Universidad Rey Juan Carlos

Computer Networks

Biomedical Engineering

GSyC Department - September 2018

Chapter 1 Introduction

These slides have been adapted from …

Computer Networking: A Top Down Approach

7th edition

Jim Kurose, Keith Ross

Pearson/Addison Wesley

April 2016

Chapter 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, physical links

1.3 network core

- packet/circuit switching, network structure

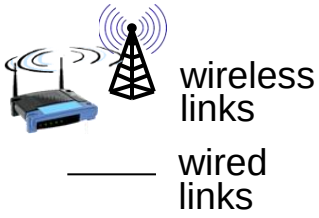
1.4 protocol layers, service models

our goal:

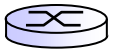
- get "feel" and terminology
- more depth, detail *later* in course
- approach: use Internet as example

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

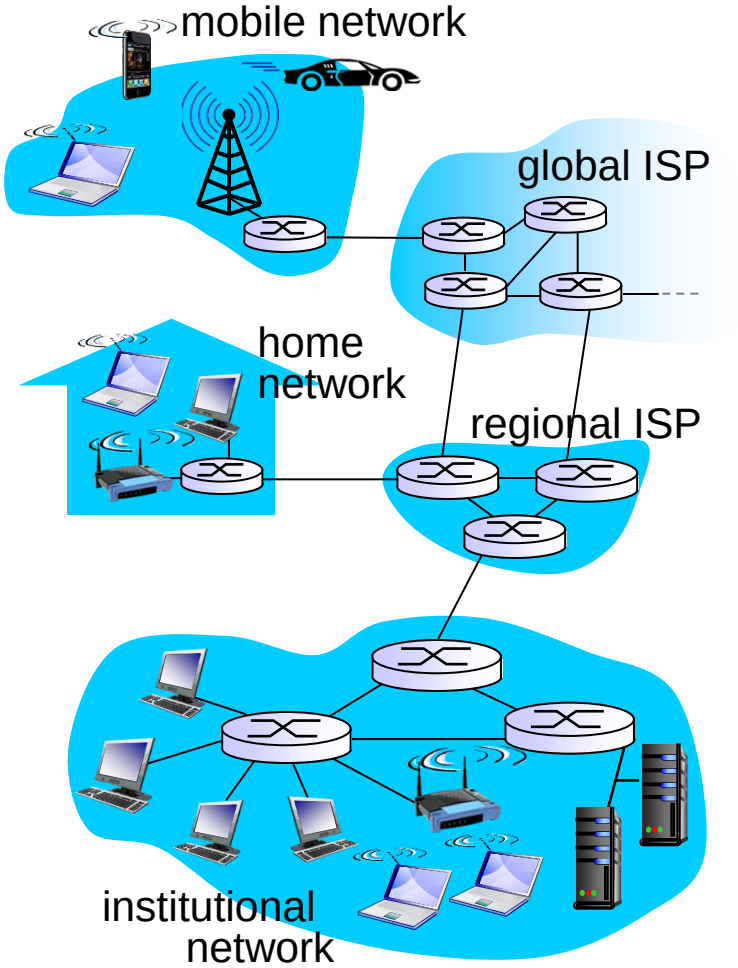
- millions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*



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

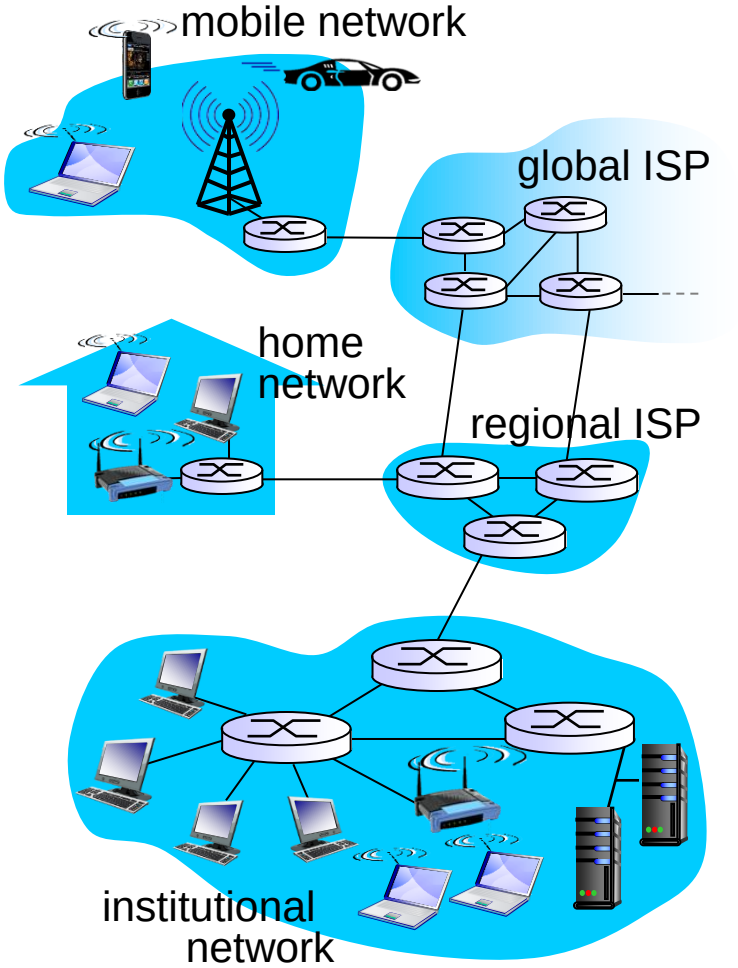


- *packet switching devices:* forward packets (chunks of data)
  - *routers* and *switches*

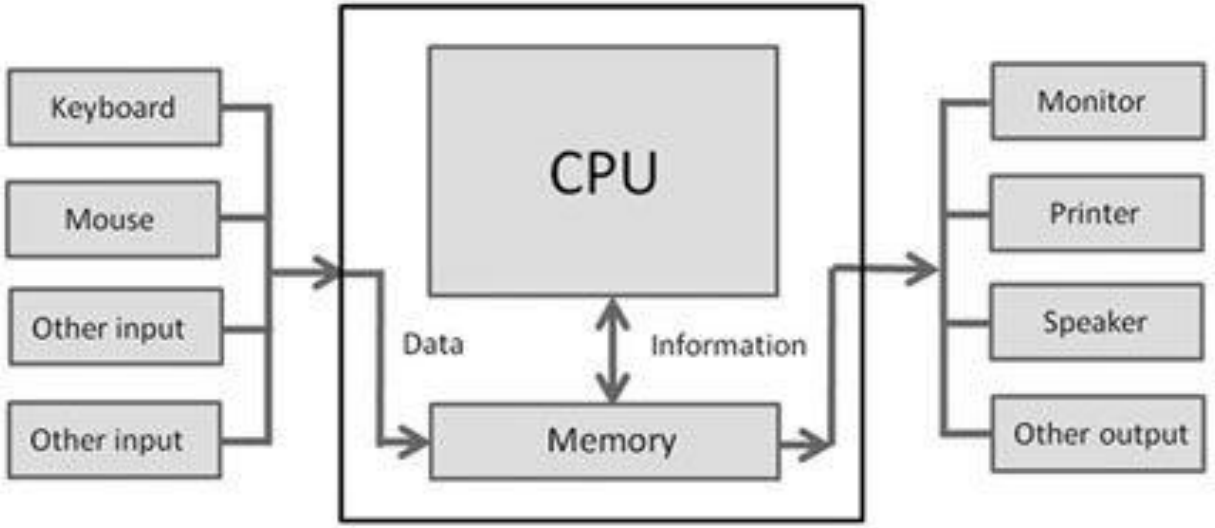


What's the Internet: "nuts and bolts" view

- *Internet:* "network of networks"
  - Interconnected ISPs
- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Ethernet, …
- *Internet standards*
  - RFC: Request for comments: publication by tech community
  - IETF: Internet Engineering Task Force: open standards organization



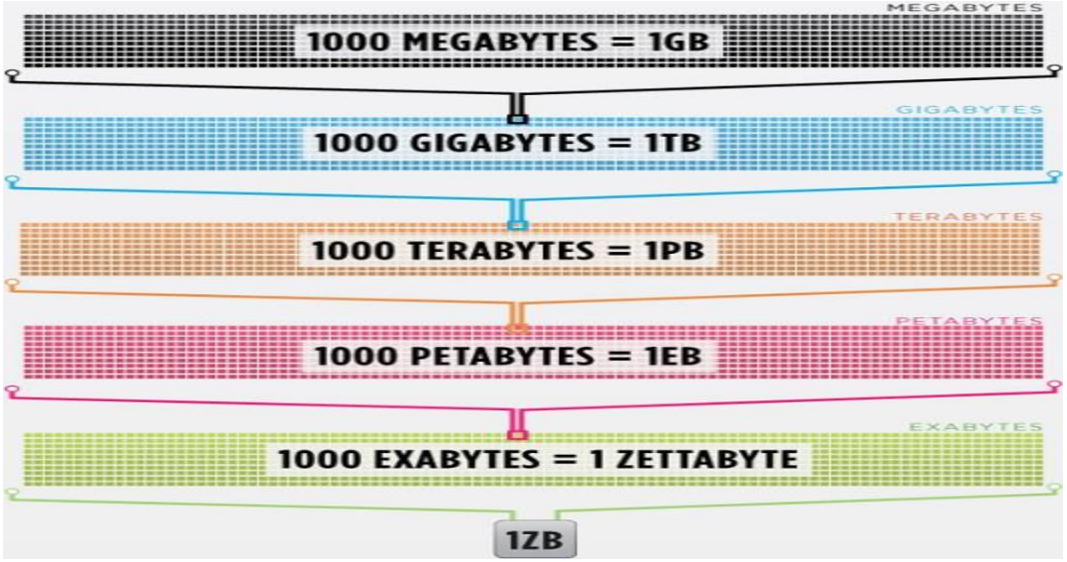
What's a computer?



- Electronic device that receives data (*input*), processes it according to a sequence of instructions (*program*) and produces a result (*output*) in the form of information
- An important I/O device is the *Network Interface Card*, that allows exchanging information with other computers

What's a computer?

- Computers use the **binary system** internally
- *Bit*: Binary digit. Only two values allowed: 0/1
- *Byte*: Group of 8 bits operated on as a single unit
- *Word*: natural unit of data used by a particular processor design, handled as a unit by processor HW (8,16,32,64,…)
- 1000 BYTES = 1 KB, 1000 KB = 1 MB, …



"Fun" internet appliances

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

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

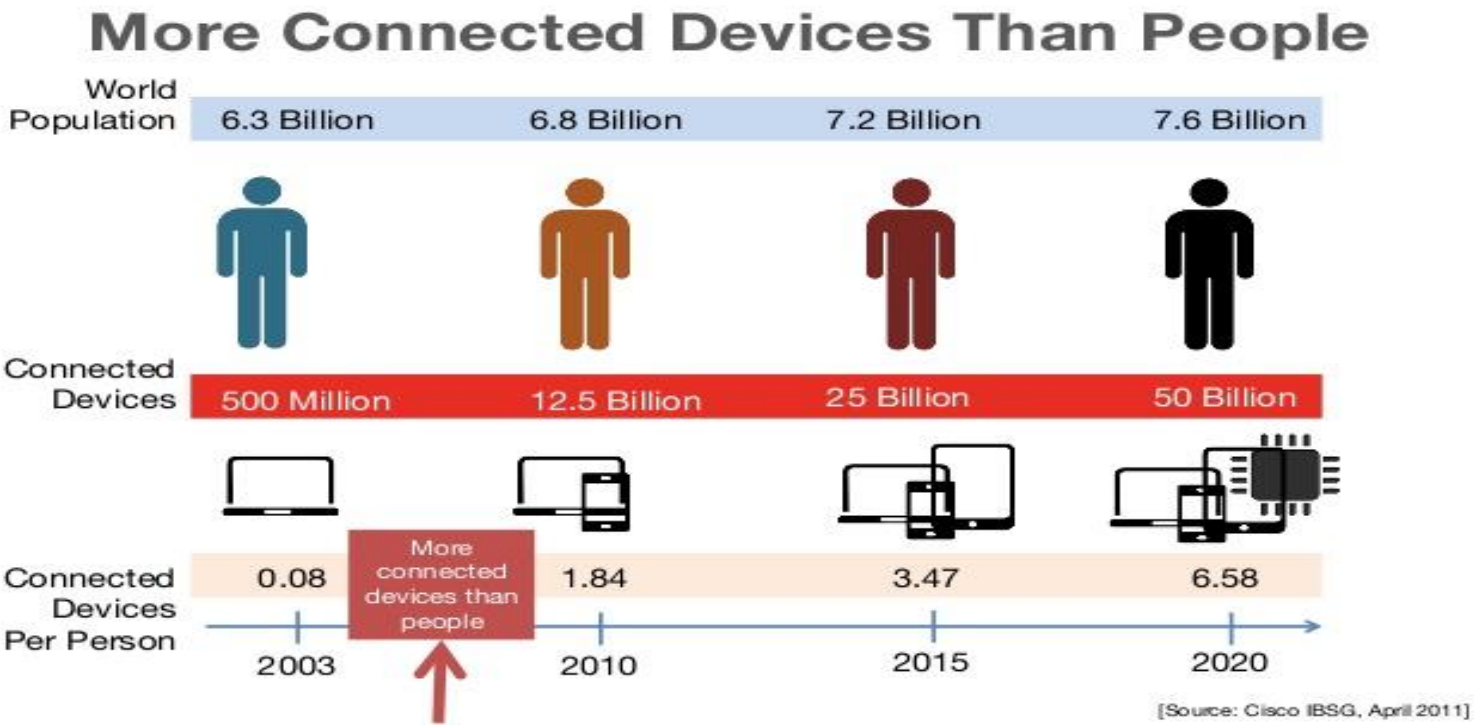
Internet
refrigerator

Slingbox: watch,
control cable TV remotely

Internet phones

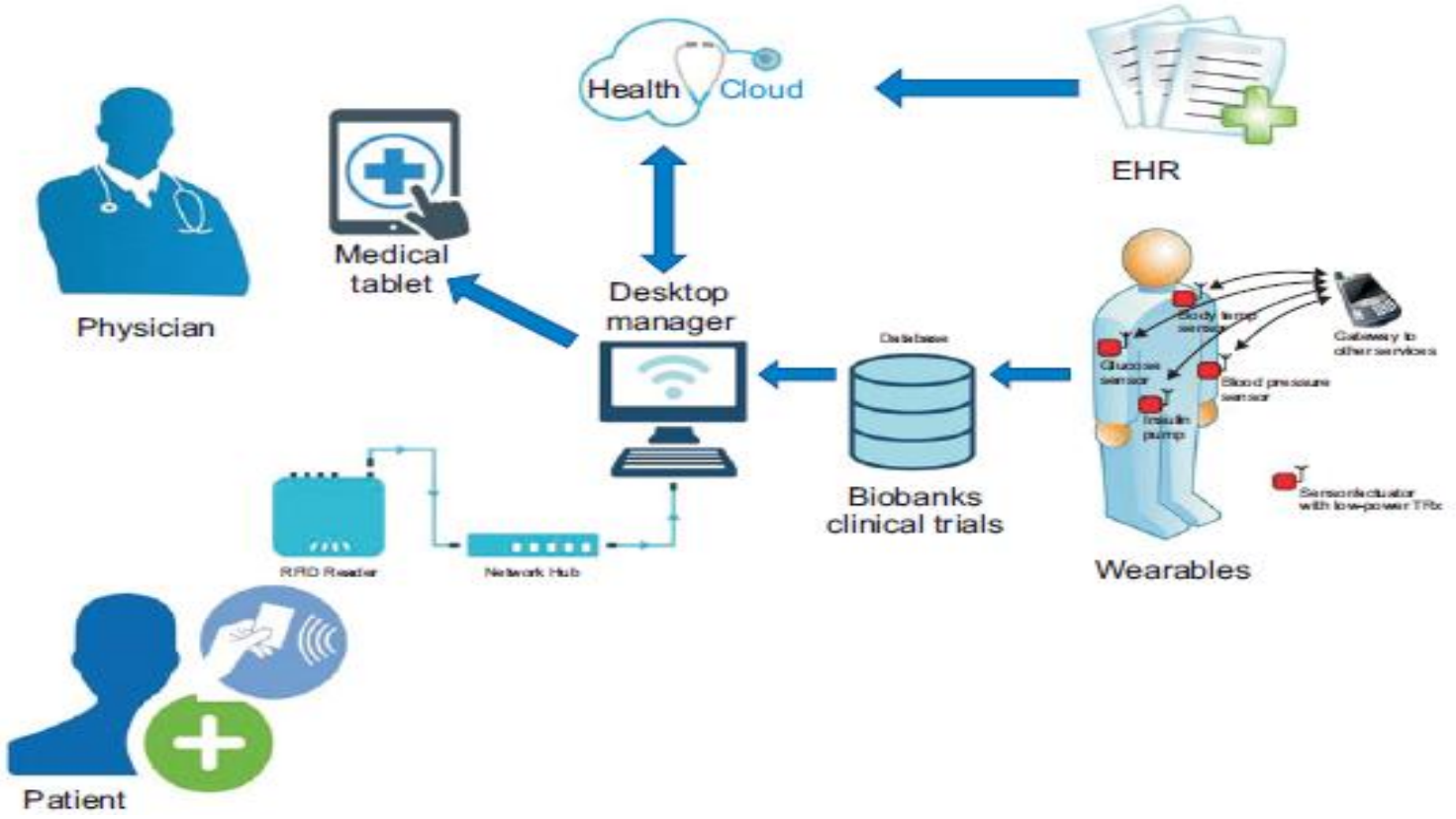
Internet of Things

- **IoT**: network of physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, actuators, and **connectivity** which enables these things to connect and exchange data



