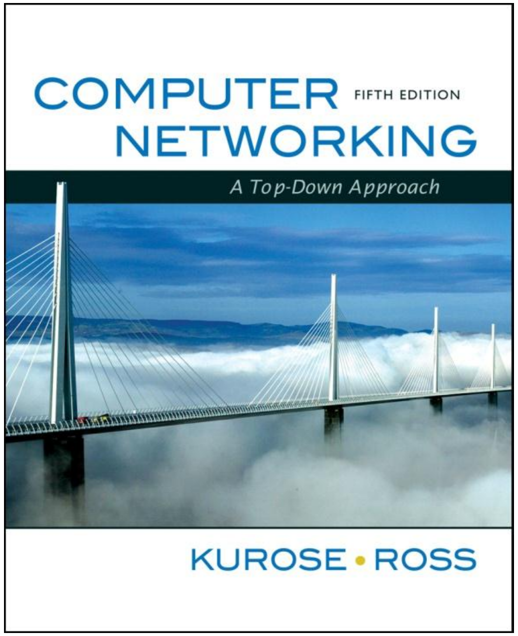
Chapter 1
Introduction



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Thanks and enjoy! JFK/KWR

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

Chapter 1: Introduction

Our goal:

- get "big picture" and terminology
- more depth, detail *later* in course
- approach:
  - use Internet as example

Overview:

- what's the Internet?
- what's a protocol?
- network edge; hosts, access net, physical media
- network core: packet/circuit switching, Internet structure
- performance: loss, delay, throughput
- security
- protocol layers, service models
- history

Chapter 1: roadmap

1.1 What *is* the Internet?

1.2 Network edge

- end systems, access networks, links

1.3 Network core

- circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks

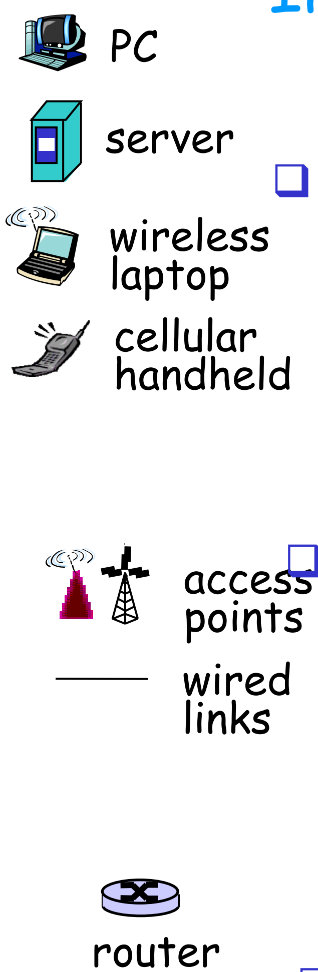
1.5 Protocol layers, service models

1.6 Networks under attack: security

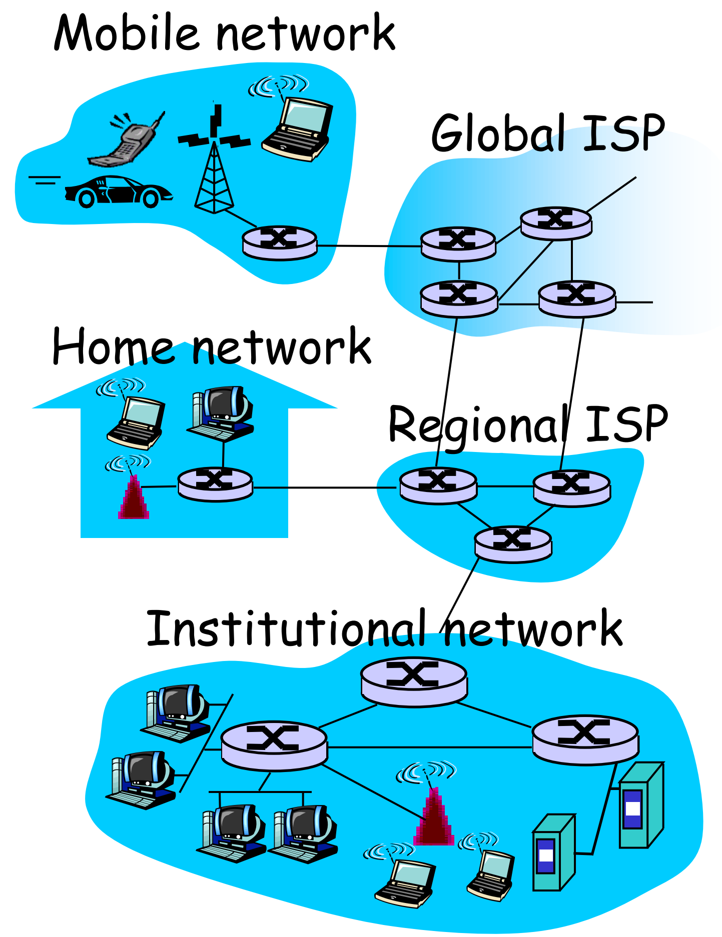
1.7 History

What's the Internet: basics

Internet: interconnection of networks



- millions of connected computing devices: *hosts = end systems*
  - running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate = *bandwidth (bps)*
- *routers:* forward packets (chunks of data)



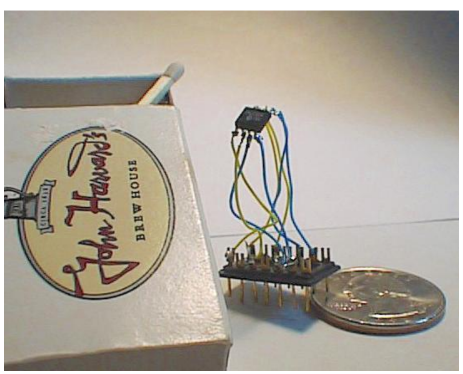
"Cool" internet appliances

Wireless NIC

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

Web-enabled toaster +
weather forecaster

Internet appliances, Blue tooth, WLAN

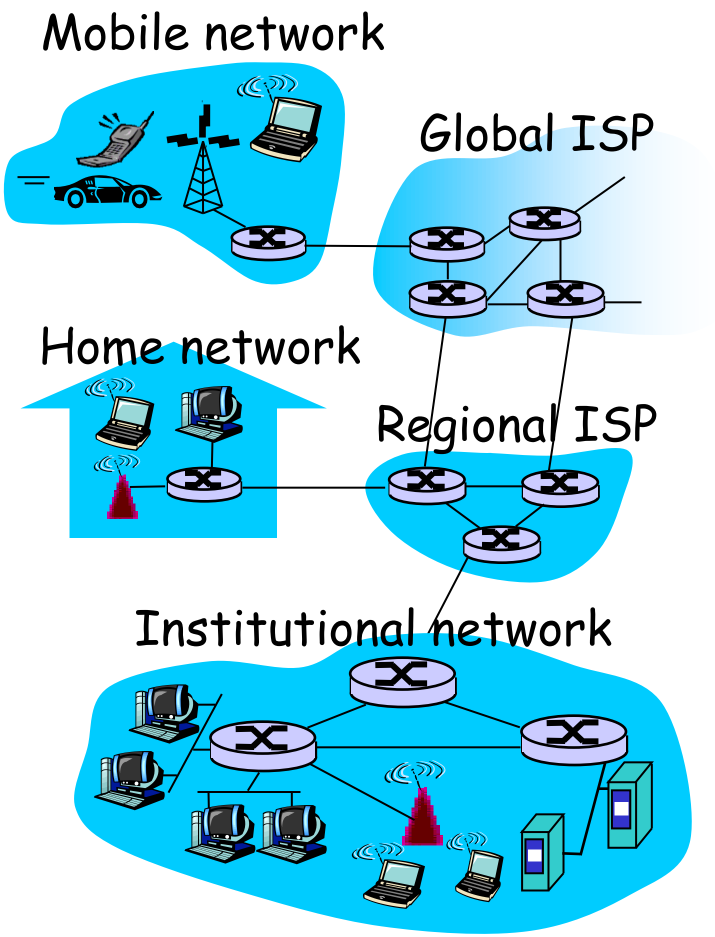


World's smallest web server
http://www-ccs.cs.umass.edu/~shri/iPic.html

Internet phones

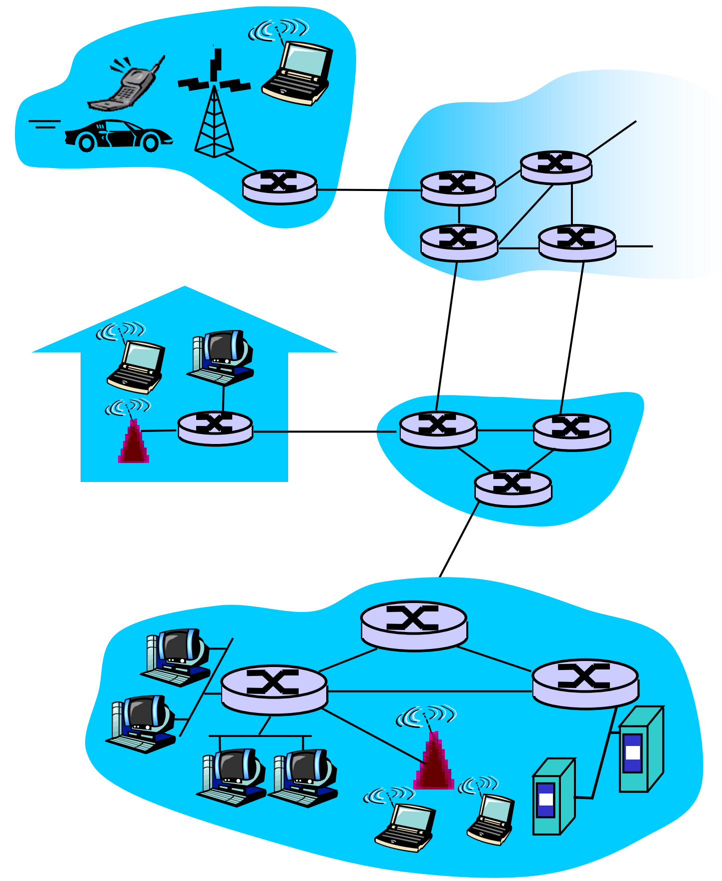
What's the Internet: basics

- *Protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, Ethernet
- *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, VoIP, email, games, e-commerce, file sharing
- communication services provided to apps:
  - *reliable* data delivery from source to destination
  - "best effort" (unreliable) data delivery



What's a protocol?

human protocols:

… specific msgs sent

… specific actions taken when msgs received, or other events

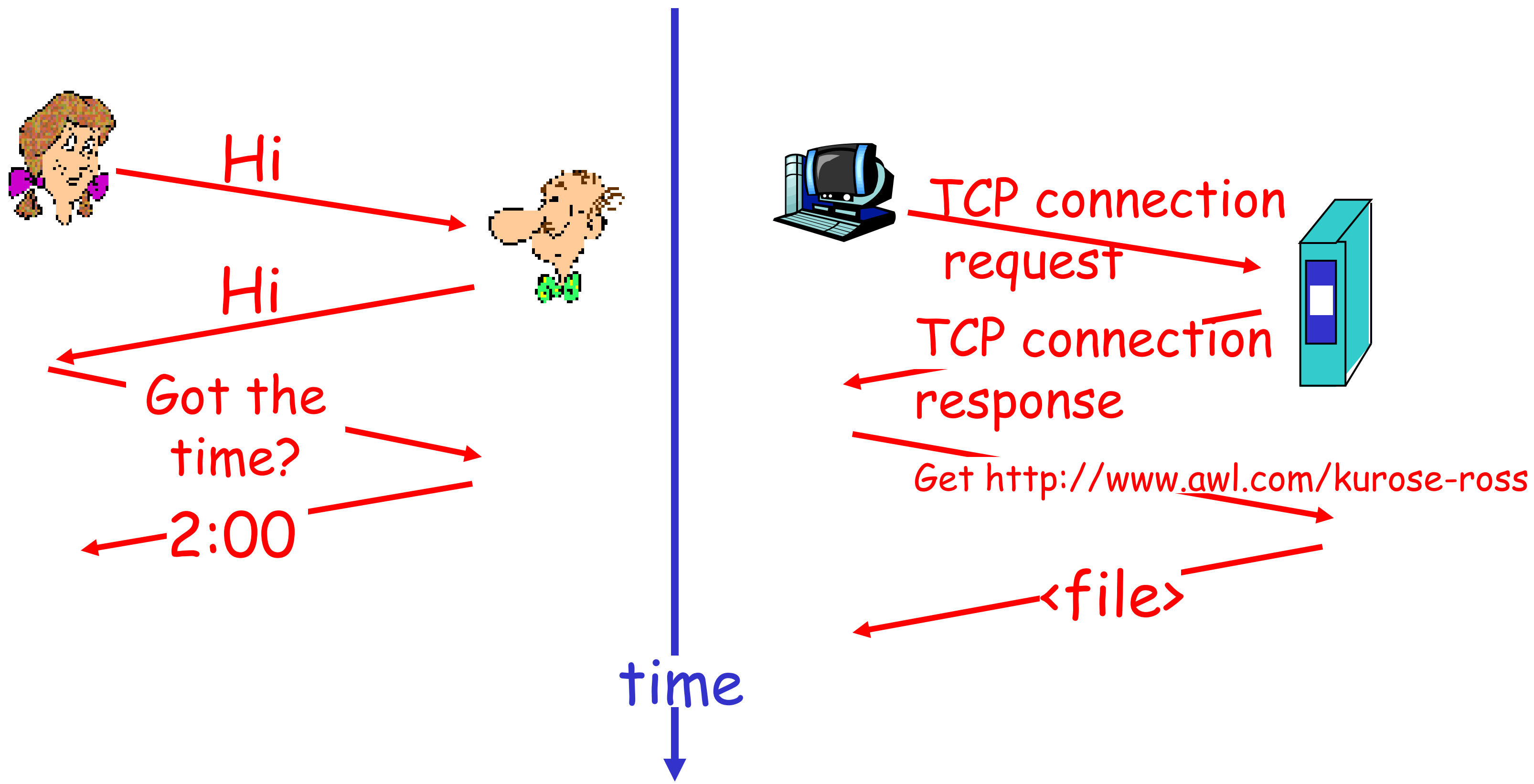
network protocols:

- machines
- all communication activity in Internet governed by protocols

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

What's a protocol?

a human protocol and a computer network protocol:



Chapter 1: roadmap

1.1 What *is* the Internet?

1.2 Network edge

- end systems, access networks, links

1.3 Network core

- circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks

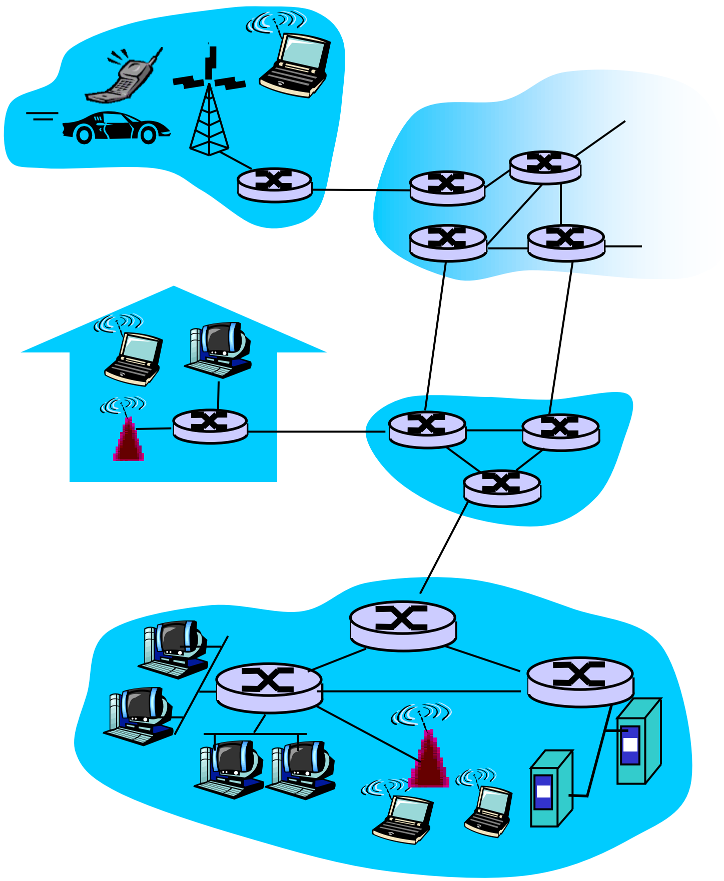
1.5 Protocol layers, service models

1.6 Networks under attack: security

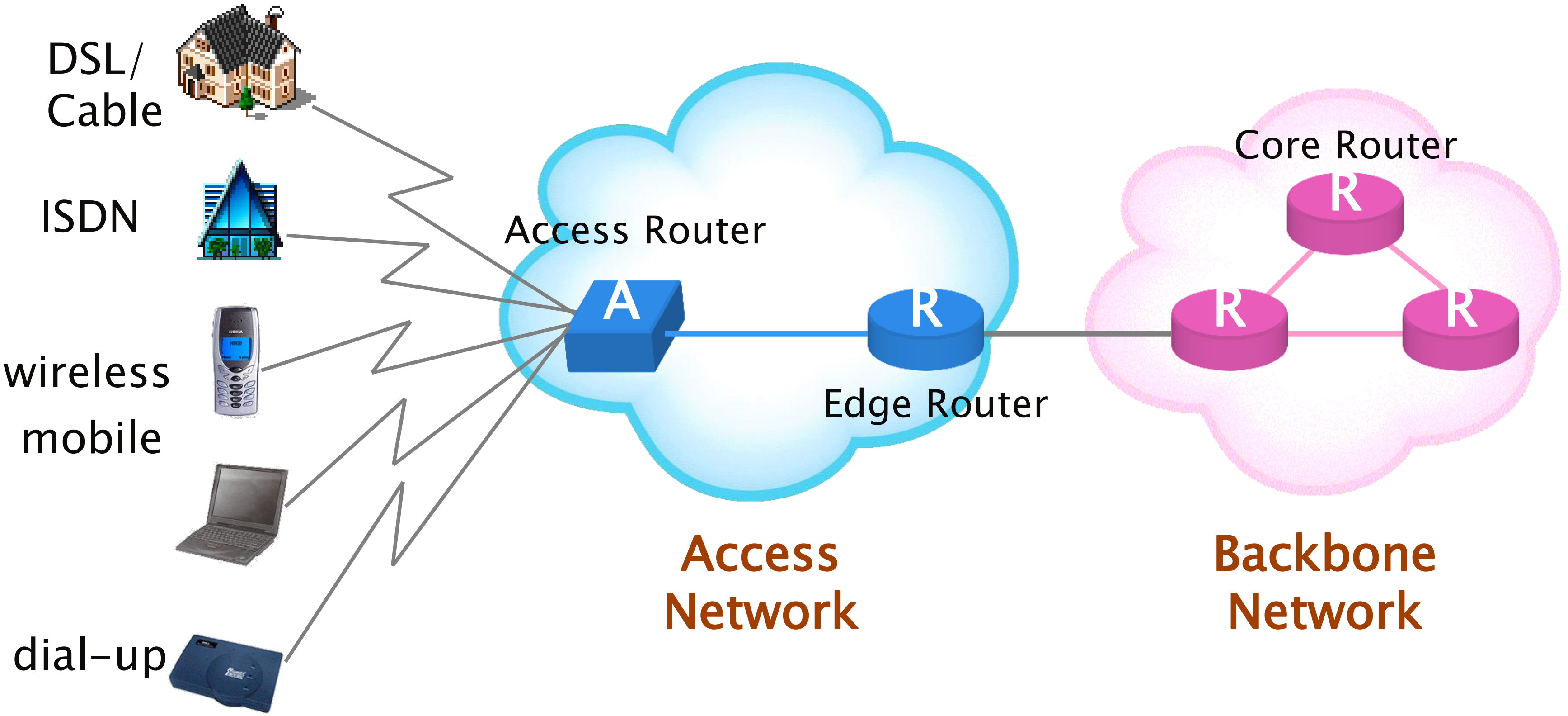
1.7 History

A closer look at network structure:

- network edge: applications and hosts
- access networks, physical media: wired, wireless communication links
- network core:
  - interconnected routers
  - network of networks



A closer look at network structure

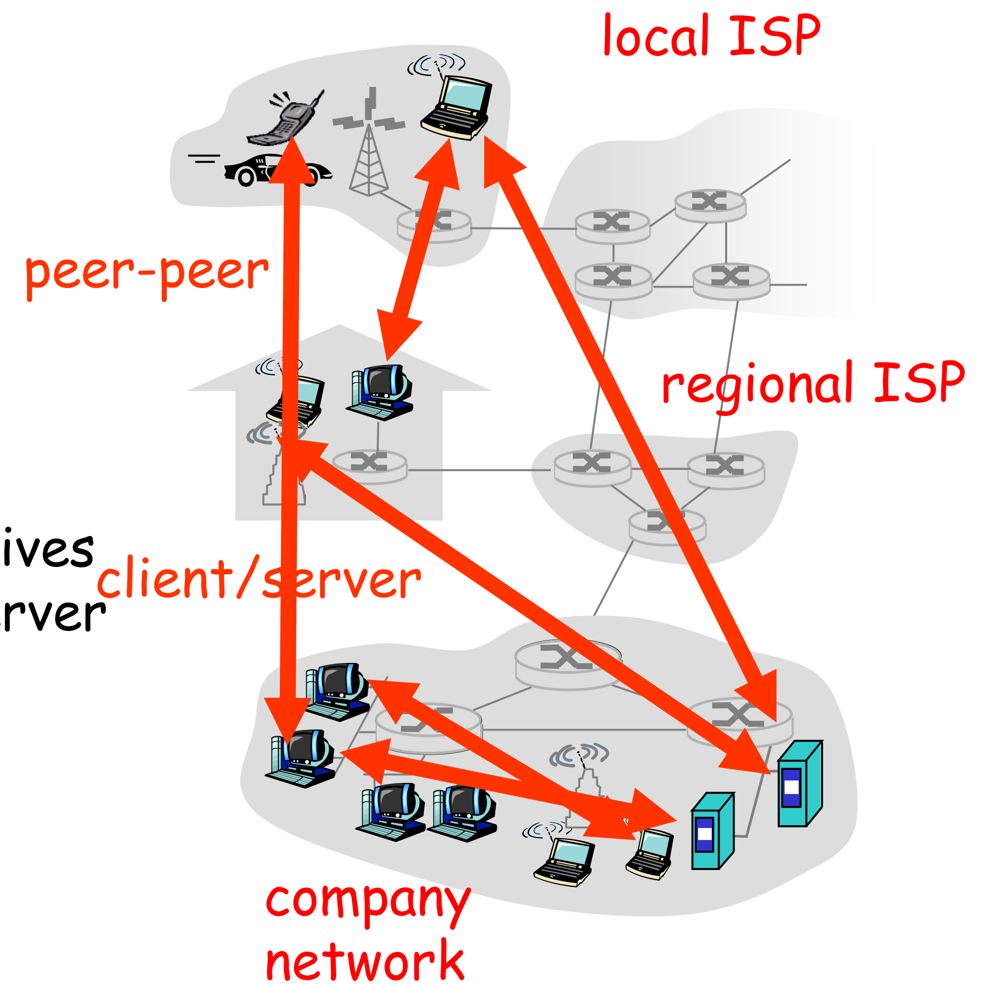


The network edge:

- end systems (hosts):
  - run application programs
  - e.g. Web, email
  - at "edge of network"

Interaction paradigms

- 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



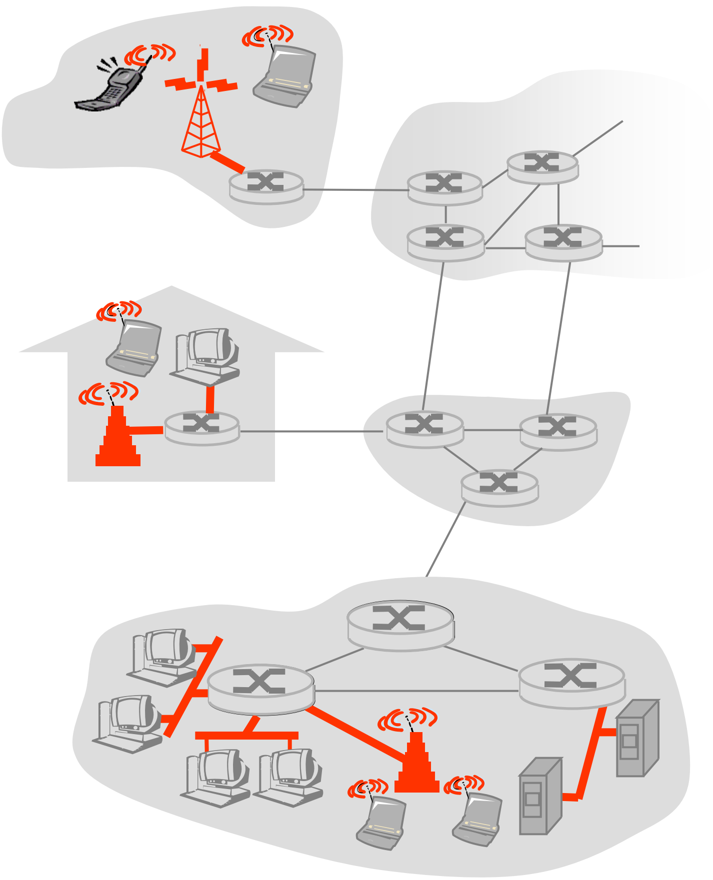
“Access networks” and physical media

Q: How to connect end systems to edge router?

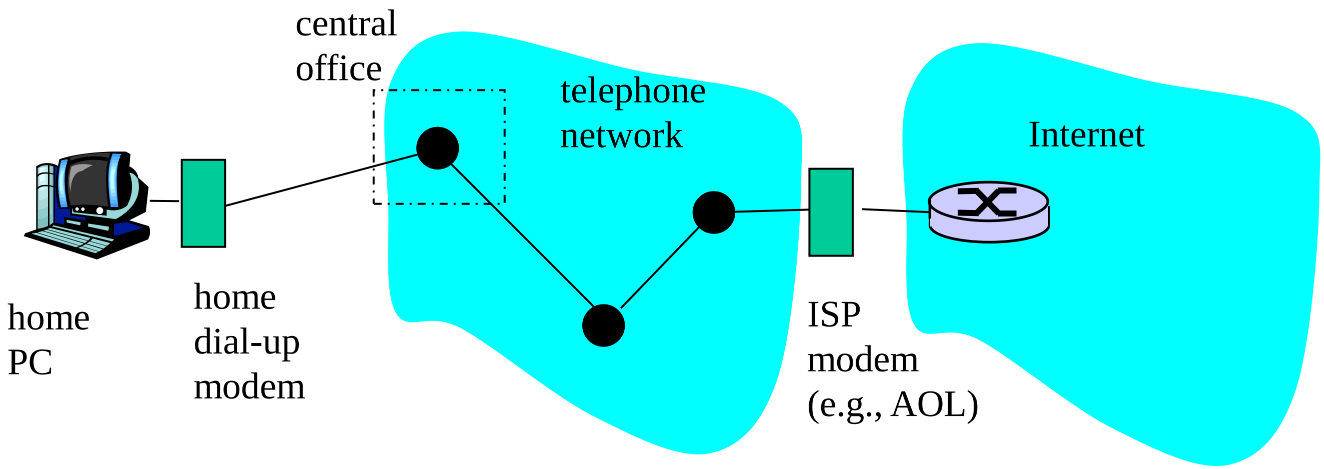
- residential access nets
- institutional access networks (school, company)
- mobile access networks

Keep in mind:

- bandwidth (bits per second) of access network?
- shared or dedicated?

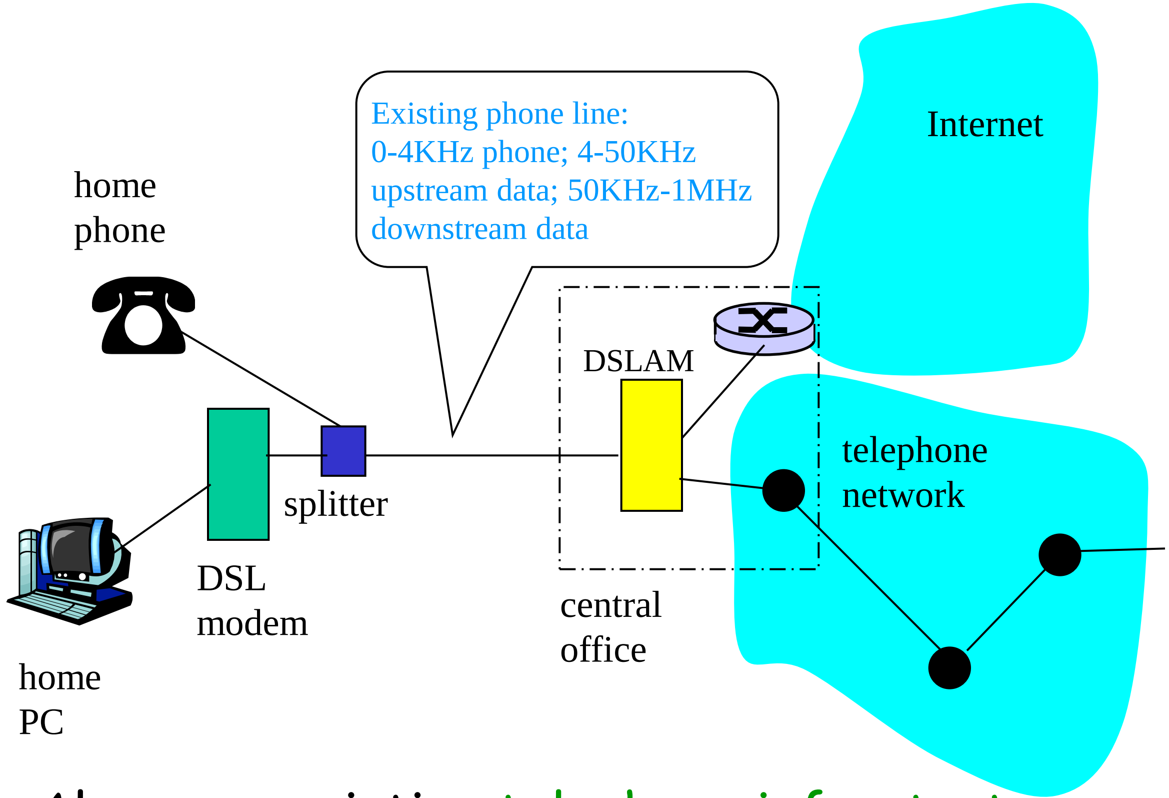


Dial-up Modem



- Uses existing telephony infrastructure
  - Home is connected to central office
- up to 56Kbps direct access to router
- Can't surf and phone at same time: not "always on"

Digital Subscriber Line (DSL)



- Also uses existing telephone infrastruture
- Asymmetric bandwidth (ADSL)
  - Upstream: up to 1 Mbps (today typically < 256 kbps)
  - Downstream: up to 8 Mbps (today typically < 1 Mbps)
- dedicated physical line to telephone central office

Residential access: cable modems

- Does *not* use telephone infrastructure
- Use *cable TV infrastructure*
- HFC: hybrid fiber coax
  - network of cable and fiber attaches homes to ISP router
- asymmetric:
  - downstream: up to 30Mbps,
  - upstream:2 Mbps
- homes share access to router

Residential access: cable modems

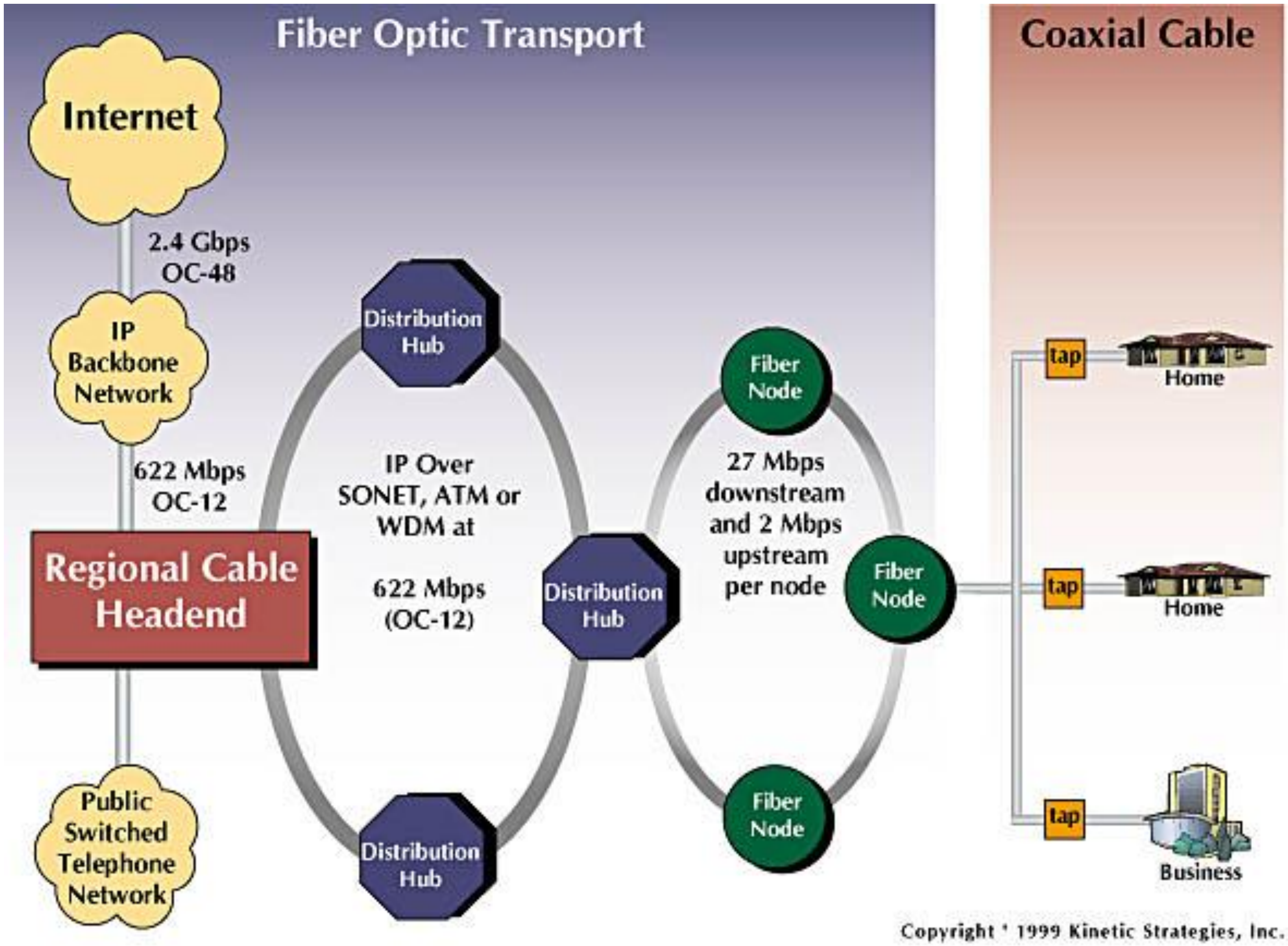
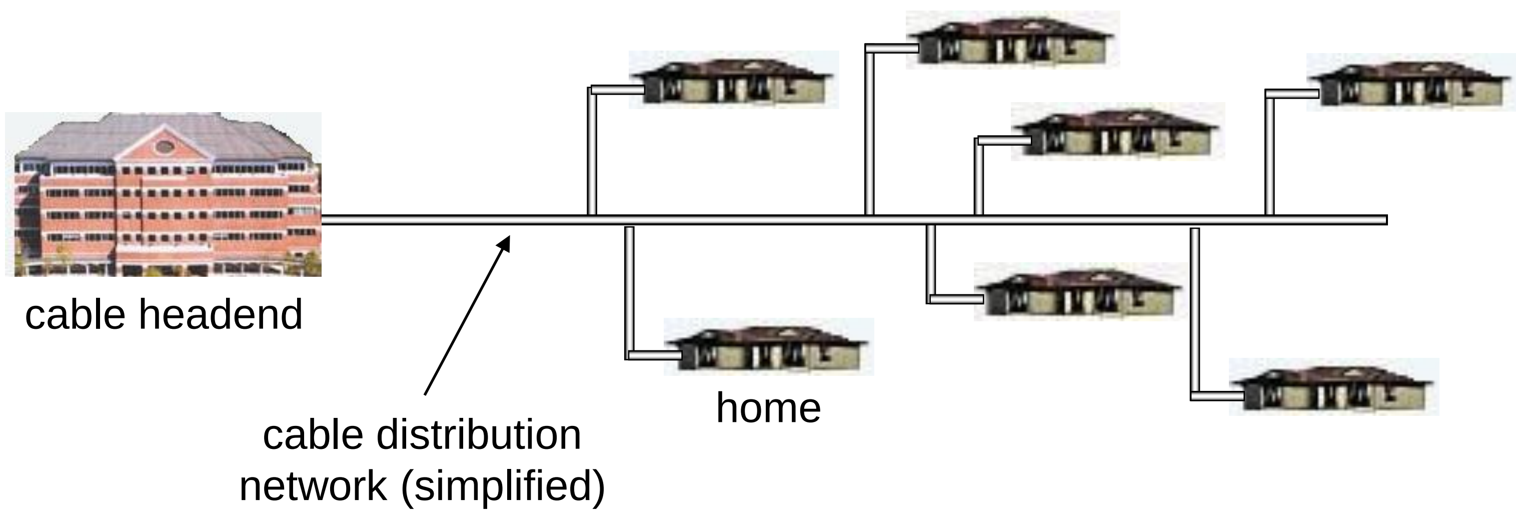


Diagram: http://www.cabledatacomnews.com/cmic/diagram.html

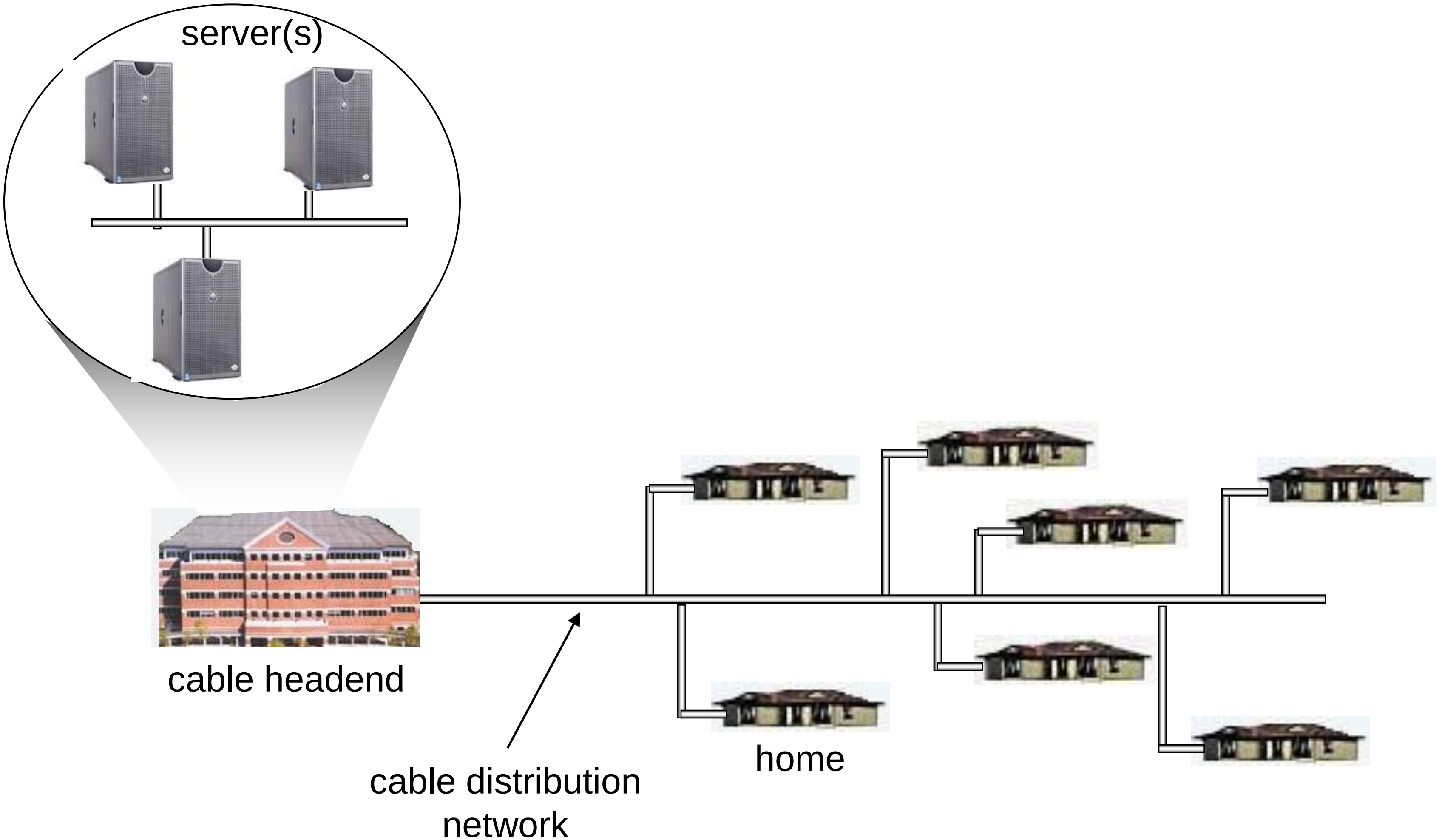
Cable Network Architecture: Overview

homes share access to router

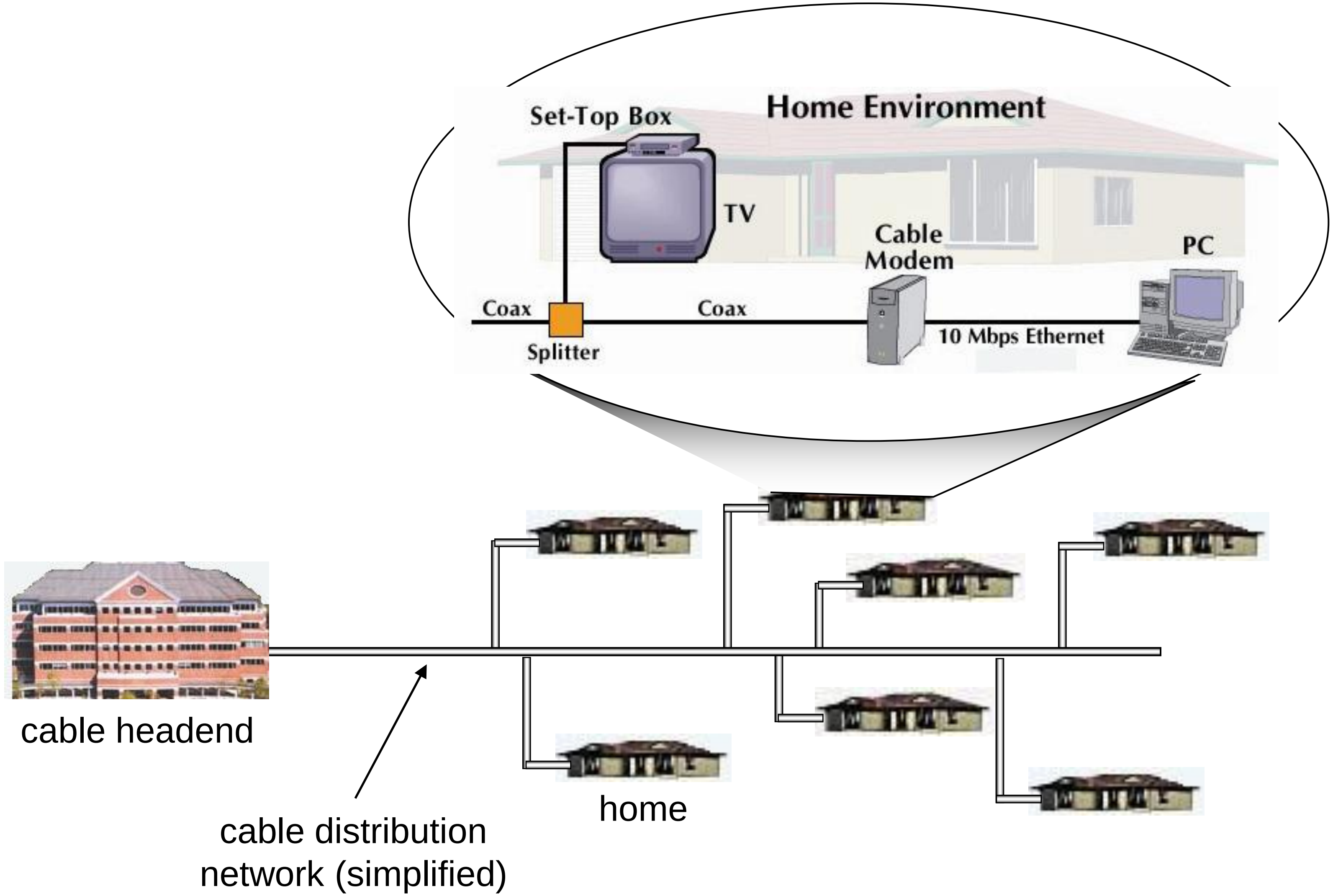
Typically 500 to 5,000 homes



Cable Network Architecture: Overview

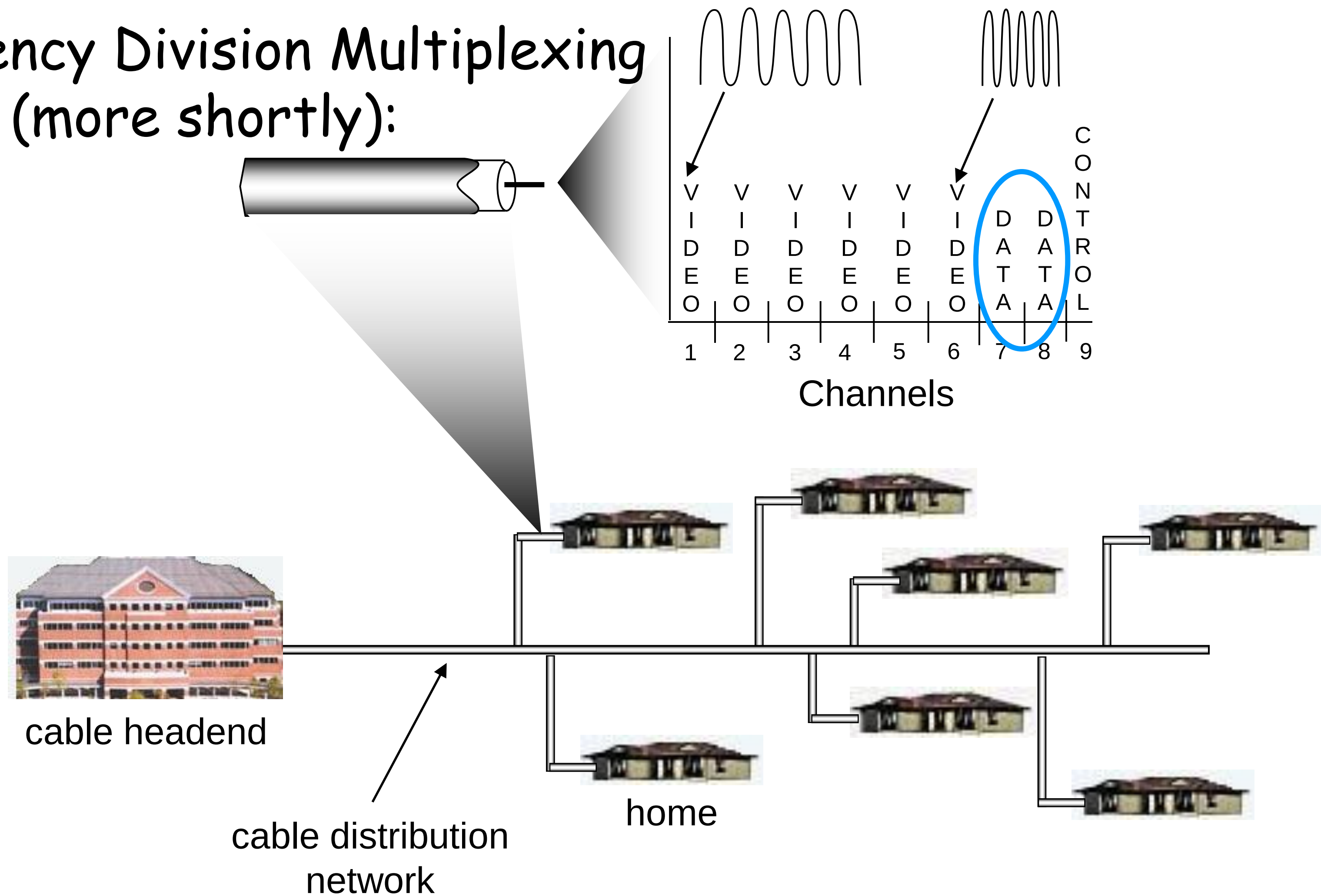


Cable Network Architecture: Overview

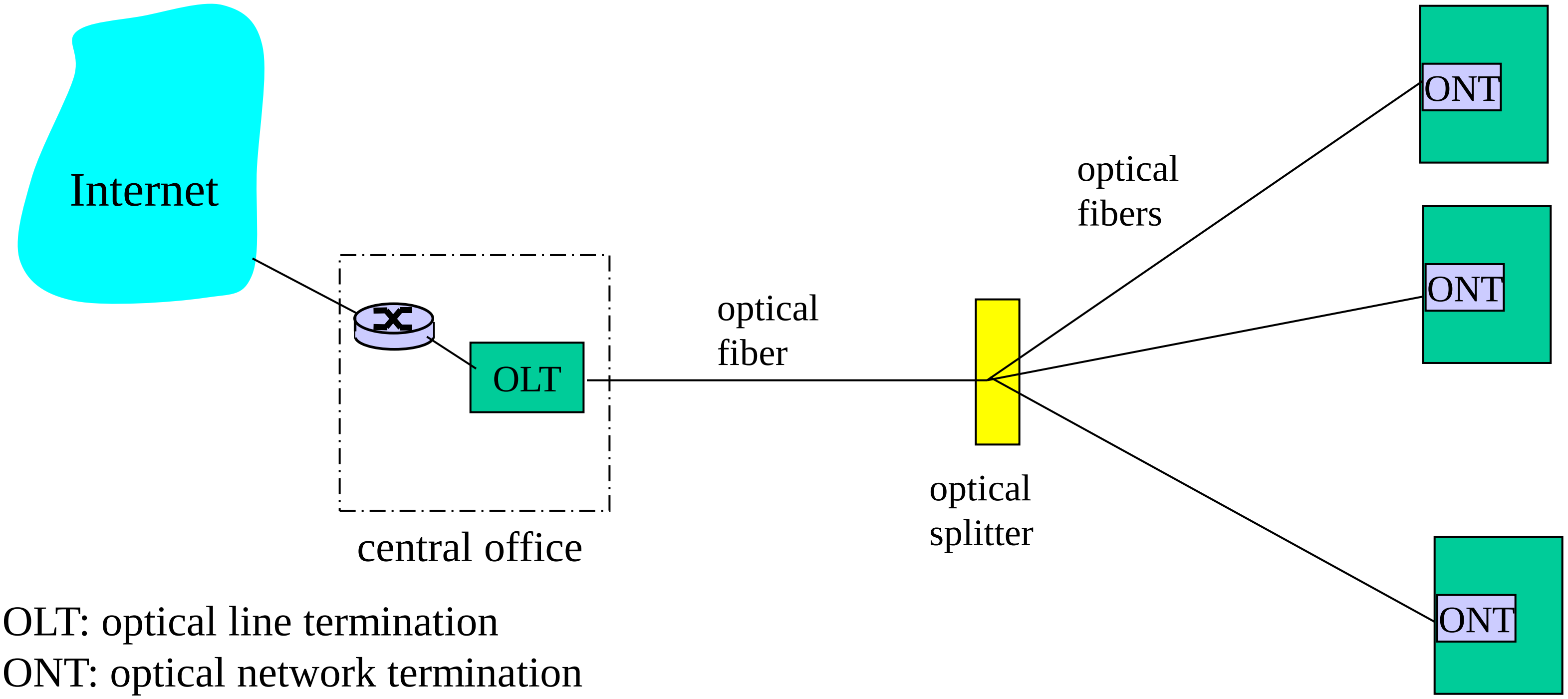


Cable Network Architecture: Overview

Frequency Division Multiplexing (FDM) (more shortly):



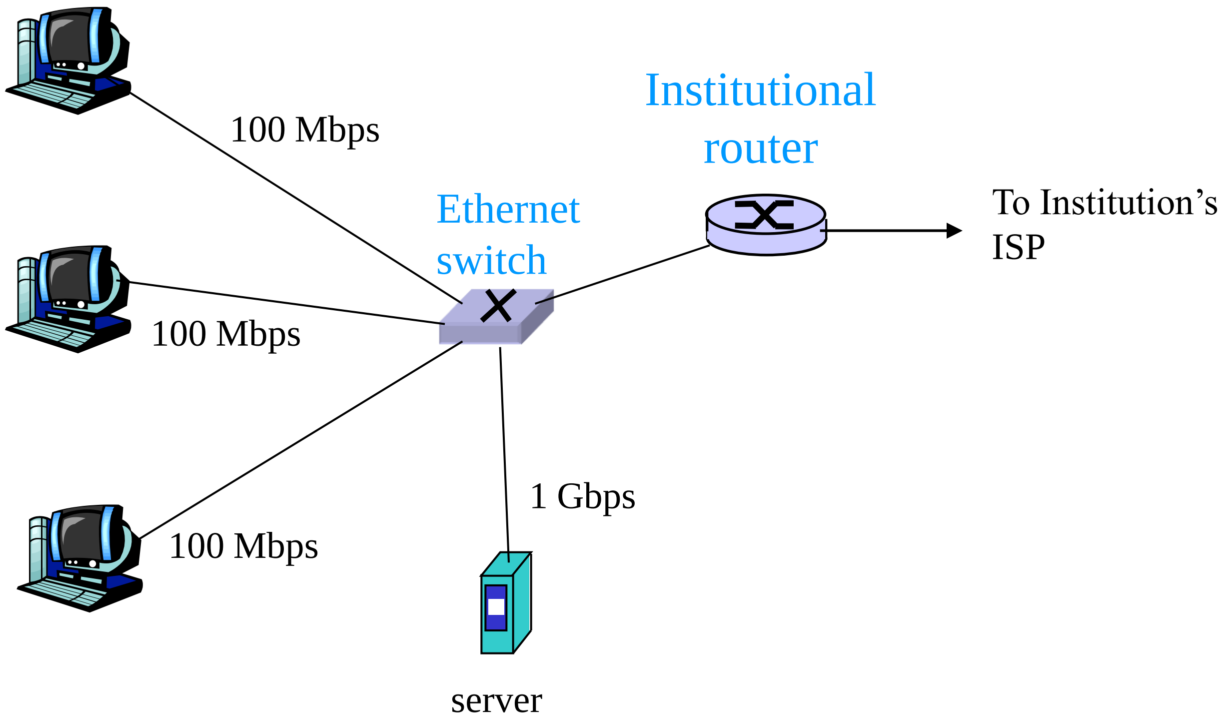
Fiber to the Building/Home



OLT: optical line termination
ONT: optical network termination

- Optical links from central office to the buidling/home
- Two competing optical technologies:
  - Passive Optical network (PON)
  - Active Optical Network (PAN)
- Much higher Internet rates; fiber also carries television and phone services

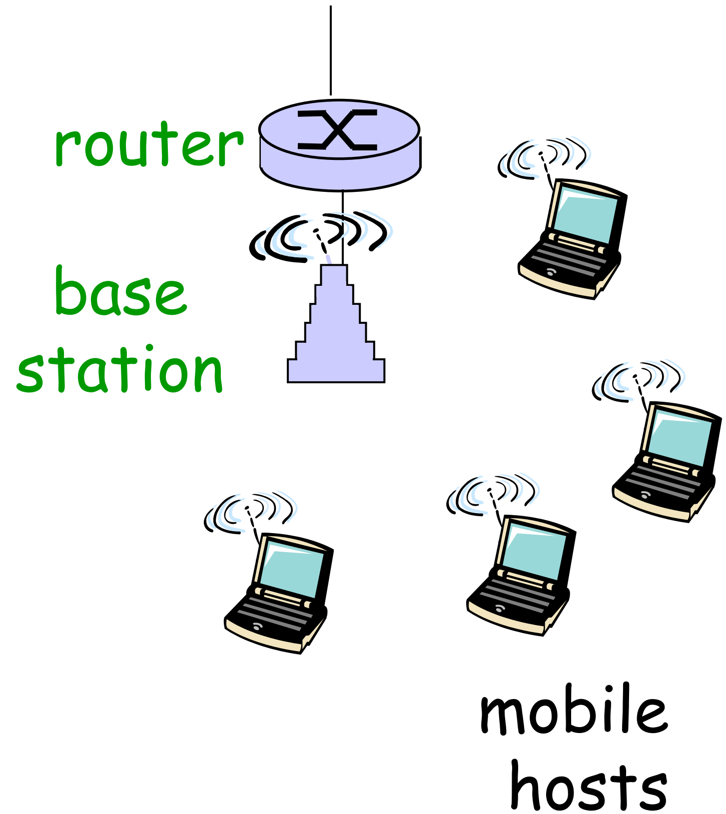
Ethernet Internet access



- Typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps Ethernet
- Today, end systems typically connect into Ethernet switch

