CSC/CPE 138 - Computer Network Fundamentals

Introduction

The presentation was adapted from the textbook: *Computer Networking: A Top-Down Approach* 8th edition Jim Kurose, Keith Ross, Pearson, 2020

SACRAMENTO STATE

Redefine the Possible™

About me

Instructor: Bang Tran

Ph.D. University of Nevada, Reno

MS Tokyo Institute of Technology and Thammasat University

Google Scholar:
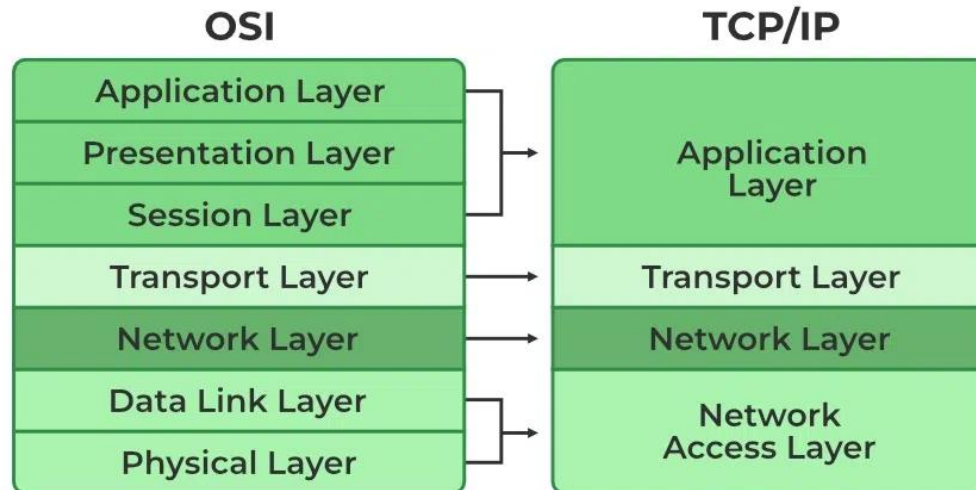https://scholar.google.com/citations?user=dg12E4sAAAAJ&hl=en

Office: Riverside Hall 5042

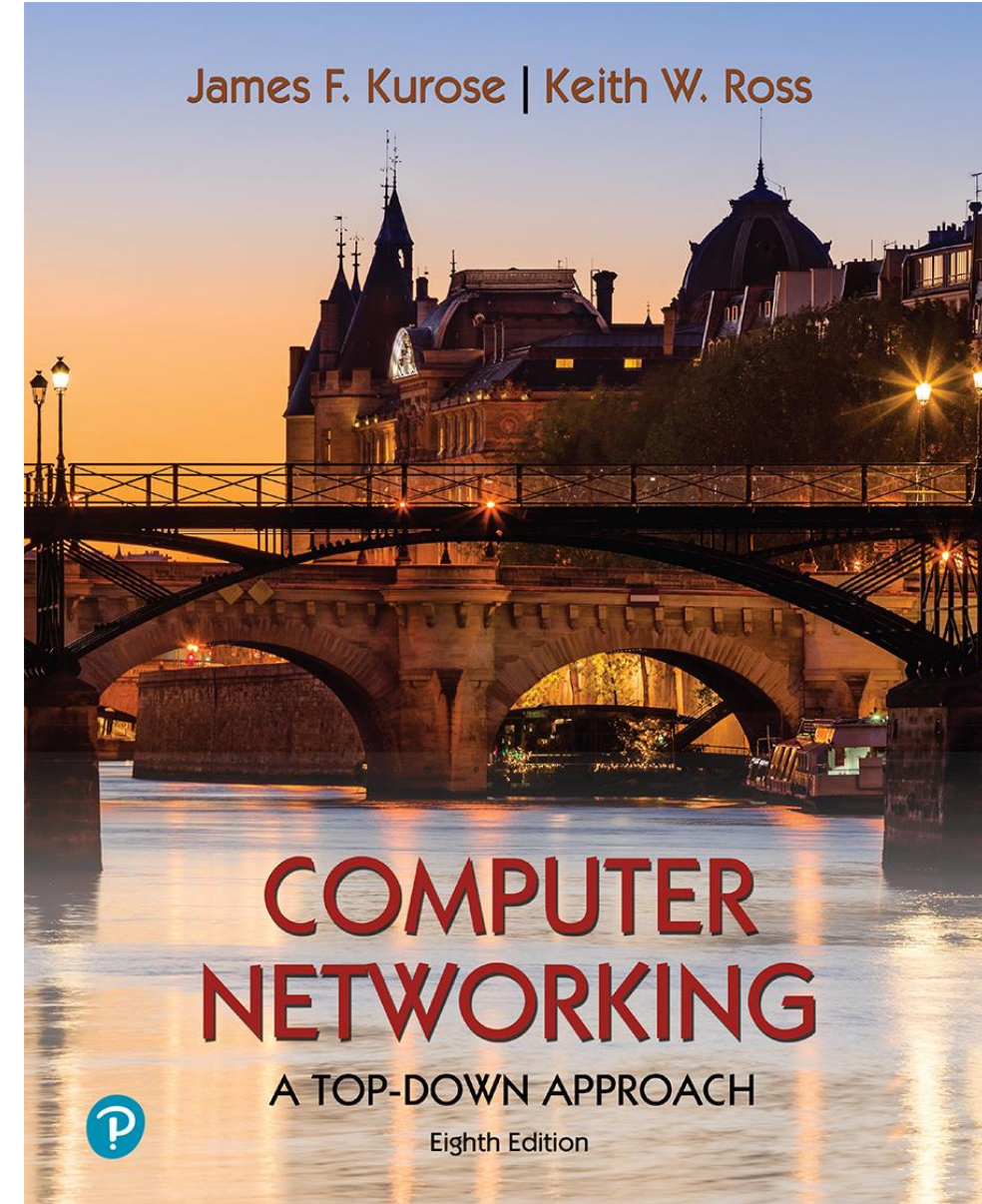Office Hours: Tuesday, 3 p.m.– 4:30 p.m. and Thursday 3 p.m. – 4:30 p.m.

Research Areas: Bioinformatics, Data Science and Machine Learning

- Cancer Sub-typing
- Cancer risk prediction
- Single-cell RNA sequencing analysis
- Pathway analysis

7	Application Layer	Human-computer interaction layer, where applications can access the network services
6	Presentation Layer	Ensures that data is in a usable format and is where data encryption occurs
5	Session Layer	Maintains connections and is responsible for controlling ports and sessions
4	Transport Layer	Transmits data using transmission protocols including TCP and UDP
3	Network Layer	Decides which physical path the data will take
2	Data Link Layer	Defines the format of data on the network
1	Physical Layer	Transmits raw bit stream over the physical medium

OSI

- Application Layer
- Presentation Layer
- Session Layer
- Transport Layer
- Network Layer
- Data Link Layer
- Physical Layer

TCP/IP

- Application Layer
- Transport Layer
- Network Layer
- Network Access Layer

(https://www.geeksforgeeks.org/

James F. Kurose | Keith W. Ross

COMPUTER NETWORKING
A TOP-DOWN APPROACH
Eighth Edition

Chapter goal:

- Get "feel," "big picture," introduction to terminology
  - more depth, detail *later* in course

Overview/roadmap:
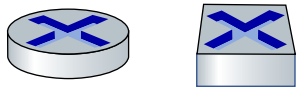
- What *is* the Internet? What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Protocol layers, service models
- Security
- History

Billions of connected computing *devices*:

- *hosts = end systems*
- running *network apps* at Internet's "edge"

Packet switches: forward packets (chunks of data)
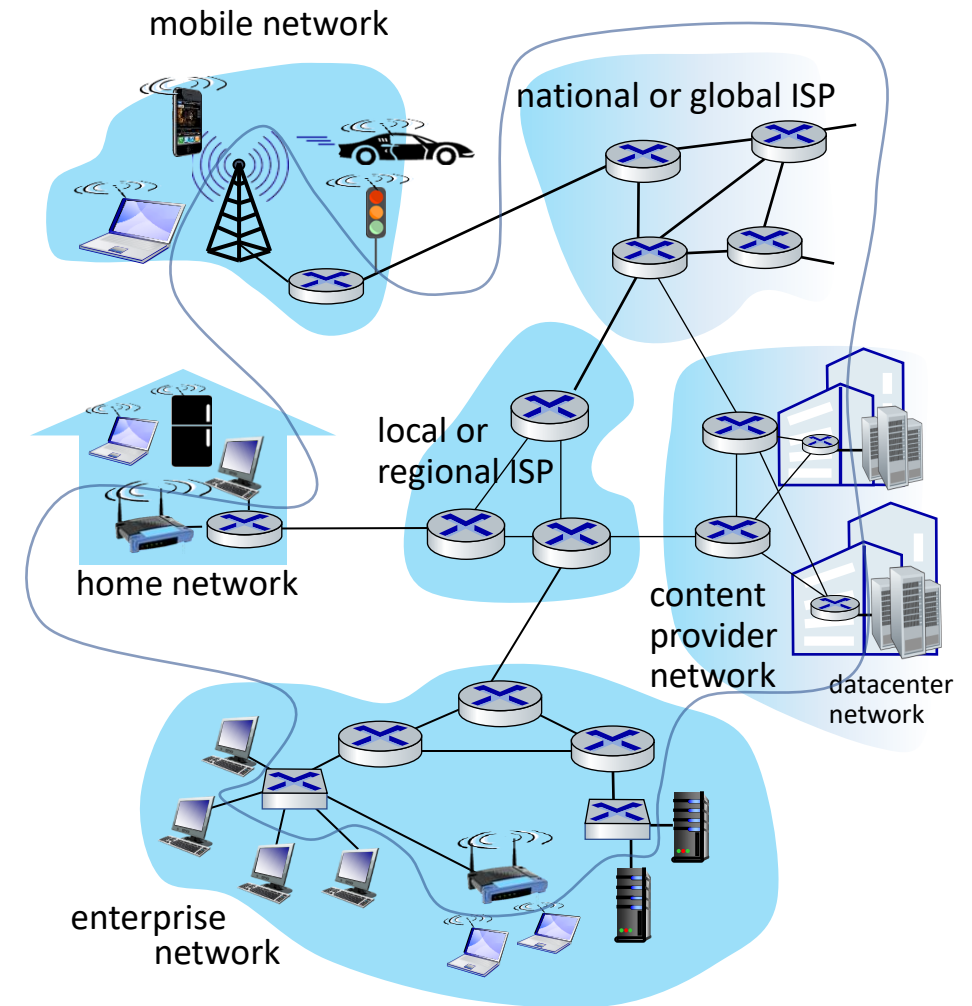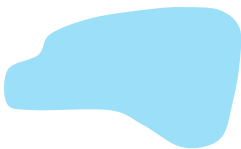
- *routers, switches*

