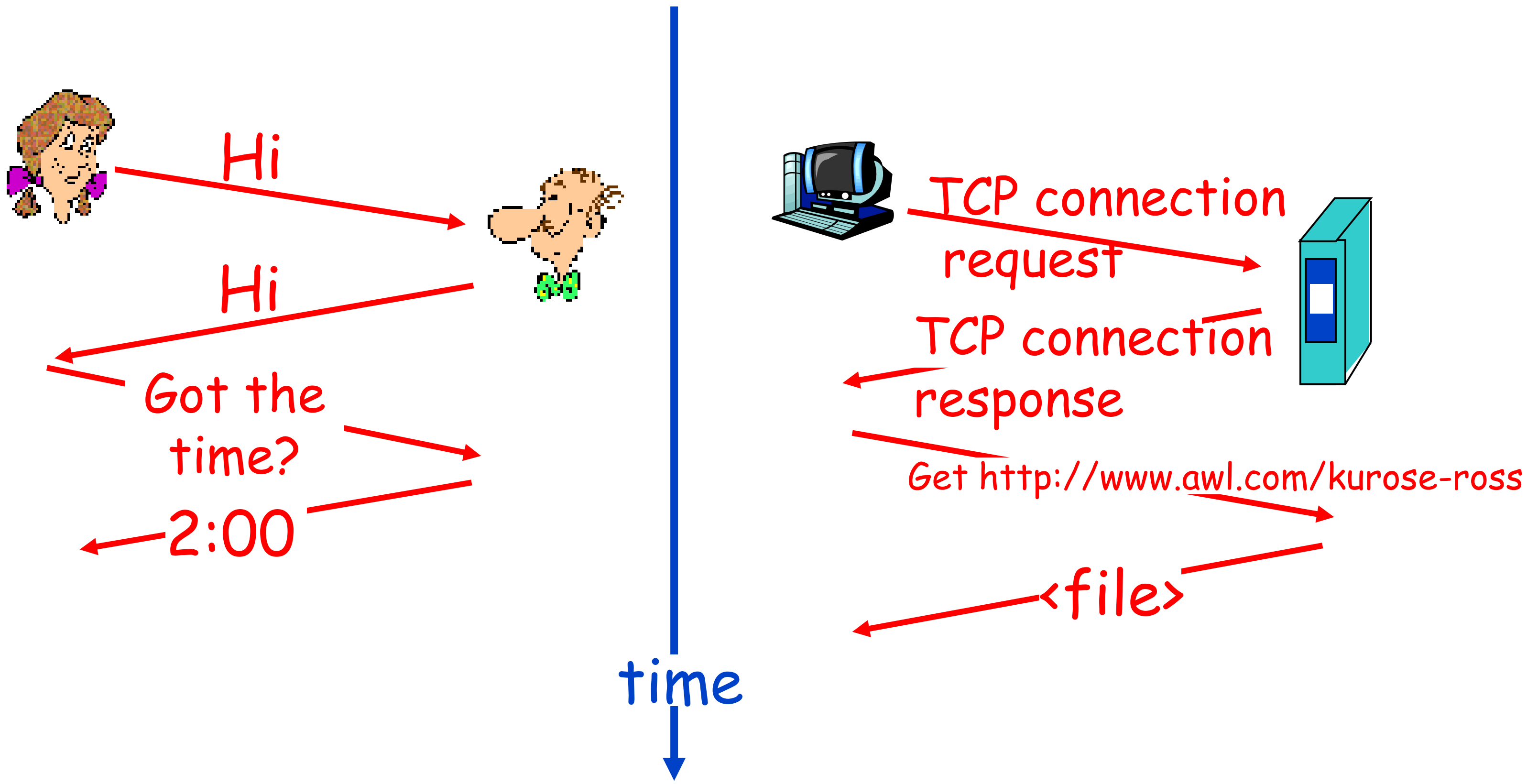
Network protocols

- Machines rather than humans
- All communication activity in the Internet governed by protocols

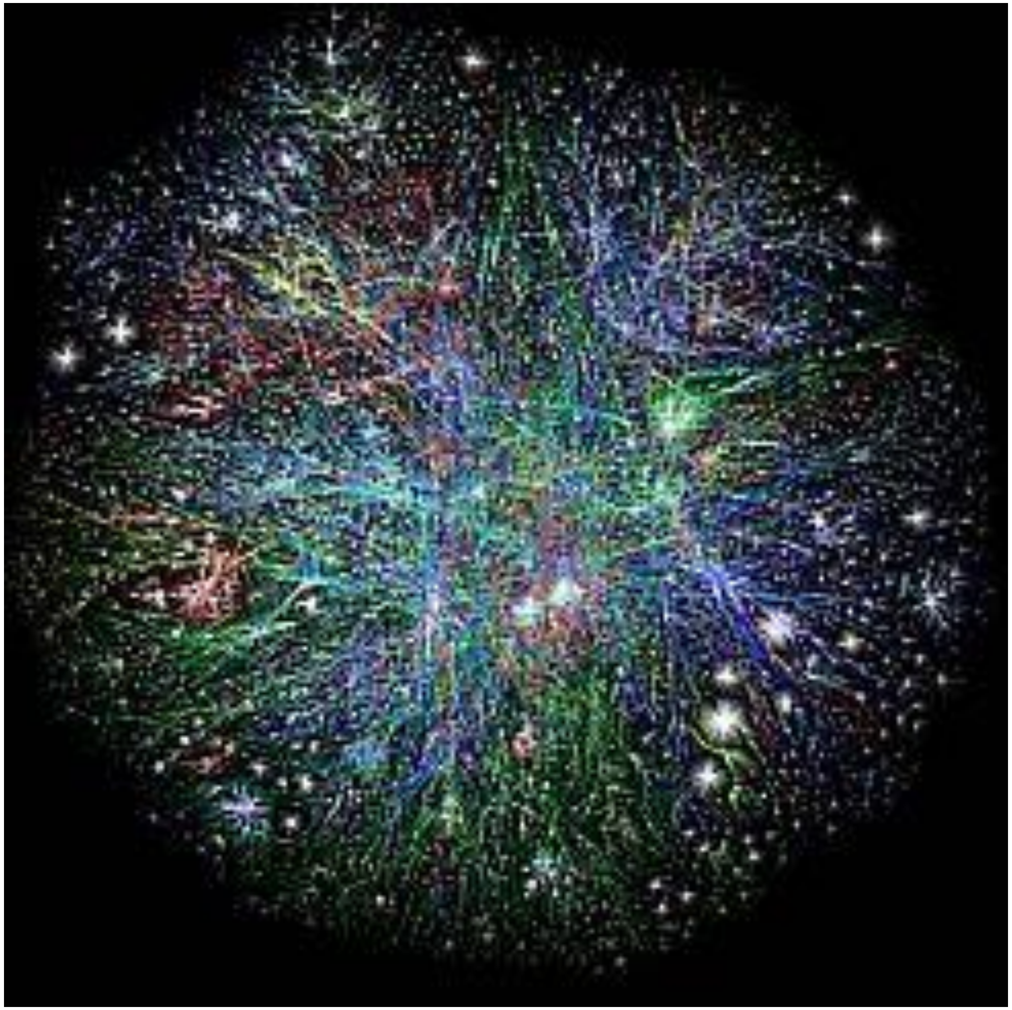
Protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

What's a protocol?

A human protocol and a computer network protocol:



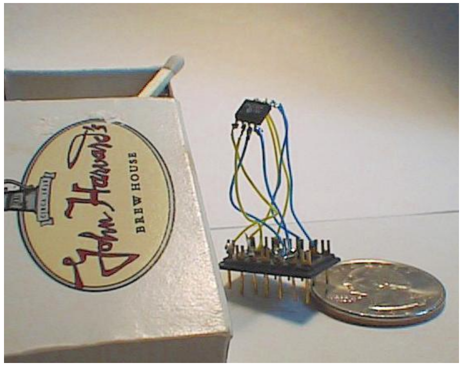
How does the Internet look like?



“Cool” Internet appliances

IP picture frame
http://www.ceiva.com/

Web-enabled toaster + weather forecaster



World’s smallest web server
http://www-ccs.cs.umass.edu/~shri/iPic.html

Internet phones

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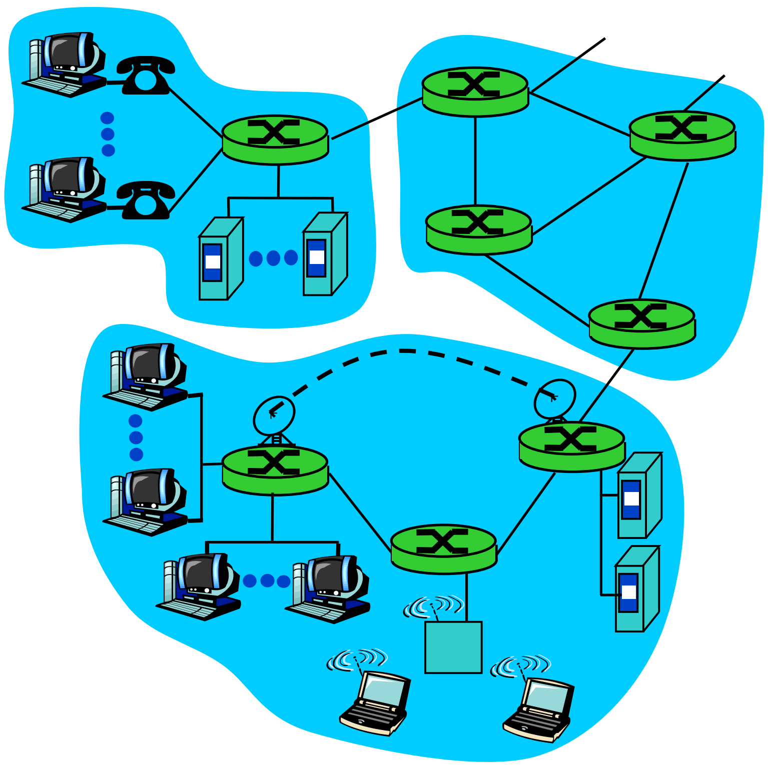
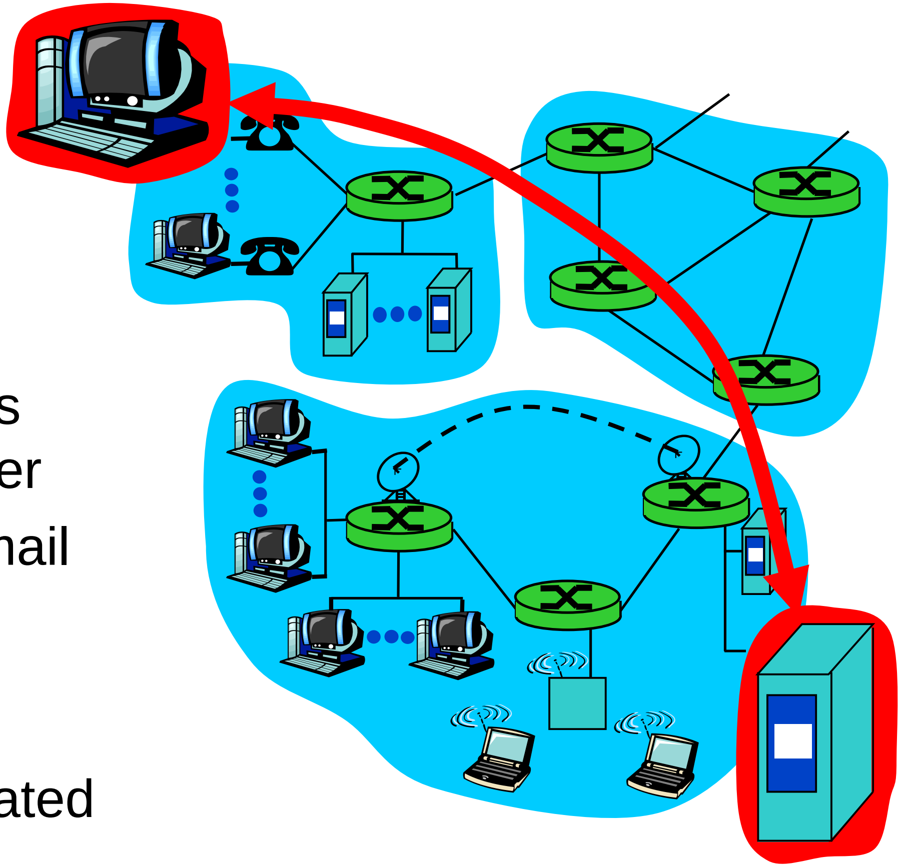
A closer look at network structure

- Network edge
  - applications and hosts
- Network core
  - routers
  - network of networks
- Access networks, physical media
  - communication links



The network edge

- End systems (hosts)
  - run application programs
  - e.g. Web, email
  - at “edge of network”
- Client/server model
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- Peer-peer model
  - minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent, KaZaA



Network edge: Connection-oriented service

Goal: data transfer between end systems

- *Handshaking:* setup (prepare for) data transfer ahead of time
  - hello, hello back human protocol
  - *set up "state"* in two communicating hosts
- TCP - Transmission Control Protocol
  - Internet's connection-oriented service

TCP service [RFC 793]

- *Reliable, in-order* byte-stream data transfer
  - loss: acknowledgements and retransmissions
- *Flow control*
  - sender won't overwhelm receiver
- *Congestion control*
  - senders "slow down sending rate" when network congested

Network edge: Connectionless service

Goal: data transfer between end systems

- same as before!