Wireless access networks

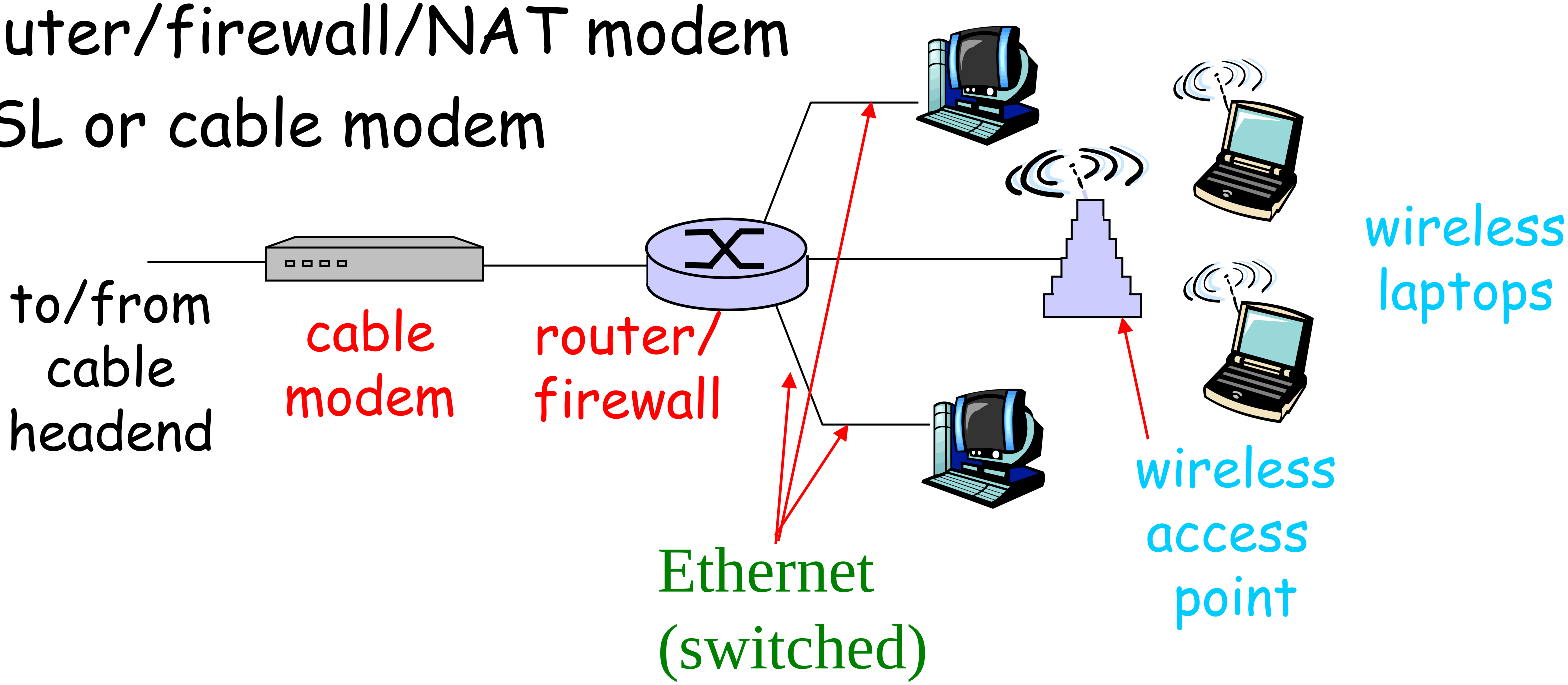
- shared *wireless* access network connects end system to router
  - via base station aka "access point"
- wireless LANs:
  - 802.11b/g/a (WiFi): 11 or 54 Mbps
- wider-area wireless access
  - provided by telco operator
  - ~1Mbps over cellular system (EVDO, HSDPA)
  - next up: WiMAX (10's Mbps) over wide area



Home networks

Typical home network components:

- wireless access point
- Ethernet
- router/firewall/NAT modem
- DSL or cable modem



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

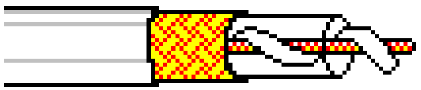
Twisted Pair (TP)

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5: 100Mbps 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 point-to-point transmission (e.g., 10's-100's Gps)
- low error rate: repeaters spaced far apart; *immune* to electromagnetic noise

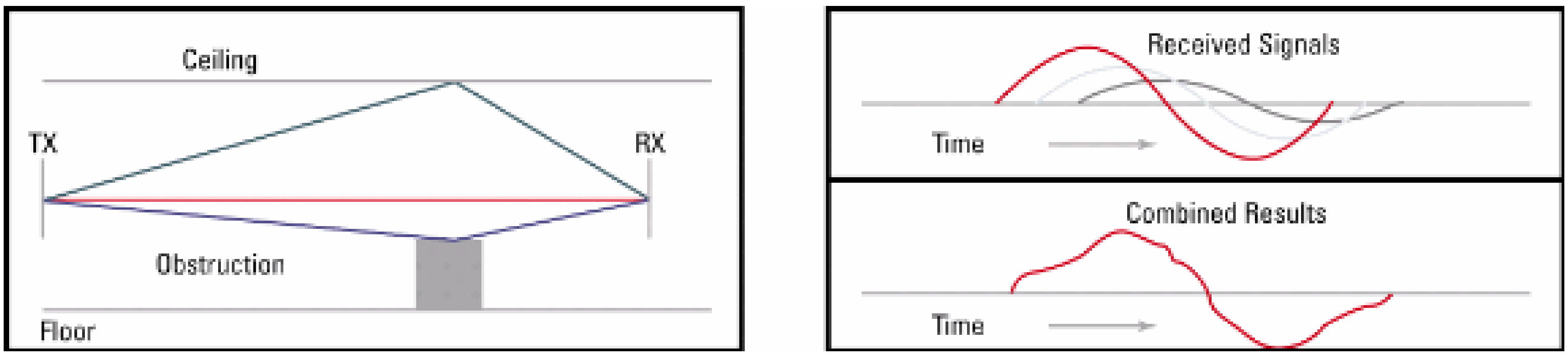
Physical media: radio

- 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)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ 1 Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-to-end delay
  - geosynchronous versus low altitude

Multipath effects



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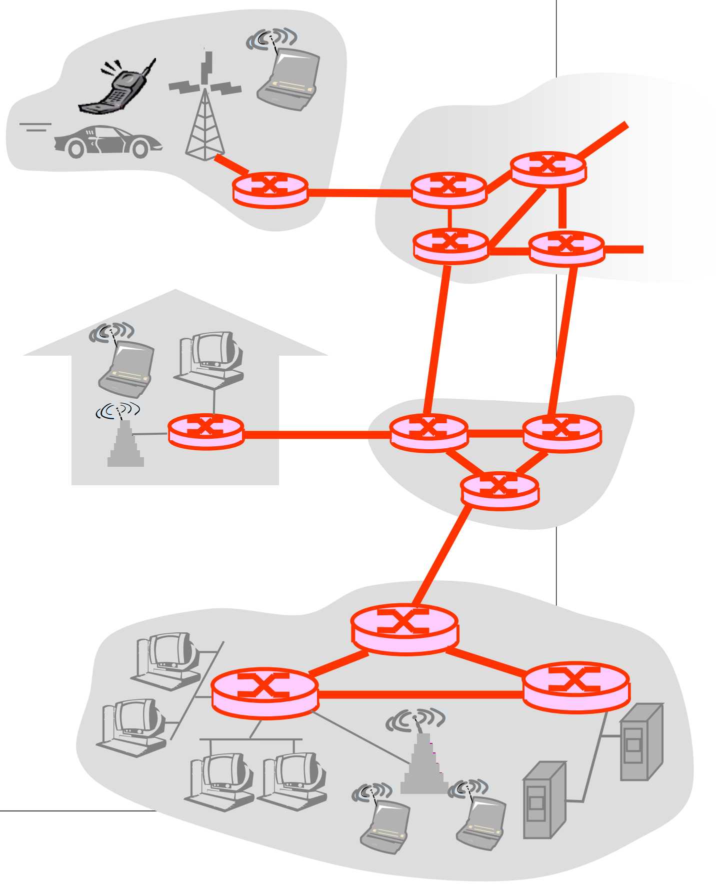
The Network Core

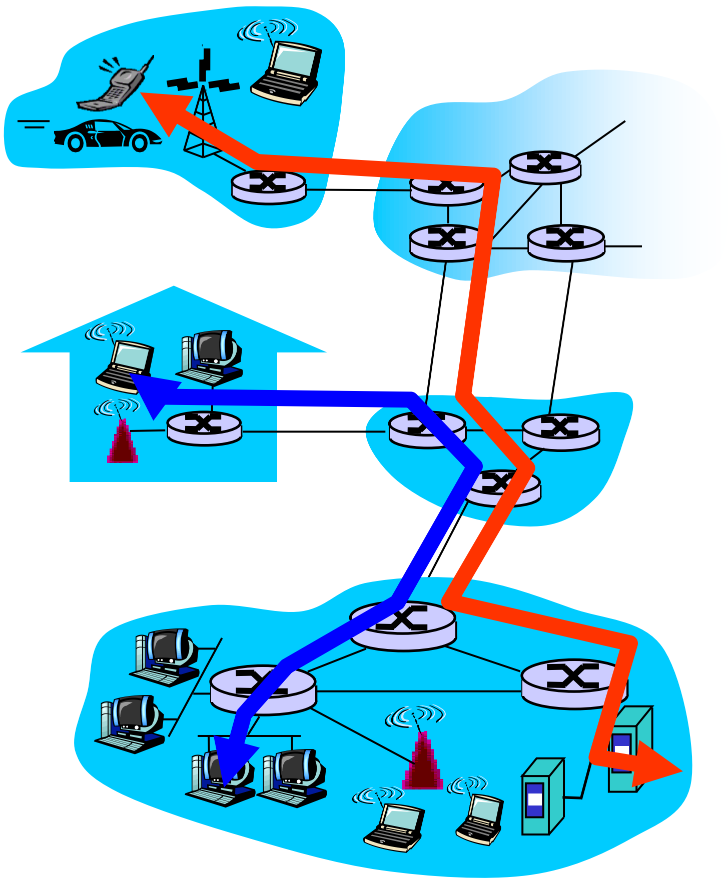
- mesh of interconnected routers
- how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



Network Core: Circuit Switching

End-to-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 becomes *idle* if not used by owning call *(no sharing)*

- dividing link bandwidth into "pieces"
  - frequency division
  - time division

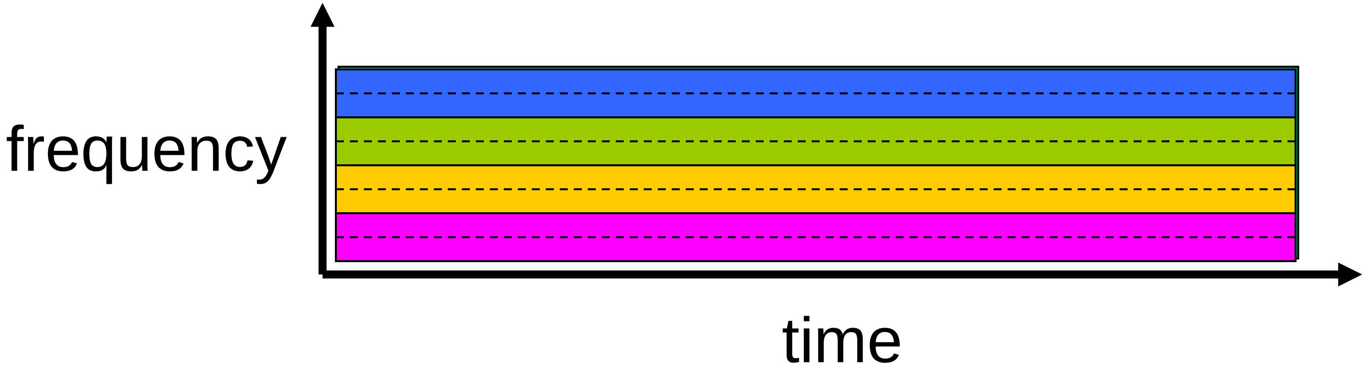
- FDM: frequency division multiplexing
- TDM: time division multiplexing

Circuit Switching: FDM and TDM

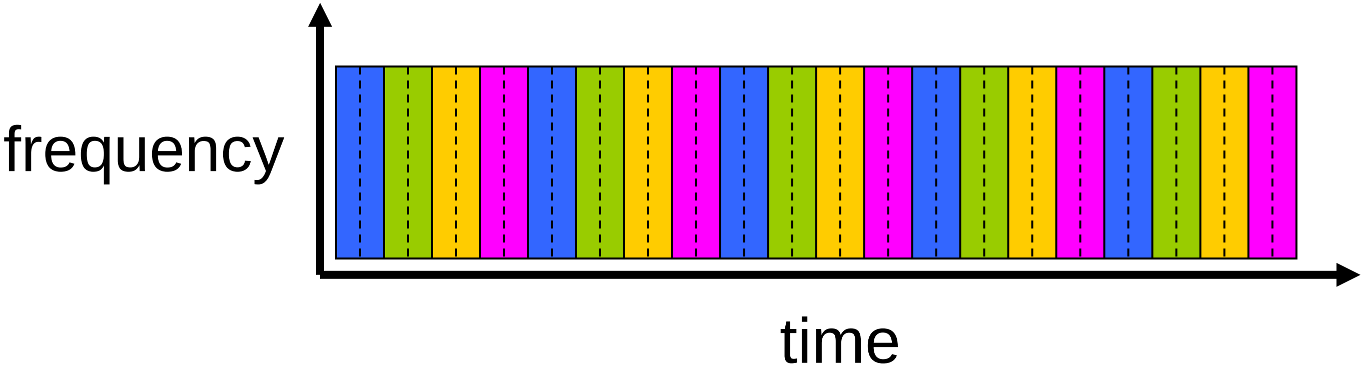
Example:

4 users

FDM



Static TDM



Numerical example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Network Core: Packet Switching

each end-to-end data stream divided into *packets*

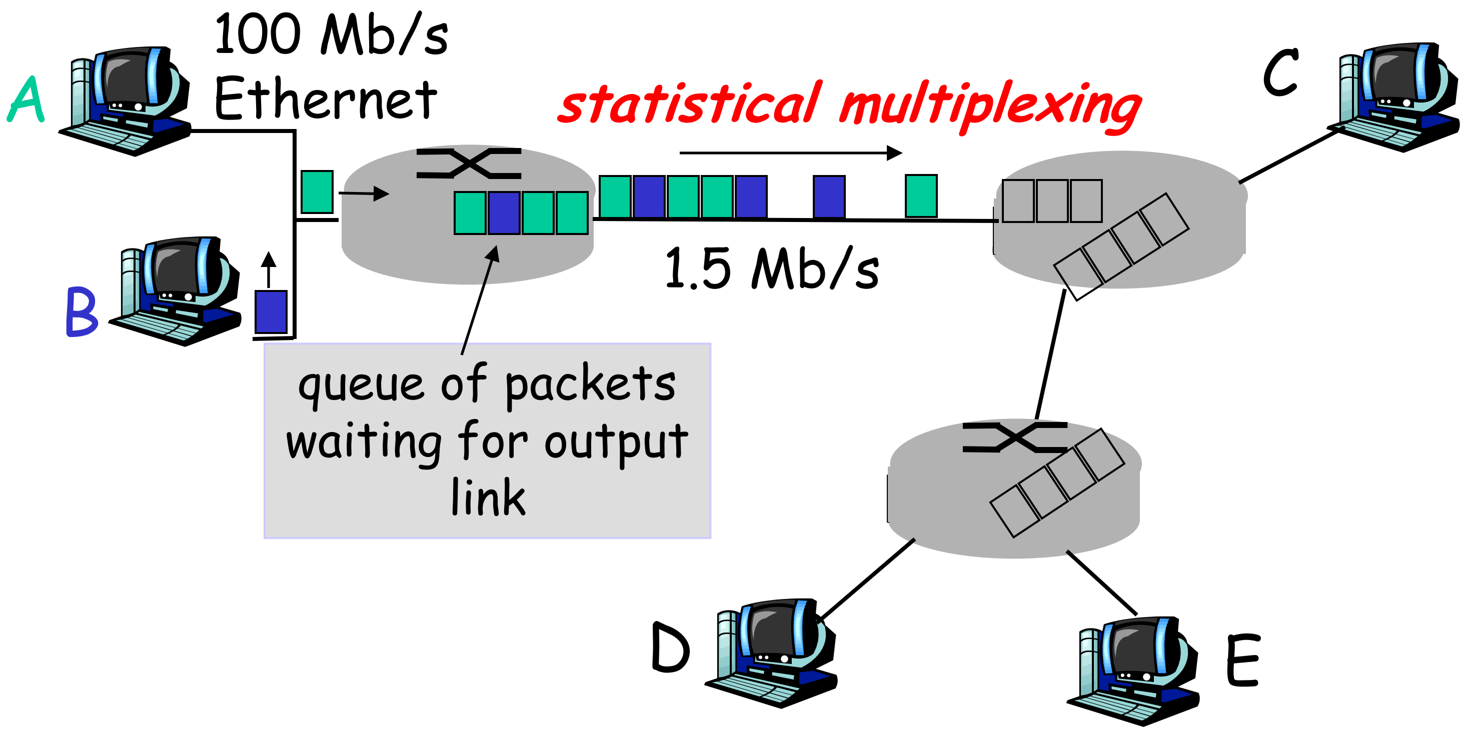
- user A, B packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*

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

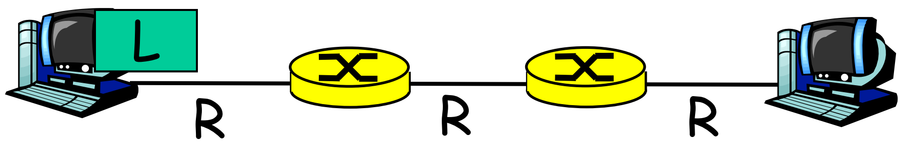


Time Division Multiplexing (TDM)

Dynamic TDM:

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

Packet-switching: store-and-forward



- Takes L/R seconds (transmission time) to transmit (push out) packet of L bits on to link or R bps
- *Store and forward:* entire packet must arrive at router before it can be transmitted on next link
- End-to-end delay = 3L/R

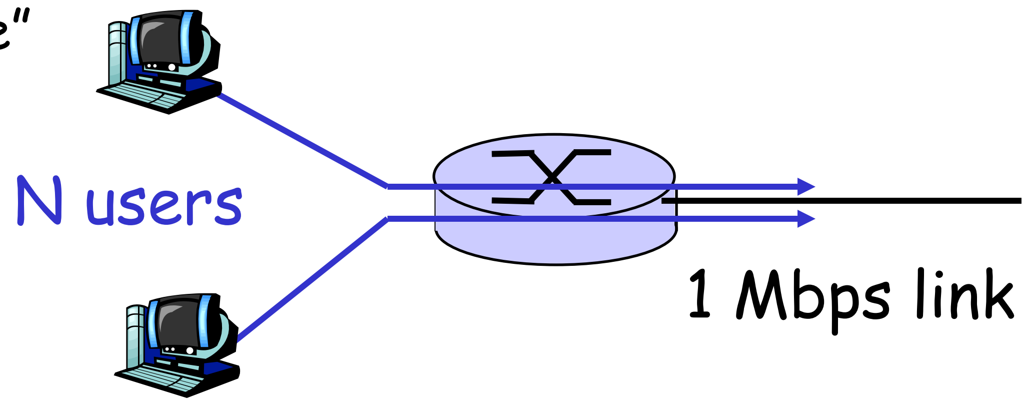
Example:

- L = 7.5 Mbits (data)
- R = 1.5 Mbps (link capacity)
- delay = 15 sec (total transmission time, from source to destination)
- Assume zero propagation delay, queueing delay and processing delay.

Packet switching versus circuit switching

Packet switching allows more users to use network!

- 1 Mbps link
- each user:
  - 100 kbps 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



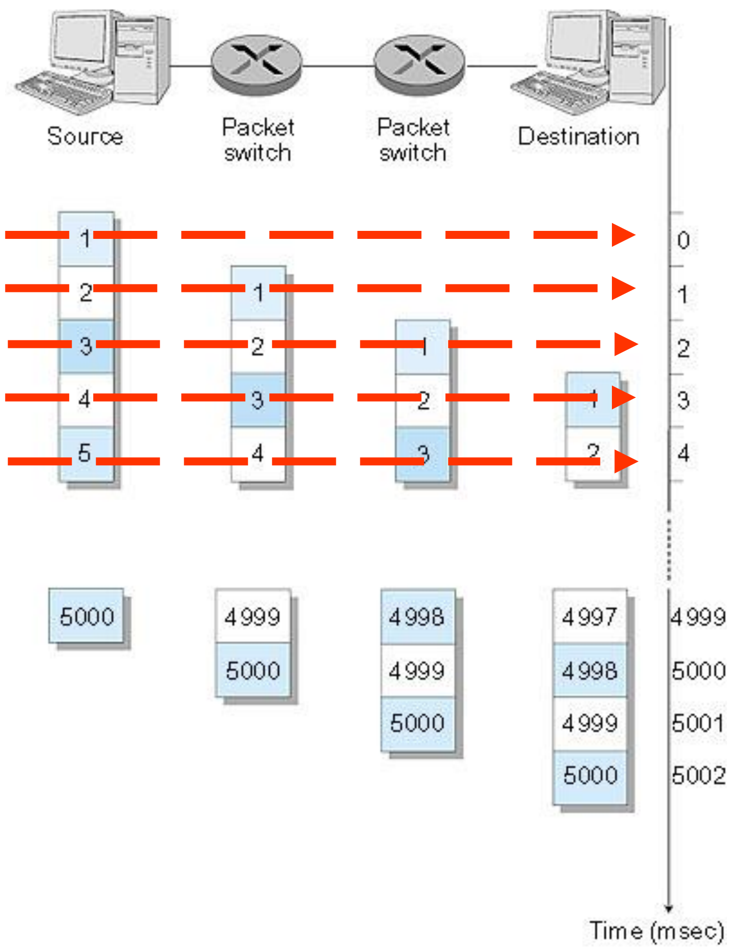
Q: how did we get value 0.0004?

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 (chapter 7)

Packet Switching: Message Segmenting



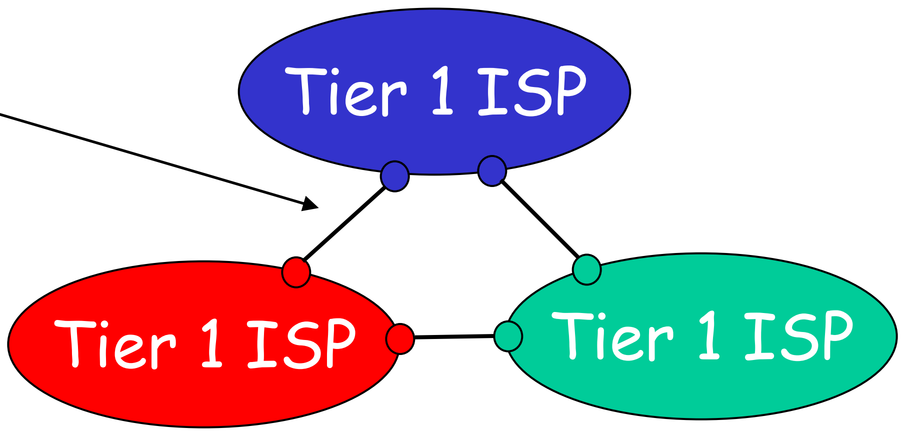
Now break up the message into 5000 packets

- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- *pipelining:* each link works in parallel
  - Delay reduced from 15 sec to 5.002 sec
  - (0.001x3x5000= 15sec; 0.001x3+0.001x4999=5.002 sec)

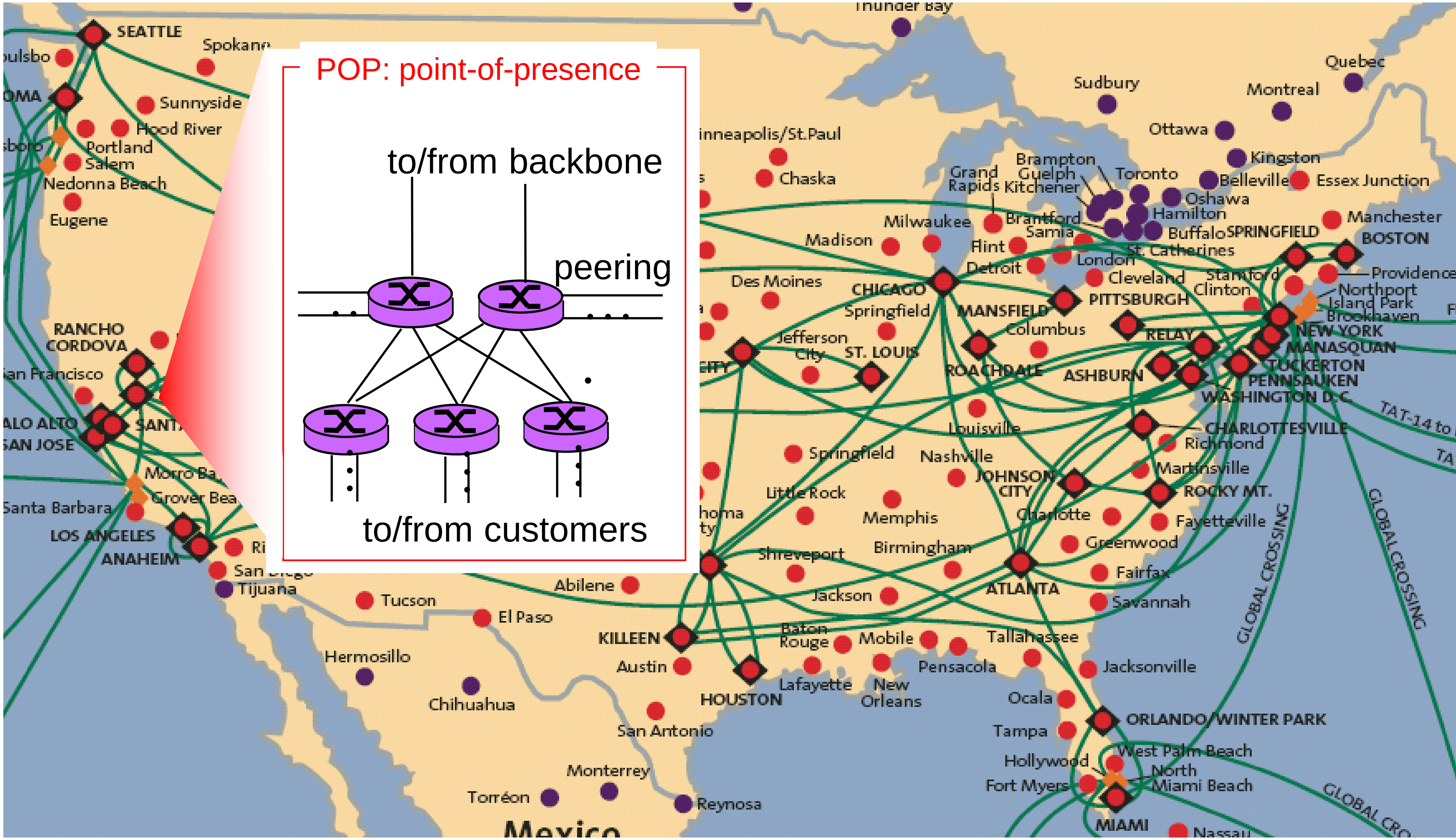
Internet structure: network of networks

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

Tier-1 providers interconnect (peer) privately



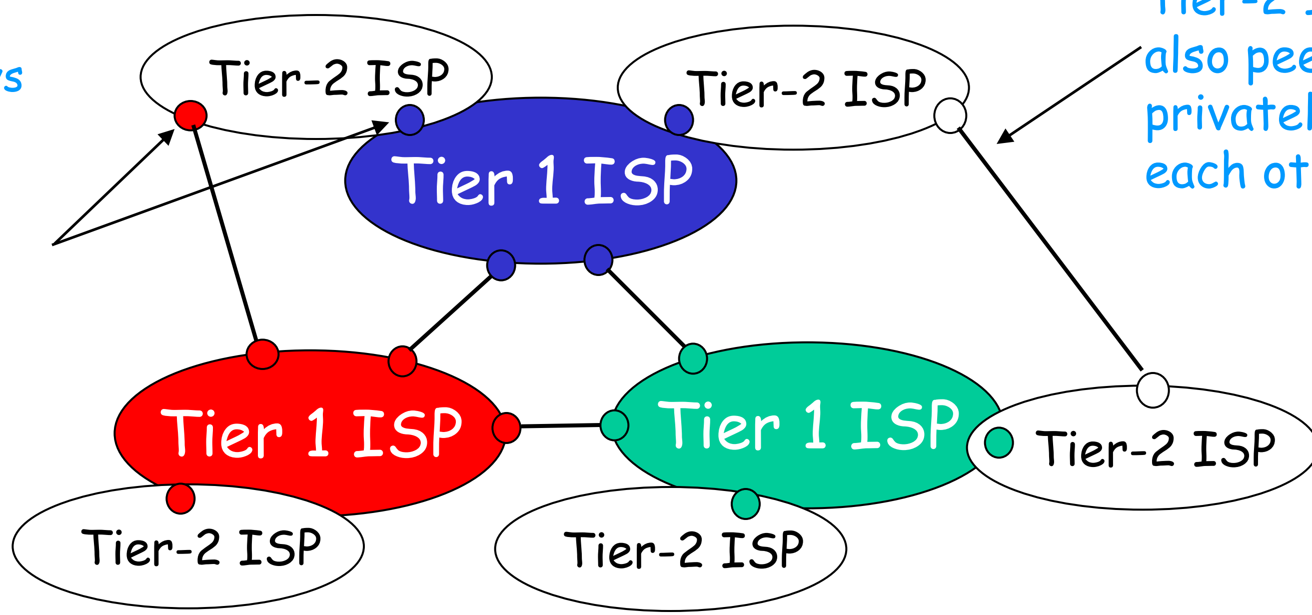
Tier-1 ISP: e.g., Sprint



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

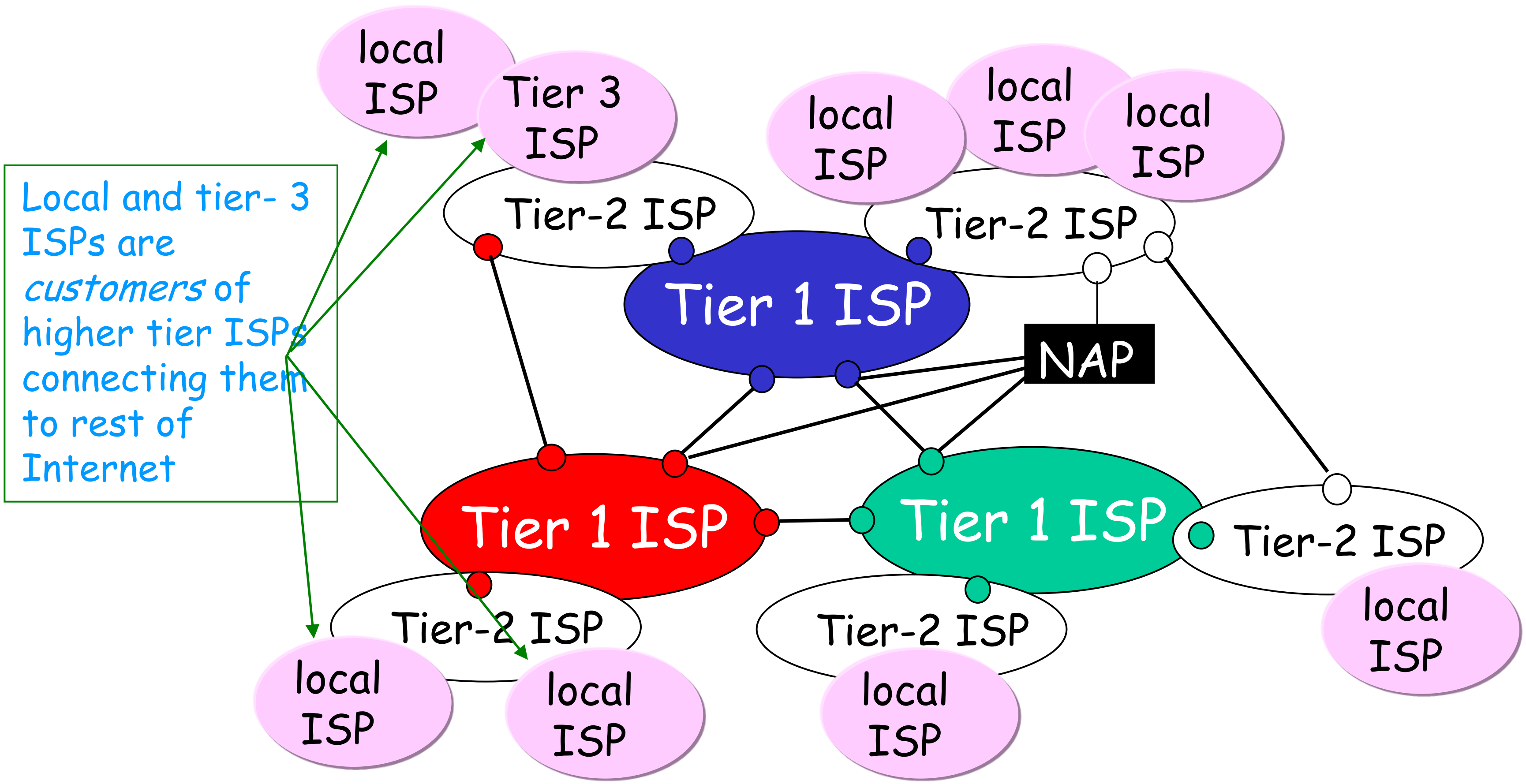
- Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet
- tier-2 ISP is *customer* of tier-1 provider



Tier-2 ISPs also peer privately with each other.

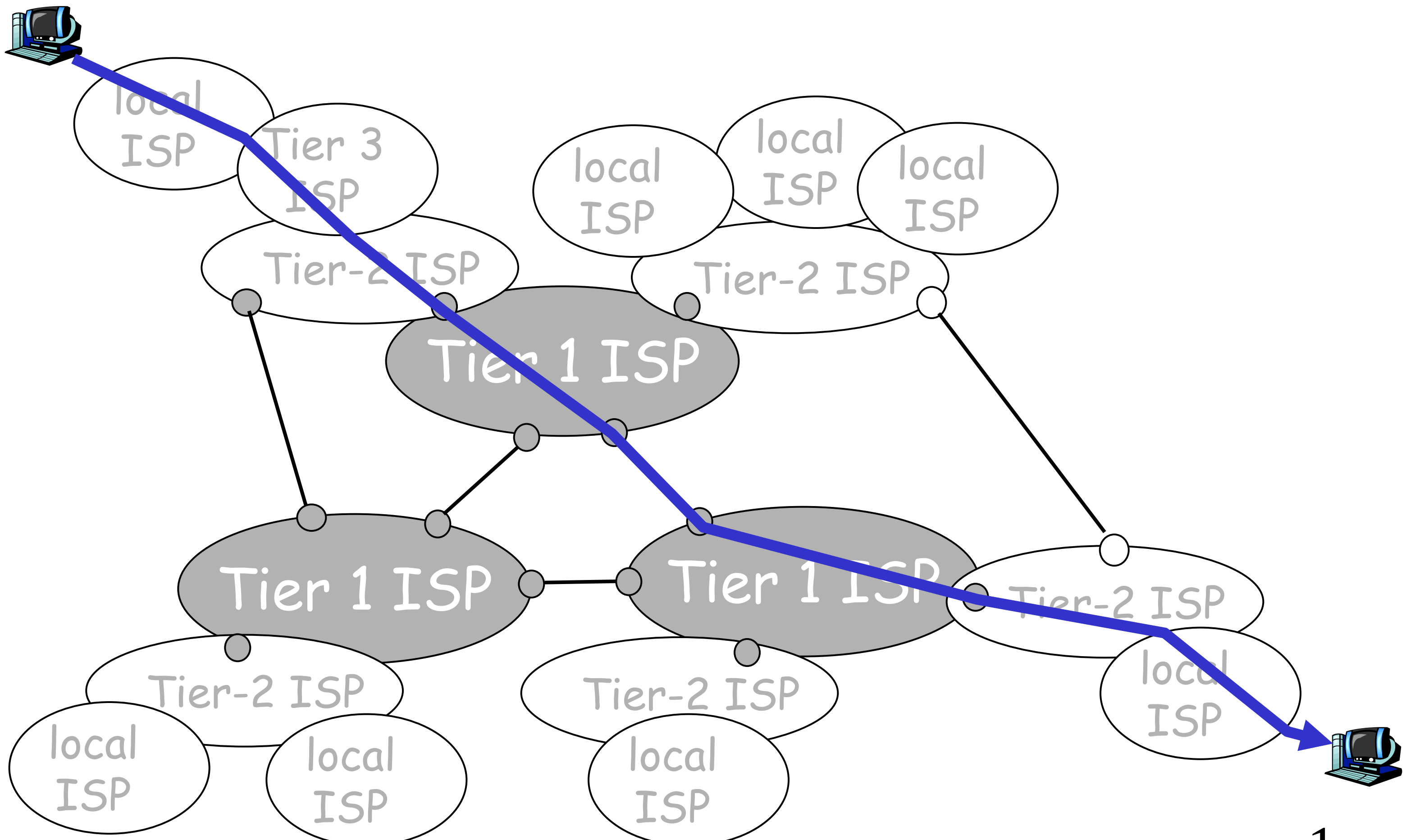
Internet structure: network of networks

- "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!

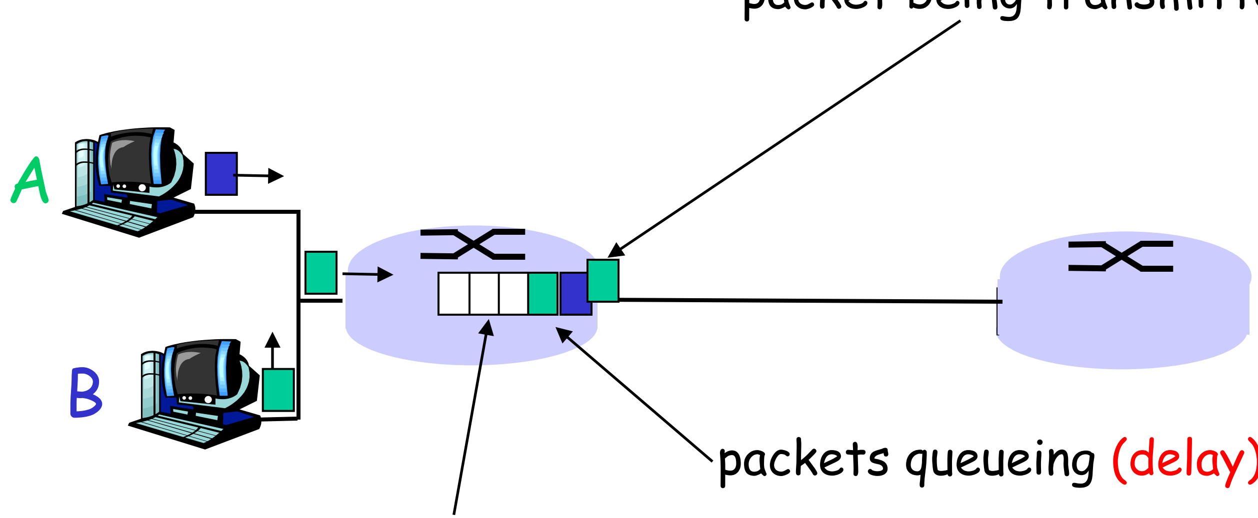


Chapter 1: roadmap

How do delay and loss occur?

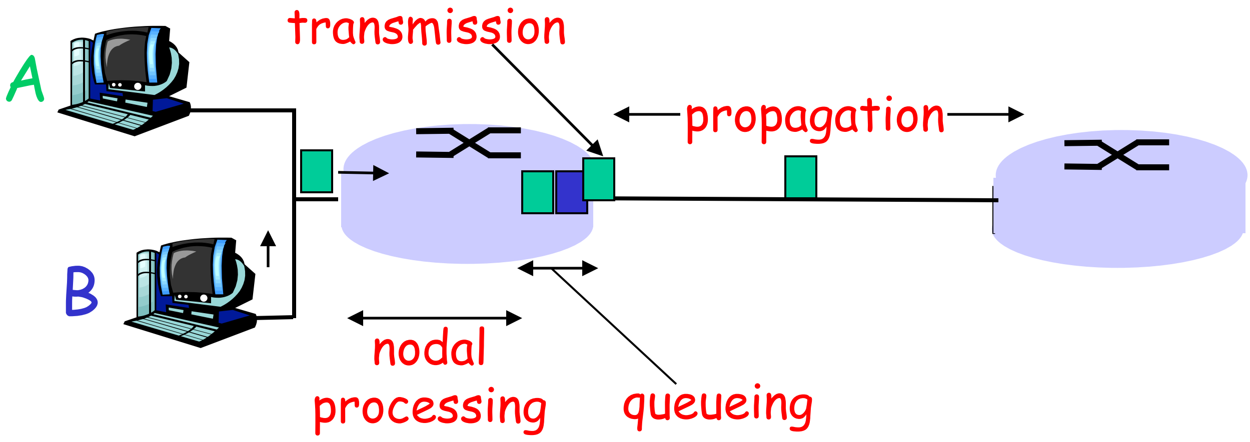
packets ***queue*** in router **buffers**

- packet **arrival rate** to link <u>exceeds</u> 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

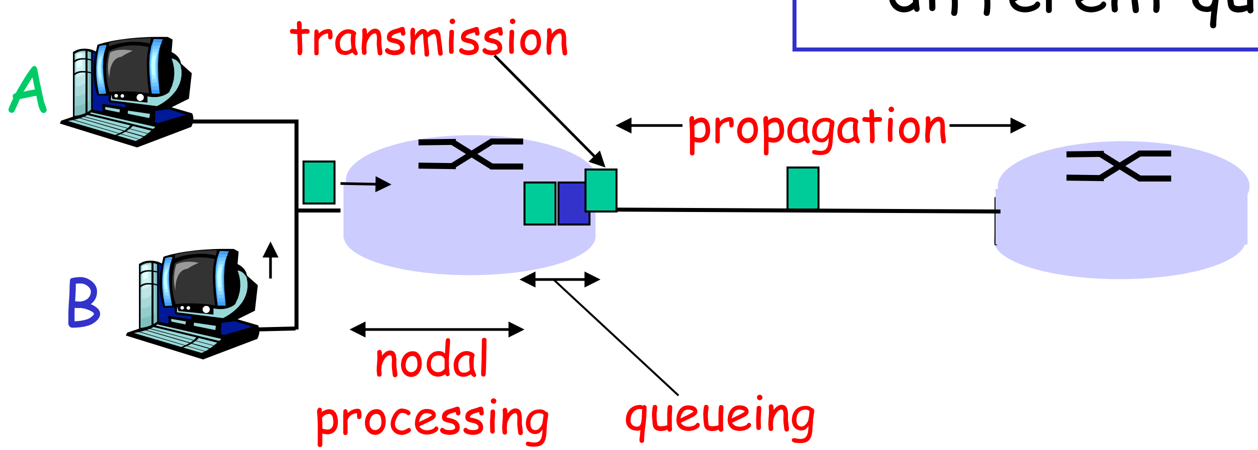
3. Transmission delay:

- 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!



Nodal delay

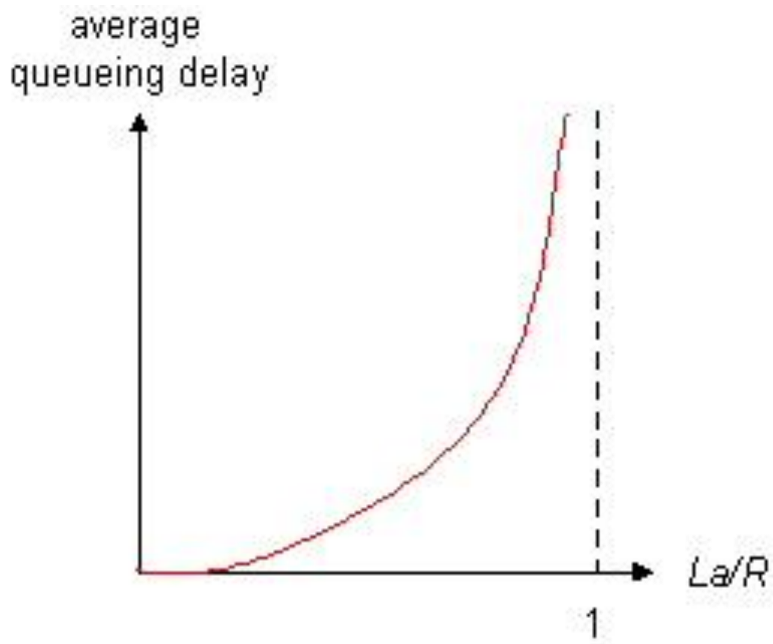
$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

- 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

Queueing delay (revisited)

- R=link bandwidth (bps)
- L=packet length (bits)
- a=average packet arrival rate

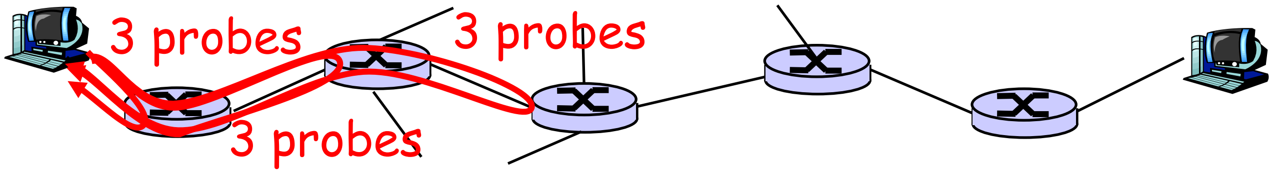
traffic intensity = La/R



- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

"Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- **Traceroute program:** provides delay measurement from source to router along end-to-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

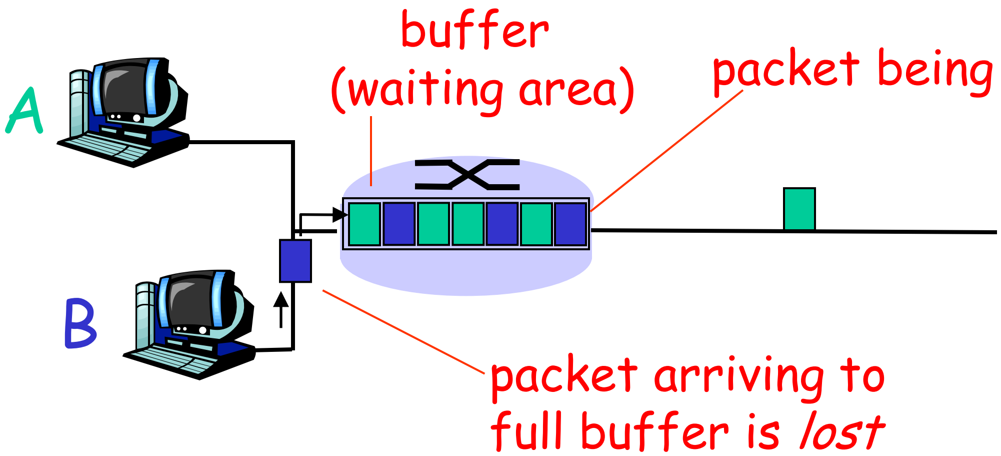
trans-oceanic link

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

tracert in Windows

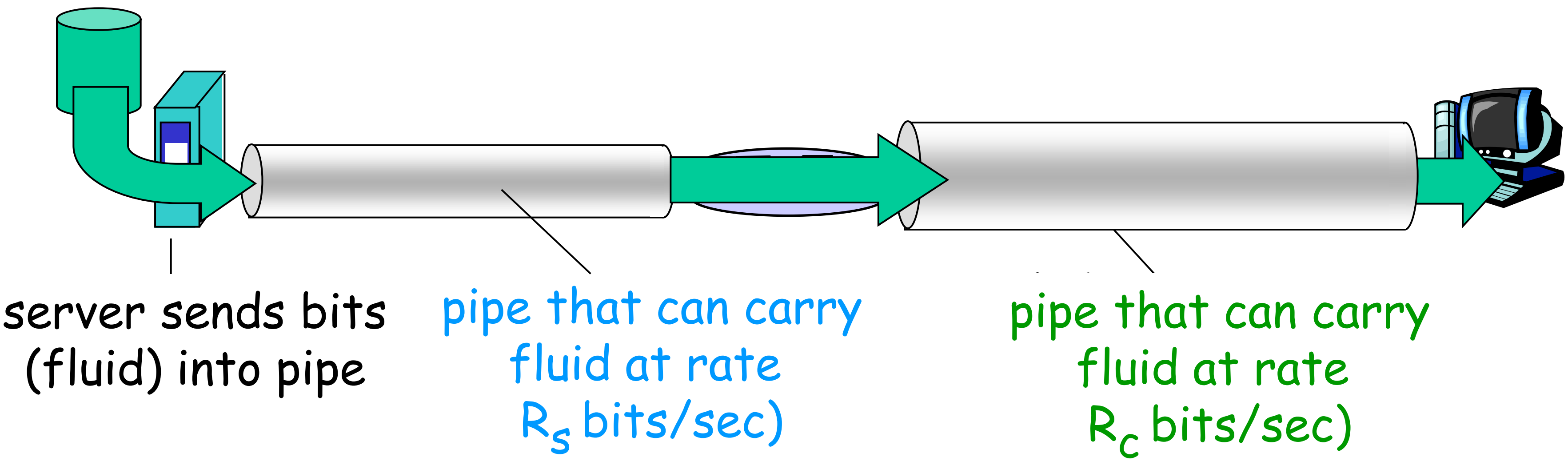
Packet loss

- queue (aka buffer) preceding link in buffer has **finite** capacity
- packet arriving to full queue **dropped** (aka **lost**)
- lost packet may be **retransmitted** by previous node, by source end system, or not at all



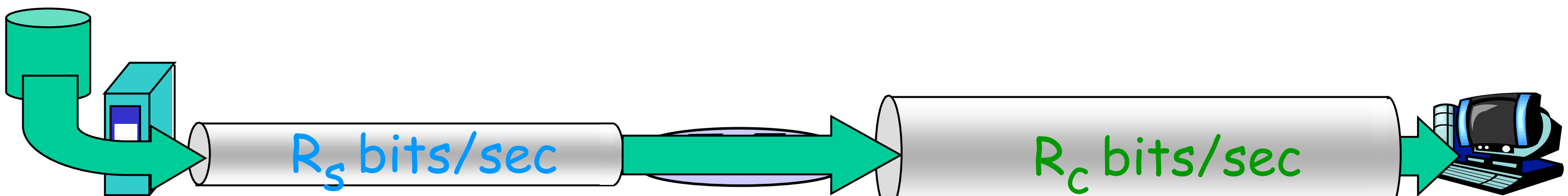
Throughput

- *throughput:* rate (**bits/time unit**) at which bits transferred between sender/receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over long(er) period of time

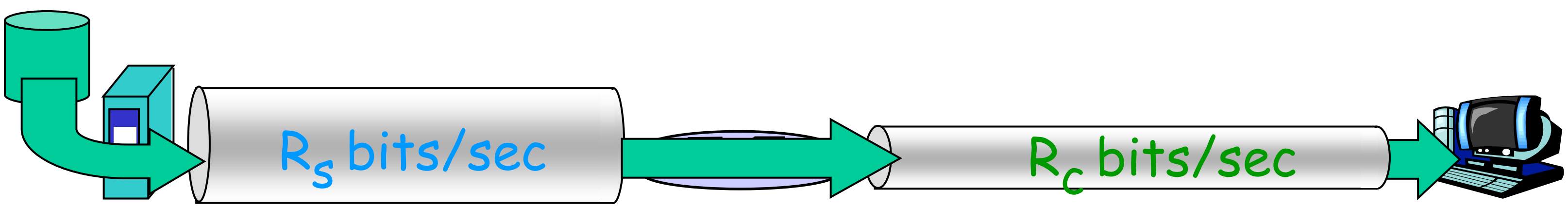


Throughput (more)

- $R_s < R_c$ What is average end-end throughput?



- $R_s > R_c$ What is average end-end throughput?

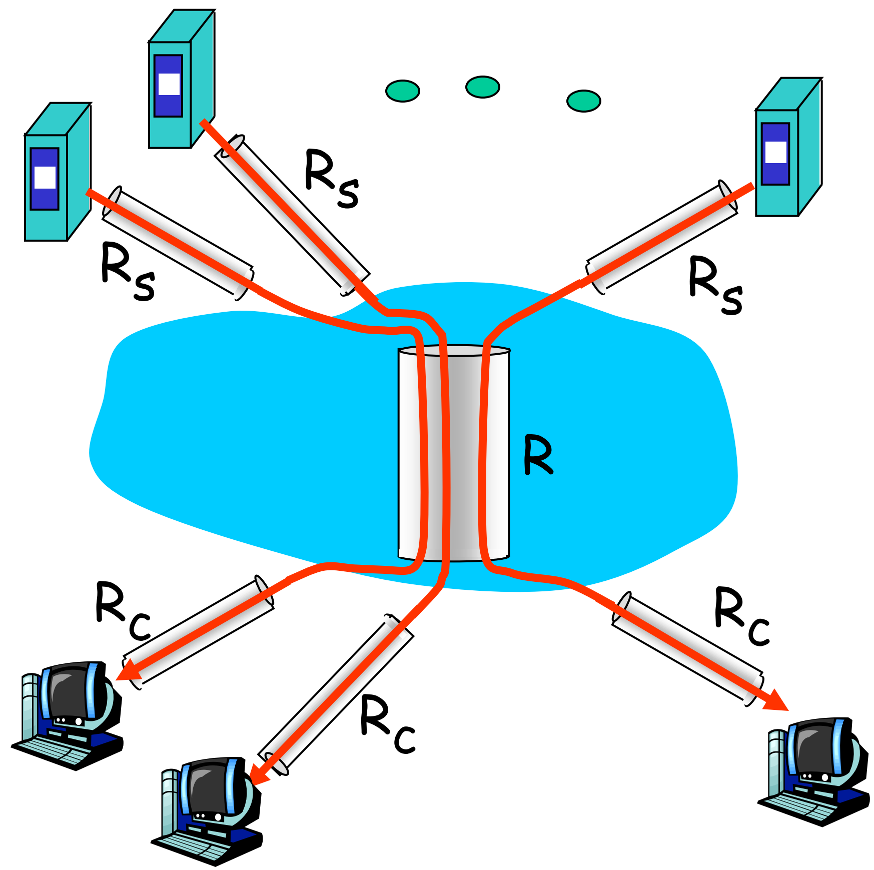


bottleneck link

link on end-to-end path that constrains end-to-end throughput

Throughput: Internet scenario

- per-connection **end-to-end throughput**: $\min(R_c, R_s, R/10)$
- in practice: R_c or R_s is often **bottleneck**



10 connections (fairly) share backbone bottleneck link R bits/sec

Chapter 1: roadmap

1.1 What *is* the Internet?

1.2 Network edge

- end systems, access networks, links

1.3 Network core

- circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks

1.5 Protocol layers, service models

1.6 Networks under attack: security

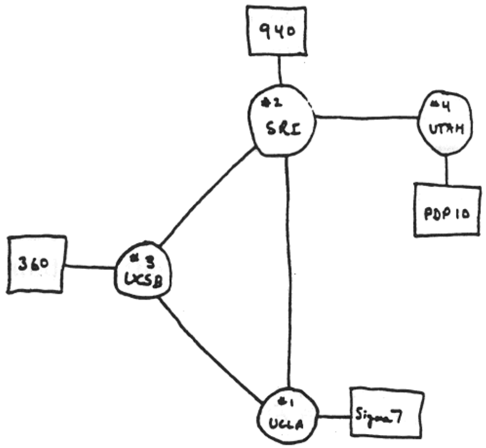
1.7 History

Internet History

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: 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



THE ARPA NETWORK

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late70'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

2007:

- ~500 million hosts
- Voice, Video over IP
- P2P applications: BitTorrent (file sharing), Skype (VoIP), PPLive (video)
- more applications: YouTube, gaming
- **wireless, mobility, social networking**

Introduction: Summary

Covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
  - Internet structure
- performance: loss, delay, throughput
- layering, service models
- security
- history

You now have:

- context, overview, "feel" of networking
- more depth, detail *to follow!*

The end. ☺

Homework #1

- R1, R8, R9, R10, R11, R12, R15, R18

Homework #2

- R22, P4, P14, P15, P16, P22