Operating systems and Networks (G6059)

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Locations & Times

Lectures (Spring term Weeks 9 and 10):

- Wednesday, 1200 – 1300 in Arundel 401.
- Fridays, 1300 - 1400 in Arundel 401.

Literature

Computer Networking: A Top-Down Approach Featuring the Internet, by J. Kurose and K. Ross, 5th edition, Addison-Wesley, 2009. Has a nice website!

There are many other good books. E.g.:

- Computer Networks by Andrew Tanenbaum, 4th edition, Prentice Hall, 2002.

Course Overview

- Understand structure of the Internet
- Understand techniques used in computer networks
- Use this understanding to solve basic networking problems, design simple protocols and write programs which communicate over networks.

Introduction

Our goal:

- get context, overview, “feel” of networking
- approach:
  - descriptive
  - use Internet as example

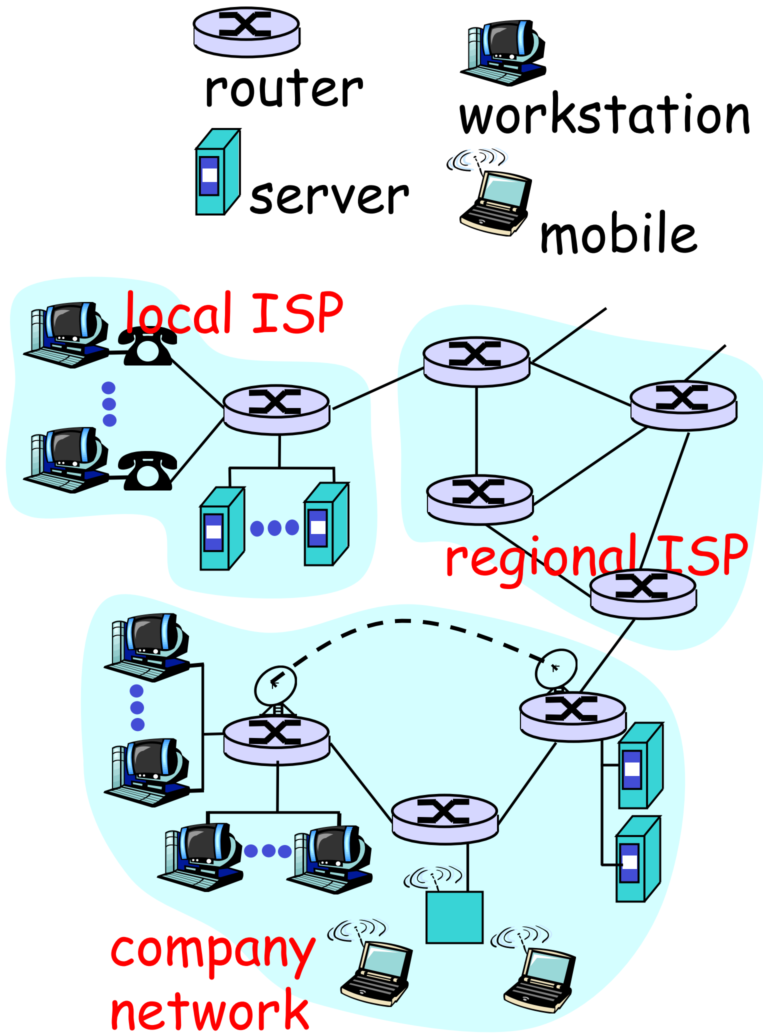
Overview:

- what’s the Internet
- what’s a protocol?
- network edge
- network core
- access net, physical media
- performance: loss, delay
- protocol layers, service models
- backbones, NAPs, ISPs
- history

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

- millions of connected computing devices: *hosts, end-systems*
  - pc's workstations, servers
  - PDA's phones, toasters

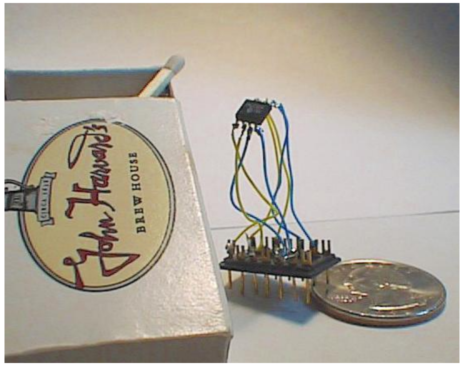
  running *network appls*
- *communication links*
  - fiber, copper, radio, satellite
- *routers:* forward packets (chunks) of data thru network



“Cool” internet appliances

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

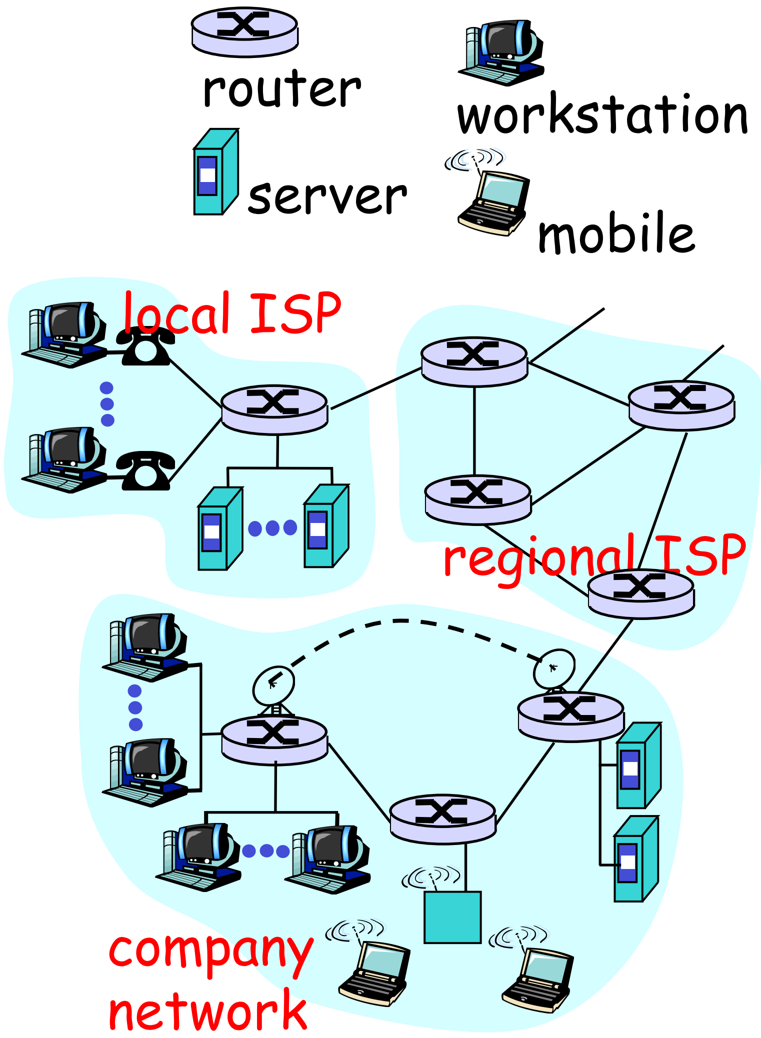
Web-enabled toaster+weather forecaster
http://dancing-man.com/robin/toasty/



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

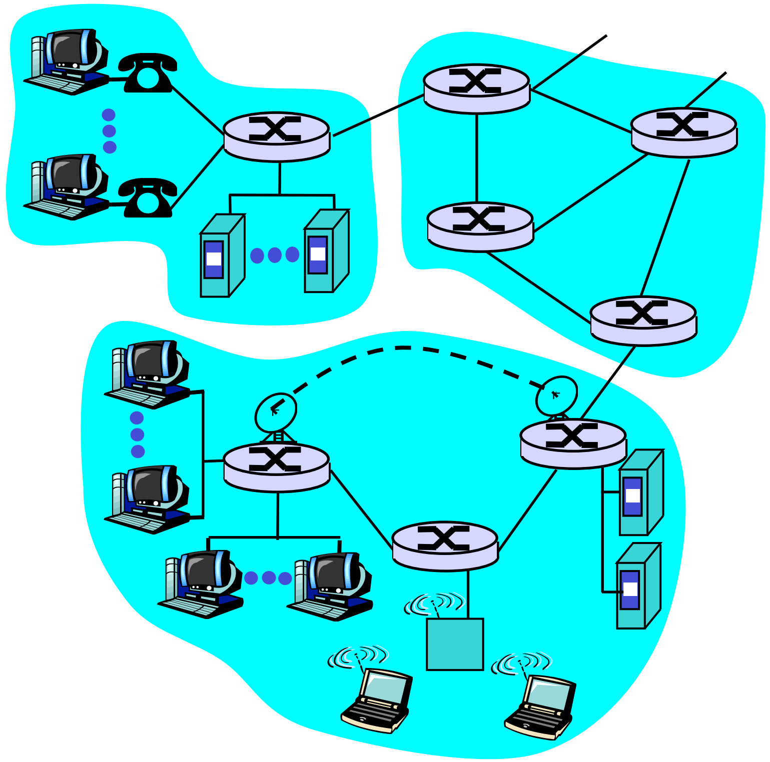
What's the Internet: "nuts and bolts" view

- *protocols*: control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, FTP, PPP
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet



What's the Internet: a service view

- Communication *infrastructure* enables distributed applications:
  - WWW, email, games, e-commerce, database., voting, file (MP3) sharing
- communication services provided:
  - connectionless
  - connection-oriented