Communication links

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

Networks

- collection of devices, routers, links: managed by an organization

mobile network

national or global ISP

local or regional ISP

home network

content provider network

datacenter network

enterprise network

Amazon Echo

Internet refrigerator

IP picture frame

Pacemaker & Monitor

Tweet-a-watt: monitor energy use

bikes

Web-enabled toaster + weather forecaster

cars

Security Camera

Slingbox: remote control cable TV

AR devices

Fitbit

scooters

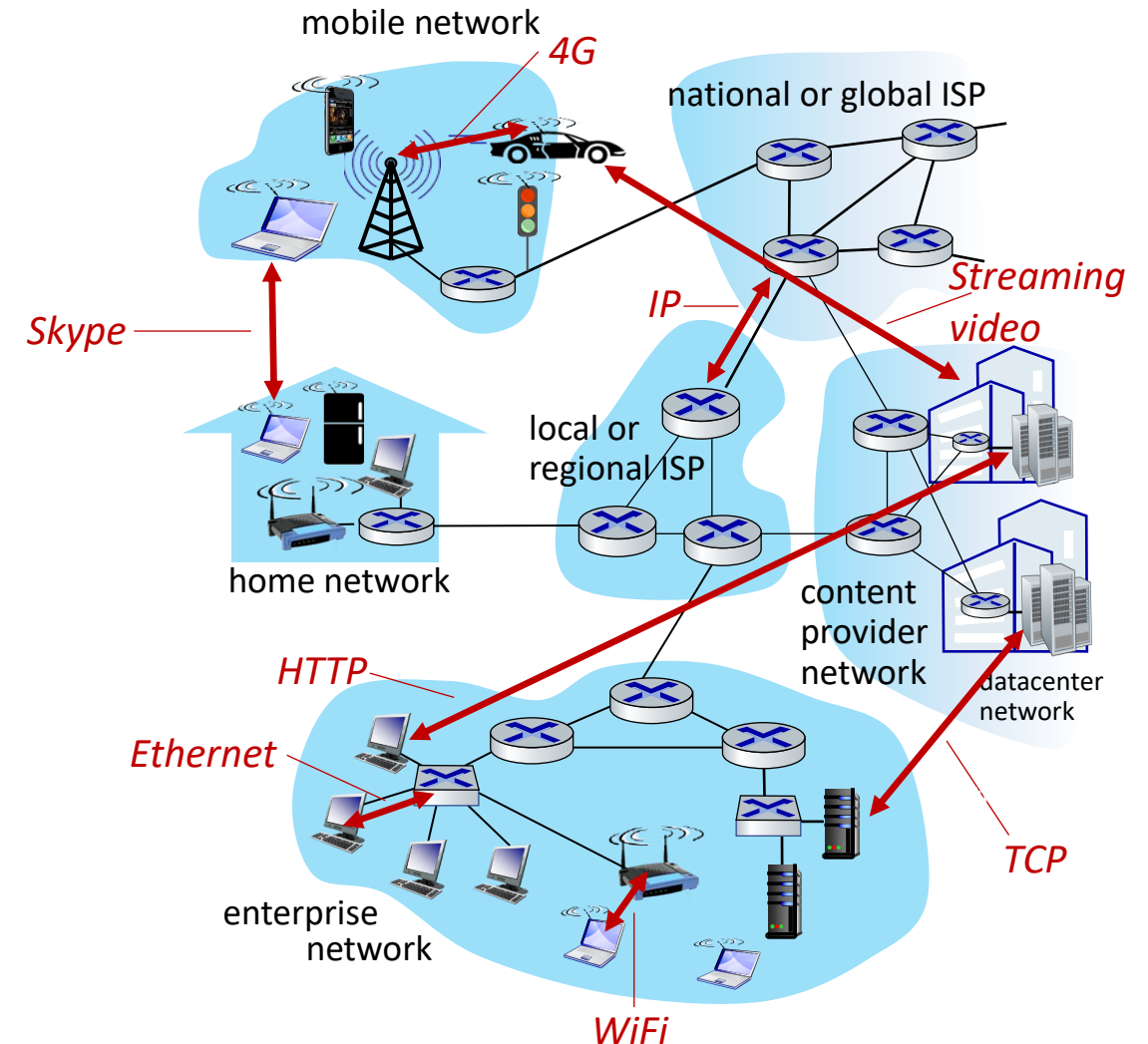Internet phones
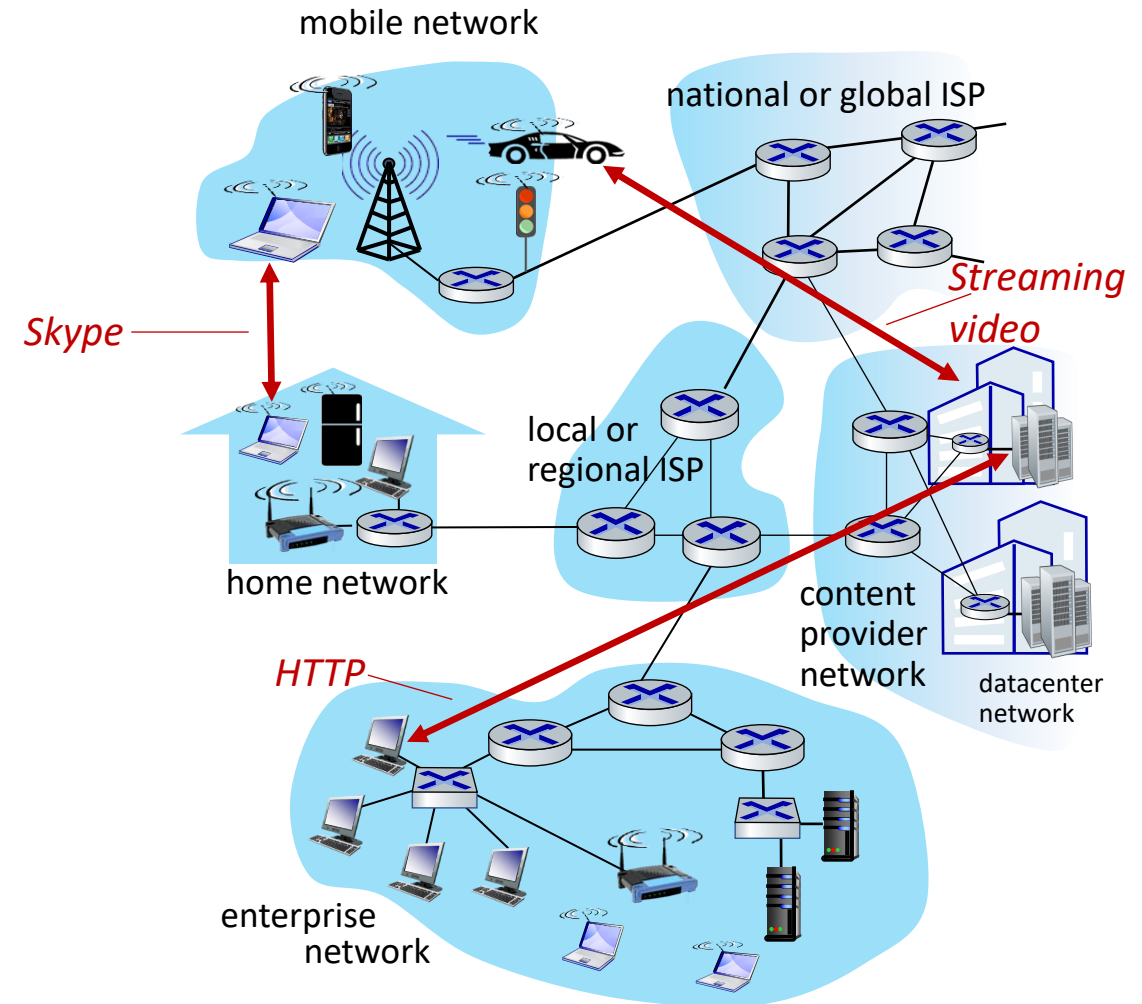
Gaming devices

sensorized, bed mattress

diapers

Others?

- *Internet:* "network of networks"
  - Interconnected ISPs

- *protocols* are *everywhere*
  - control sending, receiving of messages
  - e.g., HTTP (Web), streaming video, Skype, TCP, IP, WiFi, 4/5G, Ethernet

- Internet standards
  - RFC: Request for Comments
  - IETF: Internet Engineering Task Force

- *Infrastructure* that provides services to applications:
  - Web, streaming video, multimedia teleconferencing, email, games, e-commerce, social media, inter-connected appliances, …

- provides *programming interface* to distributed applications:
  - "hooks" allowing sending/receiving apps to "connect" to, use Internet transport service
  - provides service options, analogous to postal service

mobile network

national or global ISP

Streaming video

Skype

local or regional ISP

home network

content provider network

datacenter network

HTTP

enterprise network

Human protocols:

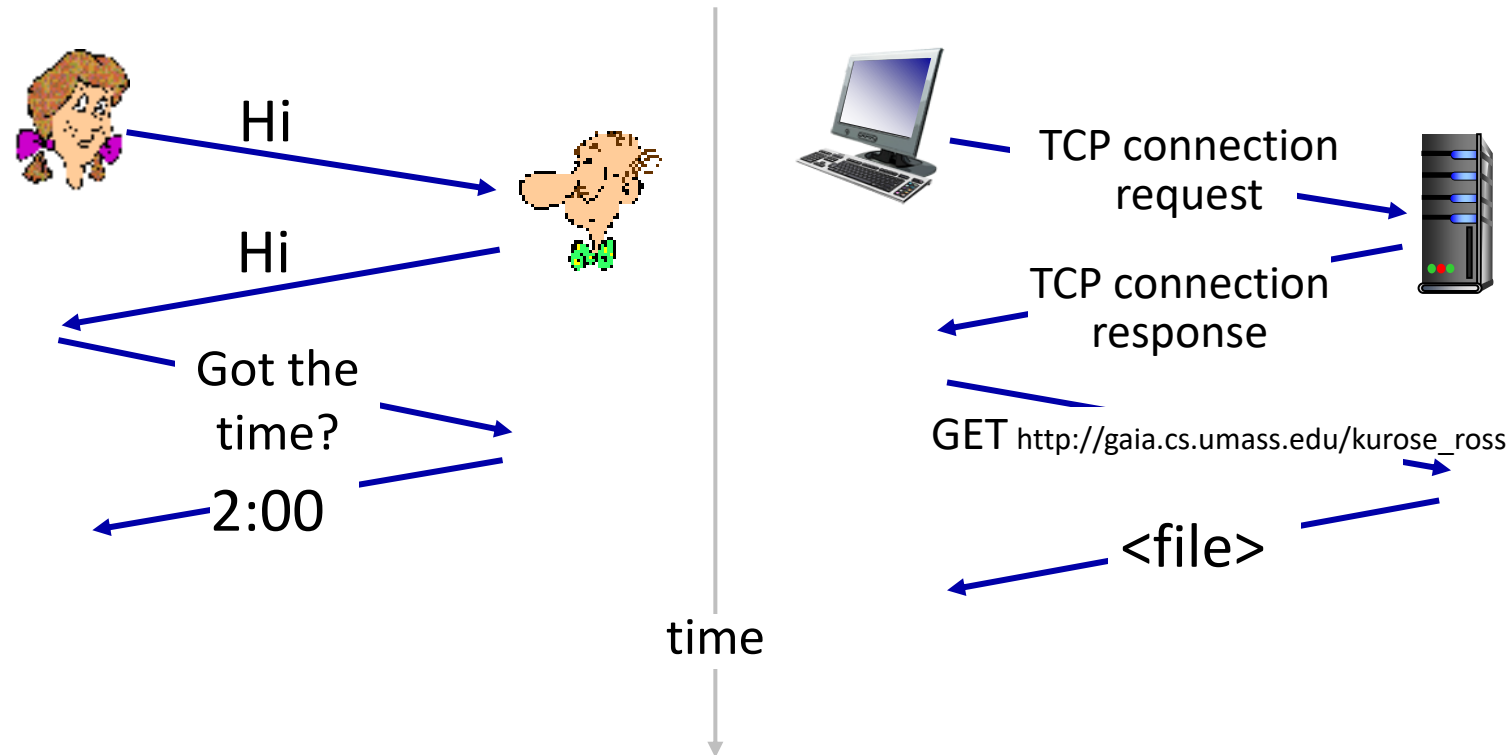- "what's the time?"
- "I have a question"
- introductions

Rules for:
… specific messages sent
… specific actions taken when message received, or other events

Network protocols:

- computers (devices) rather than humans
- all communication activity in Internet governed by protocols

Protocols define the format, order of messages sent and received among network entities, and actions taken on message transmission, receipt

A human protocol and a computer network protocol:

Hi

Hi

Got the time?

2:00

TCP connection request

TCP connection response
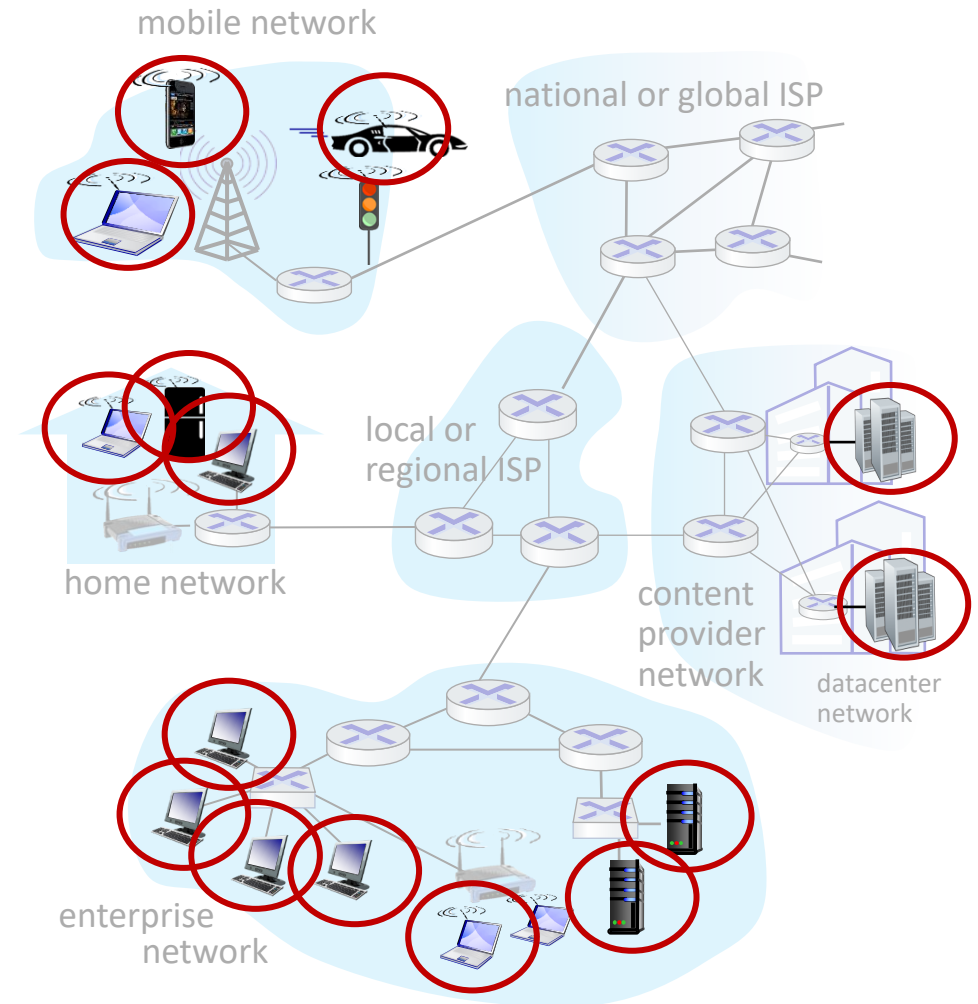
GET http://gaia.cs.umass.edu/kurose_ross

<file>

time

Q: other human protocols?

- What *is* the Internet?

- What *is* a protocol?