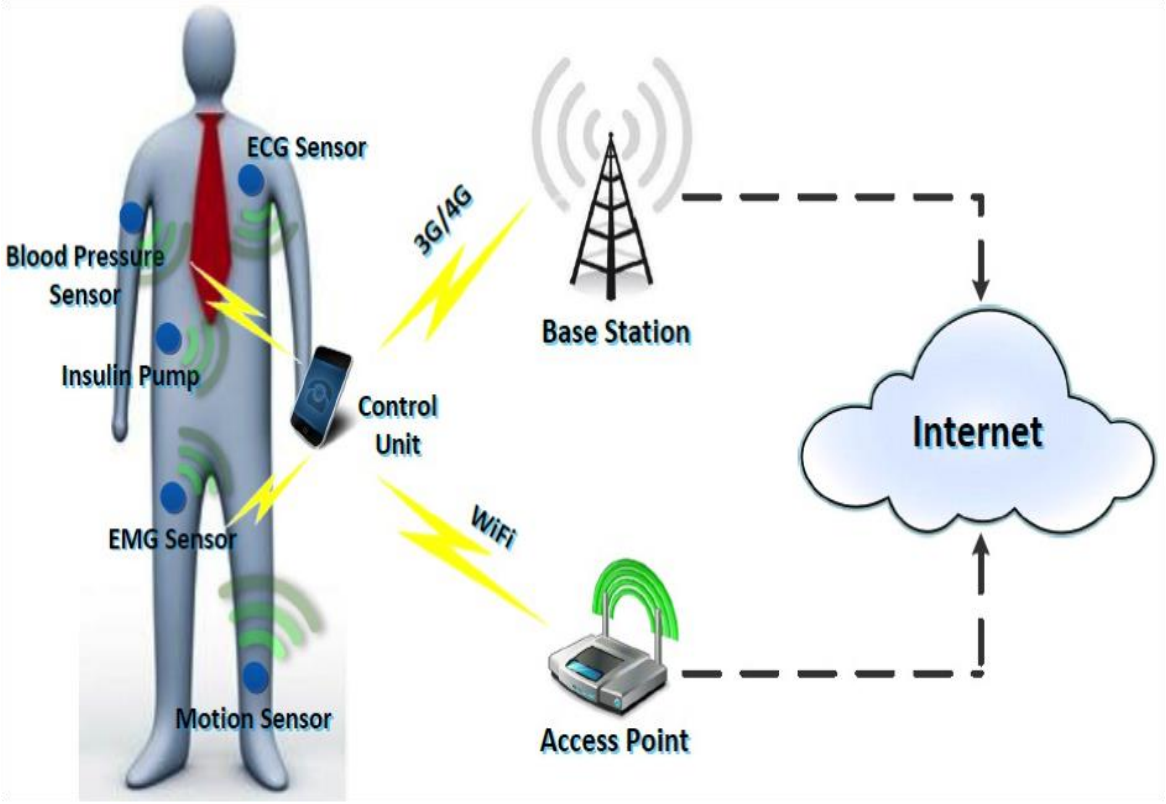
Internet of (Medical) Things

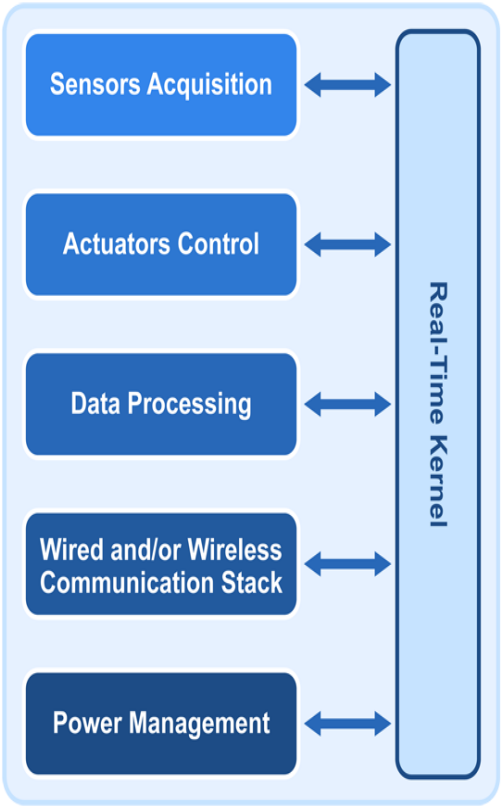
- collection of medical devices and applications that connect to healthcare IT systems through online computer networks



Body Area Networks

- WBAN: wireless network of wearable computing devices

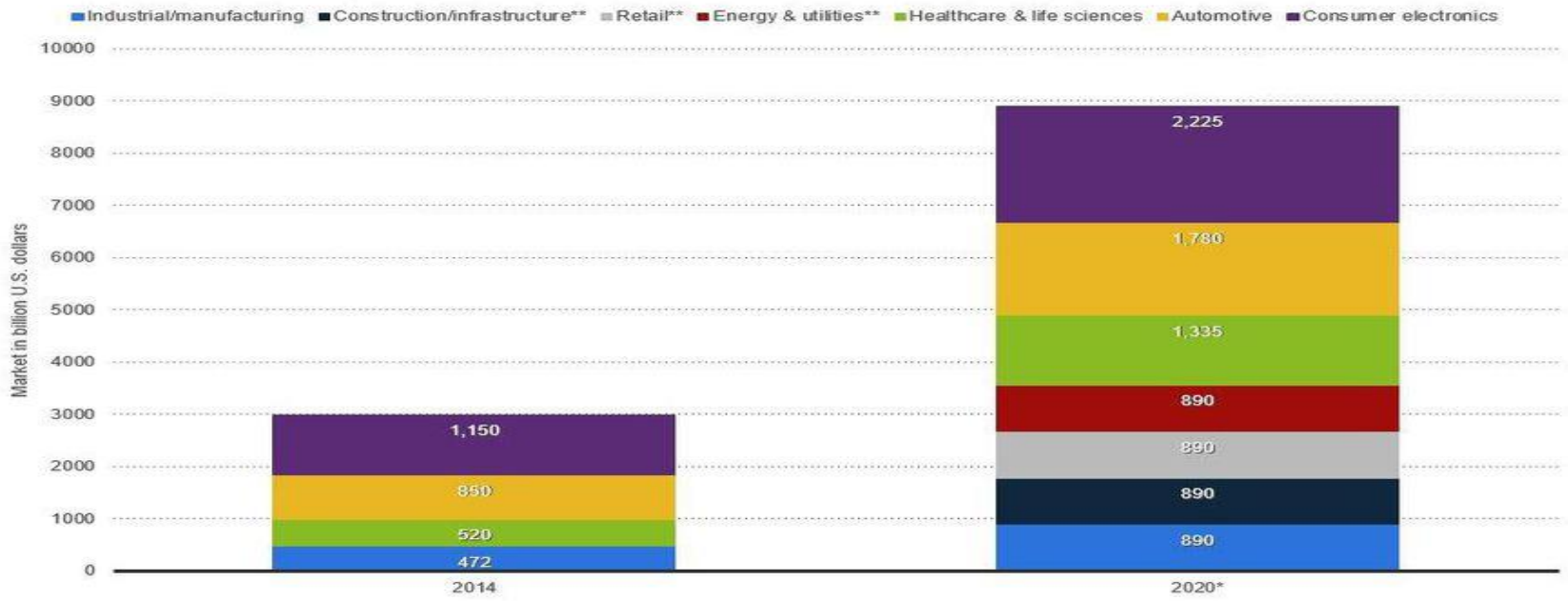




Dec. 2017 IoT forecasts

- The global IoT market is projected to grow from $2.99T in 2014 to $8.9T in 2020, attaining a 19.92% CAGR

Size of the Internet of Things market worldwide in 2014 and 2020, by industry (in billion U.S. dollars)

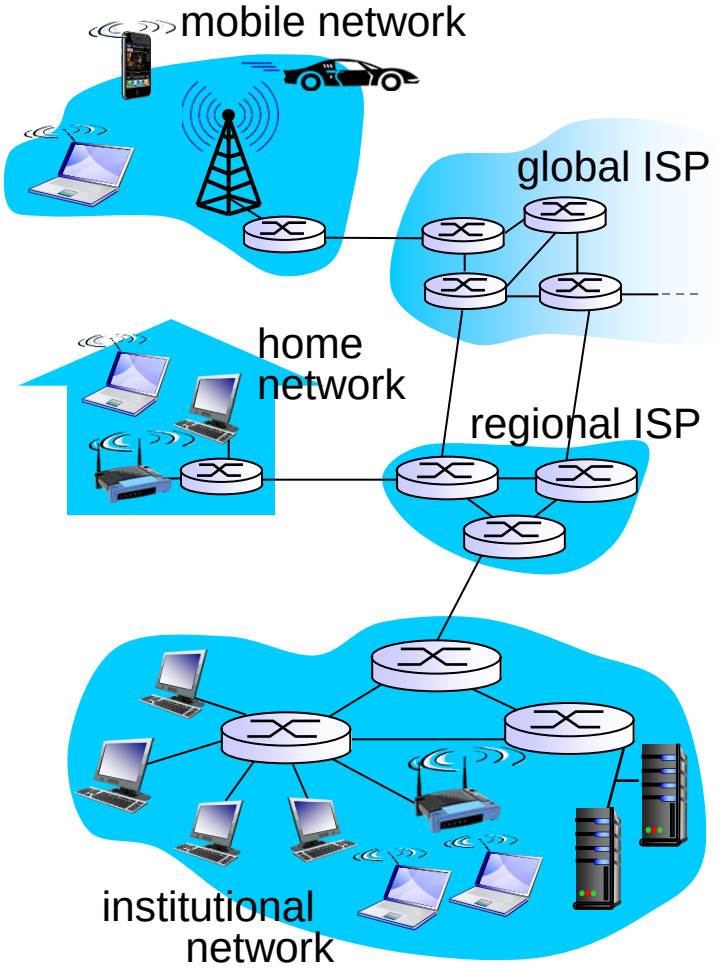


Big Data in healthcare

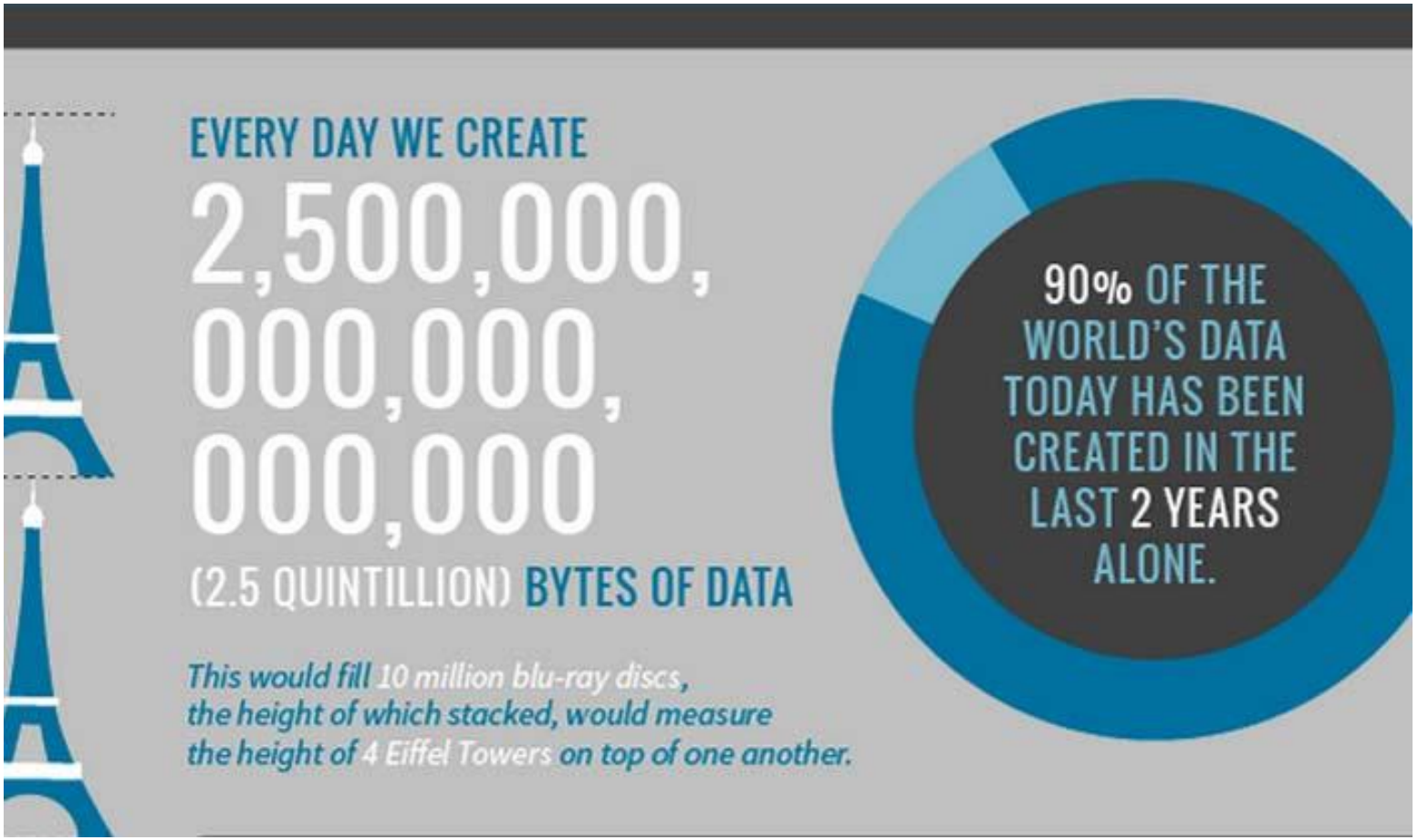
- Patients predictions for an improved staffing
- Real-Time Alerting (e.g. blood pressure increase)
- Using Health Data For Informed Strategic Planning ("heat maps")
- Predictive Analytics (e.g. predict risk of diabetes)
- Telemedicine
- Integrating Big Data With Medical Imaging (algorithms analyze images)
- Electronics Health Records
- Big Data Might Just Cure Cancer
- …