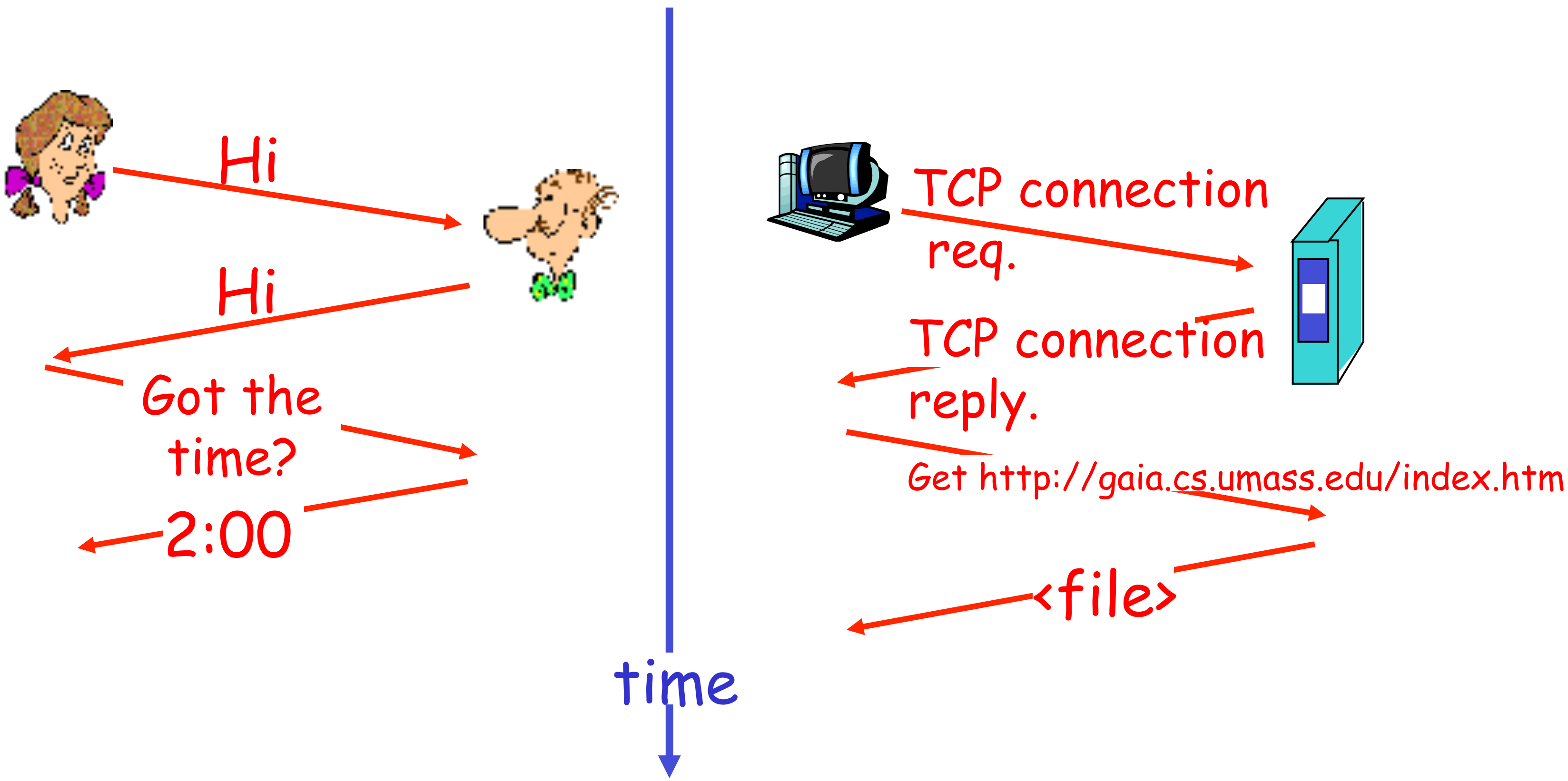
What's a protocol?

human protocols:

network protocols:

What's a protocol?

a human protocol and a computer network protocol:



Q: Other human protocol?

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

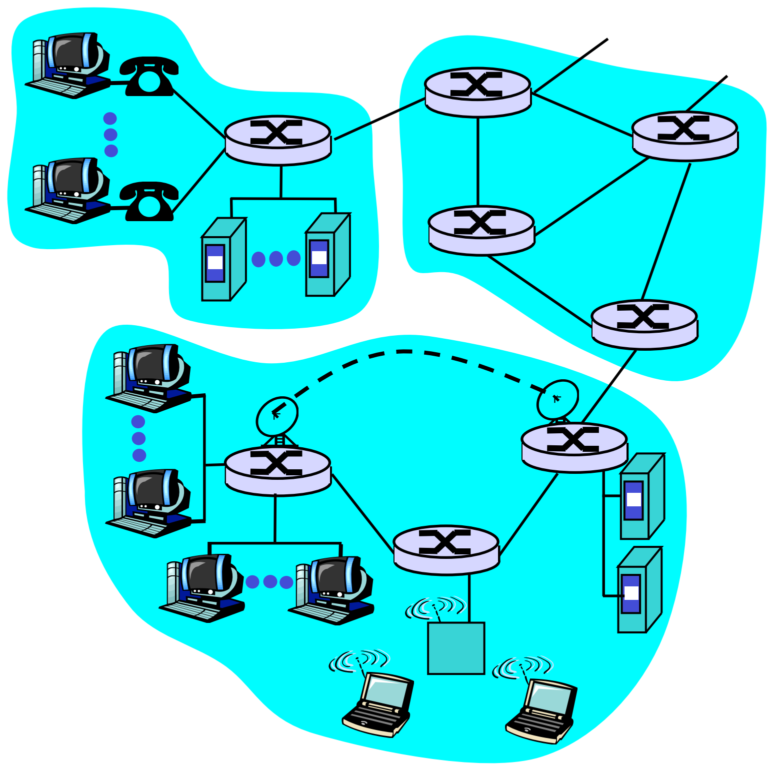
network protocols:

- 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

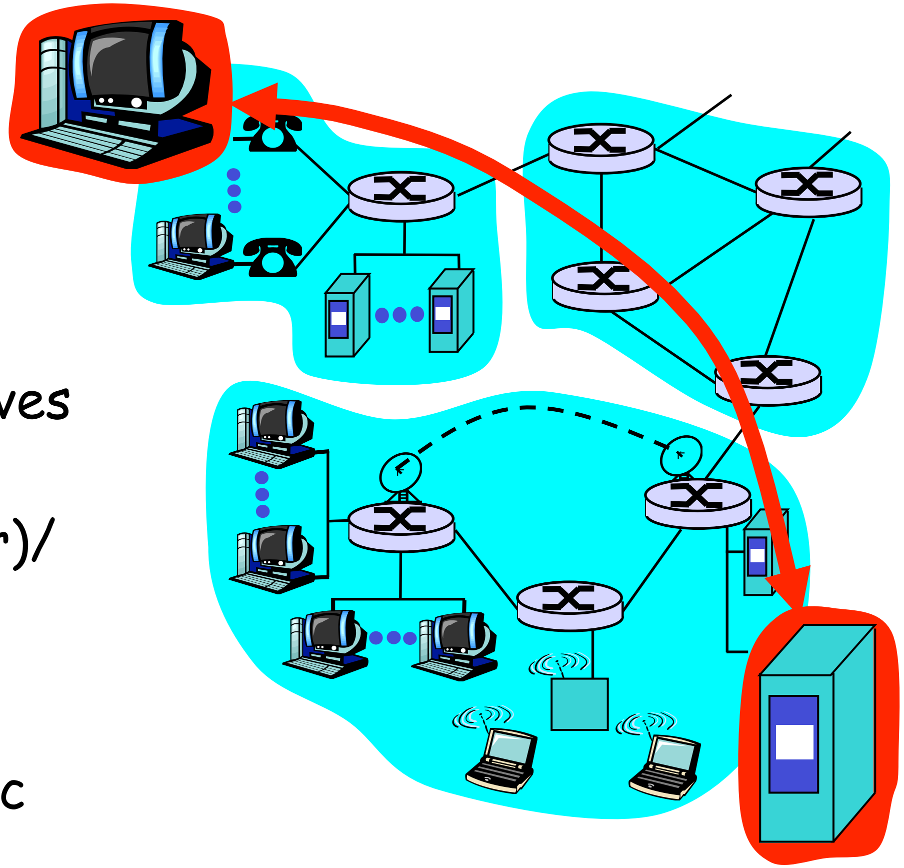
A closer look at network structure:

- **Network edge:** applications and hosts
- **Network core:**
  - routers
  - network of networks
- **Access networks, Physical media:** communication links



The network edge:

- End Systems (hosts):
  - run application programs
  - e.g., WWW, email
  - at “edge of network”
- Client/Server model
  - client host requests, receives service from server
  - e.g., WWW client (browser)/ server; email client/server
- Peer-to-Peer model:
  - host interaction symmetric
  - e.g.: Gnutella, KaZaA



Network edge: connection-oriented service

Goal: data transfer between end systems

- *handshaking:* setup (prepare for) data transfer ahead of time
  - Hello, hello back human protocol
  - *set up "state"* in two communicating hosts
- TCP - Transmission Control Protocol
  - Internet's connection-oriented service

TCP Service

- *reliable, in-order* byte-stream data transfer
  - loss: acknowledgements and retransmissions
- *flow control:*
  - sender won't overwhelm receiver
- *congestion control:*
  - senders "slow down sending rate" when network congested

Network edge: connectionless service

Goal: data transfer between end systems
- same as before!

