CMPT-371: Data Communication and Networking

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Course Details and Evaluation Breakdown

Calendar Objective/Description

❖ Data communication fundamentals (data types, rates, and transmission media). Network architectures for local and wide areas. Communications protocols suitable for various architectures. ISO protocols and internetworking. Performance analysis under various loadings and channel error rates.

Instructor's Objectives

❖ Computer networks and the Internet have become an essential part of our everyday life; almost every device that we use is either already connected to the Internet or soon will be. This course is an introduction to the principles and practical aspects of designing and operating computer networks as well as analyzing their performance.

Prerequisites

❖ CMPT 225, CMPT/ENSC 150 and MATH 151 (MATH 150). MATH 154 or 157 with a grade of at least B+ may be substituted for MATH 151 (MATH 150)

Topics to be covered

❖ Analysis and design of computer networks.

❖ Understanding layered architecture of Internet.

❖ Protocol layers and their service models.

❖ Principles of HTTP, FTP, and SMTP.

❖ Understanding peer-to-peer applications.

❖ Network socket programming using Java.

❖ Understanding TCP and UDP.

❖ Flow and congestion control.

❖ Understanding network layer services.

❖ Forwarding and routing.

❖ Virtual-circuit networks.

❖ Datagram networks.

❖ Broadcast and multicast routing.

❖ Introduction to link-layer and its services.

❖ Simple error-detection and error-correction techniques.

❖ Simple multiple-access protocols.

❖ Local area networks

Grading Scheme

❖ **Grading**

- Assignments and Projects 25%;
- Midterm(s) 25%;
- Final Exam 50% (tentative distribution - to be discussed during first week of classes).

❖ **Required Books**

- Computer Networking: A Top-Down Approach, 6th Edition, James F. Kurose and Keith W. Ross, Pearson, 2013, 9780132856201

Manpreet Singh <mssingh@sfu.ca>

❖ **Reference Books**

- Computer Networks, 5th Edition, Andrew S. Tanenbaum, Prentice Hall, 2011, 9780132126953
- Data and Computer Communications, William Stallings, Prentice Hall, 2013, 9780133506488, 10th Edition

❖ TA: "Manpreet Singh: mssingh@sfu.ca"
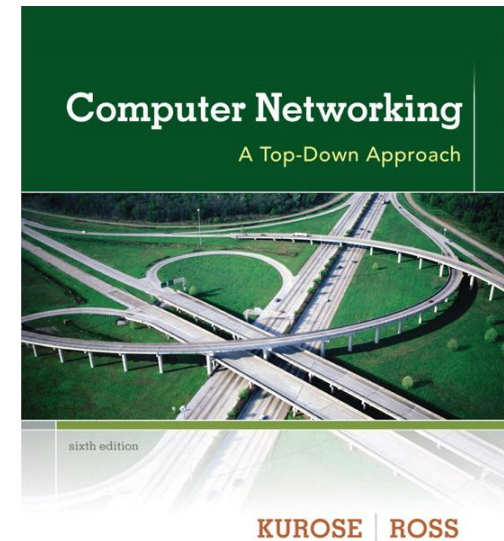
Chapter 1
Introduction

A note on the use of these ppt slides:

We're making these slides freely available to all (faculty, students, readers). They're in PowerPoint form so you see the animations; and can add, modify, and delete slides (including this one) and slide content to suit your needs. They obviously represent a *lot* of work on our part. In return for use, we only ask the following:

❖ If you use these slides (e.g., in a class) that you mention their source (after all, we'd like people to use our book!)

❖ If you post any slides on a www site, that you note that they are adapted from (or perhaps identical to) our slides, and note our copyright of this material.

Thanks and enjoy! JFK/KWR

Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

Chapter 1: introduction

our goal:

- ❖ get "feel" 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

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

PC

server

wireless laptop

smartphone

❖ millions of connected computing devices:
  ▪ *hosts = end systems*
  ▪ running *network apps*

wireless links

_____ wired links
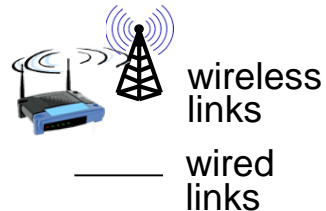
❖ *communication links*
  ▪ fiber, copper, radio, satellite
  ▪ transmission rate: *bandwidth*
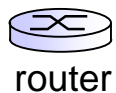
router

❖ *Packet switches:* forward packets (chunks of data)
  ▪ *routers* and *switches*

mobile network

global ISP

home network

regional ISP

institutional network
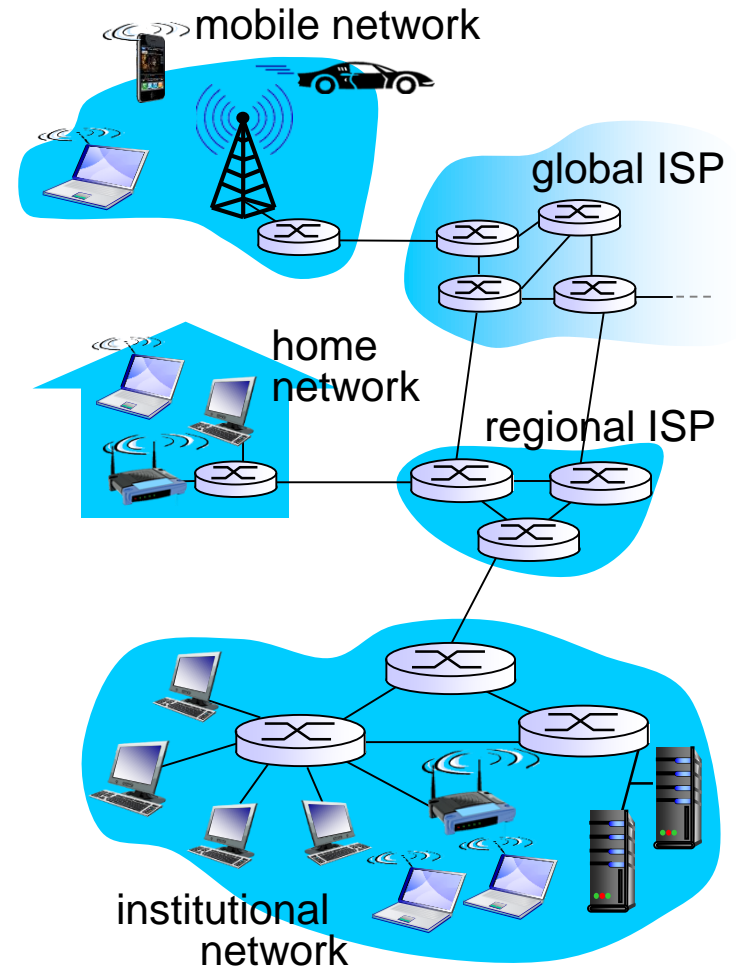
"Fun" internet appliances

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

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

Internet
refrigerator

Slingbox: watch,
control cable TV remotely

Internet phones

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

❖ *Internet: "network of networks"*
  ▪ Interconnected ISPs
❖ *protocols* control sending, receiving of msgs
  ▪ e.g., TCP, IP, HTTP, Skype, 802.11
❖ *Internet standards*
  ▪ RFC: Request for comments
  ▪ IETF: Internet Engineering Task Force

mobile network

global ISP

home network

regional ISP

institutional network
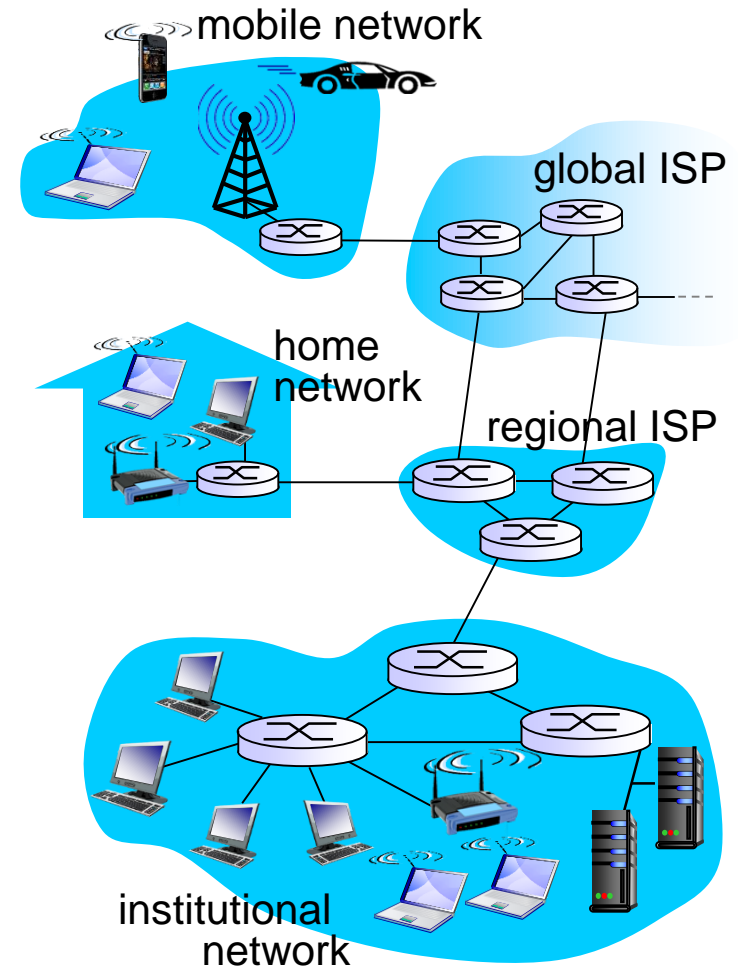
What's the Internet: a service view

❖ *Infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social nets, …

❖ *provides programming interface to apps*
  - hooks that allow sending and receiving app programs to "connect" to Internet
  - provides service options, analogous to postal service

mobile network

global ISP

home network

regional ISP

institutional network
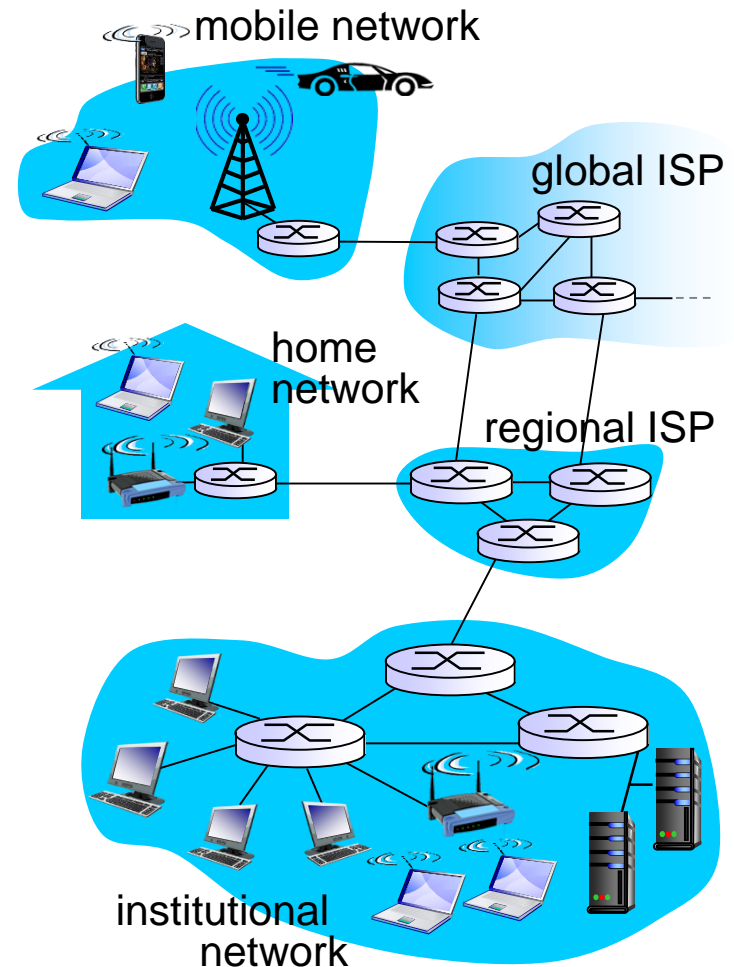
What's a protocol?

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 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:

time
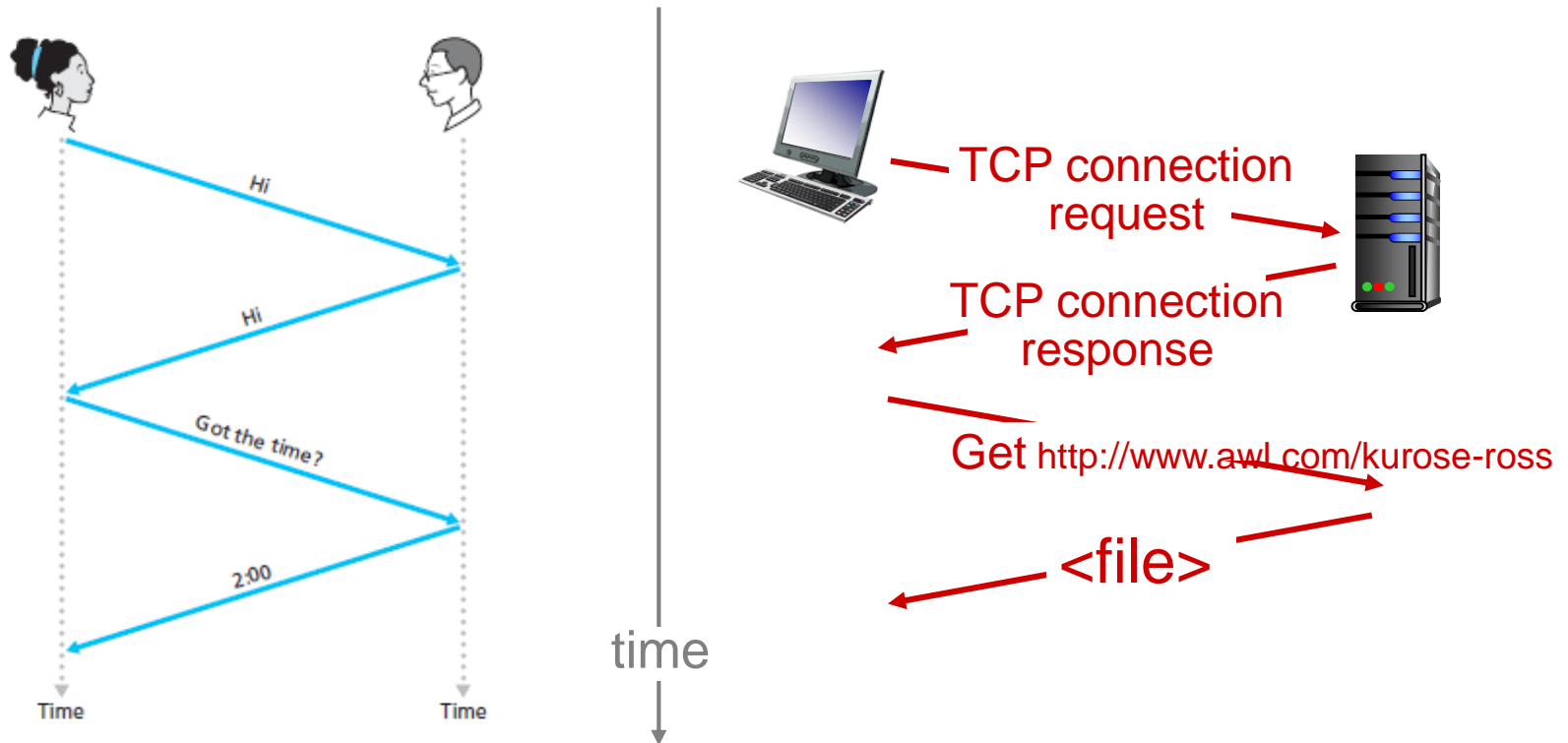
Q: other human protocols?
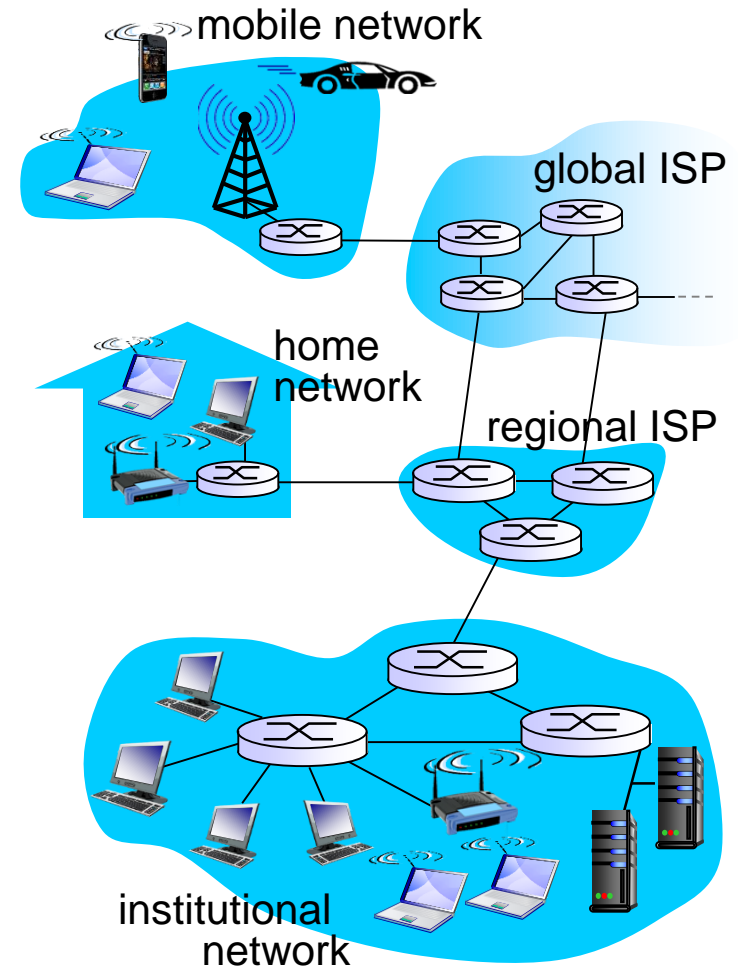
Chapter 1: roadmap