- UDP - User Datagram Protocol [RFC 768]:
  - connectionless
  - unreliable data transfer
  - no flow control
  - no congestion control

App's using TCP

- HTTP (Web), FTP (file transfer), Telnet (remote login), SMTP (email)

App's using UDP

- Streaming media, teleconferencing, DNS, Internet telephony

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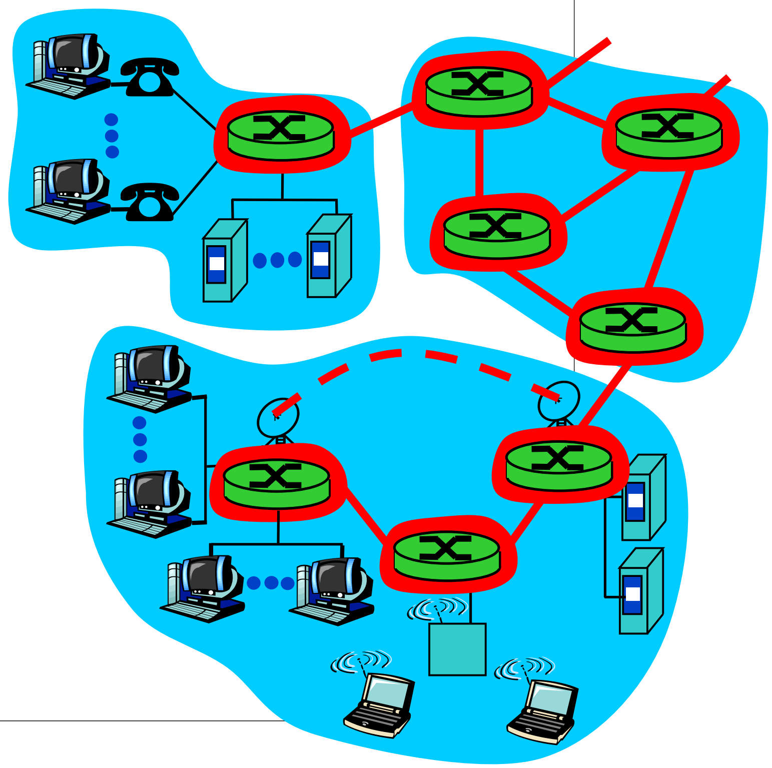
The network core

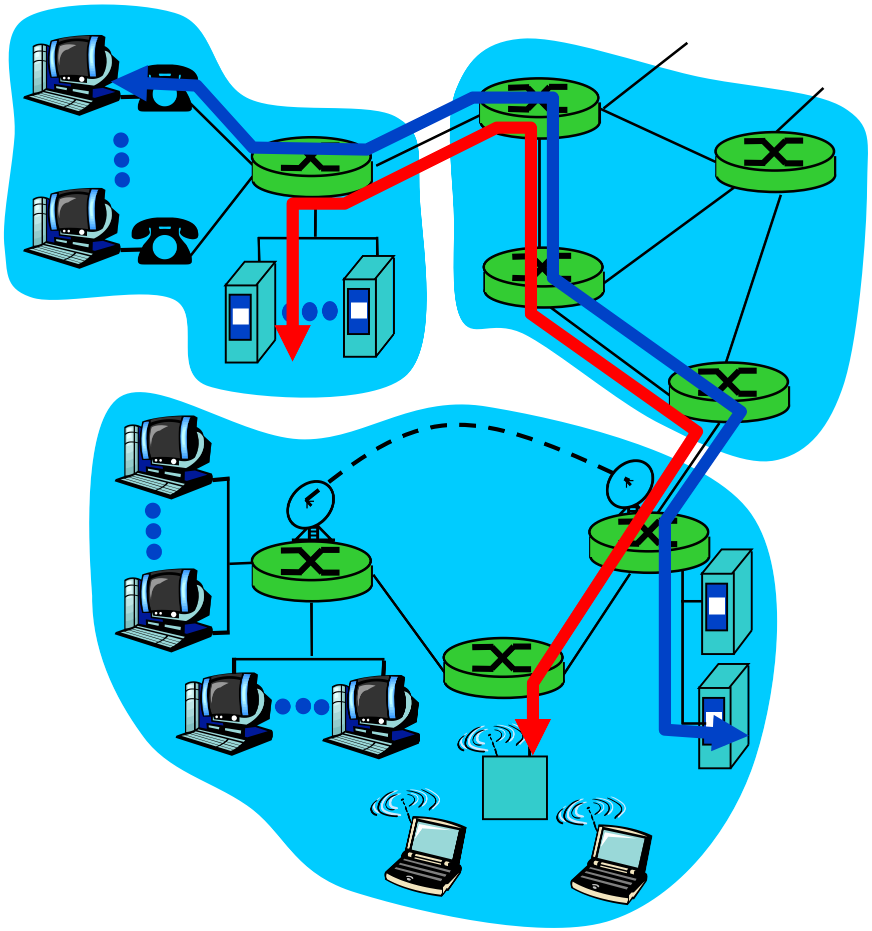
- Mesh of interconnected routers
- *The* fundamental question: how is data transferred through net?
  - Circuit-switching
    - dedicated circuit per call: telephone net
  - Packet-switching
    - data sent thru net in discrete “chunks”



Network core: Circuit-switching

End-end resources reserved for "call"

- Link bandwidth, switch capacity
- Dedicated resources: no sharing
- Circuit-like (guaranteed) performance
- Call setup required



Network core: Circuit-switching

Network resources (e.g., bandwidth) divided into “pieces”

- Pieces allocated to calls
- Resource piece *idle* if not used by owning call *(no sharing)*

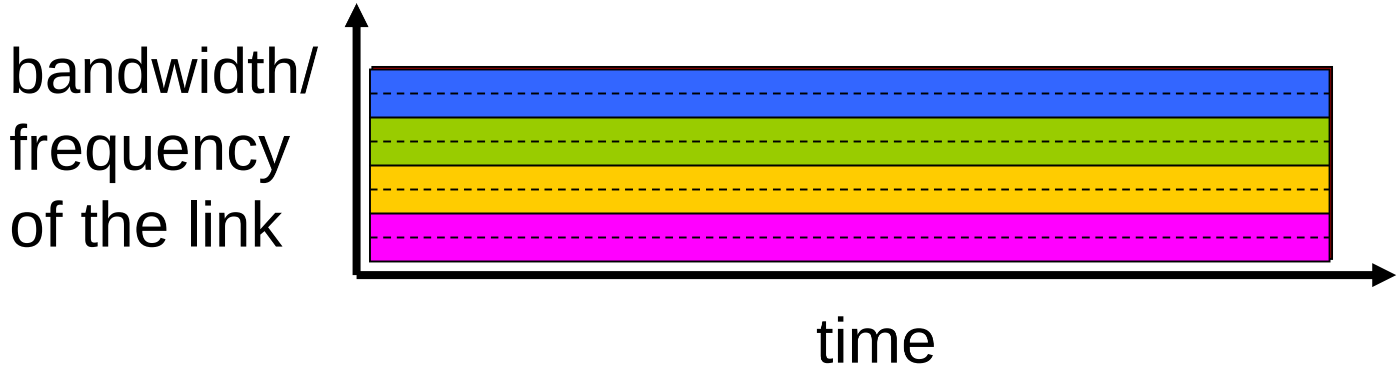
- Dividing link bandwidth into “pieces”
  - frequency division
  - time division

Circuit-switching: FDM and TDM

Example:

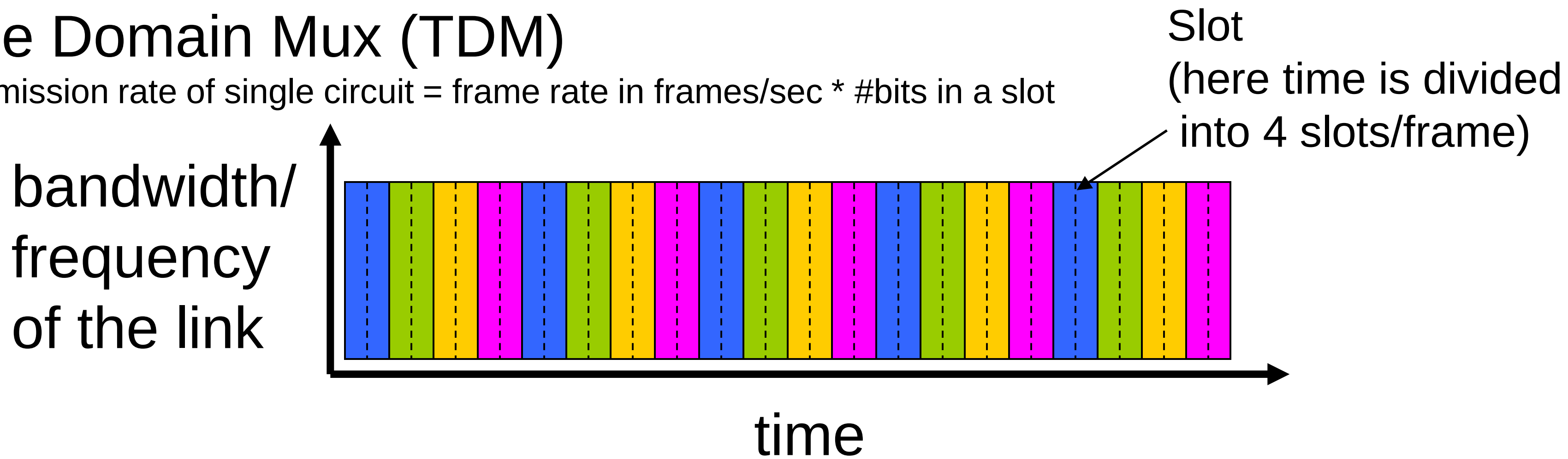
4 users

FDM



Time Domain Mux (TDM)

Transmission rate of single circuit = frame rate in frames/sec * #bits in a slot



Network core: Packet-switching

Each end-end data stream divided into *packets*

- User A, B packets *share* network resources
- Each packet uses full link bandwidth
- Resources used *as needed*

Bandwidth division into “pieces”

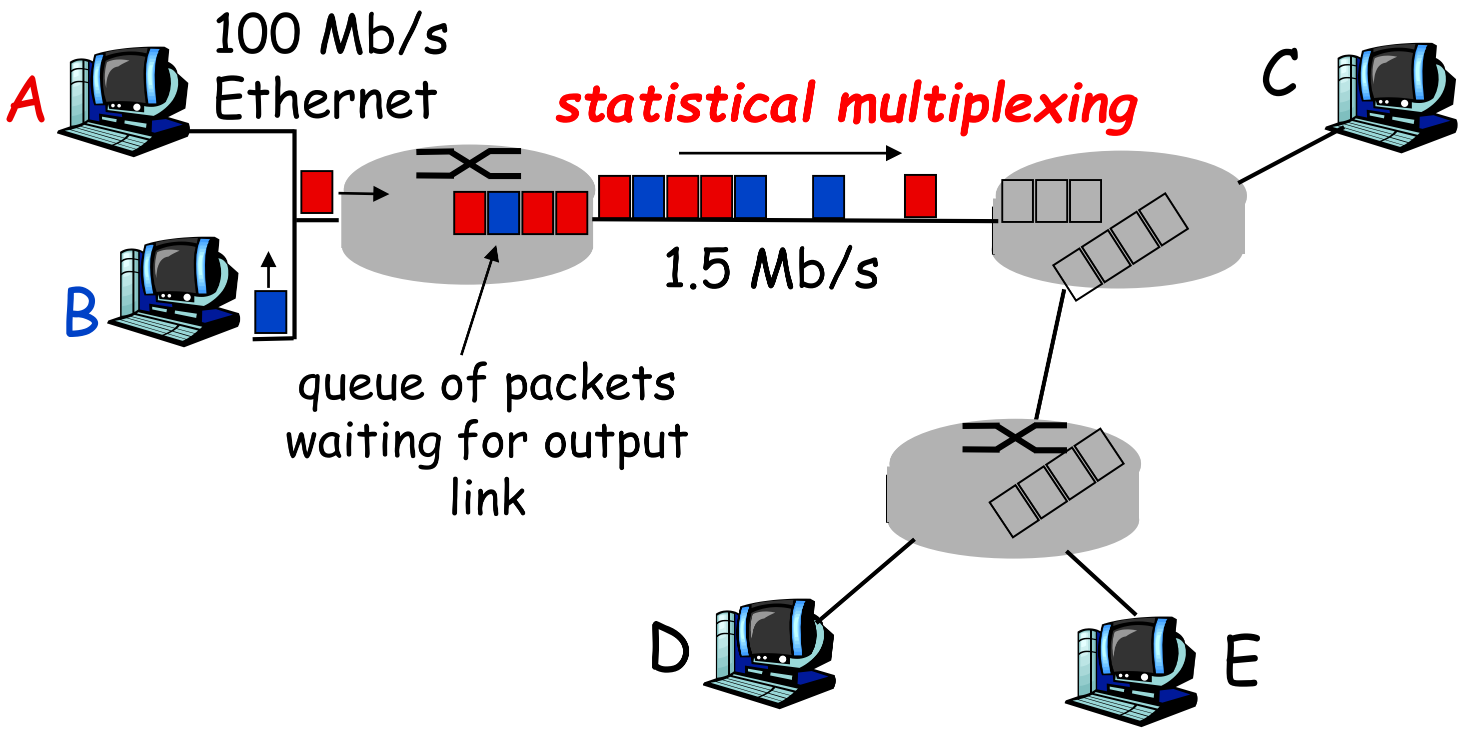
Dedicated allocation

Resource reservation

Resource contention

- Aggregate resource demand can exceed amount available
- Congestion: packets queue, wait for link use
- Store and forward: packets move one hop at a time
  - node receives complete packet before forwarding