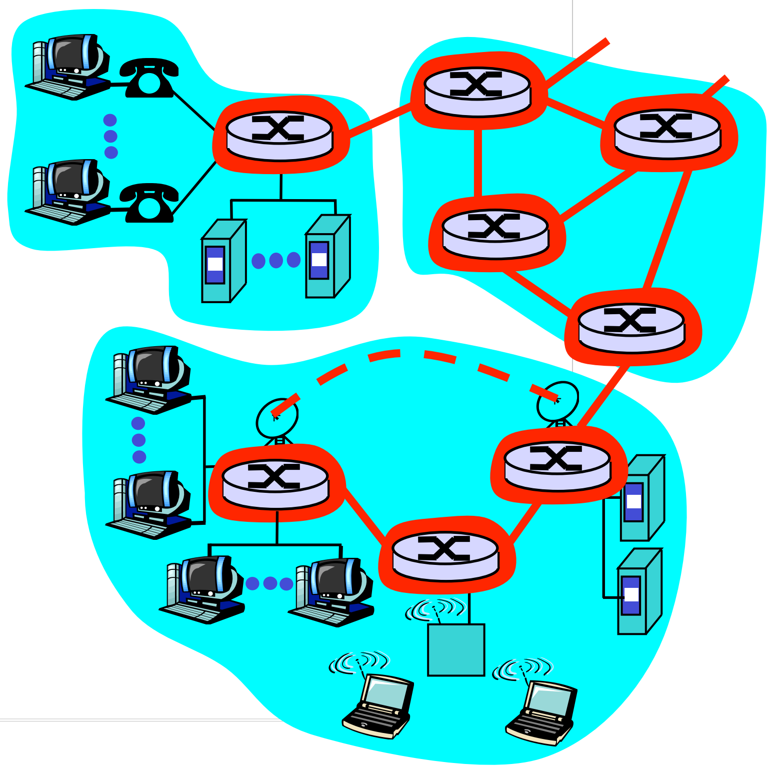
- UDP - User Datagram Protocol: Internet's connectionless service
  - unreliable data transfer
  - no flow control
  - no congestion control

Appls using TCP:
- HTTP (WWW).
- FTP (file transfer),
- Telnet (remote login)
- SMTP (email),
- ...

Appls using UDP:
- streaming media
- Teleconferencing
- Internet telephony
- ...

The Network Core

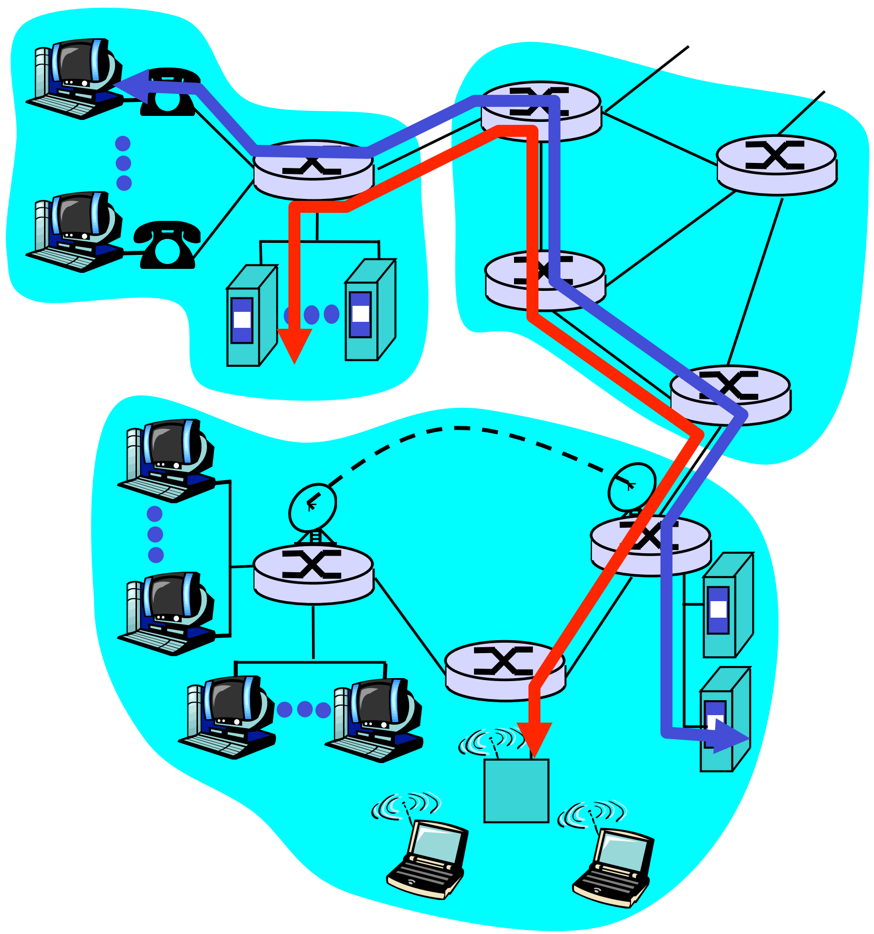
- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



Network Core: Circuit Switching

End-end resources reserved for "call"

- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required



Network Core: Circuit Switching

network resources (e.g., bandwidth) divided into "pieces"

- pieces allocated to calls
- resource piece *idle* if not used by owning call *(no sharing)*
- dividing link bandwidth into "pieces"
  - frequency division
  - time division

Network Core: Packet Switching

Each end-end *data* stream divided into *packets*

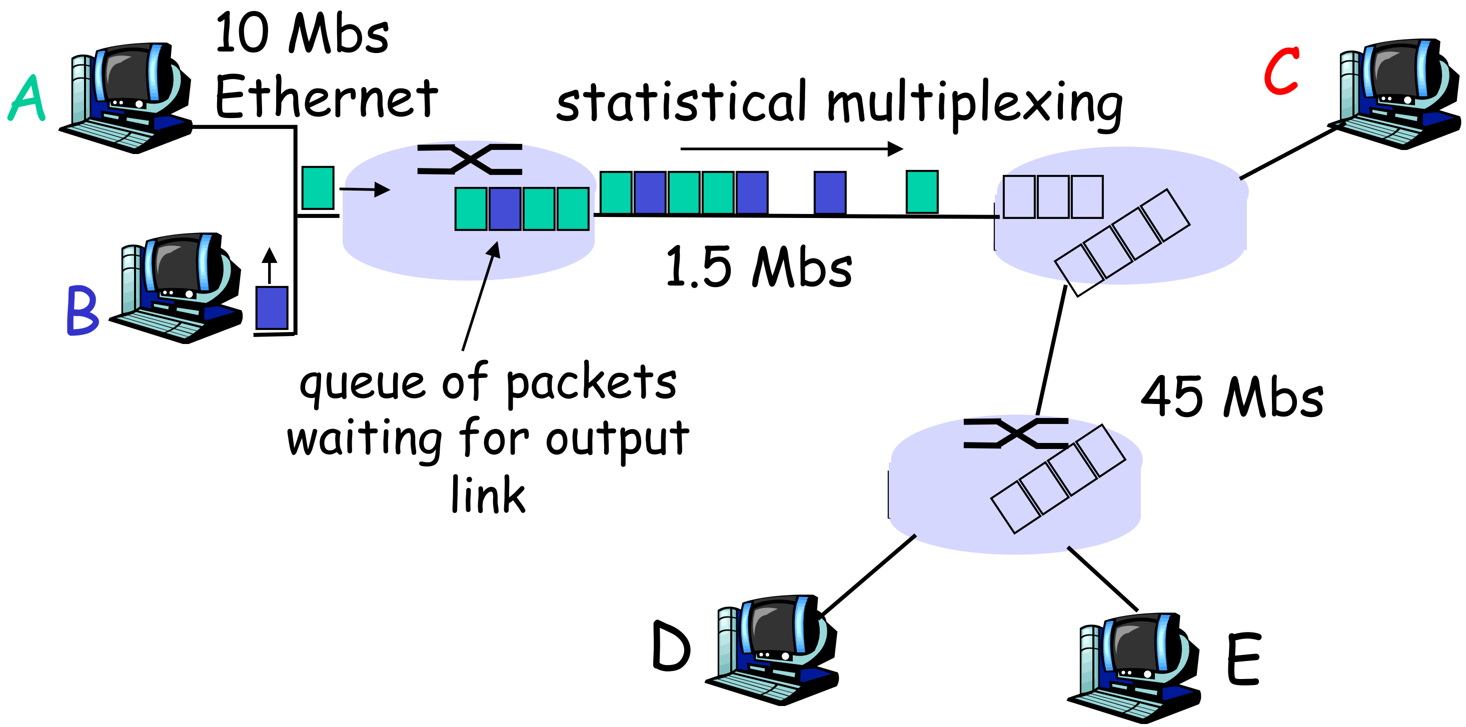
- users A and B's packets *share* network resources
- each packet uses *full link* bandwidth
- resources used *as needed*,