A closer look at network structure:

❖ *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

mobile network

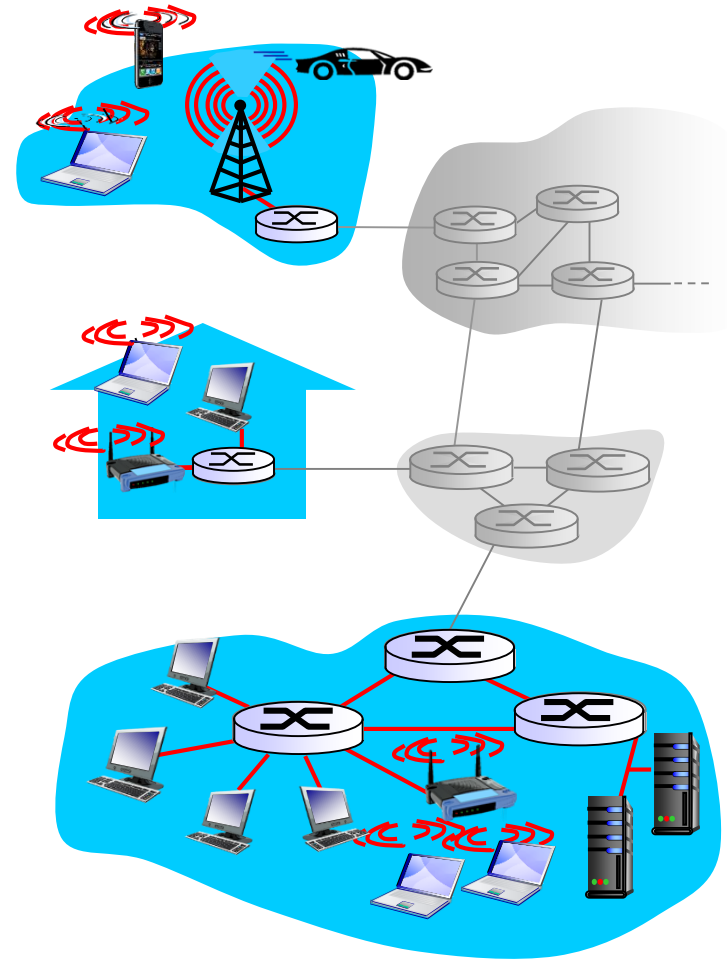global ISP

home network

regional ISP

institutional network

Access networks and physical media
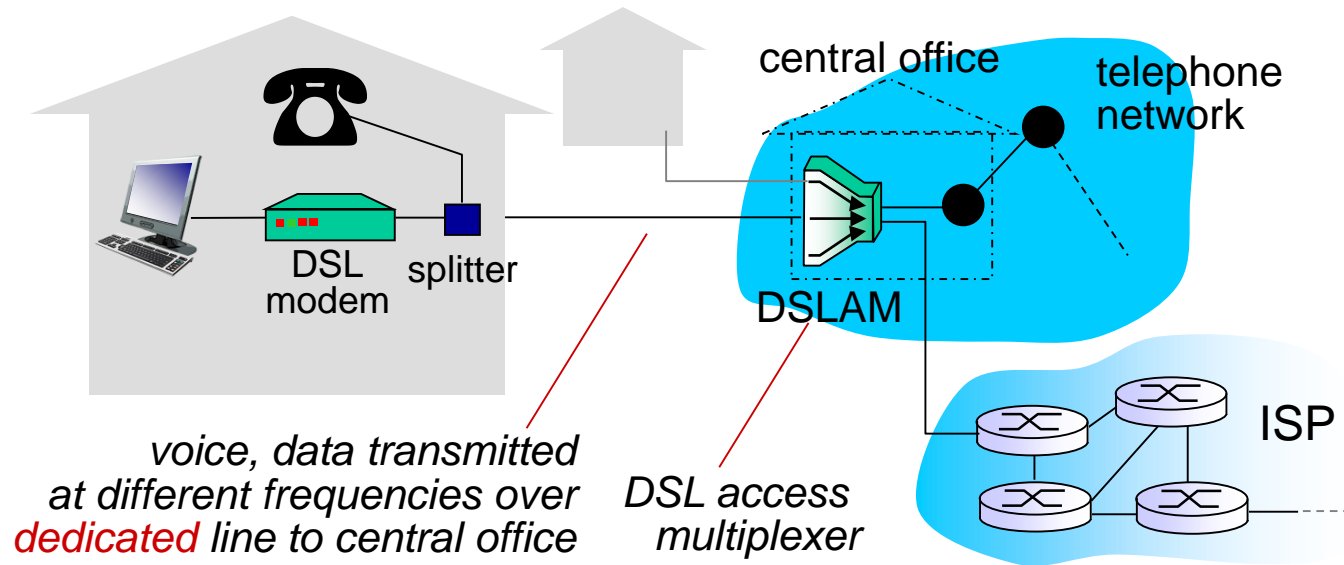
Q: How to connect end systems to edge router?

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

keep in mind:

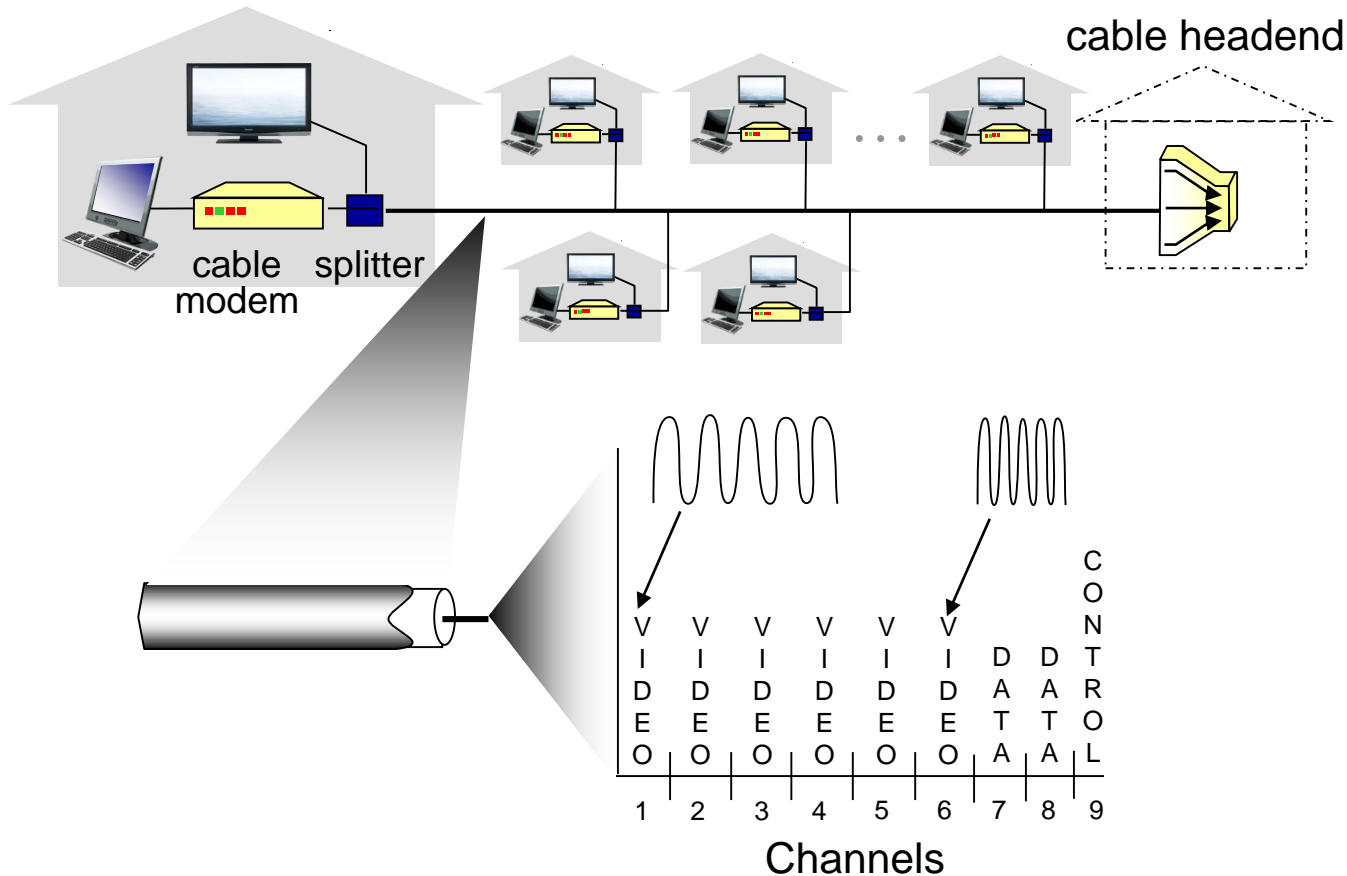❖ bandwidth (bits per second) of access network?
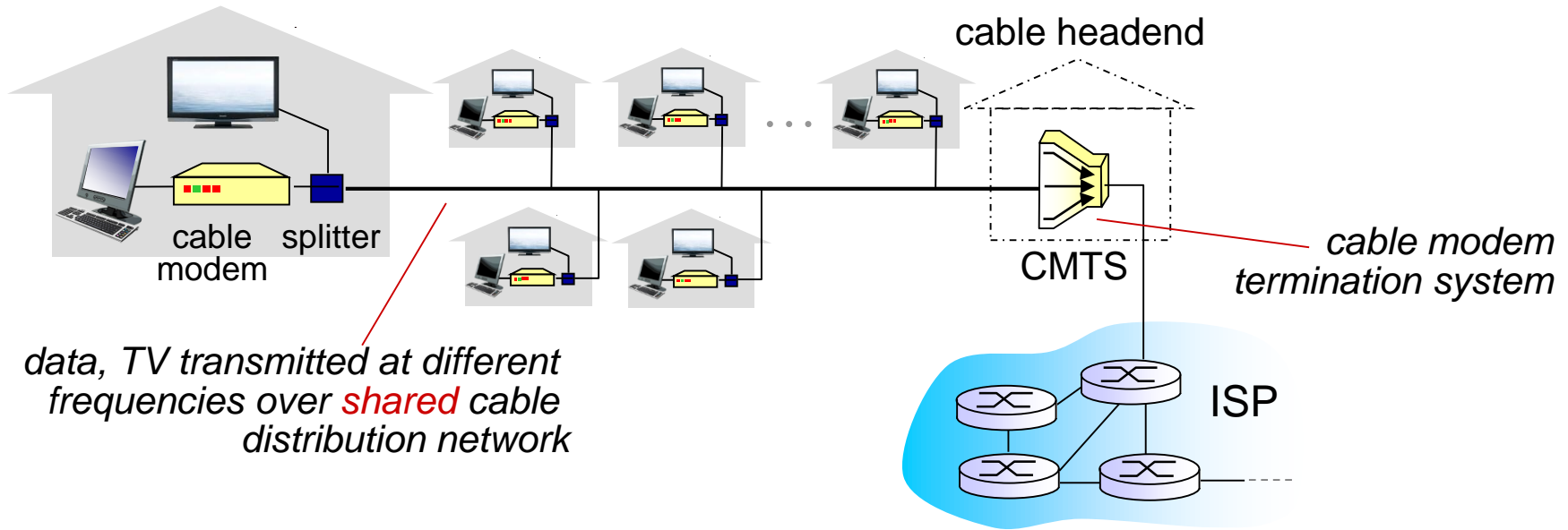❖ shared or dedicated?

Access net: digital subscriber line (DSL)

voice, data transmitted
at different frequencies over
dedicated line to central office

*DSL access
multiplexer*

❖ use *existing* telephone line to central office DSLAM
  ▪ data over DSL phone line goes to Internet
  ▪ voice over DSL phone line goes to telephone net
❖ < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
❖ < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access net: cable network

cable headend

cable modem   splitter

Channels

1 2 3 4 5 6 7 8 9

VIDEO VIDEO VIDEO VIDEO VIDEO VIDEO DATA DATA CONTROL

frequency division multiplexing: different channels transmitted in different frequency bands

Access net: cable network

cable headend

data, TV transmitted at different frequencies over *shared* cable distribution network

cable modem

splitter

CMTS

cable modem termination system

ISP
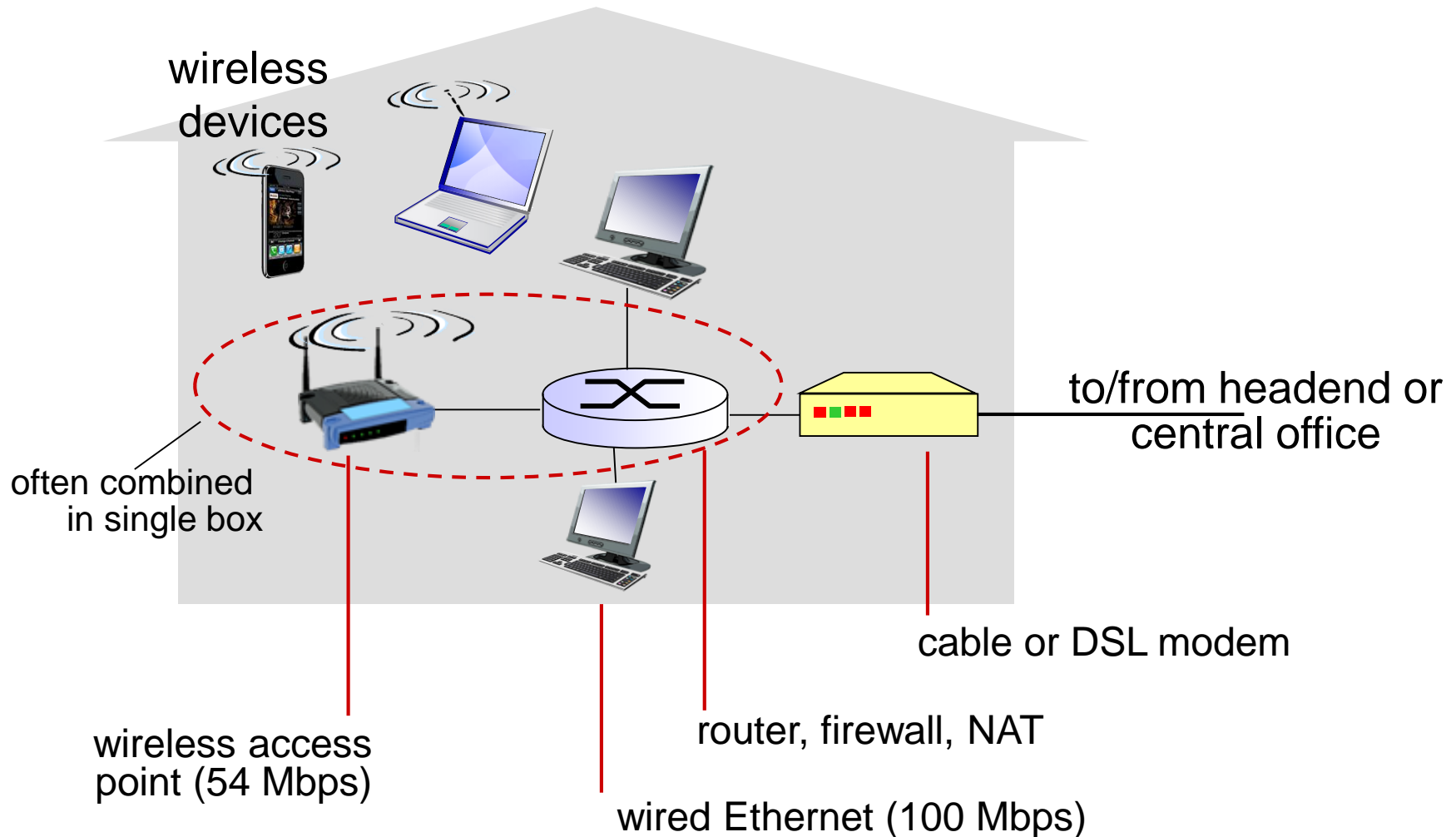
❖ HFC: hybrid fiber coax
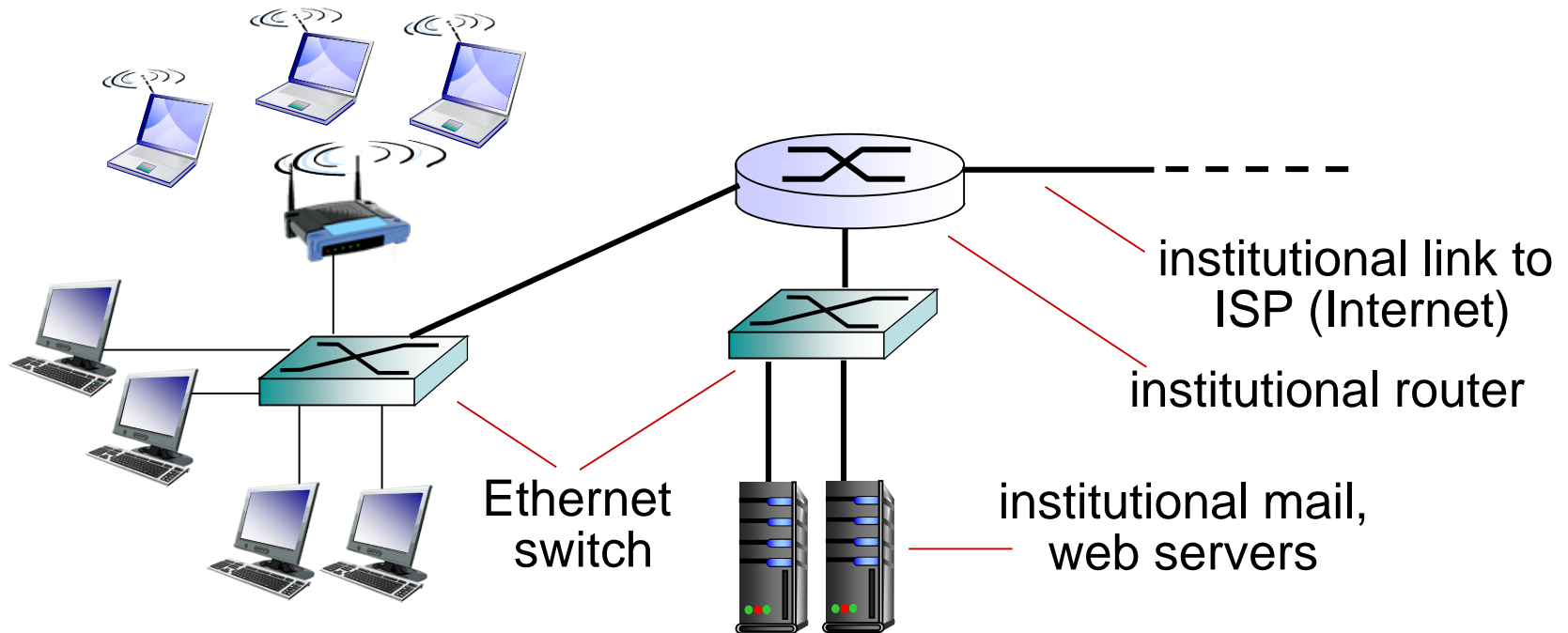- ▪ asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate

❖ network of cable, fiber attaches homes to ISP router
- ▪ homes *share access network* to cable headend
- ▪ unlike DSL, which has dedicated access to central office

Access net: home network

wireless
devices

to/from headend or
central office

often combined
in single box

wireless access
point (54 Mbps)

router, firewall, NAT

cable or DSL modem

wired Ethernet (100 Mbps)

Enterprise access networks (Ethernet)

institutional link to ISP (Internet)

institutional router

Ethernet switch

institutional mail, web servers

- ❖ typically used in companies, universities, etc
- ❖ 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- ❖ 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:

  ▪ within building (100 ft)
  ▪ 802.11b/g (WiFi): 11, 54 Mbps transmission rate
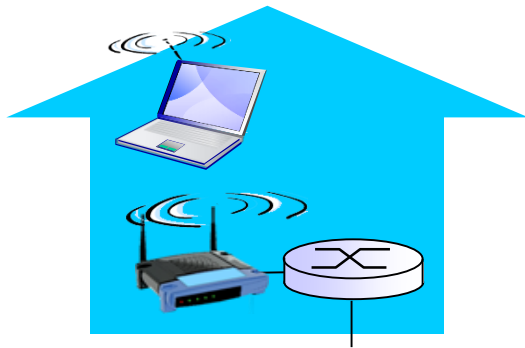
to Internet

wide-area wireless access

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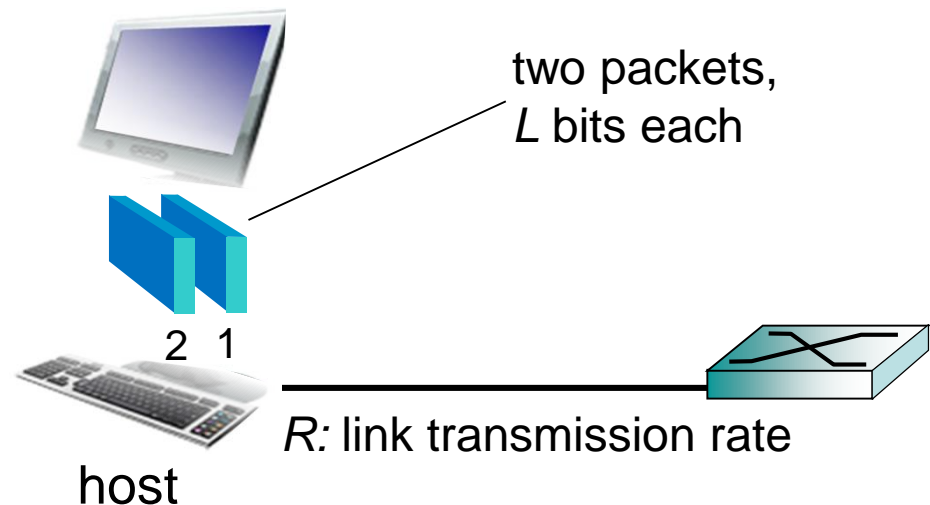 ▪ between 1 and 10 Mbps
  ▪ 3G, 4G: LTE

to Internet

Host: sends *packets* of data

host sending function:

- ❖ takes application message
- ❖ breaks into smaller chunks, known as *packets*, of length *L* bits
- ❖ transmits packet into access network at *transmission rate R*
  - link transmission rate, aka link *capacity, aka link bandwidth*

two packets, *L* bits each

2 1

host

R: link transmission rate

$$\begin{matrix} \text{packet} \\ \text{transmission} \\ \text{delay} \end{matrix} = \begin{matrix} \text{time needed to} \\ \text{transmit } L\text{-bit} \\ \text{packet into link} \end{matrix} = \dfrac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Physical media

❖ **bit:** propagates between transmitter/receiver 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 5: 100 Mbps, 1 Gpbs Ethernet
  ▪ Category 6: 10Gbps
  ▪ CAT-5 is rated to 100 Mhz
  ▪ CAT-5e is rated to 350 Mhz
  ▪ CAT-6 and CAT6e is rated to 550 Mhz or 1000 Mhz depending on your source
  ▪ CAT-7 is rated to 700 Mhz or 1000 Mhz
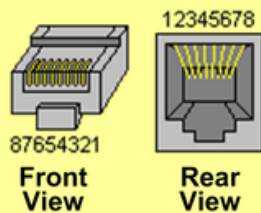 ▪ CAT-8 is rated to 2GHz.

Note: GigaBit Ethernet Requires All 4 Pairs.
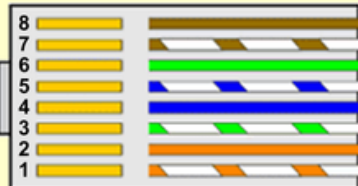
RJ45 3D View

12345678

87654321

Front View **Rear View**

RJ45 - Pinout, Wire Pair Color Coding, and Signal Identification

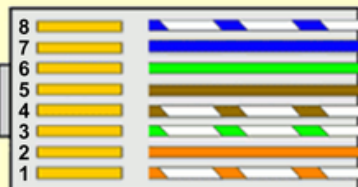| Pin	T568A	T568B	Signal 10/100BaseTx	Signal 1000BaseT
1	Wht/Grn	Wht/Org	Tx+	TP1+
2	Grn	Org	Tx-	TP1-
3	Wht/Org	Wht/Grn	Rx+	TP2+
4	Blu	Blu	Unused	TP3-
5	Wht/Blu	Wht/Blu	Unused	TP3+
6	Org	Grn	Rx-	TP2-
7	Wht/Brn	Wht/Brn	Unused	TP4+
8	Brn	Brn	Unused	TP4-

RJ45 Connector (Bottom)

Straight-Through Cable (T568B)

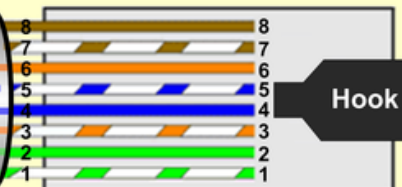**RJ45 Connector (Top)**
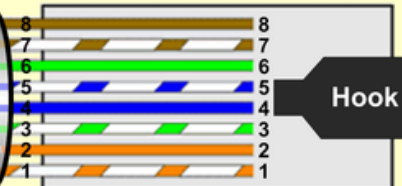
Hook

UTP Category 5/6 Cable

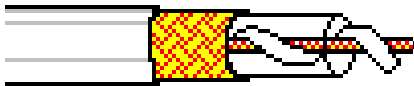**Hook Underneath**

Crossover Cable

Hook On Top

Hook

UTP Category 5/6 Cable

NST - 2011

Physical media: coax, fiber

coaxial cable:

- ❖ two concentric copper conductors
- ❖ bidirectional
- ❖ 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 Gpbs transmission rate)
- ❖ 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: ~ few Mbps

❖ satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

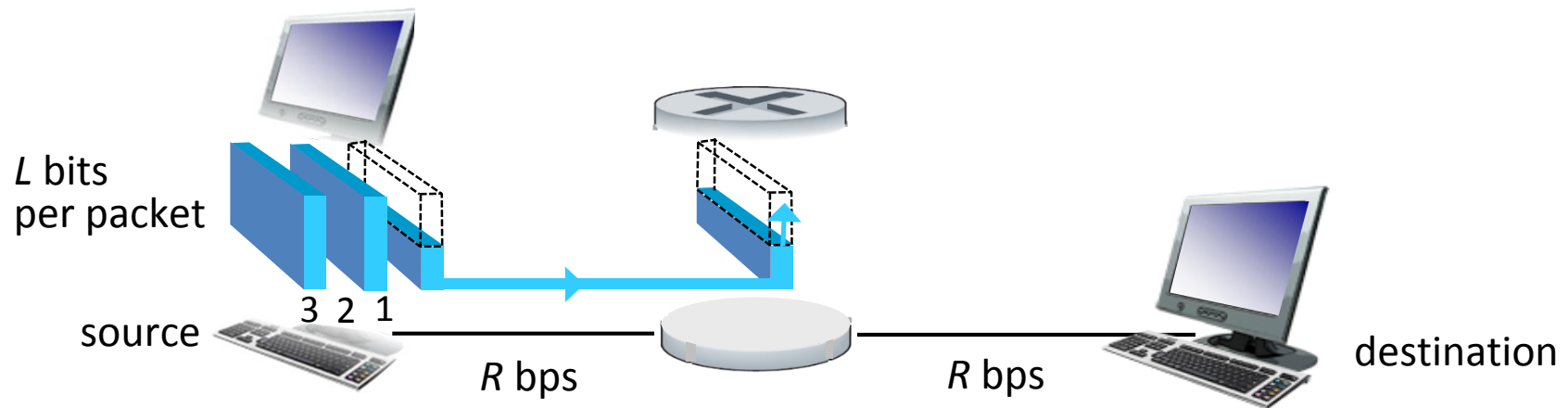# Chapter 1: roadmap

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
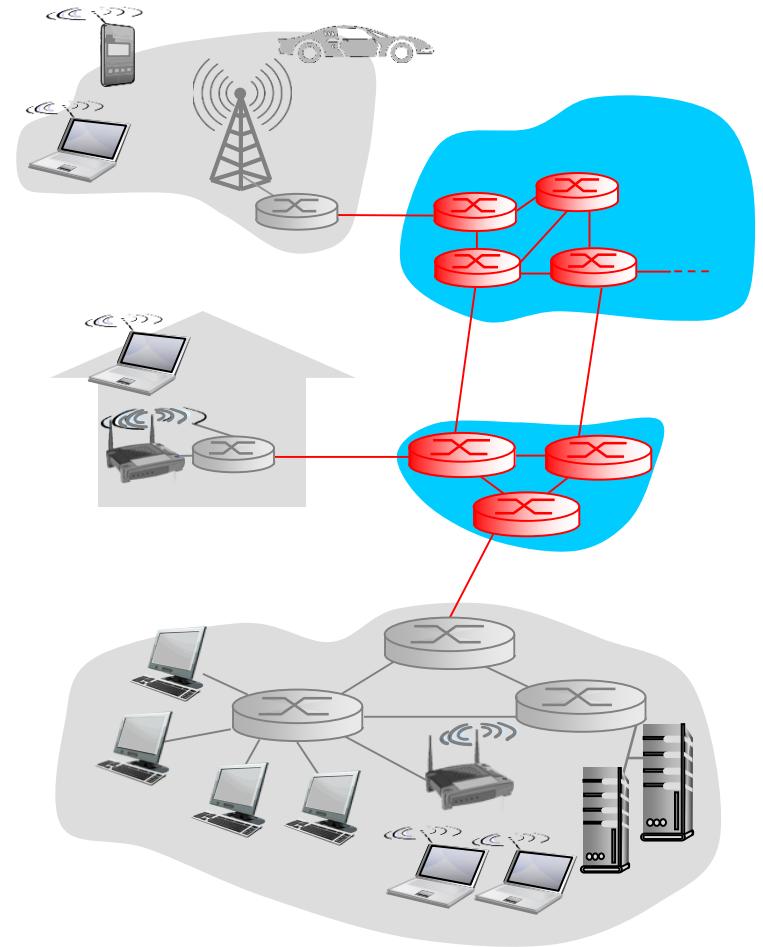
Packet-switching: store-and-forward

- ❖ 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

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

one-hop numerical example:

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

more on delay shortly …

Packet Switching: queueing delay, loss

A *R* = 100 Mb/s

C

B

R = 1.5 Mb/s

D

E

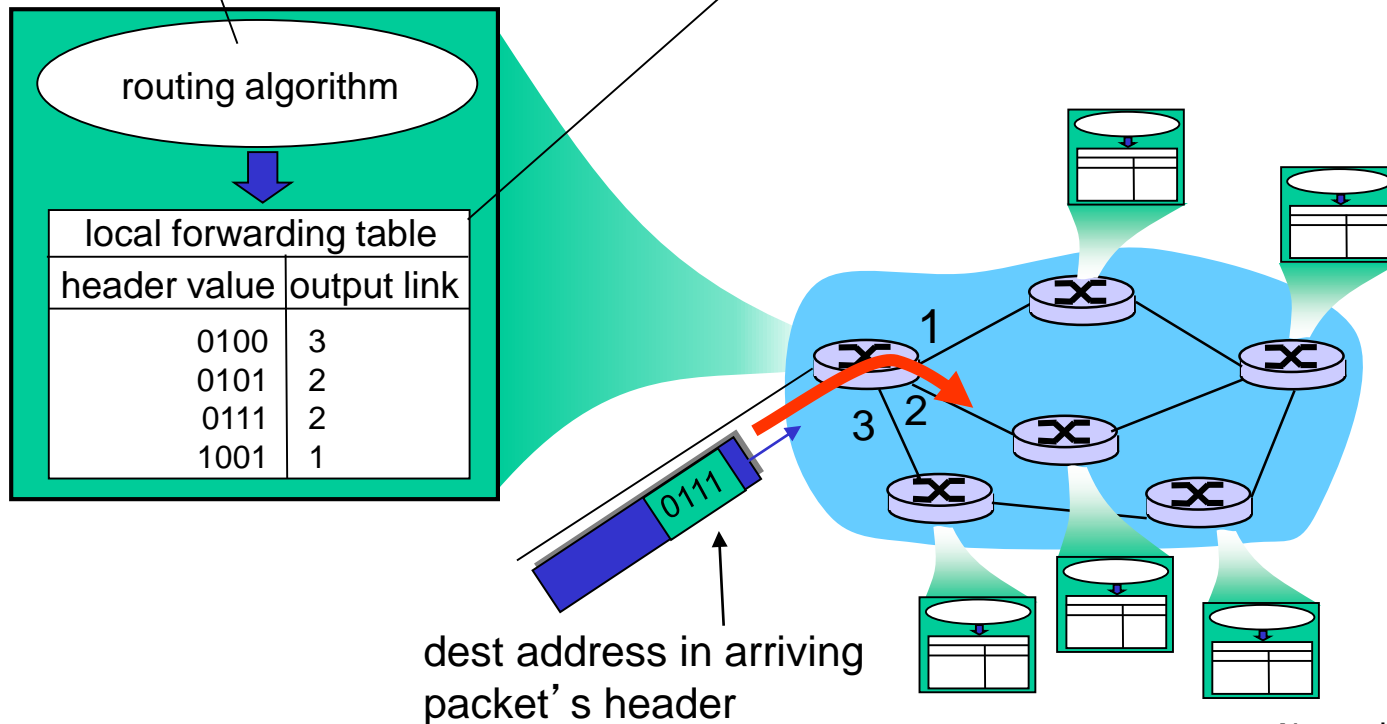queue of packets
waiting for output link
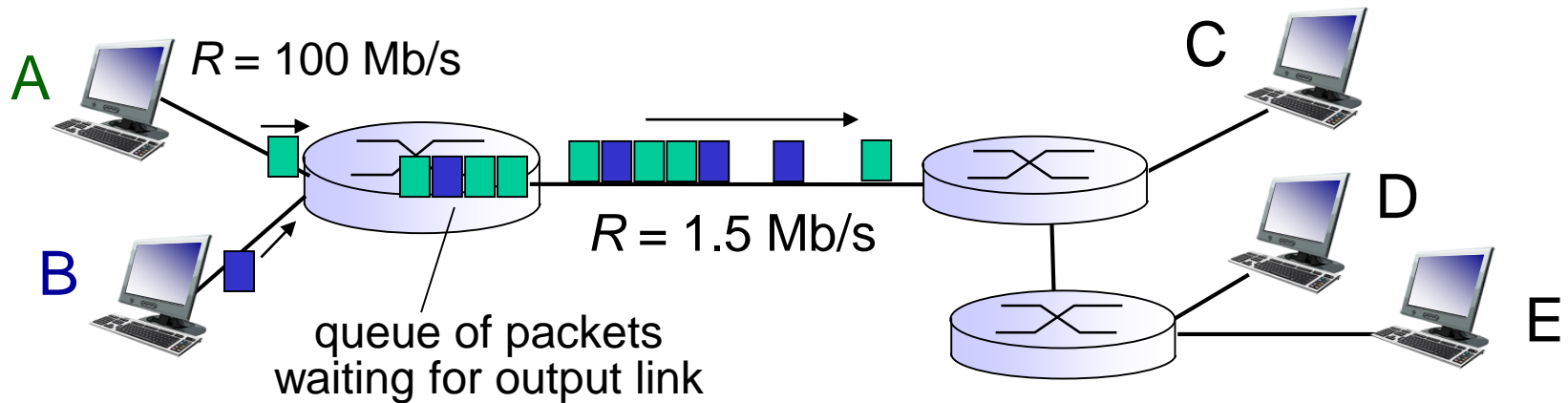
queuing and loss:

❖ 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

Two key network-core functions

*routing:* determines source-destination route taken by packets

- *routing algorithms*

forwarding: move packets from router's input to appropriate router output

routing algorithm

local forwarding table

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

0111

dest address in arriving packet's header

1

3 2

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)*

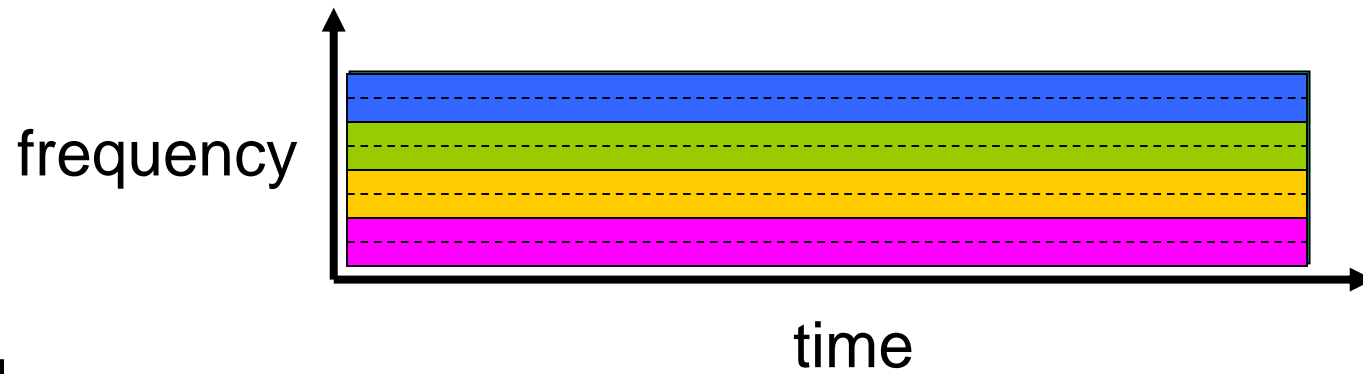❖ Commonly used in traditional telephone networks
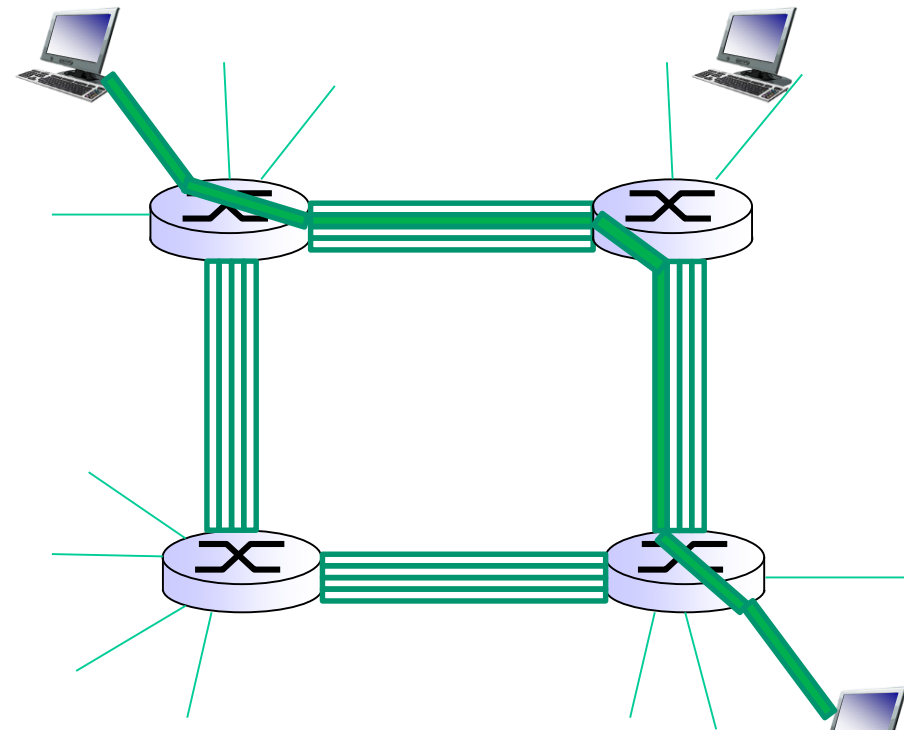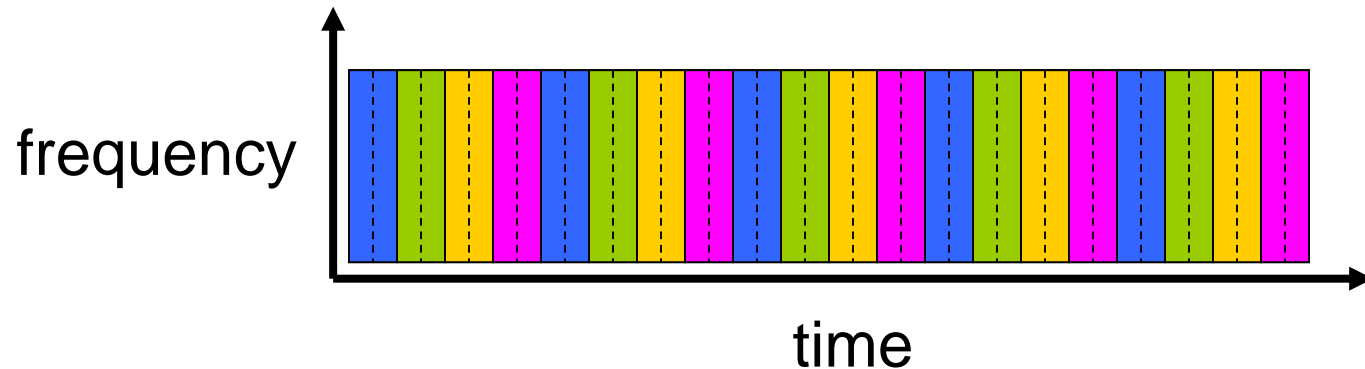
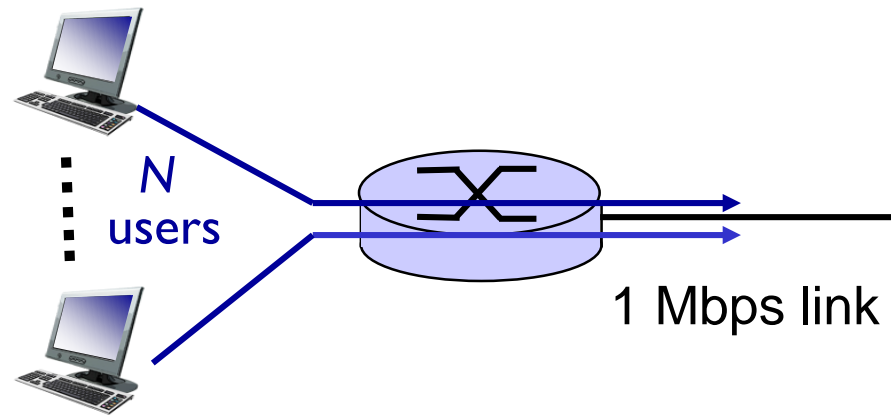# Circuit switching: FDM versus TDM

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

Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

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 7)

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

Internet structure: network of networks

- ❖ End systems connect to Internet via access ISPs (Internet Service Providers)
  - ▪ Residential, company and university ISPs
- ❖ Access ISPs in turn must be interconnected.
  - ❖ So that any two hosts can send packets to each other
- ❖ Resulting network of networks is very complex
  - ❖ Evolution was driven by economics and national policies
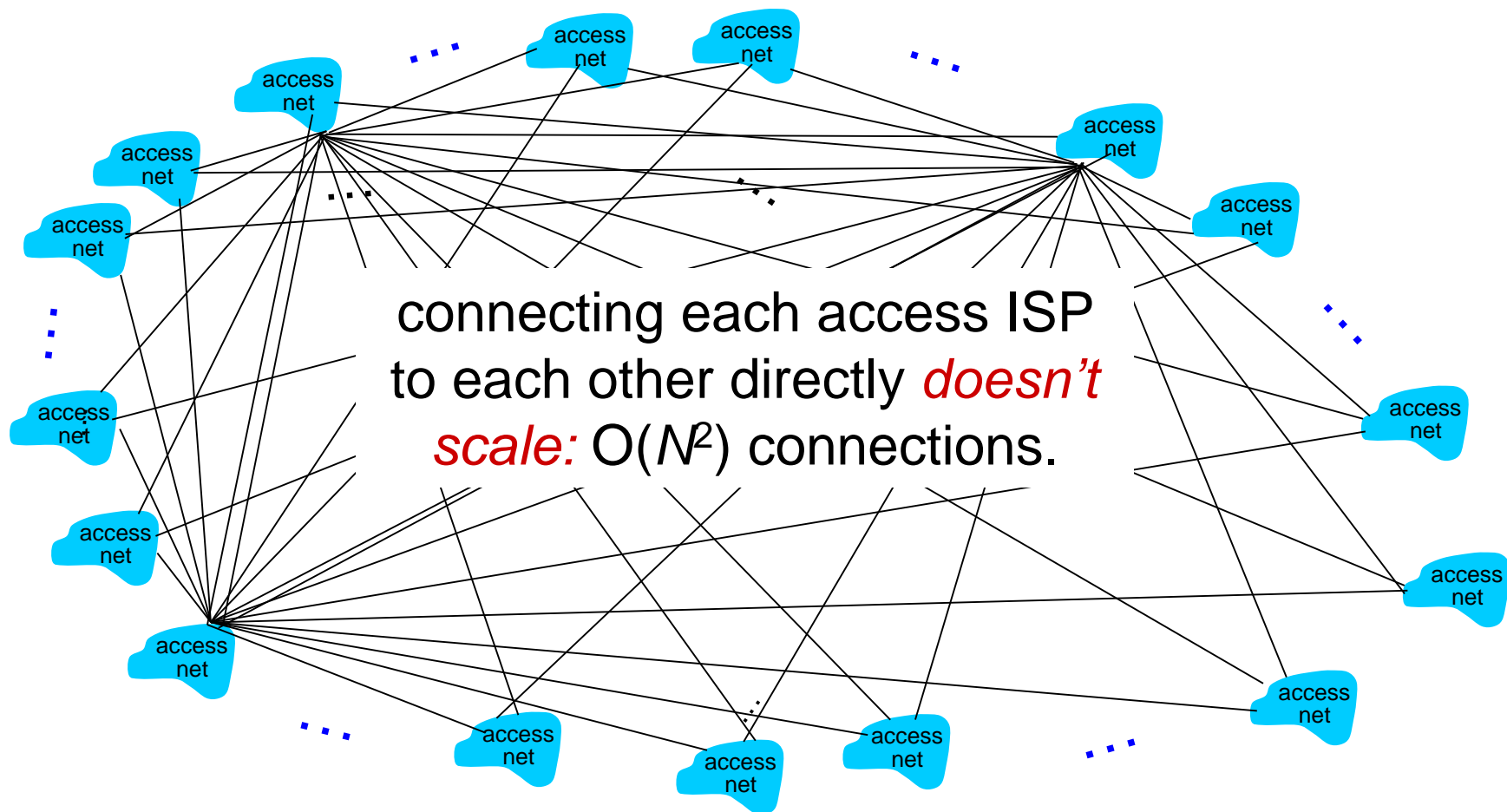- ❖ Let's take a stepwise approach to describe current Internet structure

Internet structure: network of networks

*Question:* given *millions* of access ISPs, how to connect them together?
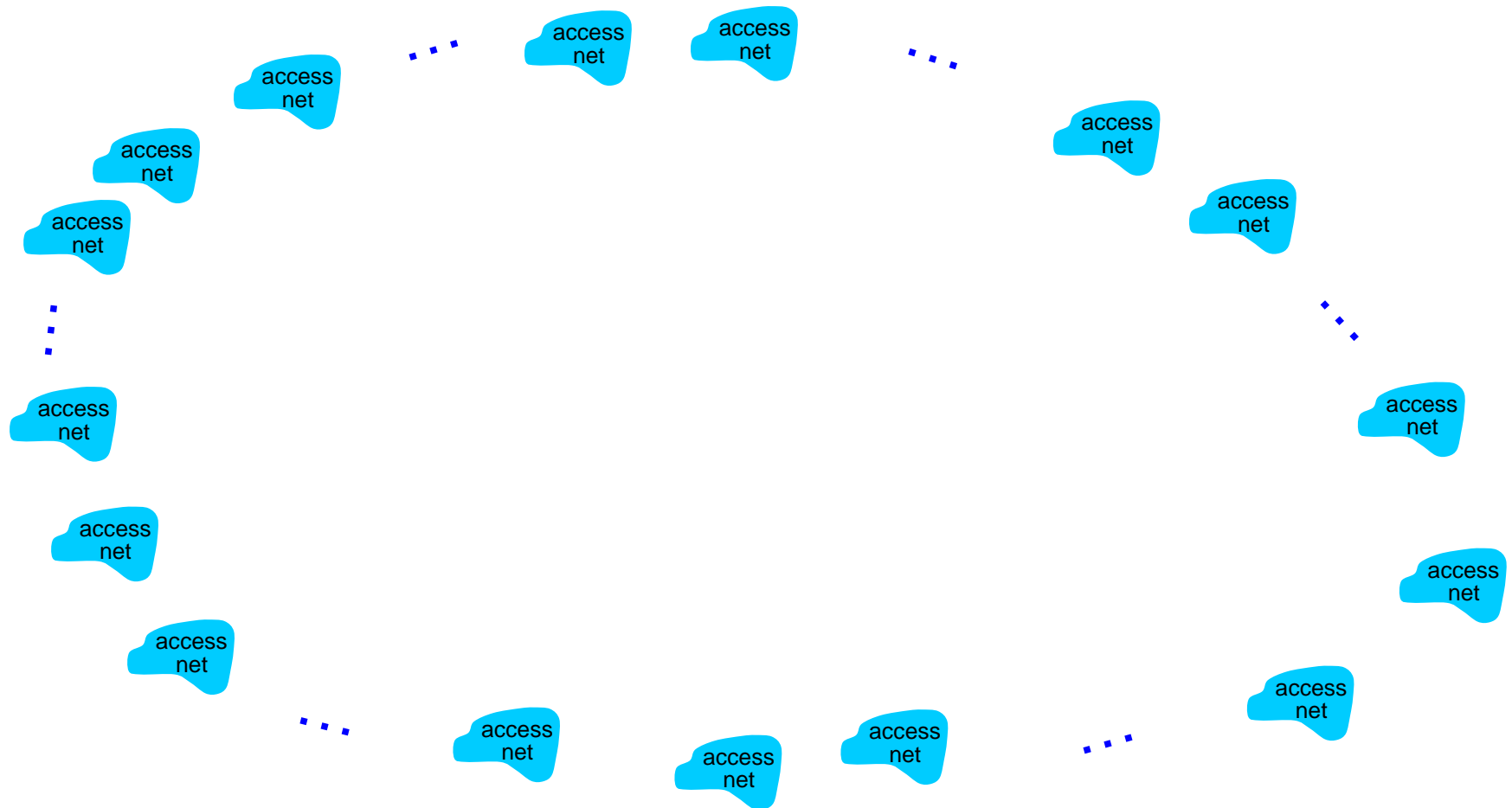
Internet structure: network of networks

Option: connect each access ISP to every other access ISP?

connecting each access ISP
to each other directly *doesn't
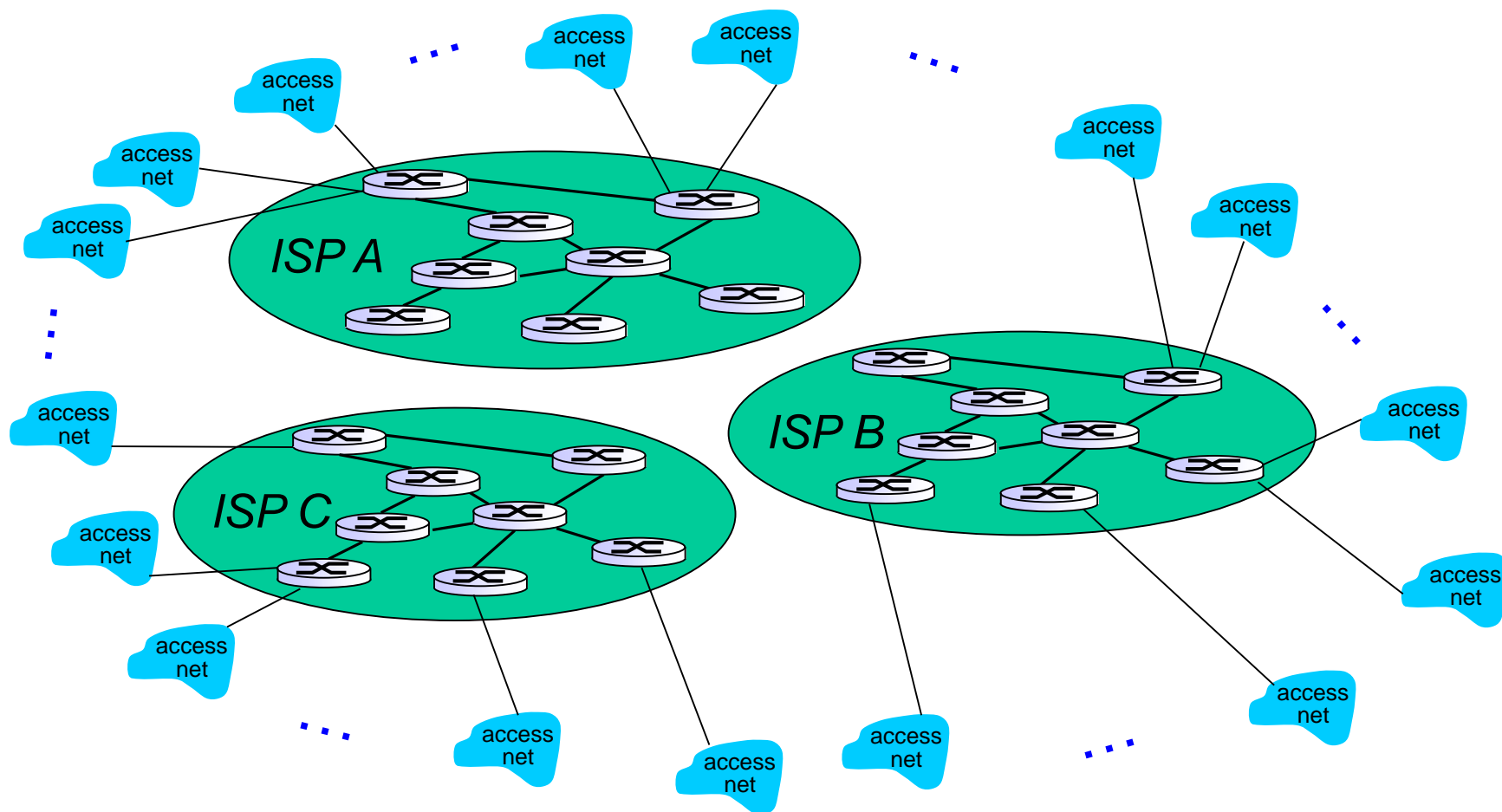scale:* O(N^2) connections.