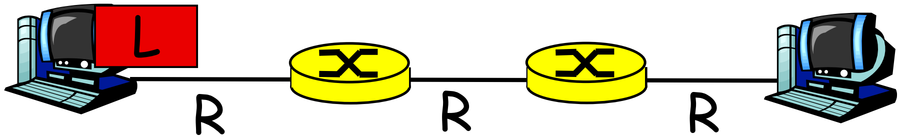
Packet switching: Statistical multiplexing



Sequence of A & B packets does not have fixed pattern, shared on demand ***statistical multiplexing***

TDM: each host gets the same slot in revolving TDM frame.

Packet switching: Store-and-forward



- Takes L/R seconds to transmit (push out) packet of L bits on to link of R bps capacity
- Entire packet must arrive at router before it can be transmitted on next link: *store-and-forward*
- delay = 3L/R (assuming zero propagation delay)

Example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- delay = 15 sec

} more on delay shortly …

Packet-switching versus circuit-switching

Is packet switching a “slam dunk winner?”

- Great for bursty data
  - resource sharing
  - simpler, no call setup
- Excessive congestion: 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

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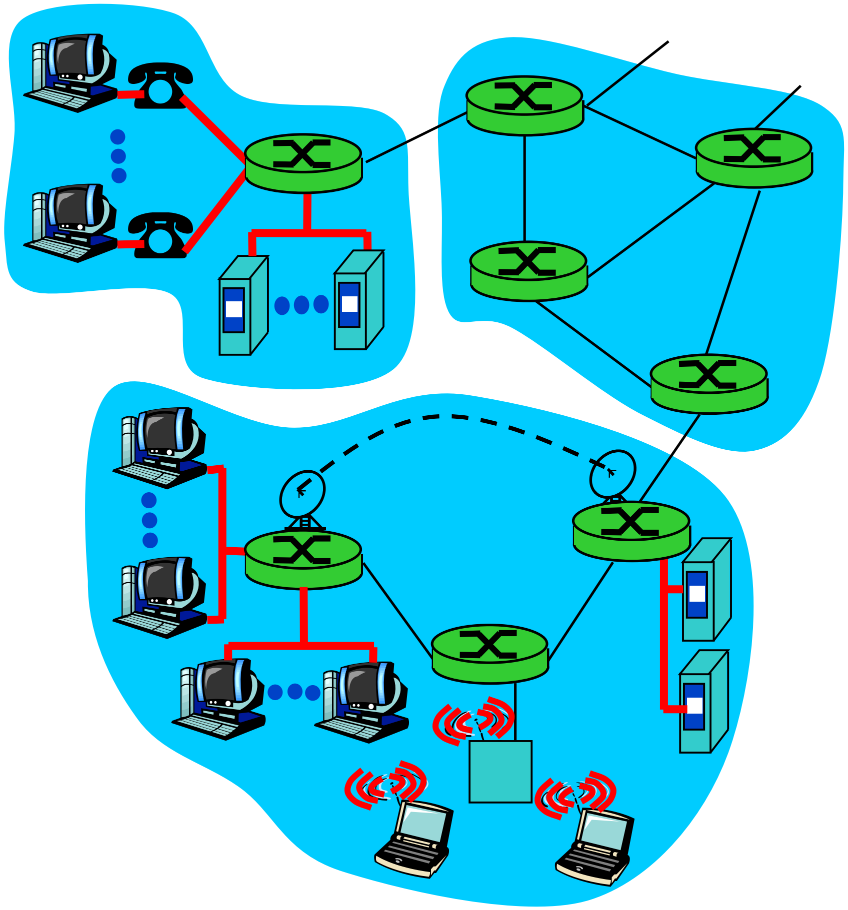
Access networks and physical media

Q: How to connect end systems to edge router?

- Residential access nets
- Institutional access networks (school, company)
- Mobile access networks

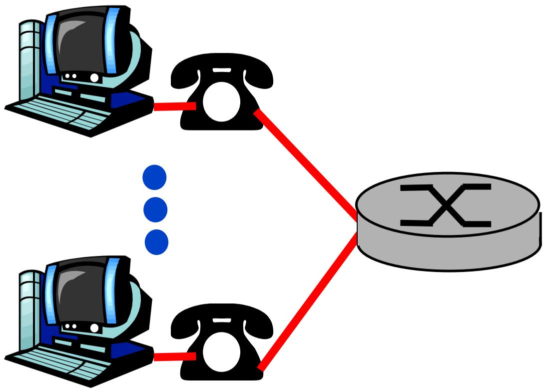


Keep in mind

- Bandwidth (bits per second) of access network?
- Shared or dedicated?

Residential access: Point-to-point access

- Dialup via modem
  - Up to 56 Kbps direct access to router (often less)
  - Can't surf and phone at same time: can't be "always on"



- ADSL: Asymmetric Digital Subscriber Lline
  - Up to 1 Mbps upstream (today typically 512-1024 kbps)
  - Up to 8 Mbps downstream (today typically 5-10 Mbps)
  - FDM: 50 kHz - 1 MHz for downstream

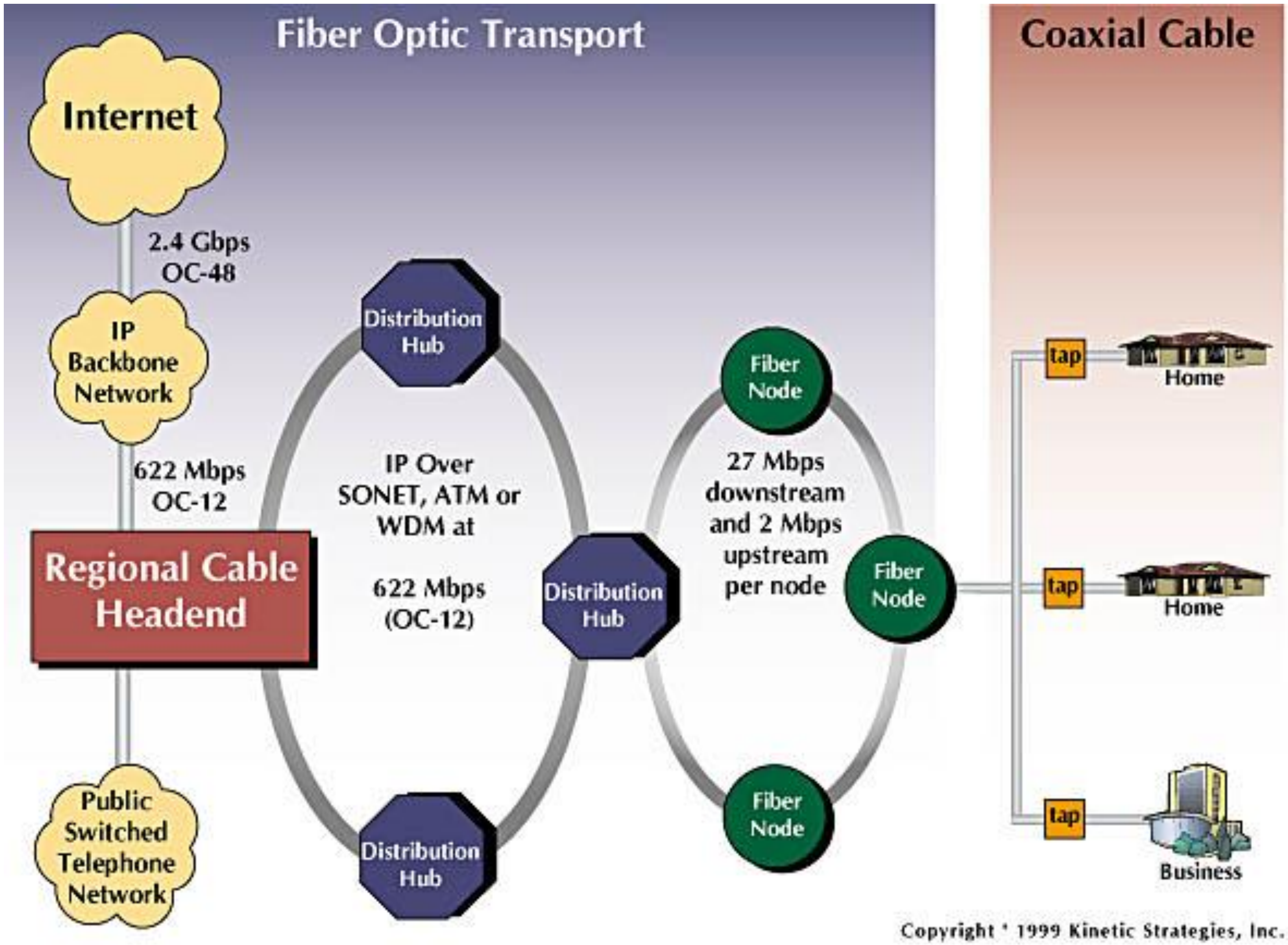
    4 kHz - 50 kHz for upstream

    0 kHz - 4 kHz for ordinary telephone

Residential access: Cable modems

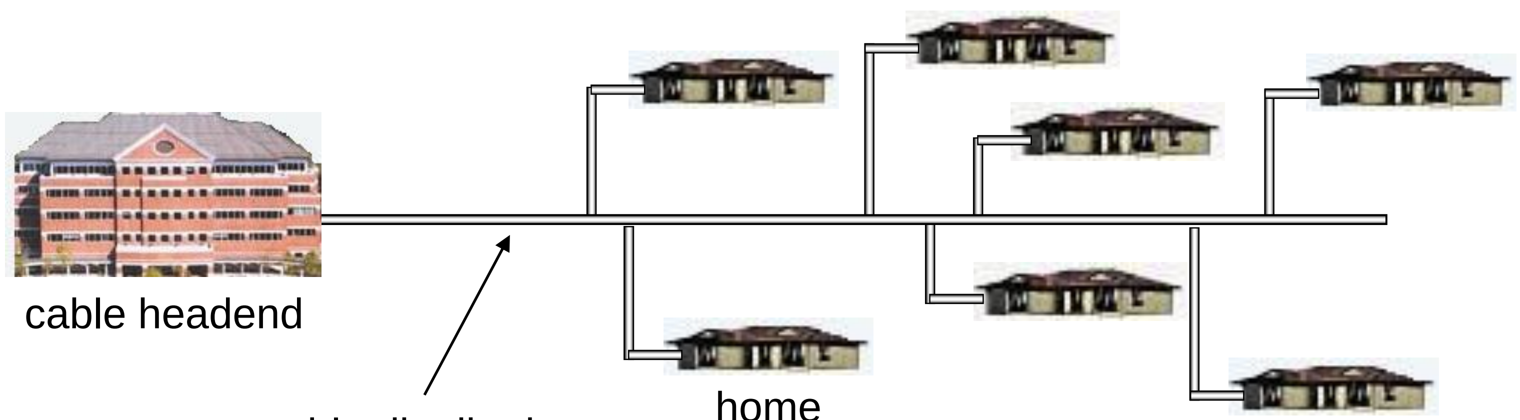
- HFC: Hybrid Fiber Coax
  - asymmetric: up to 30 Mbps downstream, 2 Mbps upstream
- Network of cable and fiber attaches homes to ISP router
  - homes share access to router
- Deployment
  - available via cable TV companies

Residential access: Cable modems

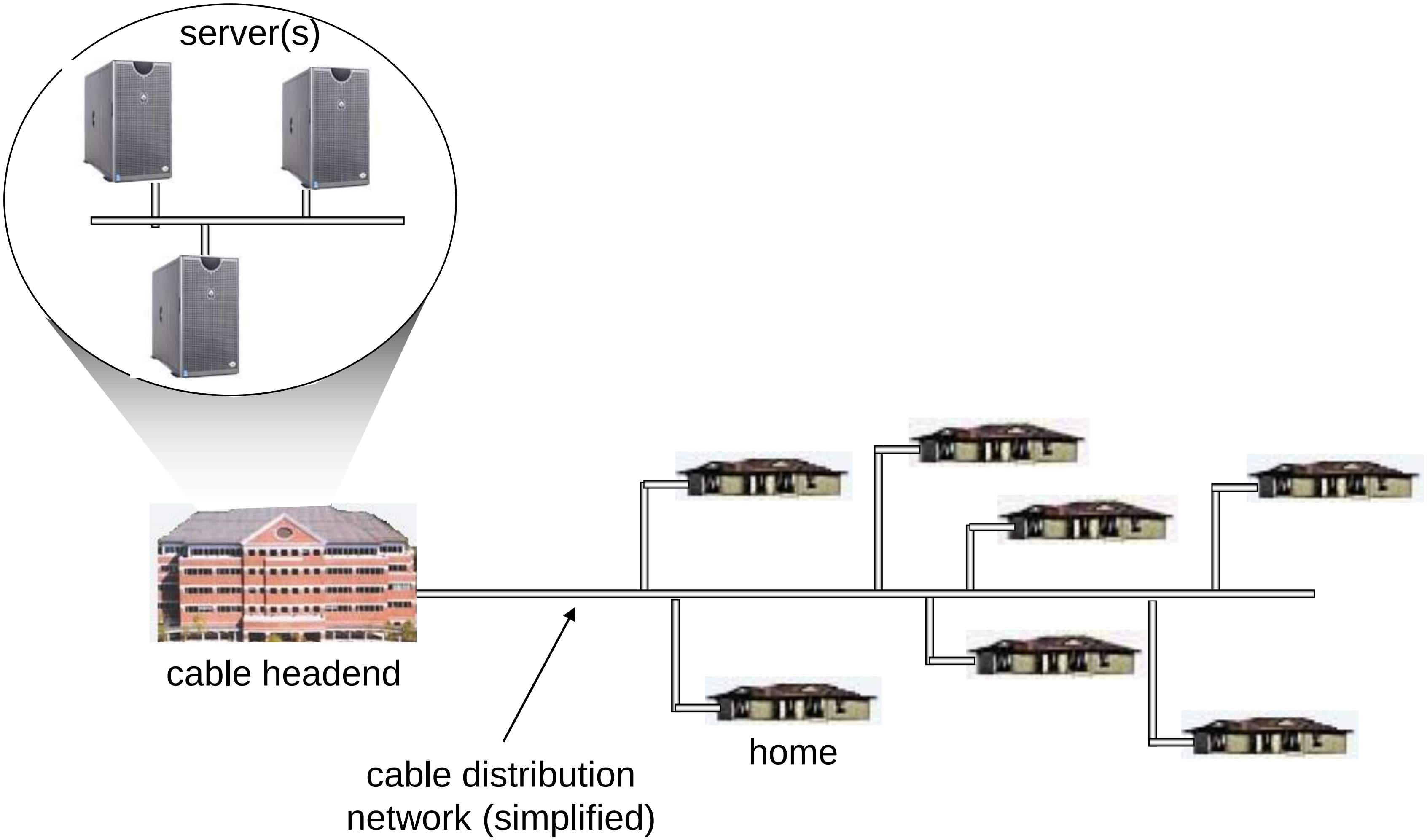


Cable network architecture: Overview

Typically 500 to 5,000 homes



Cable network architecture: Overview



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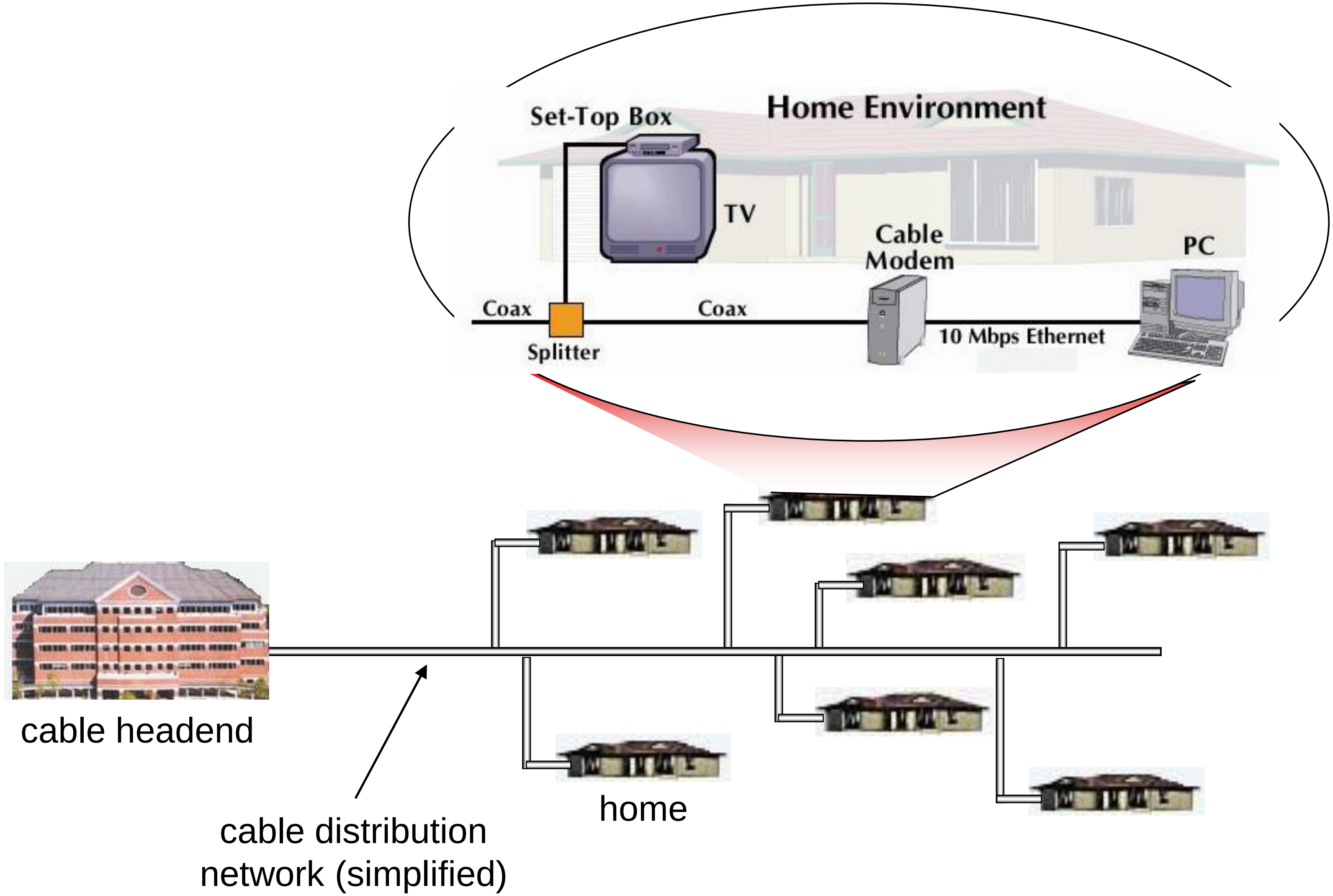
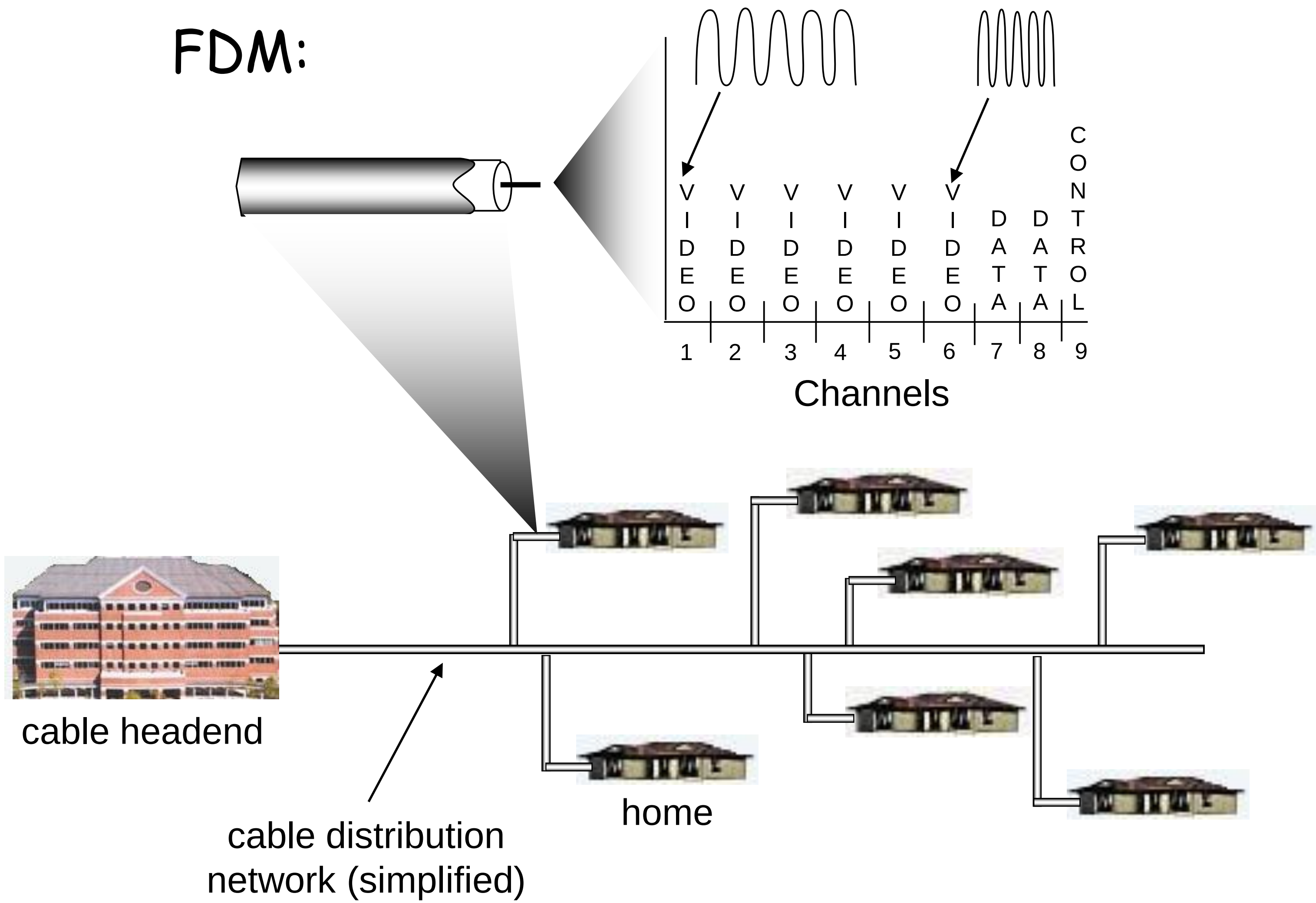
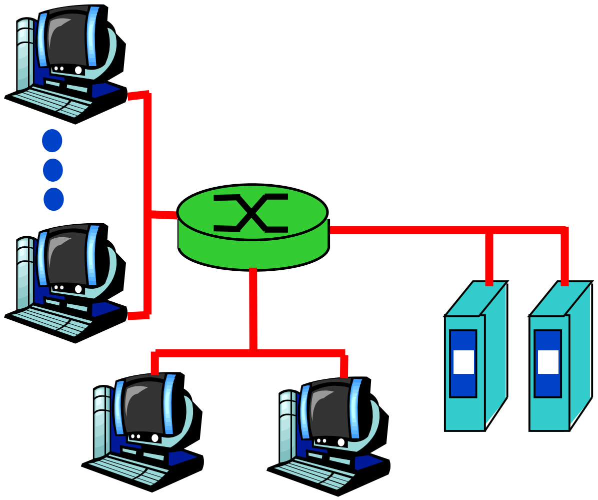