Bandwidth division into "pieces"
Dedicated allocation
Resource reservation

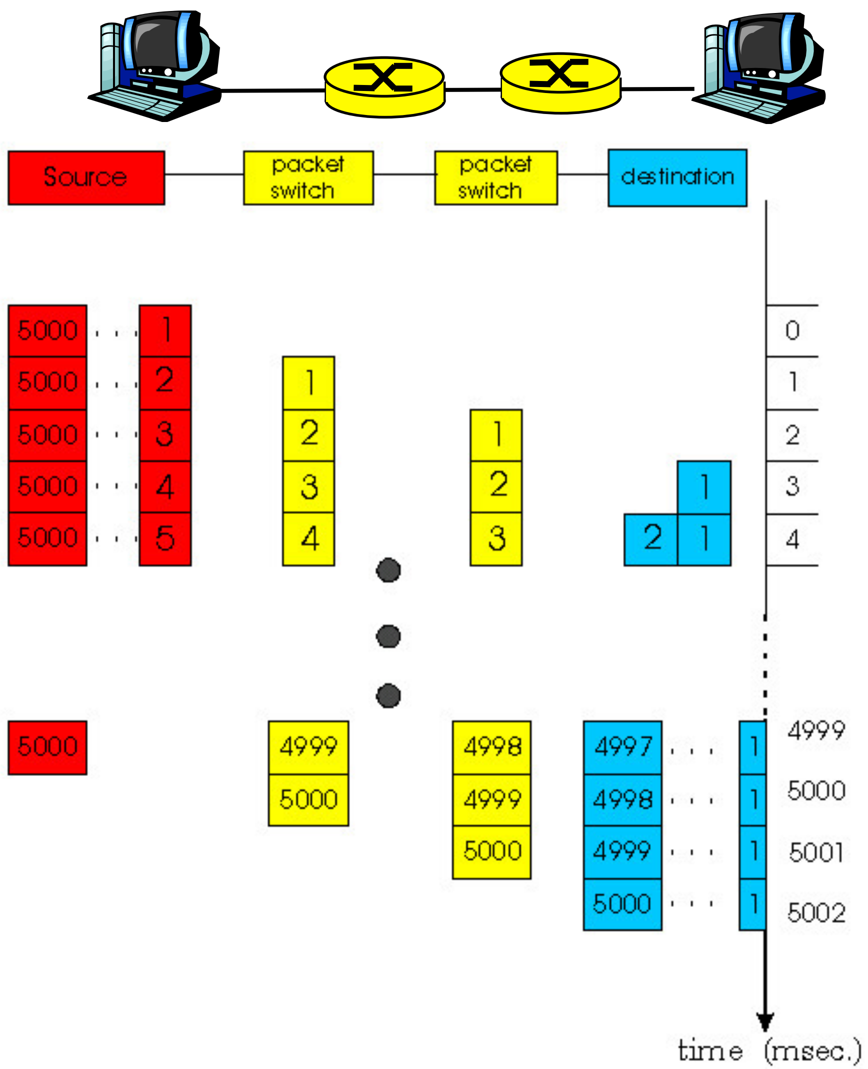
Resource Contention:

- aggregate resource demand can *exceed* amount available
- *congestion*: packets queue, wait for link use
- *store and forward*: packets move one hop at a time
  - transmit over link
  - wait turn at next link

Network Core: Packet Switching



Network Core: Packet Switching



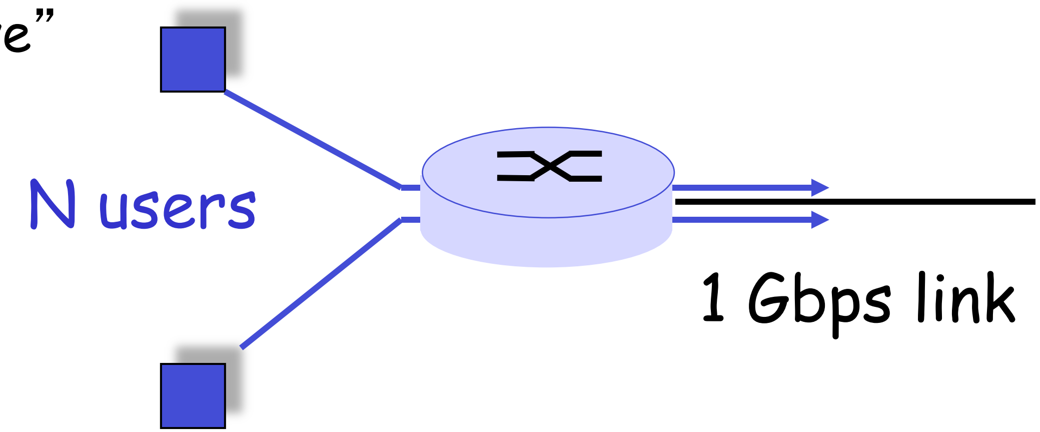
Packet-switching:

- break message into small chunks: “packets”
- Store-and-forward: switch waits until chunk has completely arrived, then forwards/routes
- Q: what if message was sent as single unit?

Packet switching versus circuit switching

Packet switching allows more users to use network!

- 1 Gbit link
- each user:
  - 100Mbps when "active"
  - active 10% of time
- circuit-switching:
  - 10 users
- packet switching:
  - with 35 users, probability > 10 active less than .0004



Packet switching versus circuit switching

Is packet switching a “slam dunk winner?”

- Great for bursty data
  - resource sharing
  - no call setup
- Excessive congestion: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- Q: How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 6)

Packet-switched networks: Routing

- *Goal:* move packets among routers from source to destination
  - we'll study two path selection algorithms (chapter 4)
- datagram network:
  - *destination address* determines next hop
  - routes may change during session
  - analogy: driving, asking directions

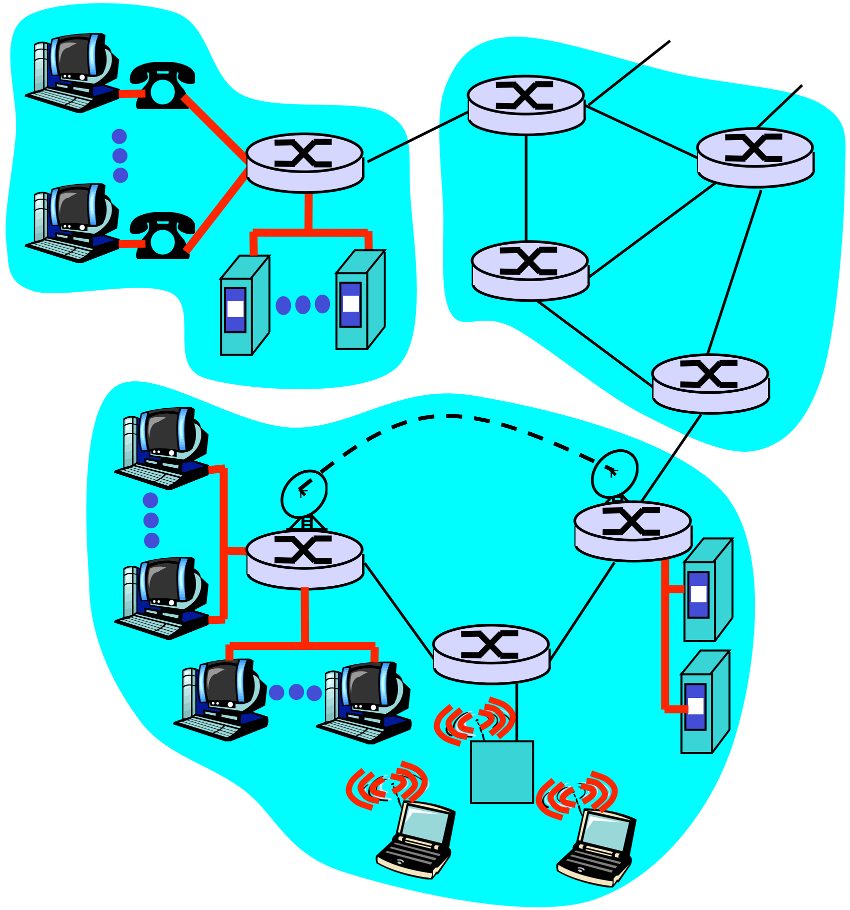
Access networks and physical media

Q: How to connect end systems to edge router?

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

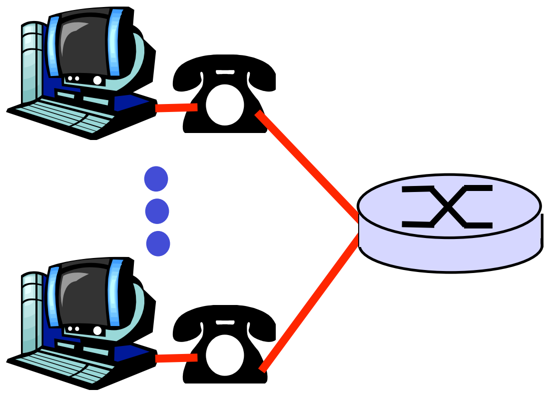
Params to keep in mind:

- bandwidth (bps) of access network?
- shared/dedicated?