Internet structure: network of networks

Option: connect each access ISP to a global transit ISP? *Customer* and *provider* ISPs have economic agreement.
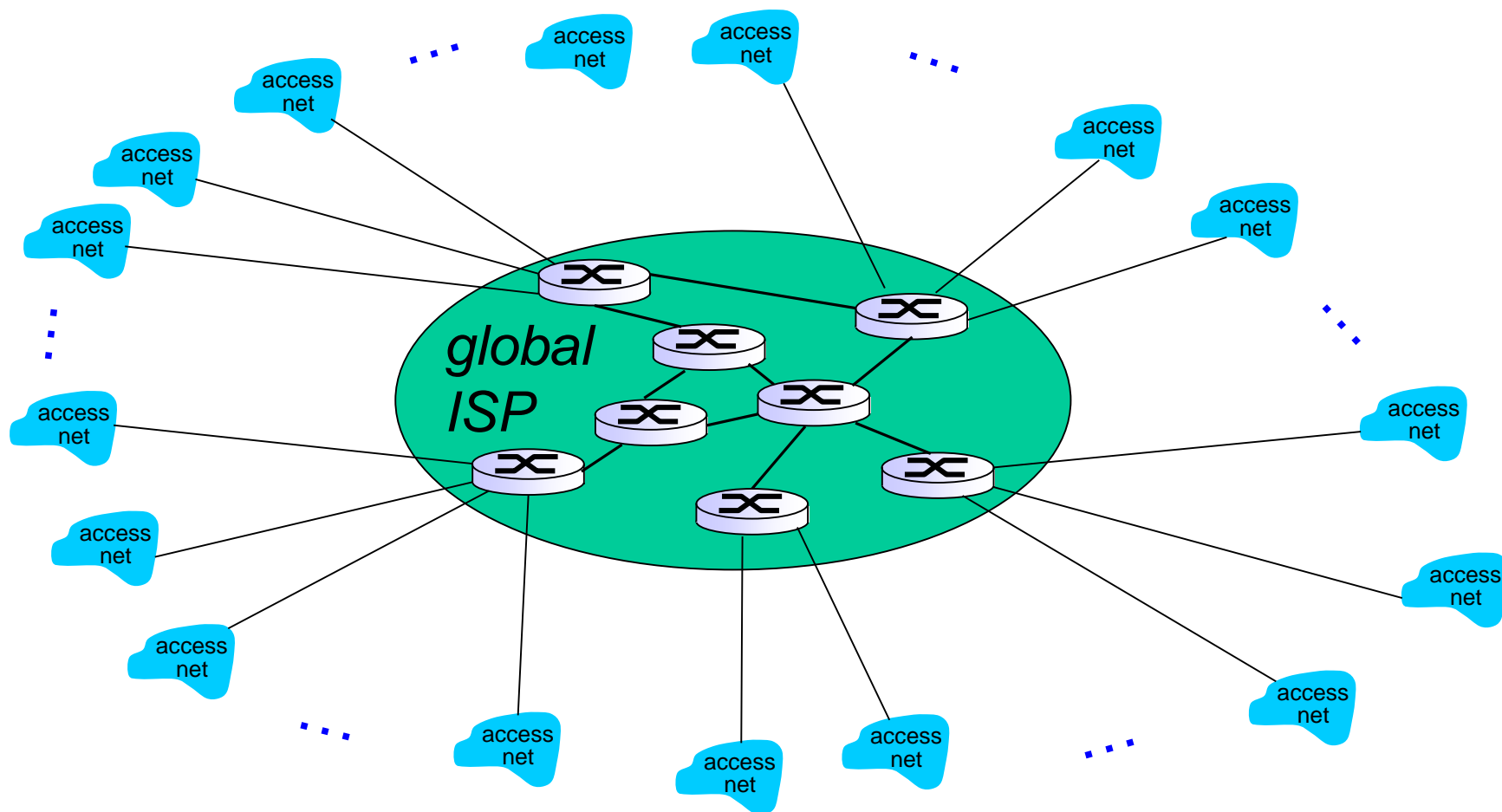
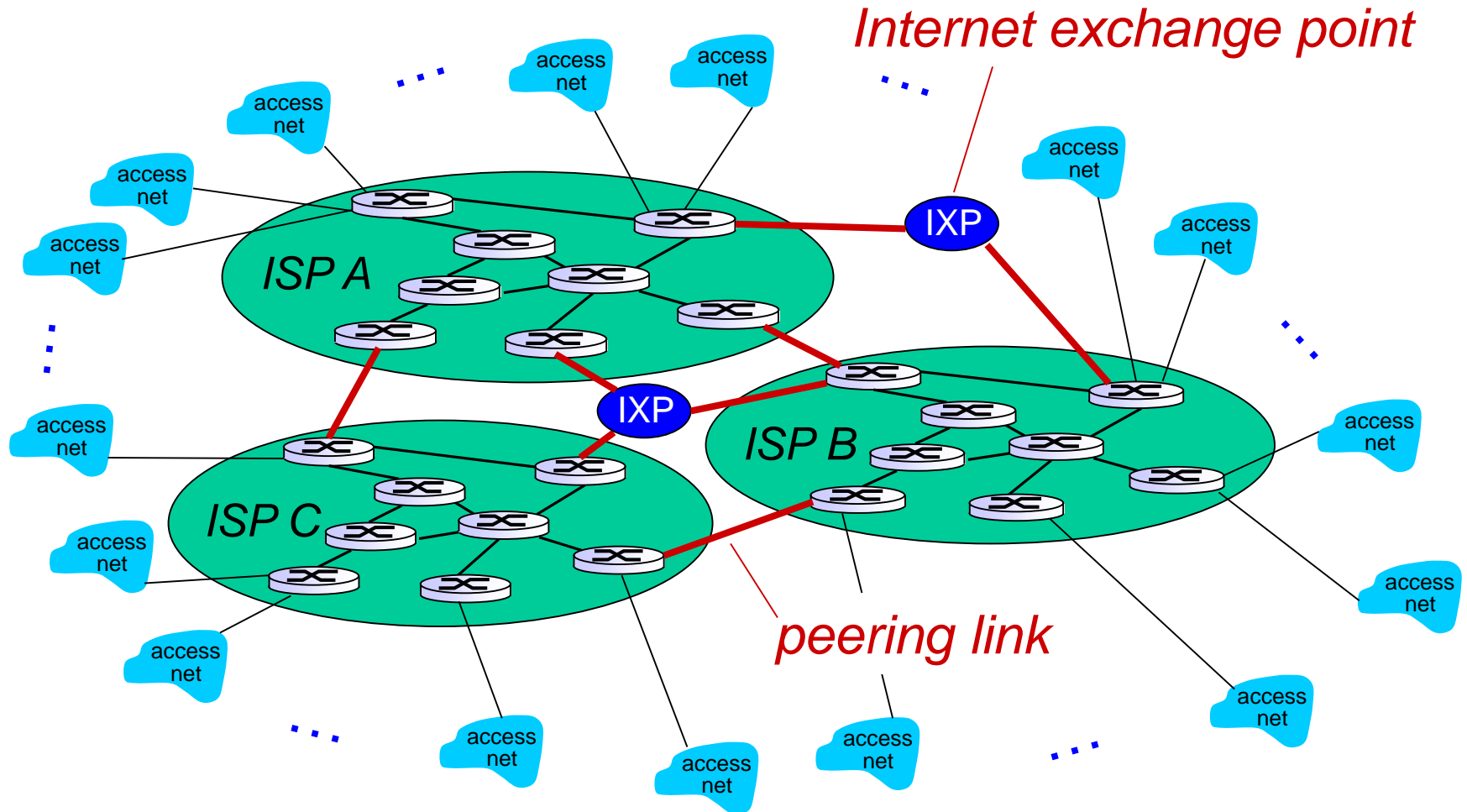# Internet structure: network of networks

But if one global ISP is viable business, there will be competitors ....

Internet structure: network of networks

But if one global ISP is viable business, there will be competitors
…. which must be interconnected

Internet exchange point

peering link

Internet structure: network of networks

… and regional networks may arise to connect access nets to ISPS
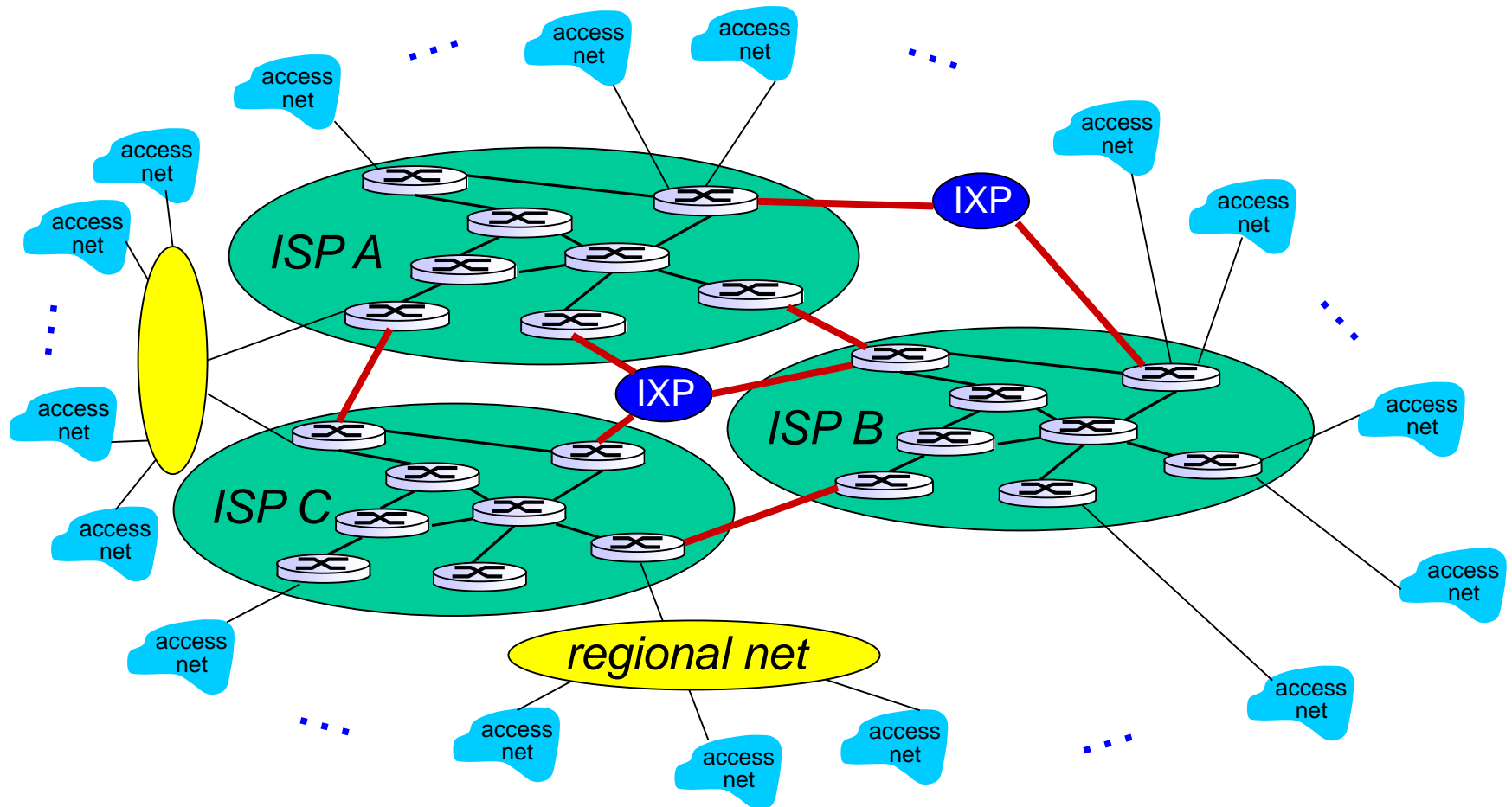
Internet structure: network of networks