- **Network edge:** hosts, access network, physical media

- Network core: packet/circuit switching, internet structure

- Performance: loss, delay, throughput

- Security

- Protocol layers, service models

- History

Network edge:

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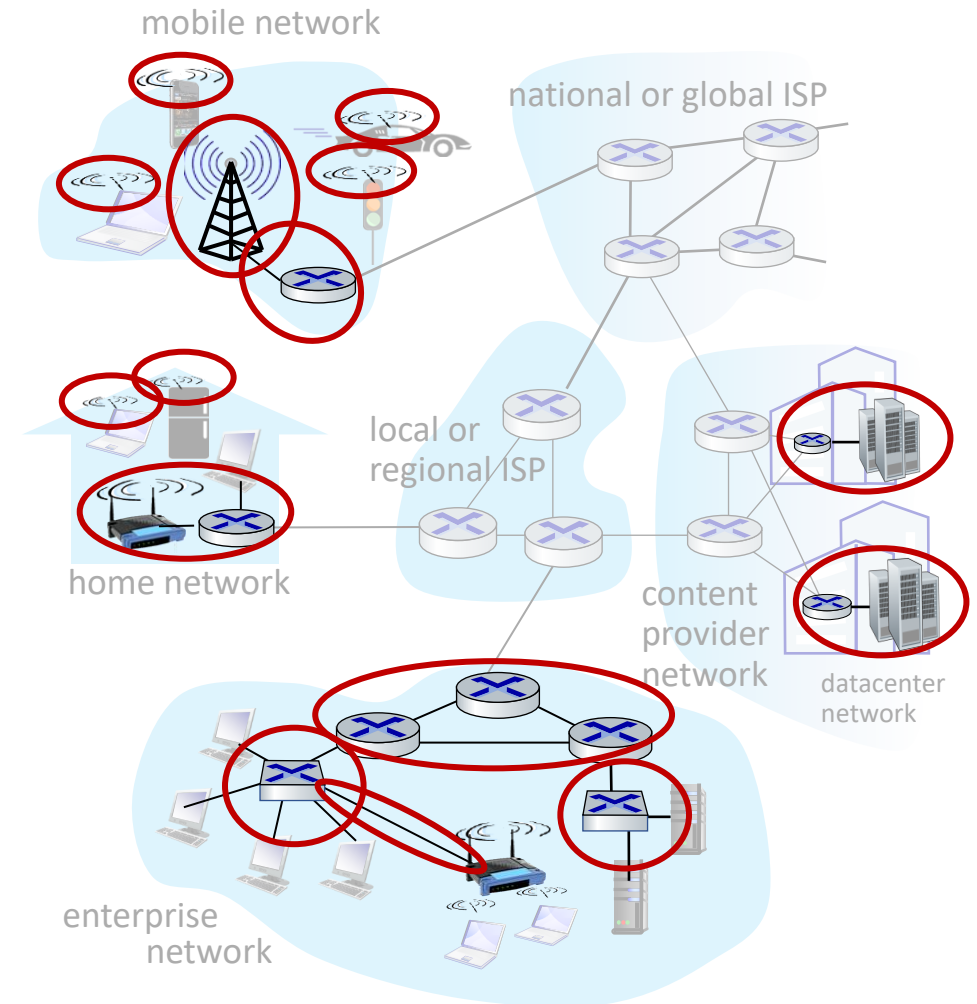- servers often in data centers

mobile network

national or global ISP

local or regional ISP

home network

content provider network

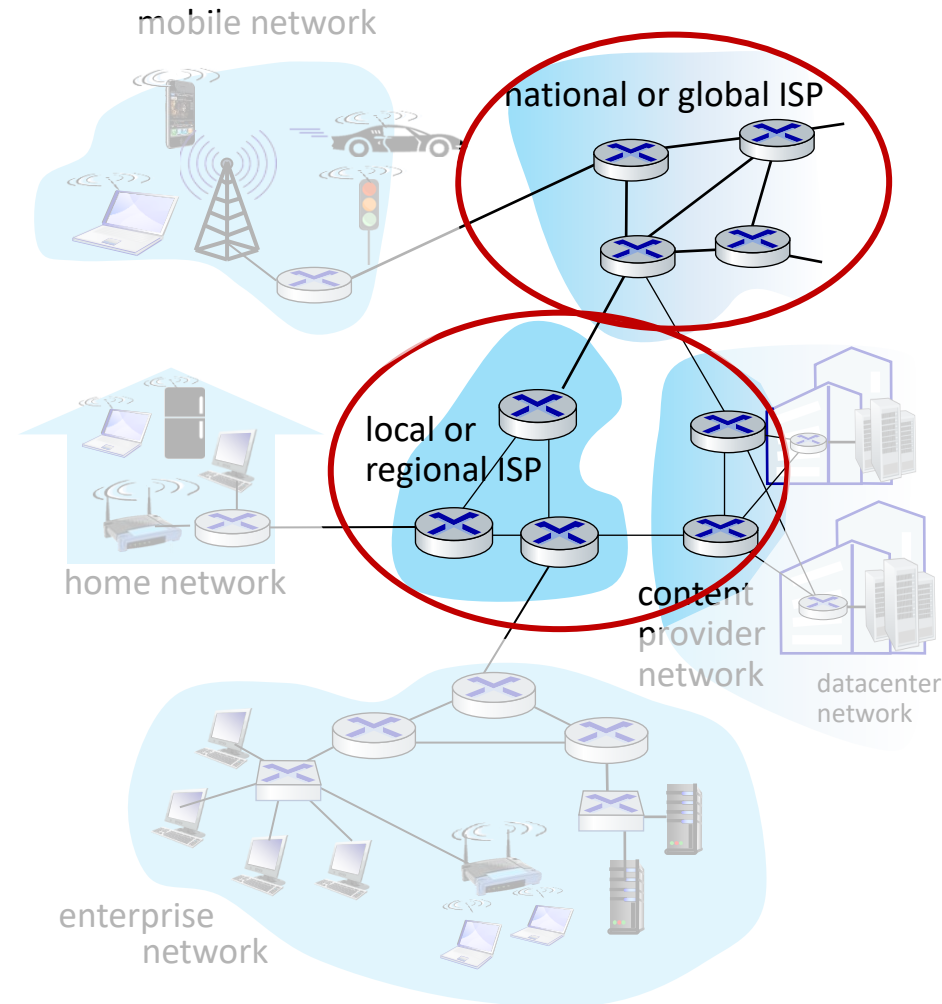datacenter network

enterprise network

Network edge:

- hosts: clients and servers

- servers often in data centers

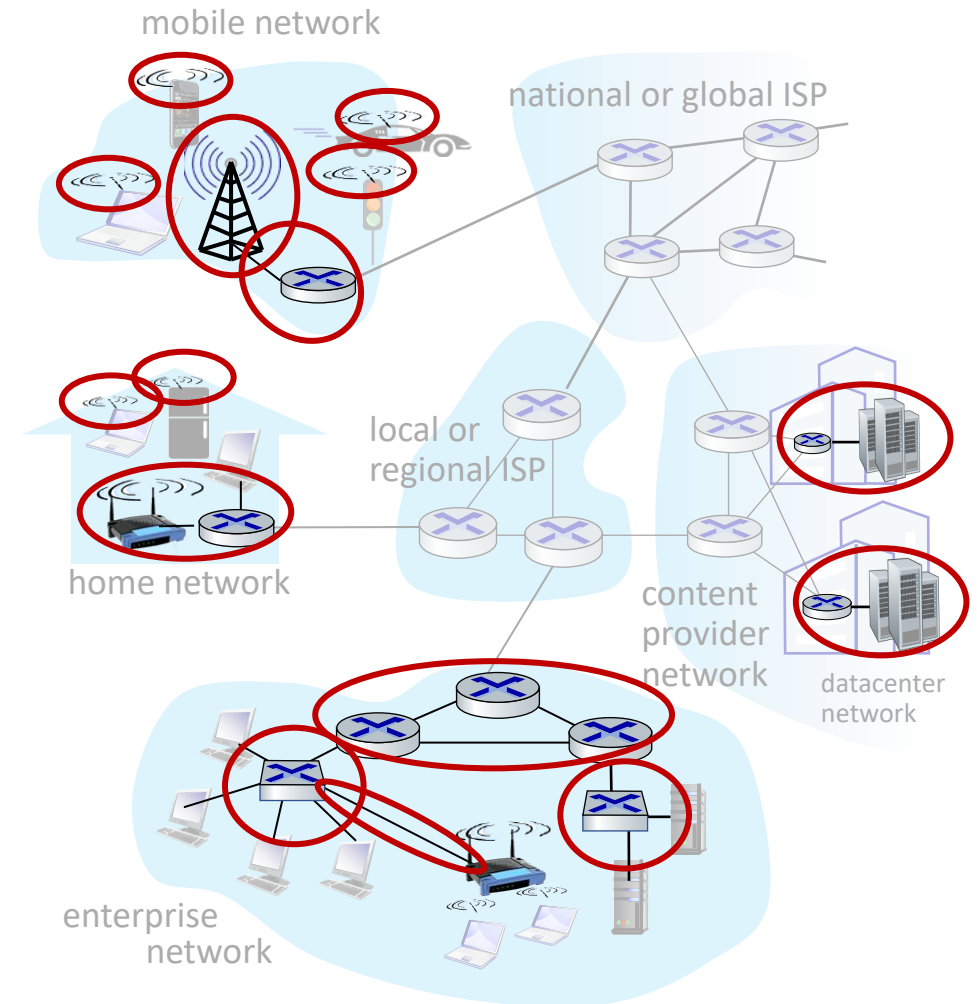Access networks, physical media:

- wired, wireless communication links

mobile network

national or global ISP

local or
regional ISP

home network

content
provider
network

datacenter
network

enterprise
network

Network edge:

- hosts: clients and servers

- servers often in data centers

Access networks, physical media:
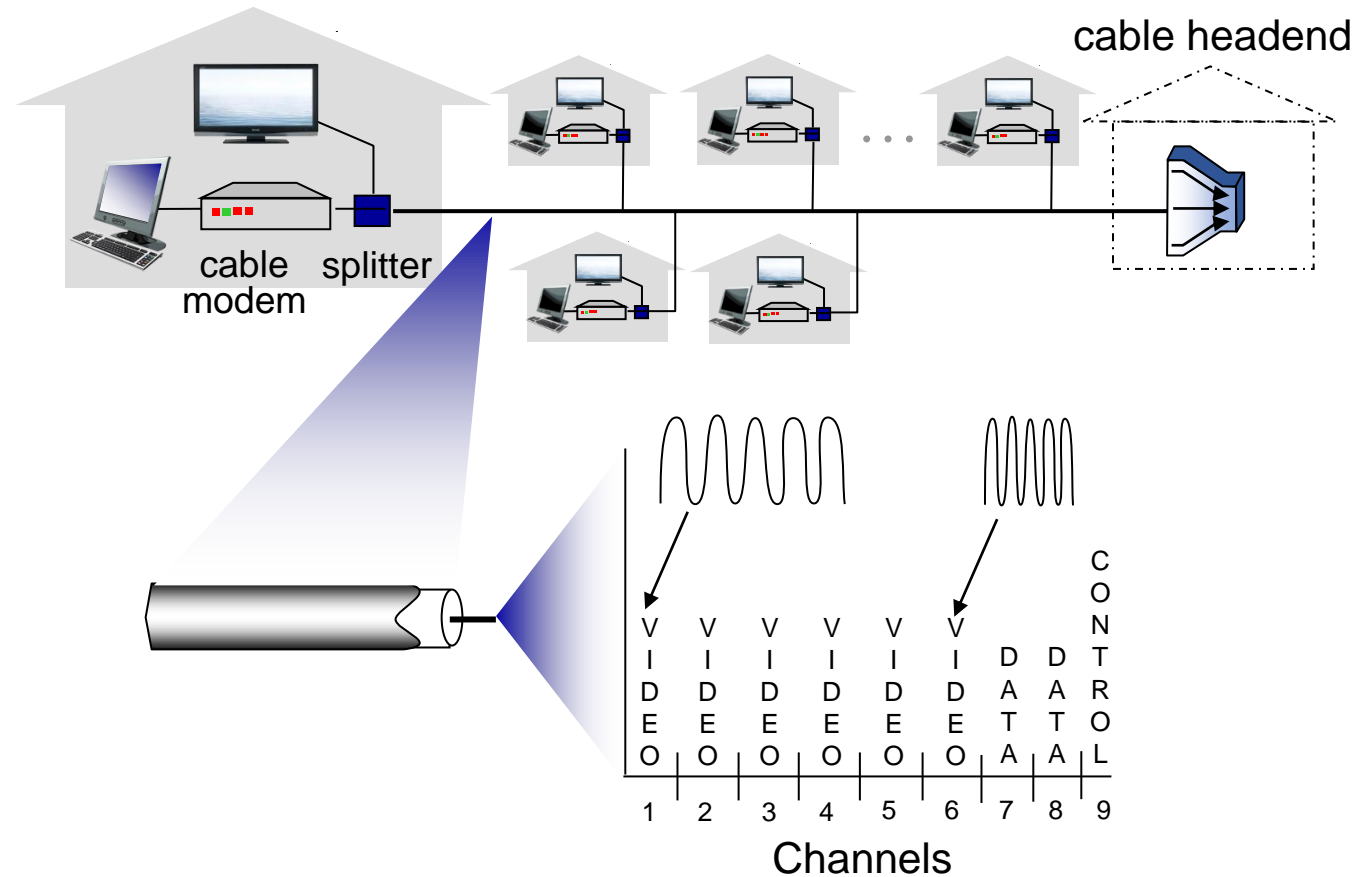
- wired, wireless communication links

Network core:

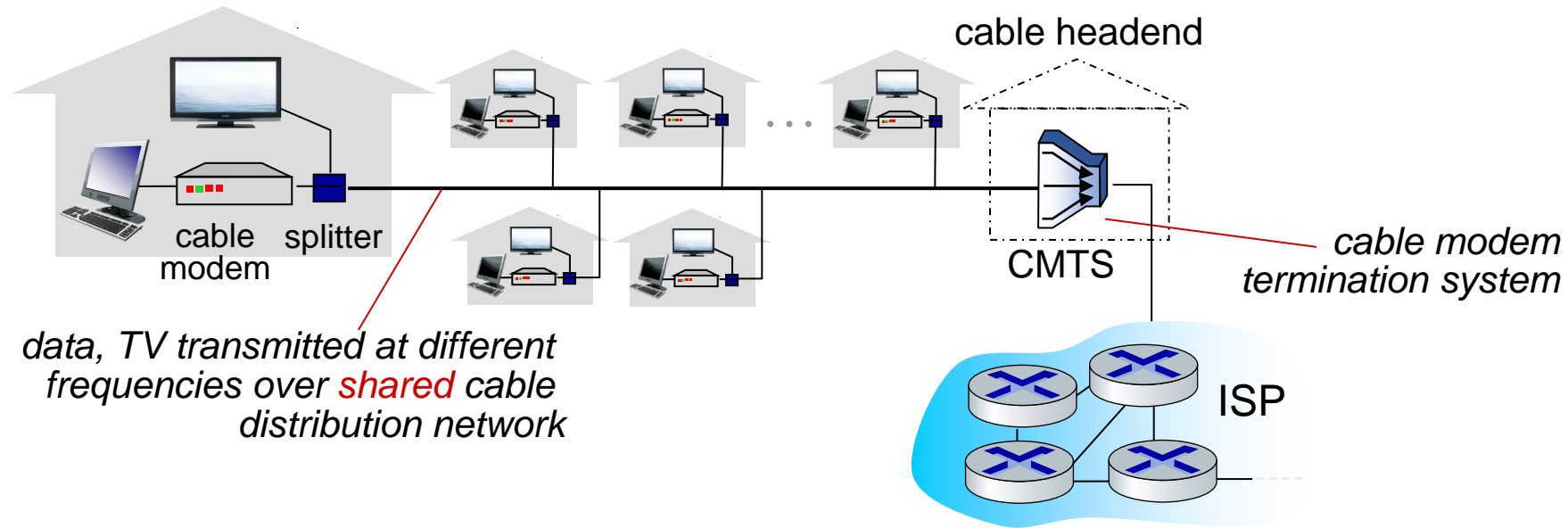- interconnected routers
- network of networks

mobile network

national or global ISP

local or regional ISP

home network

content provider network

datacenter network

enterprise network

Q: How to connect end systems to edge router?