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



What's the Internet: a service view



What's a protocol?

human protocols:

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

… specific msgs sent

… specific actions taken when msgs received, or other events

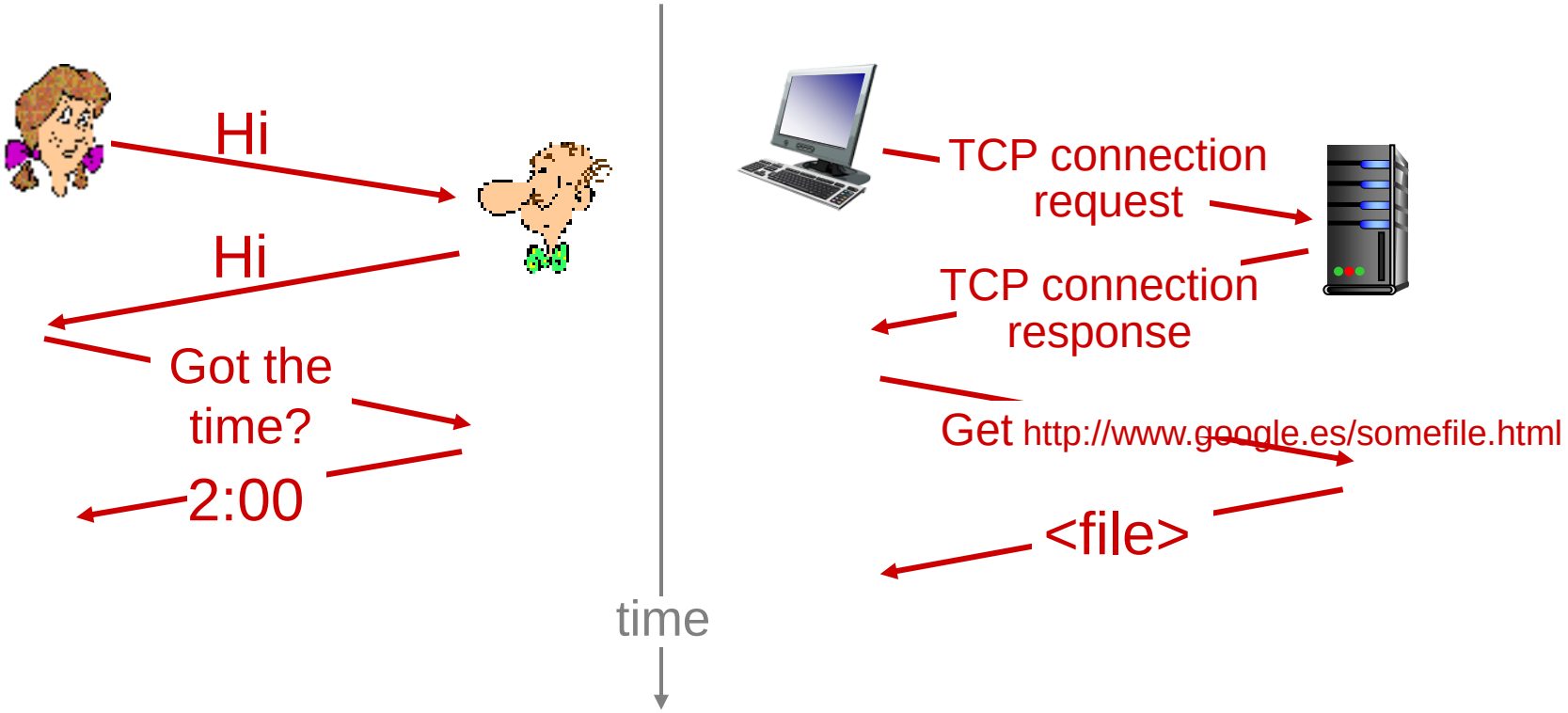
network protocols:

- 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:



Chapter 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

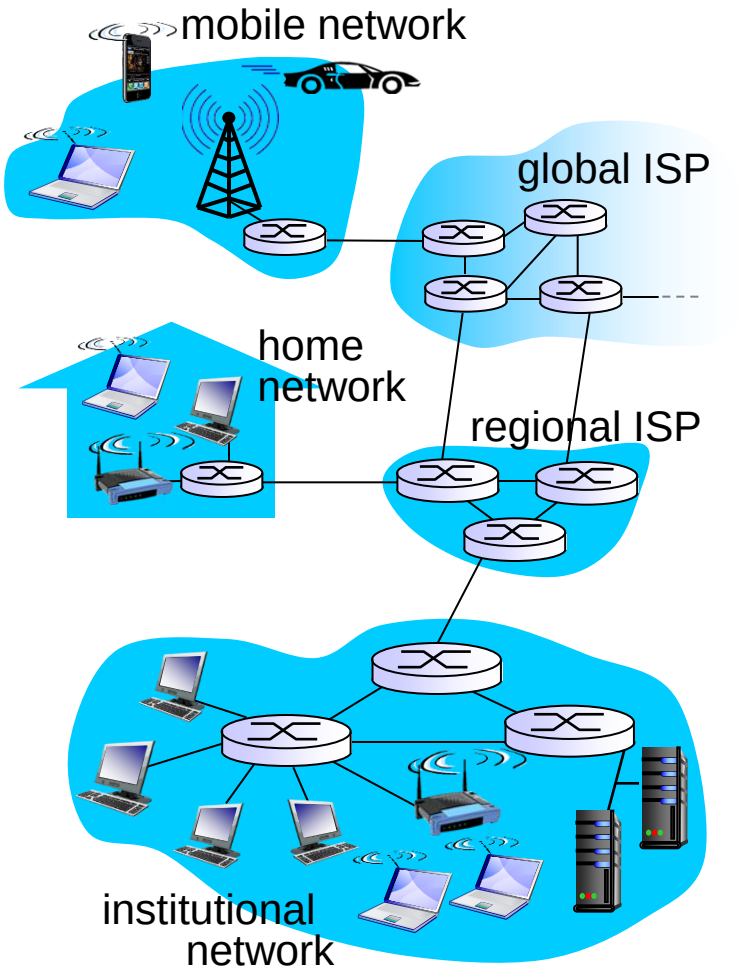
- packet switching, circuit switching, network structure

1.4 protocol layers, service models

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
- *Q: network topologies?*

  Star, ring, mesh, bus, …



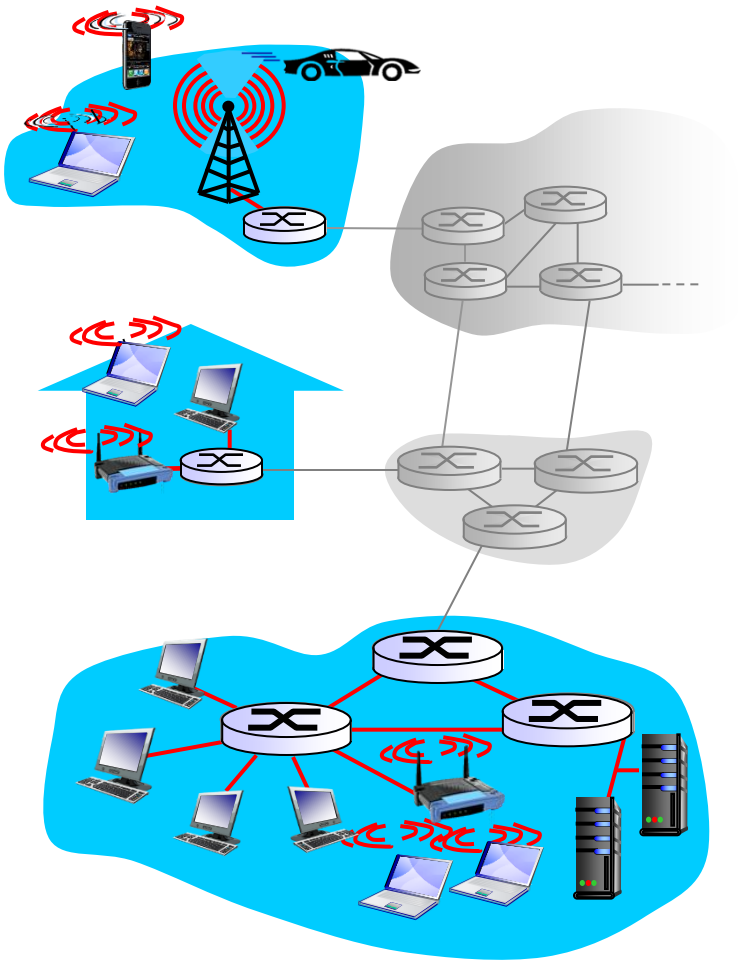
Access networks and physical media

Q: How to connect end systems to edge router?

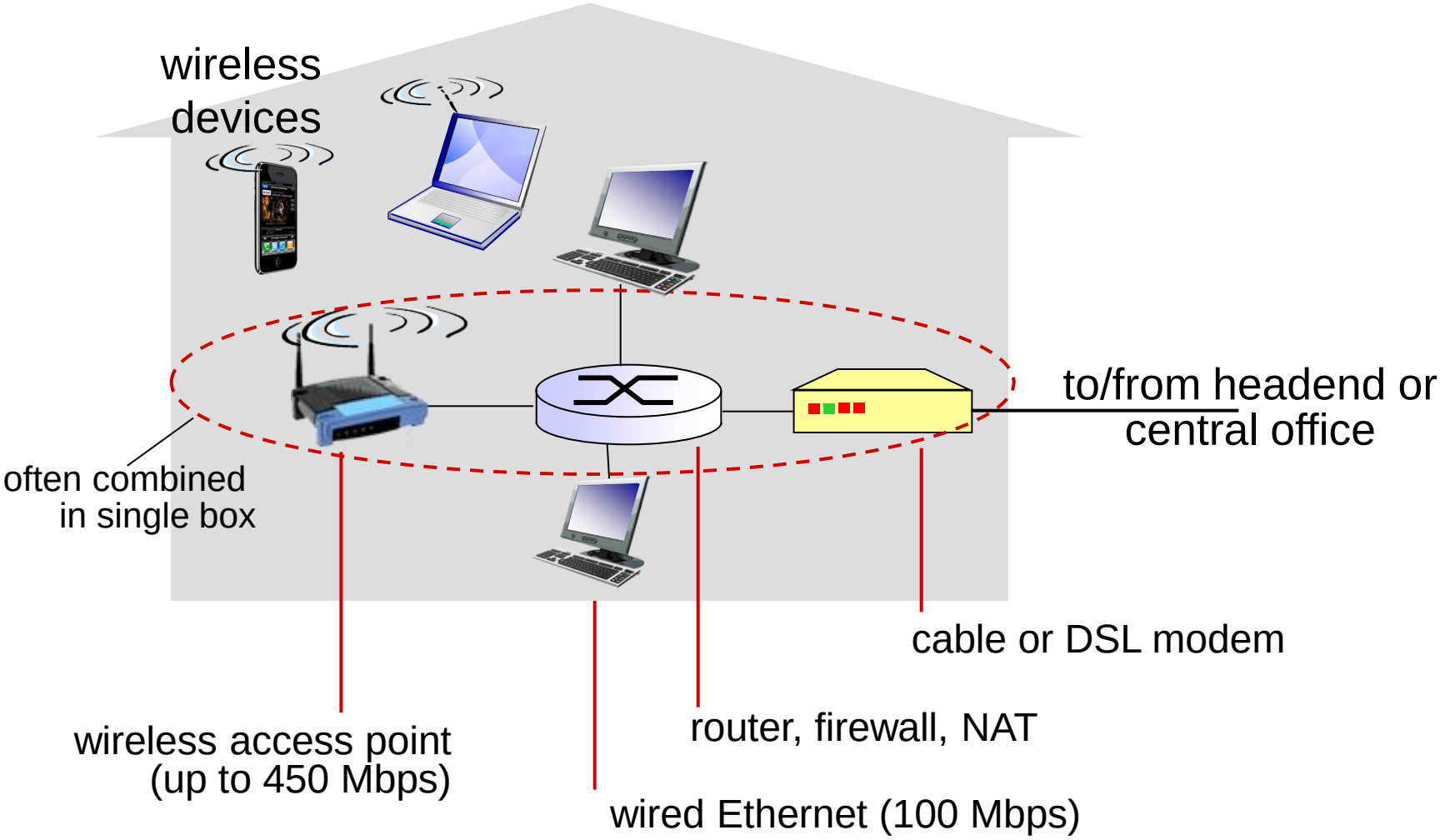
- residential access nets
- institutional access networks (school, company)
- mobile access networks

keep in mind:

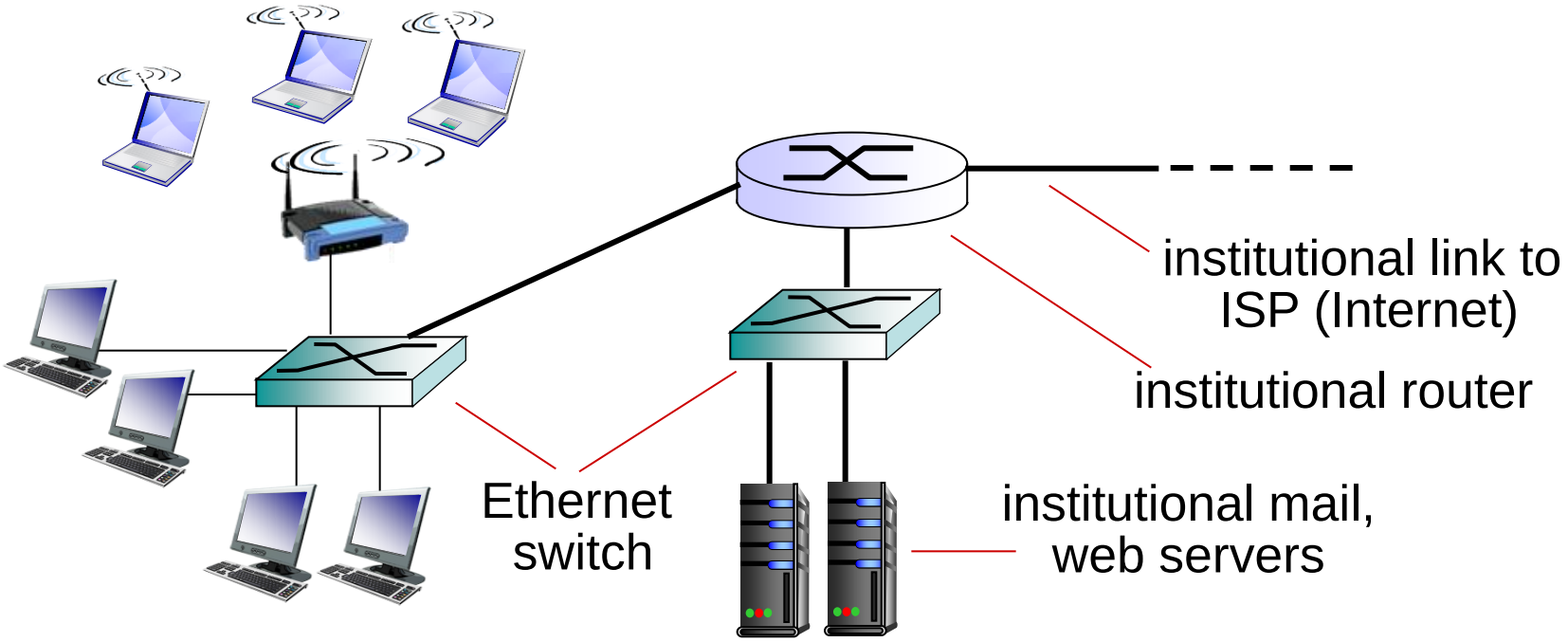
- bandwidth (bits per second) of access network?
- shared or dedicated?