Cable network architecture: Overview



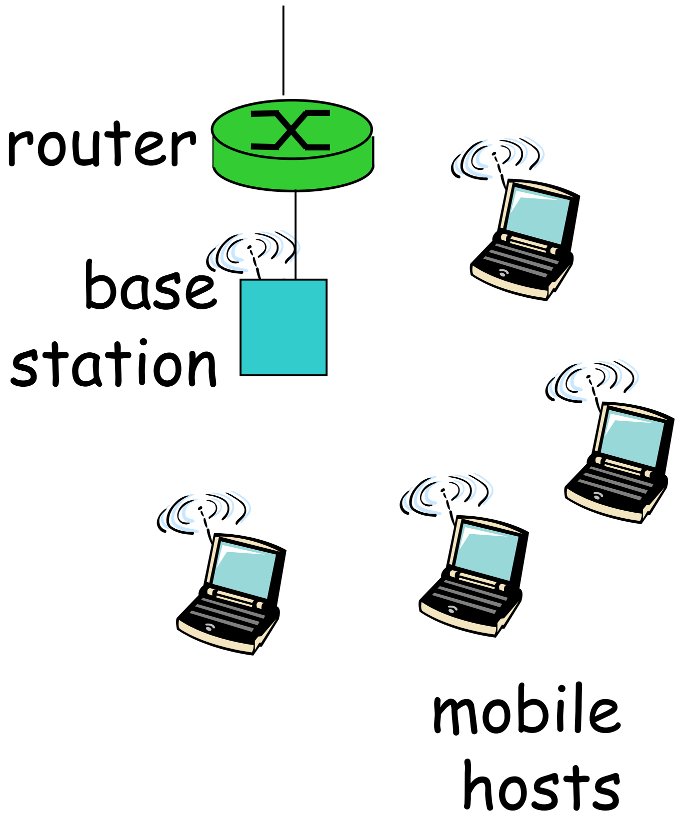
Company access: Local area networks

- Company/univ local area network (LAN) connects end system to edge router
- Ethernet
  - shared or dedicated link connects end system and router
  - 10 Mbs, 100 Mbps, Gigabit Ethernet
- LANs: chapter 5



Wireless access networks

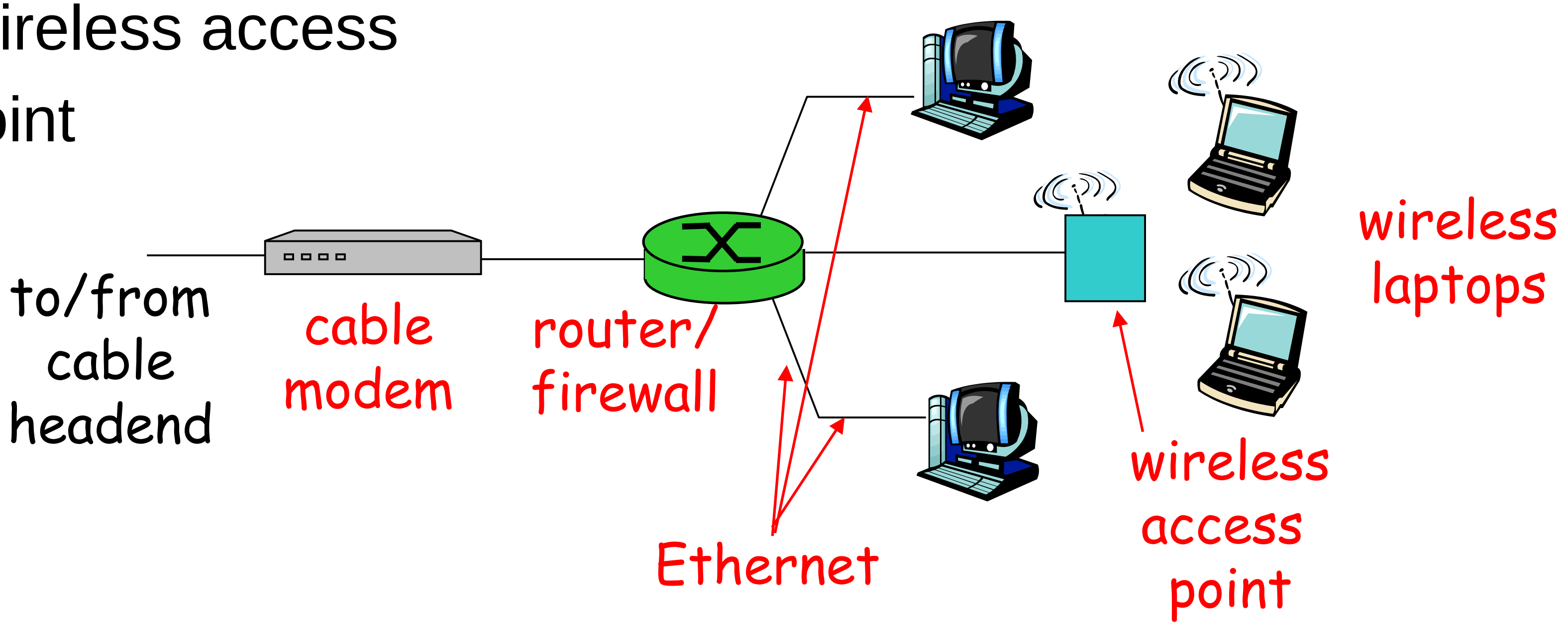
- Shared *wireless* access network connects end system to router
  - via base station aka "access point"
- Wireless LANs
  - 802.11b/g/n (WiFi): 11/54/600 Mbps
- Wider-area wireless access
  - provided by telco operator
  - GPRS in Europe/US
  - 3G ~ 384 kbps (UMTS)
  - 4G ~ couple Mbps (LTE)



Home networks

Typical home network components

- ADSL or cable modem
- Router/firewall/NAT
- Ethernet
- Wireless access point



Physical media

- Bit
  - propagates between transmitter/rcvr pairs
- Physical link
  - what lies between transmitter & receiver
- Guided media
  - signals propagate in solid media: copper, fiber, coax
- Unguided media
  - signals propagate freely, e.g., radio

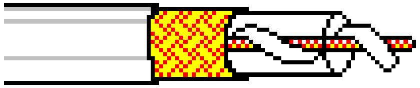
Twisted Pair (TP)

- Two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5: 100 Mbps Ethernet

Physical media: Coax, fiber

Coaxial cable

- Two concentric copper conductors
- Bidirectional
- Baseband
  - single channel on cable
  - legacy Ethernet
- Broadband
  - multiple channels on cable
  - HFC



Fiber optic cable

- Glass fiber carrying light pulses, each pulse a bit
- High-speed operation
  - high-speed point-to-point transmission (e.g., 10's-100's Gps)
- Low error rate
  - repeaters spaced far apart; immune to electromagnetic noise

Physical media: Radio

Radio

- Signal carried in electromagnetic spectrum
- No physical “wire”
- Bidirectional
- Propagation environment effects
  - reflection
  - obstruction by objects
  - interference

Radio link types

- Terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., Wifi)
  - 11 Mbps, 54 Mbps
- Wide-area (e.g., cellular)
  - e.g. 3G: hundreds of kbps
- Satellite
  - kbps to 45 Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

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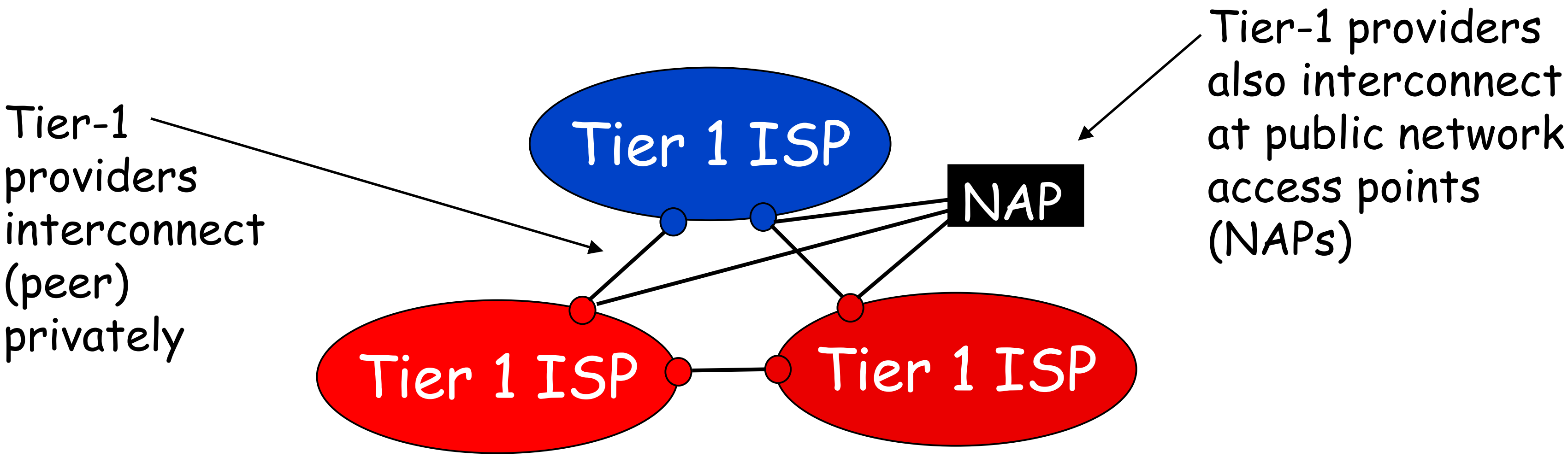
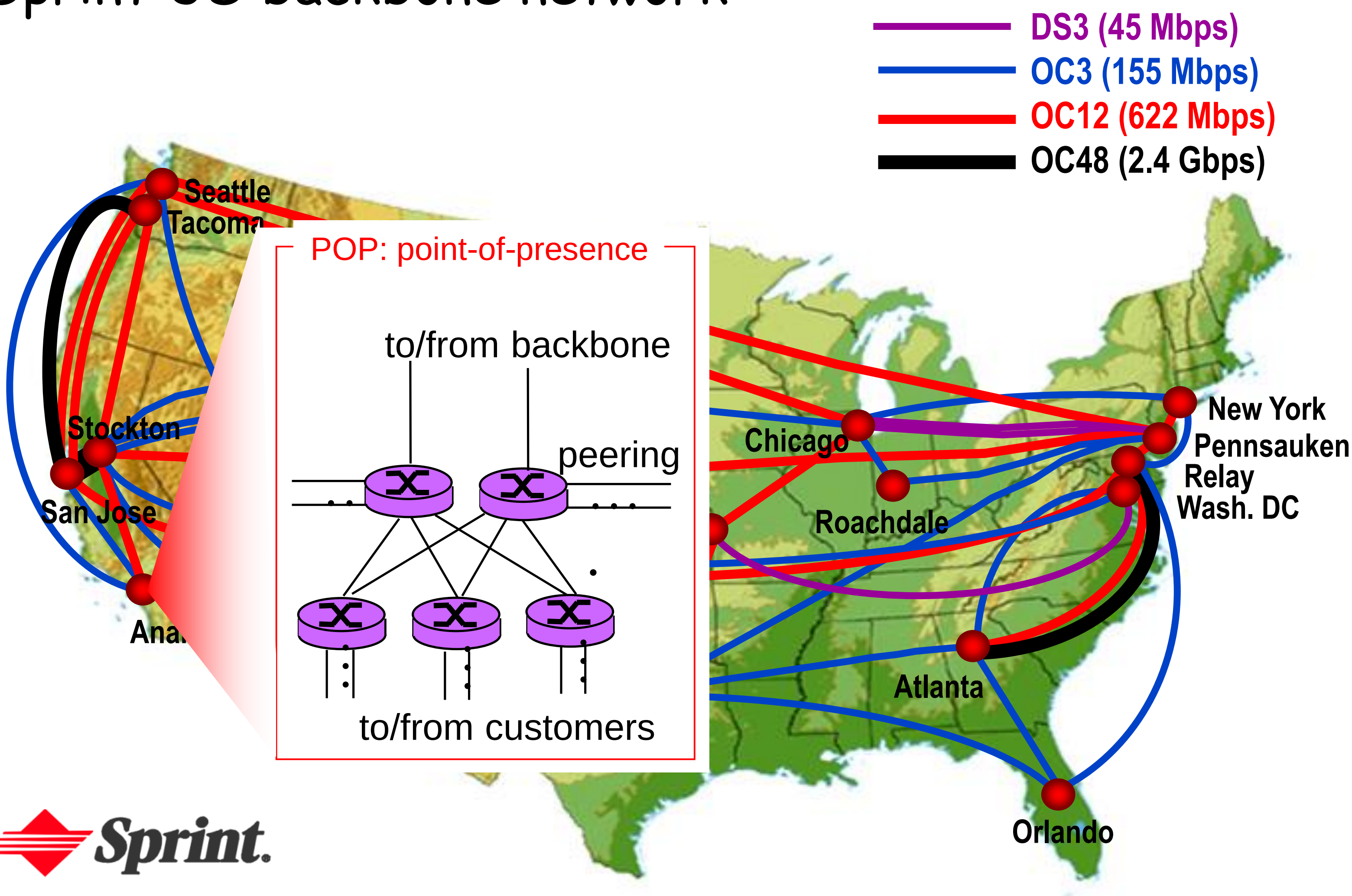
Internet structure: Network of networks

- Roughly hierarchical
- At center: "tier-1" ISPs (e.g., MCI, Sprint, AT&T, Cable and Wireless), national/international coverage
  - treat each other as equals



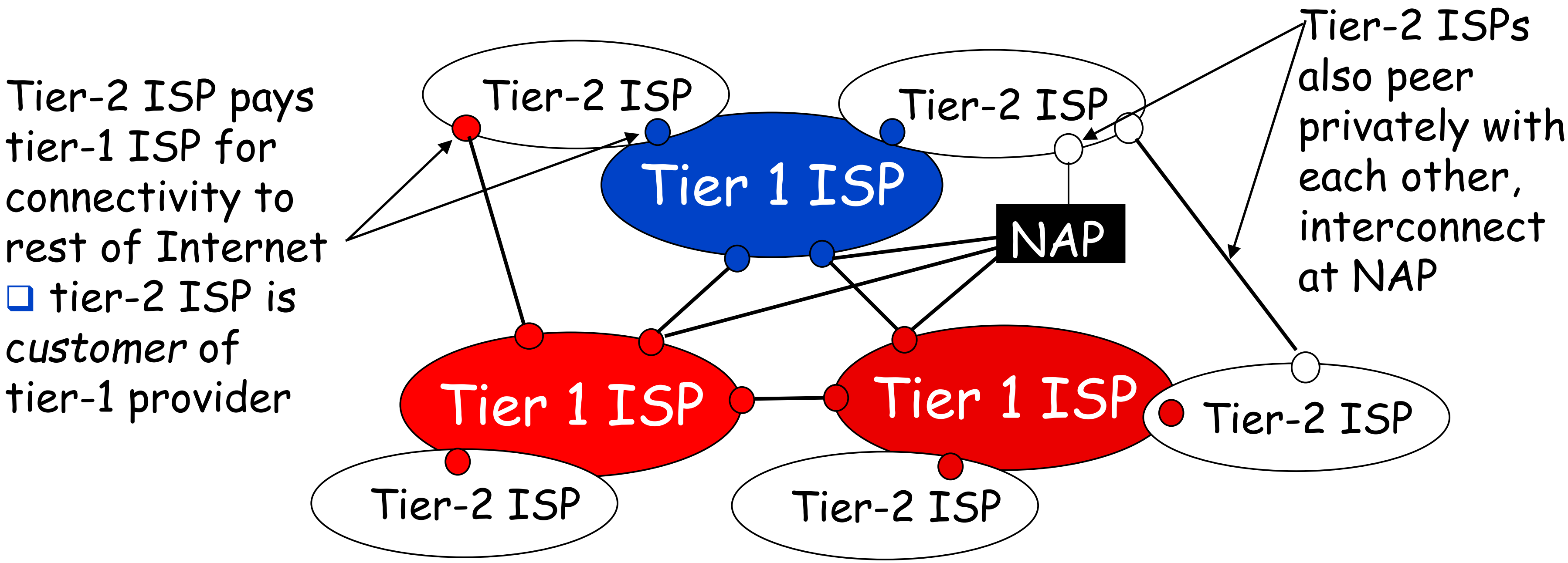
Tier-1 ISP: E.g., Sprint

Sprint US backbone network



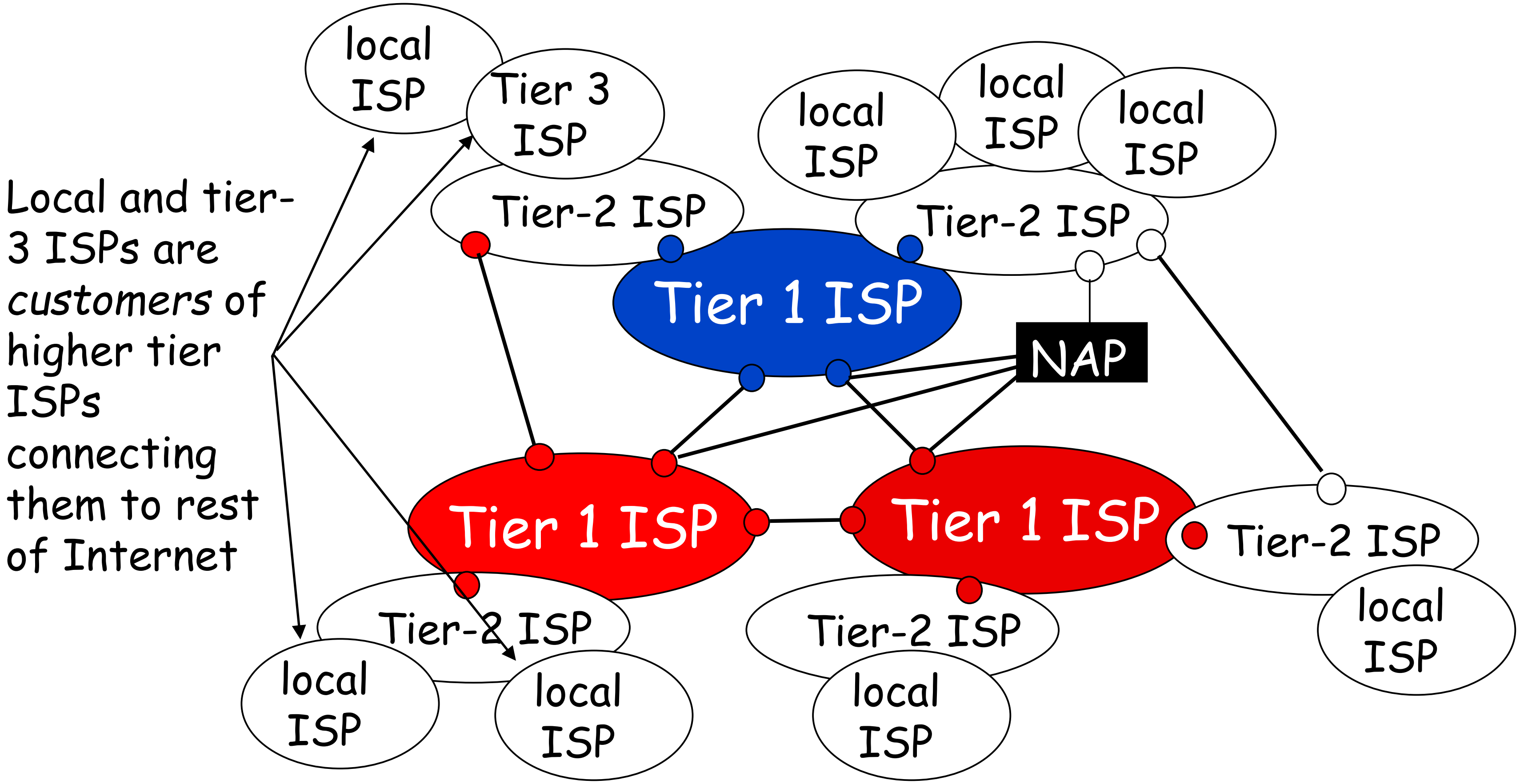
Internet structure: Network of networks

- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs



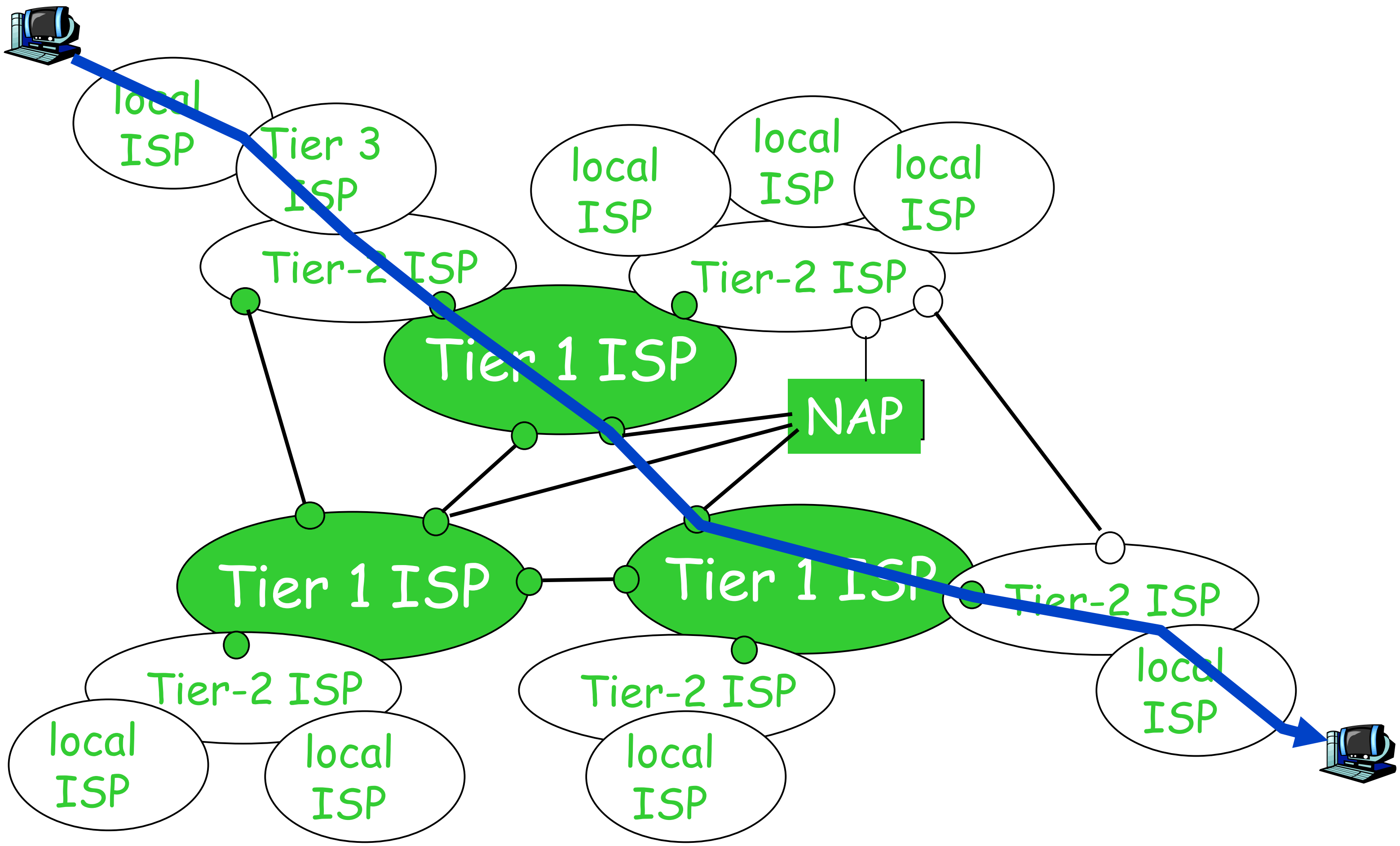
Internet structure: Network of networks

- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)



Internet structure: Network of networks

- A packet passes through many networks!



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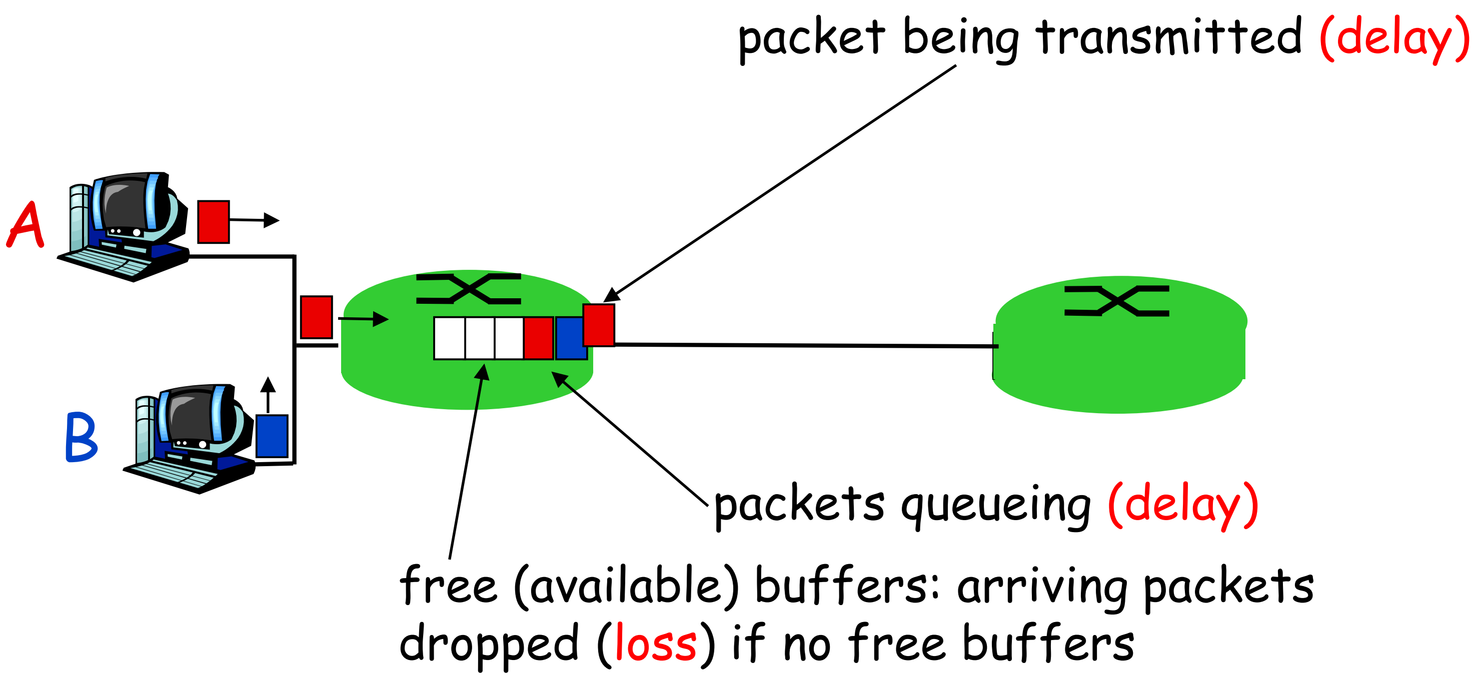
How do loss and delay occur?