- residential access nets

- institutional access networks (school, company)

- mobile access networks (WiFi, 4G/5G)

mobile network

national or global ISP

local or regional ISP

home network

content provider network

datacenter network

enterprise network

frequency division multiplexing (FDM): different channels transmitted in different frequency bands

cable headend

cable modem

splitter

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

CMTS

cable modem termination system

ISP

- HFC: hybrid fiber coax
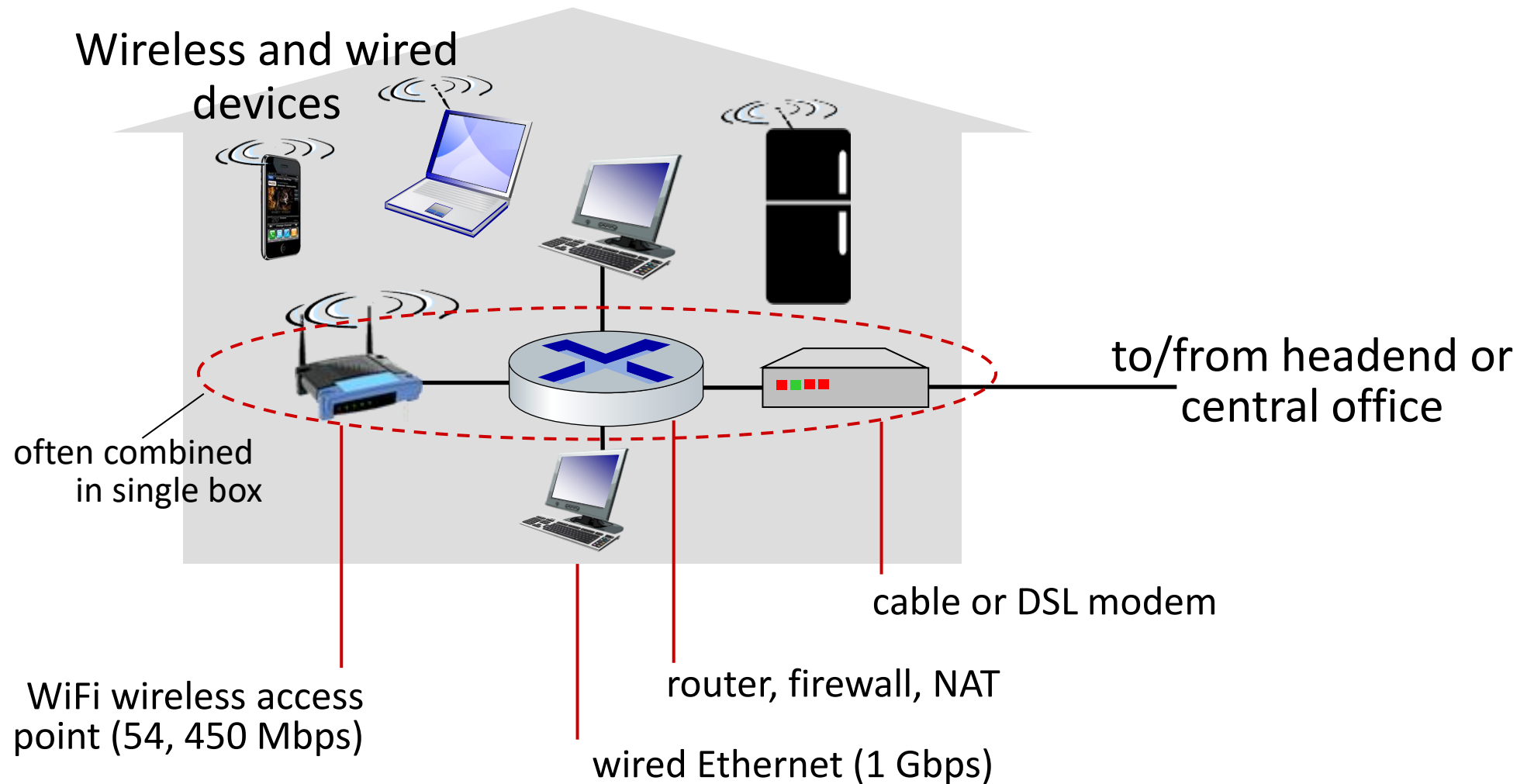 - asymmetric: up to 40 Mbps – 1.2 Gbps downstream transmission rate, 30-100 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
 - homes *share access network* to cable headend

central office

telephone network

DSL modem

splitter

DSLAM

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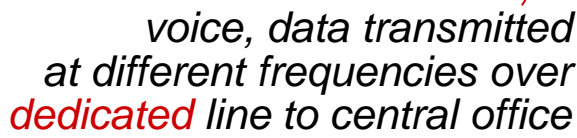
DSL access multiplexer

ISP

- 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
- 24-52 Mbps dedicated downstream transmission rate
- 3.5-16 Mbps dedicated upstream transmission rate

Wireless and wired devices

often combined in single box

to/from headend or central office

cable or DSL modem

router, firewall, NAT

WiFi wireless access point (54, 450 Mbps)

wired Ethernet (1 Gbps)

Shared *wireless* access network connects end system to router

- via base station aka "access point"

Wireless local area networks (WLANs)

- typically within or around building (~100 ft)
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate

to Internet
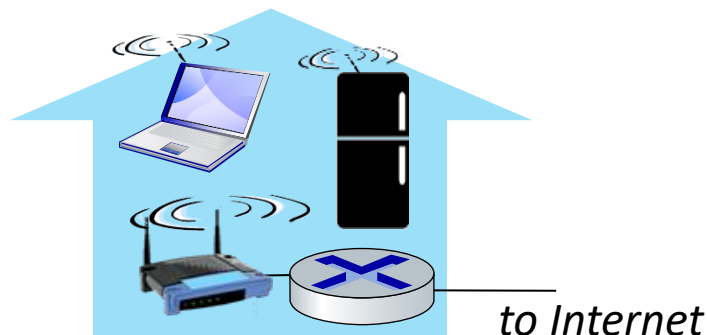
Wide-area cellular access networks

- provided by mobile, cellular network operator (10's km)
- 10's Mbps
- 4G/5G cellular networks

to Internet

Enterprise link to
ISP (Internet)
institutional router

Ethernet
switch

institutional mail,
web servers
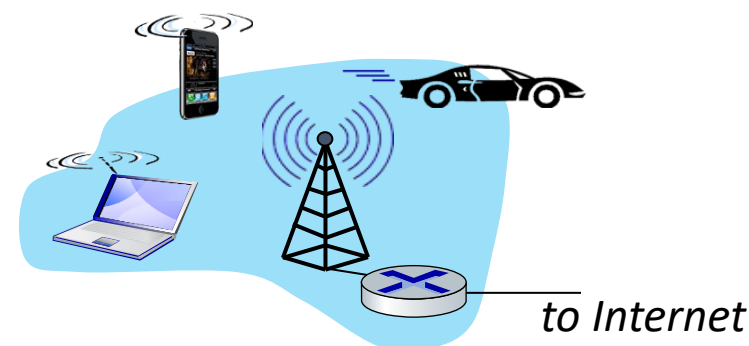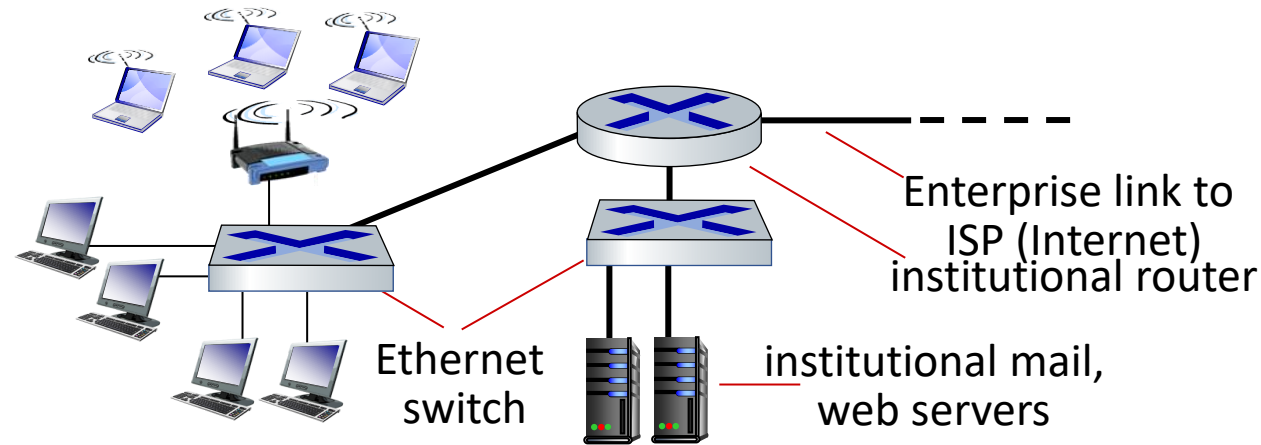
- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
  - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
  - WiFi: wireless access points at 11, 54, 450 Mbps

- high-bandwidth links (10s to 100s Gbps) connect hundreds to thousands of servers together, and to Internet

Courtesy: Massachusetts Green High Performance Computing Center (mghpcc.org)
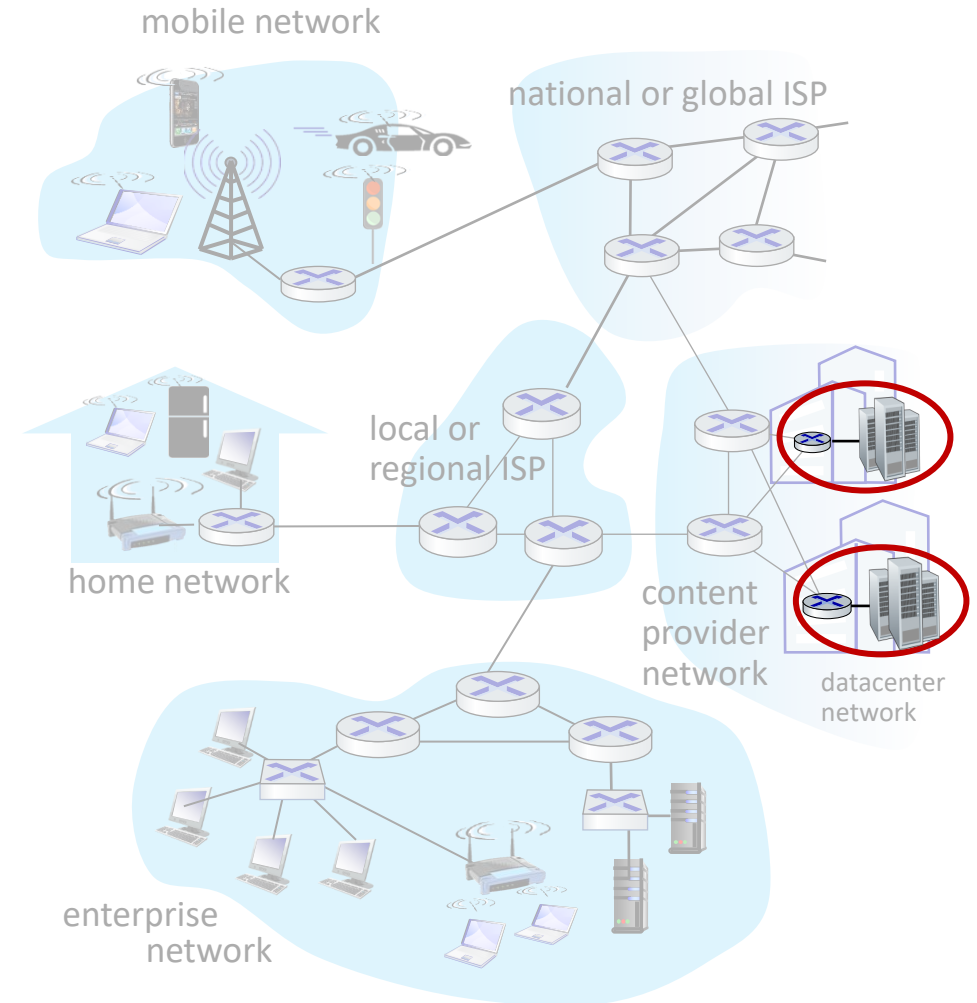
host sending function:

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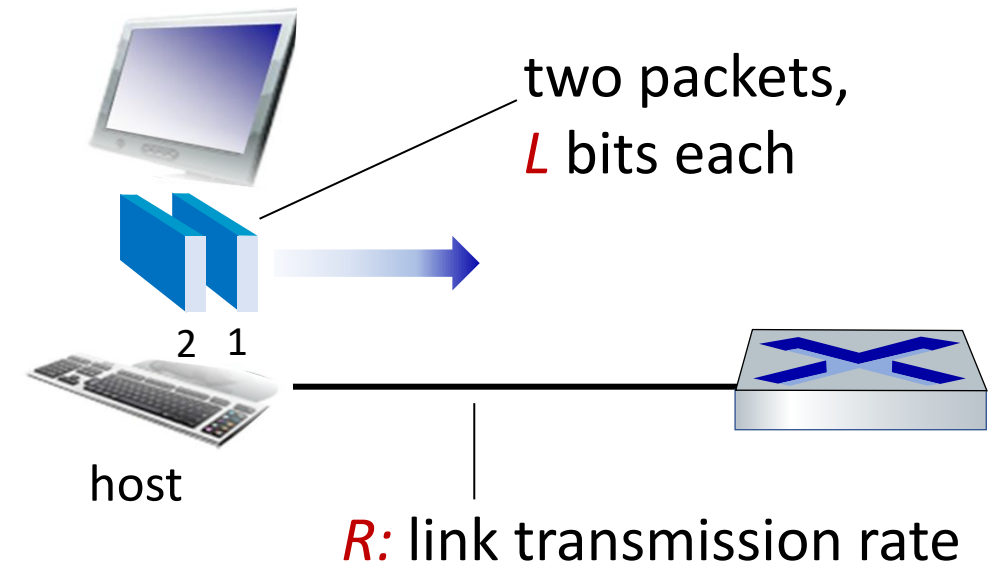
$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