… and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users

Internet structure: network of networks

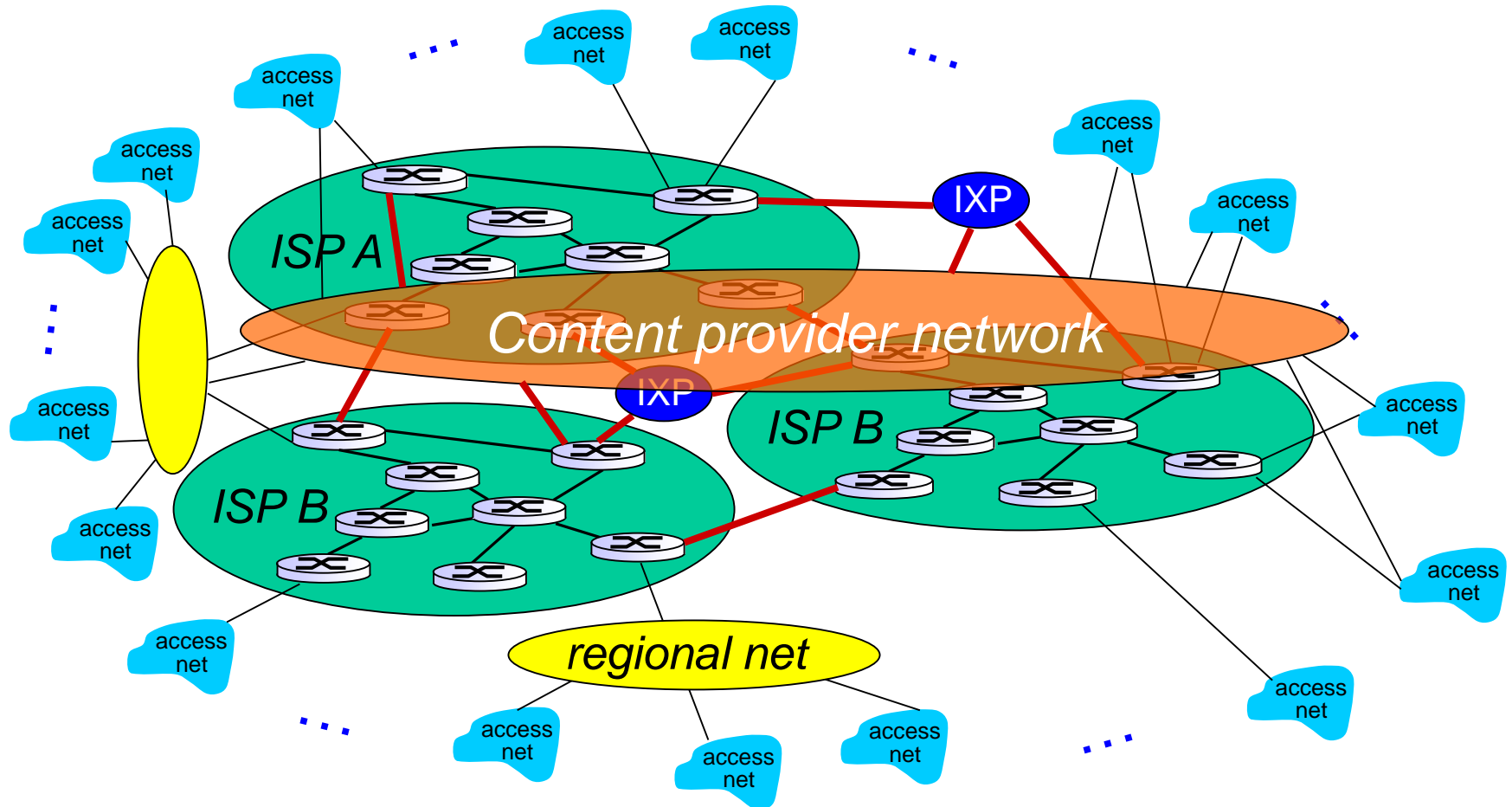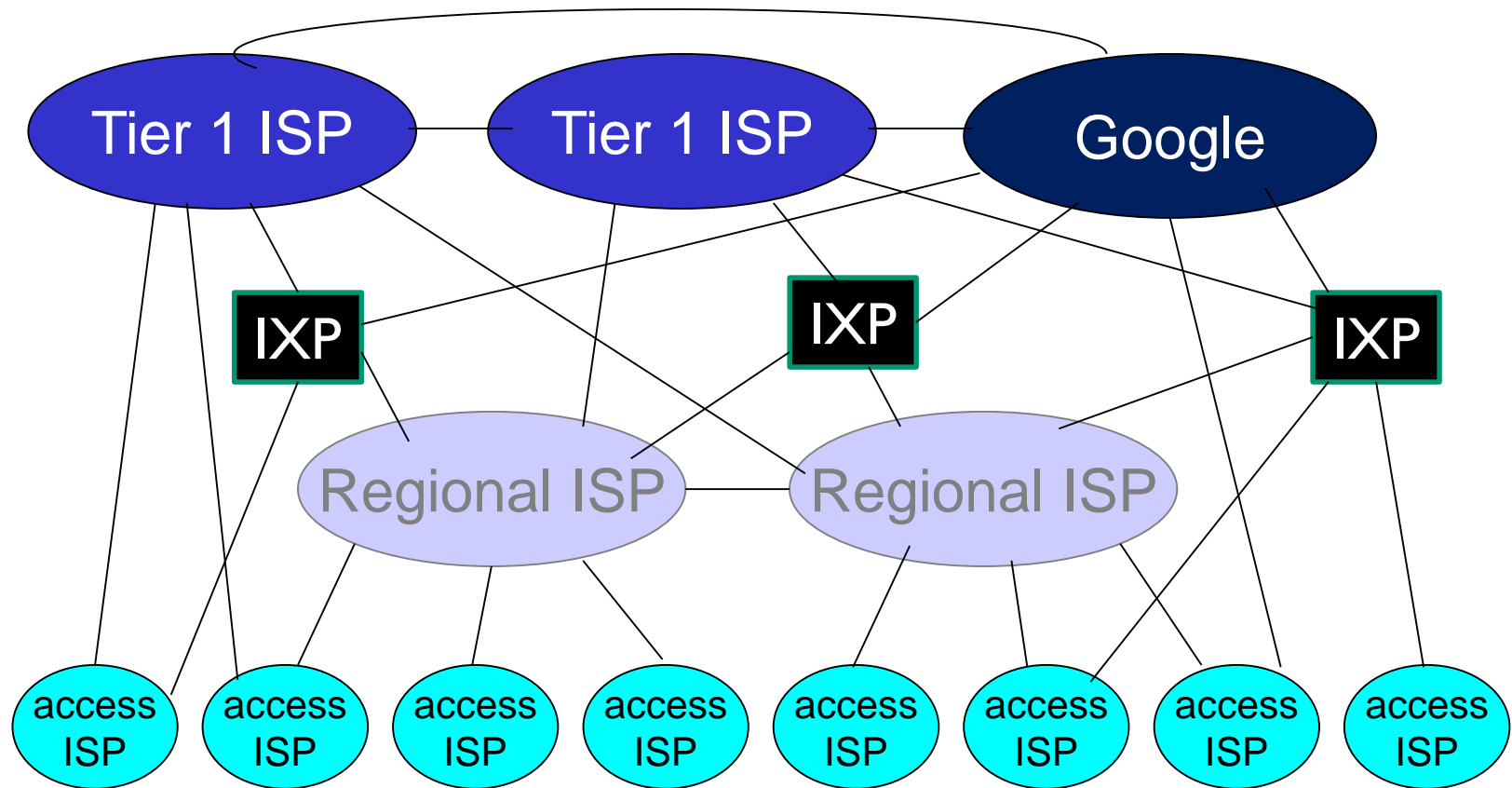- ❖ at center: small # of well-connected large networks
  - ▪ "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - ▪ content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Tier-1 ISP: e.g., Sprint
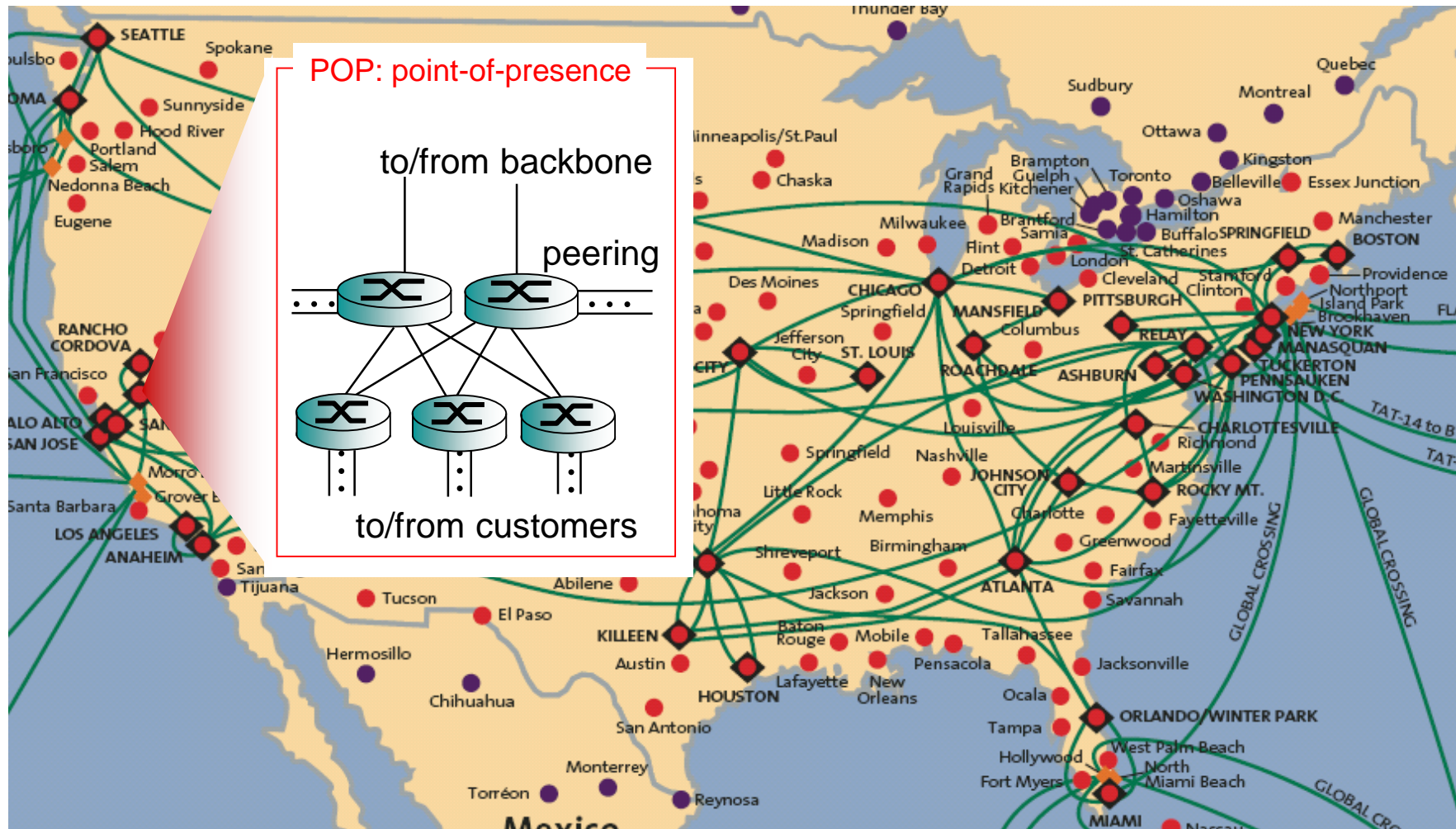
POP: point-of-presence

to/from backbone

peering

to/from customers

Chapter 1: roadmap

How do loss and delay occur?

packets *queue* in router buffers

❖ packet arrival rate to link (temporarily) exceeds output link capacity

❖ packets queue, wait for turn

packet being transmitted (delay)

A

B

packets queueing (delay)

free (available) buffers: arriving packets dropped (loss) if no free buffers
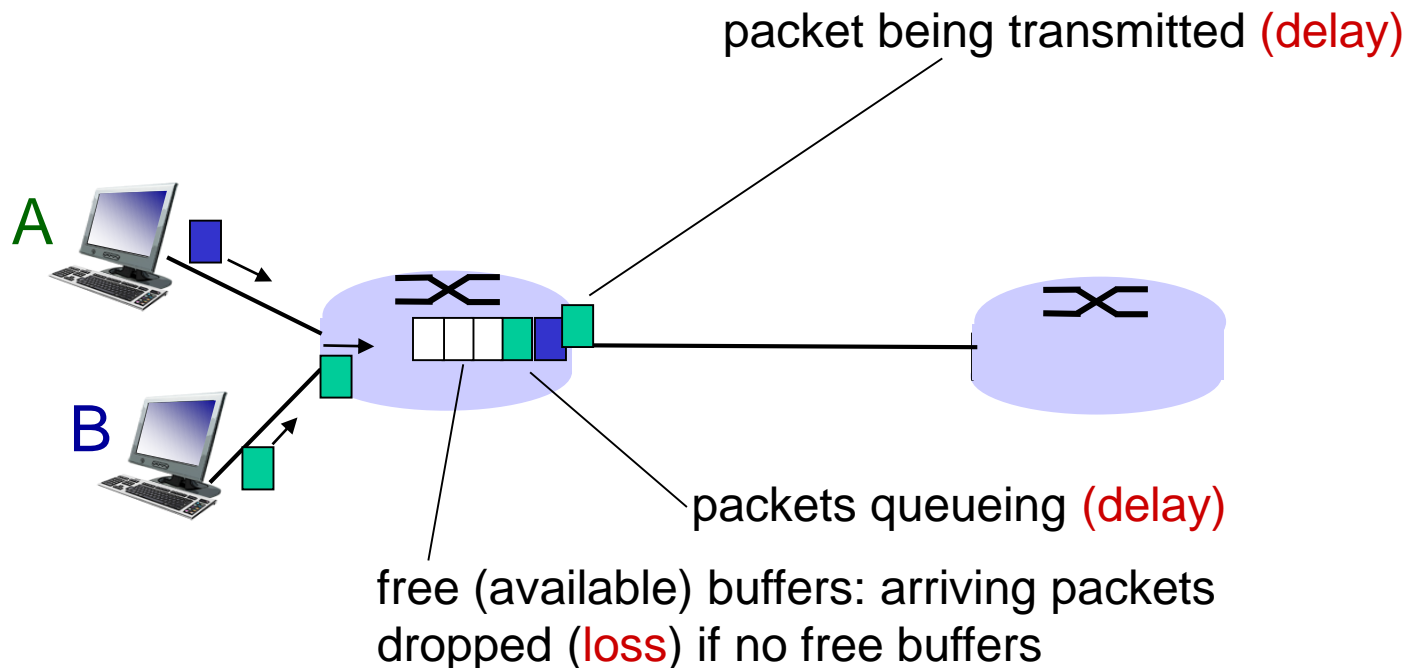
Four sources of packet delay
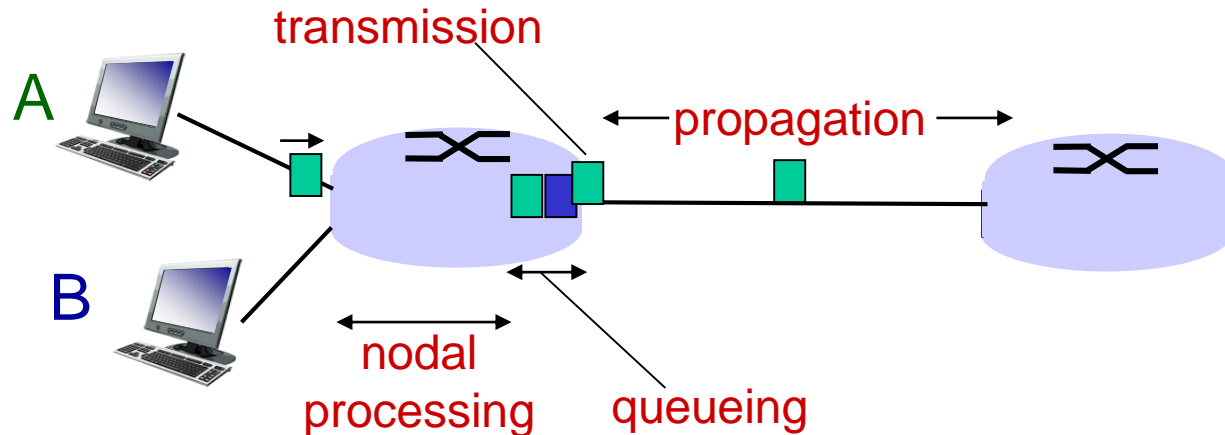
$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

d_{proc}: nodal processing
- check bit errors
- determine output link
- typically < msec

d_{queue}: queueing delay
- time waiting at output link for transmission
- depends on congestion level of router

Four sources of packet delay
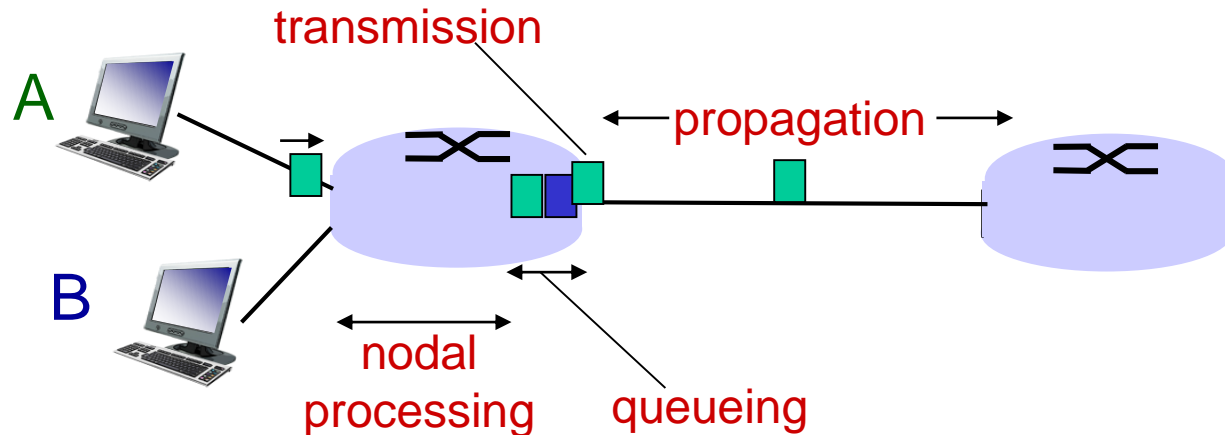
$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

d_{trans}: transmission delay:
- *L*: packet length (bits)
- *R*: link *bandwidth (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay:
- *d*: length of physical link
- *s*: propagation speed in medium ($\sim 2 \times 10^8$ m/sec)
- $d_{prop} = d/s$

d_{trans} and d_{prop} *very* different

* Check out the Java applet for an interactive animation on trans vs. prop delay

Caravan analogy

ten-car caravan   toll booth   100 km   toll booth   100 km
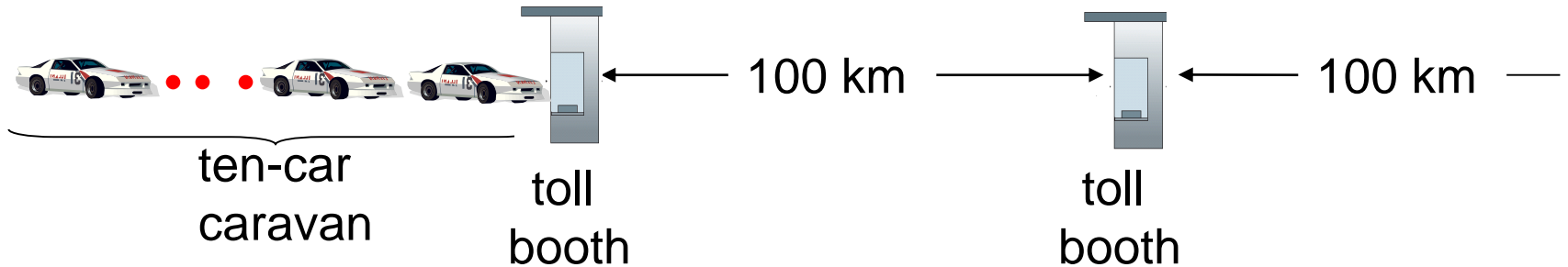
❖ cars "propagate" at 100 km/hr
❖ toll booth takes 12 sec to service car (bit transmission time)
❖ car~bit; caravan ~ packet
❖ *Q: How long until caravan is lined up before 2nd toll booth?*

▪ 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)

ten-car caravan   toll booth   100 km   toll booth   100 km
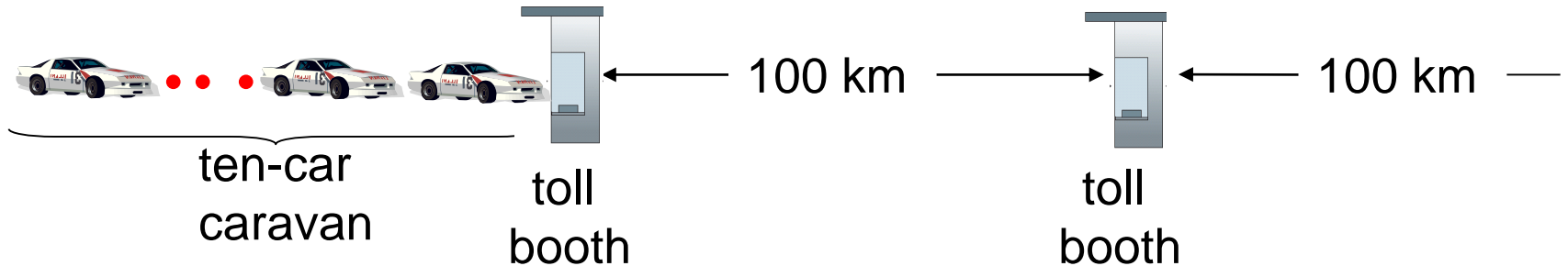
❖ suppose cars now "propagate" at 1000 km/hr

❖ and suppose toll booth now takes one min to service a car

❖ *Q:* Will cars arrive to 2nd booth before all cars serviced at first booth?

▪ *A: Yes!* after 7 min, 1st car arrives at second booth; three cars still at 1st booth.

Queueing delay (revisited)

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

average queueing delay

traffic intensity = La/R

La/R

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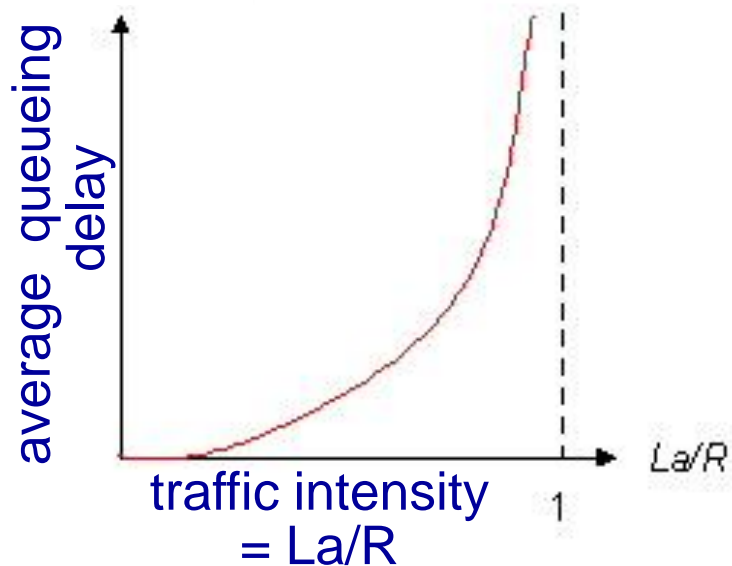
- *La/R ~ 0:* avg. queueing delay small
- *La/R -> 1:* avg. queueing delay large
- *La/R > 1:* more "work" arriving than can be serviced, average delay infinite!

La/R ~ 0

La/R -> 1

* Check out the Java applet for an interactive animation on queuing and loss

"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.

3 probes   3 probes

3 probes
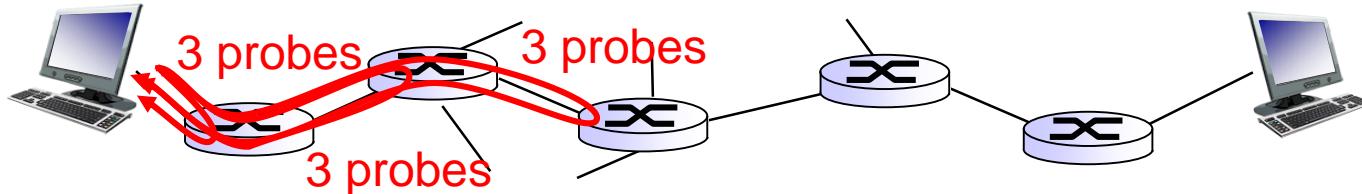
"Real" Internet delays, routes

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

3 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)

* Do some traceroutes from exotic countries at www.traceroute.org

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
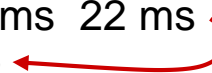

buffer
(waiting area)

packet being transmitted

A

B

packet arriving to
full buffer is *lost*

* Check out the Java applet for an interactive animation on queuing and loss
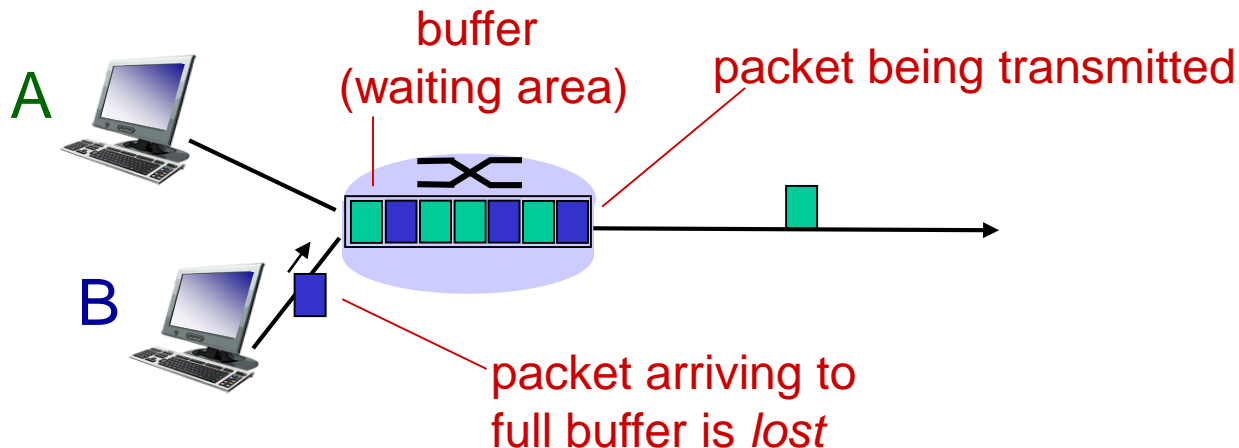
Throughput

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

server sends bits
(fluid) into pipe

pipe that can carry
fluid at rate
R_s bits/sec)

pipe that can carry
fluid at rate
R_c bits/sec)
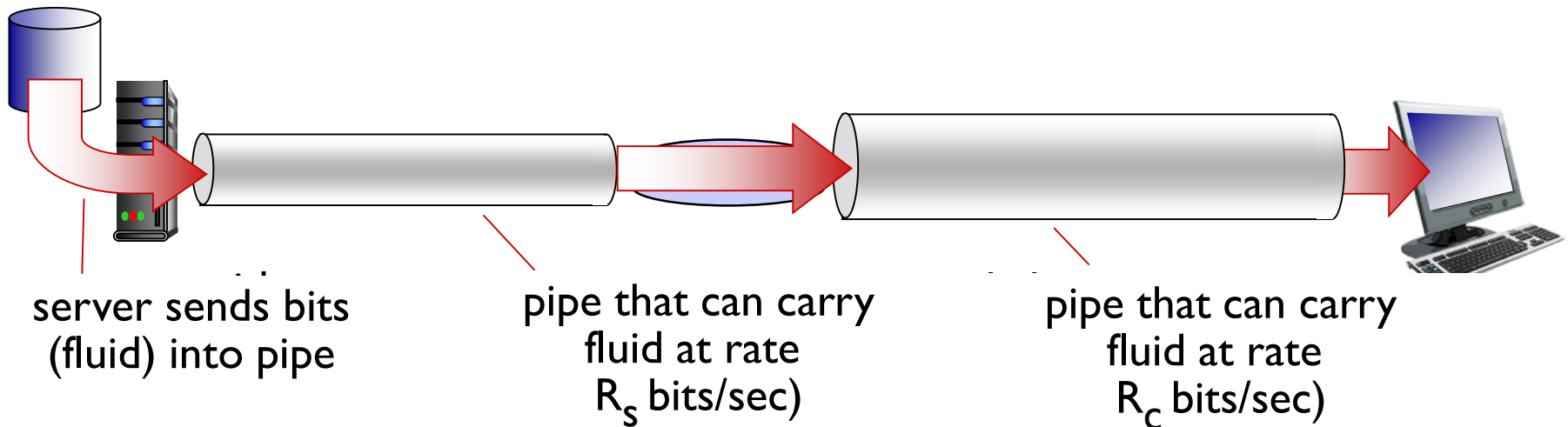
Throughput (more)

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

R$_s$ bits/sec   R$_c$ bits/sec

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

R$_s$ bits/sec   R$_c$ bits/sec
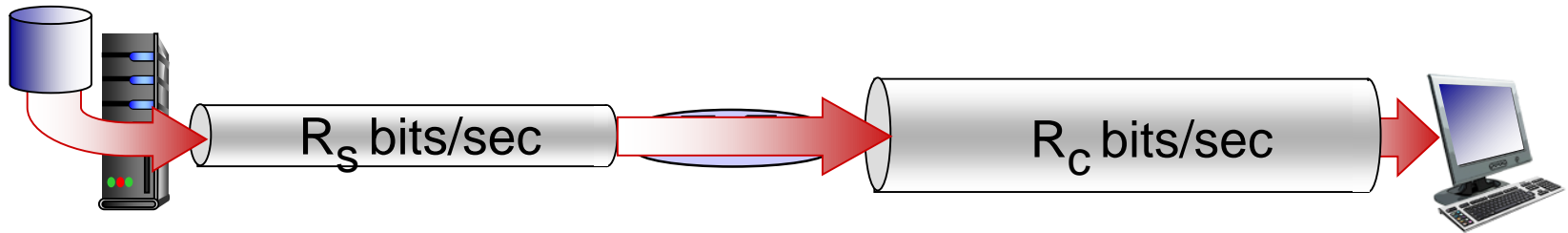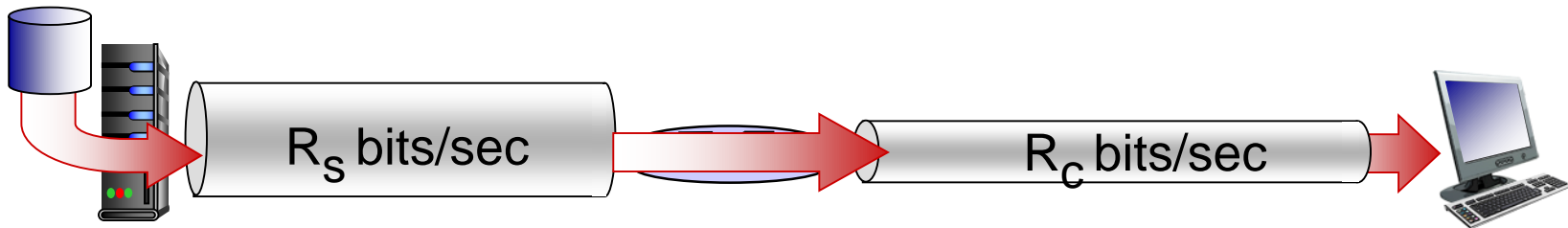
bottleneck link

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

Throughput: Internet scenario

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

R_s

R_s

R_s

R

R_c

R_c

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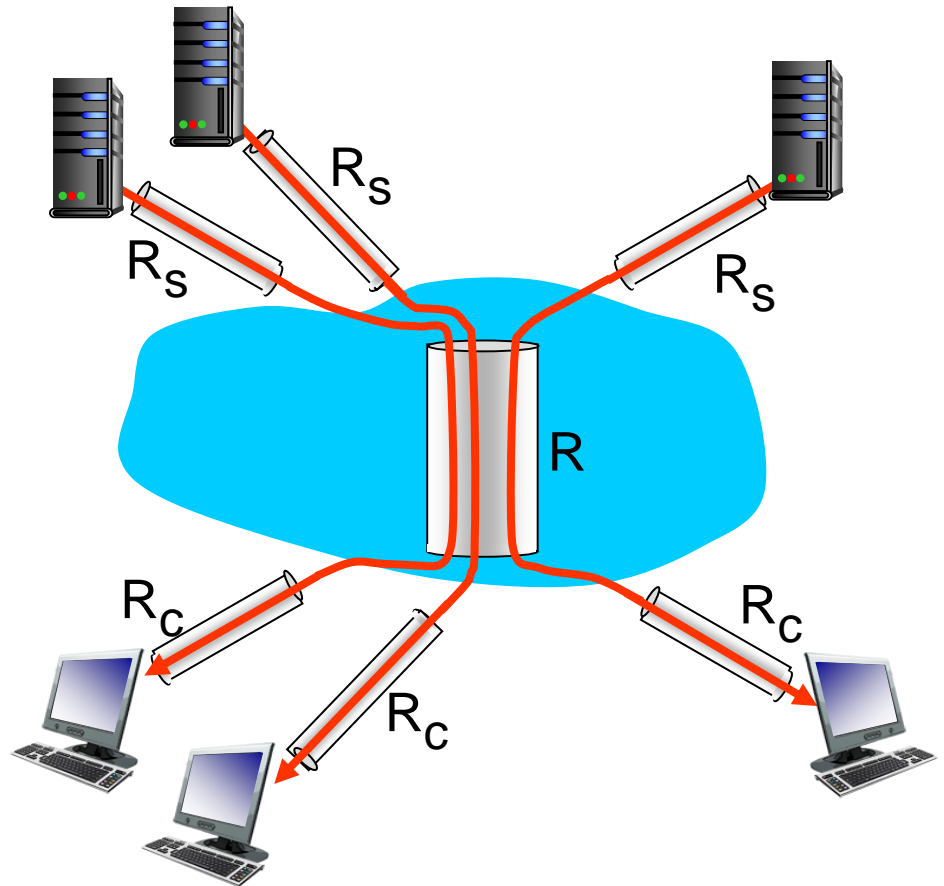
10 connections (fairly) share backbone bottleneck link R bits/sec

Chapter 1: roadmap

Protocol "layers"

Networks are complex, with 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

ticket (purchase)   ticket (complain)

baggage (check)   baggage (claim)

gates (load)   gates (unload)

runway takeoff   runway landing

airplane routing   airplane routing

airplane routing
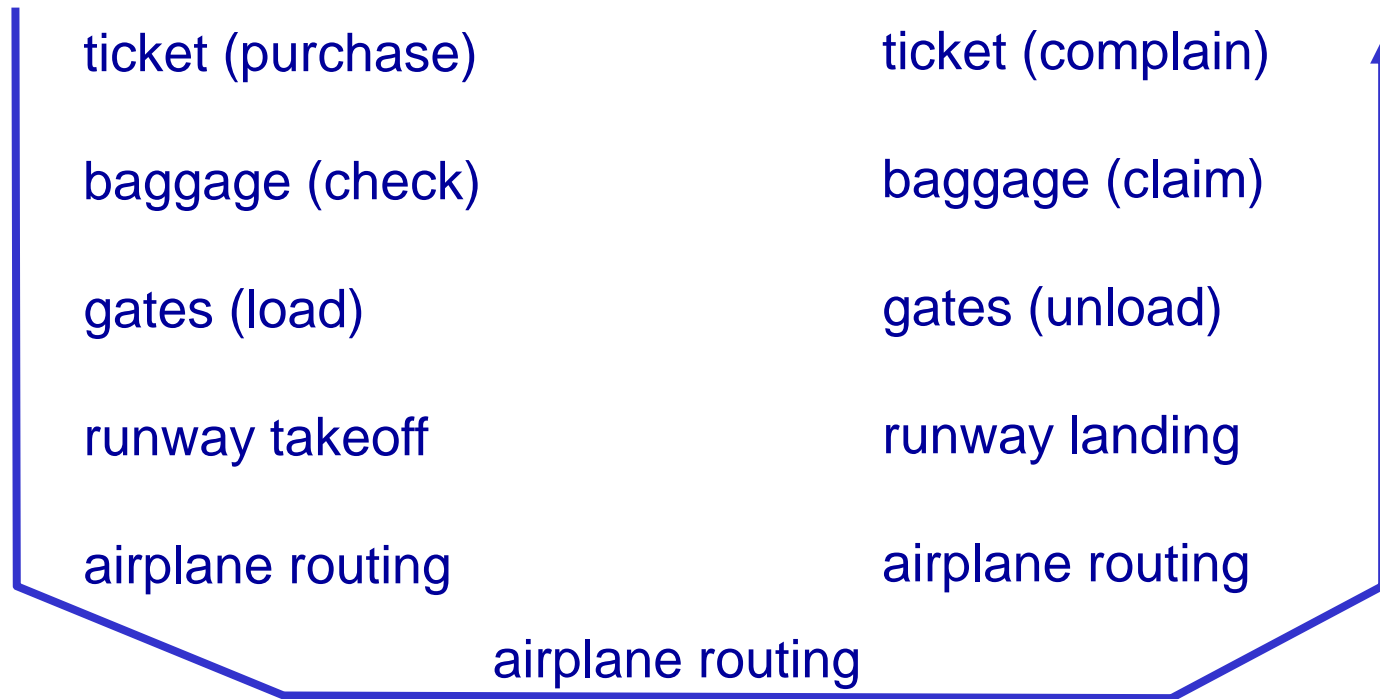
❖ a series of steps

Layering of airline functionality

departure airport	intermediate air-traffic control centers	arrival airport	
ticket (purchase)		ticket (complain)	ticket
baggage (check)		baggage (claim	baggage
gates (load)		gates (unload)	gate
runway (takeoff)		runway (land)	takeoff/landing
airplane routing	airplane routing airplane routing	airplane routing	airplane routing
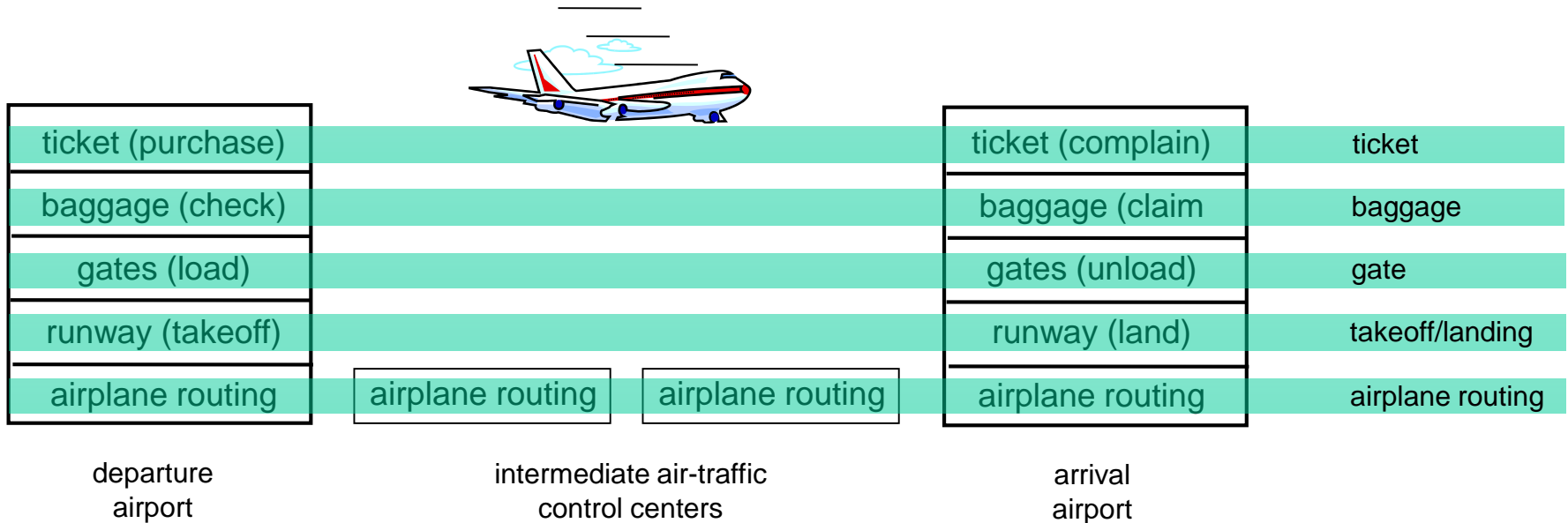
layers: each layer implements a service
- via its own internal-layer actions
- relying on services provided by layer below

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
  - ▪ Ethernet, 802.111 (WiFi), PPP
- ❖ *physical:* bits "on the wire"

application
transport
network
link
physical
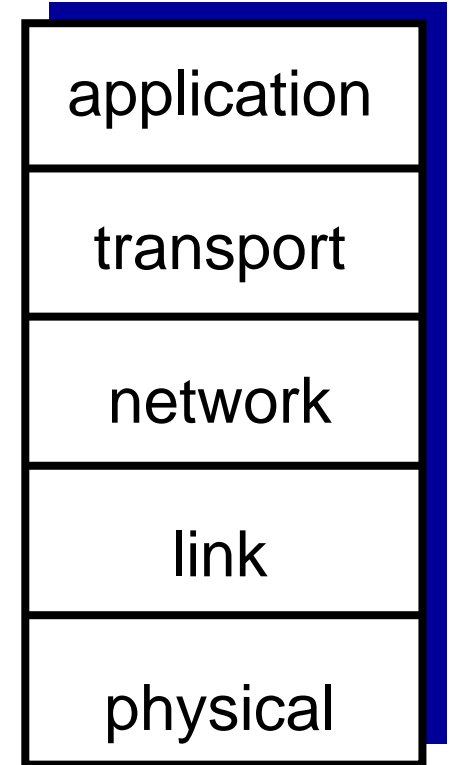
ISO/OSI reference model

❖ *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions

❖ *session:* synchronization, checkpointing, recovery of data exchange

❖ Internet stack "missing" these layers!

- these services, *if needed,* must be implemented in application
- needed?
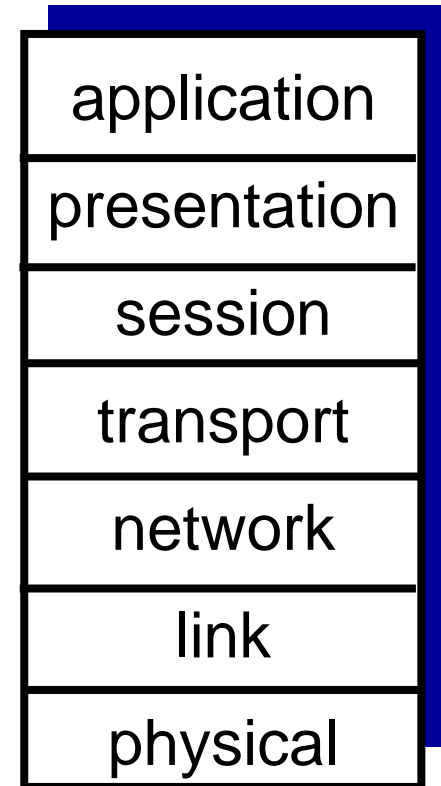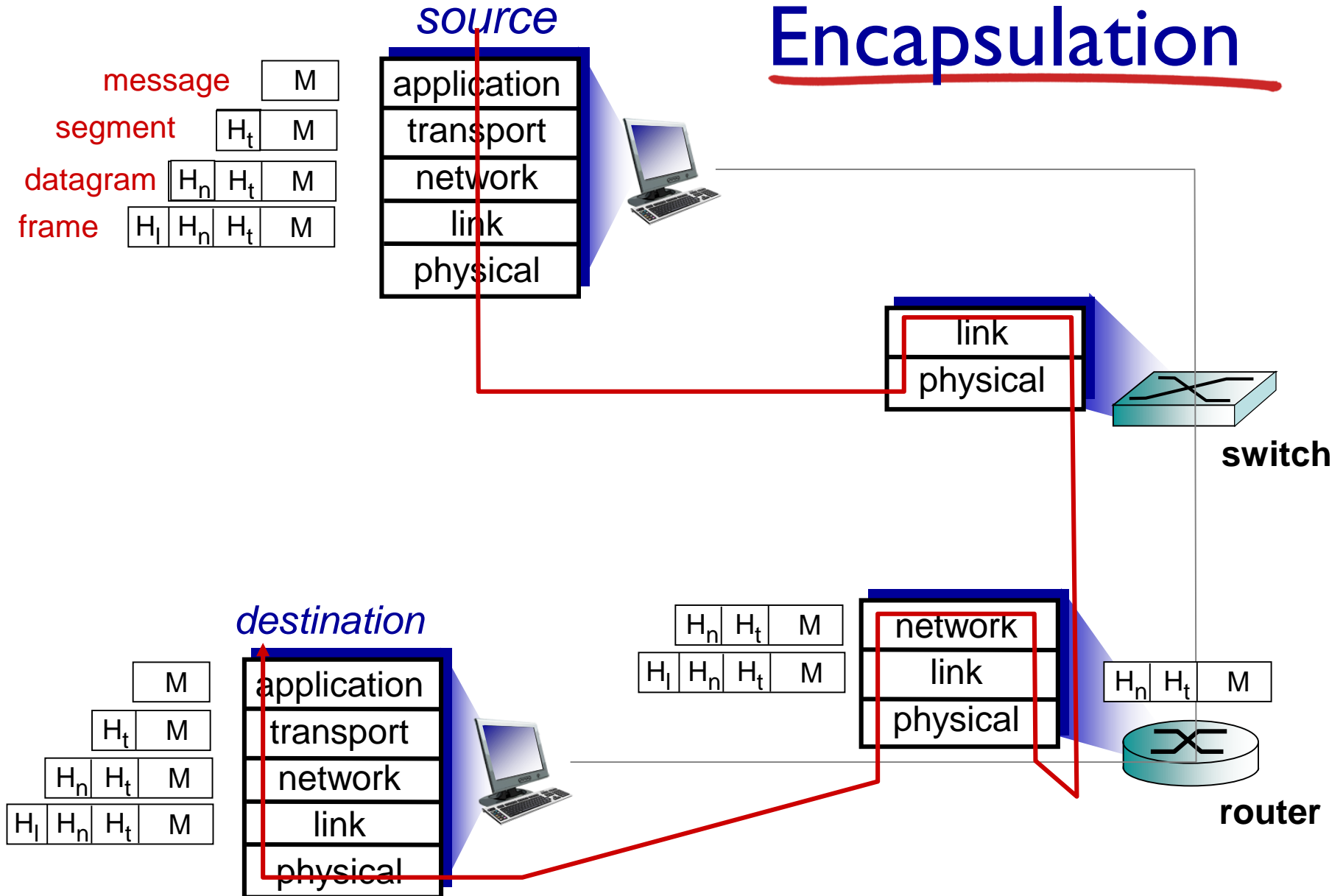
application
presentation
session
transport
network
link
physical

Encapsulation

message | M
segment | H_t | M
datagram | H_n | H_t | M
frame | H_l | H_n | H_t | M

source

| application |
| transport |
| network |
| link |
| physical |

| link |
| physical |

switch

destination

| M |
H_t	M
H_n	H_t	M
H_l	H_n	H_t	M

| application |
| transport |
| network |
| link |
| physical |

| H_n | H_t | M |
| H_l | H_n | H_t | M |

| network |
| link |
| physical |

| H_n | H_t | M |

router

Chapter 1: roadmap

Network security

❖ field of network security:
  ▪ how bad guys can attack computer networks
  ▪ how we can defend networks against attacks
  ▪ how to design architectures that are immune to attacks

❖ Internet not originally designed with (much) security in mind
  ▪ *original vision:* "a group of mutually trusting users attached to a transparent network" ☺
  ▪ Internet protocol designers playing "catch-up"
 ▪ security considerations in all layers!

Bad guys: put malware into hosts via Internet

❖ malware can get in host from:

  ▪ *virus:* self-replicating infection by receiving/executing object (e.g., e-mail attachment)

  ▪ *worm:* self-replicating infection by passively receiving object that gets itself executed

❖ spyware malware can record keystrokes, web sites visited, upload info to collection site

❖ infected host can be enrolled in botnet, used for spam. DDoS attacks

Bad guys: attack server, network infrastructure

Denial of Service (DoS): attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic
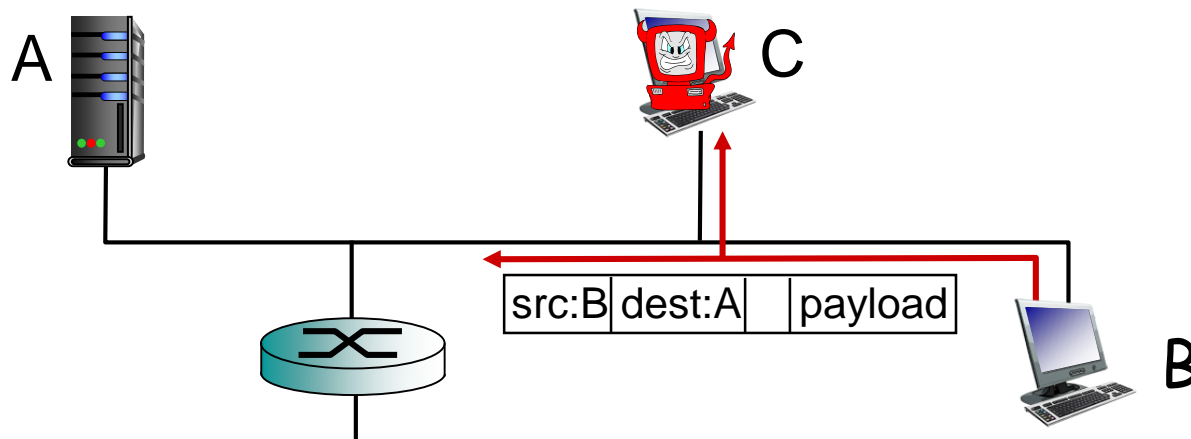
1. select target

2. break into hosts around the network (see botnet)

3. send packets to target from compromised hosts

target
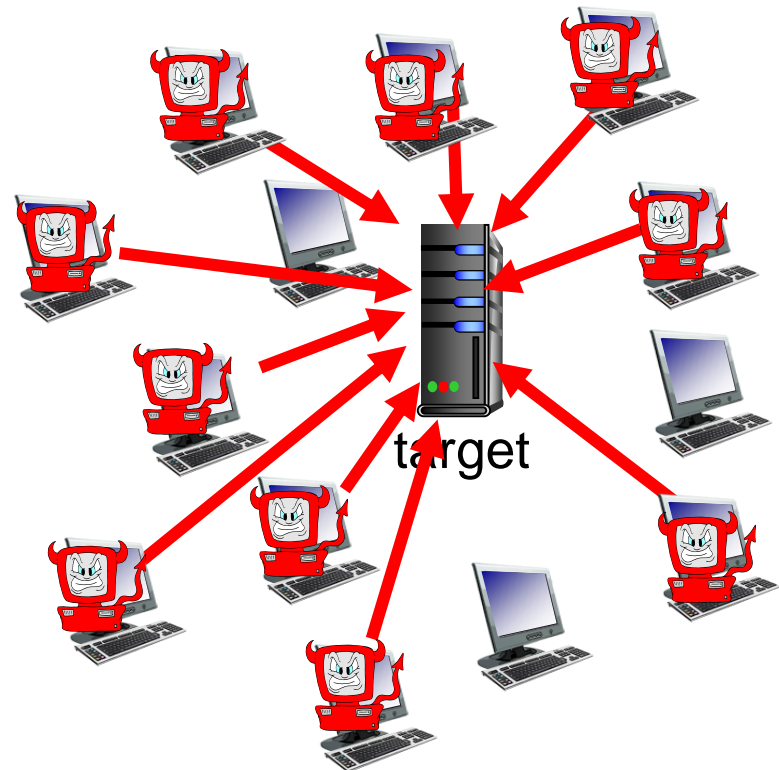
# Bad guys can sniff packets

packet "sniffing":

- broadcast media (shared ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by

A   C

src:B dest:A   payload

B

❖ wireshark software used for end-of-chapter labs is a (free) packet-sniffer

Bad guys can use fake addresses

IP spoofing: send packet with false source address

A
C
src:B dest:A payload
B
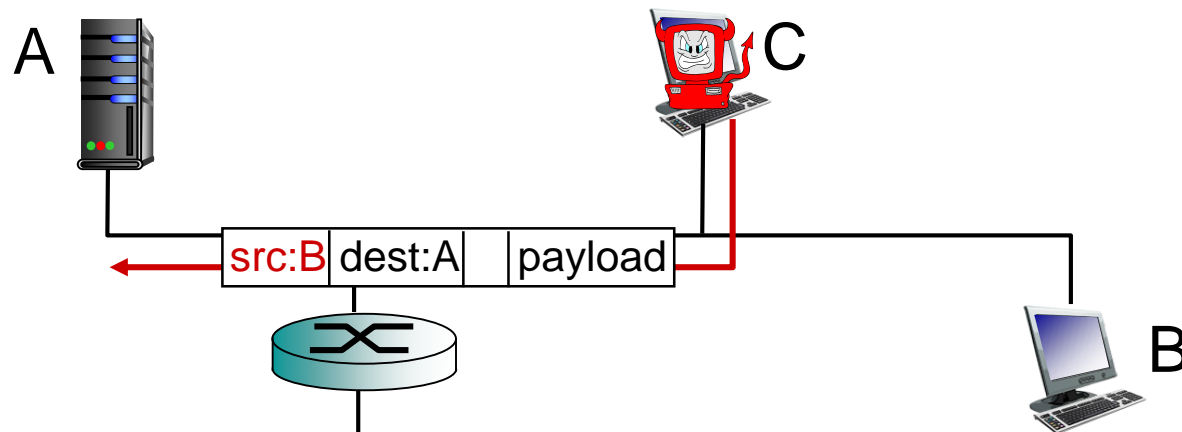
… lots more on security (throughout, Chapter 8)

Chapter 1: roadmap

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 demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet (Adv Res Pr Agency) has 15 nodes

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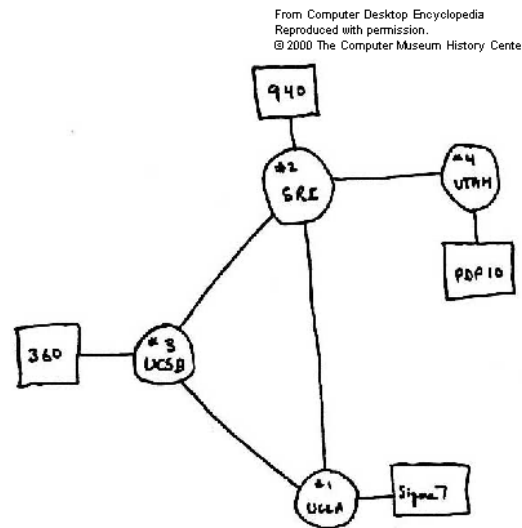
Internet history

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

2005-present

❖ ~750 million hosts
  ▪ Smartphones and tablets

❖ Aggressive deployment of broadband access

❖ Increasing ubiquity of high-speed wireless access

❖ Emergence of online social networks:
  ▪ Facebook: soon one billion users

❖ Service providers (Google, Microsoft) create their own networks
  ▪ Bypass Internet, providing "instantaneous" access to search, emai, etc.

❖ E-commerce, universities, enterprises running their services in "cloud" (eg, Amazon EC2)

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!*