Packets *queue* in router buffers

- Packet arrival rate to link exceeds output link capacity
- Packets queue, wait for turn



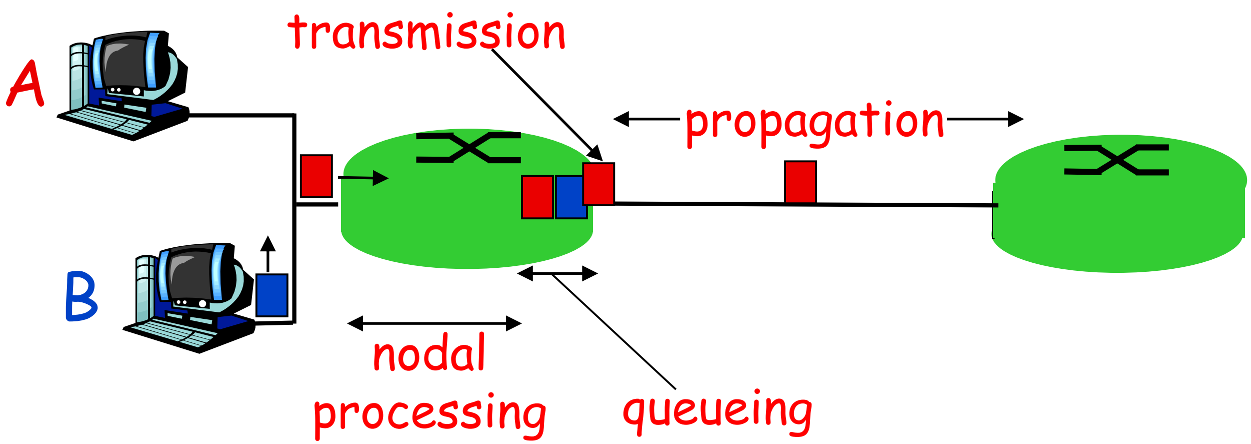
Four sources of packet delay

1. Nodal processing

- check bit errors
- determine output link

2. Queueing

- time waiting at output link for transmission
- depends on congestion level of router



Delay in packet-switched networks

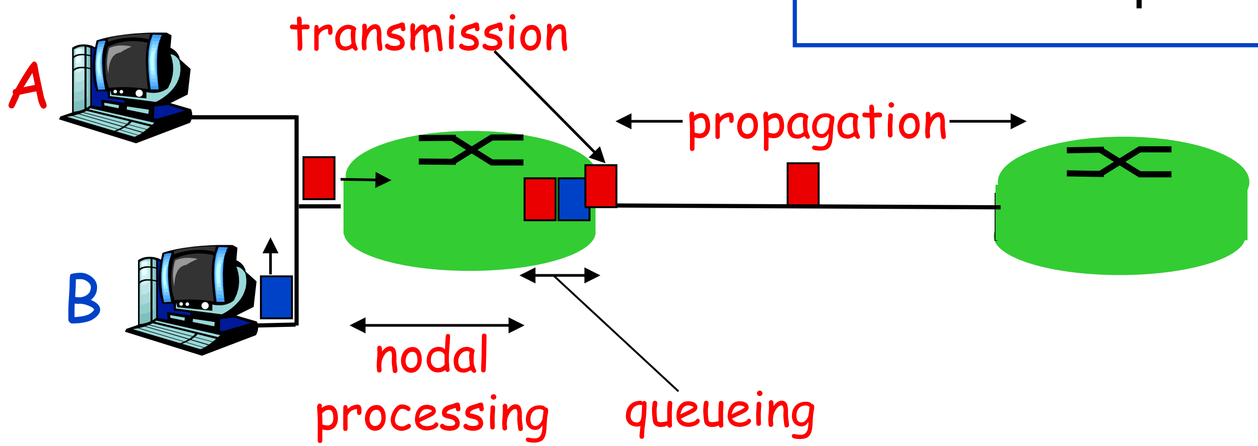
3. Transmission delay

- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

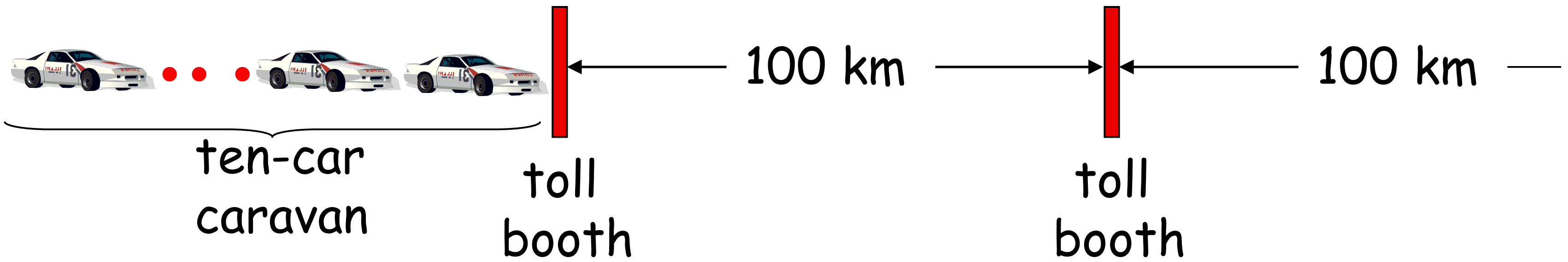
4. Propagation delay

- d = length of physical link
- s = propagation speed in medium (~2x10^8 m/sec)
- propagation delay = d/s

Note: s and R are *very* different quantities!

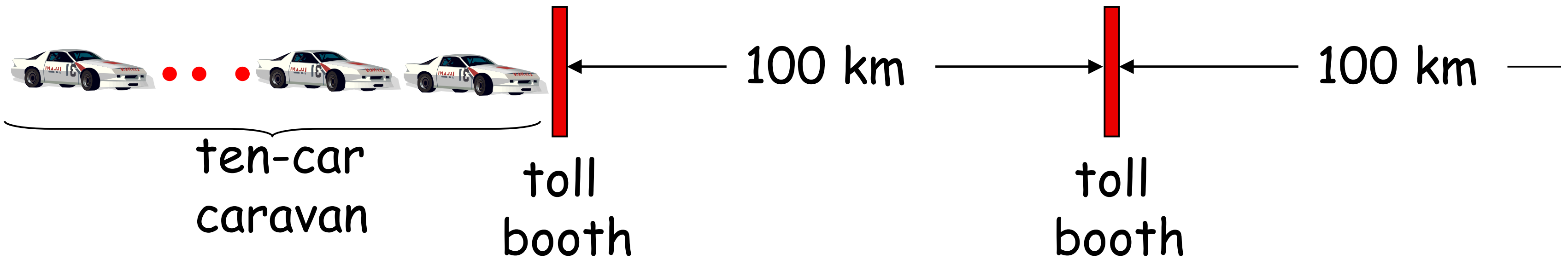


Caravan analogy



- Cars “propagate” at 100 km/hr
- Toll booth takes 12 sec to service a car (transmission time)
- car~bit; caravan ~ packet
- Q: How long until caravan is lined up before 2nd toll booth?
- Time to “push” entire caravan through toll booth onto highway = 12*10 = 120 sec
- Time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
- A: 62 minutes

Caravan analogy (more)



- Cars now "propagate" at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive at 2nd booth before all cars serviced at 1st booth?
- Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!

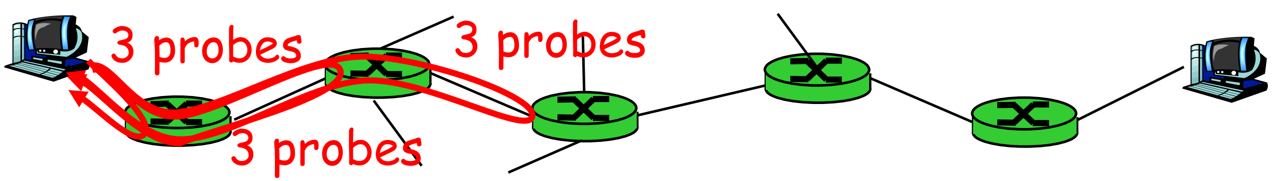
Nodal delay

$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay
  - depends on congestion
- d_{trans} = transmission delay
  - = L/R, significant for low-speed links
- d_{prop} = propagation delay
  - a few microsecs to hundreds of msecs

"Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- `Traceroute` program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply



"Real" Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

Three delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

1 cs-gw (128.119.240.254) 1 ms 1 ms 2 ms
2 border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145) 1 ms 1 ms 2 ms
3 cht-vbns.gw.umass.edu (128.119.3.130) 6 ms 5 ms 5 ms
4 jn1-at1-0-0-19.wor.vbns.net (204.147.132.129) 16 ms 11 ms 13 ms
5 jn1-so7-0-0-0.wae.vbns.net (204.147.136.136) 21 ms 18 ms 18 ms
6 abilene-vbns.abilene.ucaid.edu (198.32.11.9) 22 ms 18 ms 22 ms
7 nycm-wash.abilene.ucaid.edu (198.32.8.46) 22 ms 22 ms 22 ms
8 62.40.103.253 (62.40.103.253) 104 ms 109 ms 106 ms
9 de2-1.de1.de.geant.net (62.40.96.129) 109 ms 102 ms 104 ms
10 de.fr1.fr.geant.net (62.40.96.50) 113 ms 121 ms 114 ms
11 renater-gw.fr1.fr.geant.net (62.40.103.54) 112 ms 114 ms 112 ms
12 nio-n2.cssi.renater.fr (193.51.206.13) 111 ms 114 ms 116 ms
13 nice.cssi.renater.fr (195.220.98.102) 123 ms 125 ms 124 ms
14 r3t2-nice.cssi.renater.fr (195.220.98.110) 126 ms 126 ms 124 ms
15 eurecom-valbonne.r3t2.ft.net (193.48.50.54) 135 ms 128 ms 133 ms
16 194.214.211.25 (194.214.211.25) 126 ms 128 ms 126 ms
17 * * *
18 * * *
19 fantasia.eurecom.fr (193.55.113.142) 132 ms 128 ms 136 ms

trans-oceanic link

* means no response (probe lost, router not replying)

Packet loss

- Queue (aka buffer) preceding link in buffer has finite capacity
- When packet arrives in full queue, packet is dropped (aka lost)
- Lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all

Chapter 1: Roadmap

1.1 What *is* the Internet?

1.2 Network edge

1.3 Network core

1.4 Network access and physical media

1.5 Internet structure and ISPs

1.6 Delay & loss in packet-switched networks

1.7 Protocol layers, service models

1.8 History

Protocol “layers”

Networks are complex!