- **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 Gbps Ethernet
 - Category 6: 10Gbps Ethernet
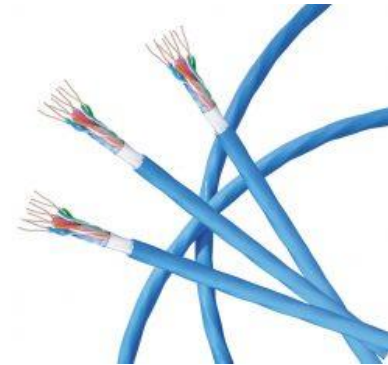
Coaxial cable:

- two concentric copper conductors

- bidirectional

- broadband:
  - multiple frequency channels on cable
  - 100's Mbps per channel

Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (10's-100's Gbps)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise
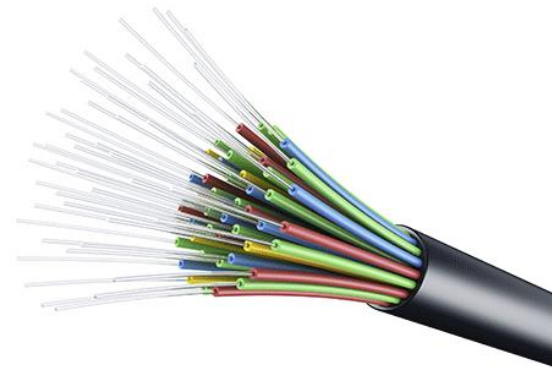
Wireless radio

- signal carried in various "bands" in electromagnetic spectrum
- no physical "wire"
- broadcast, "half-duplex" (sender to receiver)
- propagation environment effects:
  - reflection
  - obstruction by objects
  - Interference/noise

Radio link types:

- Wireless LAN (WiFi)
  - 10-100's Mbps; 10's of meters
- wide-area (e.g., 4G/5G cellular)
  - 10's Mbps (4G) over ~10 Km
- Bluetooth: cable replacement
  - short distances, limited rates
- terrestrial microwave
  - point-to-point; 45 Mbps channels
- satellite
  - up to < 100 Mbps (Starlink) downlink
  - 270 msec end-end delay (geostationary)

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- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into *packets*
 - network forwards packets from one router to the next, across links on path from source to destination

mobile network

national or global ISP

local or regional ISP

home network

content provider network

datacenter network

enterprise network
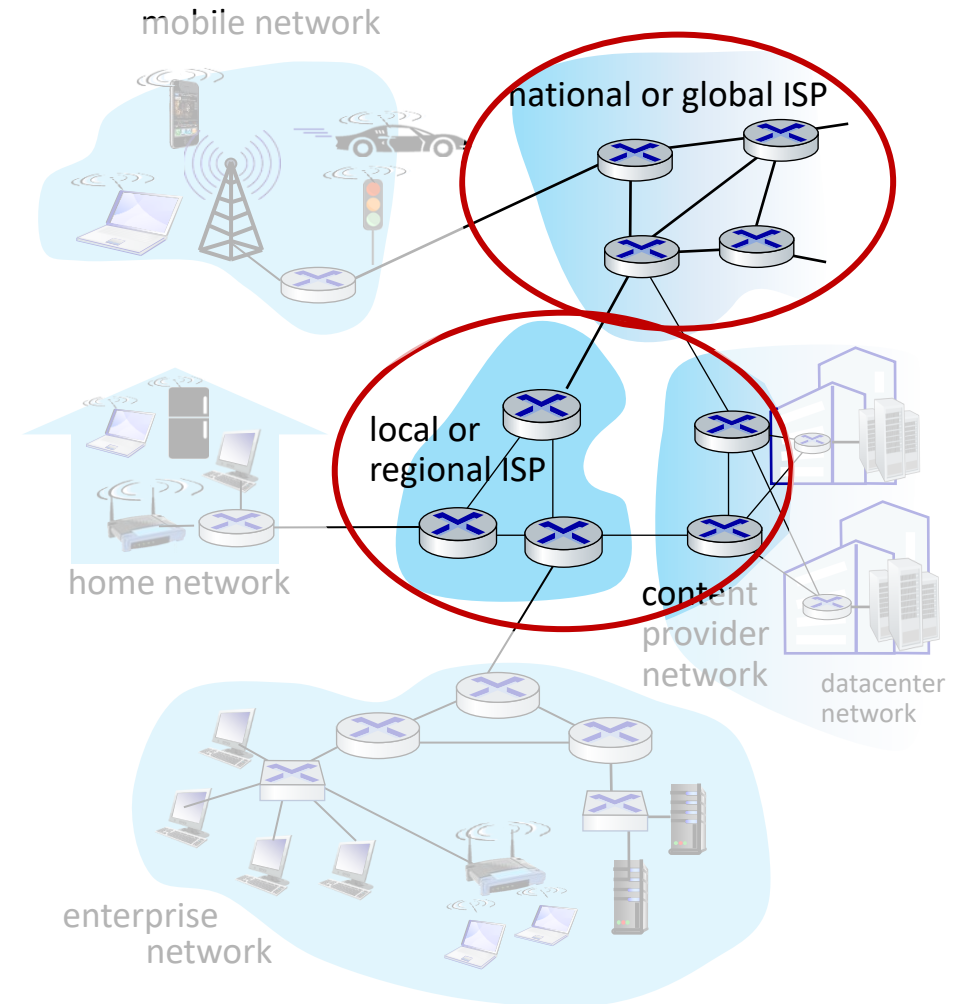
Forwarding:

- aka "switching"
- *local* action: move arriving packets from router's input link to appropriate router output link

routing algorithm

local forwarding table	
header value	output link
0100	3
0101	2
0111	2
1001	1

0111
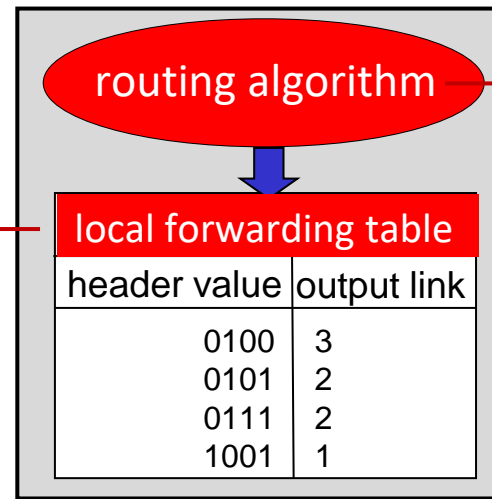
destination address in arriving packet's header

Routing:

- *global* action: determine source-destination paths taken by packets
- routing algorithms

1

3 2

routing

forwarding

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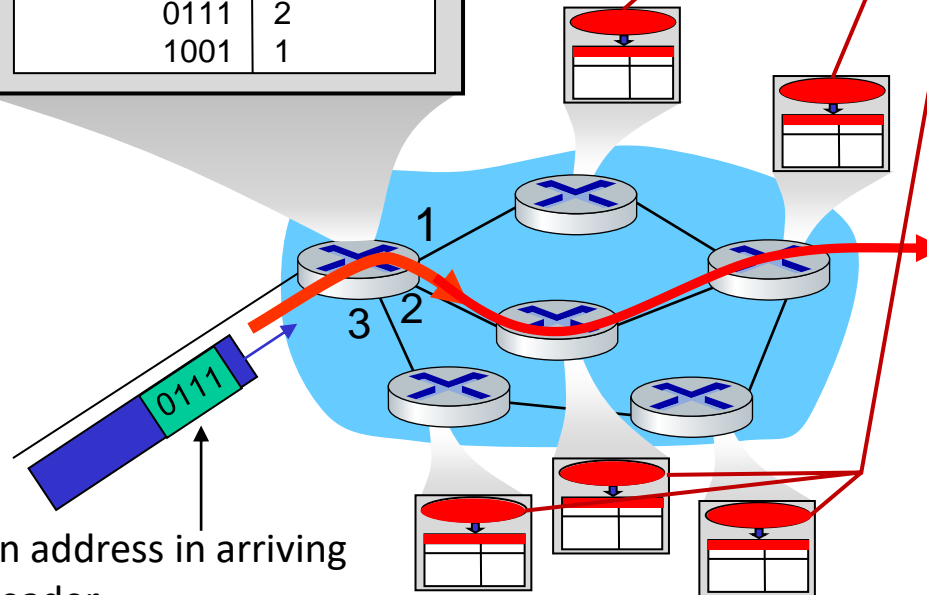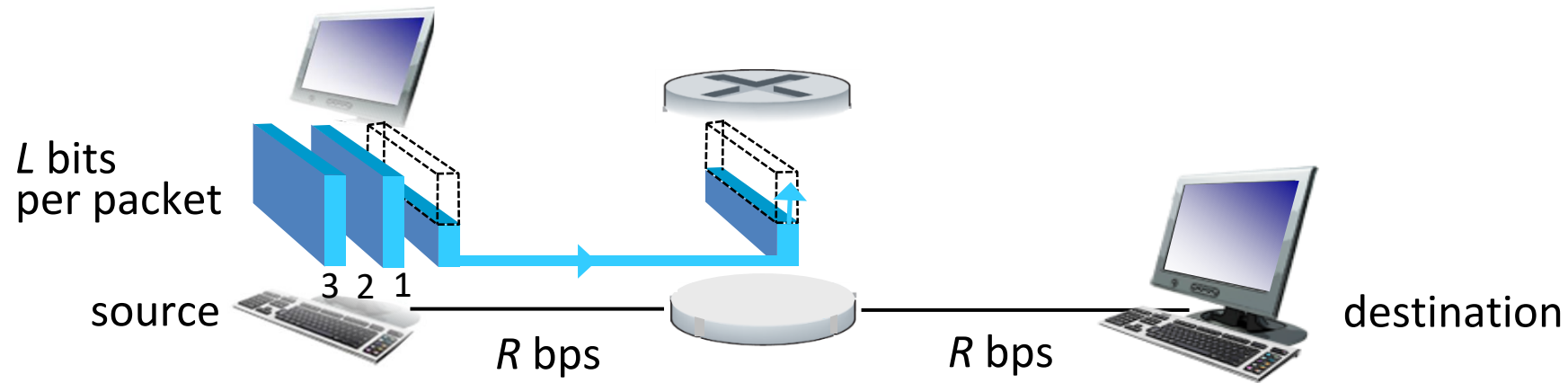
- **packet transmission delay:** takes L/R seconds to transmit (push out) L-bit packet into link at R bps

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

One-hop numerical example:
- L = 10 Kbits
- R = 100 Mbps
- one-hop transmission delay = 0.1 msec

R = 100 Mb/s

A

C

R = 1.5 Mb/s

B

D

E

queue of packets
waiting for transmission
over output link
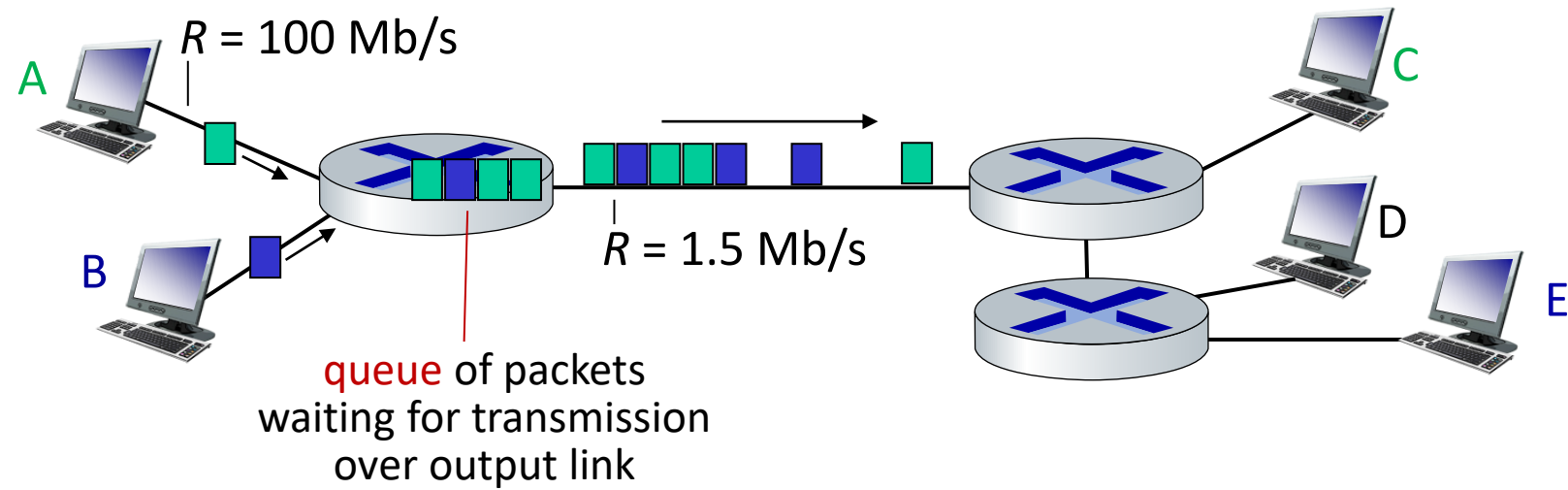
Queueing occurs when work arrives faster than it can be serviced:

R = 100 Mb/s

A

C

R = 1.5 Mb/s

B

D

E

queue of packets
waiting for transmission
over output link
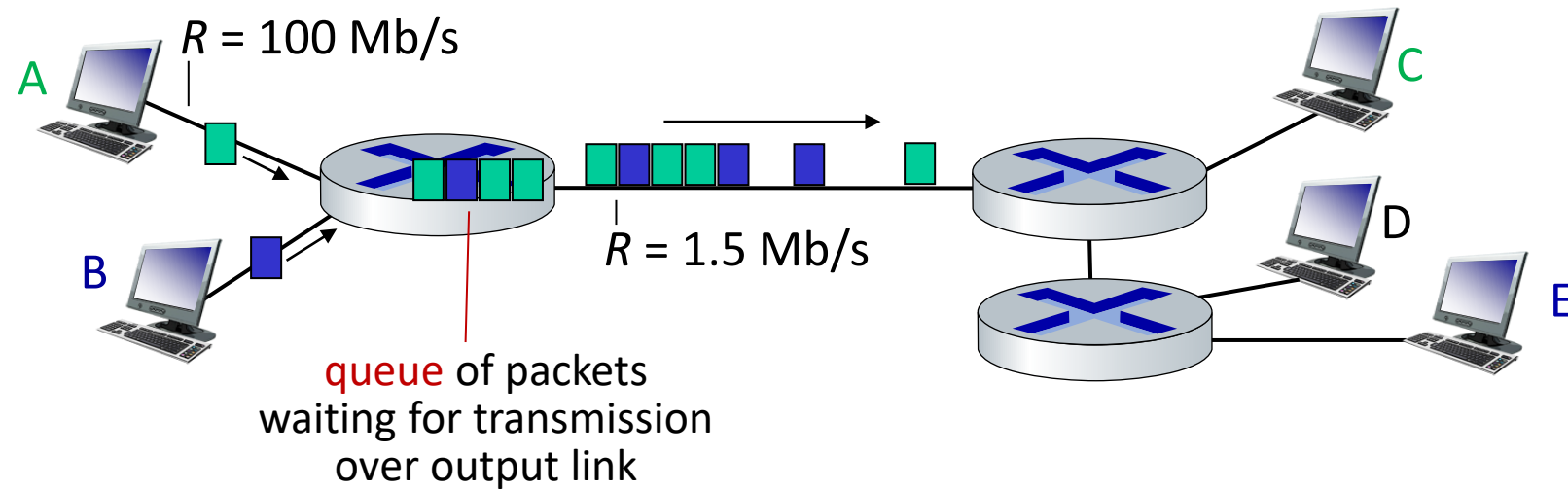
Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

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

end-end resources allocated to, reserved for "call" between source and destination

- 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
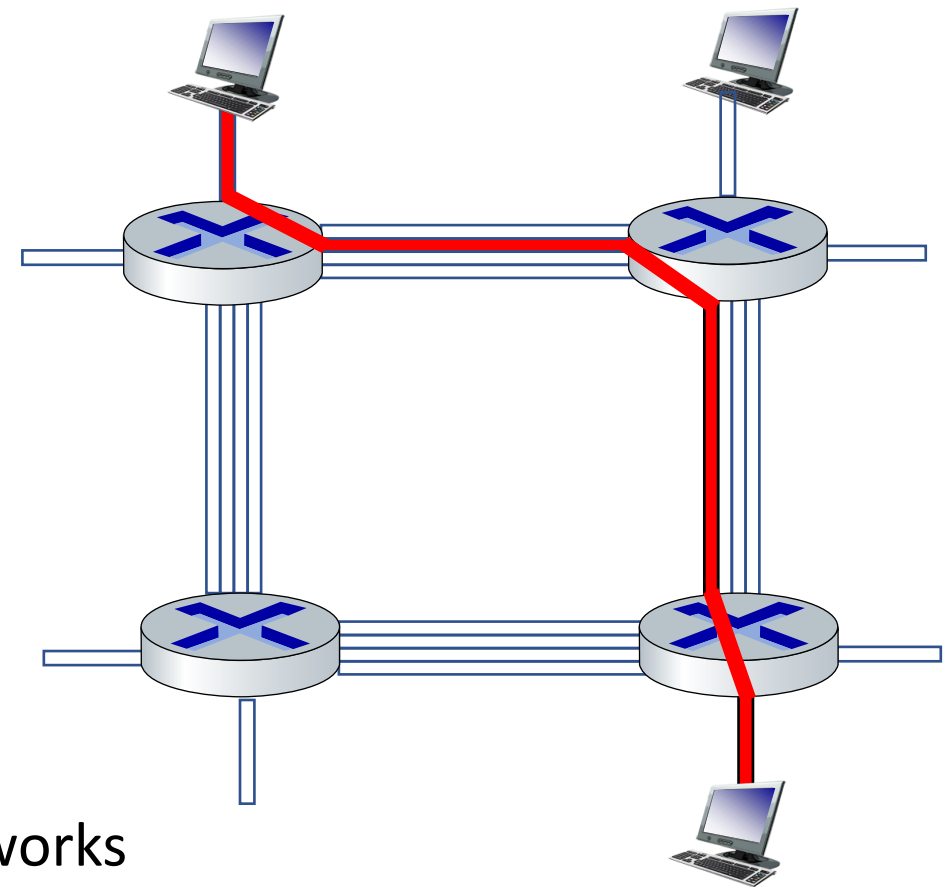
* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive

Frequency Division Multiplexing (FDM)

- optical, electromagnetic frequencies divided into (narrow) frequency bands

- each call allocated its own band, can transmit at max rate of that narrow band

Time Division Multiplexing (TDM)

- time divided into slots

- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band (only) during its time slot(s)
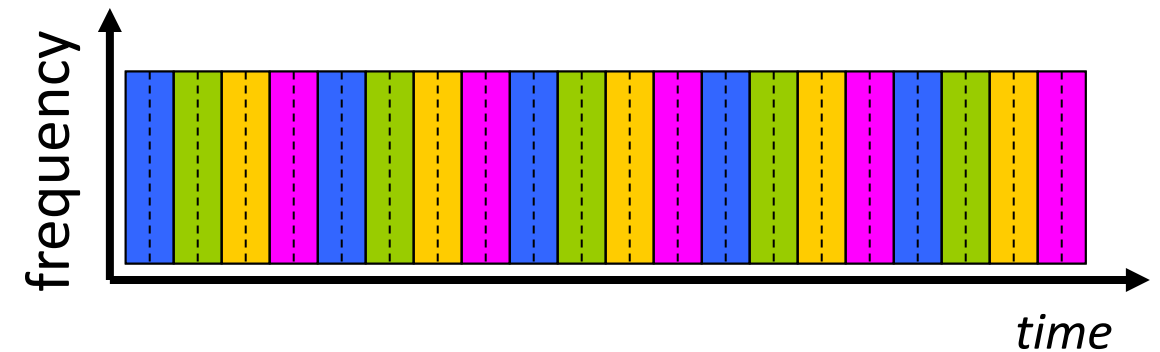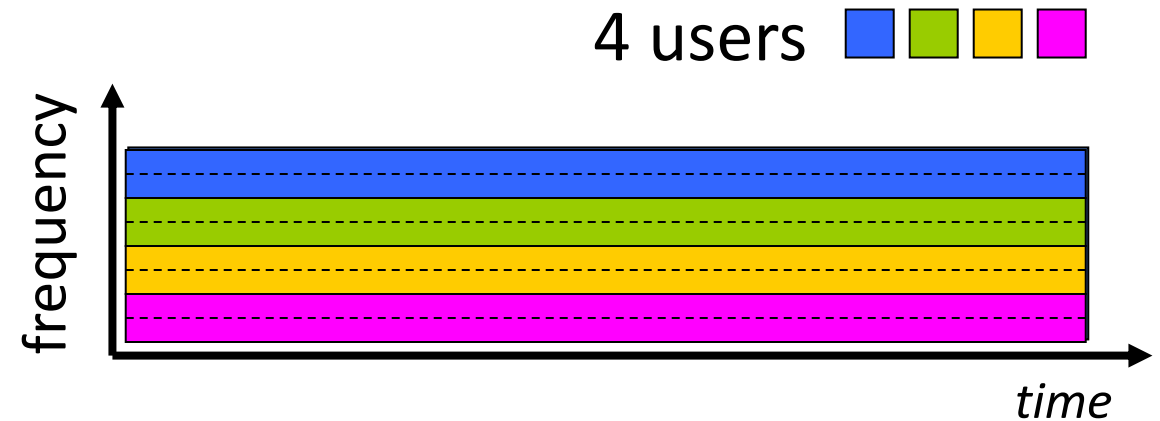
example:

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

N users

1 Gbps link
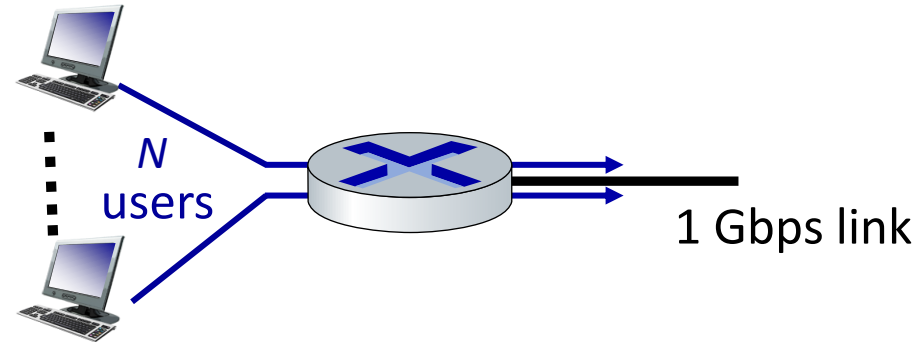
*Q:* how many users can use this network under circuit-switching and packet switching?

- *circuit-switching:* 10 users

- *packet switching:* with 35 users, probability > 10 active at same time is less than .0004 * (problem 8 from the text book)

- hosts connect to Internet via access Internet Service Providers (ISPs)

- access ISPs in turn must be interconnected
  - so that *any* two hosts *(anywhere!)* can send packets to each other

- resulting network of networks is very complex
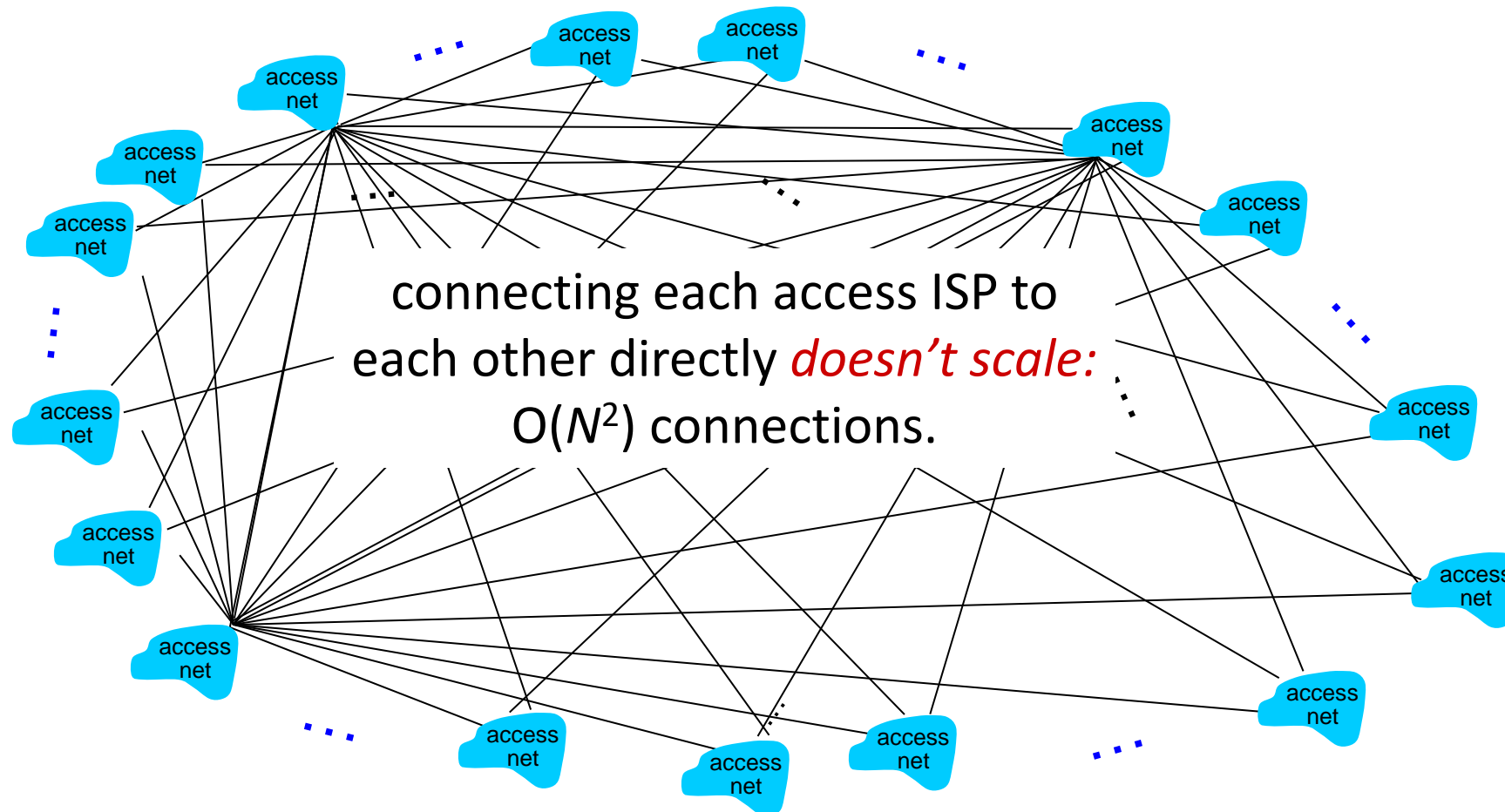 - evolution driven by economics, national policies
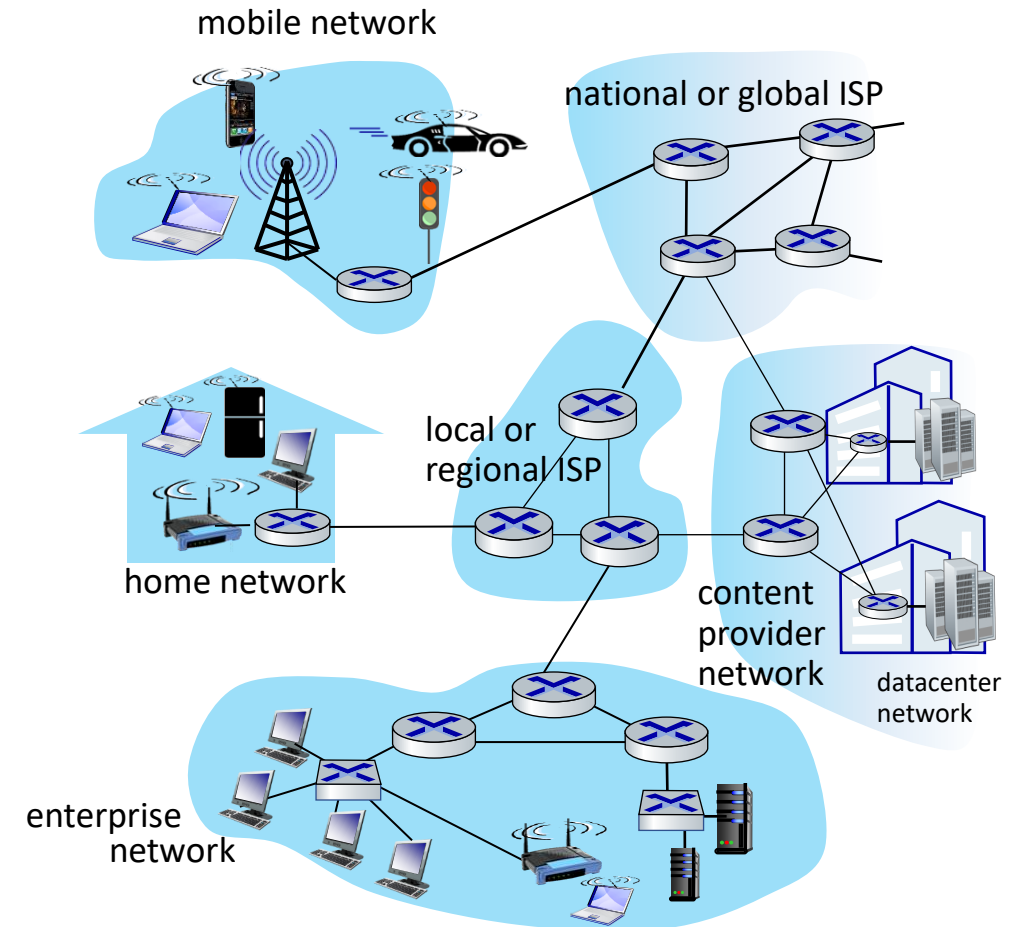
Let's take a stepwise approach to describe current Internet structure