Residential access: Point-to-Point access

- Dialup via modem
  - up to 56Kbps direct access to router (conceptually)
- ISDN: integrated services digital network: 128Kbps all-digital connect to router
- ADSL: asymmetric digital subscriber line
  - < 1 Mbps home-to-router
  - < 24 Mbps router-to-home
  - ADSL deployment: Standard
  - FTTC (Fibre to the curb)

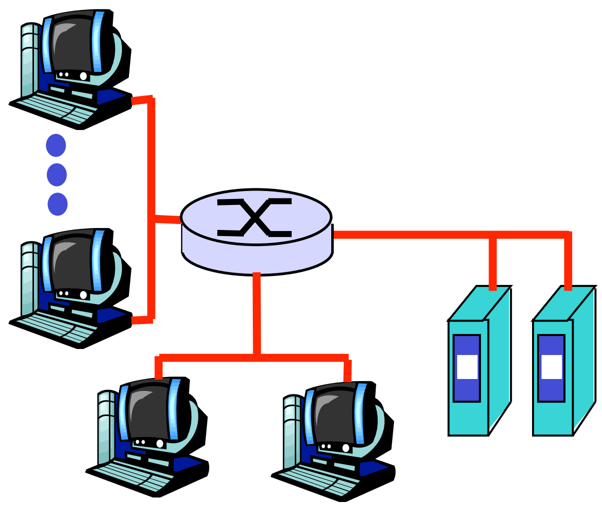


Residential access: Cable Modems

- HFC: hybrid fiber coax
  - asymmetric: up to 10Mbps upstream, 1 Mbps downstream
- network of cable and fiber attaches homes to ISP router
  - shared access to router among home
  - issues: congestion, dimensioning
- deployment: available via cable companies

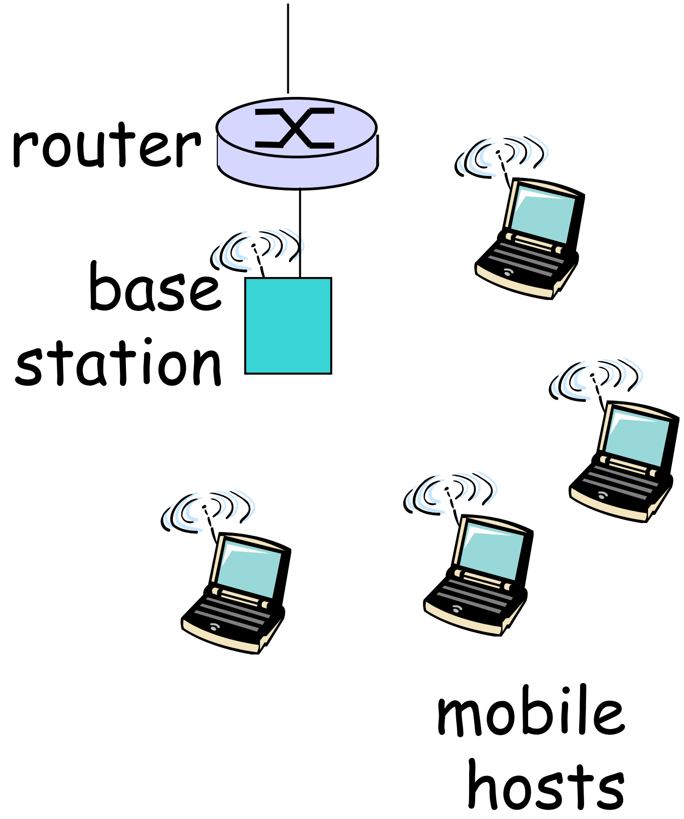
Institutional access: Local Area Networks

- company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - shared or dedicated cable connects end system and router
  - 10 Mbs, 100Mbps, Gigabit Ethernet
- deployment: institutions, home LANs happening now
- LANs: chapter 5



Wireless access networks

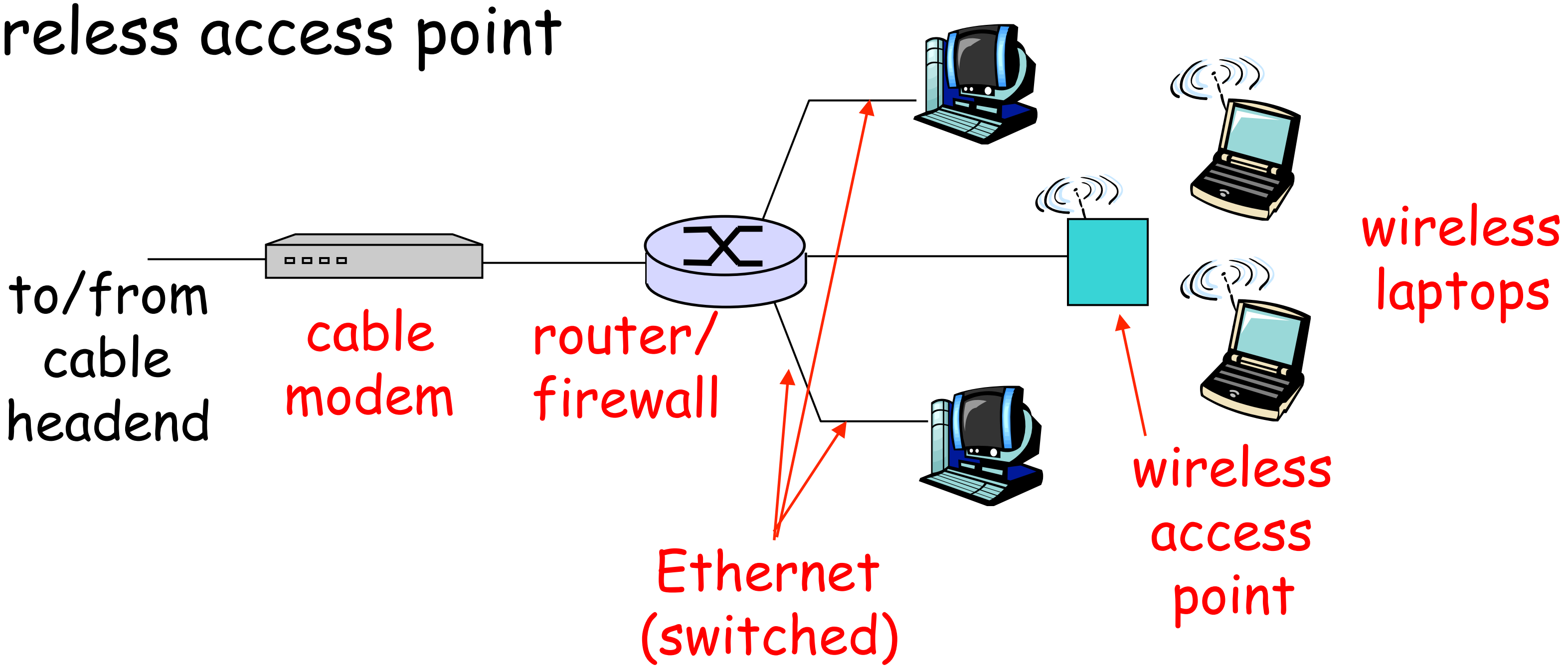
- shared *wireless* access network connects end system to router
- wireless LANs:
  - radio spectrum replaces wire
  - e.g., Lucent Wavelan 11 Mbps
- wider-area wireless access
  - CDPD: wireless access to ISP router via cellular network



Home networks

Typical home network components:

- ADSL or cable modem
- router/firewall
- Ethernet
- wireless access point



Physical Media

- **Physical link:** transmitted data bit propagates across link
- **Guided media:**
  - signals propagate in solid media: copper, fiber
- **Unguided media:**
  - signals propagate freely, e.g., radio

Twisted Pair (TP)

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5 TP: 100Mbps Ethernet

Physical Media: Coax, Fiber

Coaxial cable:

- wire (signal carrier) within a wire (shield)
  - baseband: single channel on cable
  - broadband: multiple channel on cable
- bidirectional
- common use in 10Mbs Ethernet

Fiber optic cable:

- glass fiber carrying light pulses
- high-speed operation:
  - 100Mbps Ethernet
  - high-speed point-to-point transmission (e.g., 5 Gps)
- low error rate

Physical media: Radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

Radio link types:

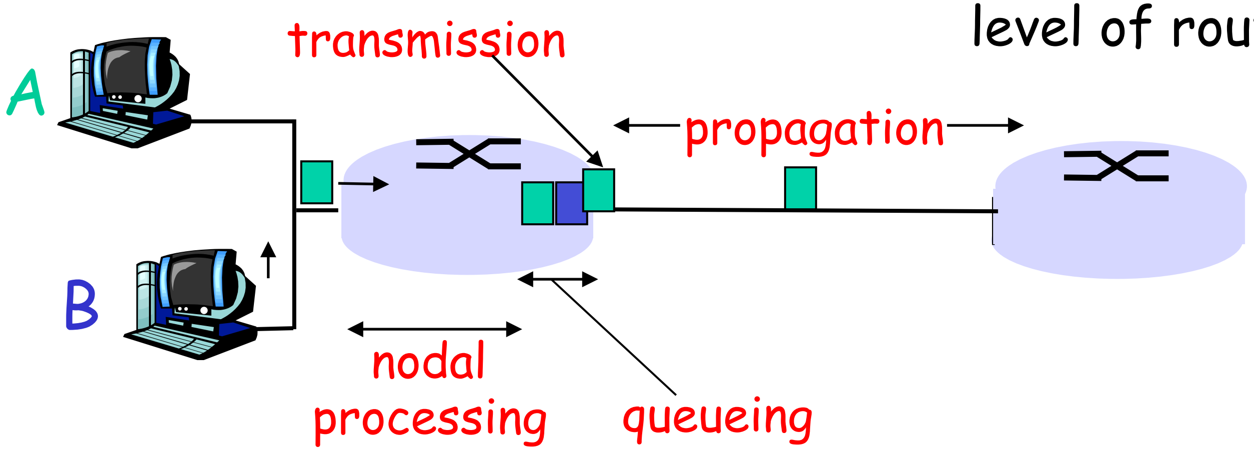
- microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WaveLAN)
  - 2Mbps, 11Mbps
- wide-area (e.g., cellular)
  - e.g. CDPD, 10's Kbps
- satellite
  - up to 50Mbps channel (or multiple smaller channels)
  - 270 Msec end-end delay
  - geosynchronous versus LEOS

Delay in packet-switched networks

packets experience delay on end-to-end path

- four sources of delay at each hop

- nodal processing:
  - check bit errors
  - determine output link
- queueing
  - time waiting at output link for transmission
  - depends on congestion level of router



Delay in packet-switched networks

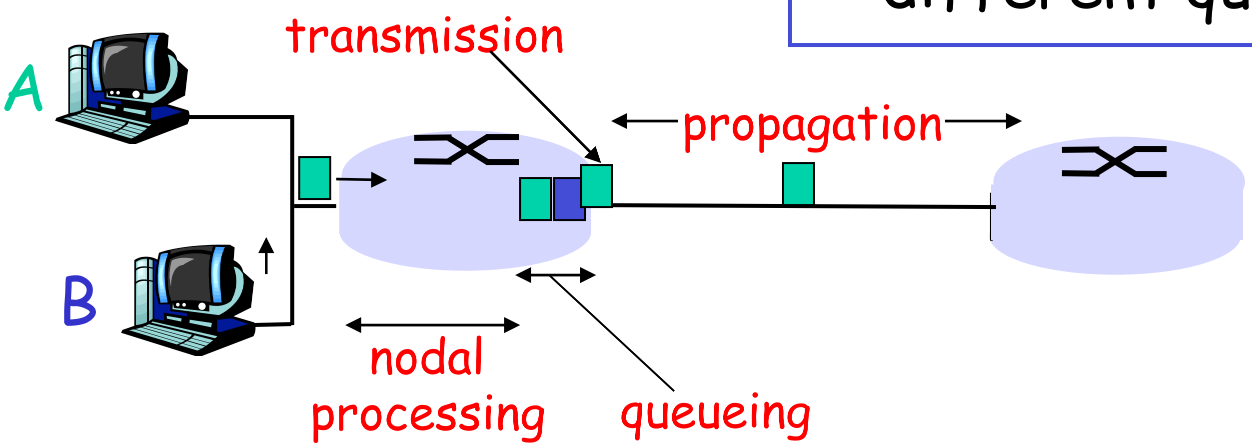
Transmission delay:

- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

Propagation delay:

- d = length of physical link
- s = propagation speed in medium (~2×10^8 m/sec)
- propagation delay = d/s

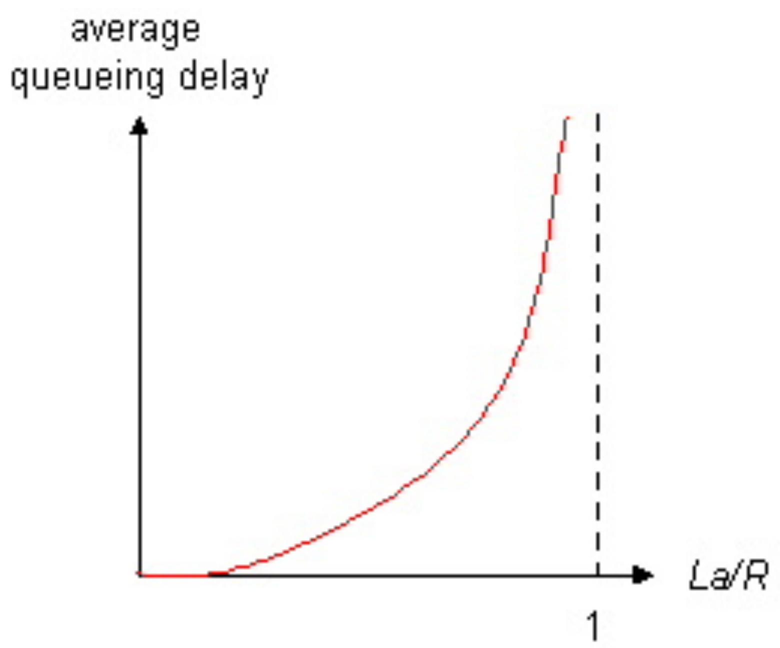
Note: s and R are *very* different quantities!



Queueing delay (revisited)

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

traffic intensity = La/R



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

“Real” Internet delays and routes

traceroute: routers, rt delays on source-dest path
also: pingplotter, various windows programs

```
1  139.184.48.6 (139.184.48.6)  0.782 ms  0.772 ms  0.769 ms
2  sw-pev-rsm.central.susx.ac.uk (139.184.10.16)  0.412 ms  0.375 ms  0.359 ms
3  212.219.151.65 (212.219.151.65)  0.943 ms  0.812 ms  0.788 ms
4  212.219.151.73 (212.219.151.73)  1.325 ms  1.040 ms  1.022 ms
5  * * *
6  146.97.40.2 (146.97.40.2)  2.518 ms  2.328 ms  2.282 ms
7  cosham-bar.ja.net (146.97.40.1)  2.128 ms  2.142 ms  5.066 ms
8  po9-0.cosh-scr.ja.net (146.97.35.21)  2.761 ms  2.133 ms  2.088 ms
9  po2-0.lond-scr.ja.net (146.97.33.41)  4.257 ms  4.154 ms  4.249 ms
10  po0-0.lond-scr3.ja.net (146.97.33.10)  4.478 ms  4.160 ms  4.120 ms
11  geant-gw.ja.net (146.97.37.82)  4.279 ms  4.168 ms  4.138 ms
12  janet.uk1.uk.geant.net (62.40.103.149)  4.404 ms  4.370 ms  4.405 ms
13  uk.fr1.fr.geant.net (62.40.96.89)  11.725 ms  11.974 ms  11.760 ms
14  fr.de1.de.geant.net (62.40.96.49)  20.298 ms  20.839 ms  20.260 ms
15  de1-1.de2.de.geant.net (62.40.96.130)  20.377 ms  20.357 ms  20.086 ms
16  abilene-gtren-gw.de2.de.geant.net (62.40.103.254)  114.130 ms  113.971 ms  114.040 ms
17  local1.abilene.magpi.net (198.32.42.209)  117.060 ms  116.994 ms  117.078 ms
18  local.phl-03.backbone.magpi.net (198.32.42.217)  118.433 ms  118.595 ms  118 .692 ms
19  local.phl-03.magpi.net (198.32.42.221)  124.470 ms  118.485 ms  118.542 ms
20  DEFAULT3-FE.ROUTER.UPENN.EDU (165.123.237.4)  118.465 ms  118.639 ms  118.564 ms
21  SUBNET-20-ROUTER.CIS.UPENN.EDU (158.130.20.1)  118.214 ms  118.286 ms  118.276 ms
22  SUBNET-21-ROUTER.CIS.UPENN.EDU (158.130.21.1)  118.452 ms  118.424 ms  118.717 ms
23  C1K.CIS.UPENN.EDU (158.130.12.9)  125.876 ms  118.913 ms  118.627 ms
```

Protocol "Layers"

Networks are complex!

- 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

Organization of air travel: a different view

ticket (purchase)	ticket (complain)
baggage (check)	baggage (claim)
gates (load)	gates (unload)
runway takeoff	runway landing
airplane routing airplane routing	airplane routing

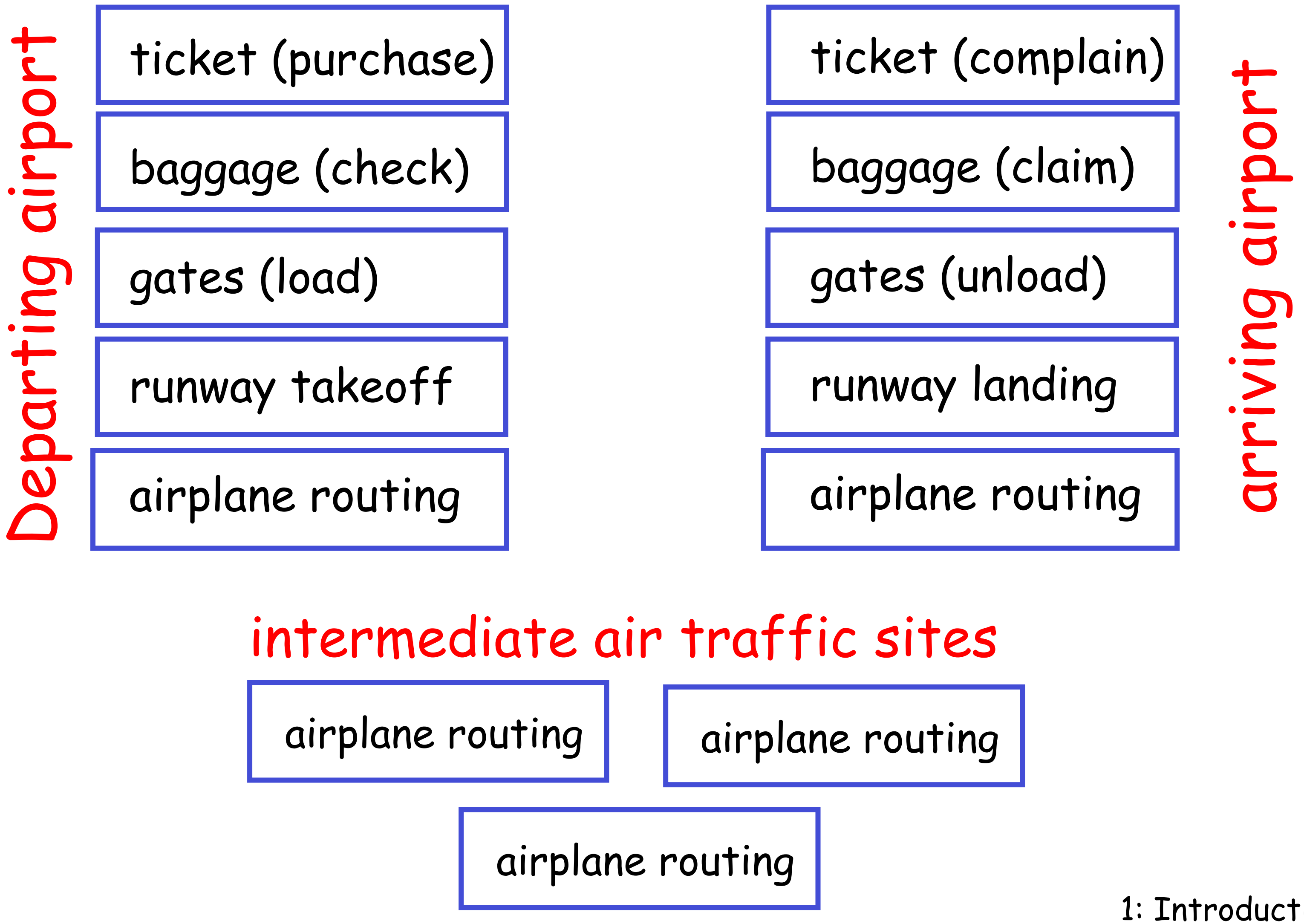
Layers: each layer implements a service

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

Layered air travel: services

Counter-to-counter delivery of person+bags
baggage-claim-to-baggage-claim delivery
people transfer: loading gate to arrival gate
runway-to-runway delivery of plane
airplane routing from source to destination

Distributed implementation of layer functionality



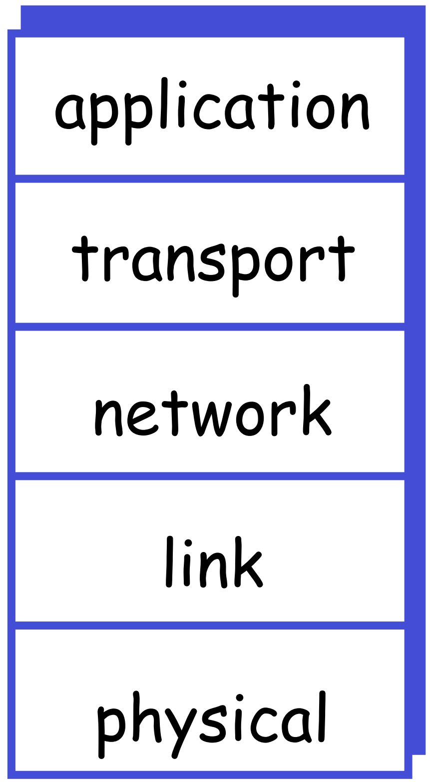
Why layering?

Dealing with complex systems:

- explicit structure allows identification of 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

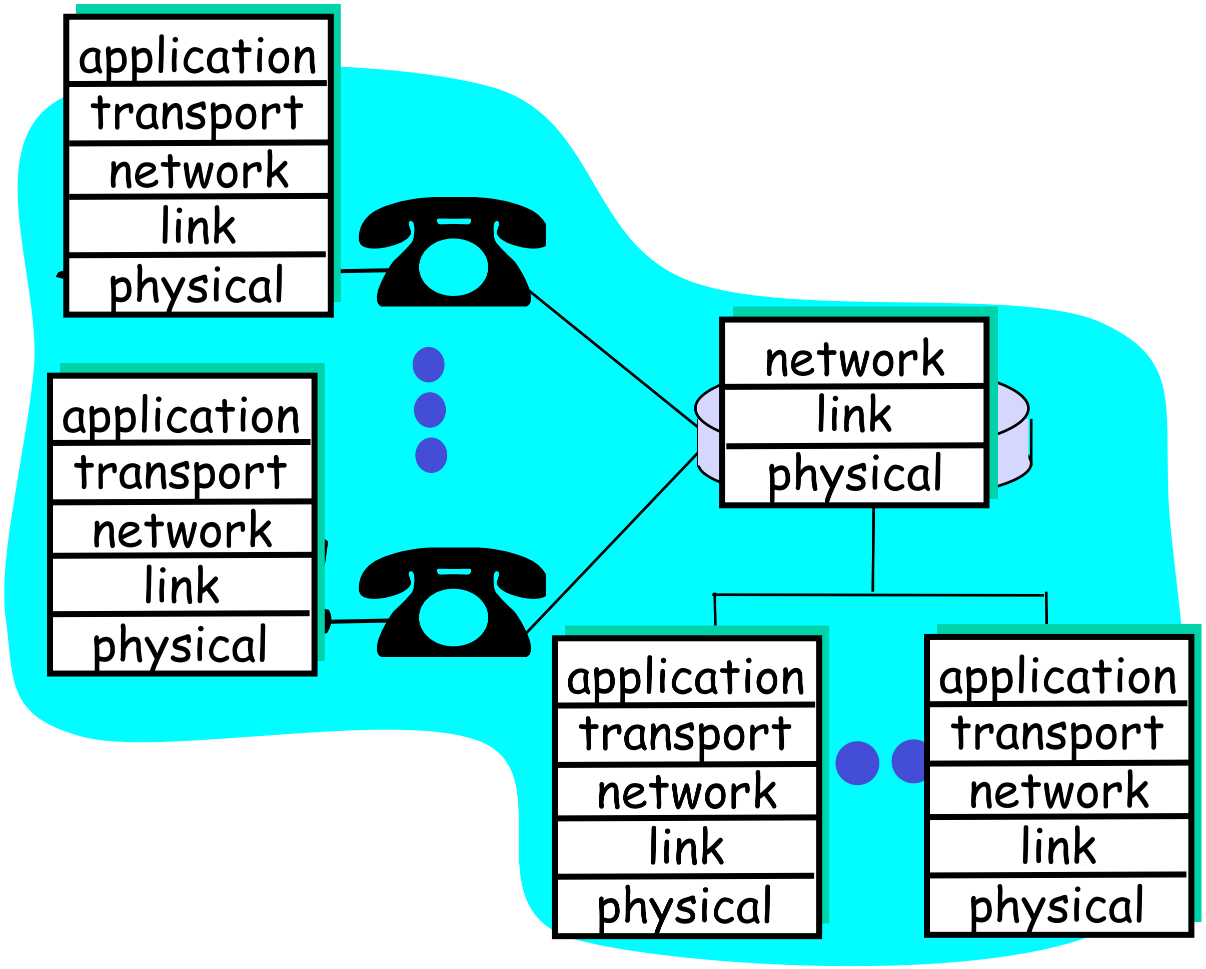
- application: supporting network applications
  - ftp, smtp, http
- transport: host-host data transfer
  - tcp, udp
- network: routing of datagrams from source to destination
  - ip, routing protocols
- link: data transfer between neighboring network elements
  - ppp, ethernet
- physical: bits "on the wire"



Layering: logical communication

Each layer:

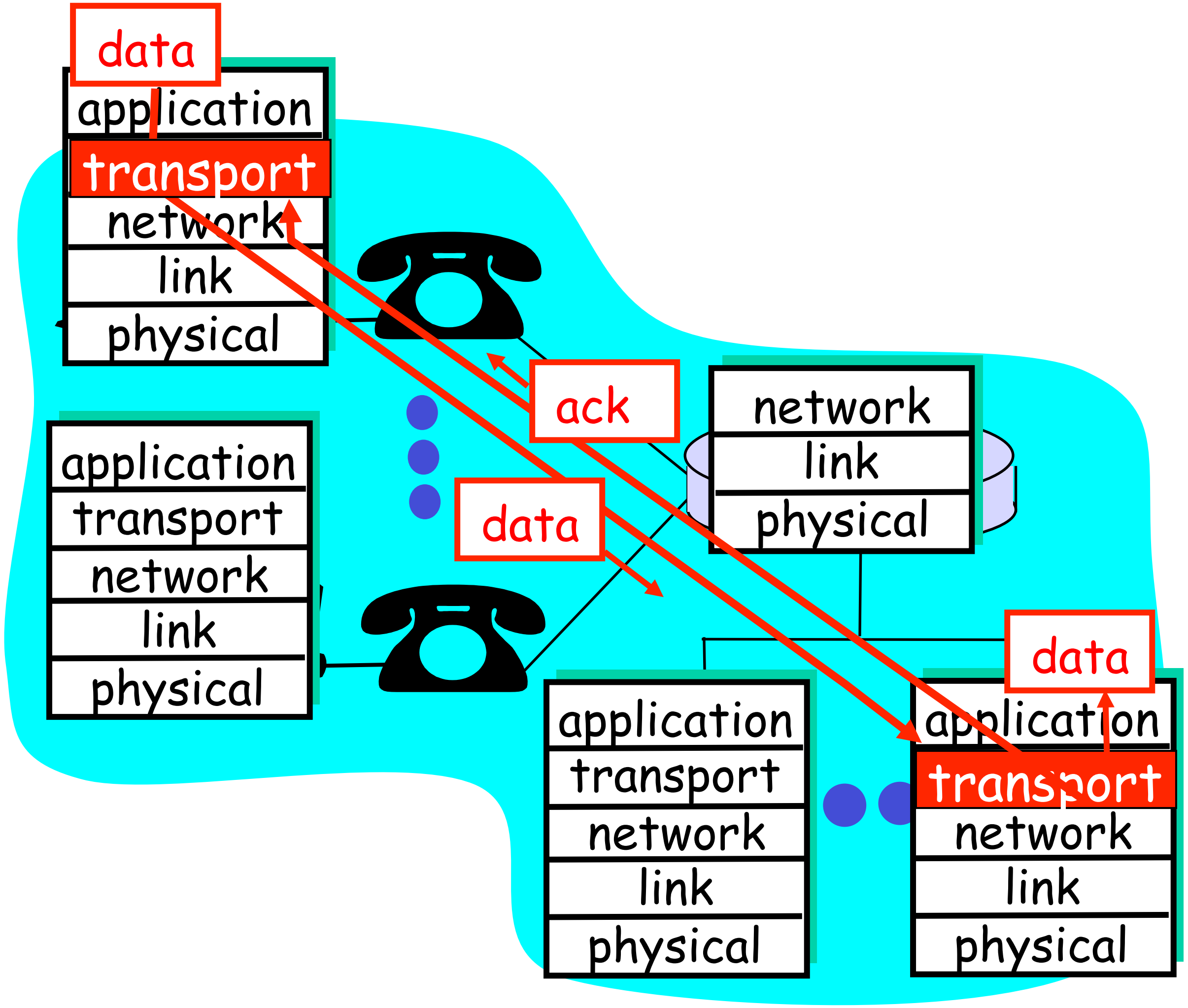
- distributed
- "entities" implement layer functions at each node
- entities perform actions, exchange messages with peers



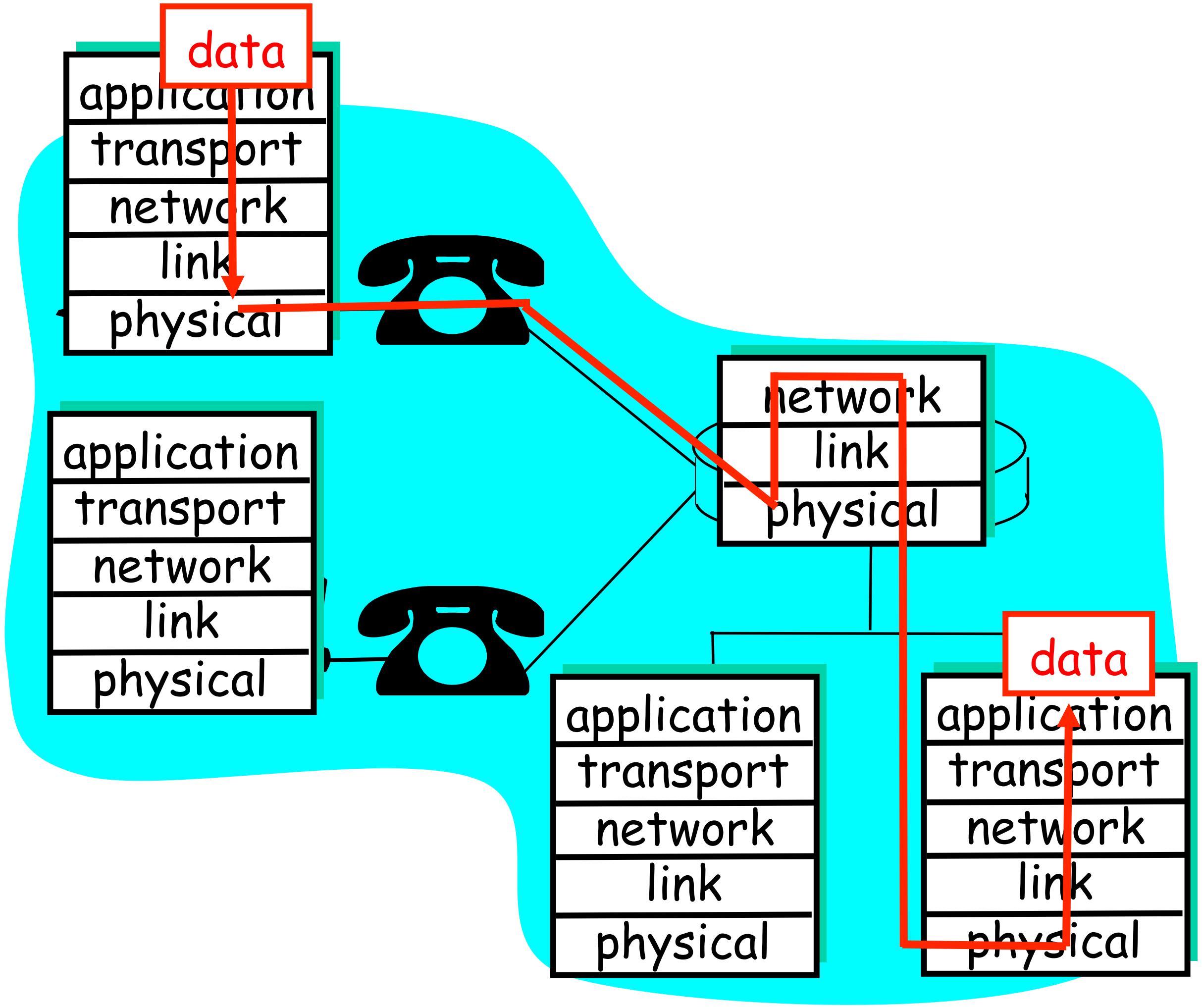
Layering: *logical* communication

E.g.: transport

- take data from app
- add addressing, reliability check info to form "datagram"
- send datagram to peer
- wait for peer to ack receipt
- analogy: post office

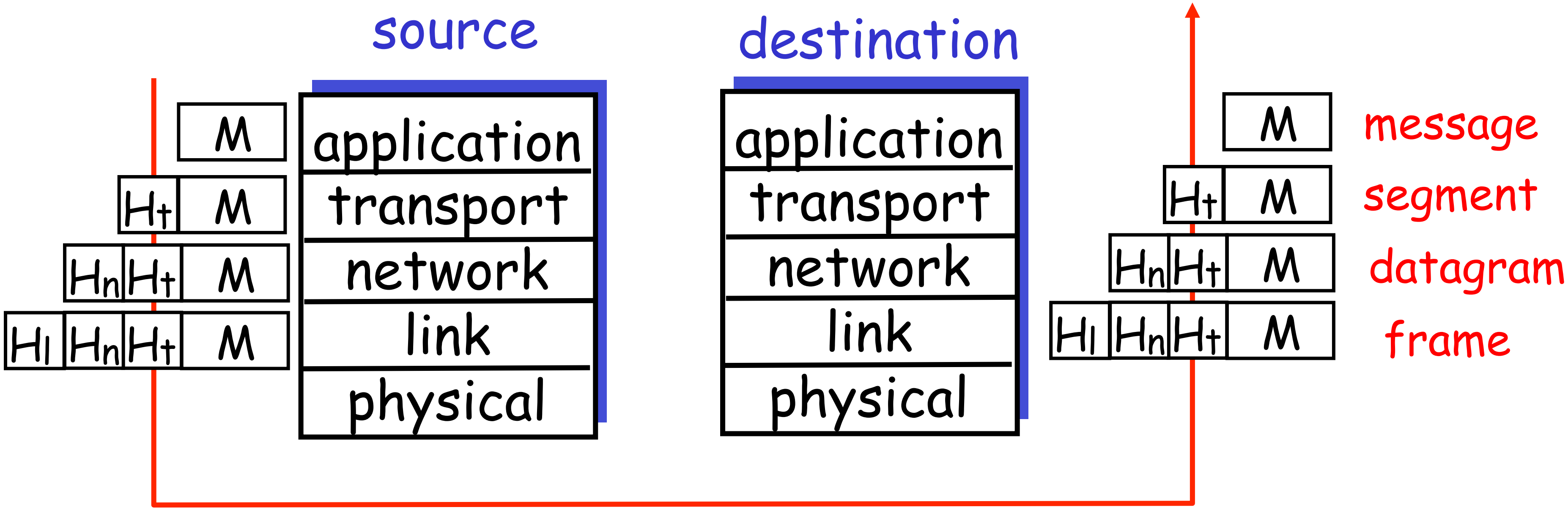


Layering: physical communication



Protocol layering and data

Each layer takes data from above
- adds header information to create new data unit
- passes new data unit to layer below



Internet History

1961-1972: Early packet-switching principles

- 1961: Kleinrock's queueing theory shows effectiveness of packet-switching
- 1964: Baran's packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1972:
  - ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1973: Metcalfe's PhD thesis proposes Ethernet
- 1974: Cerf and Kahn - architecture for interconnecting networks
- late70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets
- 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's: commercialization, the WWW

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

Late 1990's:

- est. 50 million computers on Internet
- est. 100 million+ users
- backbone links running at 1 Gbps

Internet History

2000's: everything goes IP, rise of mobile internet

- Early 2000s: VoIP goes mainstream, Myspace.
- Mid 2000s: Facebook and Google dominate the internet. Youtube, Twitter
- Late 2000s: Mobile phones with internet connectivity become ubiquitous. iPhone.

Internet History

2010's ...

- 2010: First Internet connection into space (low earth orbit)
- Early 2011: World 'runs out' of IPv4 adresses

Introduction: Summary

Covered a “ton” of material!

- Internet overview
- what’s a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
- performance: loss, delay
- layering and service models
- backbones, NAPs, ISPs
- history