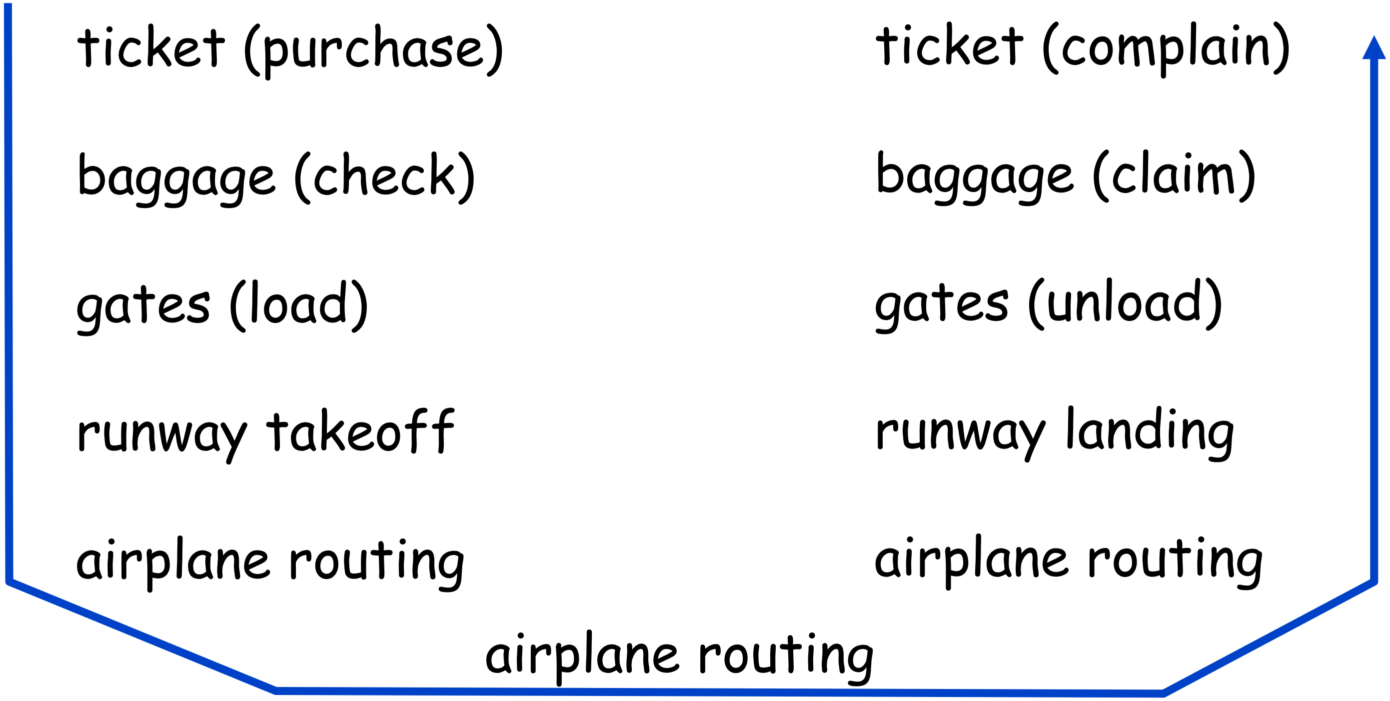
- Many “pieces”
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

Question:

Is there any hope of *organizing* structure of network?

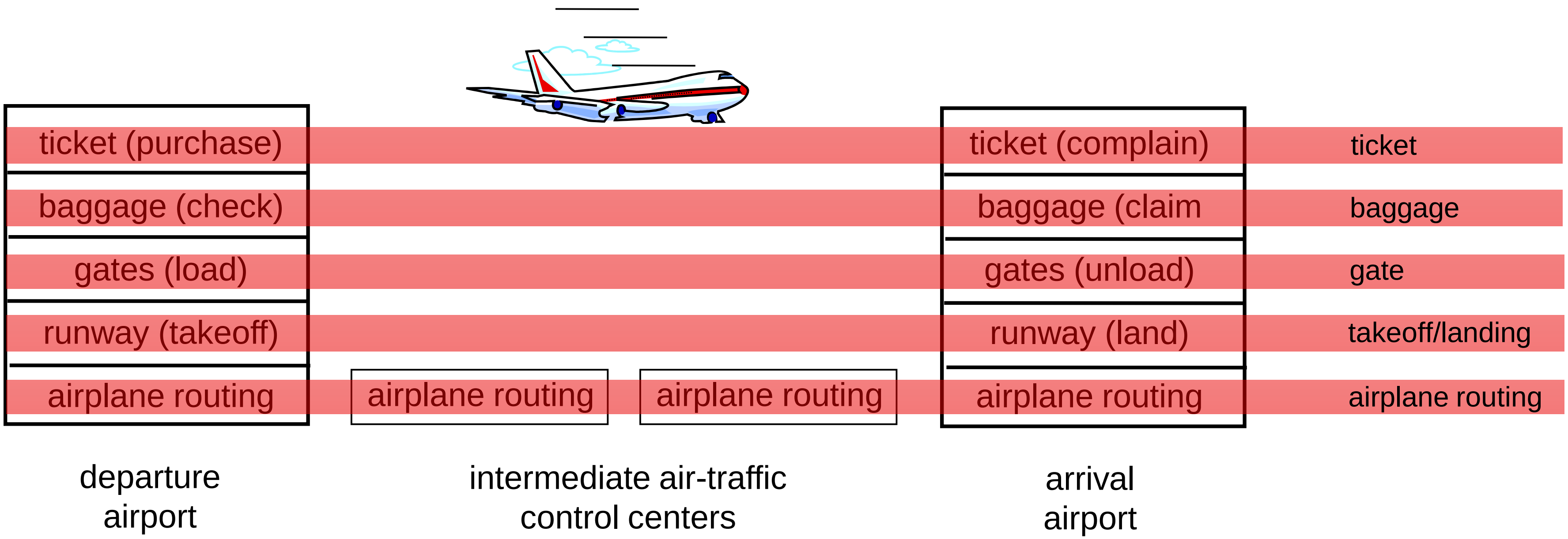
Or at least our discussion of networks?

Organization of air travel



- A series of steps

Layering of airline functionality



Layers: each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below

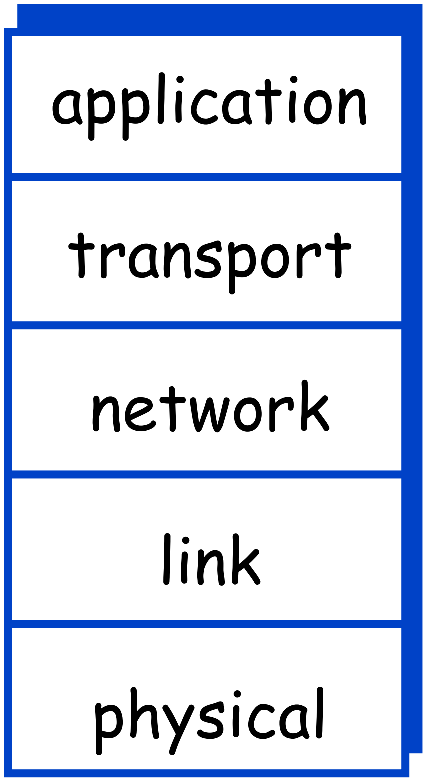
Why layering?

Dealing with complex systems

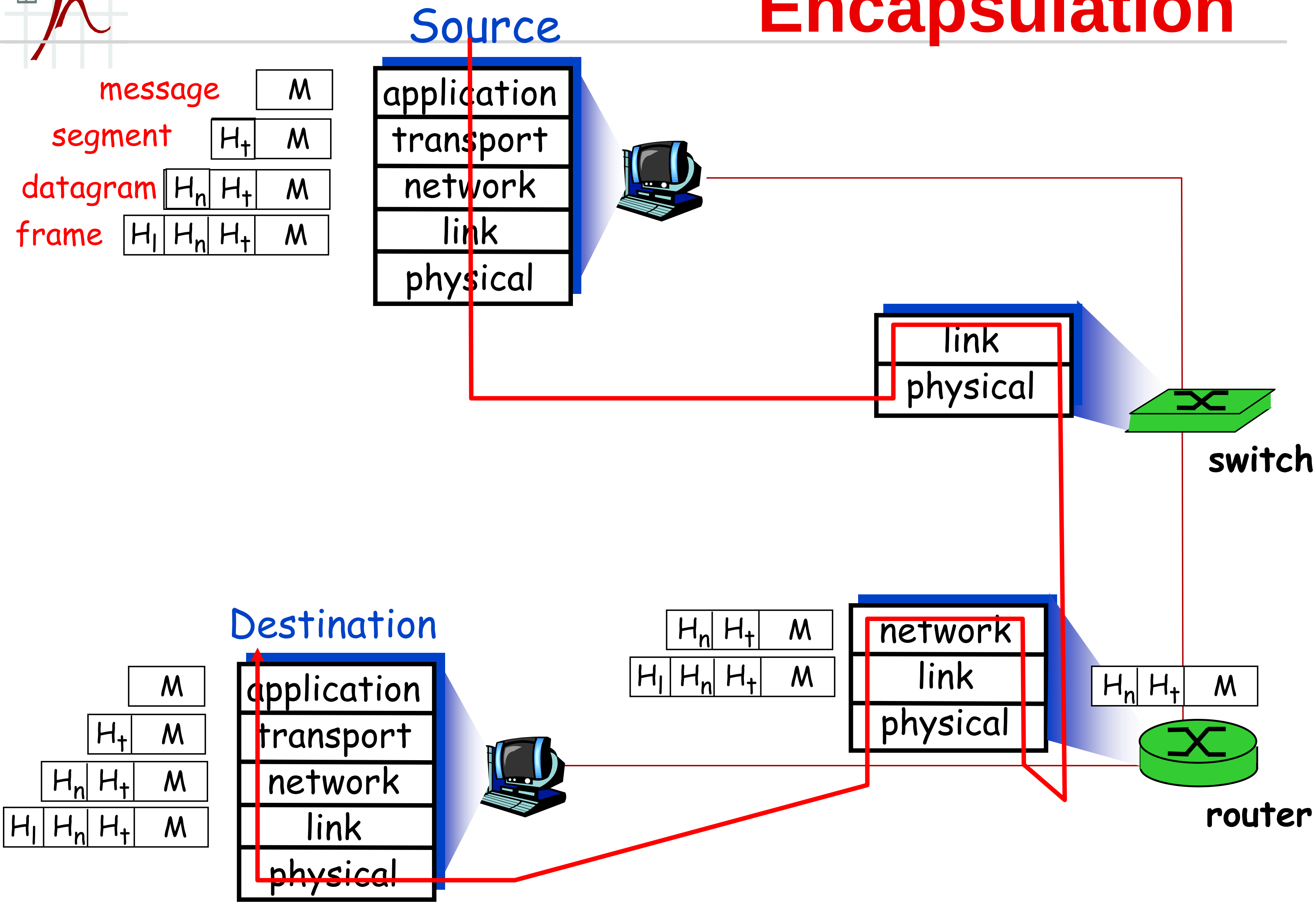
- Explicit structure allows identification, relationship of complex system's pieces
  - layered reference model for discussion
- Modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system
- Layering considered harmful?

Internet protocol stack

- Application: supporting network applications
  - FTP, SMTP, HTTP
- Transport: process-process data transfer
  - TCP, UDP
- Network: routing of datagrams from source to destination
  - IP, routing protocols
- Link: data transfer between neighboring network elements
  - PPP, Ethernet
- Physical: bits “on the wire”



Encapsulation



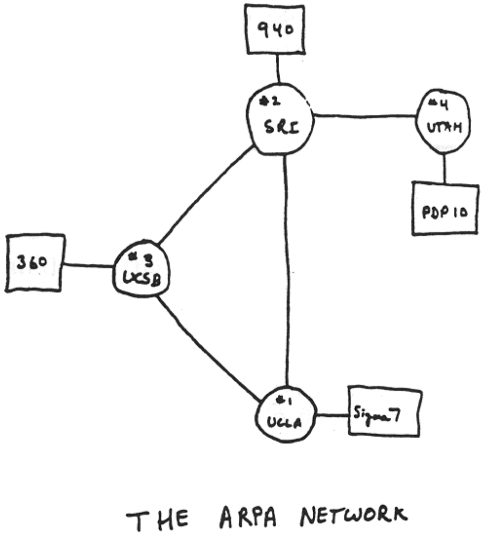
Chapter 1: Roadmap

Internet history

1961-1972: Early packet-switching principles

- 1961: Leonard Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Paul Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: First ARPAnet node operational

- 1972
  - ARPAnet public demonstration
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



Internet history

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Vint Cerf and Bob Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late 70's: Proprietary architectures: DECnet, SNA, XNA
- late 70's: Switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

Define today's Internet architecture

Internet history

1980-1990: new protocols, a proliferation of networks

- 1983: Deployment of TCP/IP
- 1982: SMTP e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: FTP protocol defined
- 1988: TCP congestion control

- New national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet history

1990, 2000's: commercialization, the Web, new apps

- Early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- Early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web
- Late 1990's – 2000's
  - more killer apps: instant messaging, P2P file sharing
  - network security to forefront
  - est. 50 million host, 100 million+ users
  - backbone links running at Gbps

Internet history

- 2010
  - ~750 million hosts
  - voice, video over IP
  - P2P applications:
    BitTorrent (file sharing)
    Skype (VoIP), PPLive (video)
  - more applications:
    YouTube, gaming, Twitter
  - wireless, mobility

Introduction: Summary

Covered a “ton” of material!

- Internet overview
- What’s a protocol?
- Network edge, core, access network
  - packet-switching versus circuit-switching
- Internet/ISP structure
- Performance: loss, delay
- Layering and service models
- History

You now have

- Context, overview, “feel” of networking
- More depth, detail *to follow!*