Access net: home network



Enterprise access networks (Ethernet)



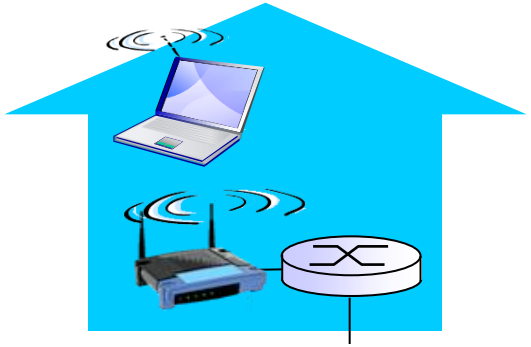
- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

Wireless access networks

- shared *wireless* access network connects end system to router
  - via base station aka "access point"

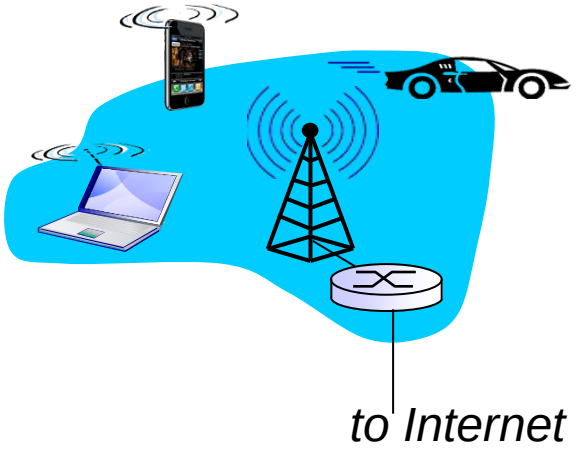
wireless LANs:

- within building (100 ft)
- 802.11a/b/g/n (WiFi): up to 450Mbps

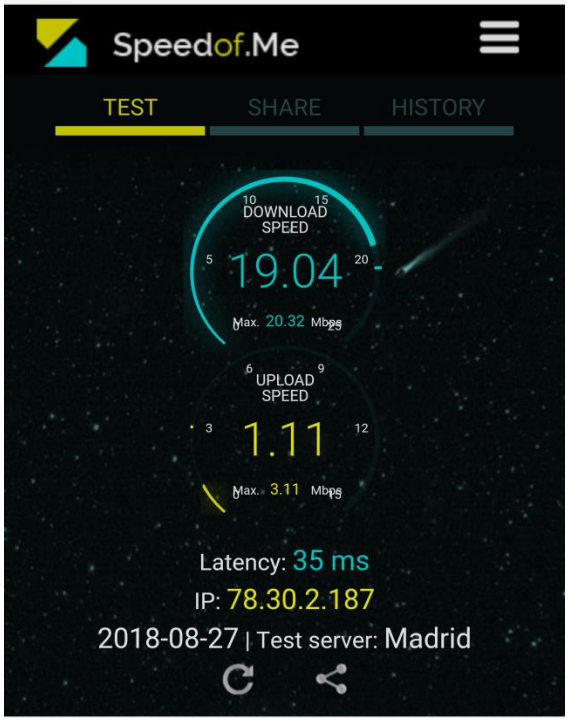


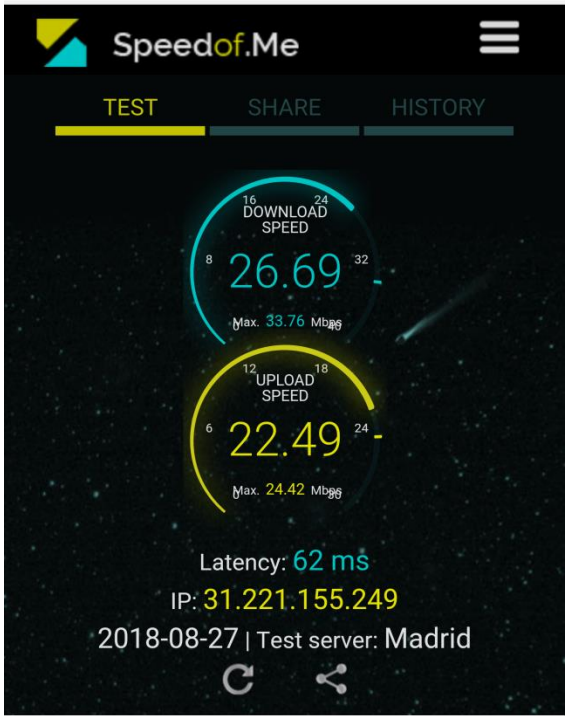
wide-area wireless access

- provided by telco (cellular) operator, 10's km
- up to 100 Mbps
- 3G, 4G: LTE



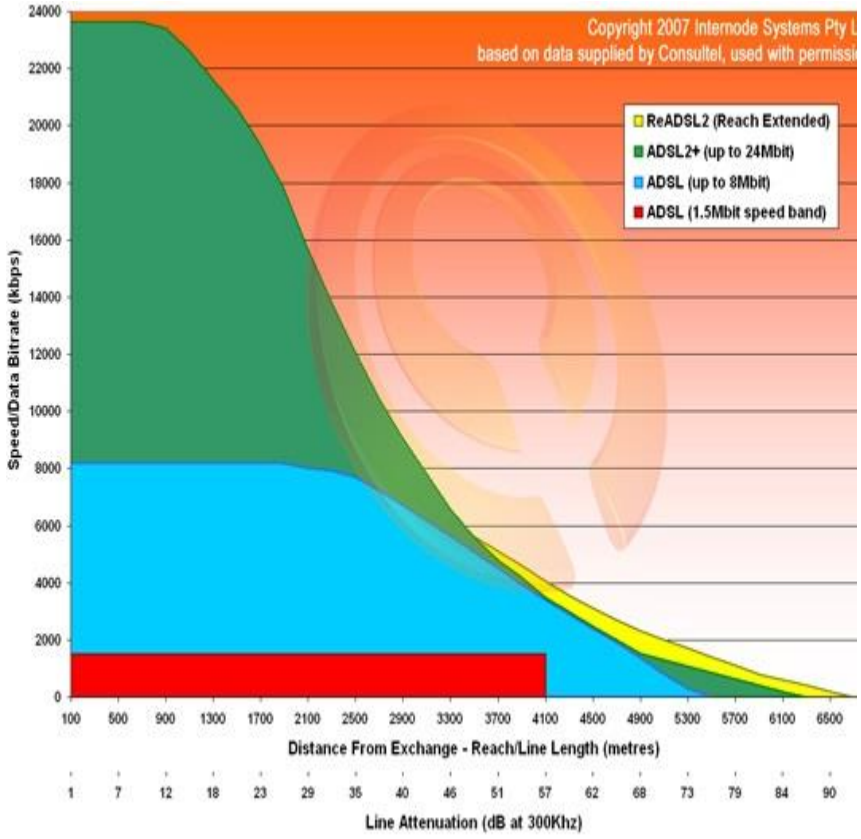
A guess game: Wi-Fi vs 4G





A guess game: Wi-Fi vs 4G

- ***Hint:*** 300Mbps Wireless N ADSL2+ Modem Router



Symbol	Standard	Full Name	Maximum Download Speed (Theoretical)	Maximum Upload Speed (Theoretical)
2G	GSM	Global System for Mobile Communications	14.4 Kbits/s	14.4 Kbits/s
G	GPRS	General Packet Radio Service	53.6 Kbits/s	26.8 Kbits/s
E	EDGE	Enhanced Data rates for GSM Evolution	217.6 Kbits/s	108.8 Kbits/s
3G	UMTS	Universal Mobile Telecommunications System	384 Kbits/s	128 Kbits/s
H	HSPA	High-Speed Packet Access	7.2 Mbits/s	3.6 Mbits/s
H+	HSPA+	Evolved High-Speed Packet Access - Release 6	14.4 Mbits/s	5.76 Mbits/s
H+	HSPA+	Evolved High-Speed Packet Access - Release 7	21.1 Mbits/s or 28.0 Mbits/s	11.5 Mbits/s
H+	HSPA+	Evolved High-Speed Packet Access - Release 8	42.2 Mbits/s	11.5 Mbits/s
H+	HSPA+	Evolved High-Speed Packet Access - Release 9	84.4 Mbits/s	11.5 Mbits/s
H+	HSPA+	Evolved High-Speed Packet Access - Release 10	168.8 Mbits/s	23.0 Mbits/s
4G	LTE	Long Term Evolution	100 Mbits/s	50 Mbits/s
4G	LTE-A	Long Term Evolution - Advanced	1 Gbits/s	500 Mbits/s

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

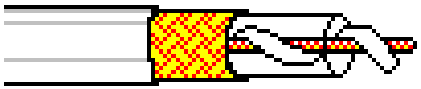
twisted pair (TP)

- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gpbs Ethernet
  - Category 6: 10Gbps

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 .. 450 Mbps
- wide-area (e.g., cellular)
  - 3G/4G cellular: up to 100 Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

Chapter 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

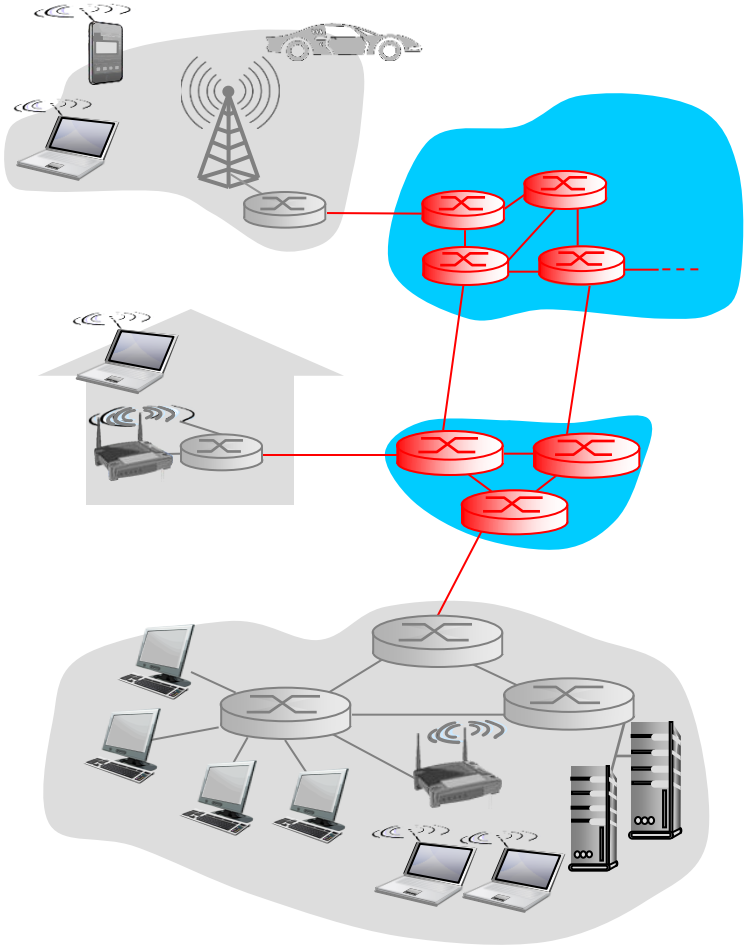
1.3 network core

- packet switching, circuit switching, network structure

1.4 protocol layers, service models

The network core

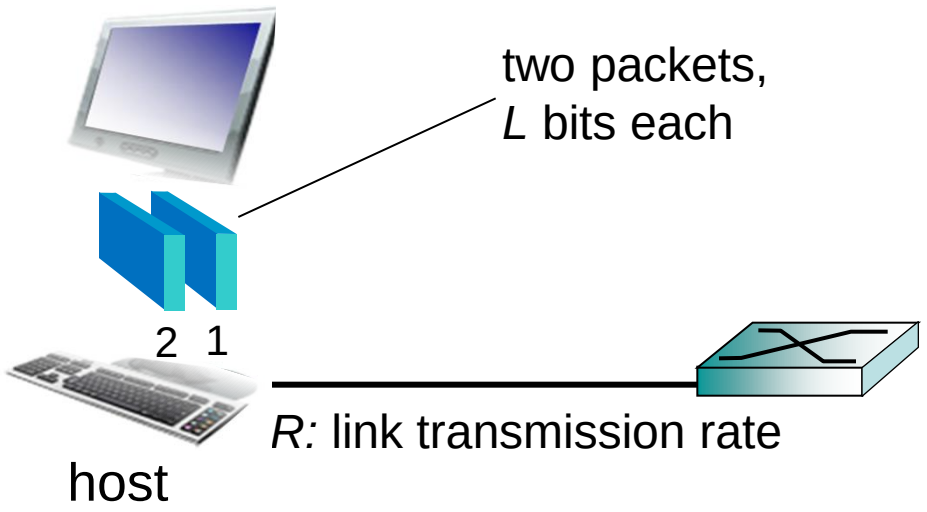
- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into *packets*
  - forward packets from one router to the next, across links on path from source to destination
  - each packet transmitted at full link capacity



Host: sends *packets* of data

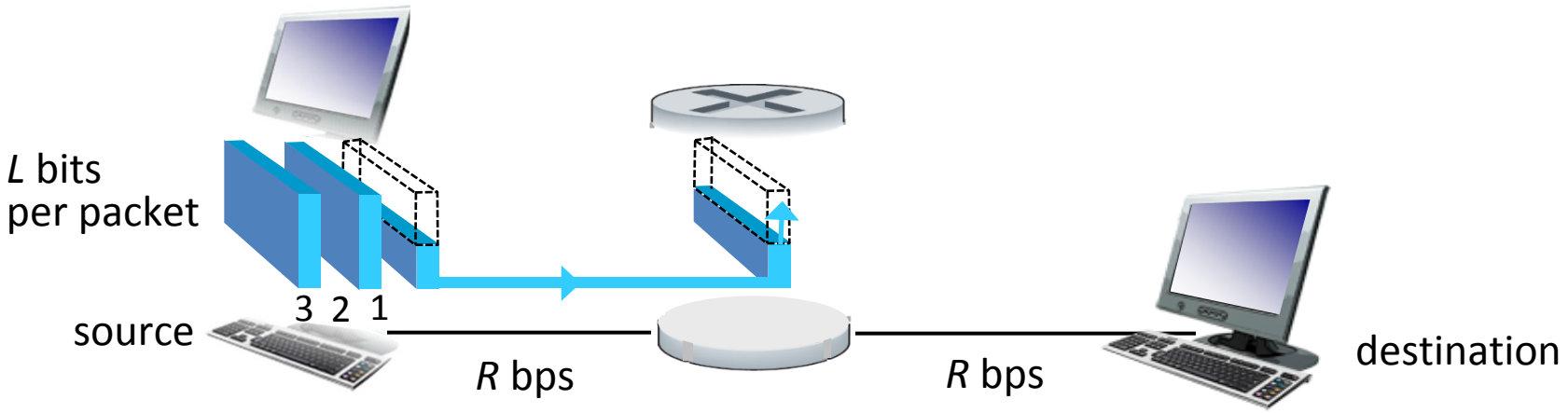
host sending function:

- 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*



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

Packet-switching: store-and-forward

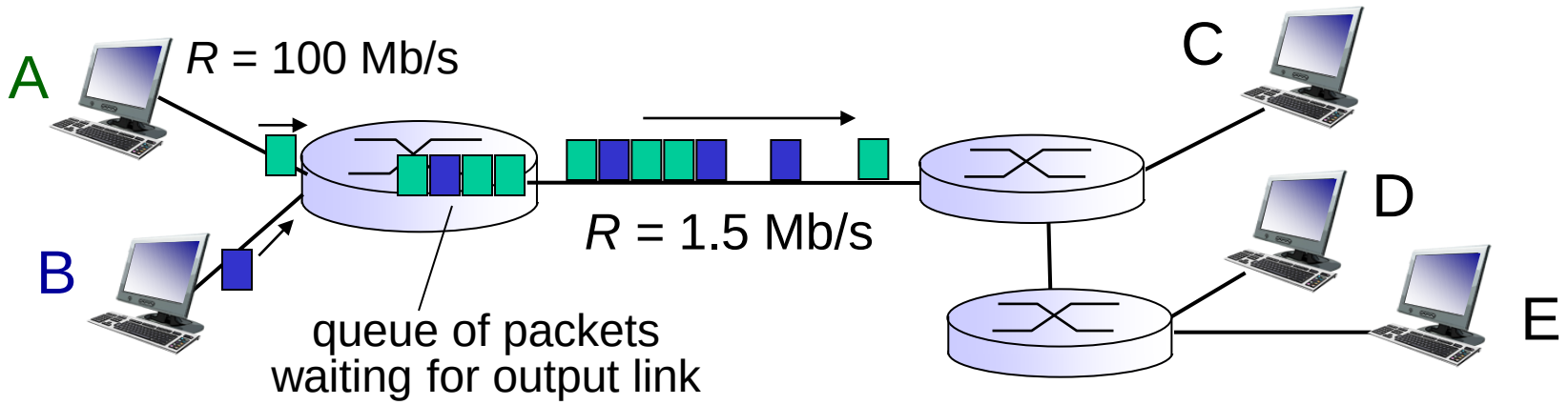


- takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- end-end delay = 2*L*/*R* (assuming zero propagation delay)

one-hop numerical example:

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

Packet Switching: queueing delay, loss



queuing and loss:

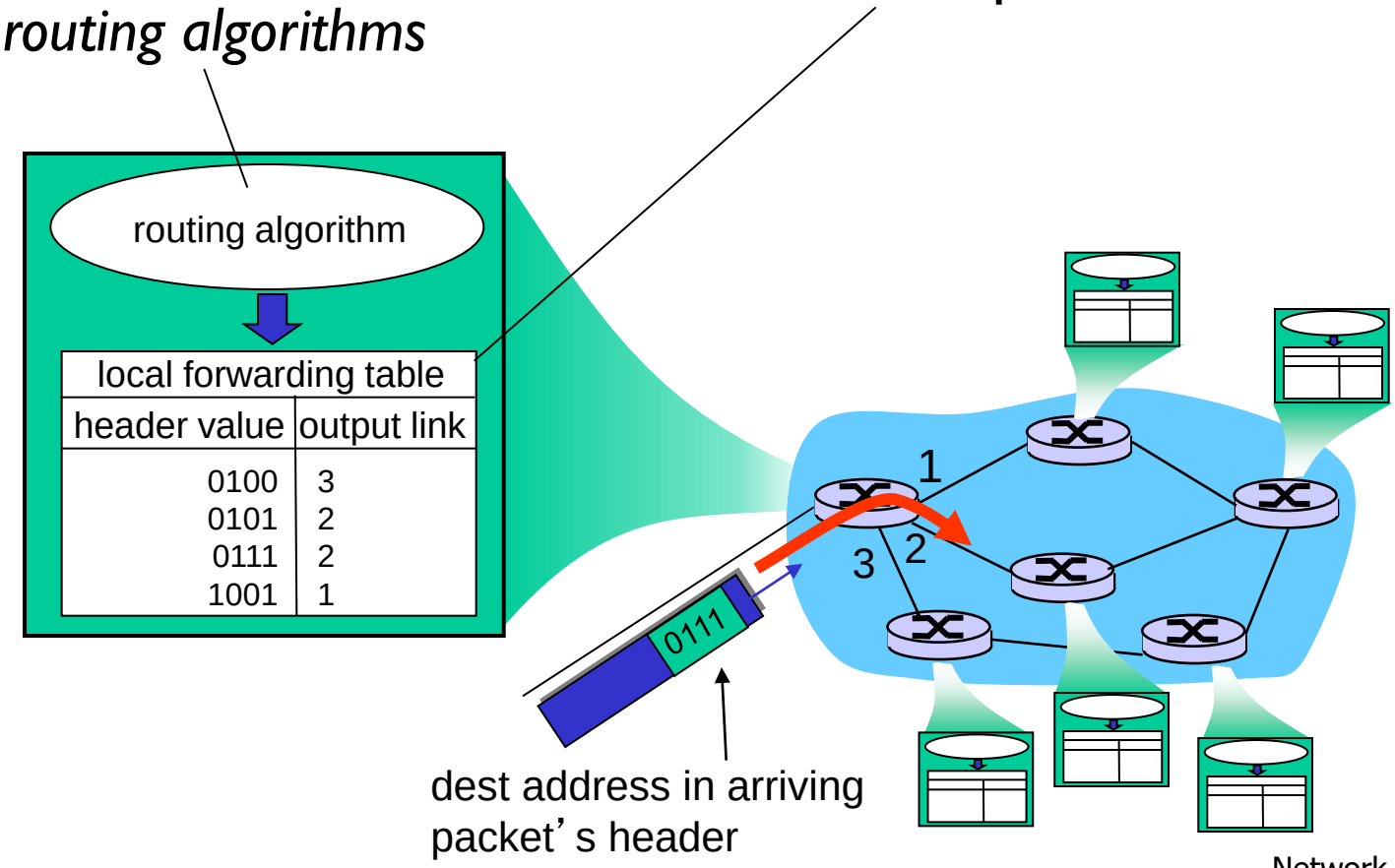
- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

Two key network-core functions

routing: determines source-destination route taken by packets

- *routing algorithms*

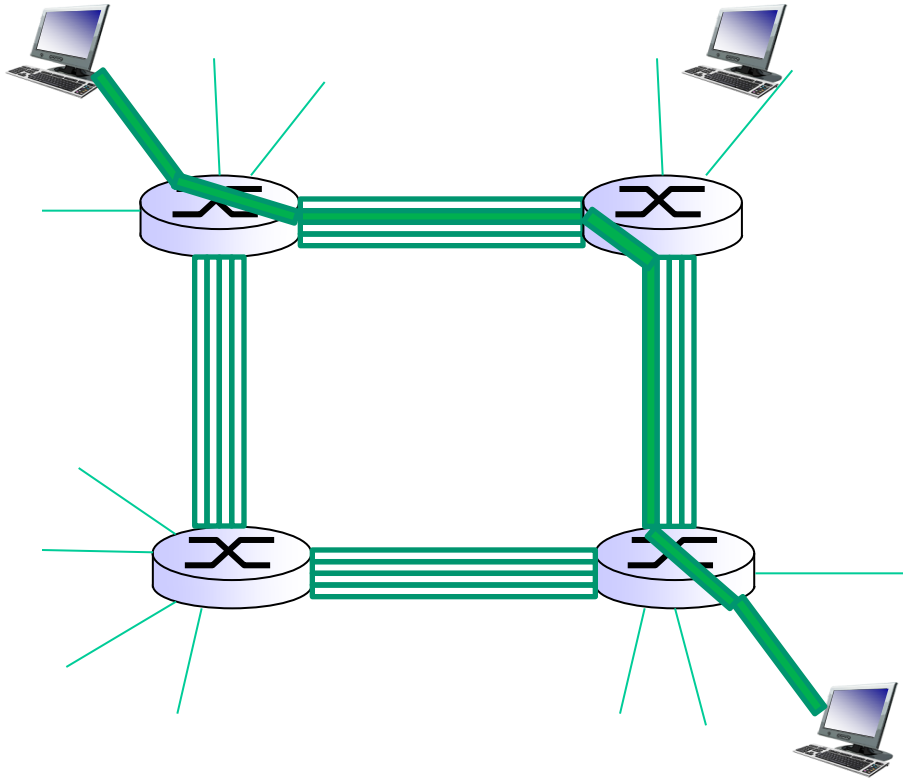
forwarding: move packets from router's input to appropriate router output



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

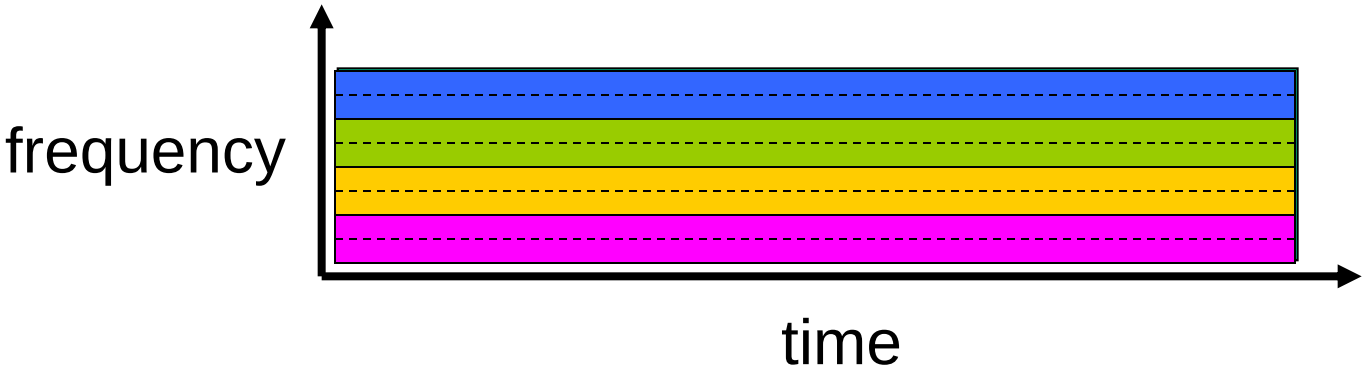


Circuit switching: FDM versus TDM

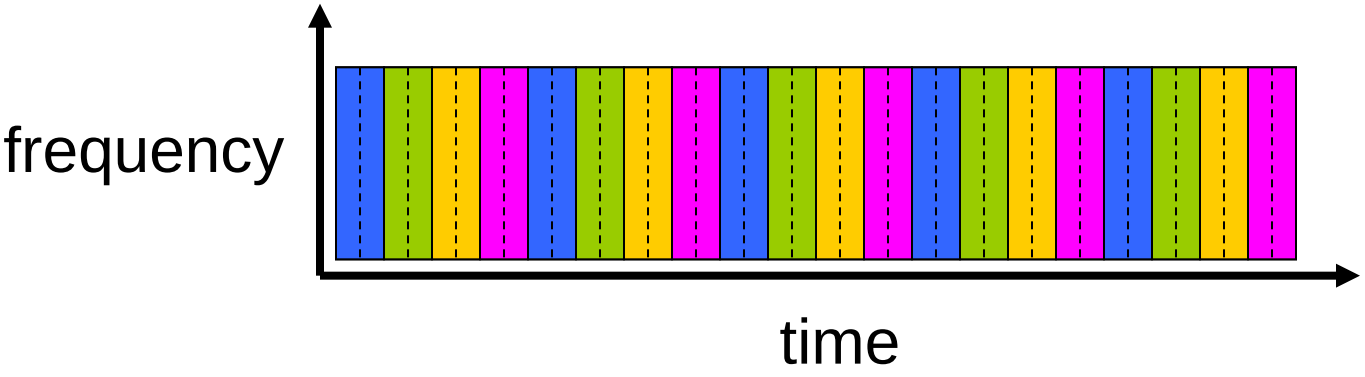
Example:

4 users

FDM



TDM

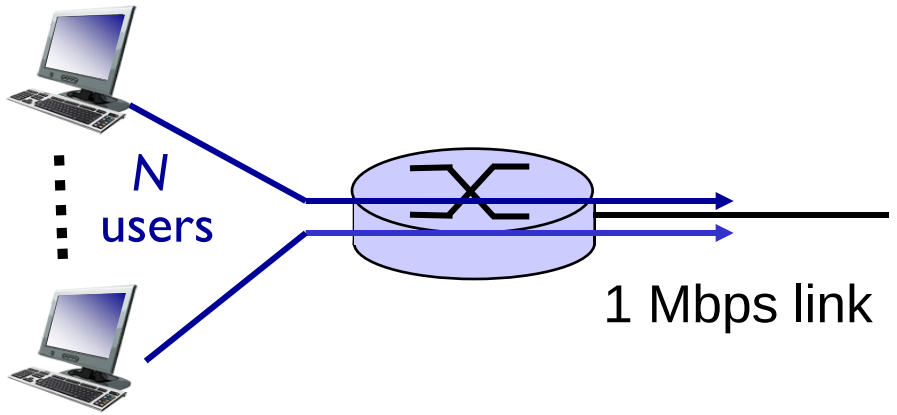


Packet switching versus circuit switching

packet switching allows more users to use network!

example:

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



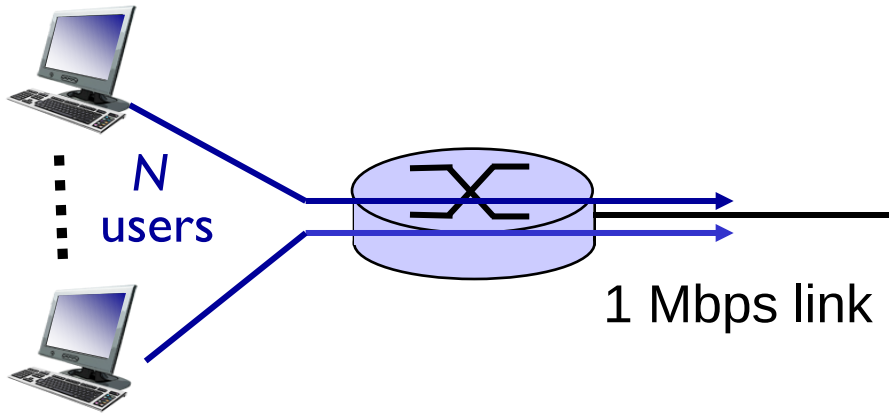
- *circuit-switching:*
  - 10 users
- *packet switching:*
  - with 35 users, probability > 10 active at same time is aprox .0004

Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

Packet switching versus circuit switching

Probability of success on a single trial	.1
Number of trials	35
Number of successes (x)	10
Binomial probability: P(X = x)	0.00131791279
Cumulative probability: P(X < x)	0.99825778961
Cumulative probability: P(X ≤ x)	0.9995757024
Cumulative probability: P(X > x)	0.0004242976
Cumulative probability: P(X ≥ x)	0.00174221039



Q: what happens if 350 users?

Cumulative probability: P(X > x)	< 0.000001

Packet switching versus circuit switching

is packet switching a "slam dunk winner?"