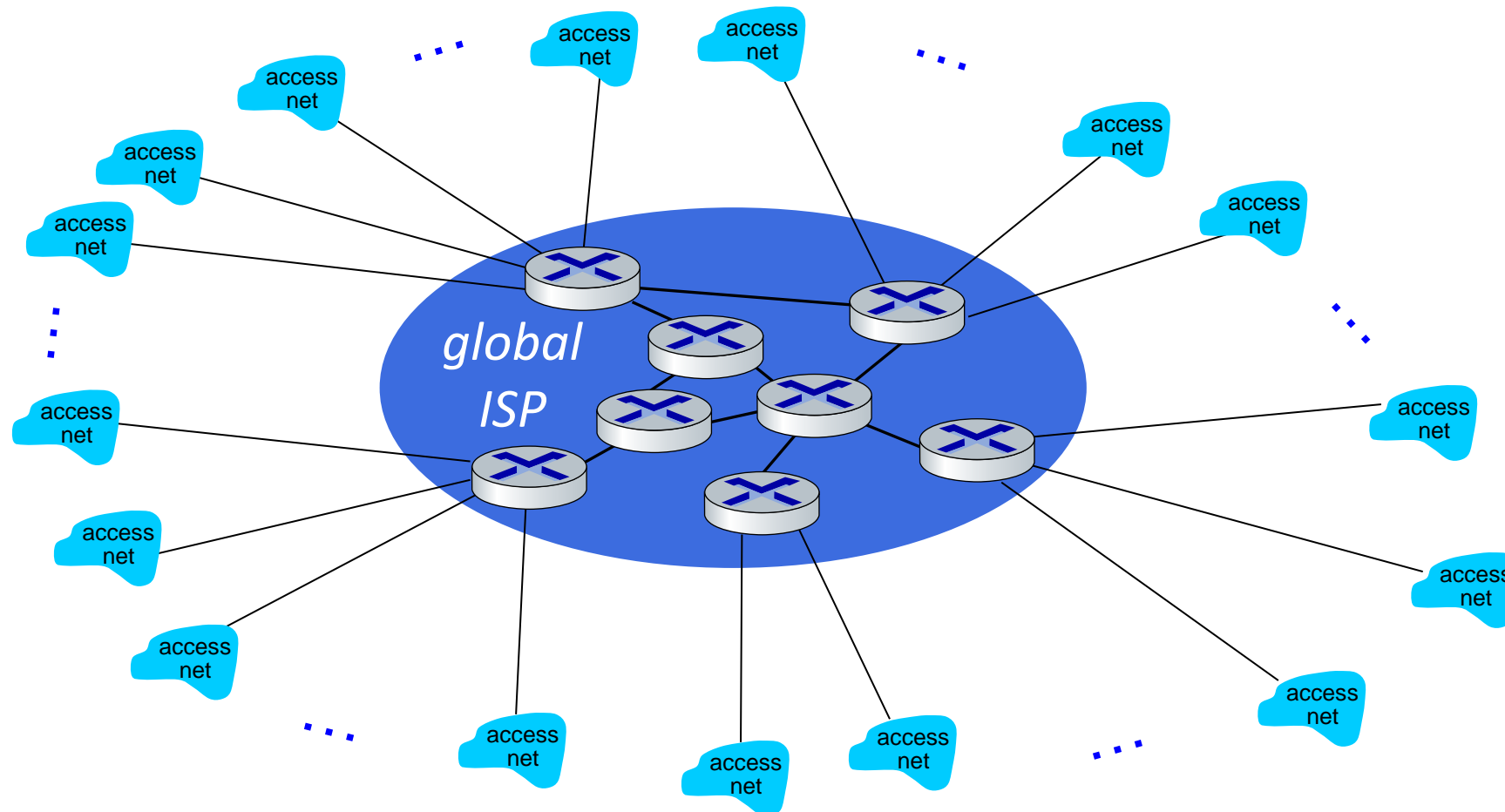*Question:* given *millions* of access ISPs, how to connect them together?

Question: given *millions* of access ISPs, how to connect them together?
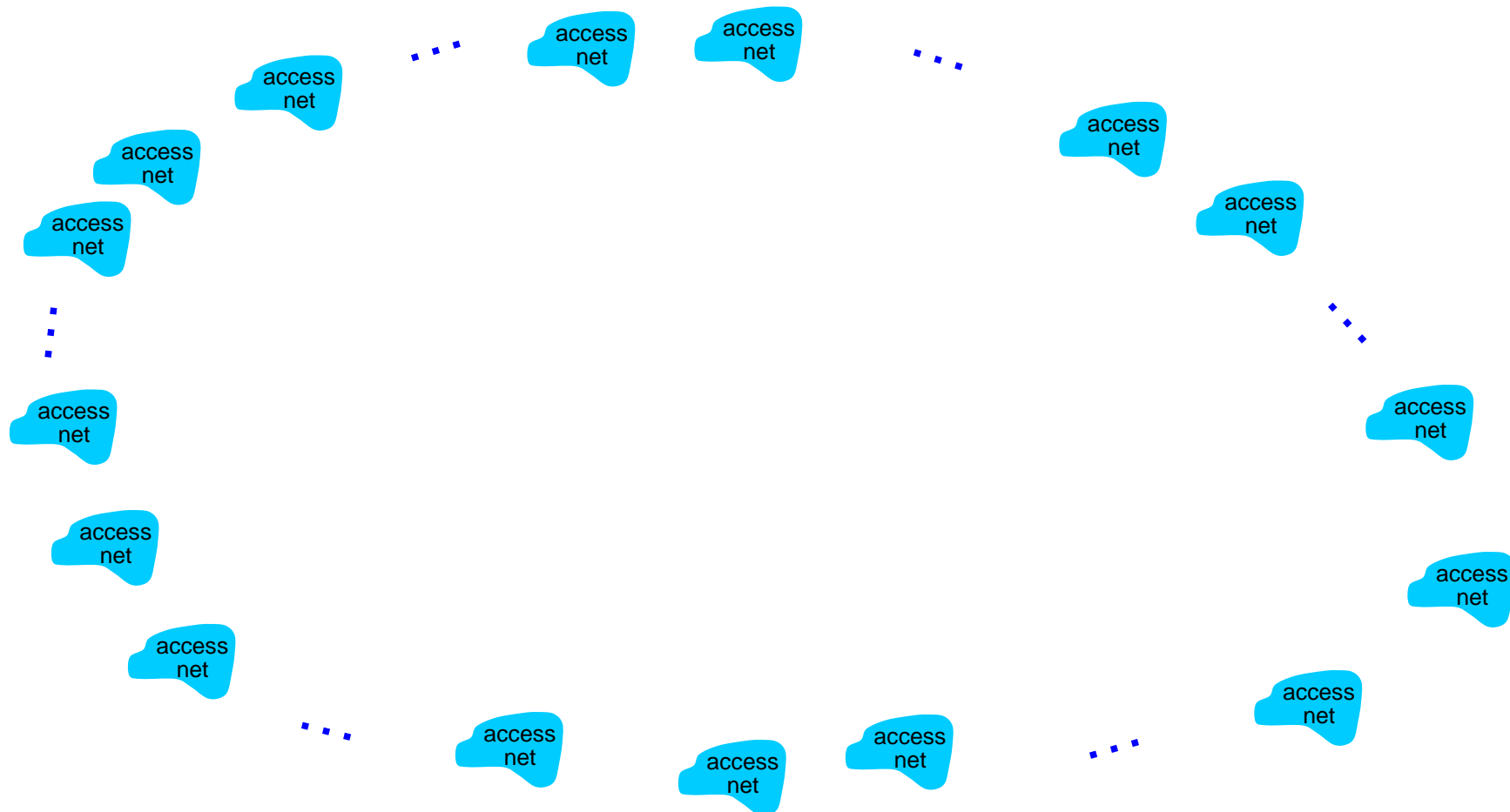
connecting each access ISP to
each other directly *doesn't scale:*
O(N^2) connections.

Option: connect each access ISP to one global transit ISP?
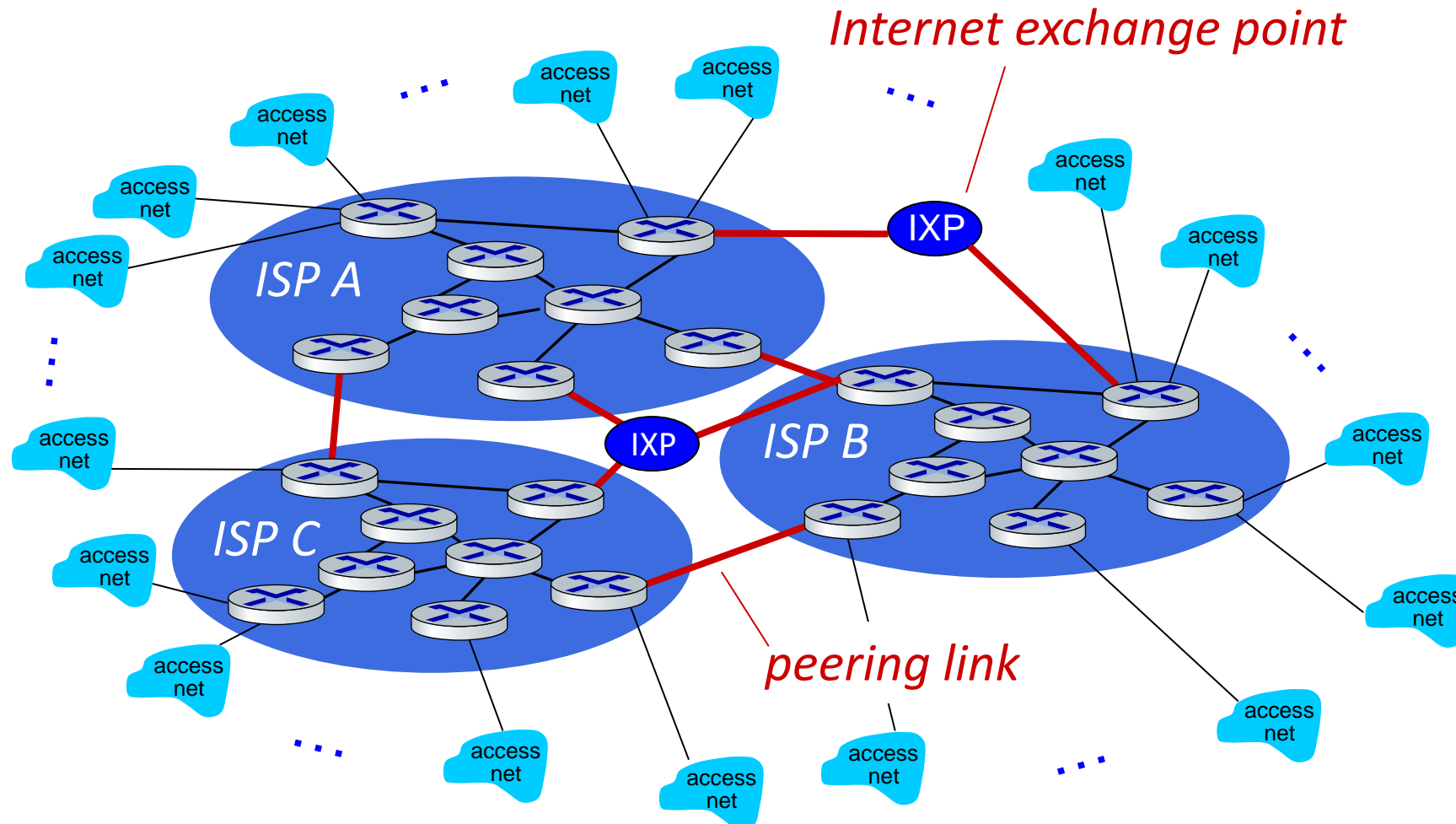*Customer* and *provider* ISPs have economic agreement.

