BLG 337E- Principles of Computer Communications

Assist. Prof. Dr. Berk CANBERK

09/09/2014

-Introduction-

References:

-*Data and Computer Communications*, William Stallings, Pearson-Prentice Hall, 9th Edition, 2010.

-*Computer Networking, A Top-Down Approach Featuring the Internet*, James F.Kurose, Keith W.Ross, Pearson-Addison Wesley, 6th Edition, 2012.

Data Communications, Data Networks, and the Internet

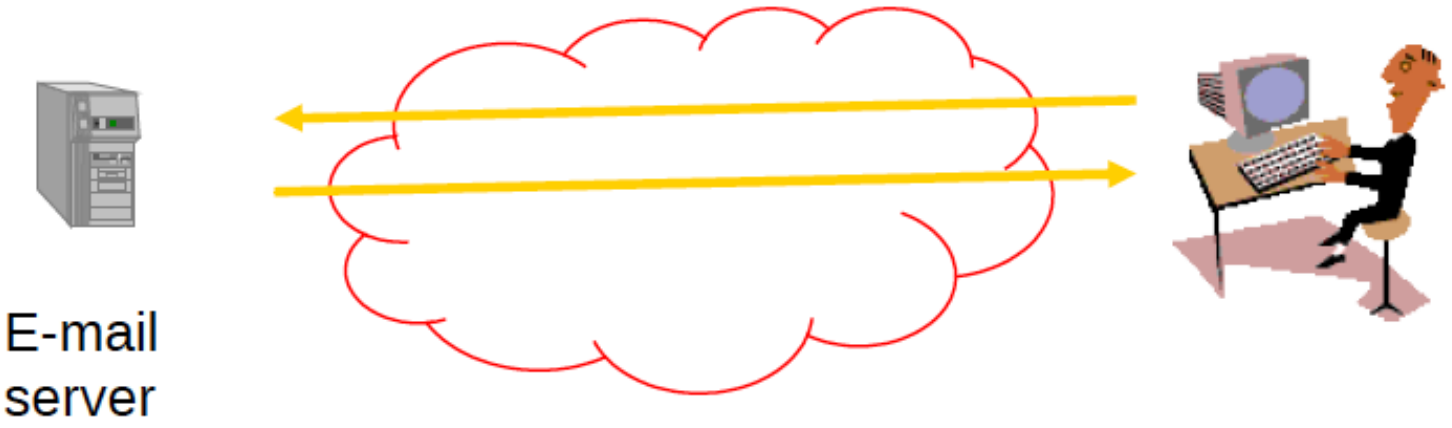
"The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point"

- *The Mathematical Theory of Communication*,

Claude Shannon

A communication service enables the exchange of information between users at different locations.

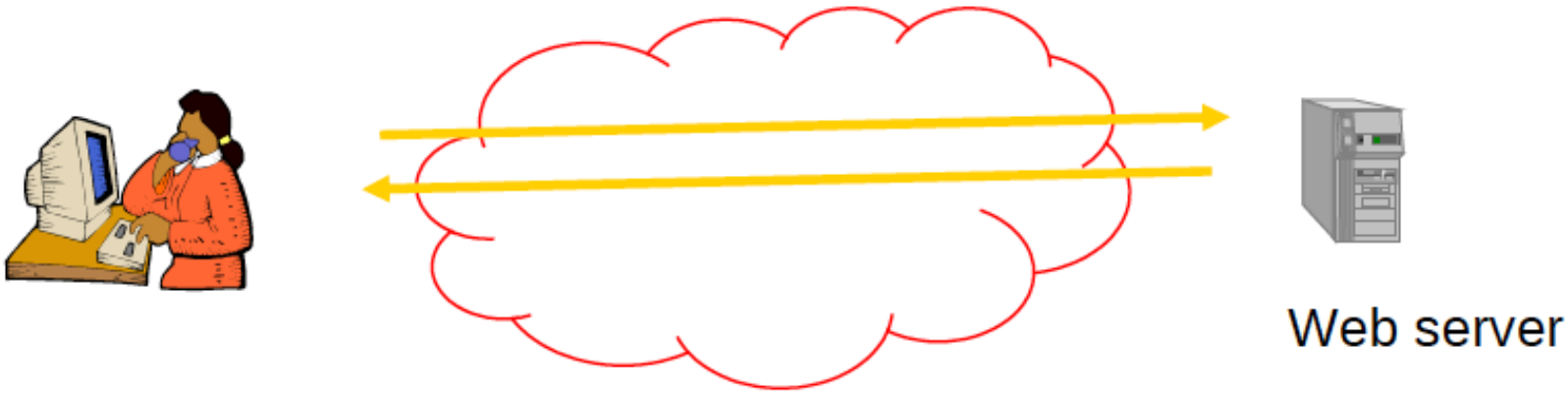
E-mail



Exchange of text messages via servers

A communication service enables the exchange of information between users at different locations.

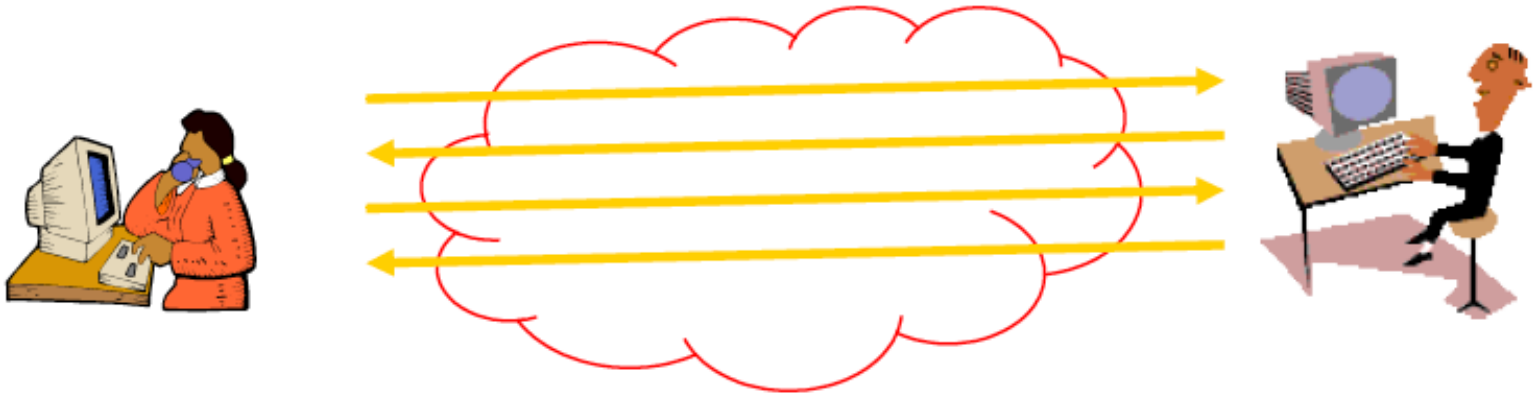
Web Browsing



Retrieval of information from web servers

A communication service enables the exchange of information between users at different locations.

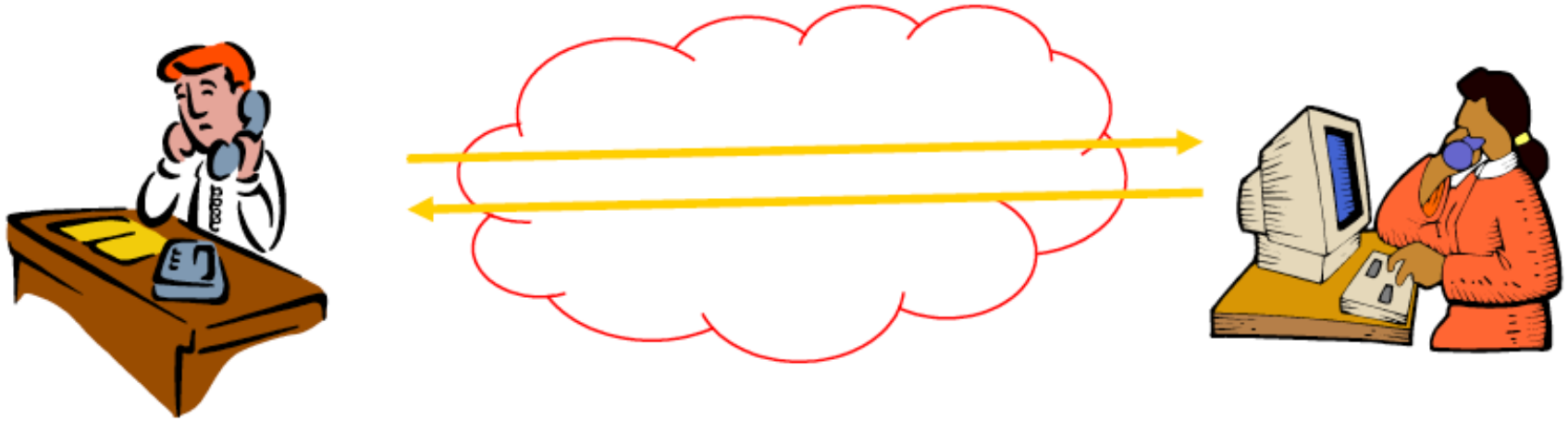
Instant Messaging



Direct exchange of text messages

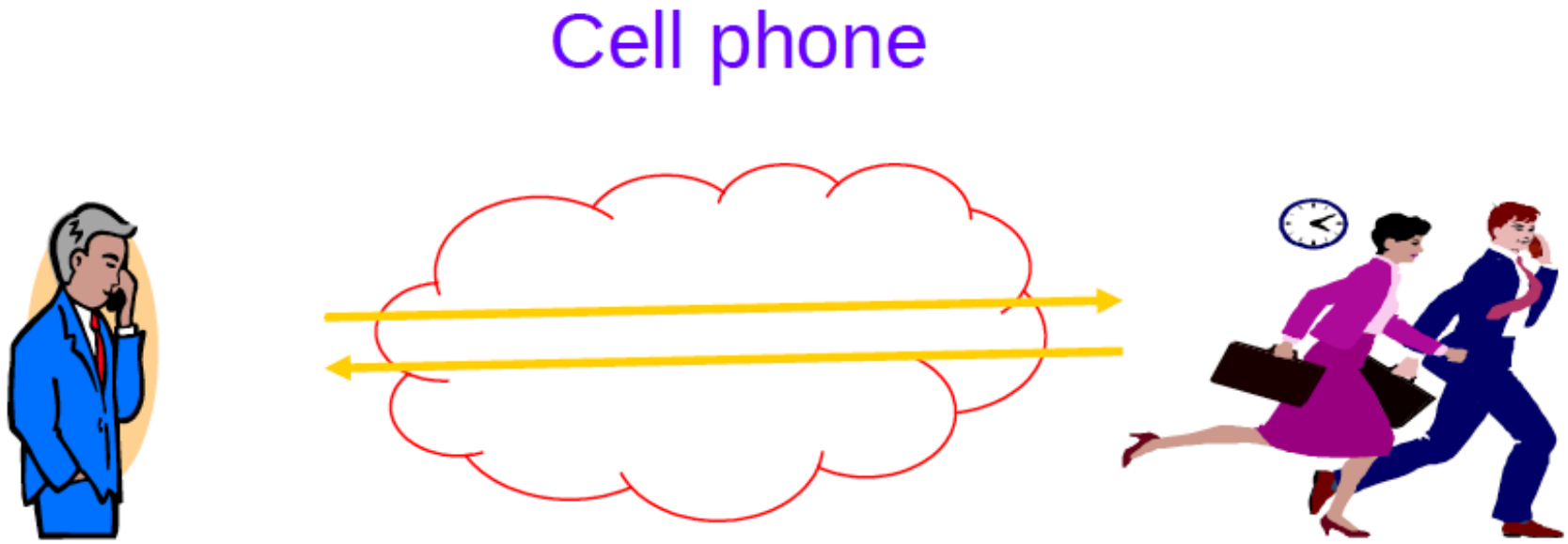
A communication service enables the exchange of information between users at different locations.

Telephone



Real-time bidirectional voice exchange

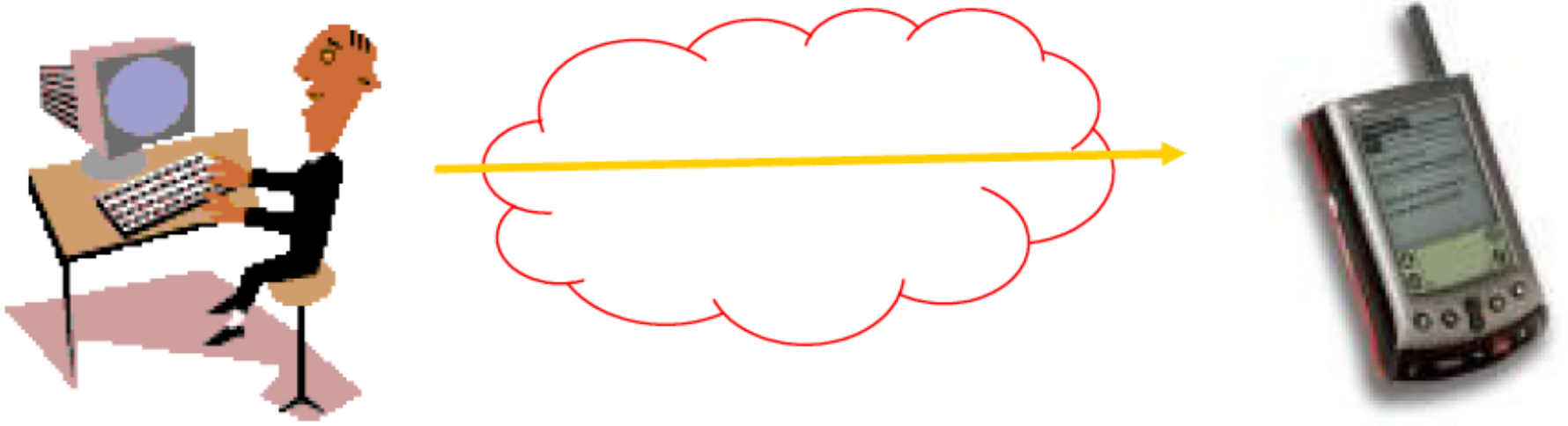
A communication service enables the exchange of information between users at different locations.



Real-time voice exchange with mobile users

A communication service enables the exchange of information between users at different locations.

Short Message Service



Fast delivery of short text messages

- Service: Basic information transfer capability
  - Internet transfer of individual block of information
  - Internet reliable transfer of a stream of bytes
  - Real-time transfer of a voice signal
- Applications build on communication services
  - E-mail & web build on reliable stream service
  - Fax and modems build on basic telephone service
- New applications build on multiple networks
  - e.g., SMS (which networks are involved???)

Why Networking??

- Point to point communication NOT usually practical
  - Devices are too far apart
  - Large set of devices would need impractical number of connections

  (have you heard of N^2 *problem* ???)
- Solution is a *communications network*

Communication Network

- (A set of) equipment (hardware & software) and facilities that provide the basic communication services (among computing entities)
- Virtually invisible to the user; usually represented by a cloud

- Equipment
  - Routers, servers, switches, multiplexers, hubs, modems, WLAN cards, cellular phones etc…
- Facilities
  - Copper wires, coaxial cables, optical fiber, air etc…

Communication Network Architecture

- *Network architecture:* the plan that specifies how the network is built and operated
  - Architecture is driven by the network services
  - Overall communication process is complex
  - *Network architecture partitions overall communication process into separate functional areas called layers (will be seen later in detail)*

History of Communication Network..

Before electronic communications were developed as they are today, people had to work hard to communicate over long distances using methods like smoke signals, light signals or waving flags.

Torch Relays: Around the 13th century BC, this method is said to have been used by the Greeks to spread word of their victory over Troy in the Trojan War. This was a slow method because torches were passed from hand to hand, and bearers had to be careful that the fire didn't go out.

Ref: http://www.japan.park.org/Japan/NTT/MUSEUM/html_st/ST_final_1_e.html

History of Communication Network..

Voice Relays: Around 550 BC, Cyrus the Great (the ruler of Persia) built rows of towers radiating out from his capital like the spokes of a wheel, with soldiers stationed atop each tower who could shout messages in a voice that could reach to the next tower. Because this was an oral relay system, messages sometimes changed somewhat along the way, as often happens when playing the 'telephone game'

Ref: http://www.japan.park.org/Japan/NTT/MUSEUM/html_st/ST_final_1_e.html

History of Communication Network..

Smoke Signals: Indians in western North America used smoke signals to communicate, just as seen in the movies. Smoke signals have been used around the world since before recorded history, but require prior agreement between the parties on a set of signals to be used and are unable to convey complex messages. The same is true of flag-based signal systems.

Ref: http://www.japan.park.org/Japan/NTT/MUSEUM/html_st/ST_final_1_e.html

History of Communication Network..

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History of Communication Network..

- Ancient postal Networks
  - Emperor Augustus created a postal network which spanned the entire Roman Empire
  - Individual stages (routing nodes) were known as "mansio posita", or resting places, from which the word "post" is derived
- Telegraph Networks
  - Message switching & digital transmission

History of Communication Network..
Optical (Visual) Telegraph

- Claude Chappe invented optical telegraph in the 1790's
- Semaphore mimicked a person with outstretched arms with flags in each hand
- Different angle combinations of arms & hands generated hundreds of signals
- Code for enciphering messages kept secret
- Signal could propagate 800 km in 3 minutes!

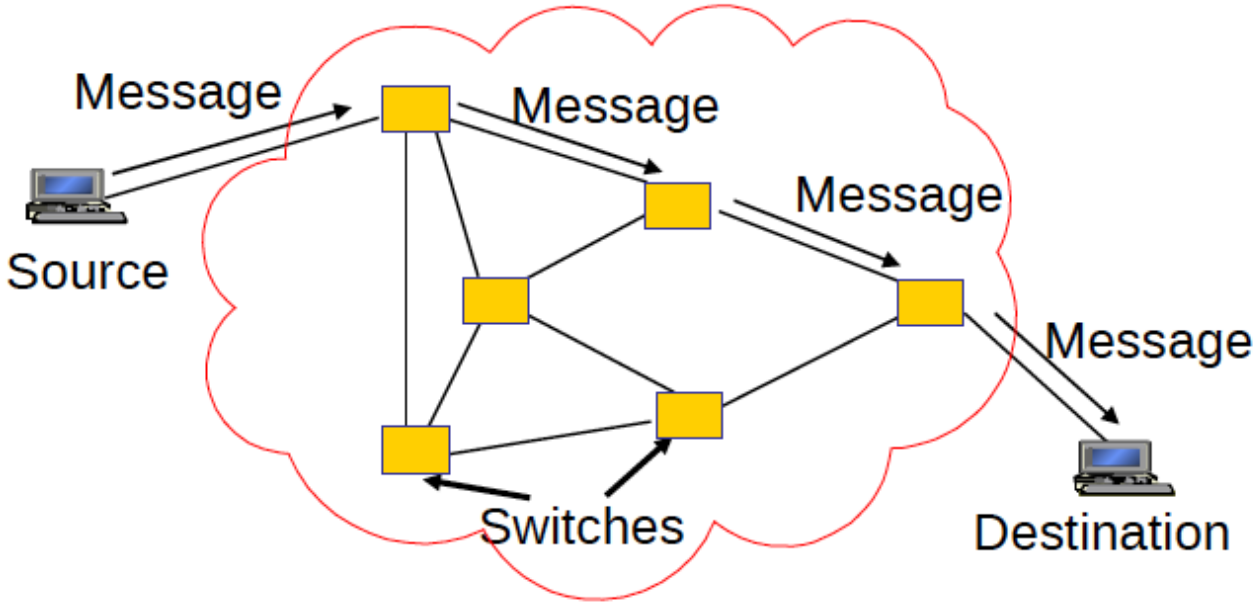
History of Communication Network.. Electric Telegraph

- William Sturgeon Electro-magnet (1825)
  - Electric current in a wire wrapped around a piece of iron generates a magnetic force
- Joseph Henry (1830)
  - Current over 1 mile of wire to ring a bell
- Samuel Morse (1835)
  - Pulses of current deflect electromagnet to generate dots & dashes
  - Experimental telegraph line over 40 miles (1840)
- Signal propagates at the speed of light!!!
  - Approximately 2 x 10^8 meters/second in cable

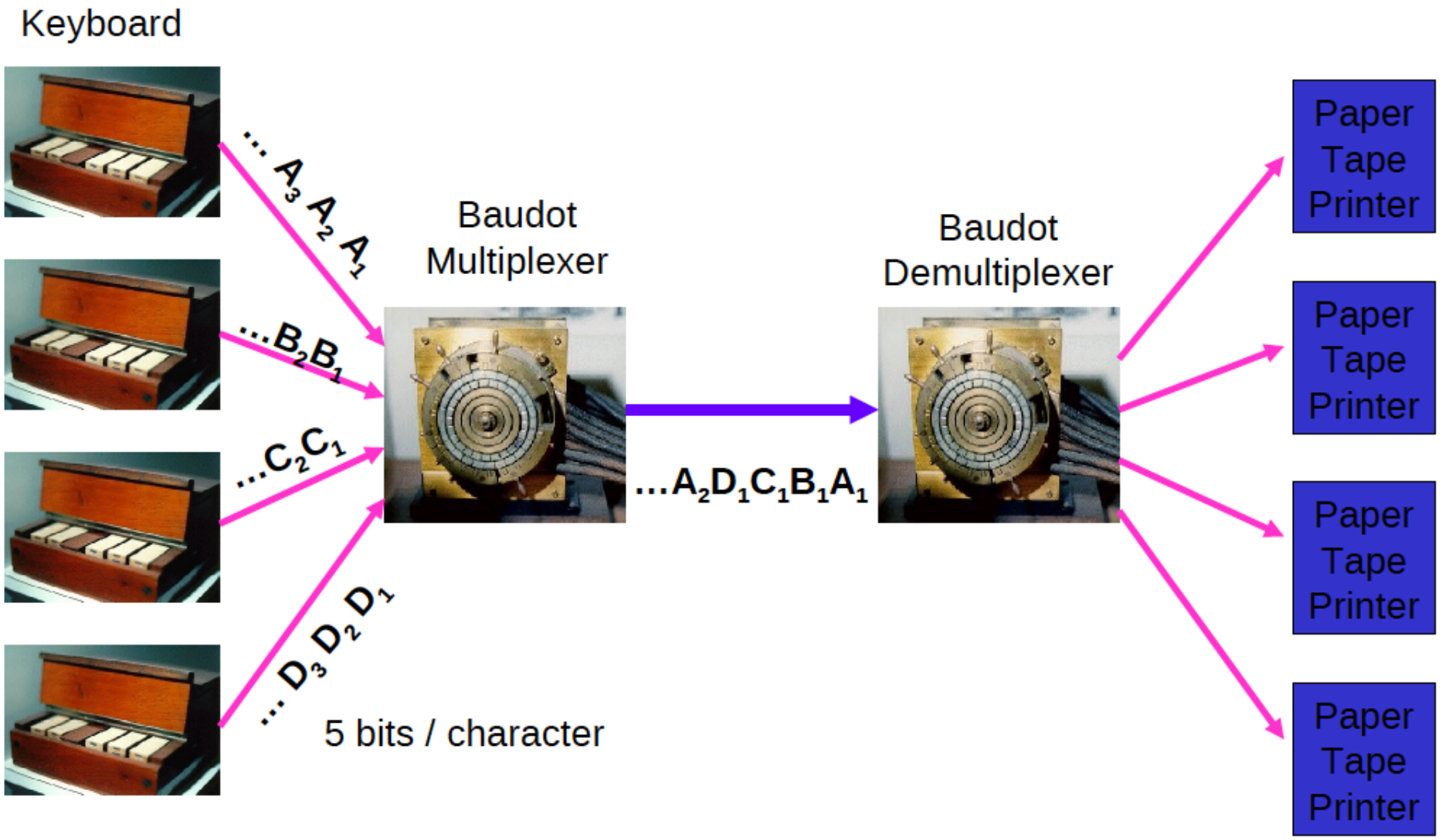
History of Communication Network..

Electric Telegraph

- Electric telegraph networks exploded
  - Message switching & Store-and-Forward operation
  - Key elements: Addressing, Routing, Forwarding
- Optical telegraph networks disappeared



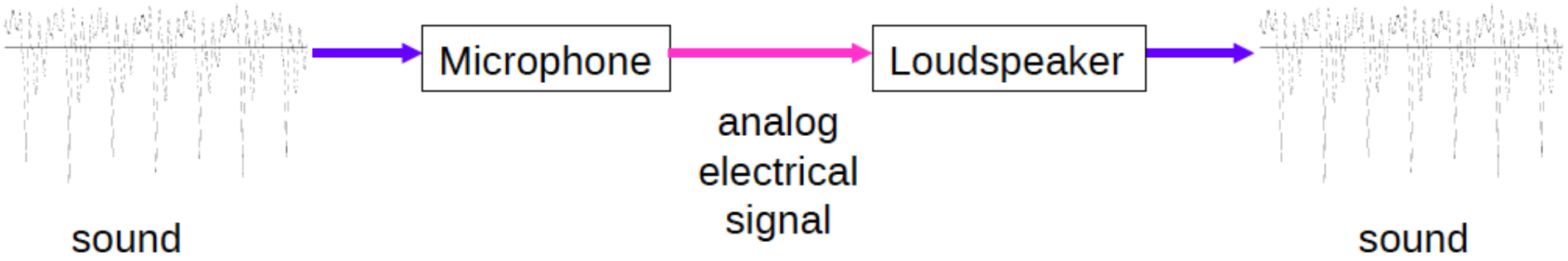
History of Communication Network..
Baudot Telegraph Multiplexer



History of Communication Network.. Bell's Telephone

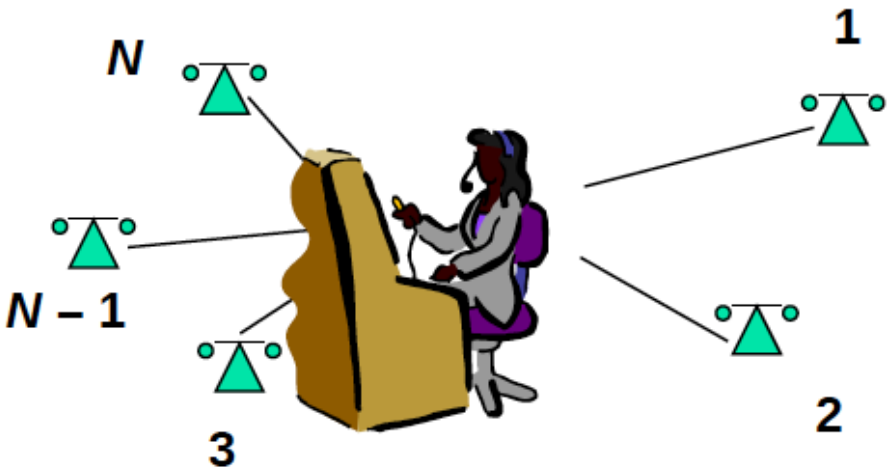
- Alexander Graham Bell (1875) working on harmonic telegraph to multiplex telegraph signals
- Discovered voice signals can be transmitted directly
  - Microphone converts voice pressure variation (sound) into *analogous* electrical signal
  - Loudspeaker converts electrical signal back into sound
- Telephone patent granted in 1876
- Bell Telephone Company founded in 1877

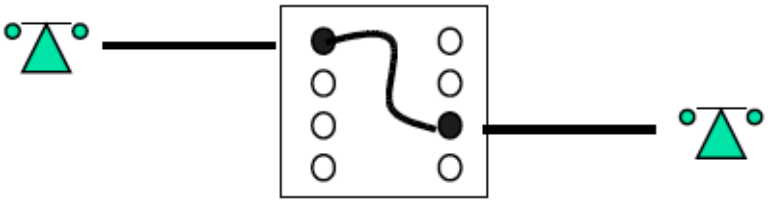
Signal for "ae" as in cat



History of Communication Network.. Bell's Telephone.. Circuit Switching

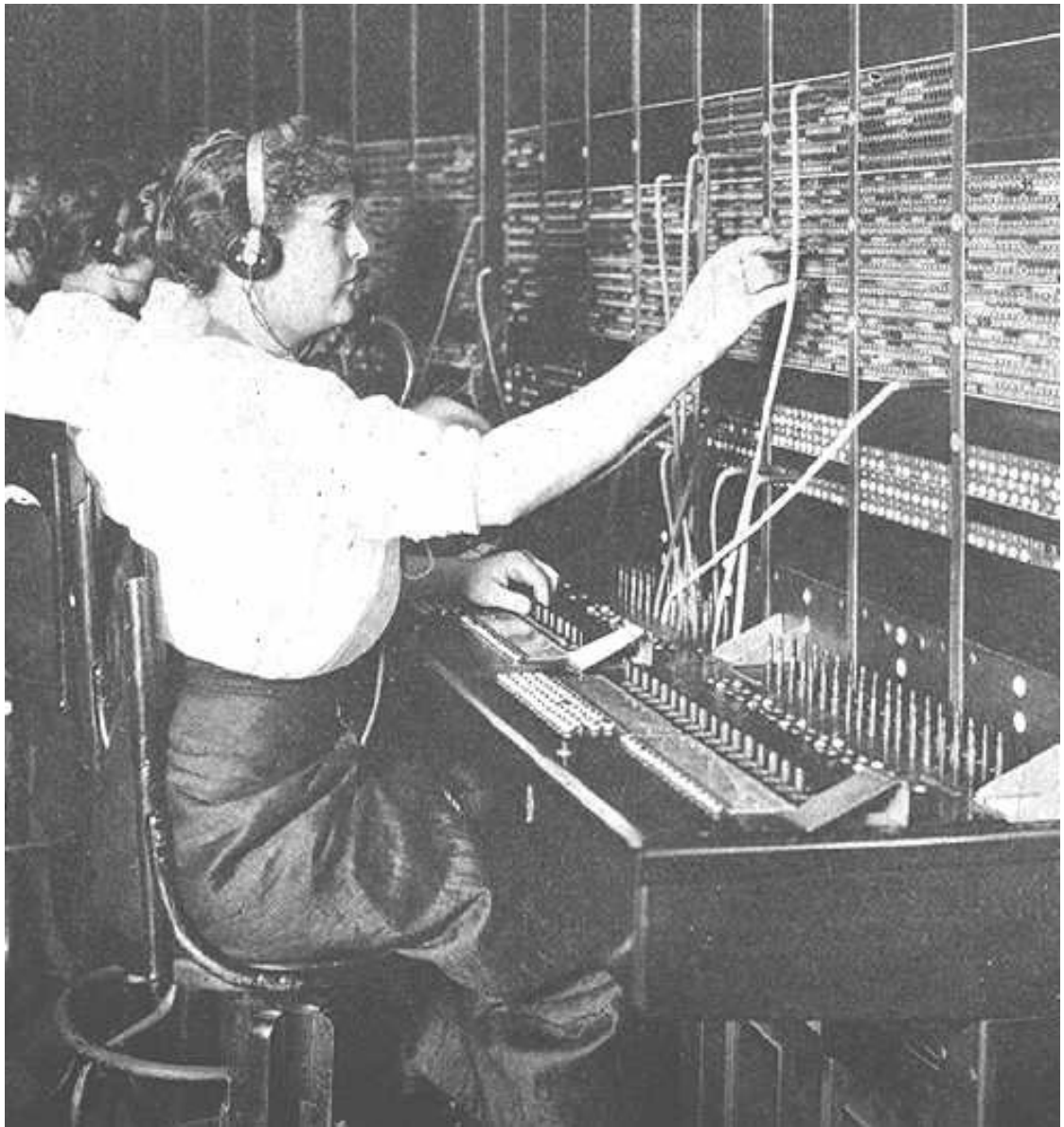
- Patchcord panel switch invented in 1877
- Operators connect users on demand
  - Establish *circuit* to allow current from inlet to outlet
- Only *N* connections required to central office





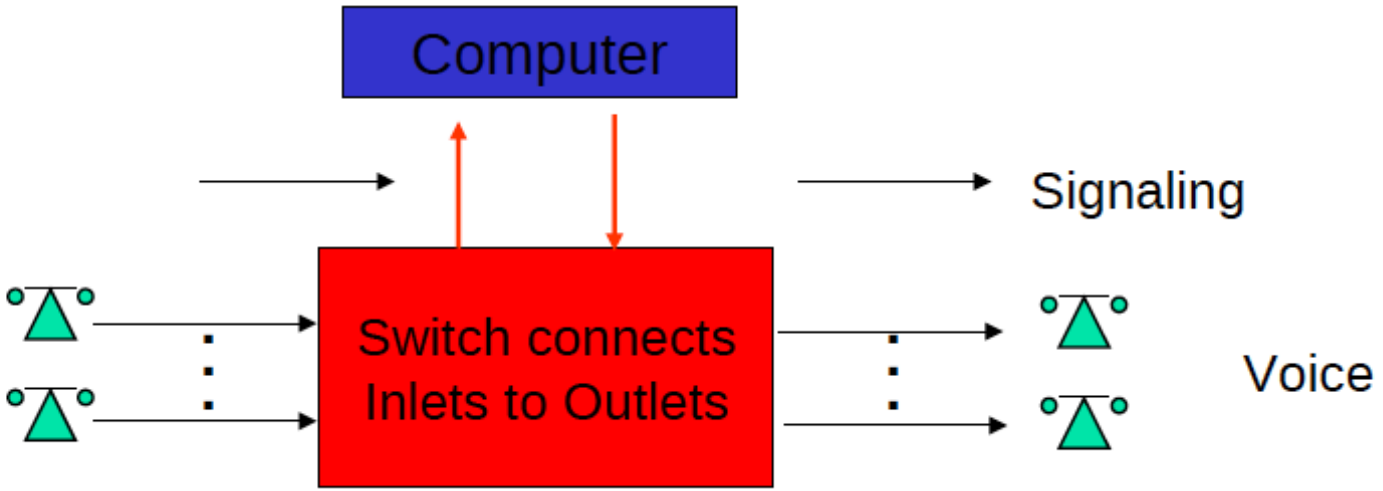
History of Communication Network..

Manual Switching



History of Communication Network.. Computer Connection Control

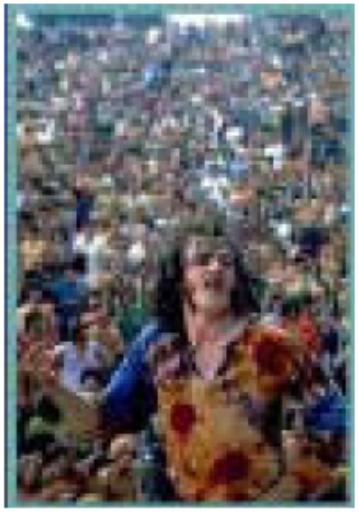
- A computer controls connection in telephone switch
- Computers exchange *signaling messages* to:
  - Coordinate set up of telephone connections
  - To implement new services such as caller ID, voice mail, . . .
  - To enable *mobility and roaming in* cellular networks
- "Intelligence" inside the network
- A separate *signaling network* is required

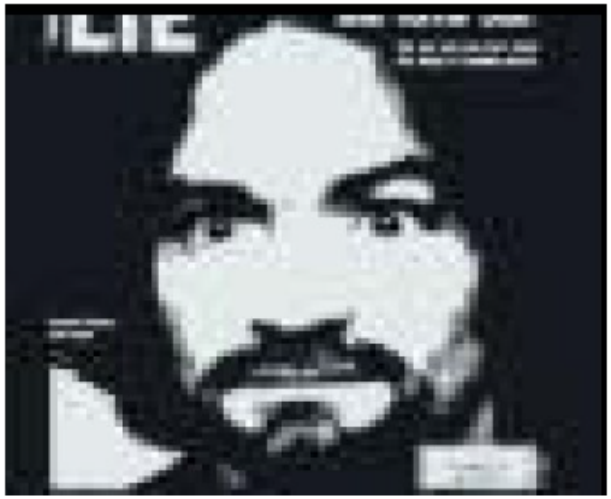


History of Communication Network..
Back to the FUTURE..

1969 was an Incredible year!!

- The first man landed on the Moon!
- The Woodstock Festival took place
- Charles Manson went on a killing spree
- THE INTERNET WAS BORN and nobody noticed!





History of Communication Network..

History of Communication Network..
What is the FIRST message ever sent on the internet??

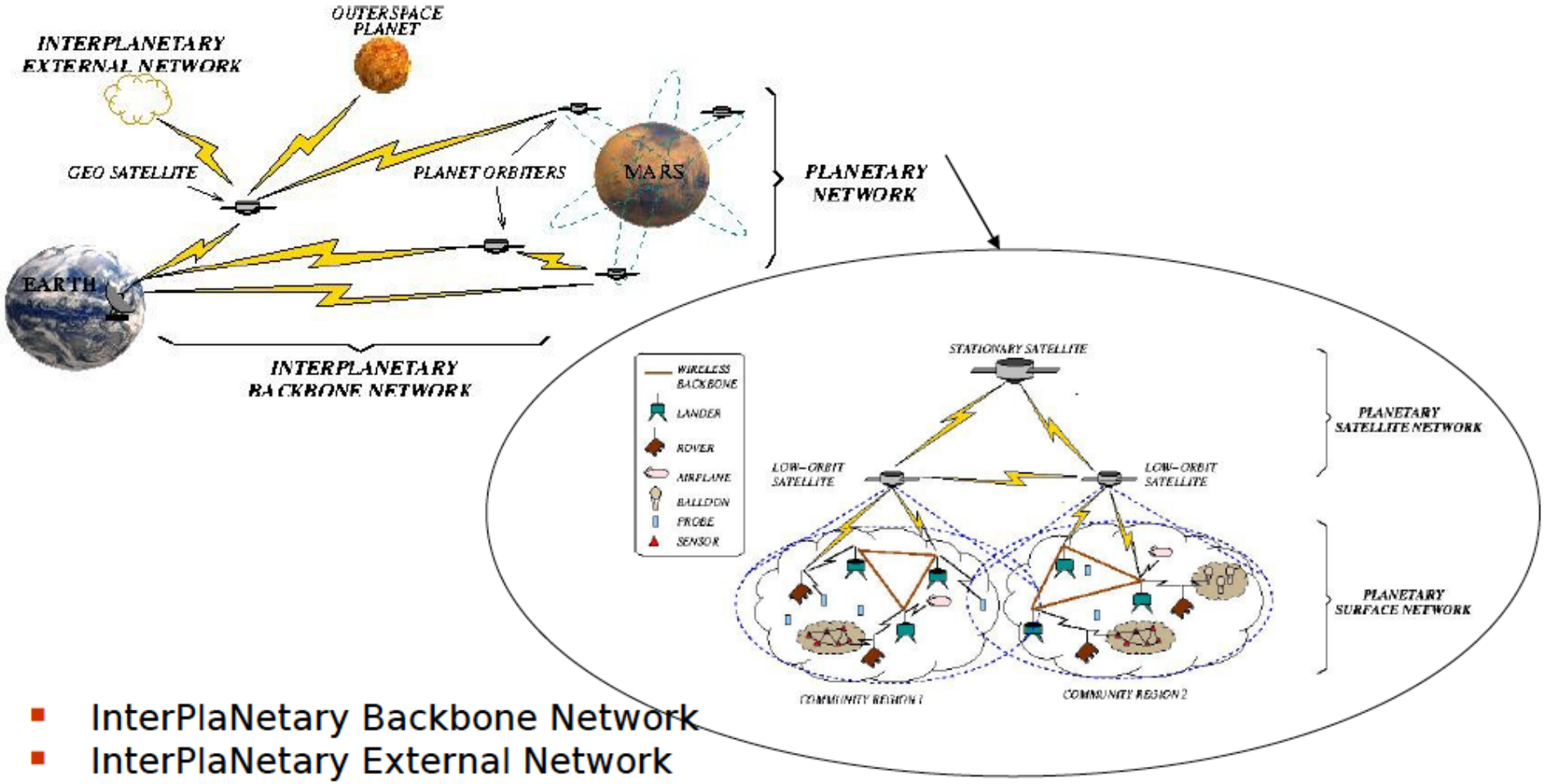
- Was it “What hath God Wrought” (Morse 1844)?
- Or “Watson, come here. I want you.” (Bell 1876)?
- Or “This is a Giant Step for Mankind” (Armstrong 1969)?

It was simply a LOGIN from the UCLA computer to the SRI computer.

- We sent an “L” - did you get the “L”? YEP!
- We sent an “O” - did you get the “O”? YEP!
- We sent a “G” - did you get the “G”?

(by Leonard Kleinrock)

And Now..



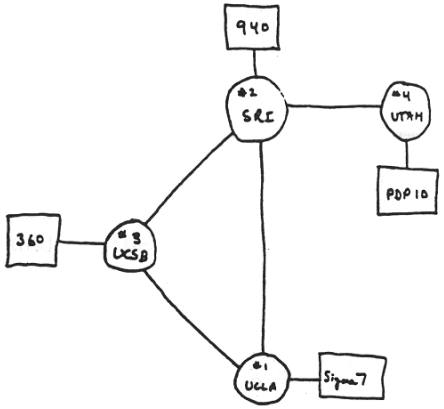
- InterPlaNetary Backbone Network
- InterPlaNetary External Network
- PlaNetary Network
  - PlaNetary Satellite Network
  - PlaNetary Surface Network

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 has 15 nodes



THE ARPA NETWORK

Internet history

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

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

define today's Internet architecture

Internet history

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control

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

Internet history

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

- early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

late 1990's – 2000's:

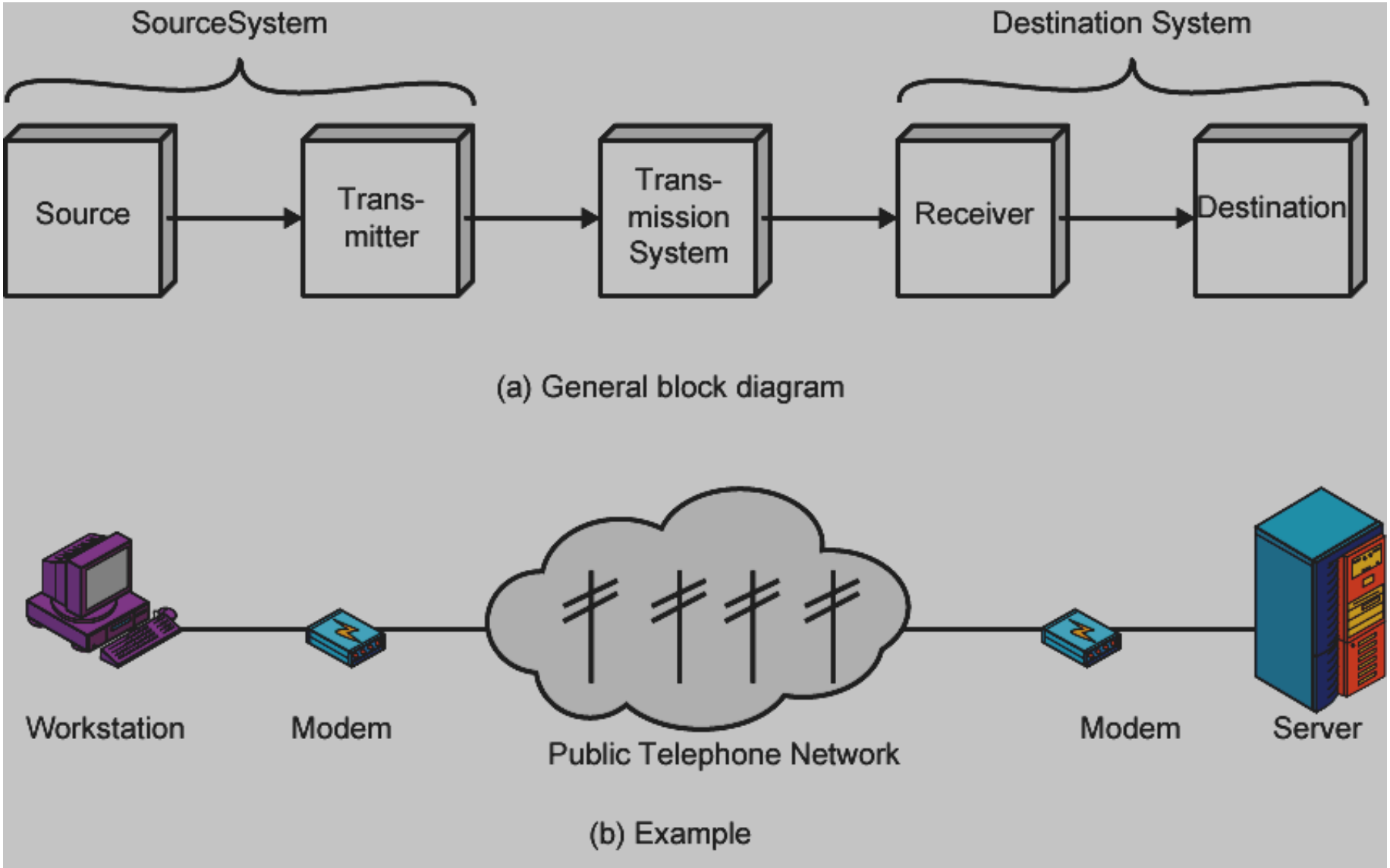
- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Internet history

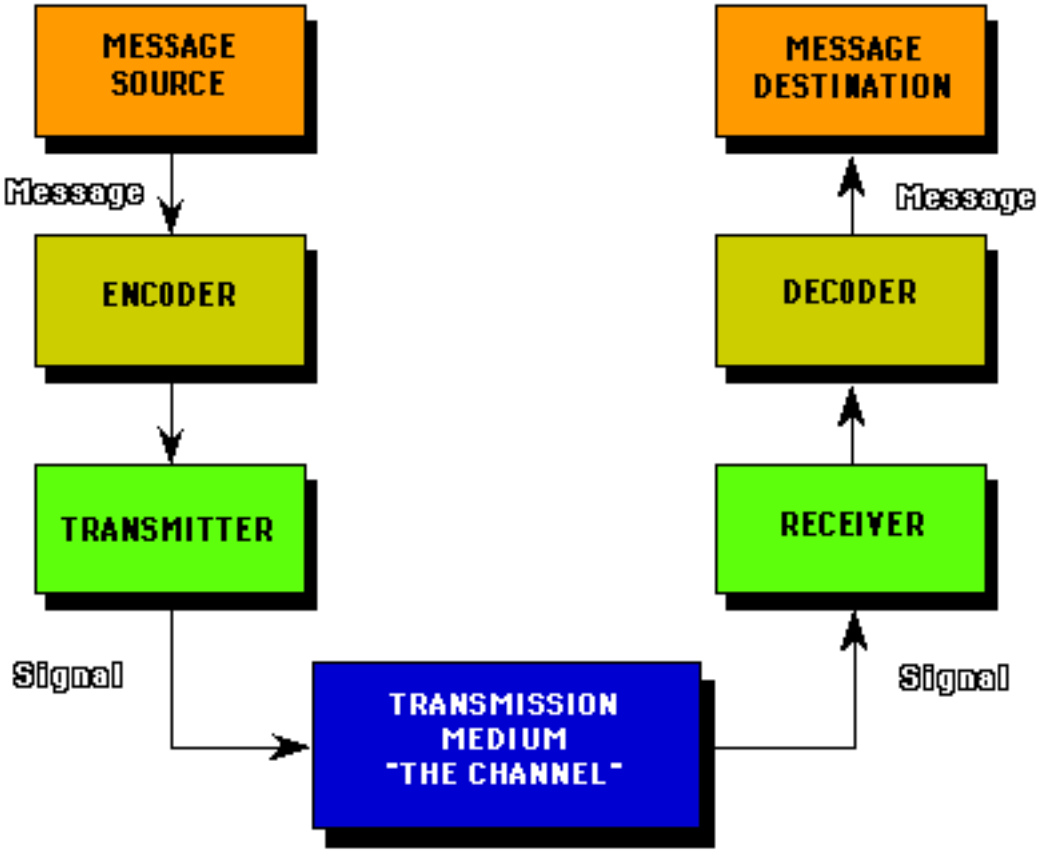
2005-present

- ~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)

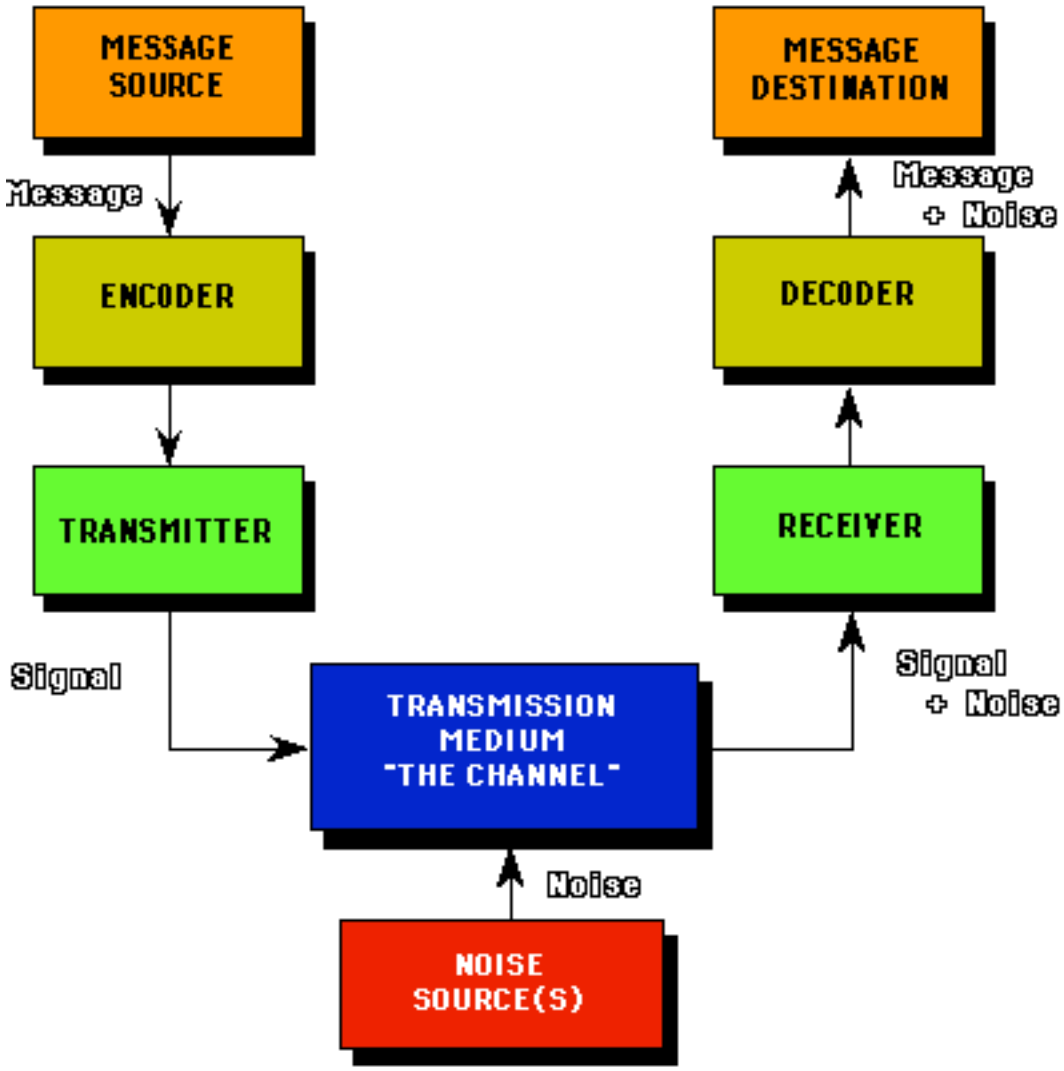
Communications Model



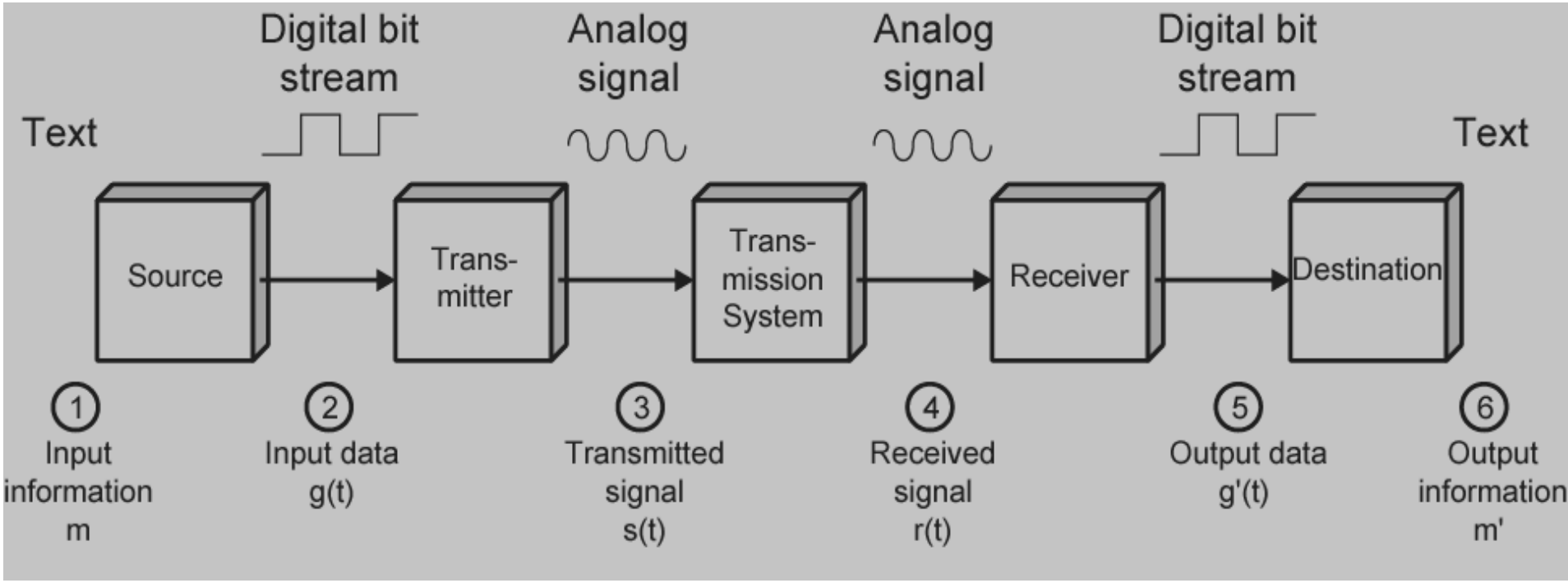
Shannon Communication Model



Shannon Communication Model



Data Communications Model



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

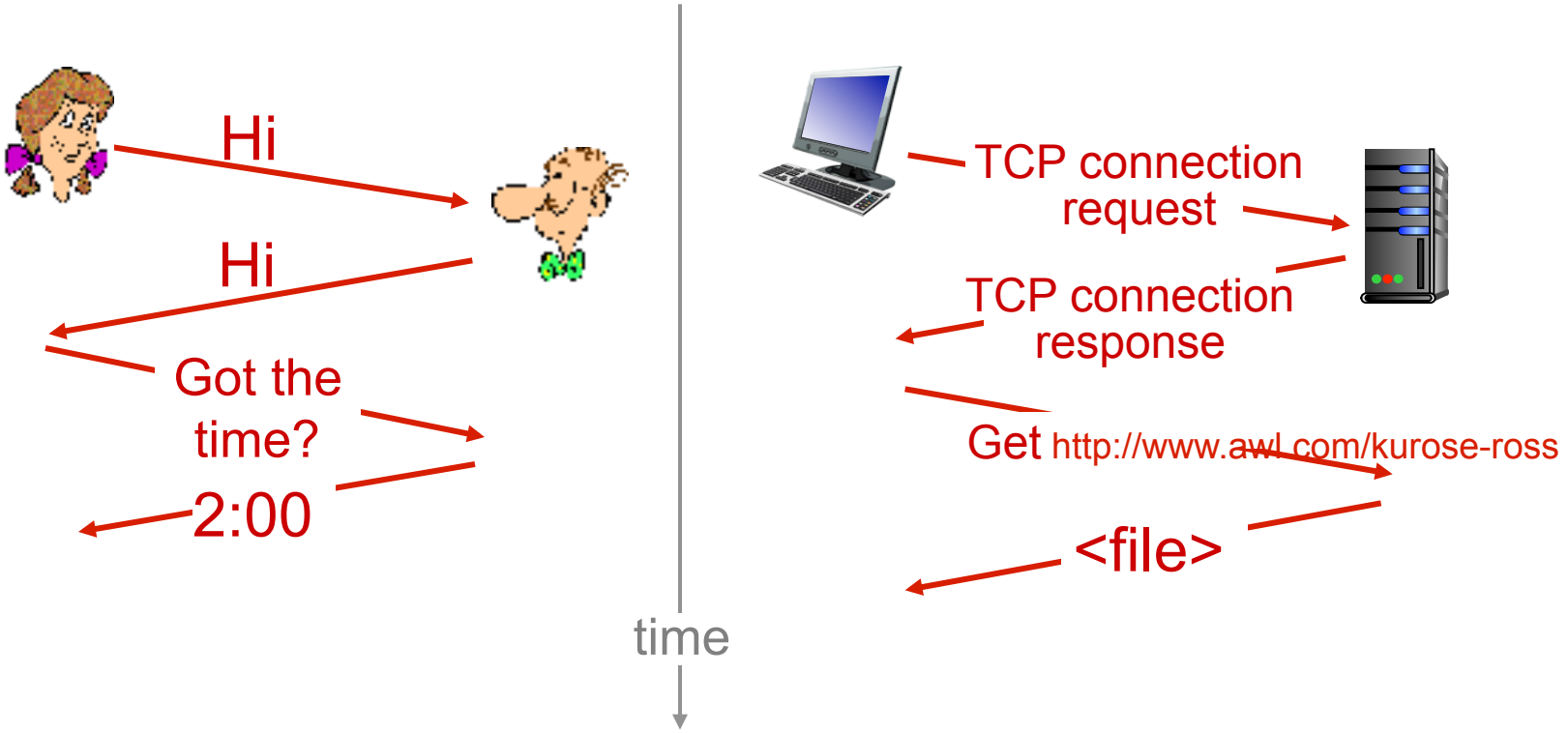
network protocols:

- 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:



Q: other human protocols?

Protocol "layers"

Networks are complex, with many "pieces":

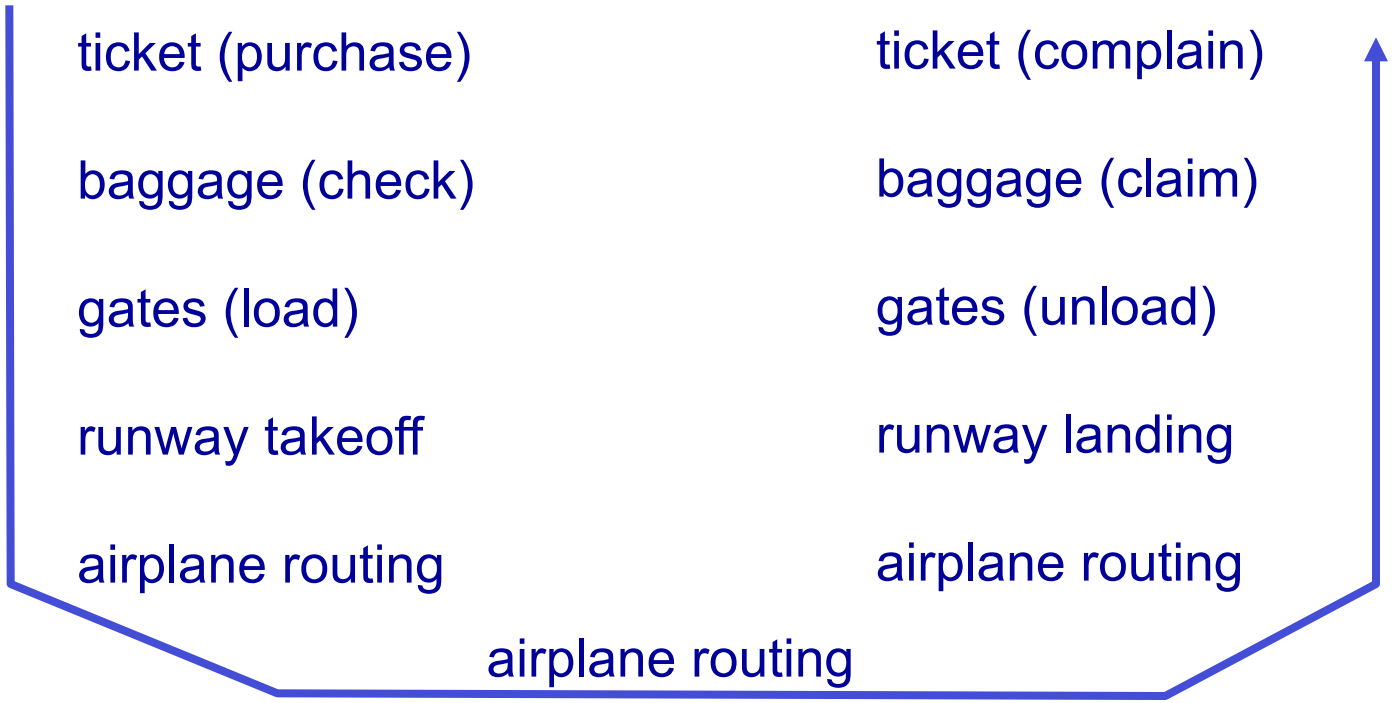
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

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

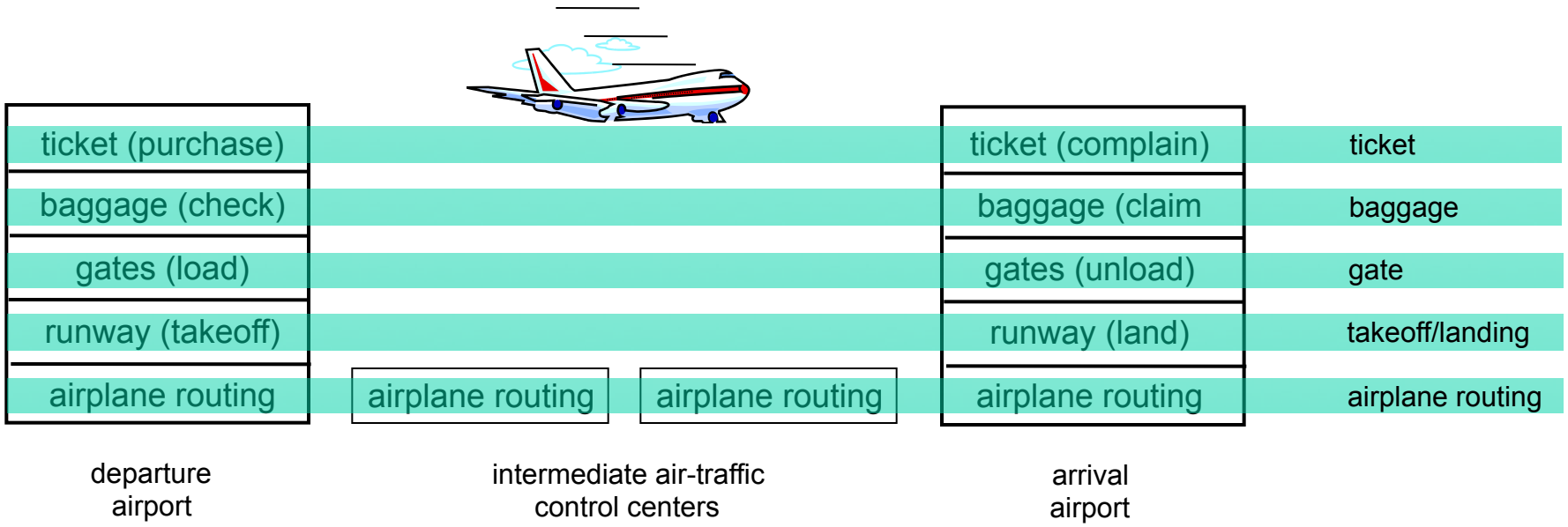
…. or at least our discussion of networks?

Organization of air travel



- a series of steps

Layering of airline functionality



layers: each layer implements a service

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

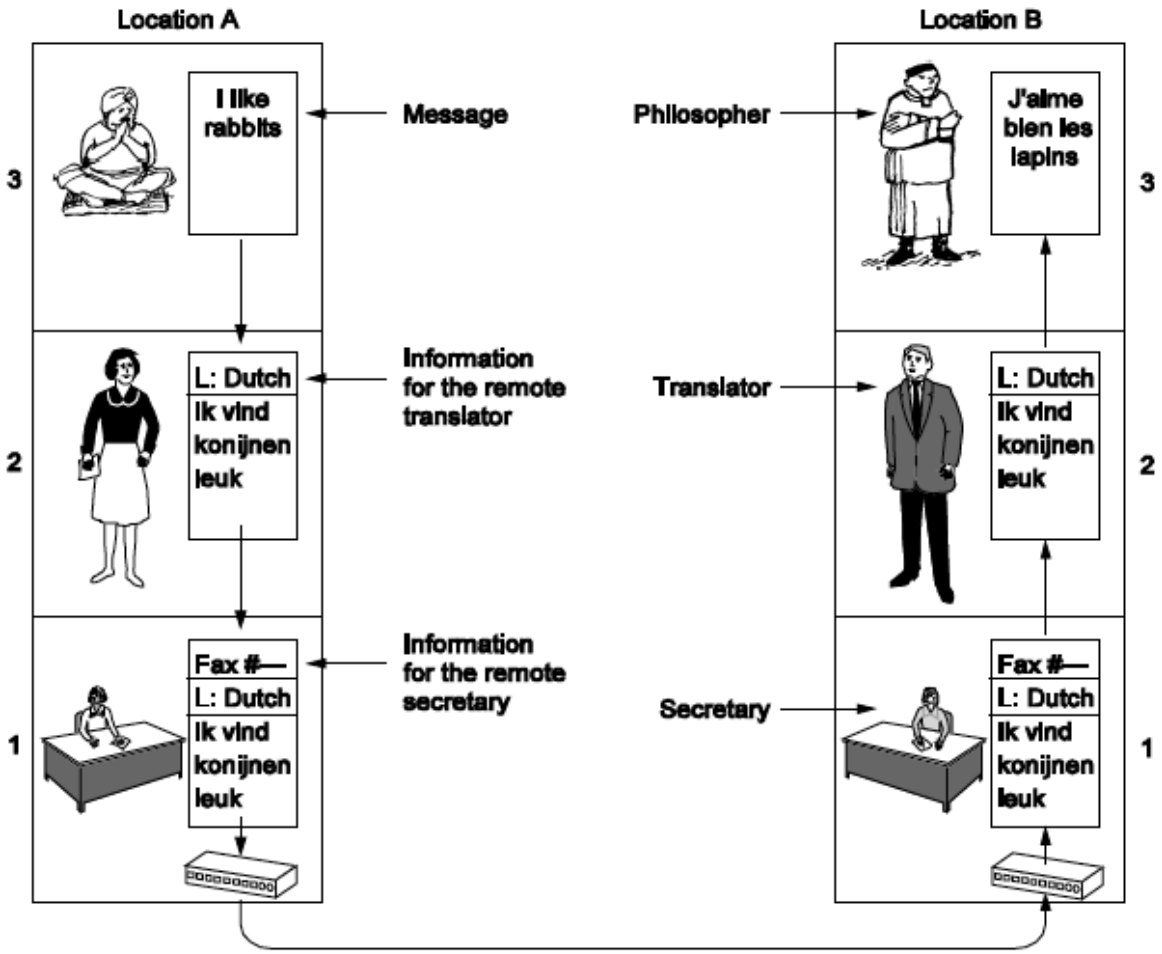
Why layering?

dealing with complex systems:

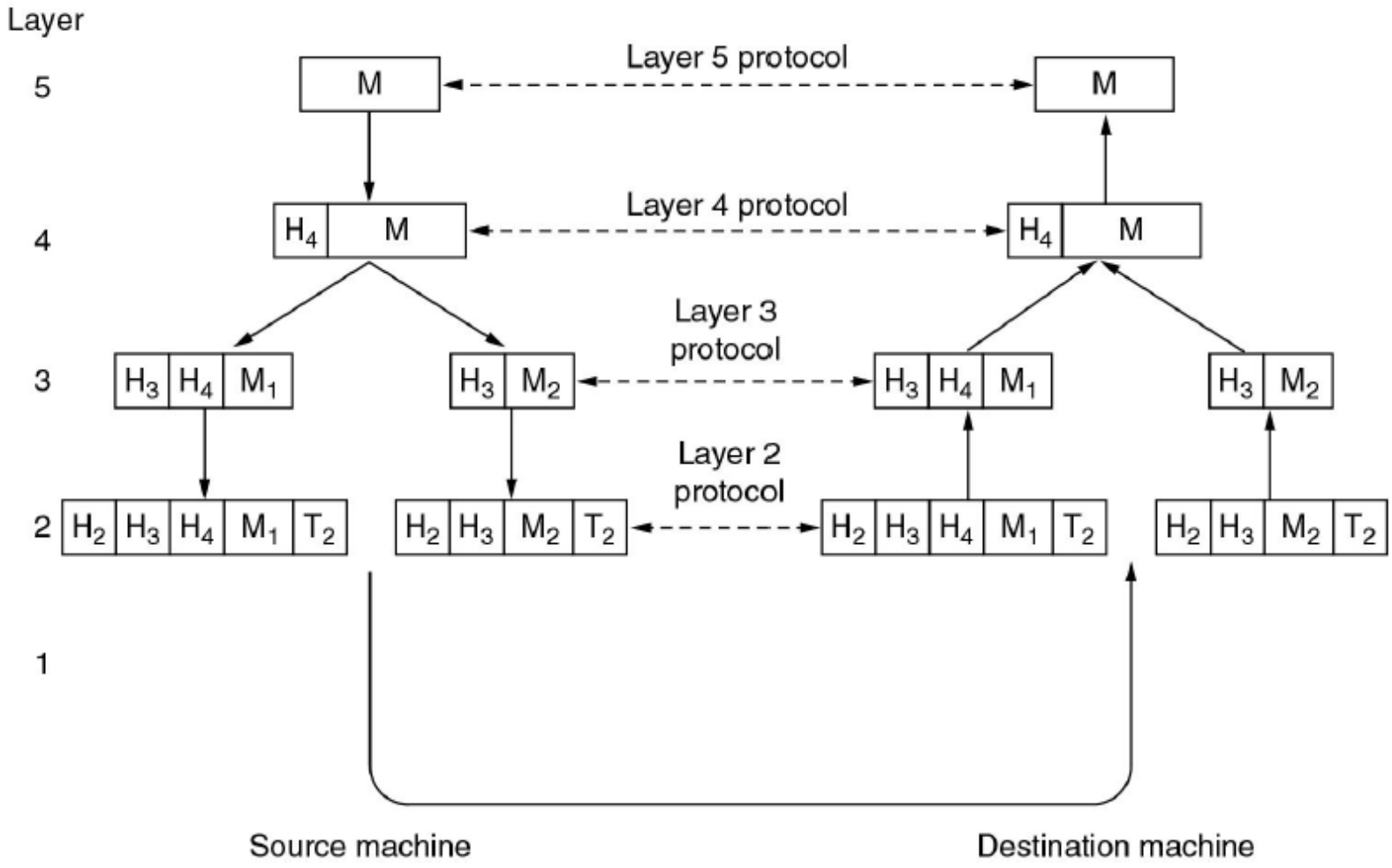
- explicit structure allows identification, relationship of complex system's pieces
  - layered *reference model* for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't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

Protocol Hierarchy..

- The philosopher-translator-secretary architecture.

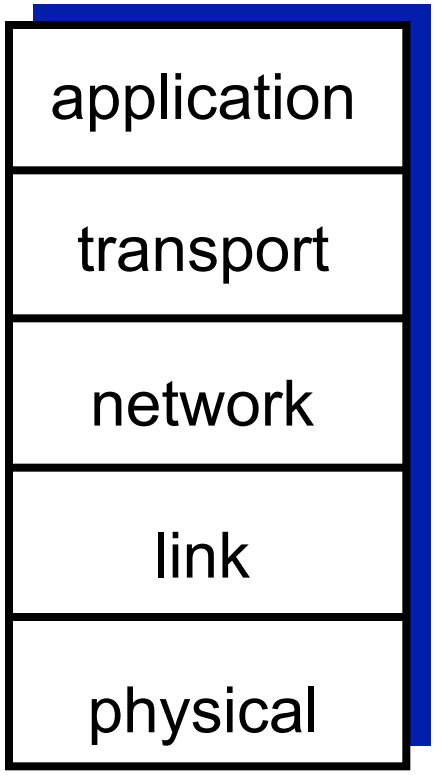


- Example information flow supporting virtual communication in layer 5.



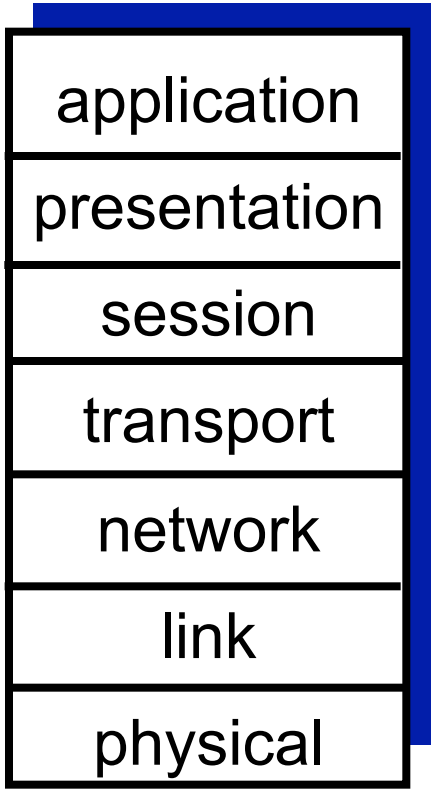
Internet protocol stack

- *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"

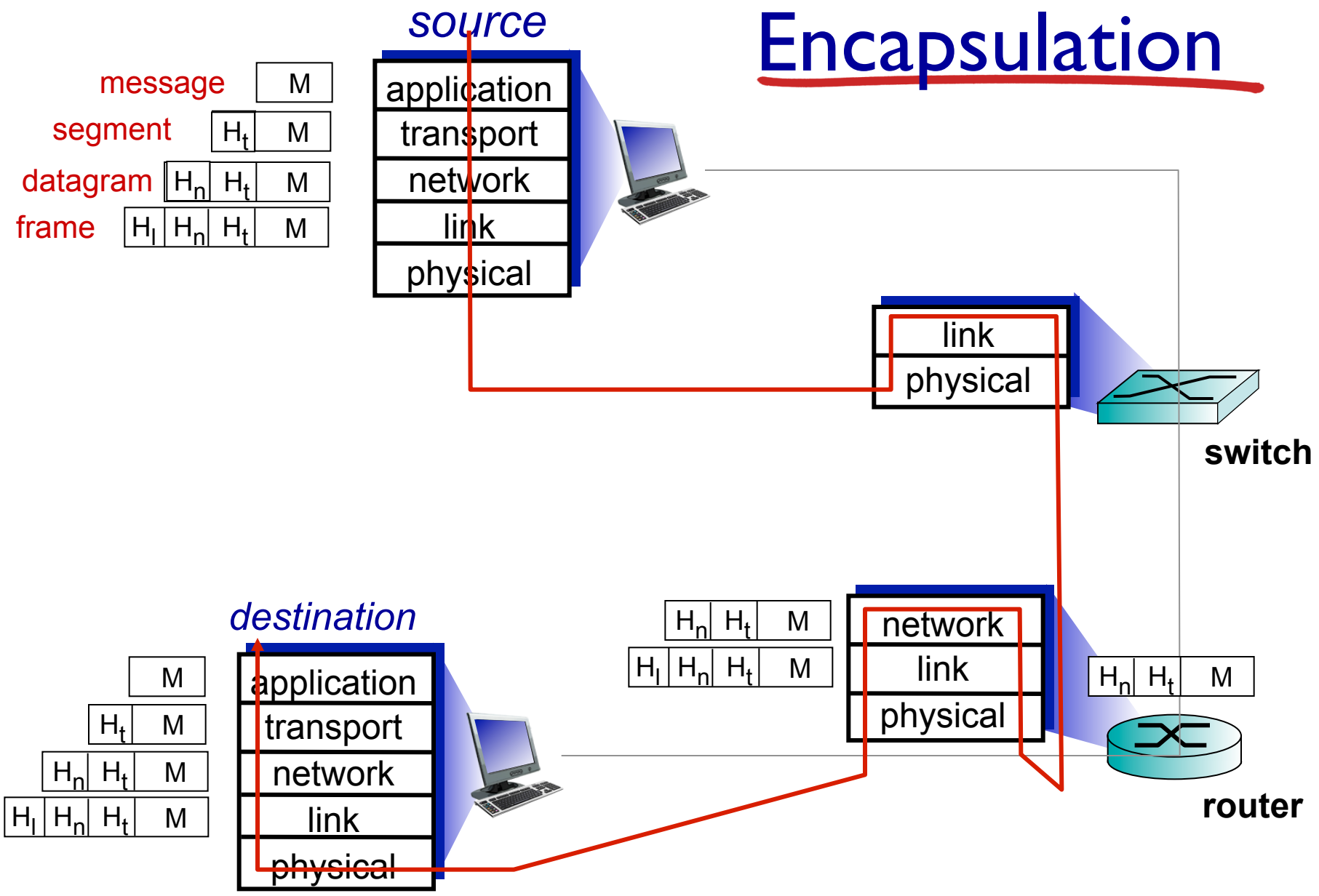


ISO/OSI reference model

- *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?



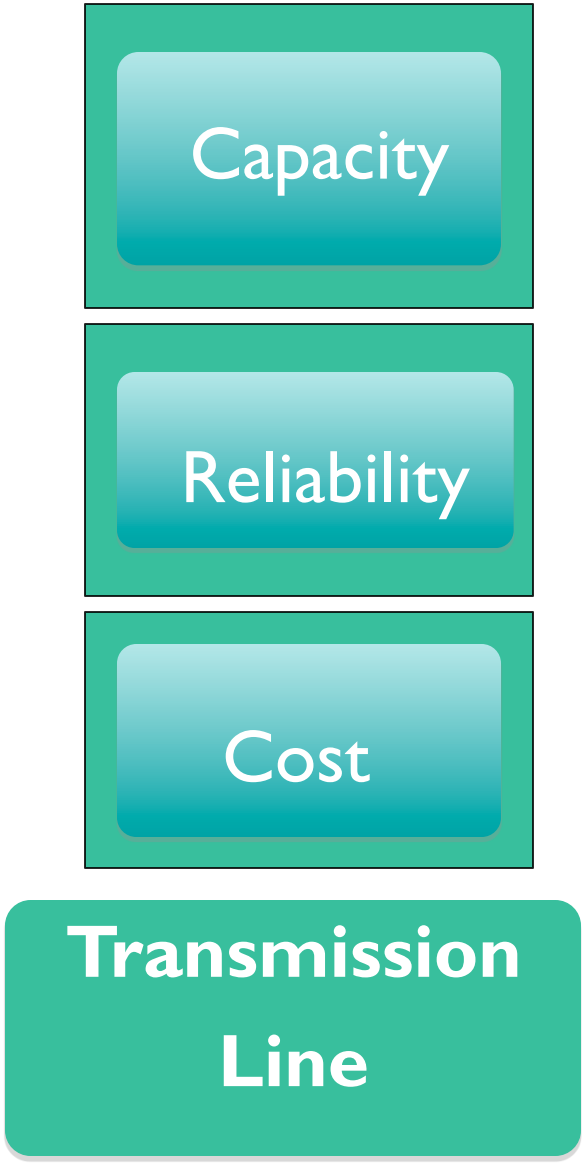
Encapsulation



Transmission Lines

The basic building block of any communications facility is the transmission line.

The business manager is concerned with a facility providing the required capacity, with acceptable reliability, at minimum cost.



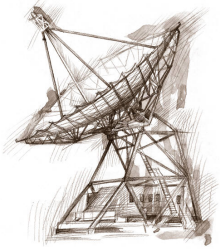
Transmission Mediums

Two mediums currently driving the evolution of data communications transmission are:

Fiber optic transmissions

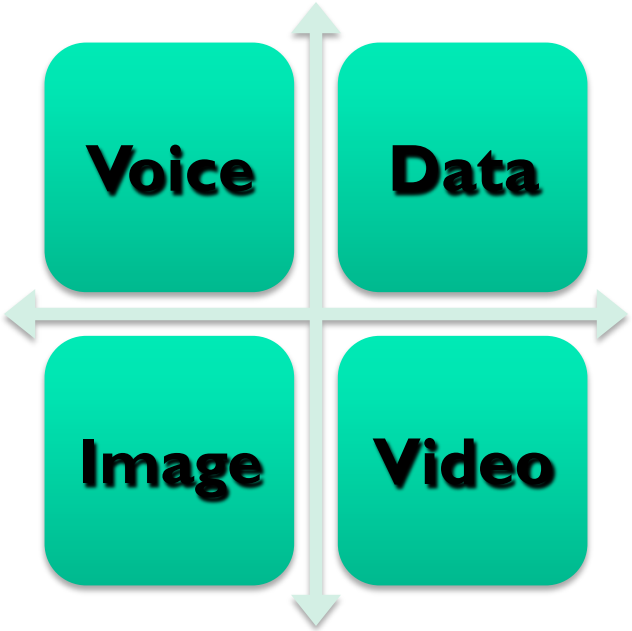
and

Wireless transmissions



Networking

Advances in technology have led to greatly increased capacity and the concept of integration, allowing equipment and networks to work simultaneously.



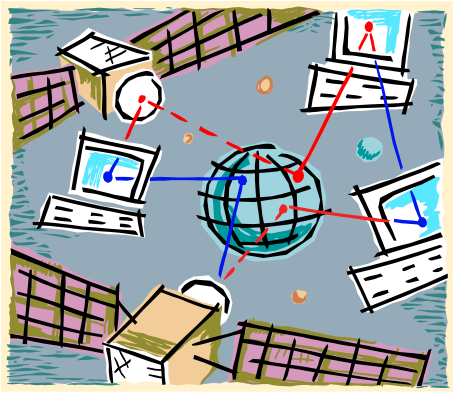
LANs and WANs

There are two broad categories of networks:

- **Local Area Networks (LAN)**
- **Wide Area Networks (WAN)**

Wide Area Networks (WANs)

- Span a large geographical area
- Require the crossing of public right-of-ways
- Rely in part on common carrier circuits
- Typically consist of a number of interconnected switching nodes



Wide Area Networks

Alternative technologies used include:

- Circuit switching
- Packet switching
- Frame relay
- Asynchronous Transfer Mode (ATM)

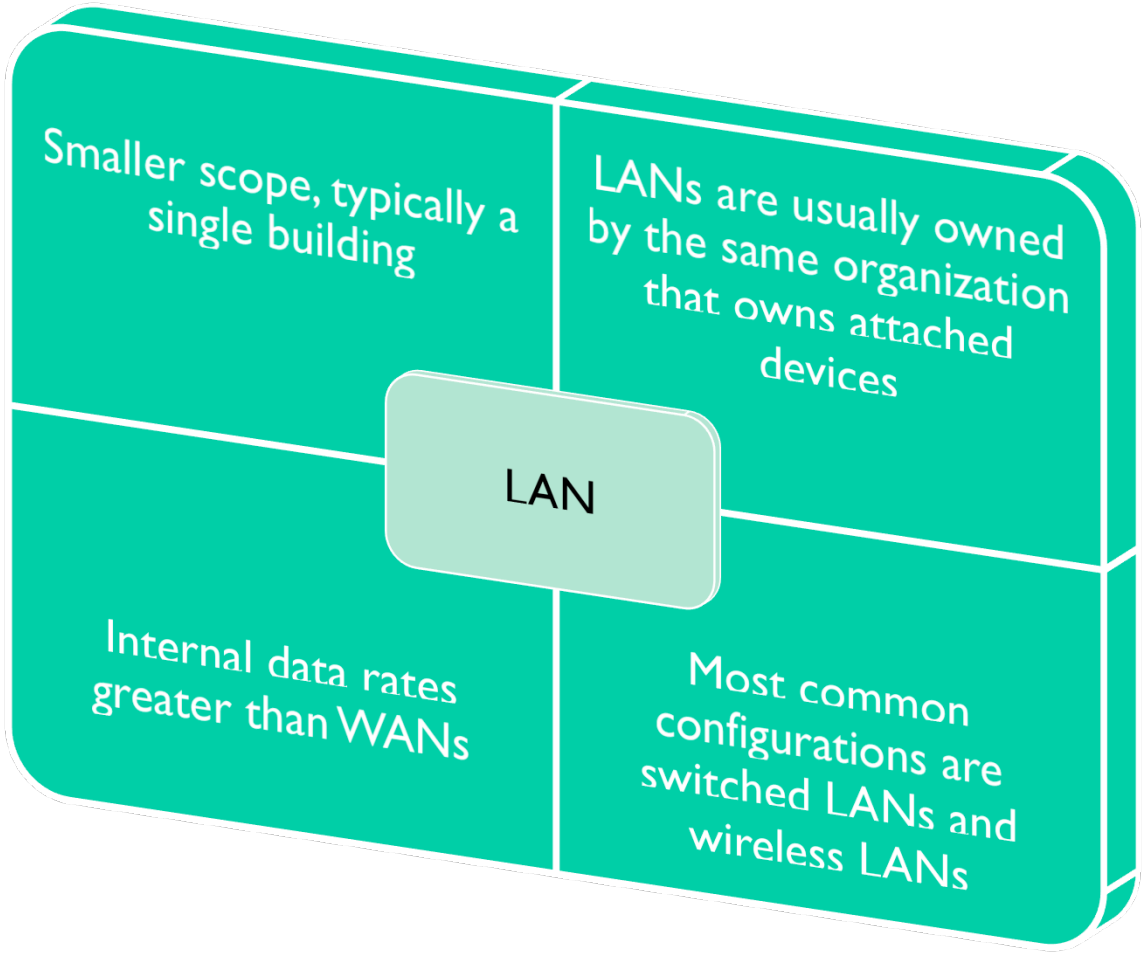
Circuit Switching

- Uses a dedicated communications path
- Connected sequence of physical links between nodes
- Logical channel dedicated on each link
- Rapid transmission
- The most common example of circuit switching is the telephone network

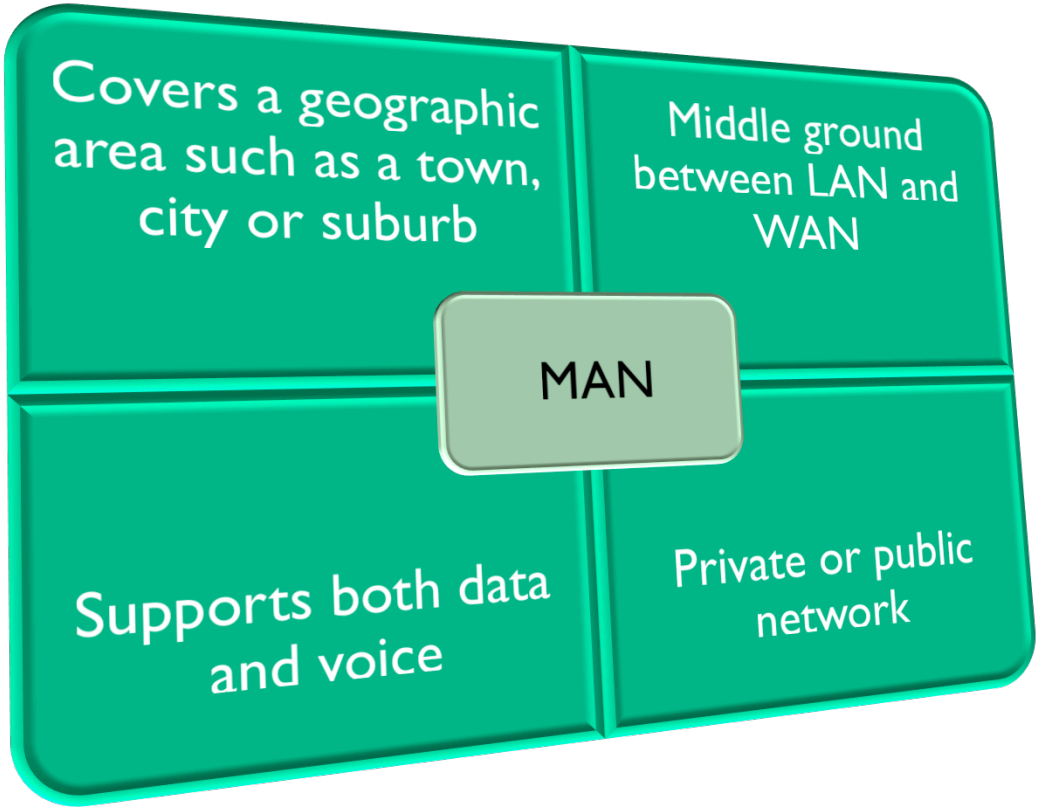
Packet Switching

- Data are sent out in a sequence of small chunks called packets
- Packets are passed from node to node along a path leading from source to destination
- Packet-switching networks are commonly used for terminal-to-terminal computer and computer-to-computer communications

Local Area Networks (LAN)

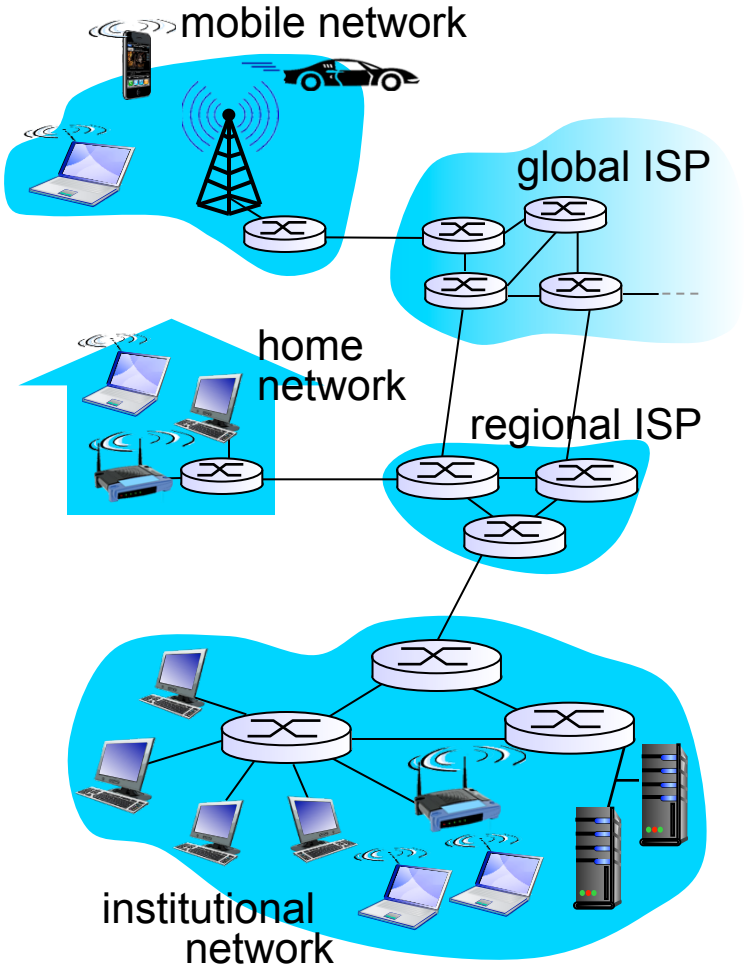


Metropolitan Area Networks (MAN)



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



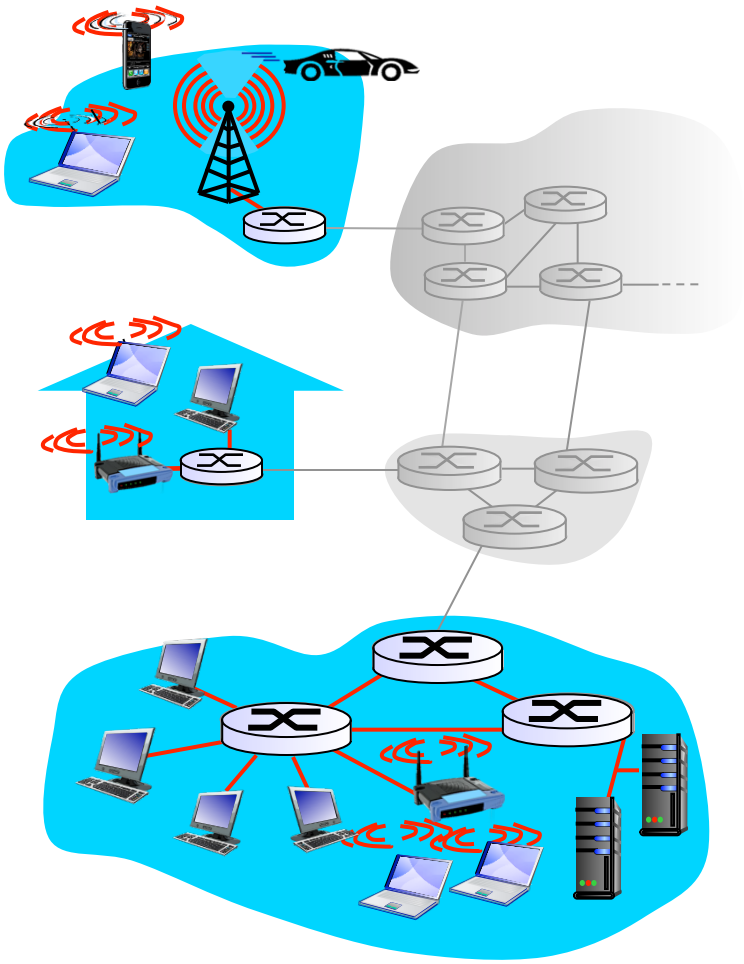
Access networks and physical media

Q: How to connect end systems to edge router?

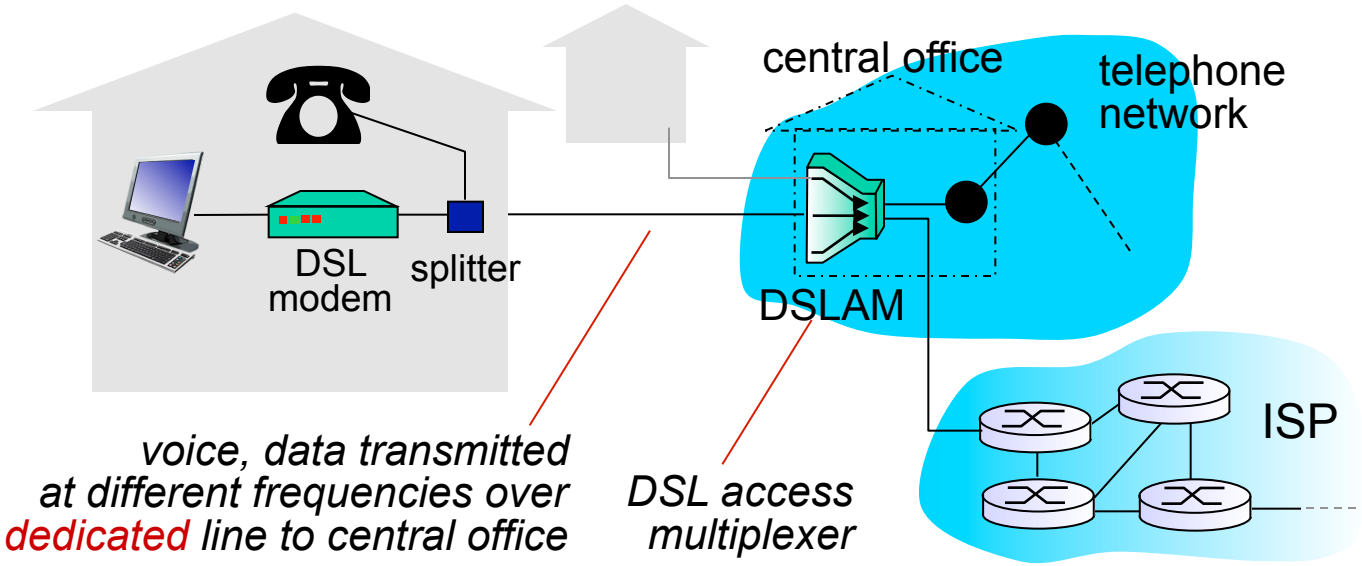
- residential access nets
- institutional access networks (school, company)
- mobile access networks

keep in mind:

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

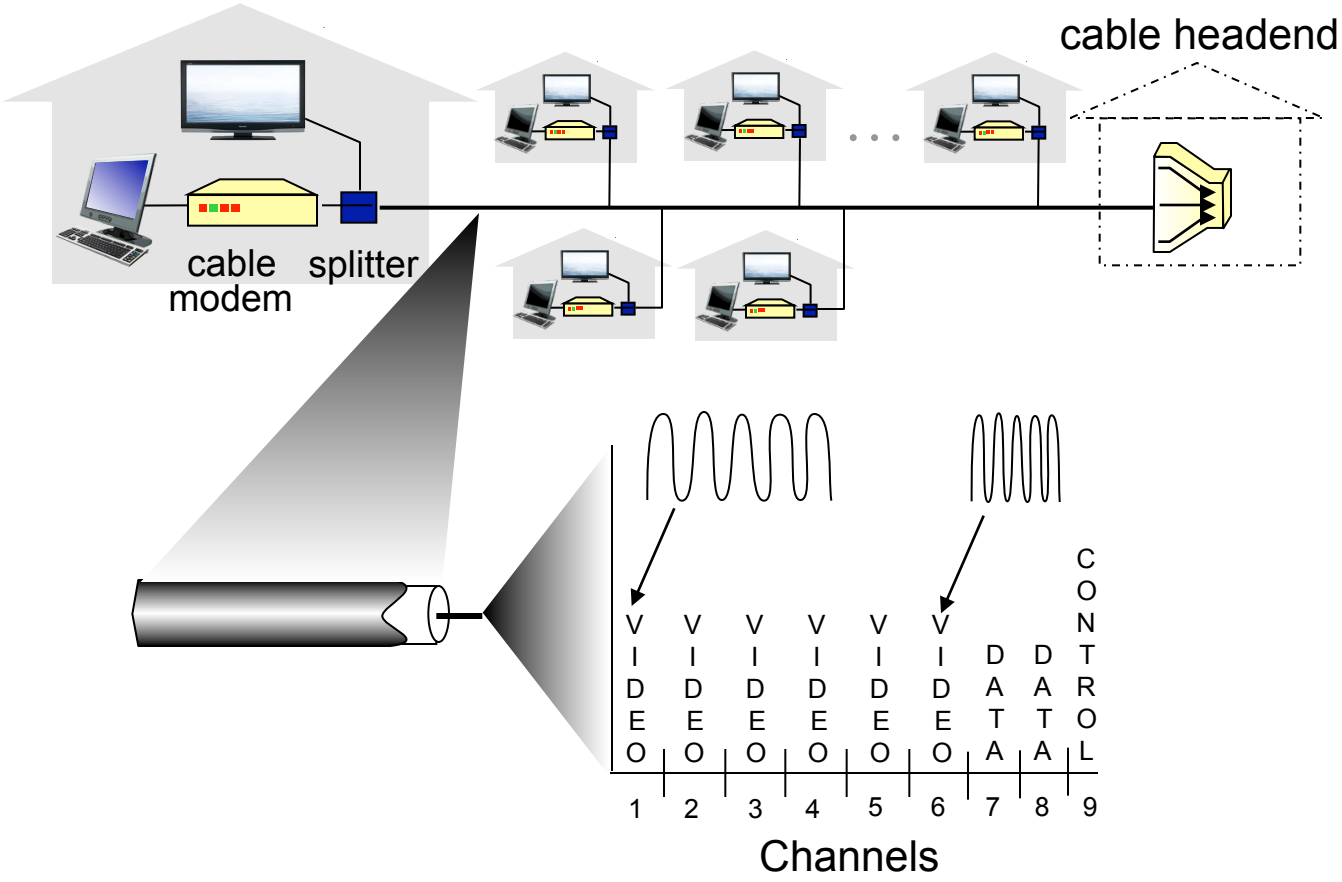


Access net: digital subscriber line (DSL)



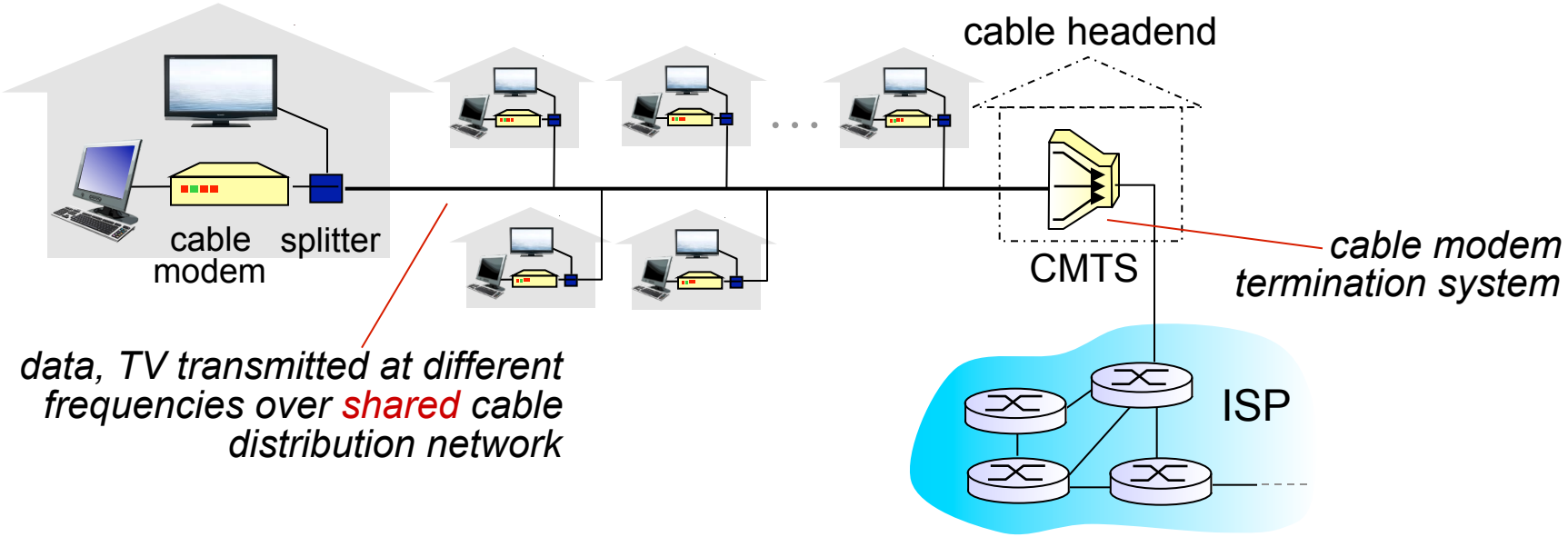
- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access net: cable network



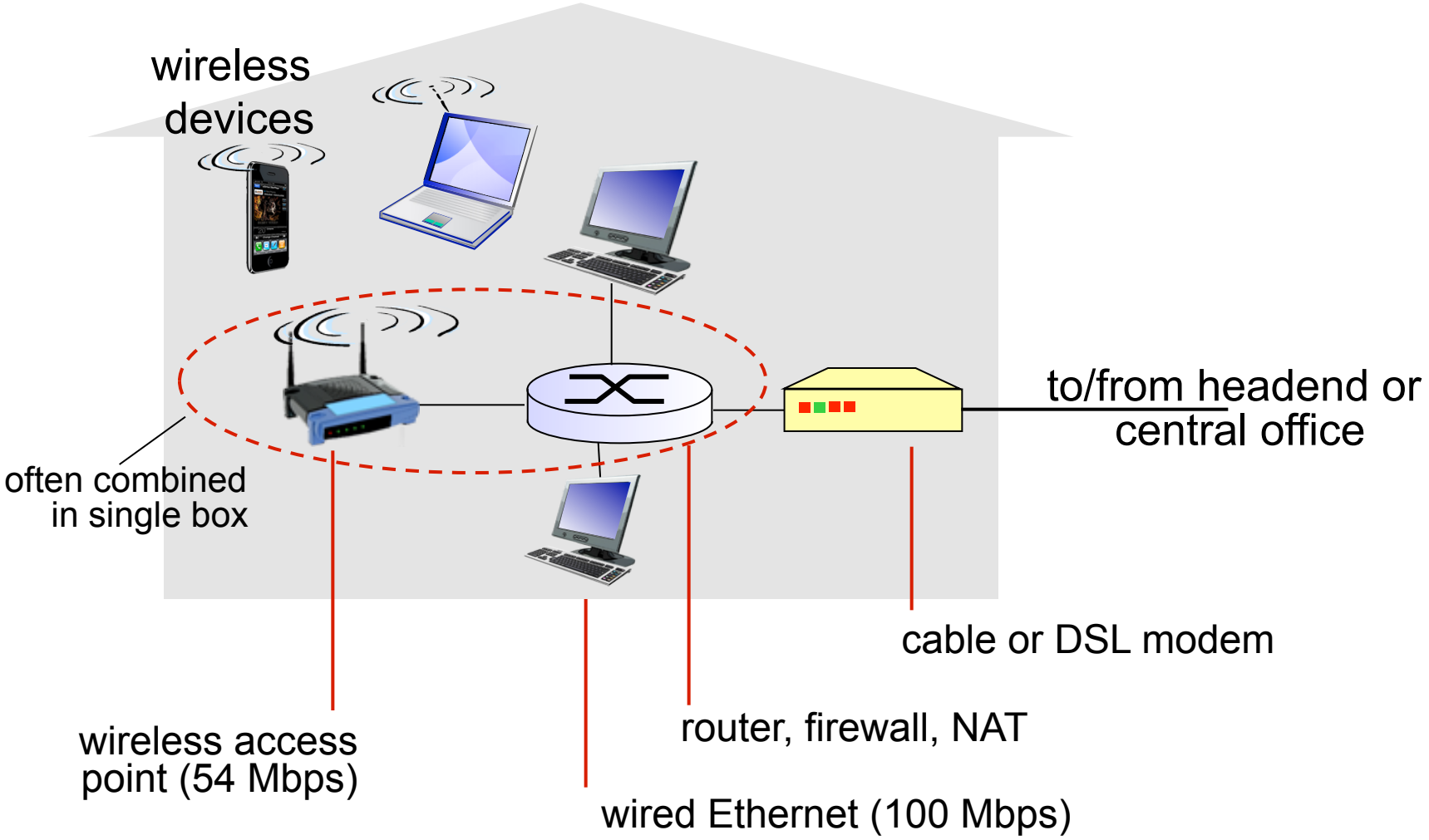
frequency division multiplexing: different channels transmitted in different frequency bands

Access net: cable network

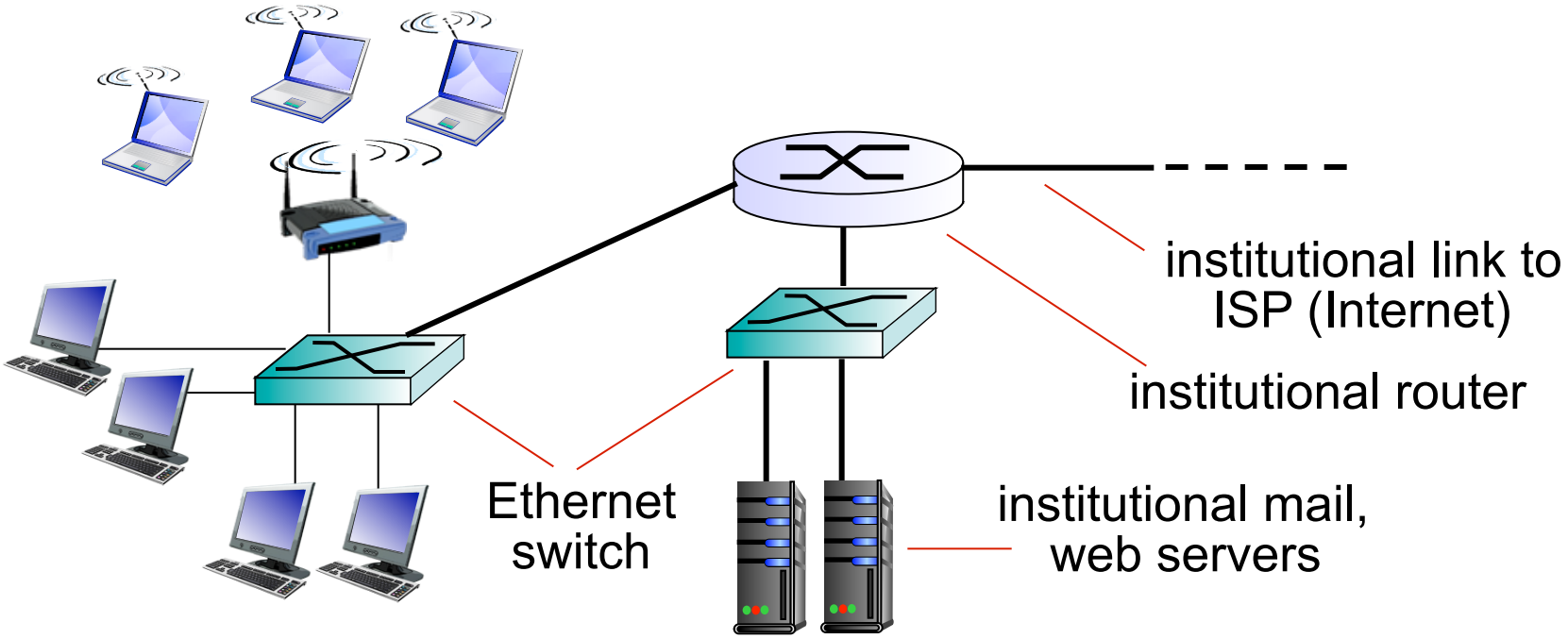


- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend
  - unlike DSL, which has dedicated access to central office

Access net: home network



Enterprise access networks (Ethernet)



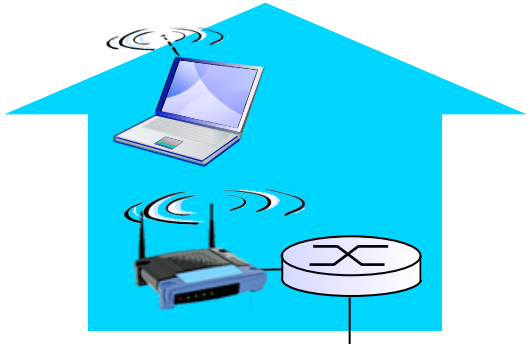
- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

Wireless access networks

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

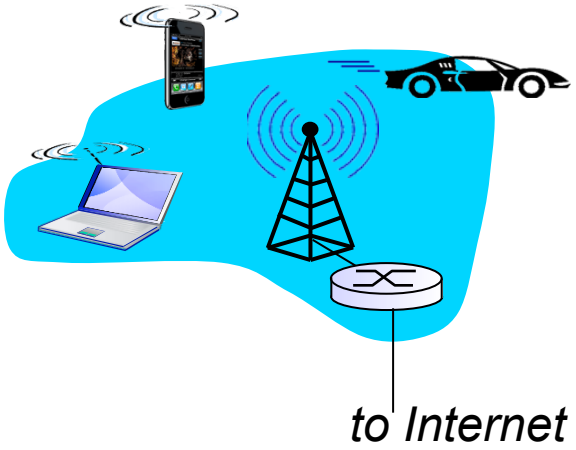
wireless LANs:

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



wide-area wireless access

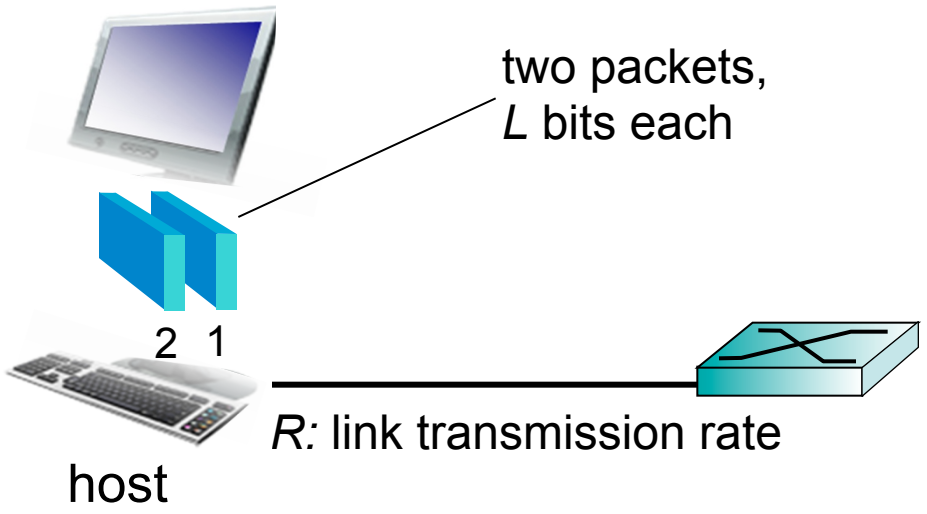
- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE



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*

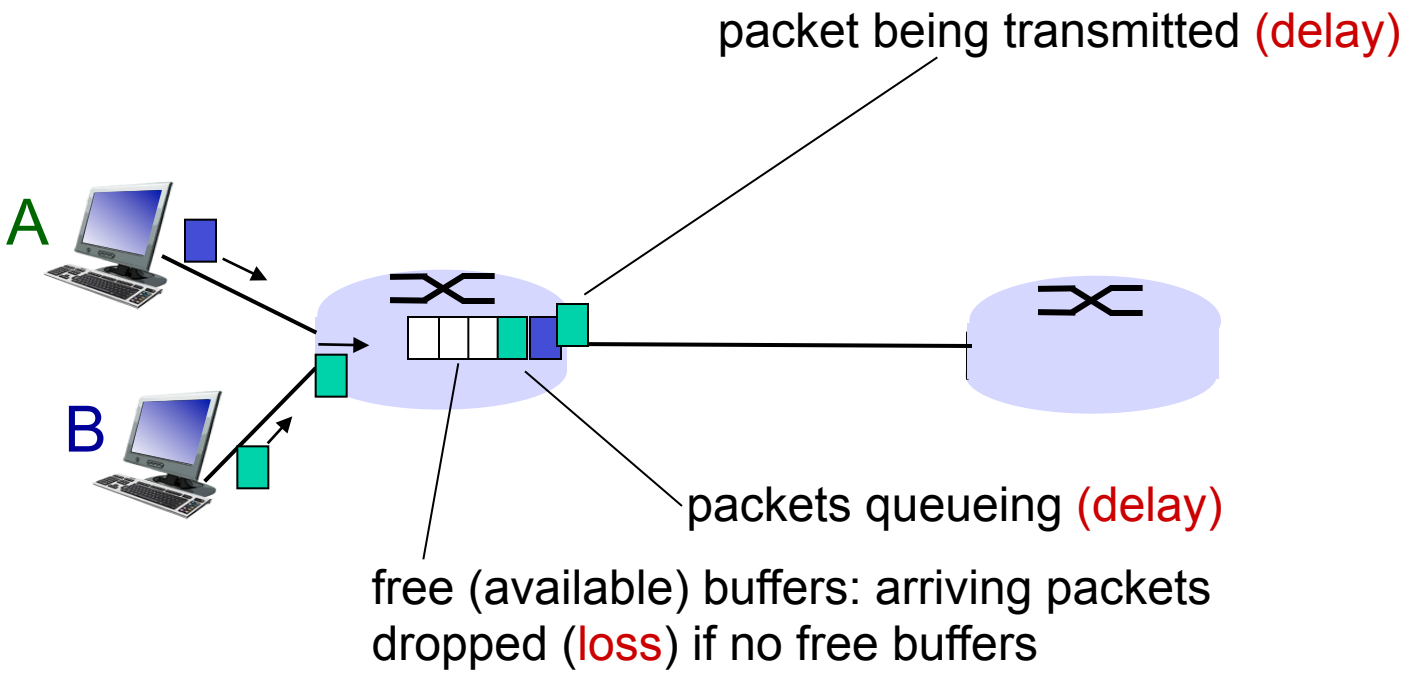


$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

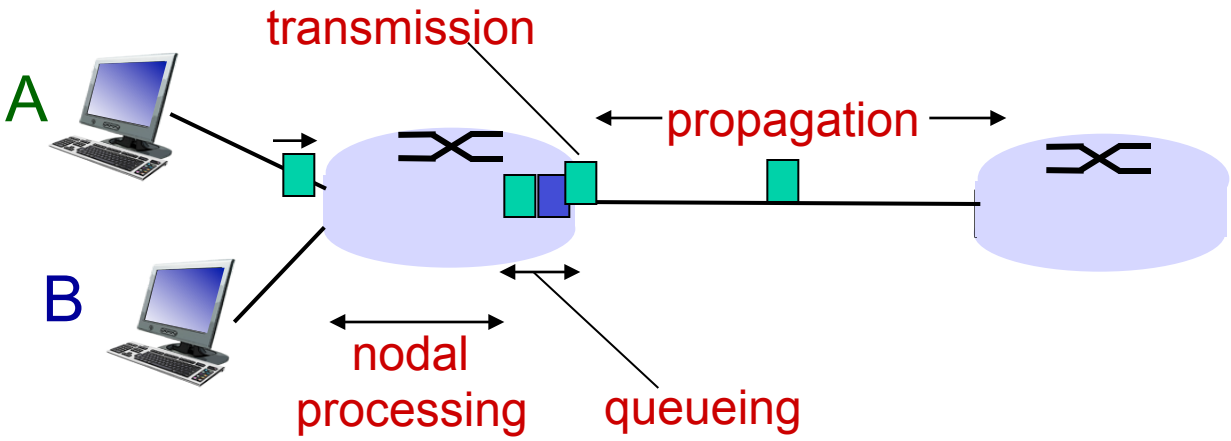
How do loss and delay occur?

packets *queue* in router buffers

- packet arrival rate to link (temporarily) exceeds output link capacity
- packets queue, wait for turn



Four sources of packet delay



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

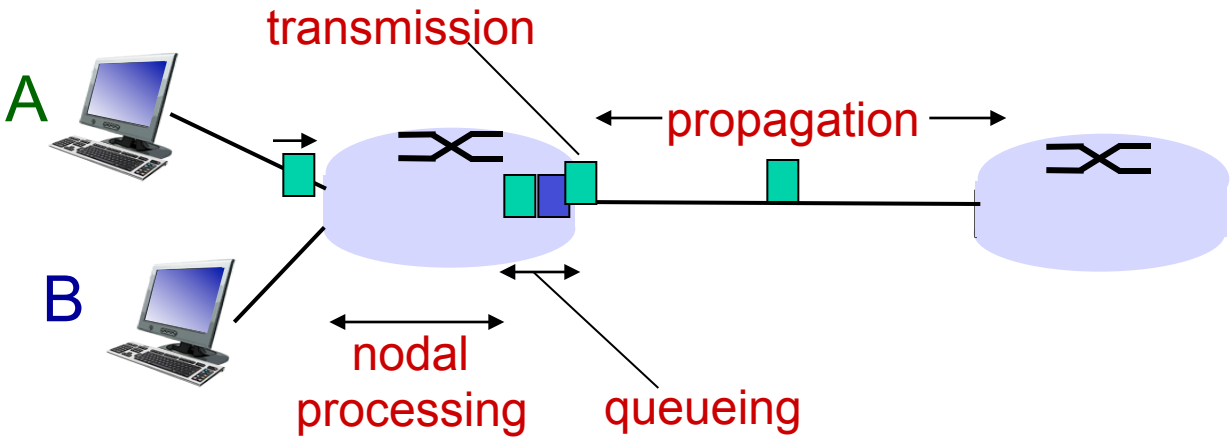
d_{proc}: nodal processing

- 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



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

d_{trans}: transmission delay:

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

d_{prop}: propagation delay:

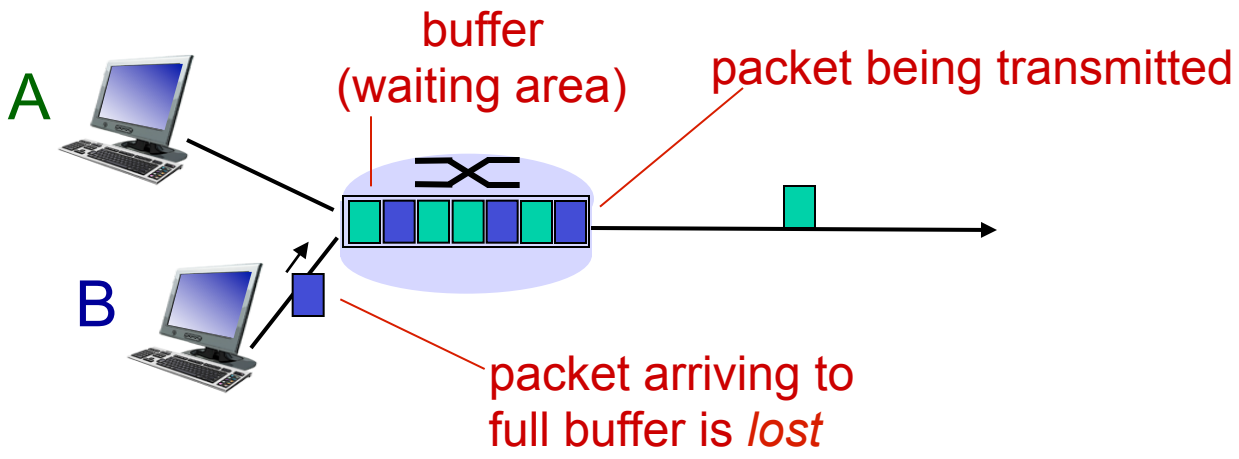
- d: length of physical link
- s: propagation speed in medium ($\sim 2 \times 10^8$ m/sec)
- $d_{prop} = d/s$

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

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

Packet loss

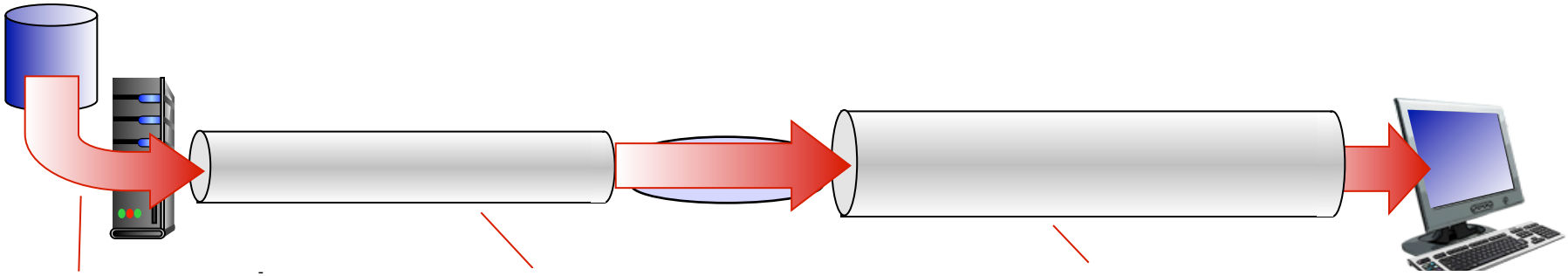
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



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

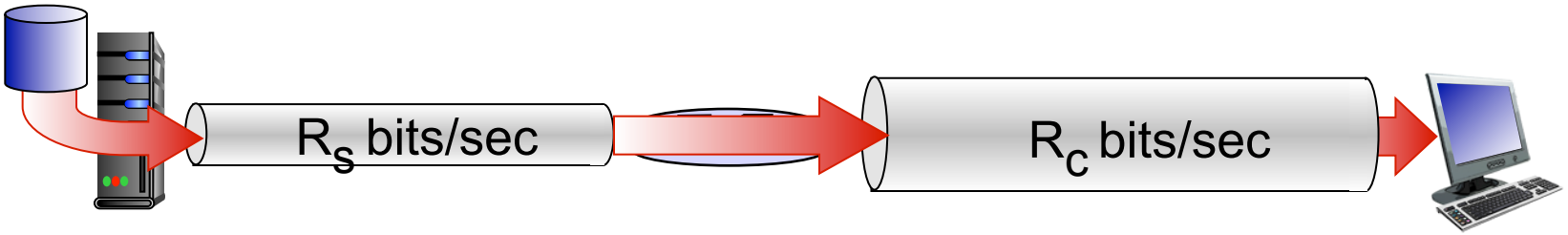
Throughput

- *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

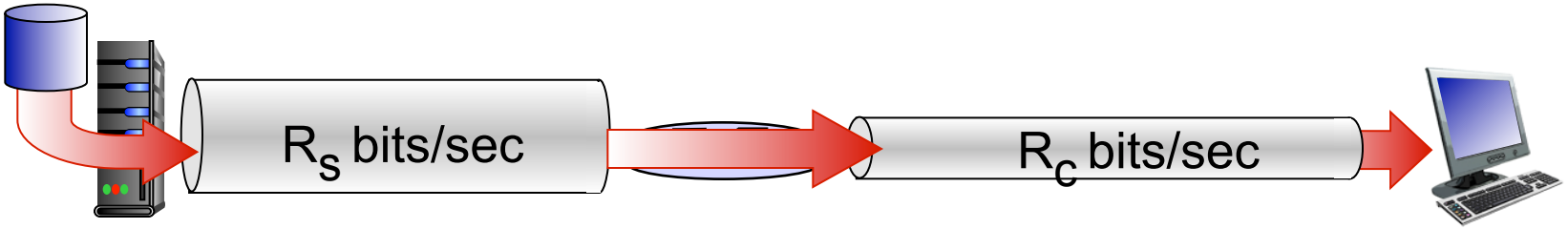


Throughput (more)

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



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

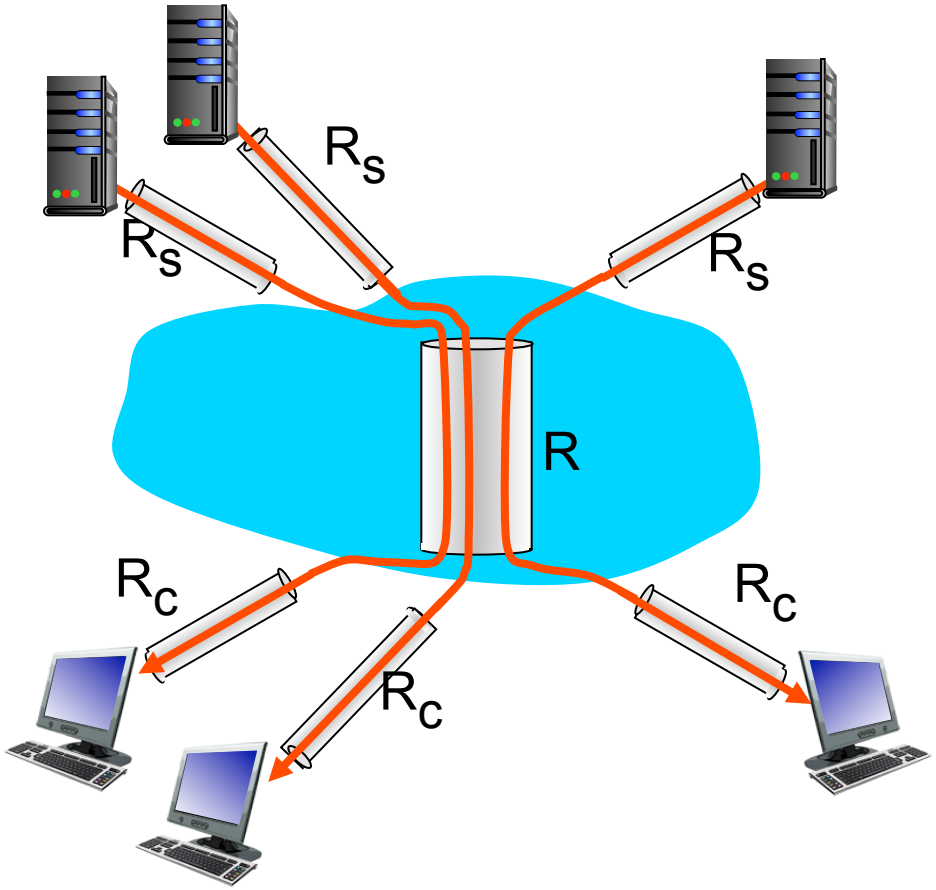


bottleneck link

link on end-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

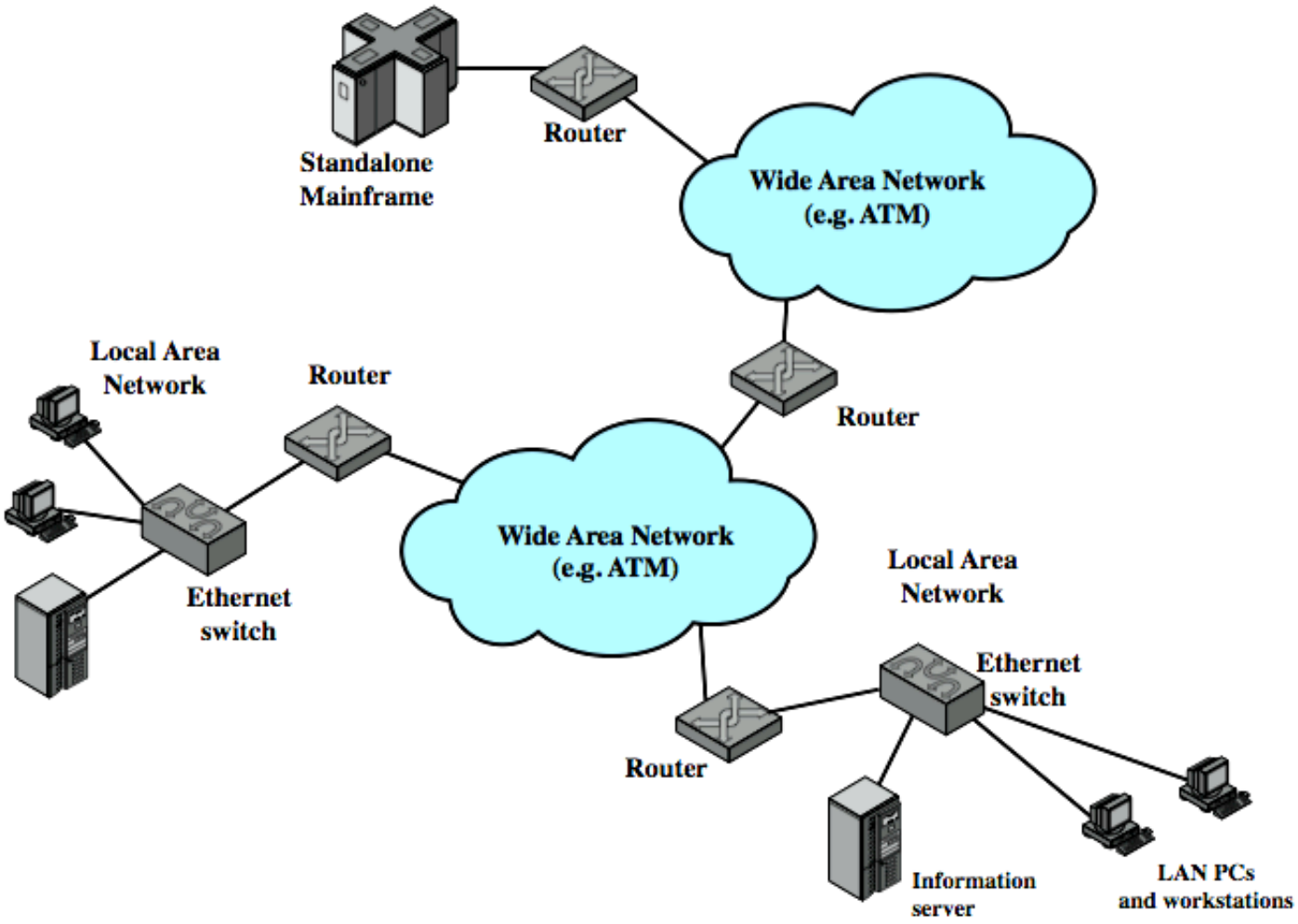


10 connections (fairly) share backbone bottleneck link R bits/sec

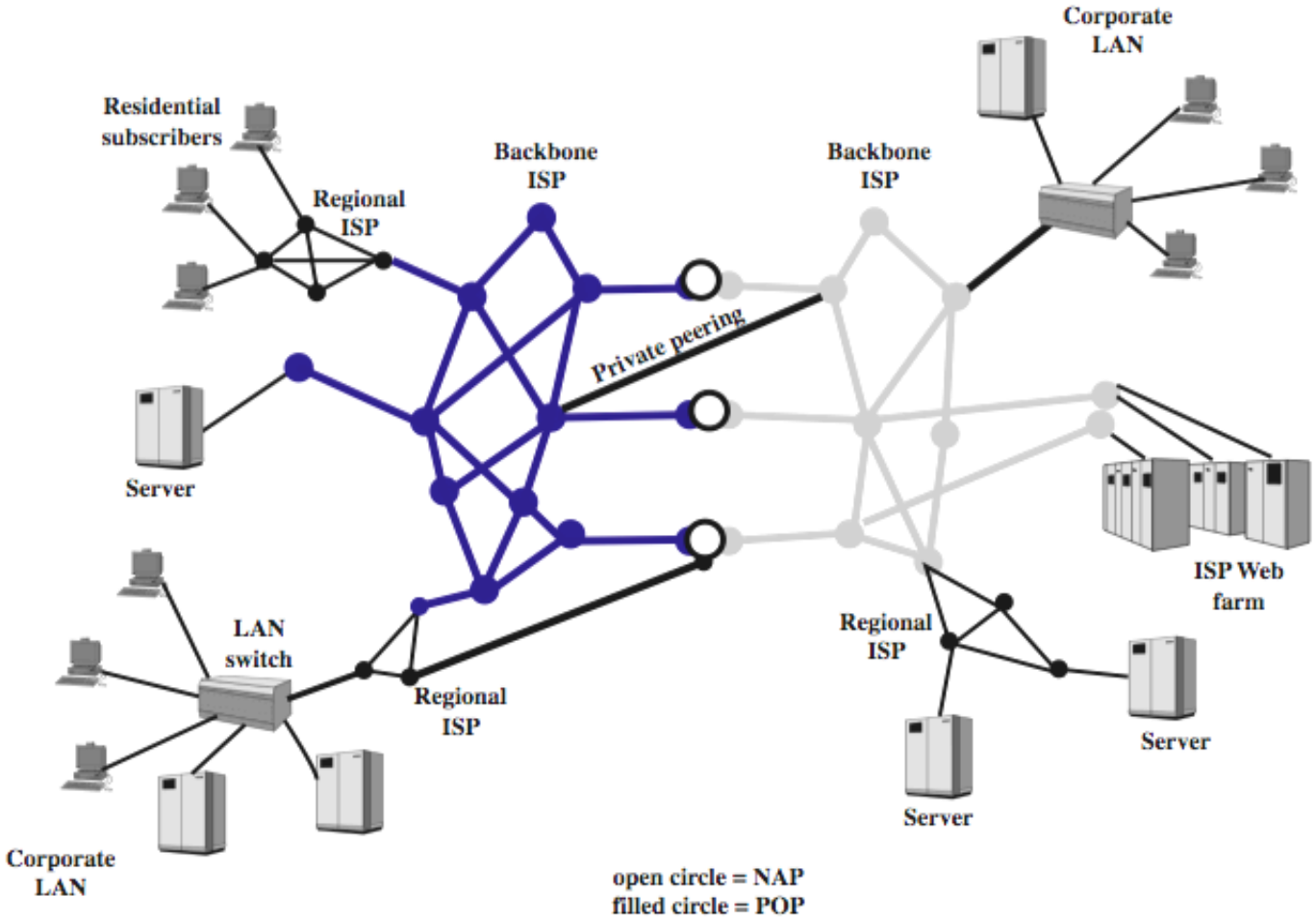
The Internet

- Internet evolved from ARPANET
- Developed to solve the dilemma of communicating across arbitrary, multiple, packet-switched network
- TCP/IP provides the foundation

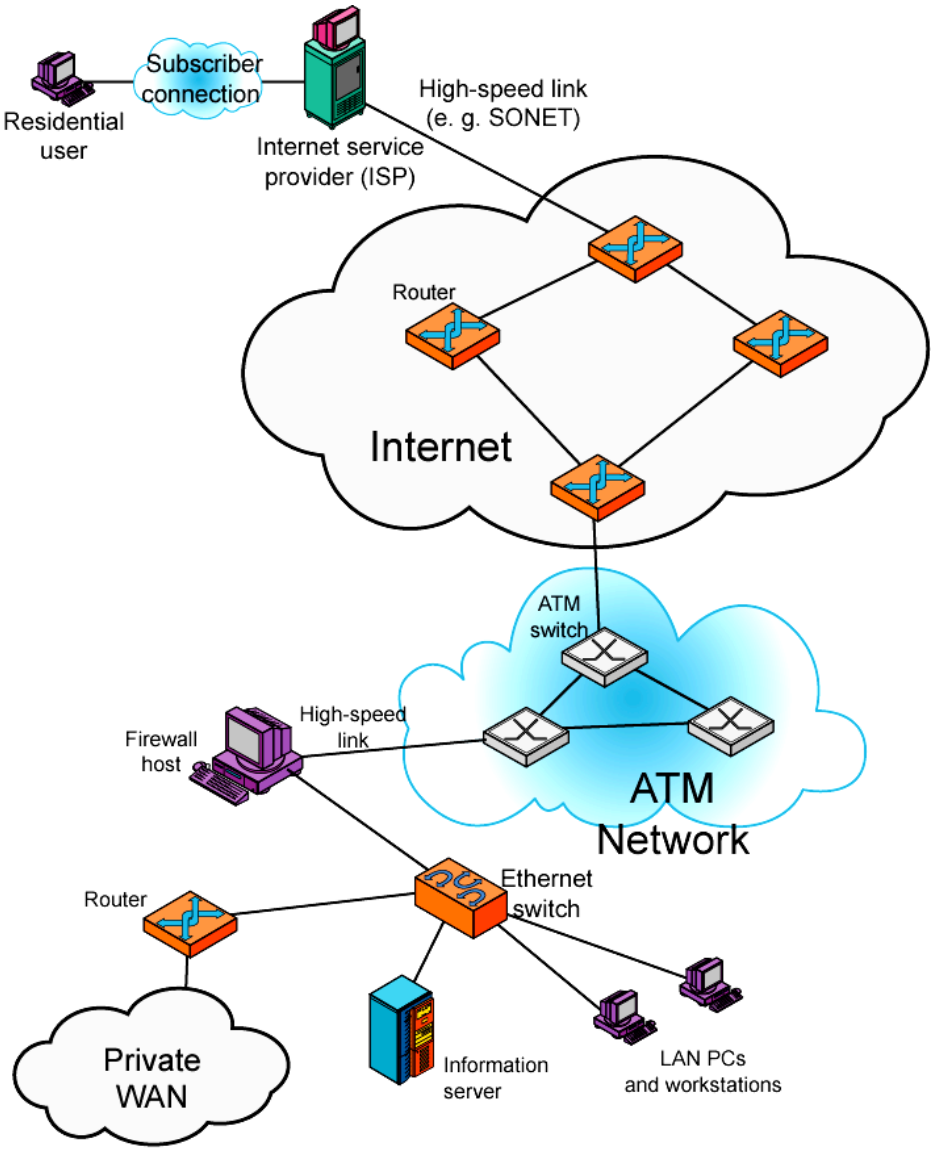
Internet Key Elements



Internet Architecture

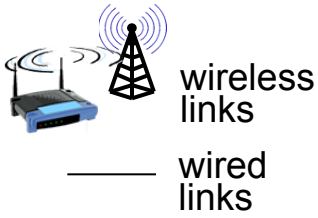


A Networking Configuration

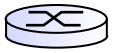


What's the Internet: "nuts and bolts" view

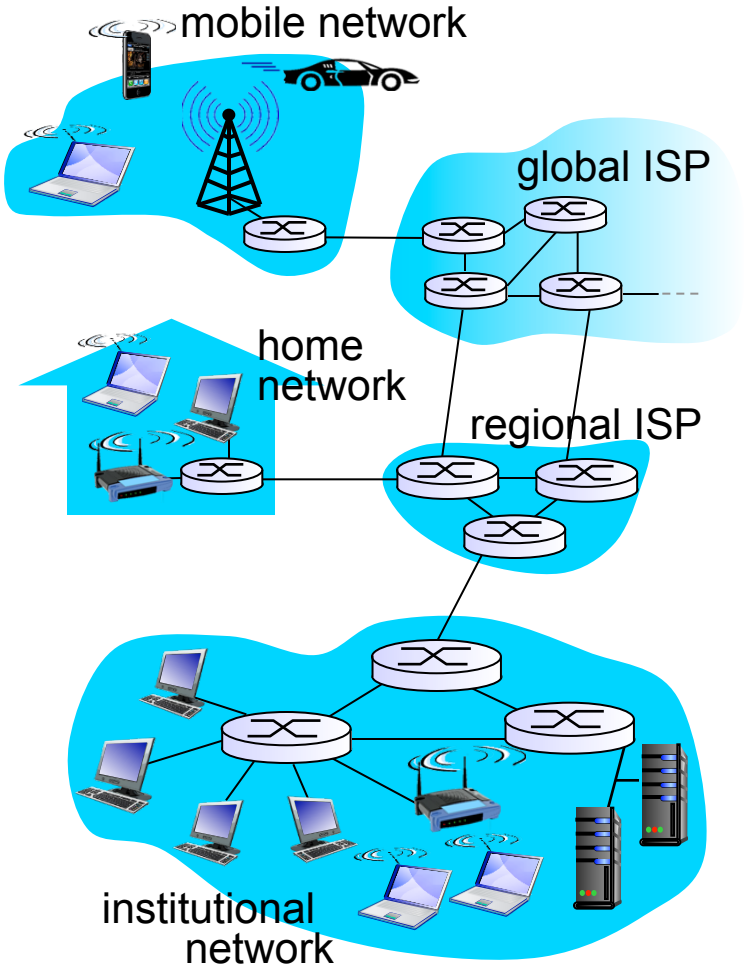
- millions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*



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



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



"Fun" internet appliances

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

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

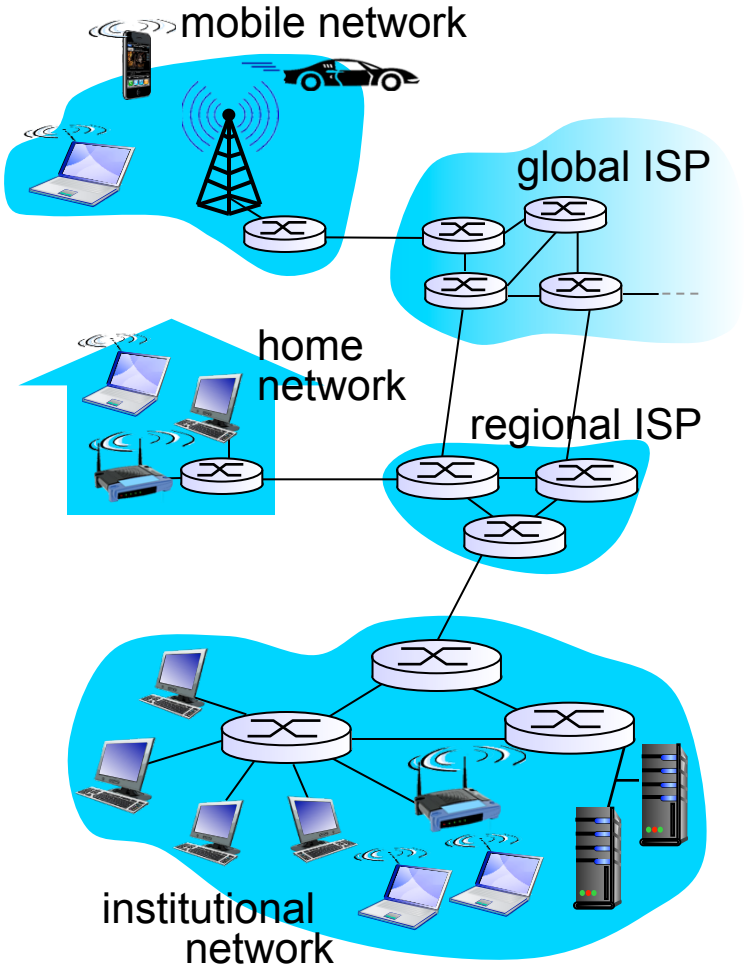
Internet
refrigerator

Slingbox: watch,
control cable TV remotely

Internet phones

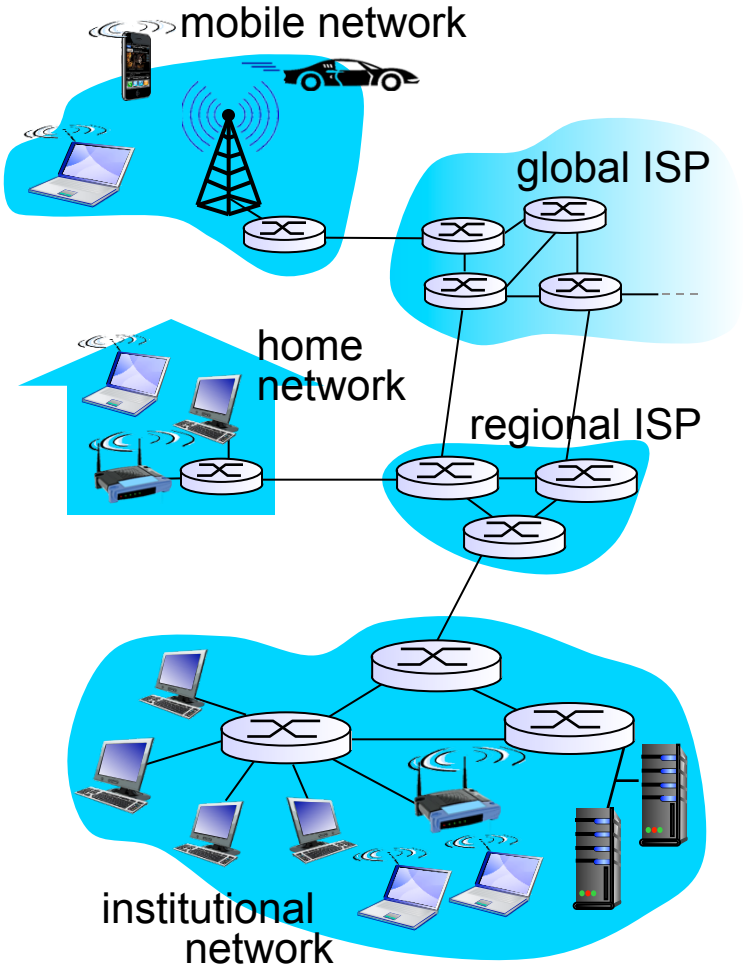
What's the Internet: "nuts and bolts" view

- *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



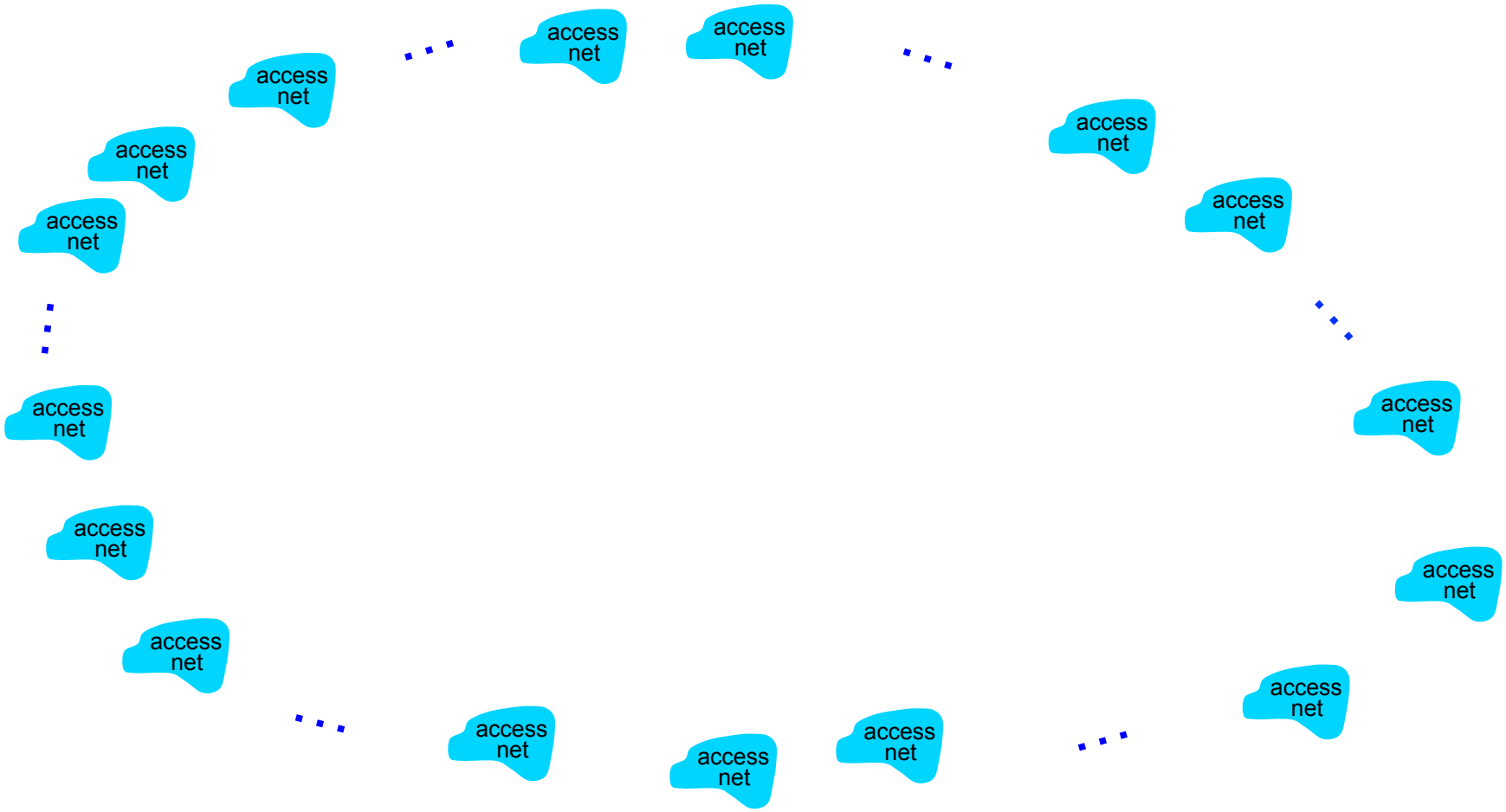
What's the Internet: a service view

- *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



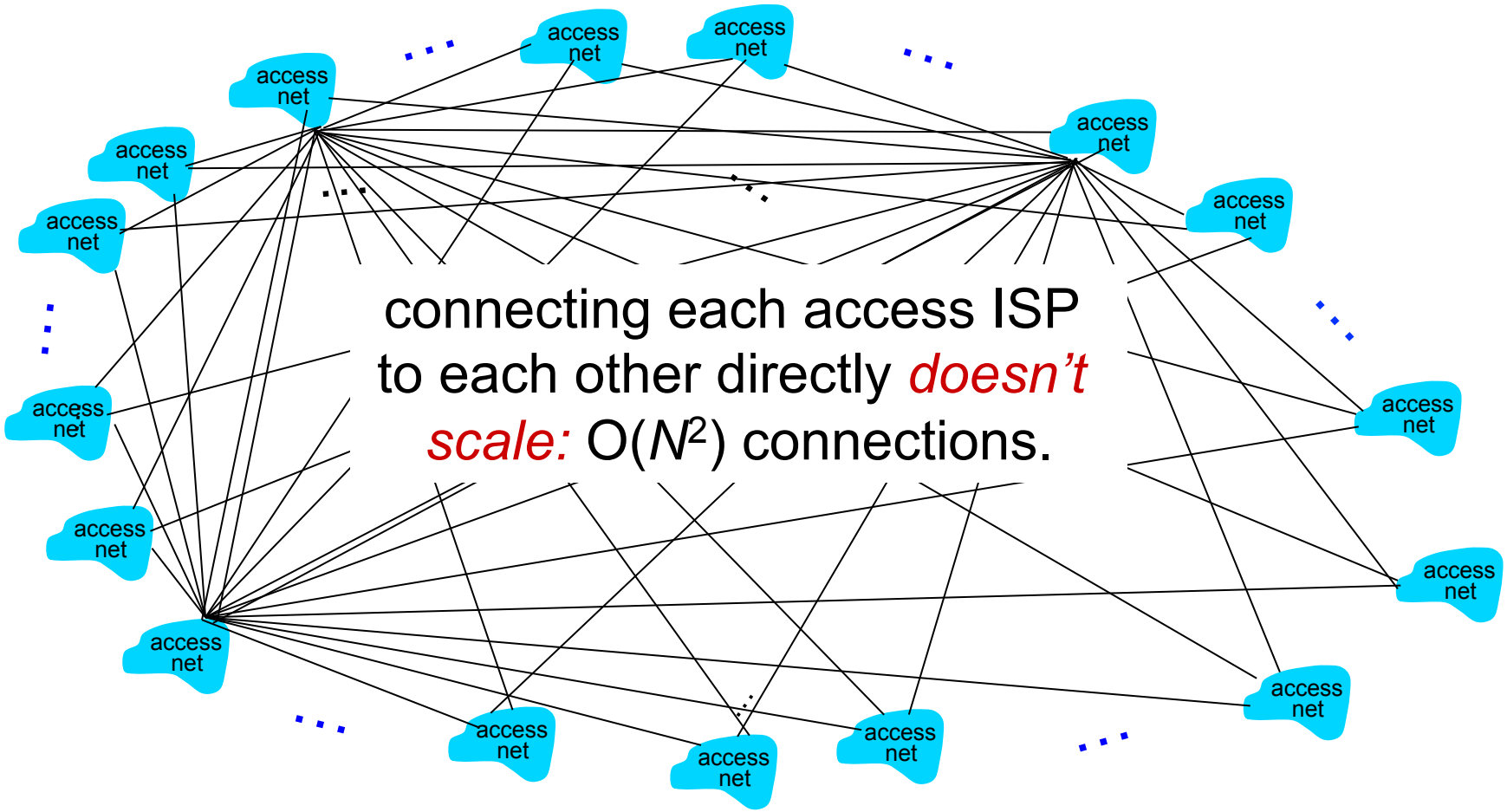
Internet structure: network of networks

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



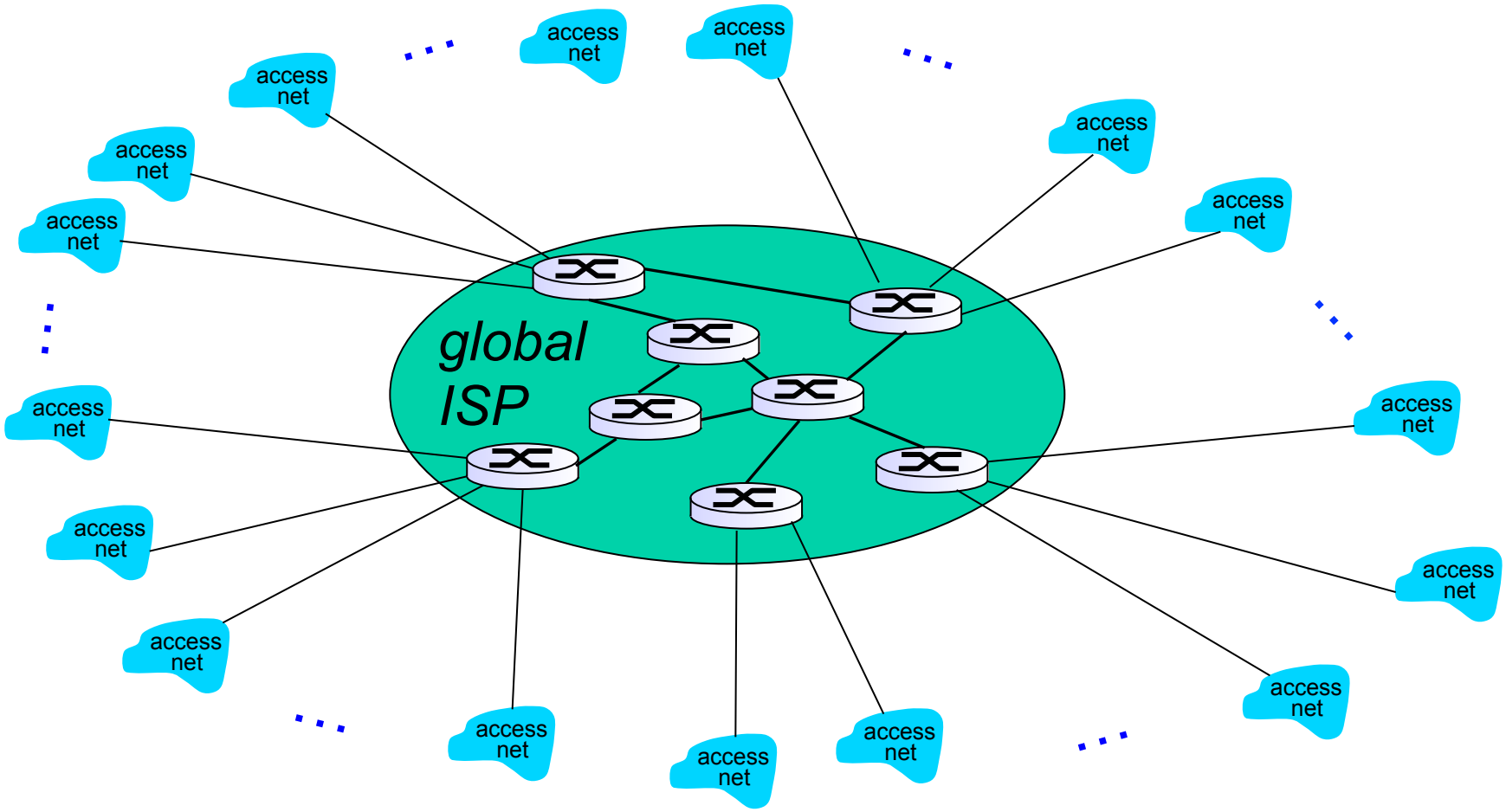
Internet structure: network of networks

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



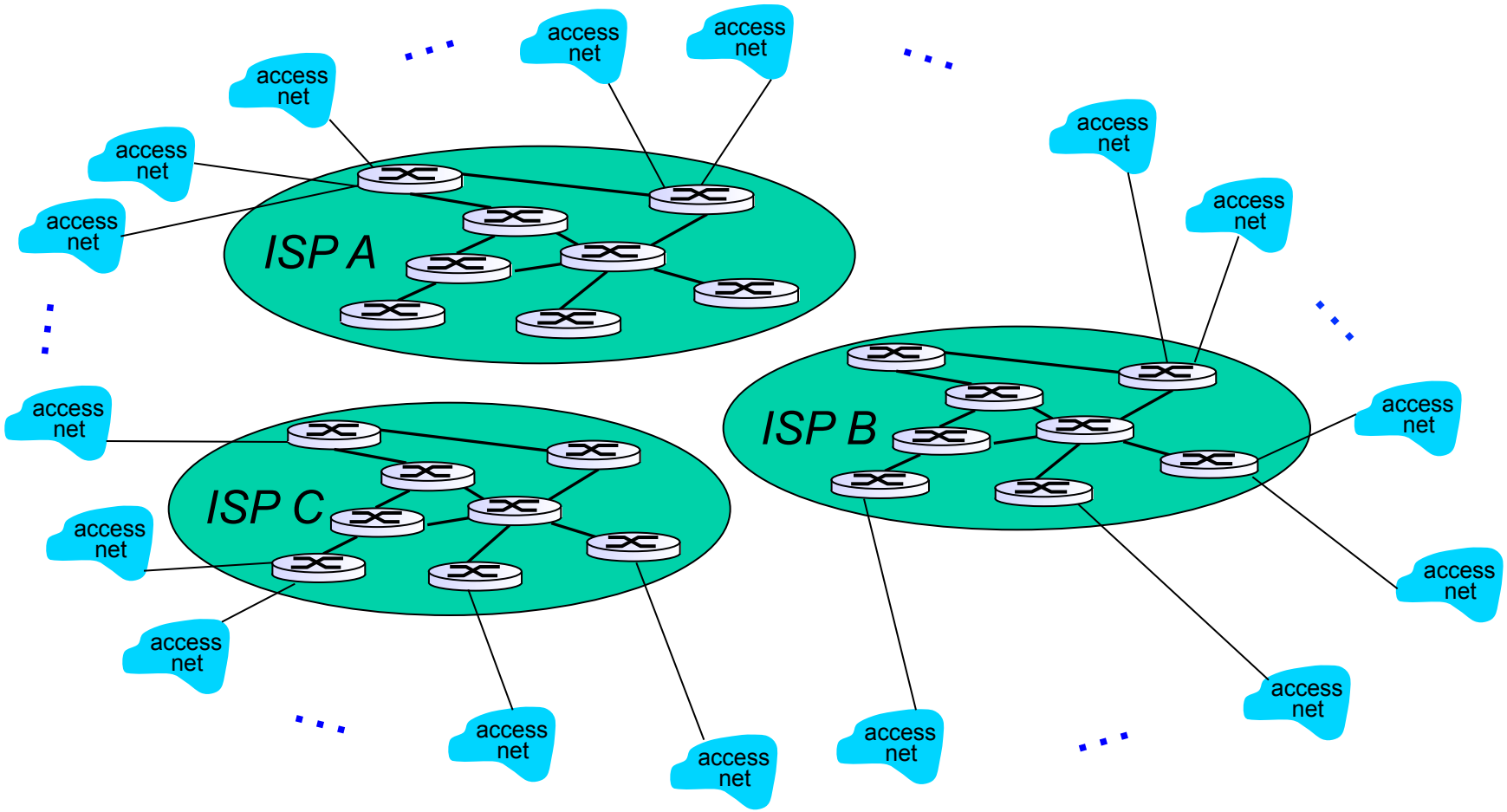
Internet structure: network of networks

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



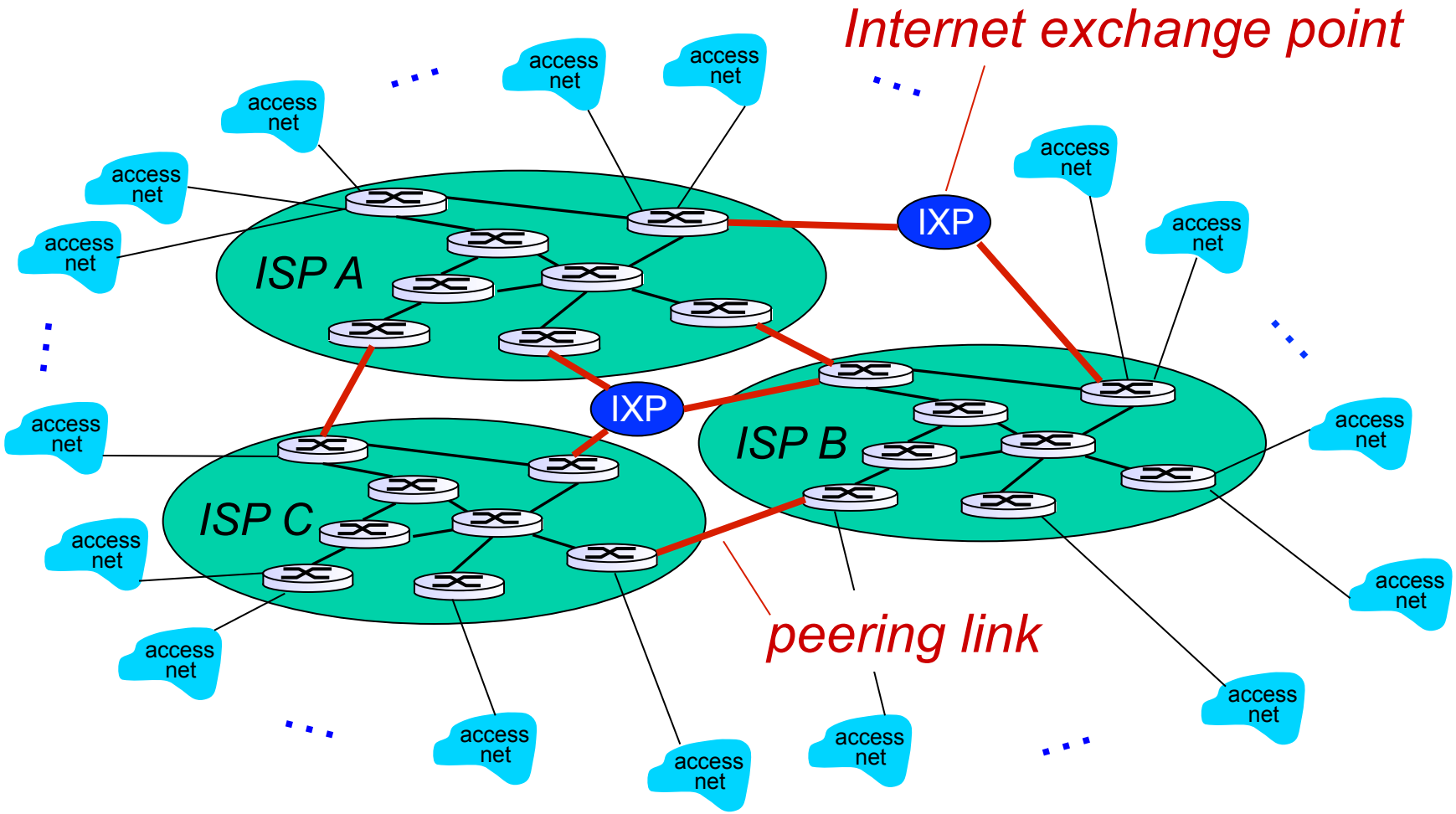
Internet structure: network of networks

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



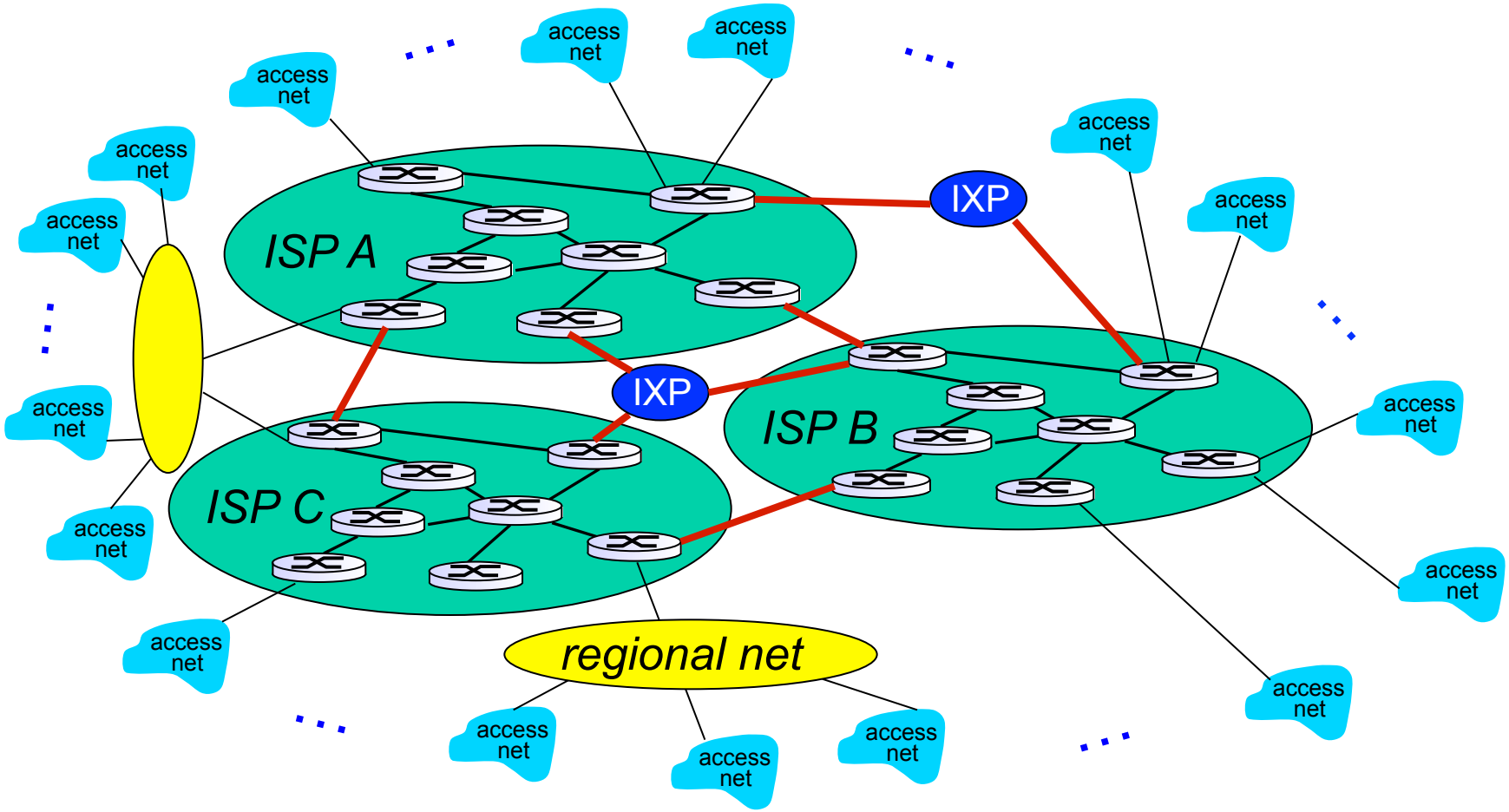
Internet structure: network of networks

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