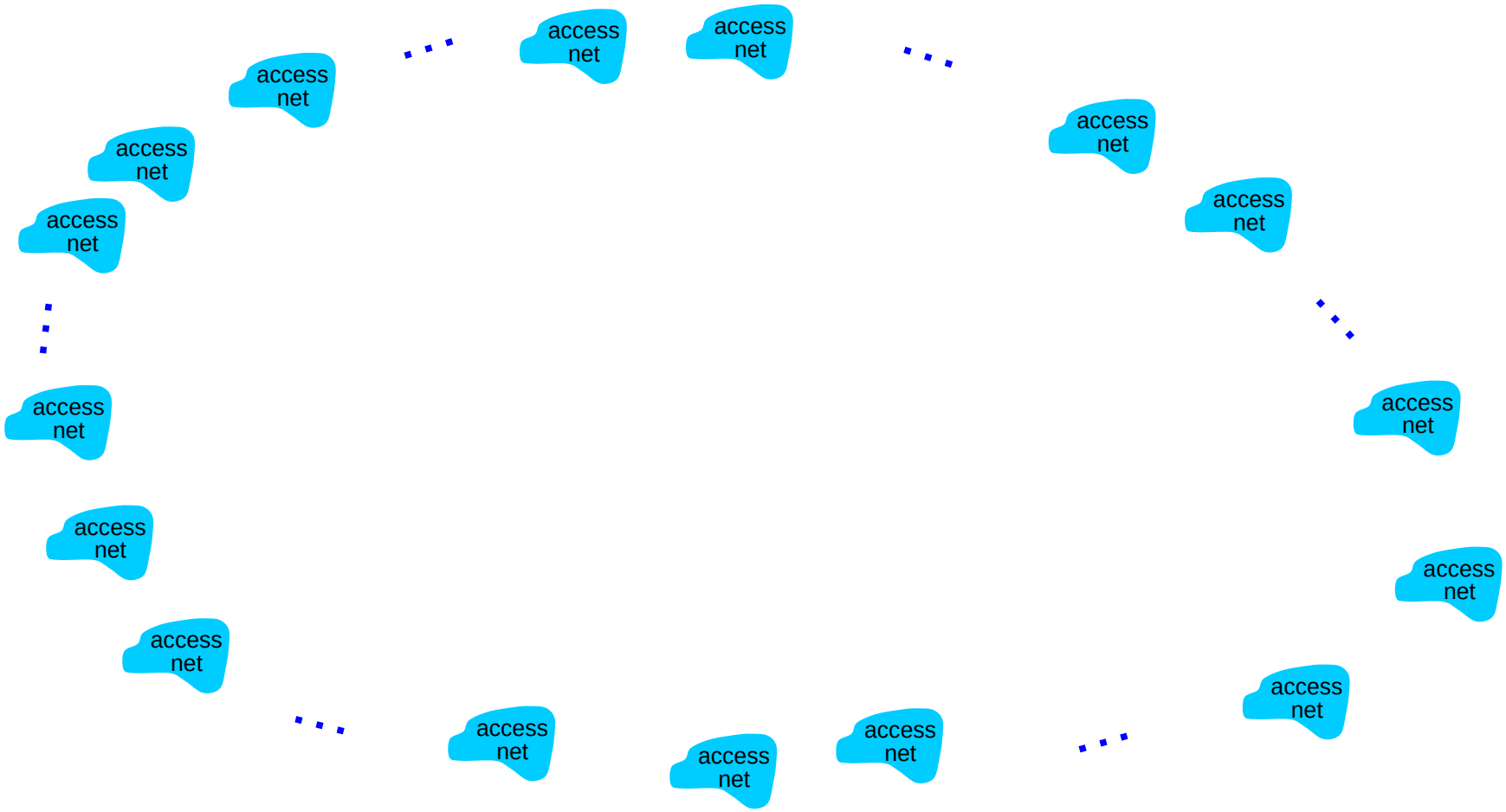
- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- *Q:* How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem

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

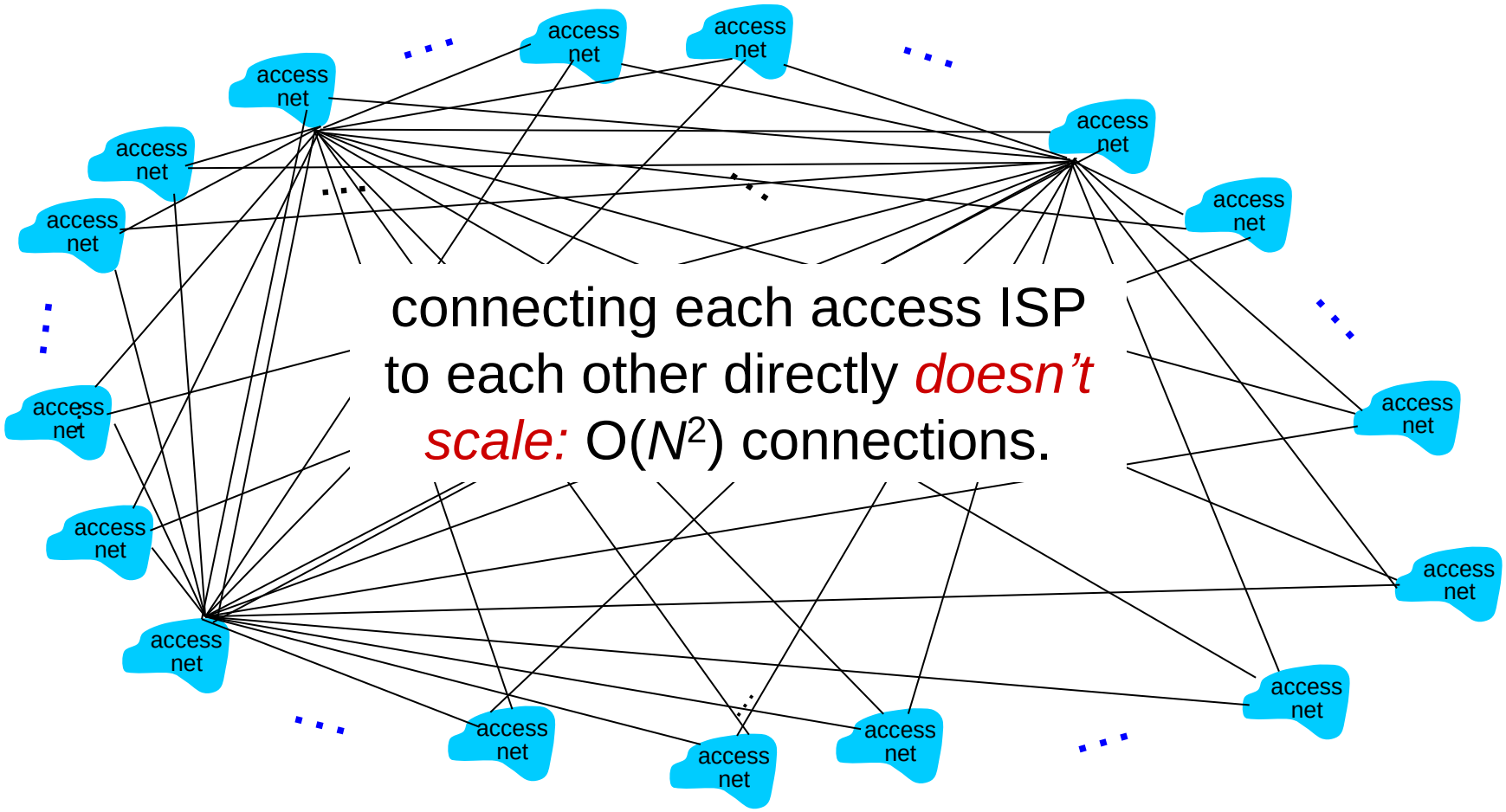
Internet structure: network of networks

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



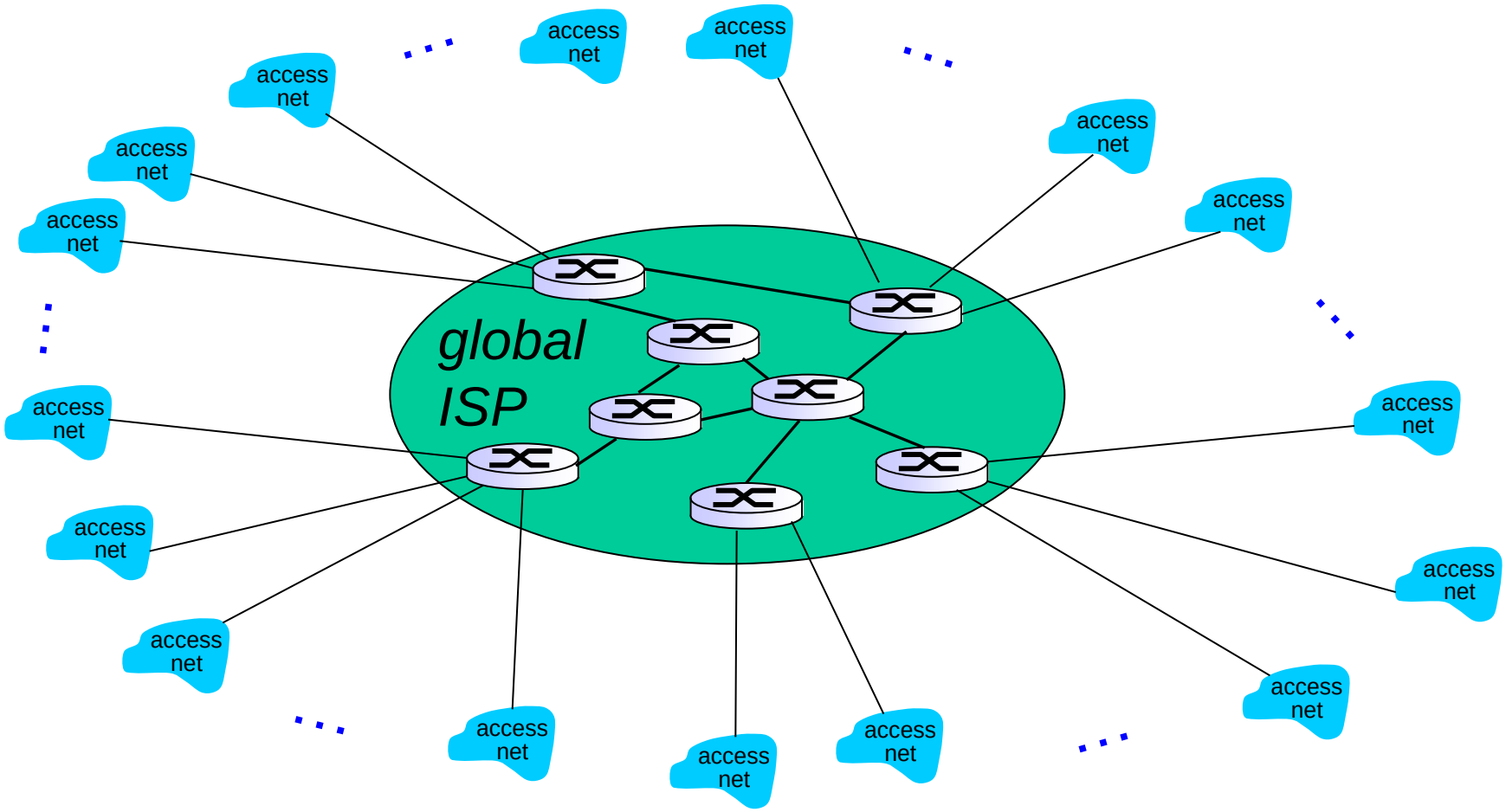
Internet structure: network of networks

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



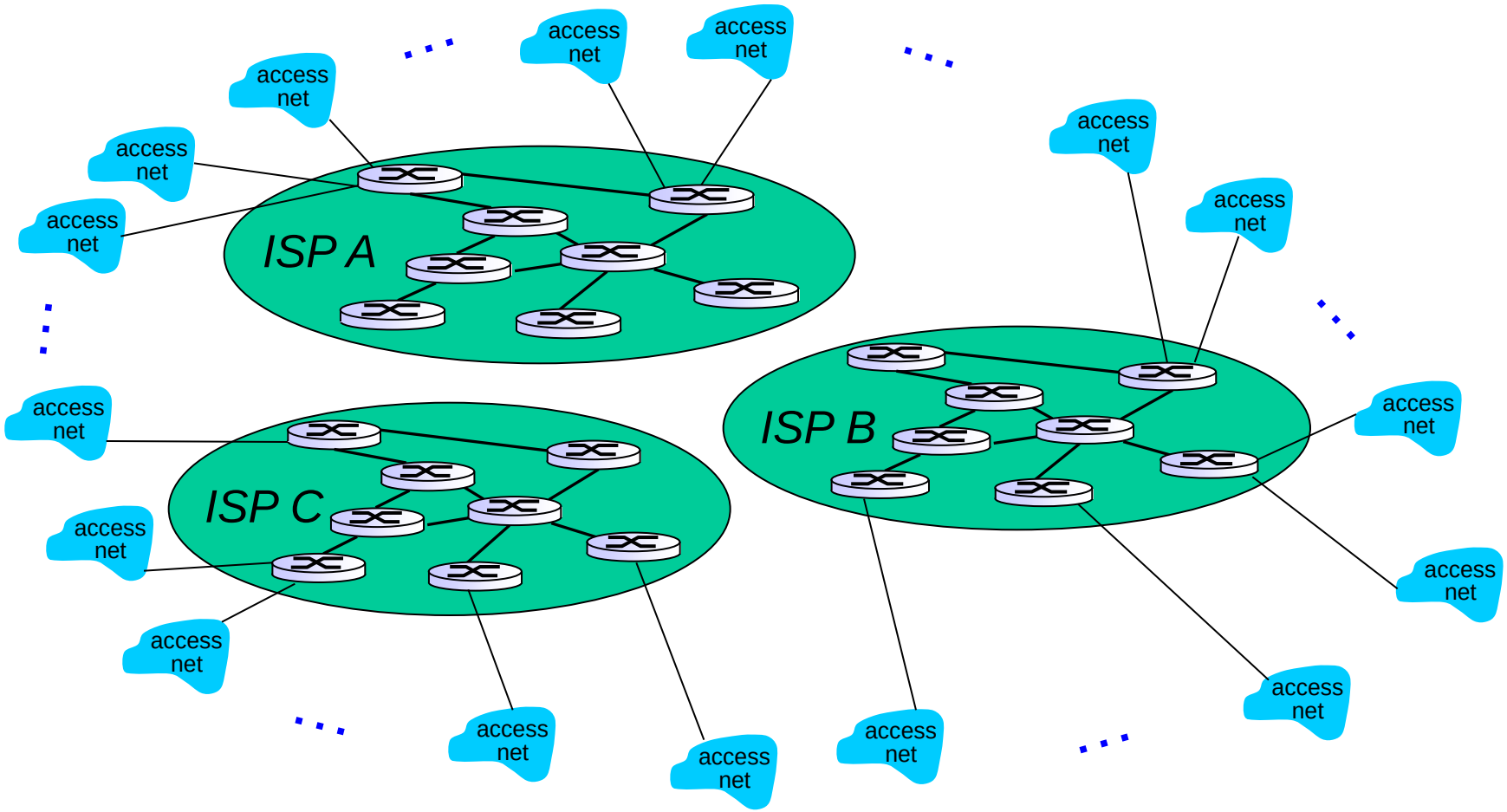
Internet structure: network of networks

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



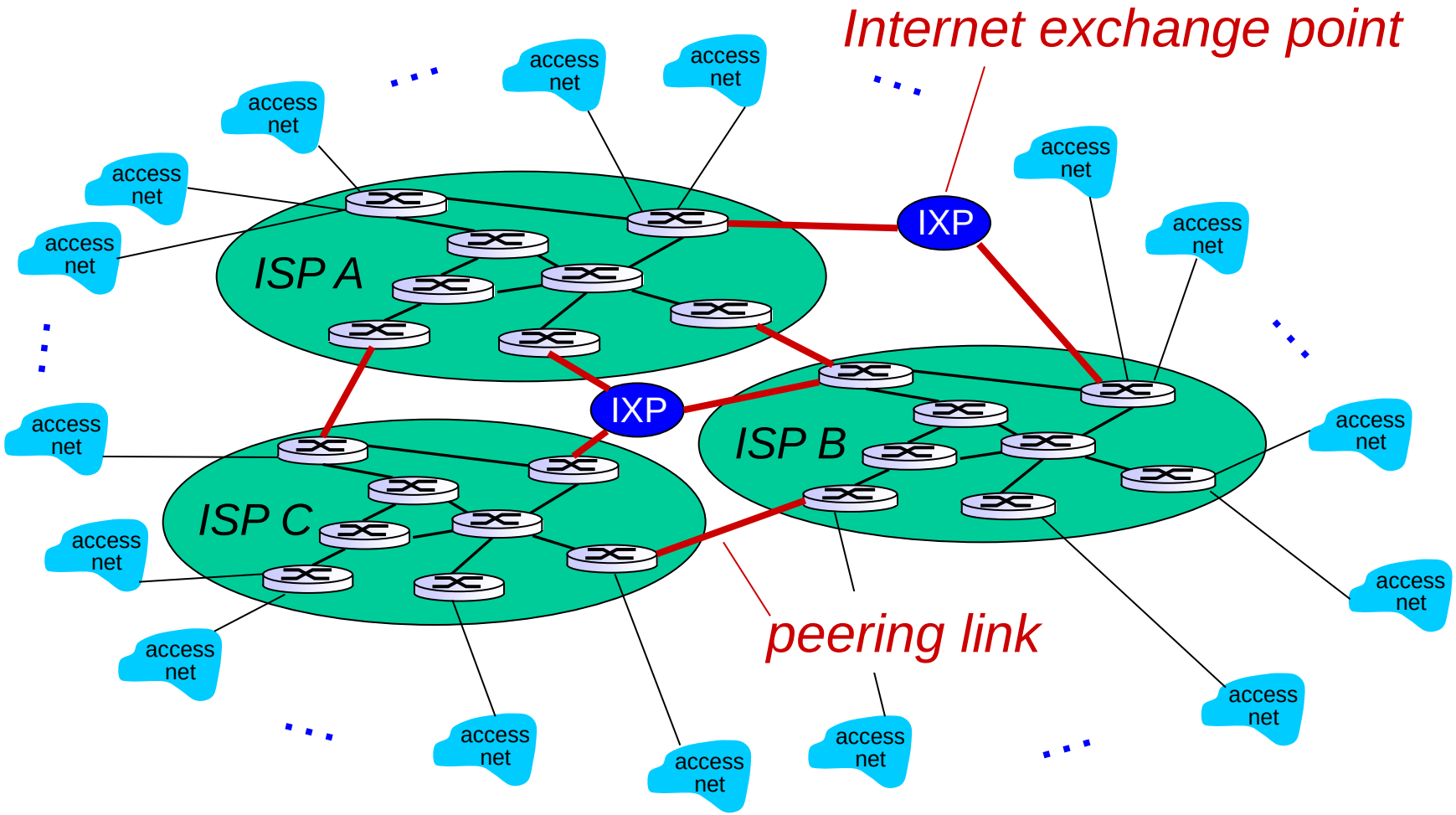
Internet structure: network of networks

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



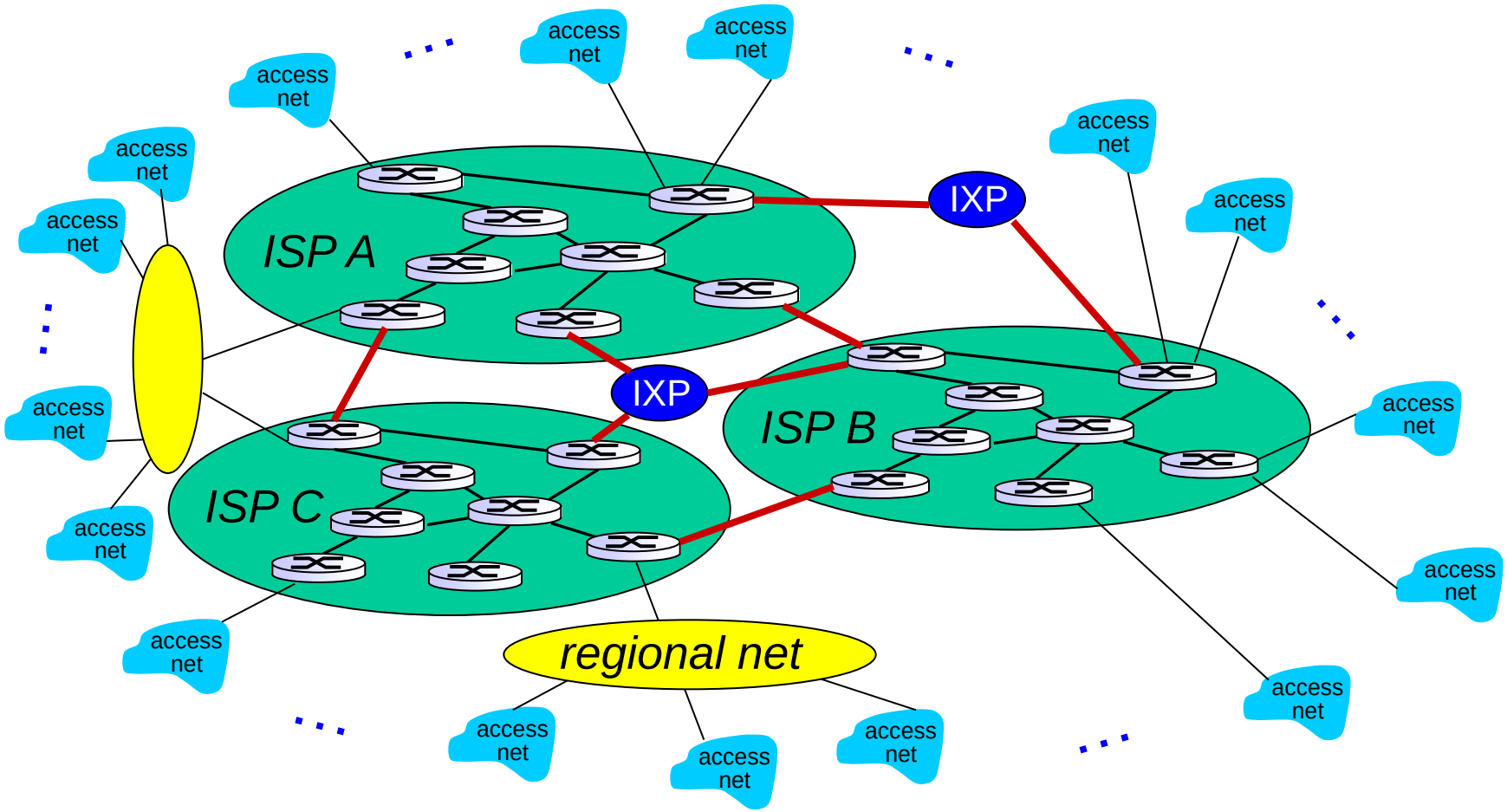
Internet structure: network of networks

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



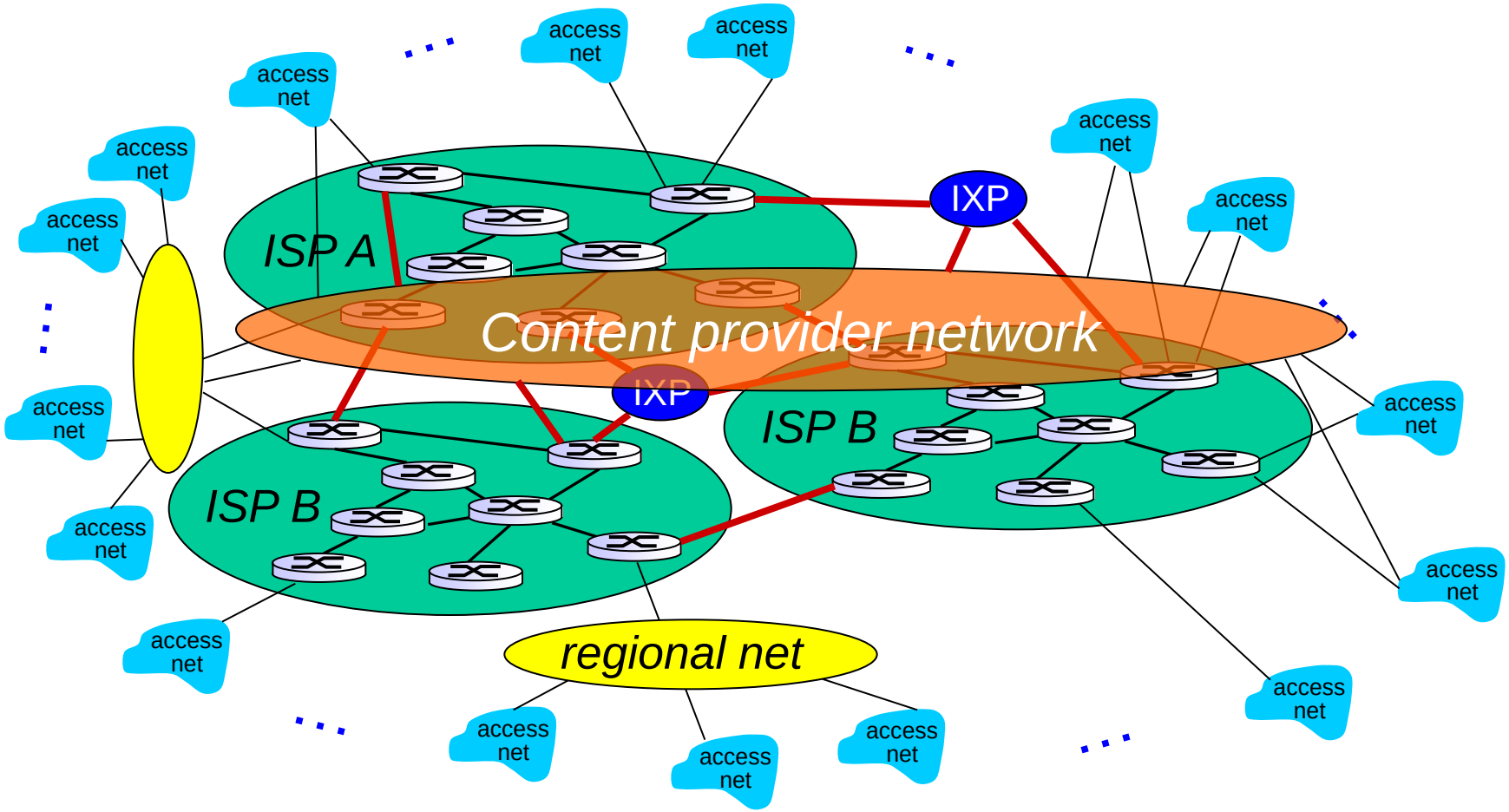
Internet structure: network of networks

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

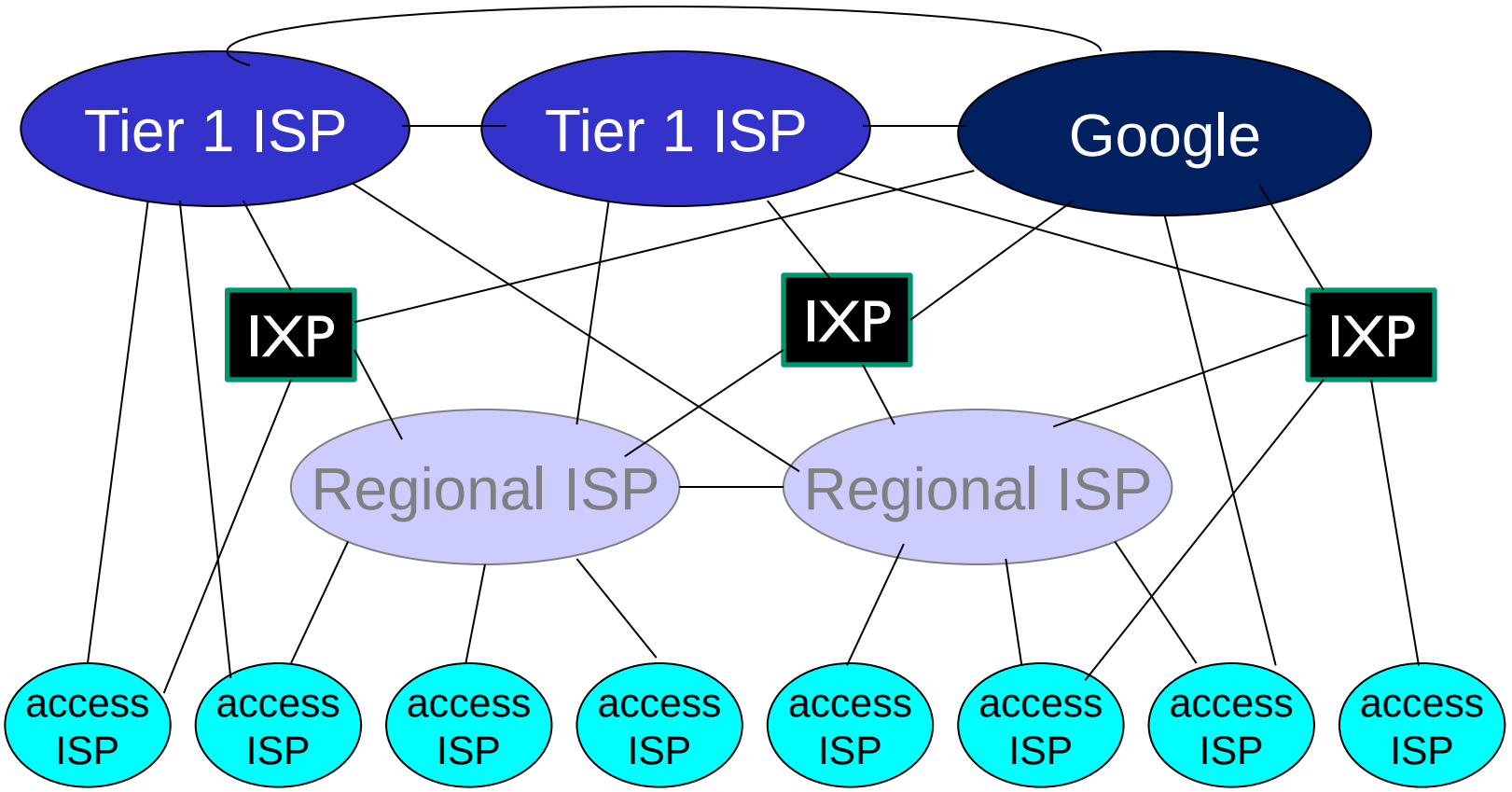


Internet structure: network of networks

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

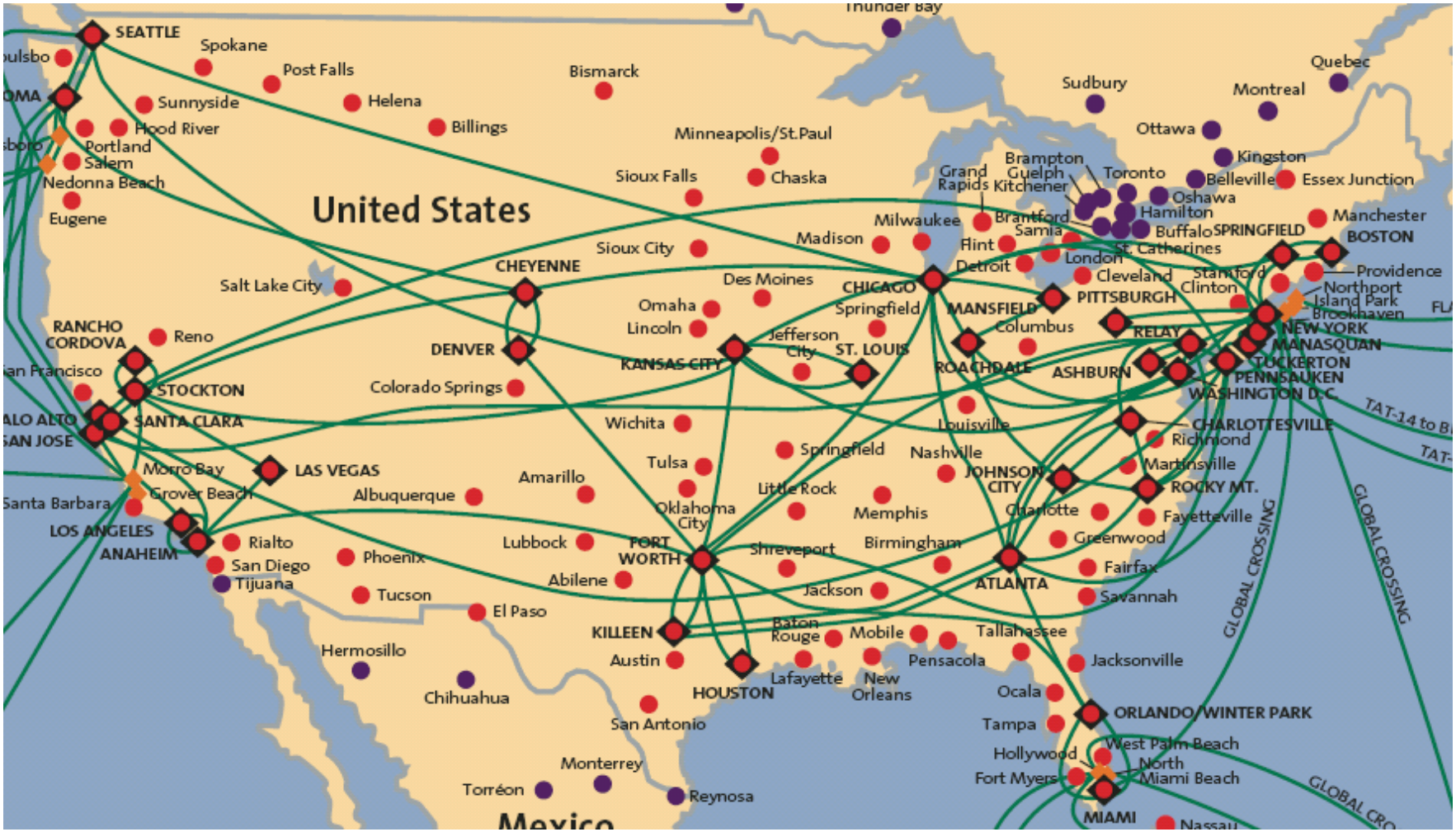


Internet structure: network of networks



- 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 data centers to Internet, often bypassing tier-1, regional ISPs

Tier-1 ISP: e.g., Sprint



Chapter 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 protocol layers, service models

Protocol "layers"

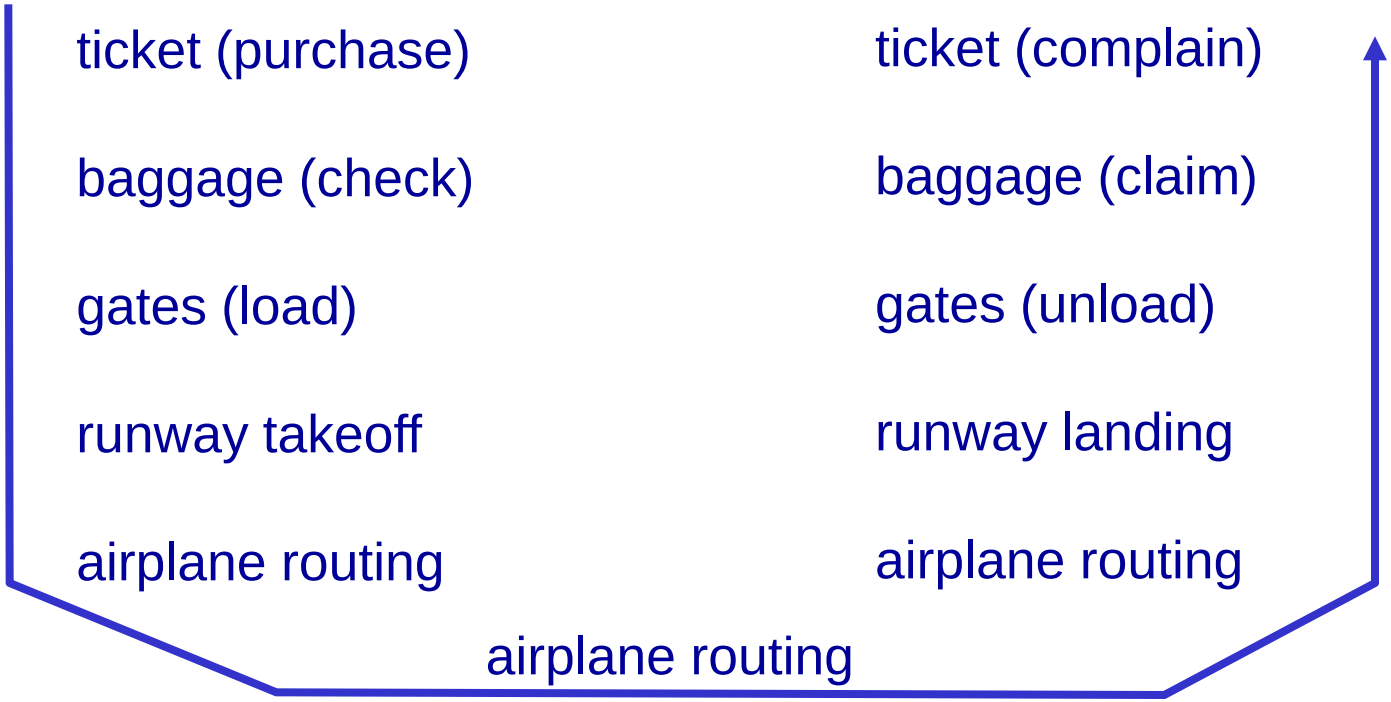
Networks are complex, with many "pieces":

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

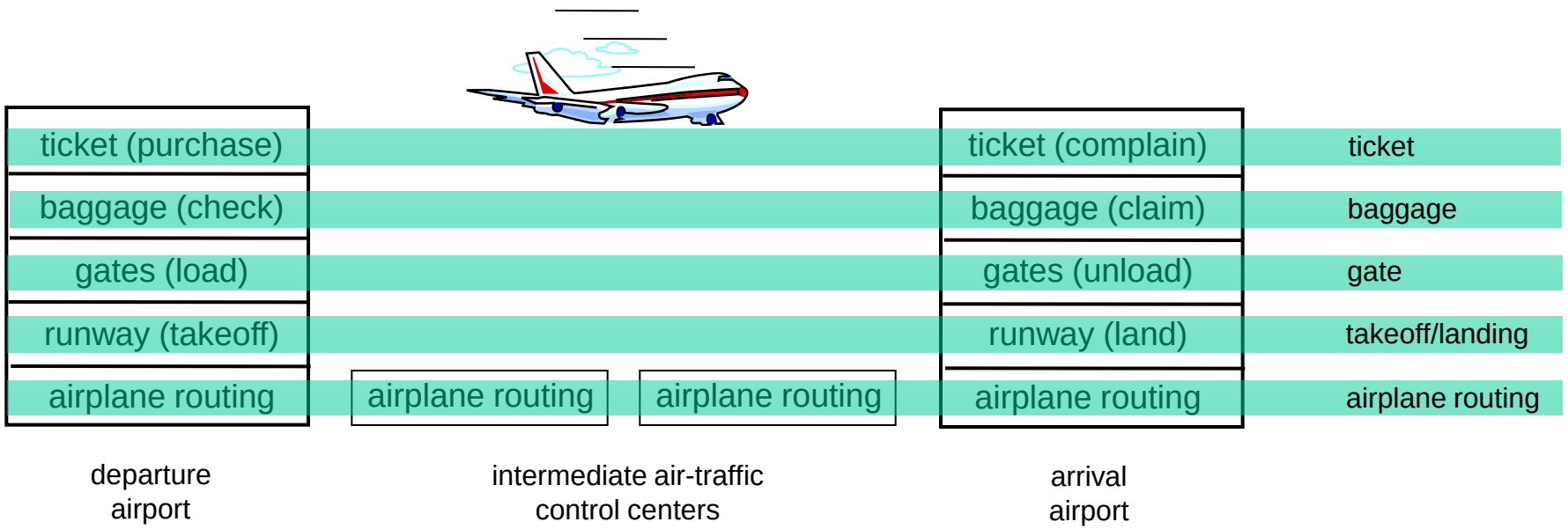
is there any hope of *organizing* structure of network?

Organization of air travel



- a series of steps

Layering of airline functionality



layers: each layer implements a service

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

Layer-n source entity "speaks" only to layer-n destination, using layer-n protocol

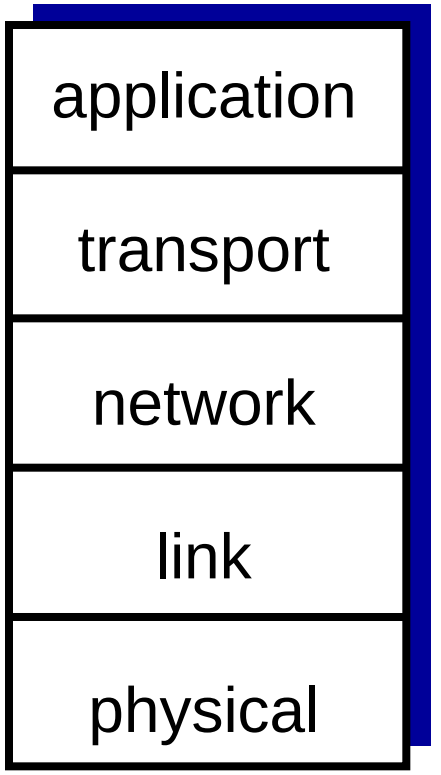
Why layering?

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 does not affect rest of system

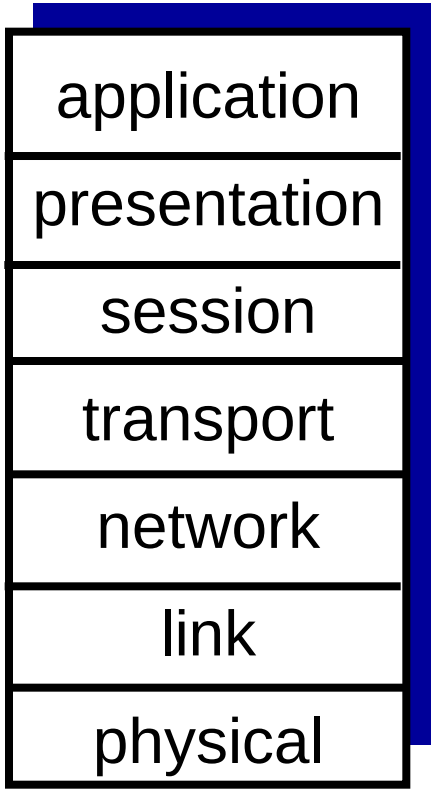
Internet protocol stack

- *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, 802.11 (WiFi), PPP
- *physical:* bits "on the wire"

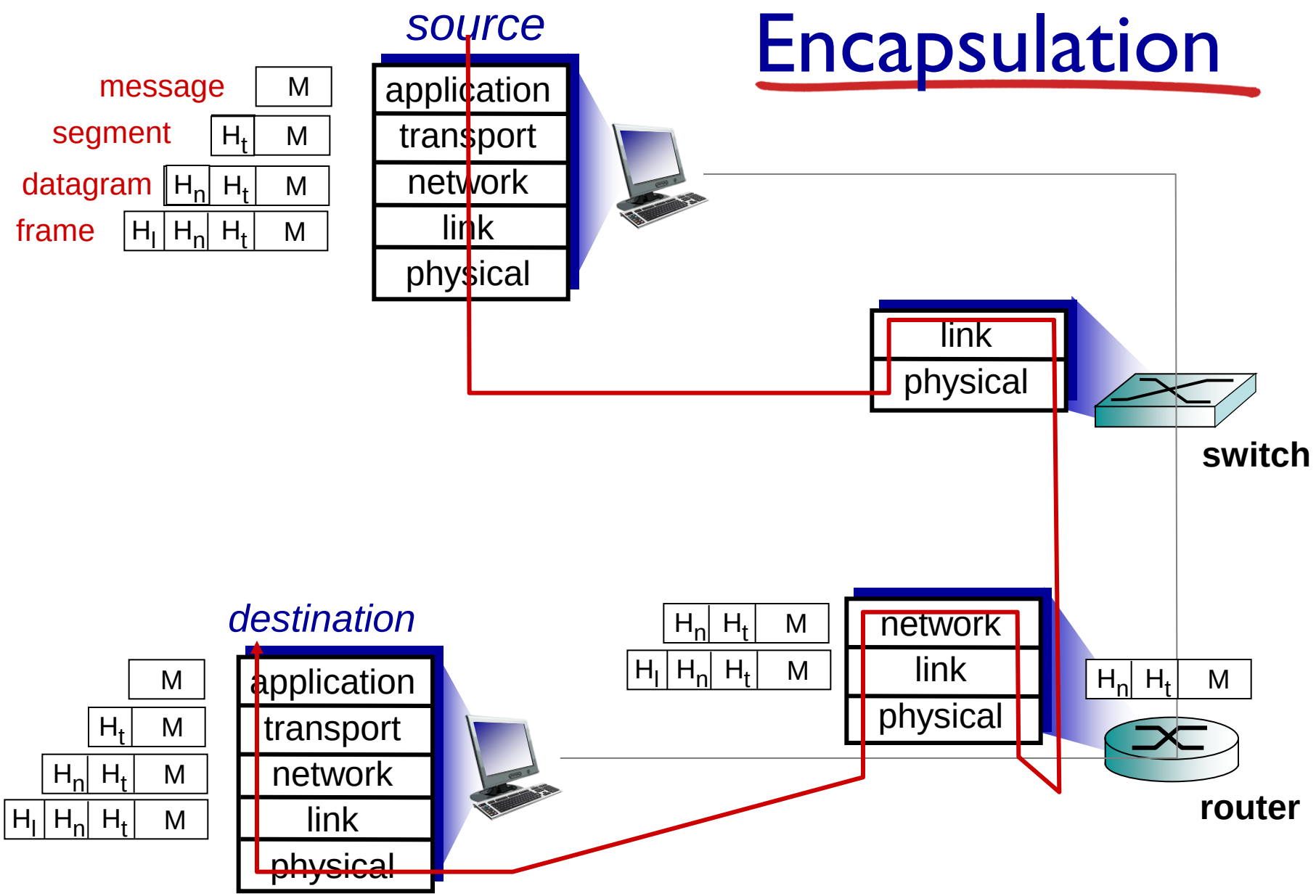


ISO/OSI reference model

- *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?



Encapsulation



Top-5 concepts to take home

- **Computer networks**: end systems + packet switches + communication links
- **Protocols**: format/order of msgs, actions
- **Layers**: layer n uses services provided by layer n-1, provides services to layer n+1
- **Encapsulation**: a layer n PDU becomes the payload of a layer n-1 PDU, which contains also a layer n-1 header
- **Packet Switching**: routing and forwarding (post-office analogy)

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
- layering, service models

you now have:

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