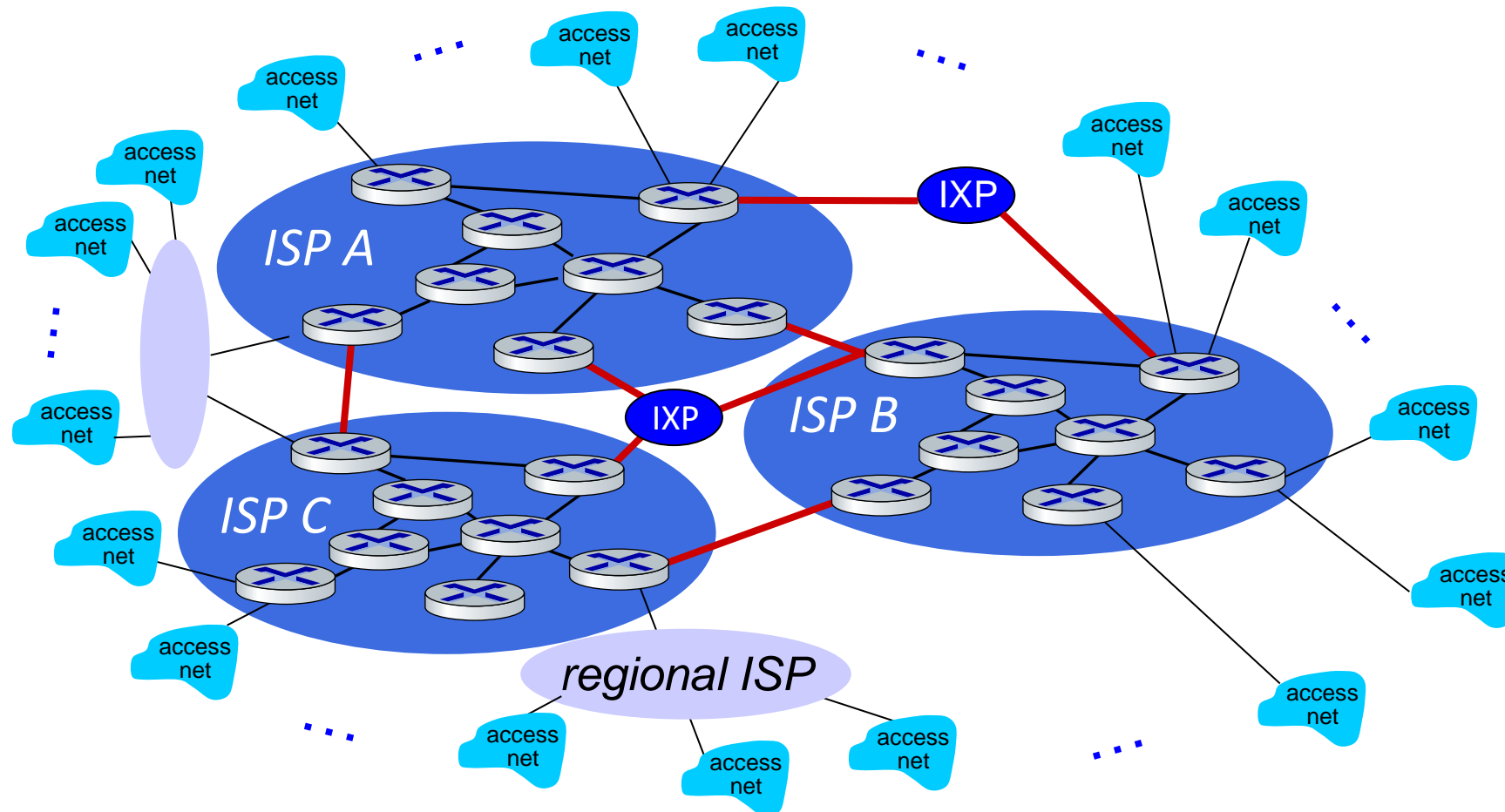But if one global ISP is viable business, there will be competitors ….
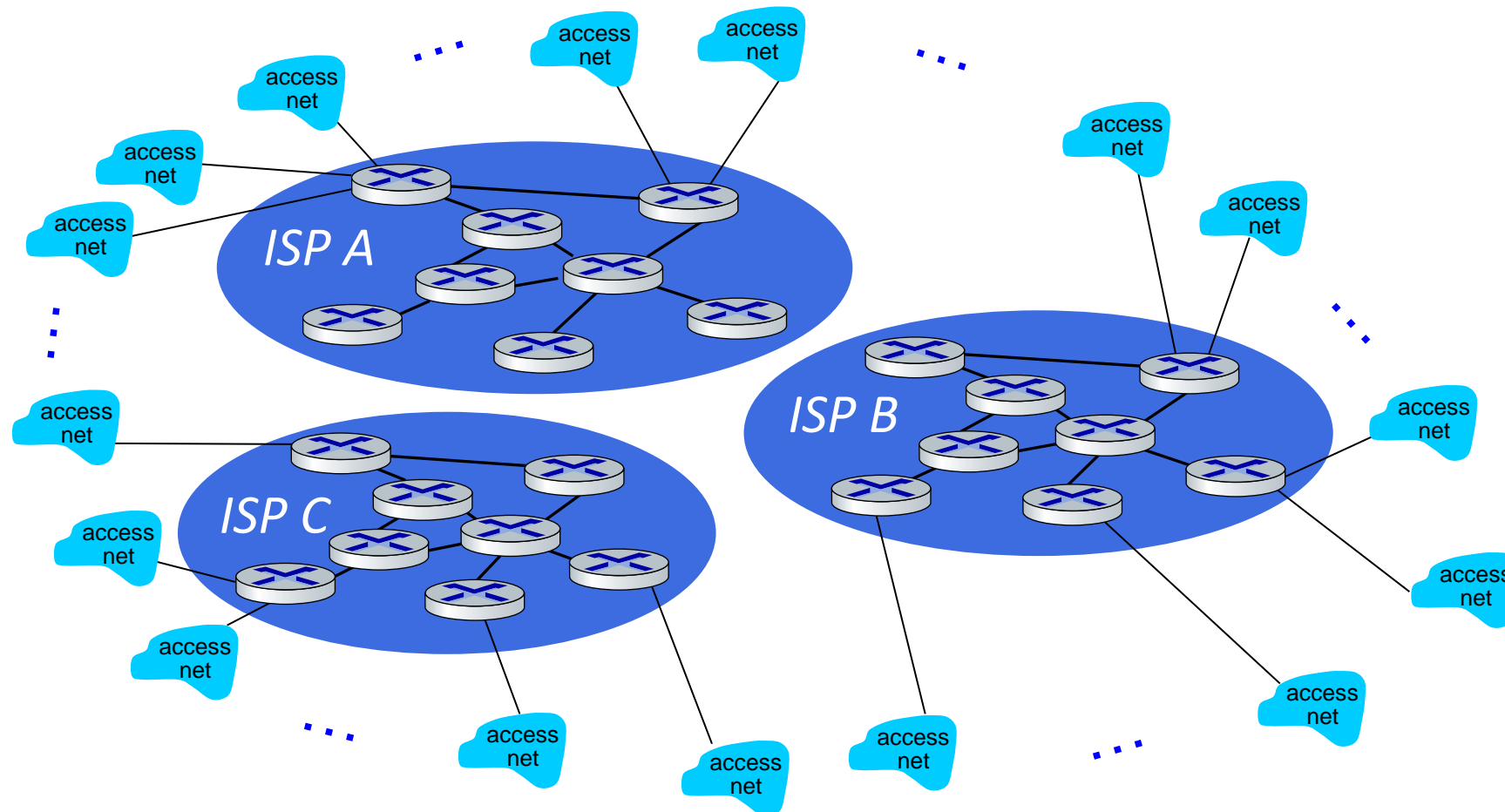
But if one global ISP is viable business, there will be competitors …. who will want to be connected
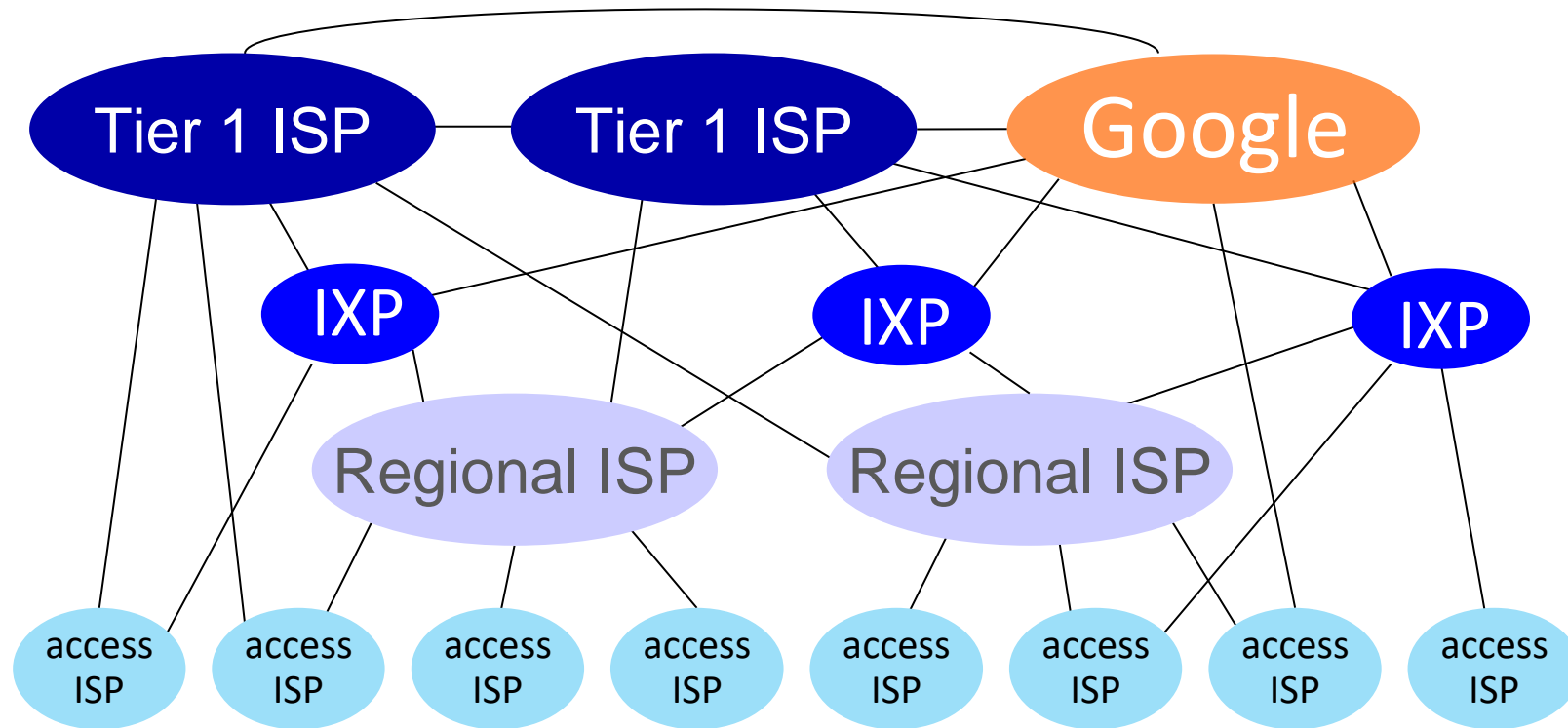

Internet exchange point

peering link

… and regional networks may arise to connect access nets to ISPs

… and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users
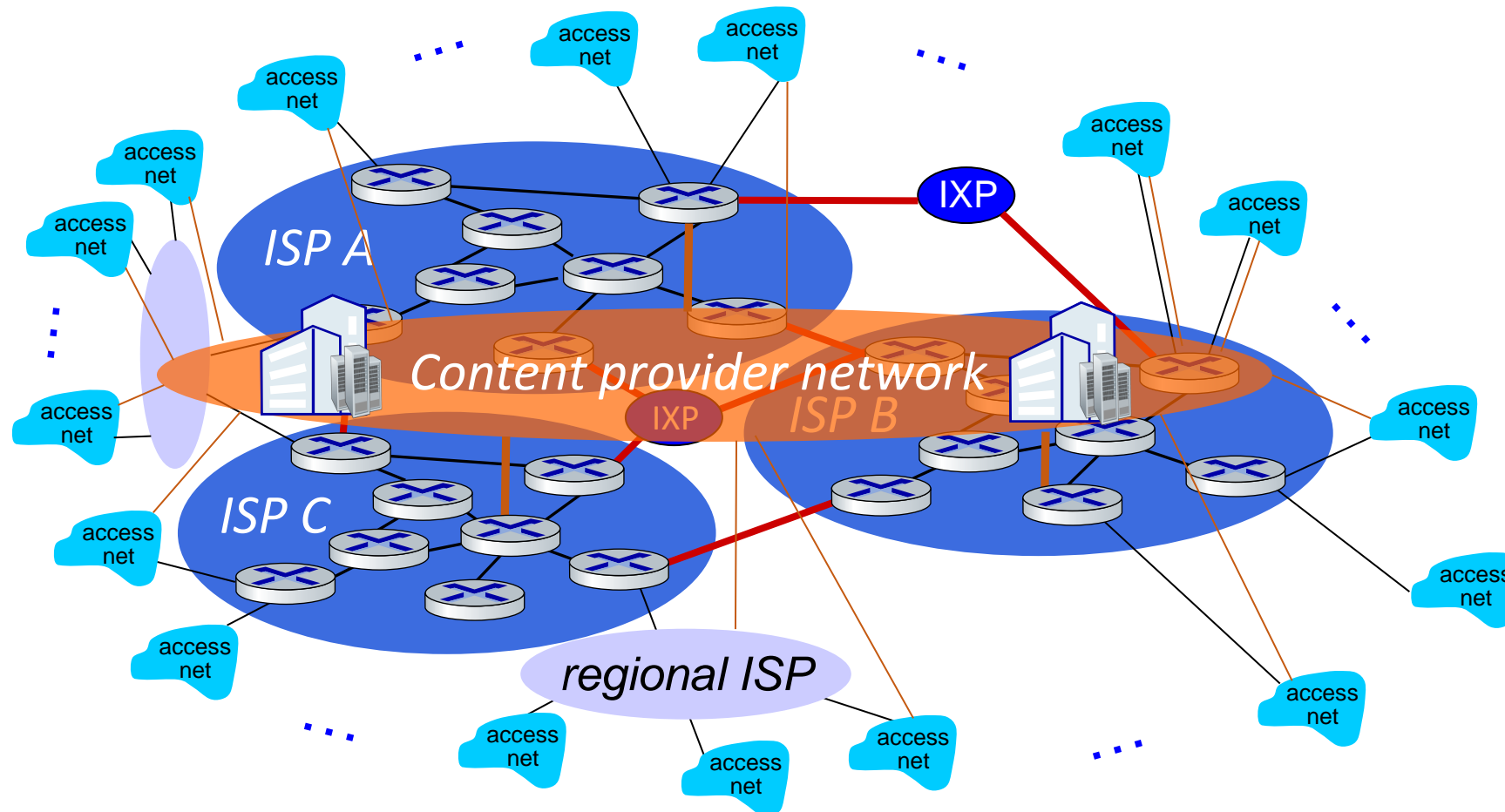
At "center": small # of well-connected large networks

- "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
- content provider networks (e.g., Google, Facebook): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs