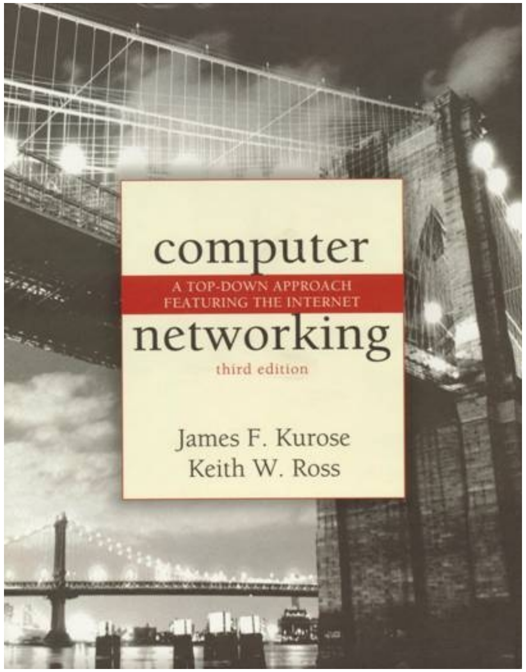
# Chapter 1
# Computer Networks and the Internet




*Computer Networking: A Top Down Approach Featuring the Internet,*

3rd edition.
Jim Kurose, Keith Ross
Addison-Wesley, July 2004.

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Thanks and enjoy! JFK/KWR

# Chapter 1: Introduction

## Our goal:

- get context, overview, "feel" of networking
- more depth, detail *later* in course
- approach:
  - descriptive
  - use Internet as example

## Overview:

- what's the Internet
- what's a protocol?
- network edge
- network core
- access net, physical media
- Internet/ISP structure
- performance: loss, delay
- protocol layers, service models
- history

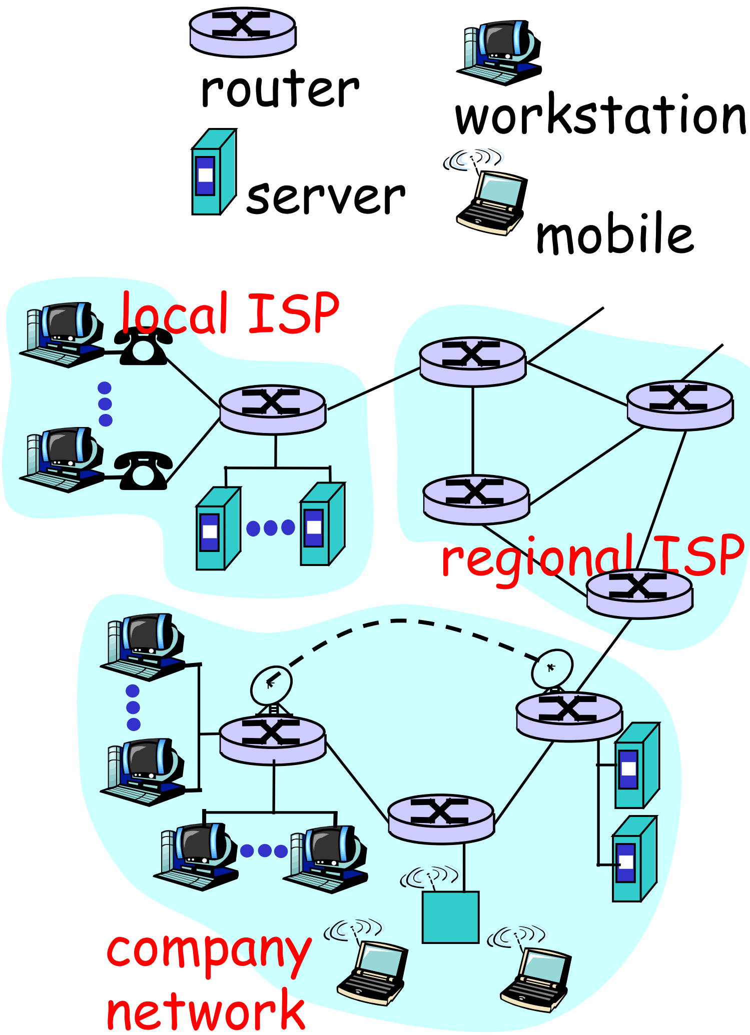
# Chapter 1: roadmap

1.1 What *is* the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

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

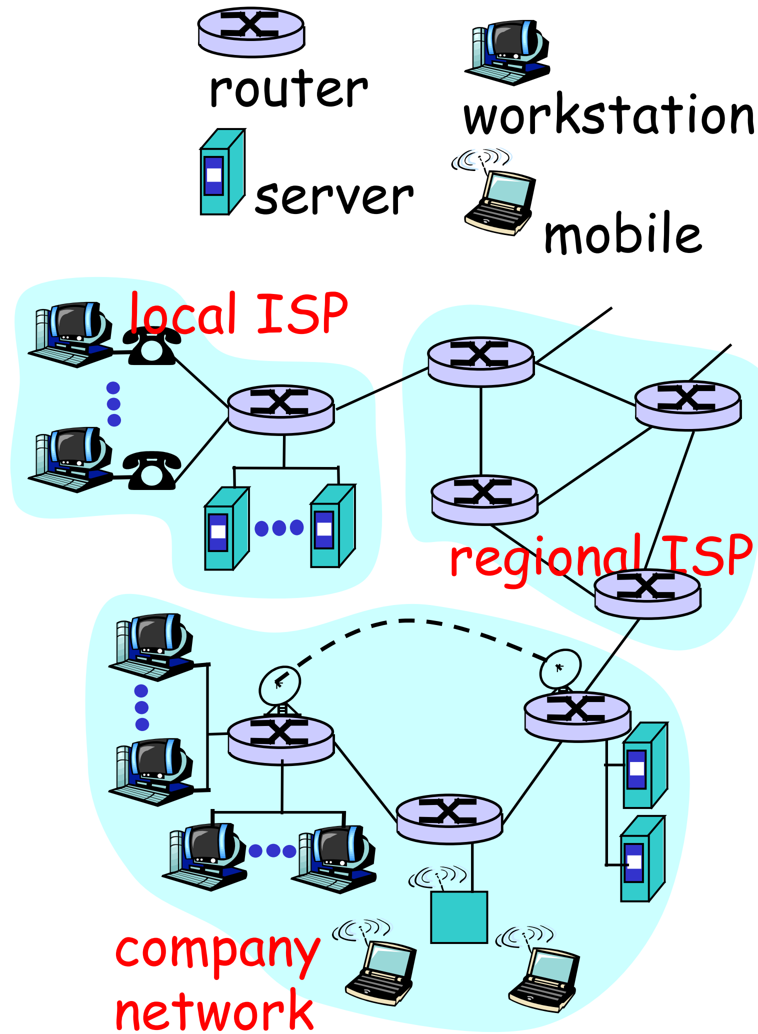
- millions of connected computing devices: *hosts = end-systems*
  - PCs workstations, servers
  - PDAs phones, toasters

  running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate = *bandwidth*
- *routers:* forward packets (chunks of data)



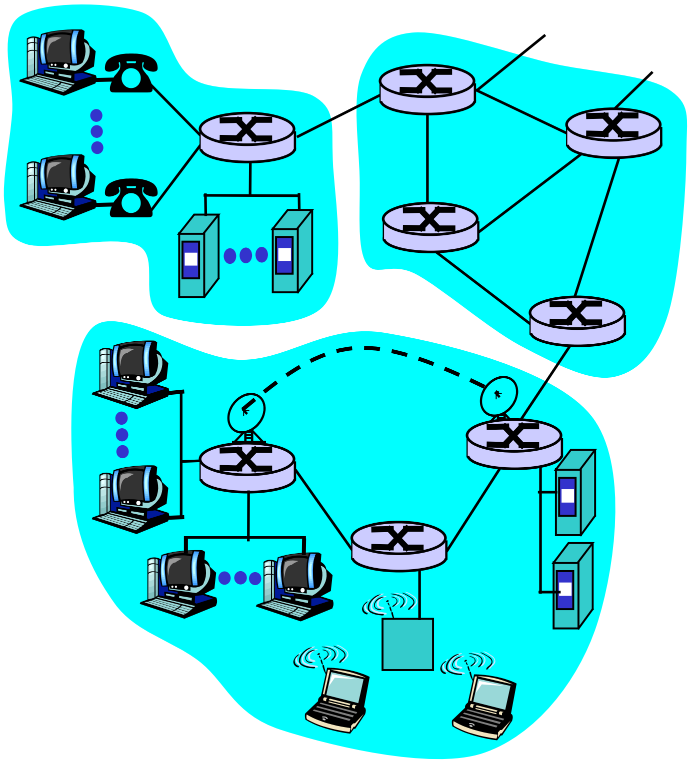
# What's the Internet: "nuts and bolts" view

- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, FTP, PPP
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



# What's the Internet: a service view

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



# What's a protocol?

human protocols:

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

… specific messages sent

… specific actions taken when messages received, or other events

network protocols:

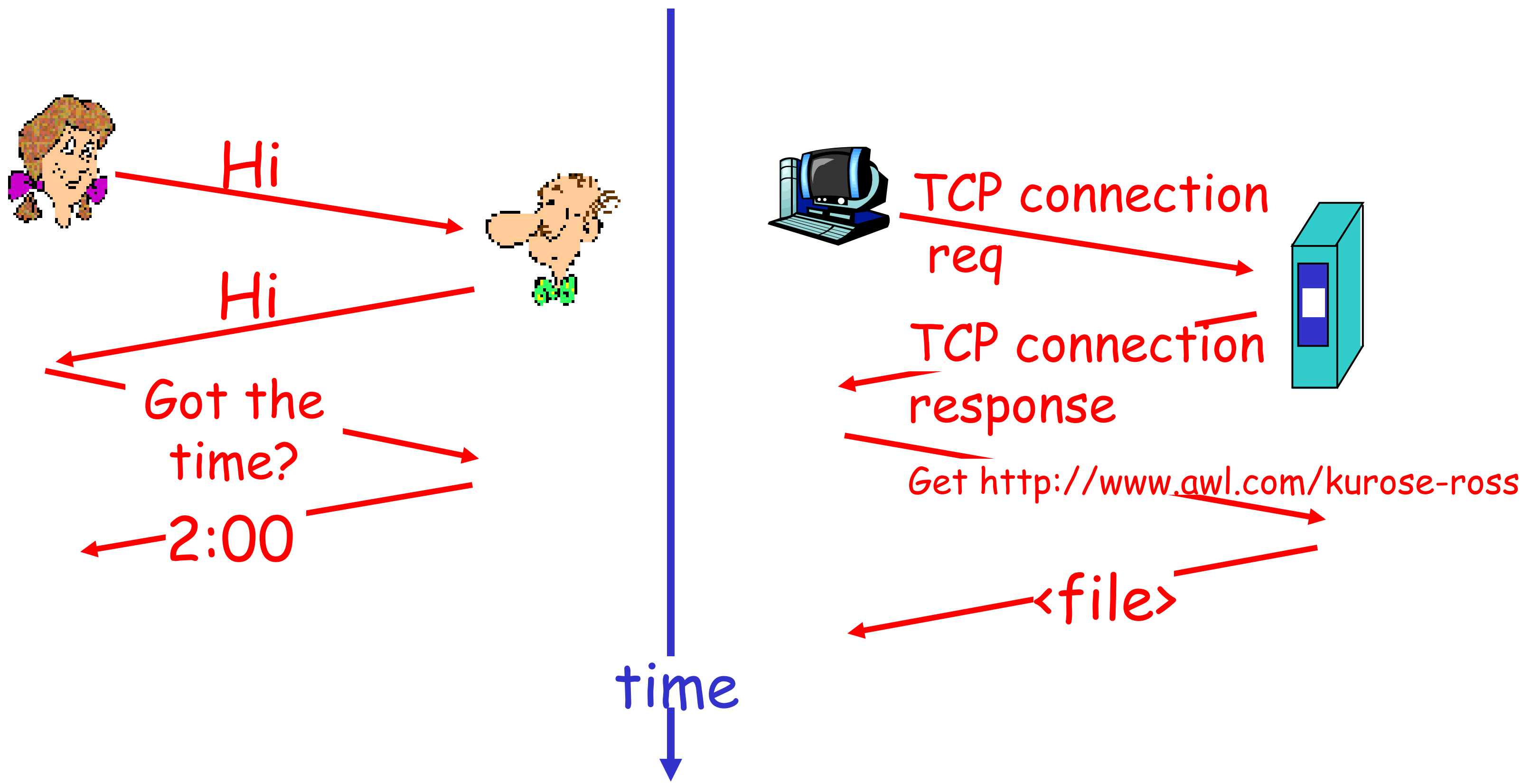
- machines rather than humans
- all communication activity in Internet governed by protocols

*protocols define*

- *format, order of messages sent and received among network entities, and*
- *actions taken on the transmission/receipt of a message*

# What's a protocol?

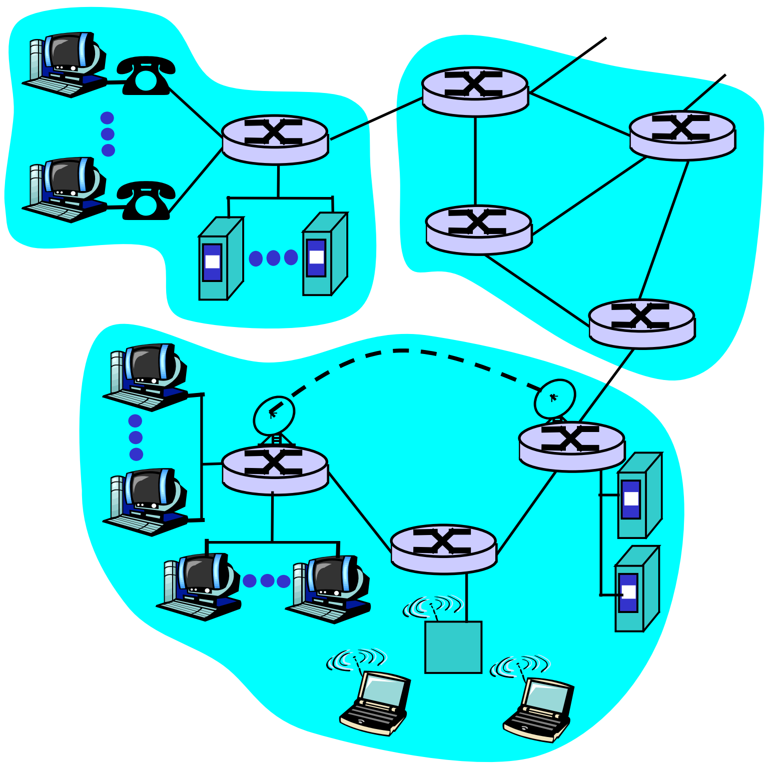
a human protocol and a computer network protocol:




Q: Other human protocols?

# A closer look at network structure:

- network edge: applications and hosts
- network core:
  - routers
  - network of networks
- access networks, physical media: communication links



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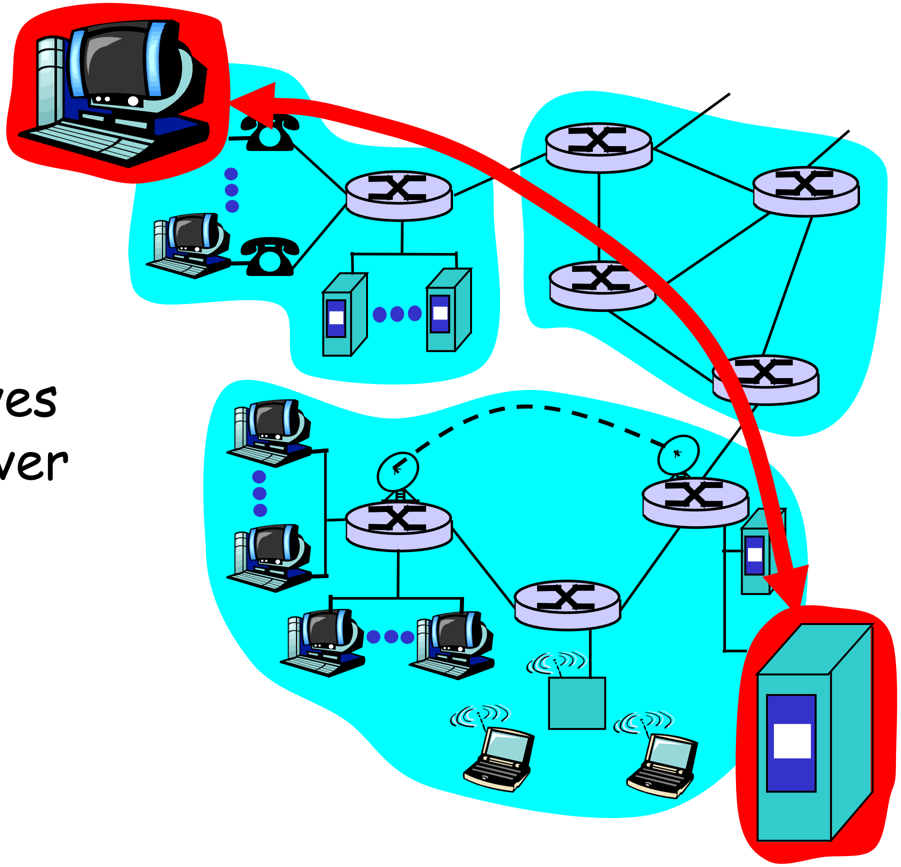
# The network edge:

- end systems (hosts):
  - run application programs
  - e.g. Web, email
  - at “edge of network”
- client/server model
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- peer-peer model:
  - minimal (or no) use of dedicated servers
  - 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 [RFC 793]

- *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 [RFC 768]: Internet's connectionless service
  - unreliable data transfer
  - no flow control
  - no congestion control

**App's using TCP:**

- HTTP (Web), FTP (file transfer), Telnet (remote login), SMTP (email)

**App's using UDP:**

- streaming media, teleconferencing, DNS, Internet telephony

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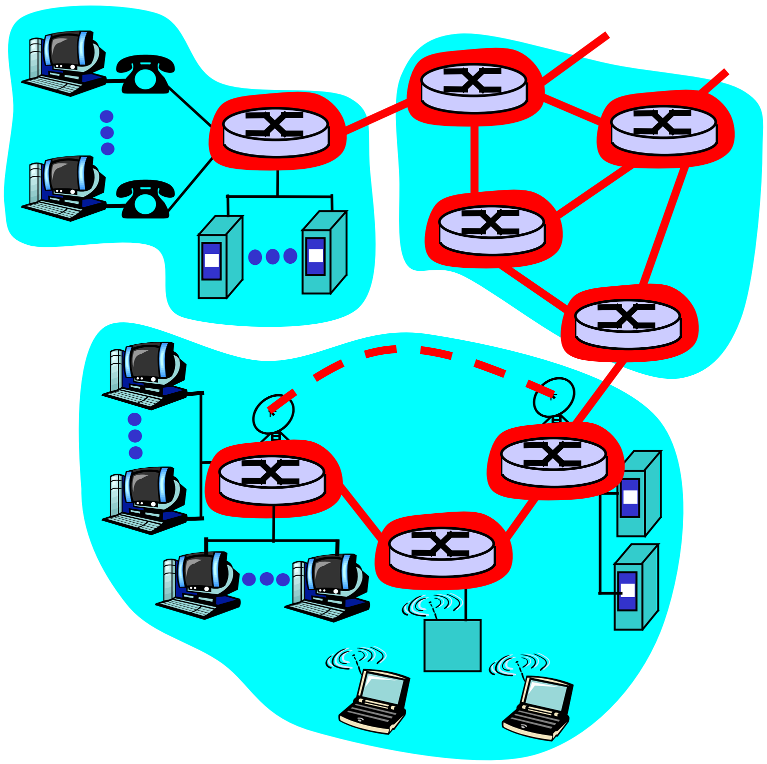
# The Network Core

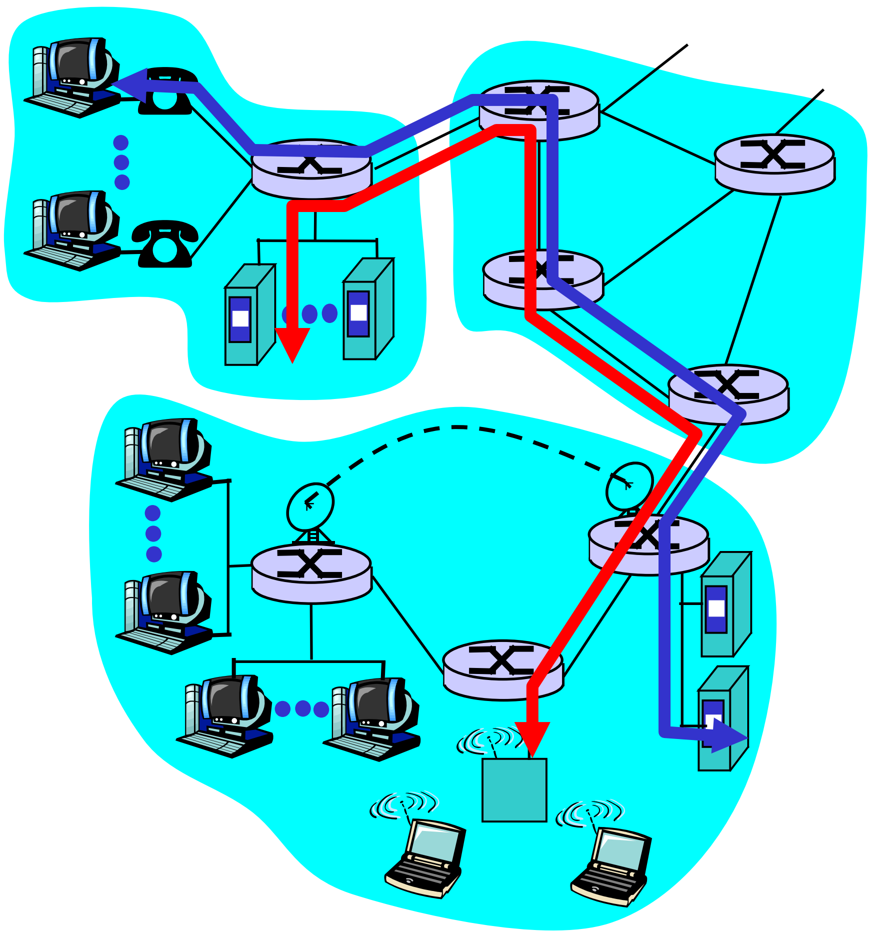
- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



# 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)*

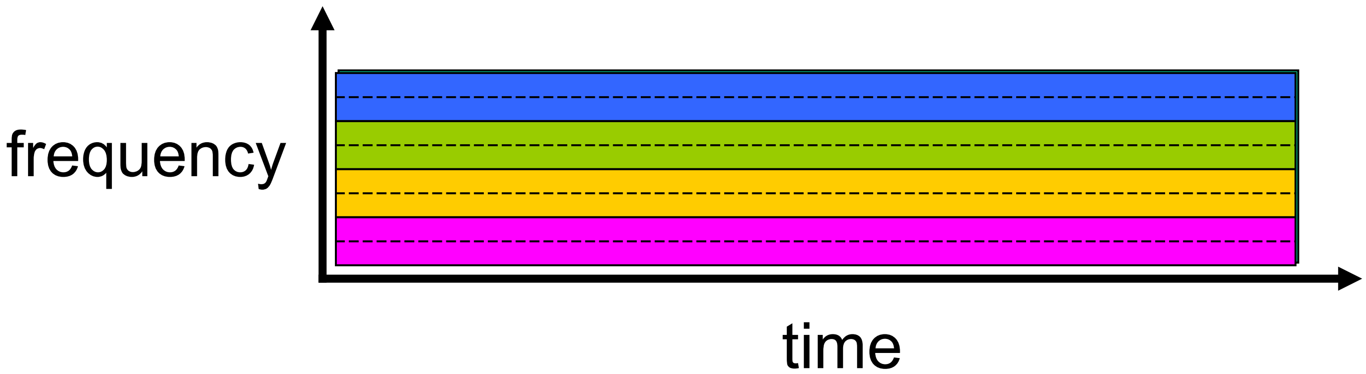
- dividing link bandwidth into "pieces"
  - frequency division
  - time division

# Circuit Switching: FDMA and TDMA

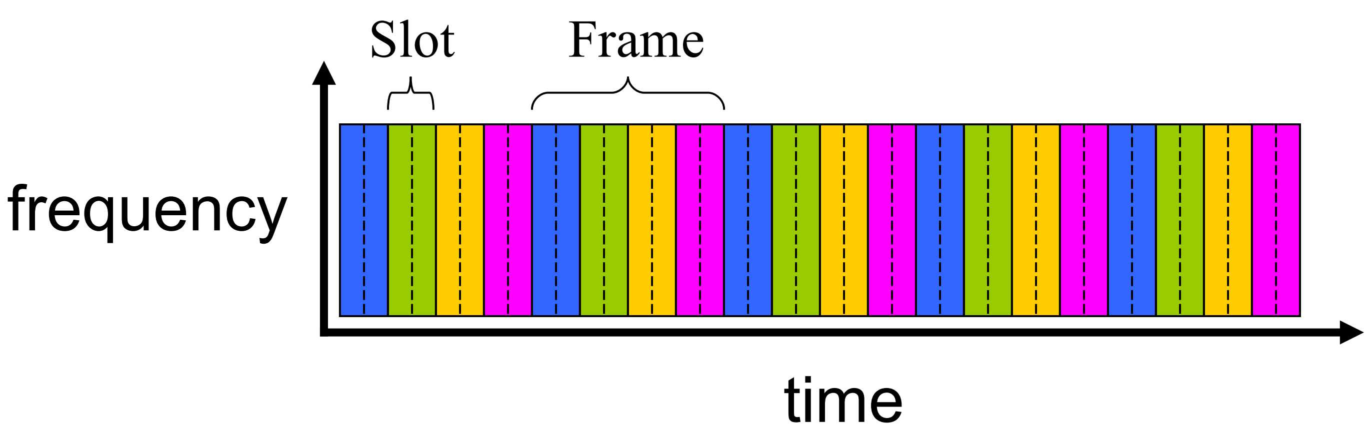
Example:

4 users

FDMA




TDMA



# Network Core: Packet Switching

each end-end data stream divided into *packets*

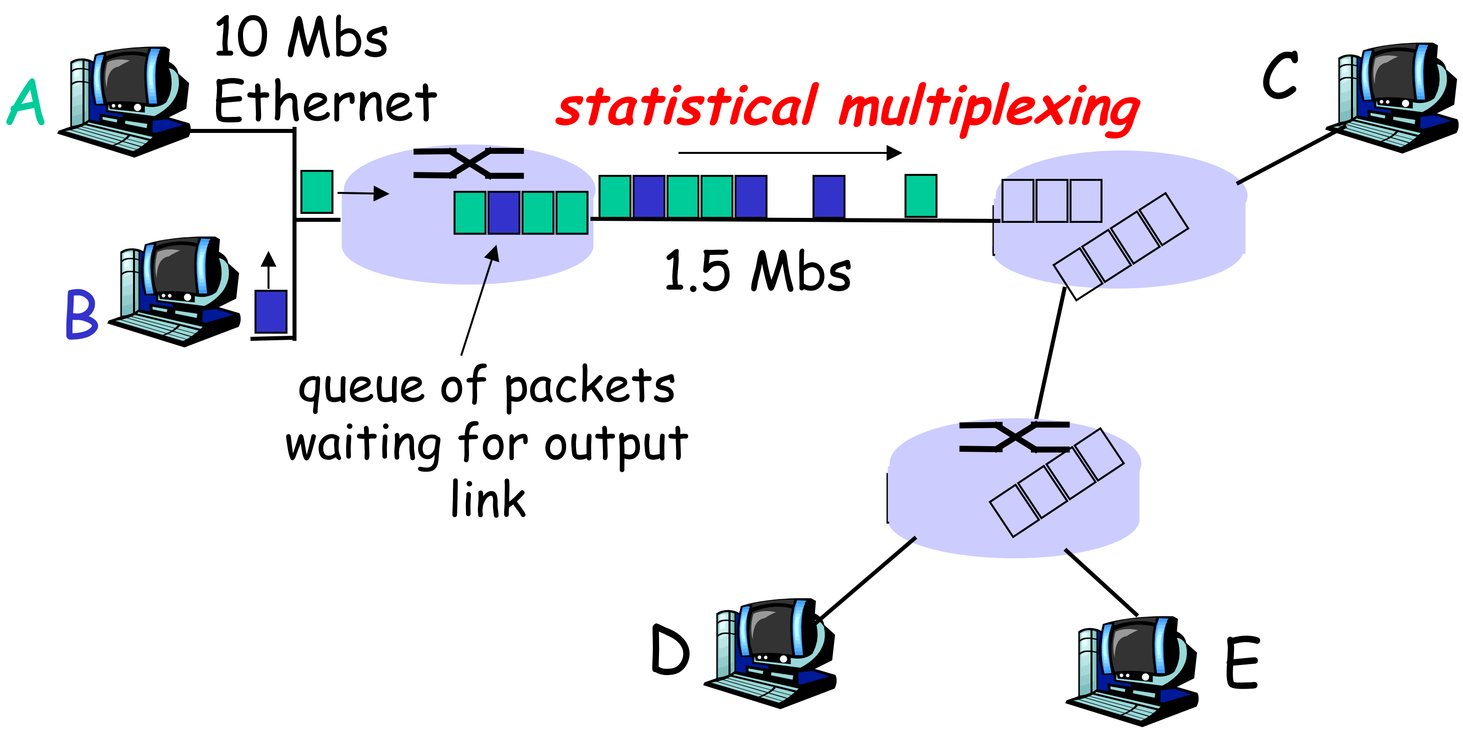
- user A, B packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*

~~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

# Packet Switching: Statistical Multiplexing



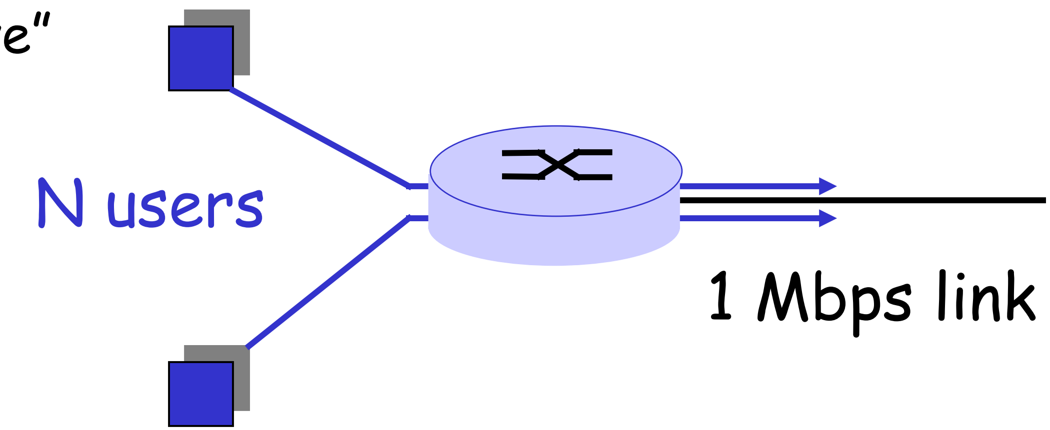

Sequence of A & B packets does not have fixed pattern  *statistical multiplexing*.

In TDM each host gets same slot in revolving TDM frame.

# Packet switching versus circuit switching

Packet switching allows more users to use network!

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

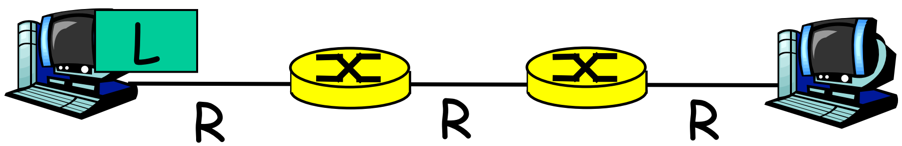


# Packet switching versus circuit switching

Is packet switching a "slam dunk winner?"

- Great for bursty data
  - resource sharing
  - simpler, 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-switching: store-and-forward

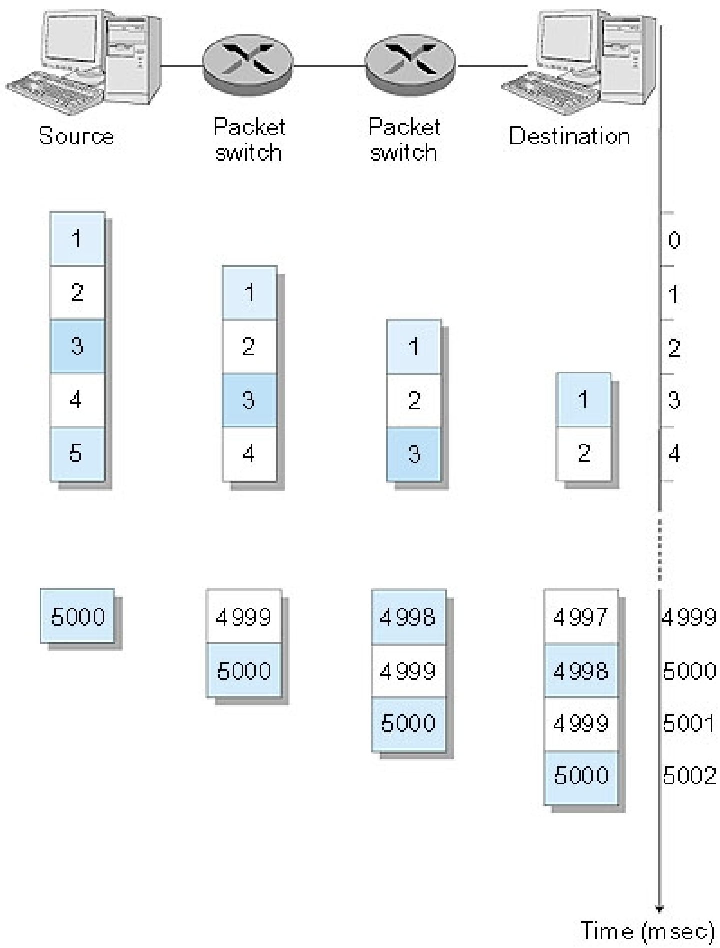



- Takes L/R seconds to transmit (push out) packet of L bits onto a link of R bps
- Entire packet must arrive at router before it can be transmitted on next link: *store and forward*
- delay = 3L/R

Example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- delay = 15 sec

# Packet Switching: Message Segmenting



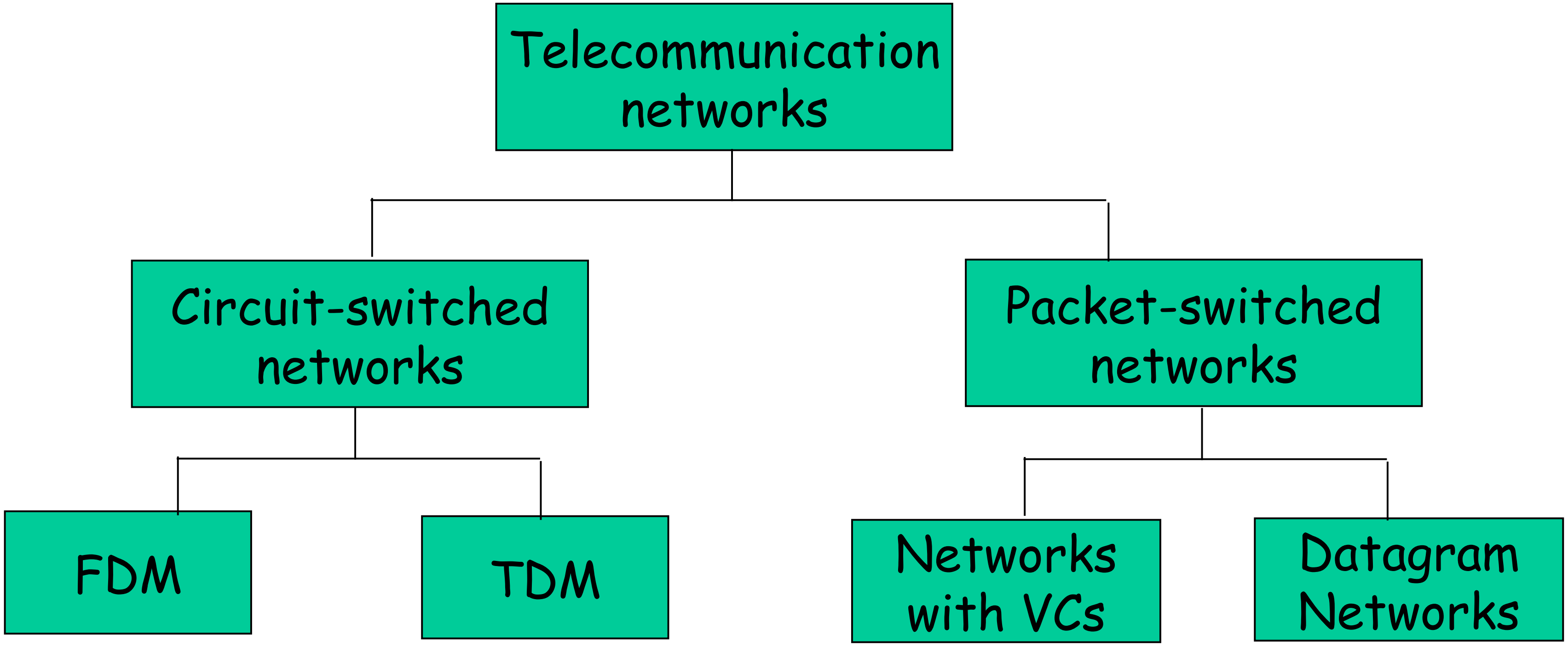

Now break up the message into 5000 packets

- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- *pipelining:* each link works in parallel
- Delay reduced from 15 sec to 5.002 sec

# Packet-switched networks: forwarding

- *Goal:* move packets through routers from source to destination
  - we'll study several path selection (i.e. routing) algorithms (chapter 4)
- datagram network:
  - *destination address* in packet determines next hop
  - routes may change during session
  - analogy: driving, asking directions
- virtual circuit network:
  - each packet carries tag (virtual circuit ID), tag determines next hop
  - fixed path determined at *call setup time*, remains fixed thru call
  - *routers maintain per-call state*

# Network Taxonomy




- Datagram network is *not* either connection-oriented or connectionless.
- Internet provides both connection-oriented (TCP) and connectionless services (UDP) to apps.

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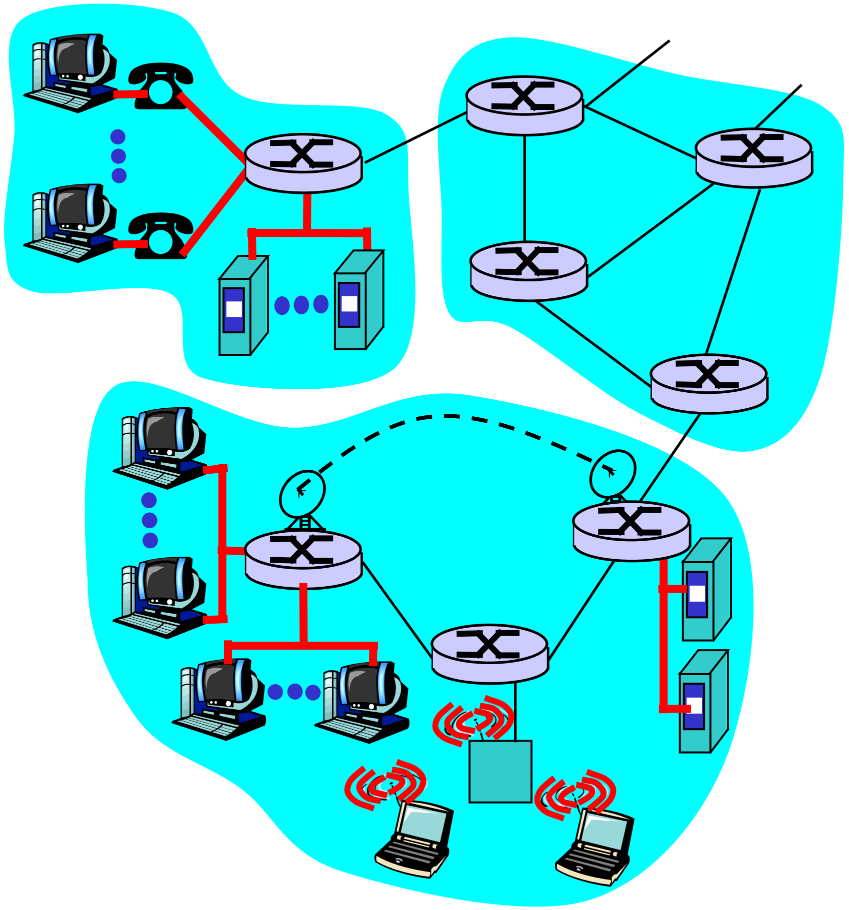
# Access networks and physical media

*Q: How to connect end systems to edge router?*

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

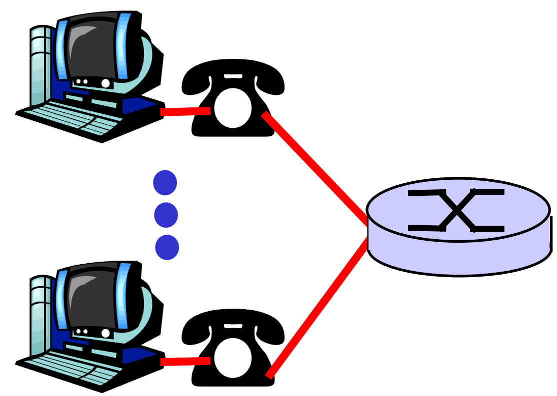
*Keep in mind:*

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



# Residential access: point to point access

- Dialup via modem
  - up to 56Kbps direct access to router (often less)
  - Can't surf and phone at same time: can't be "always on"



- ADSL: asymmetric digital subscriber line
  - up to 1 Mbps upstream (today typically < 256 kbps)
  - up to 8 Mbps downstream (today typically < 1 Mbps)
  - FDM: 50 kHz - 1 MHz for downstream

    4 kHz - 50 kHz for upstream

    0 kHz - 4 kHz for ordinary telephone

# Residential access: cable modems

- HFC: hybrid fiber coaxial cable
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- network of cable and fiber attaches homes to ISP router
  - shared access to router among home
  - issues: congestion, dimensioning
- deployment: available via cable companies, e.g., MediaOne

# Residential access: cable modems

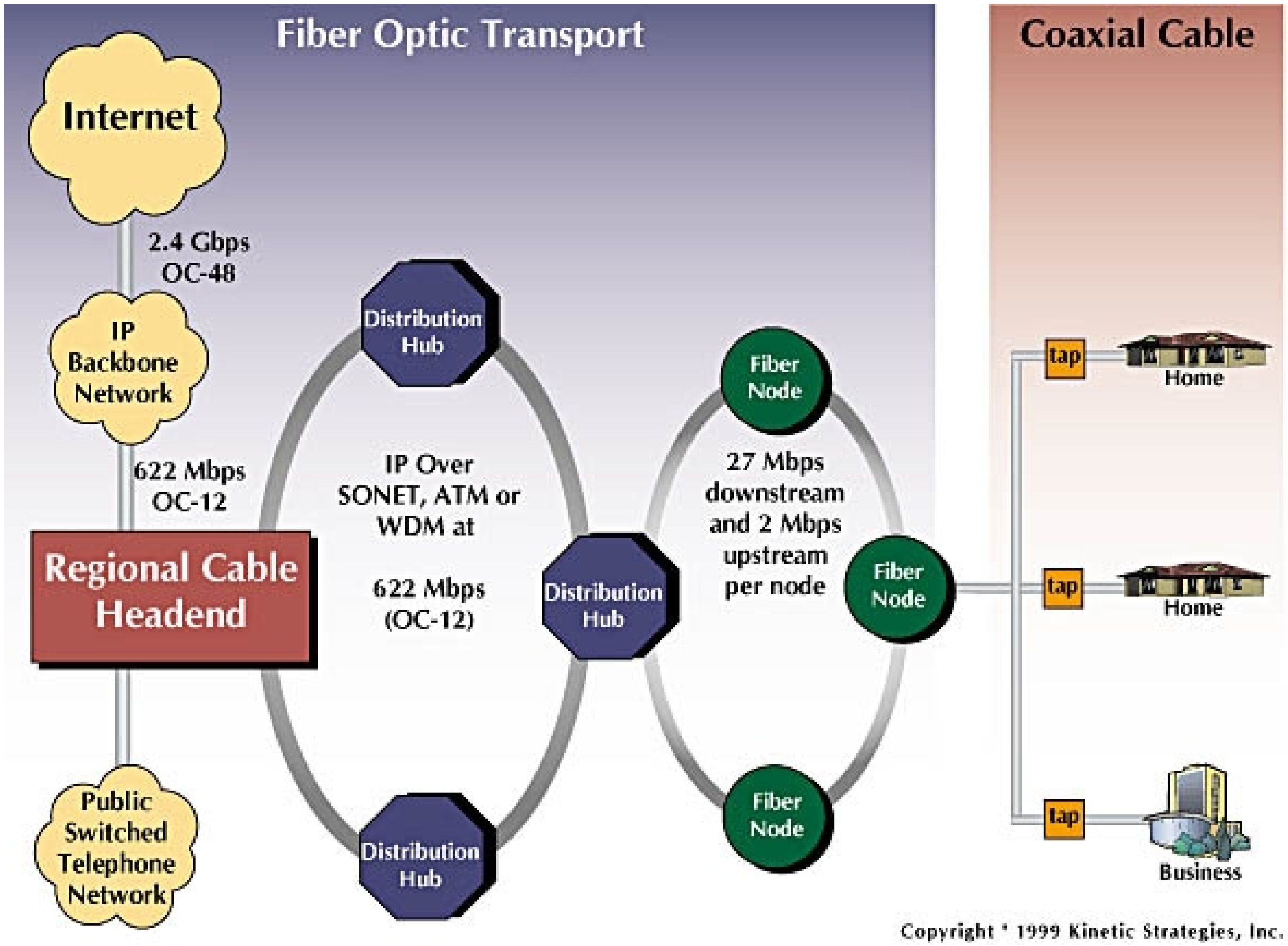
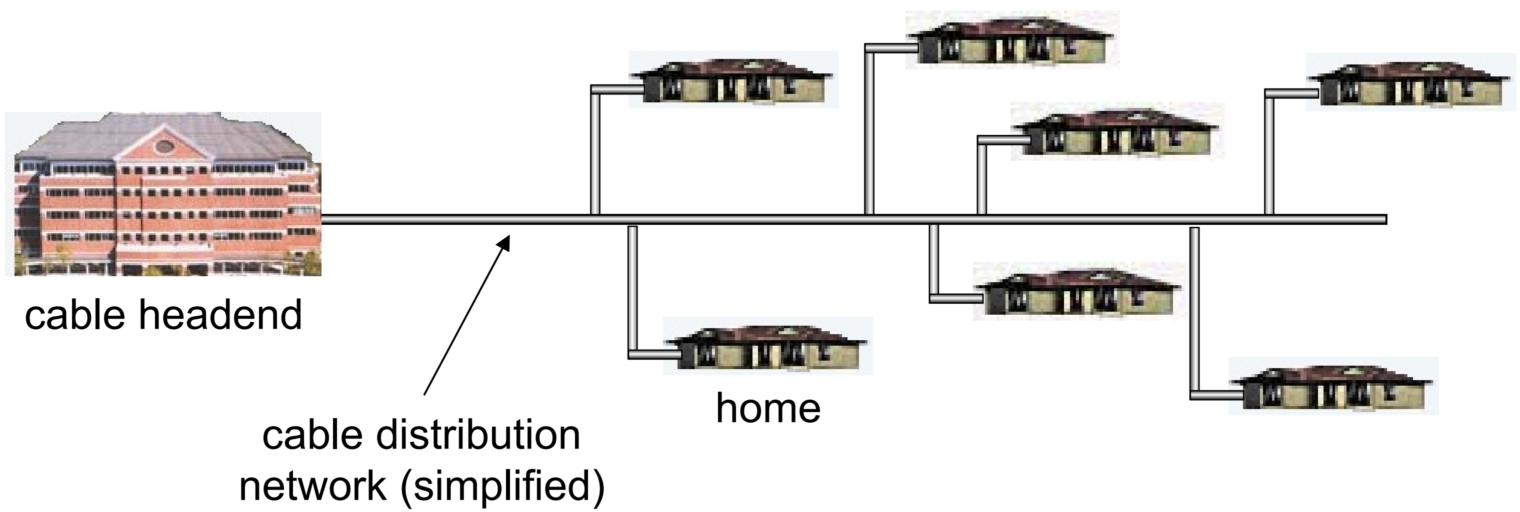


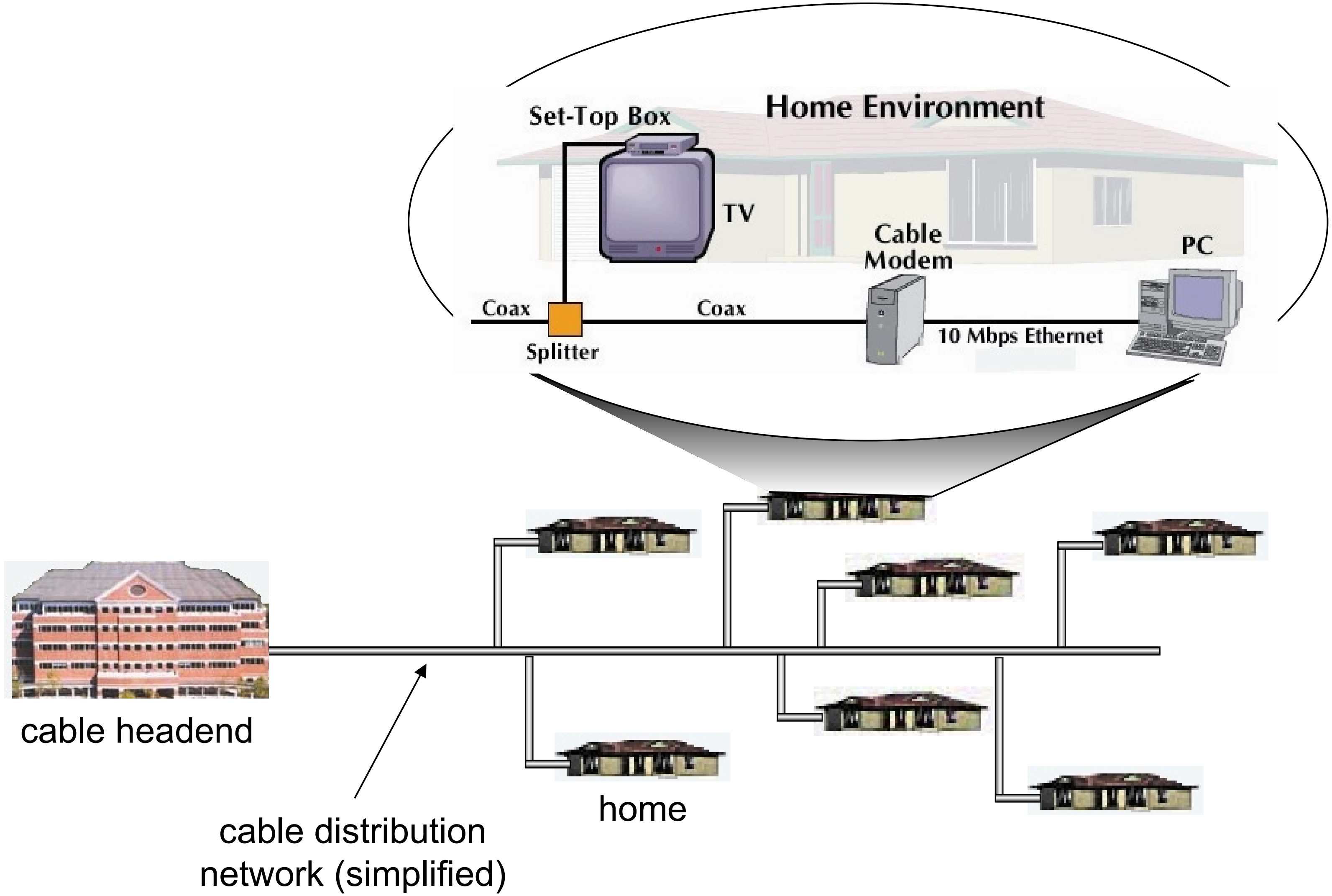

Diagram: http://www.cabledatacomnews.com/cmic/diagram.html

# Cabel Network Architecture: Overview

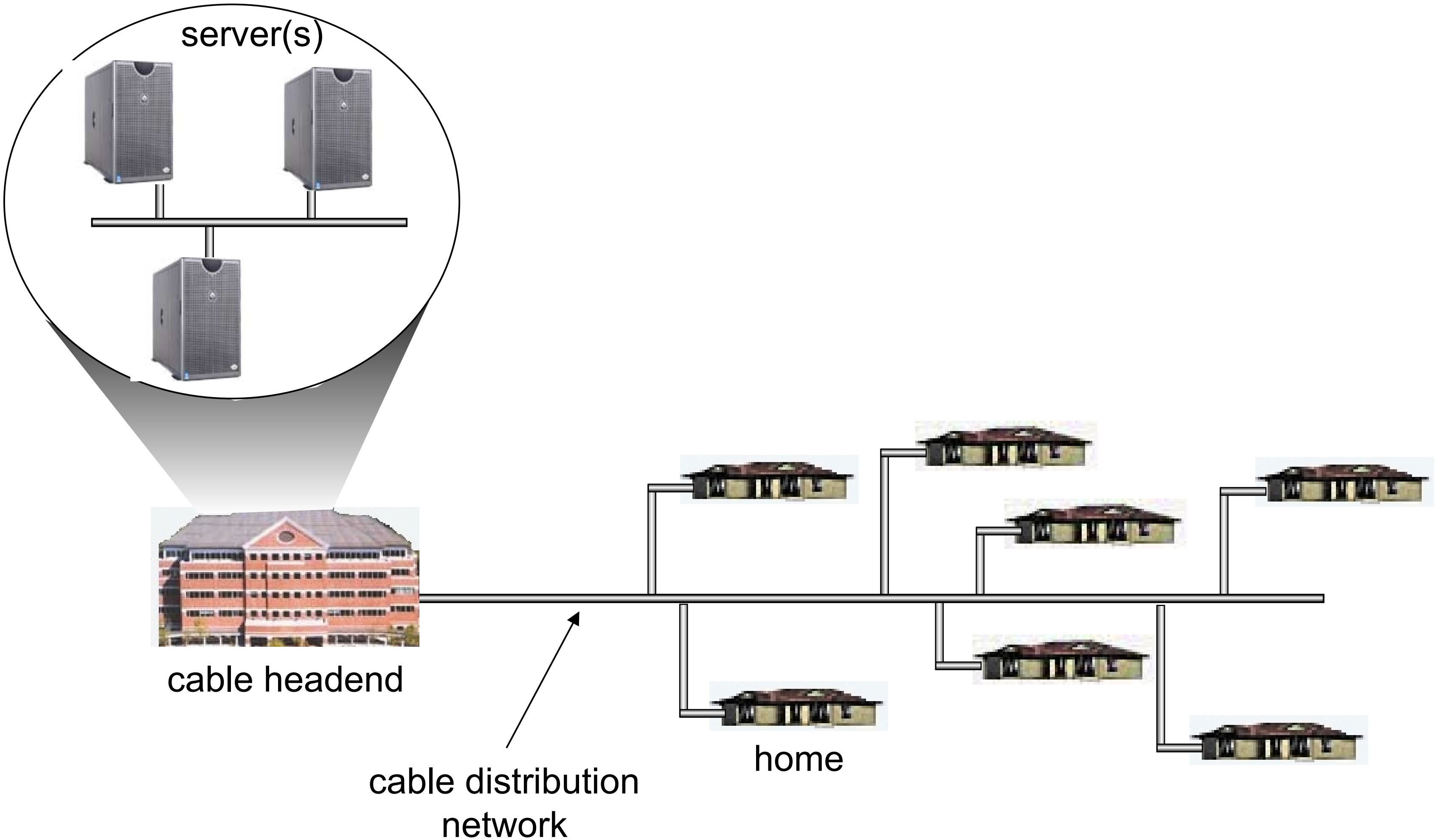
Typically 500 to 5,000 homes



# Cable Network Architecture: Overview

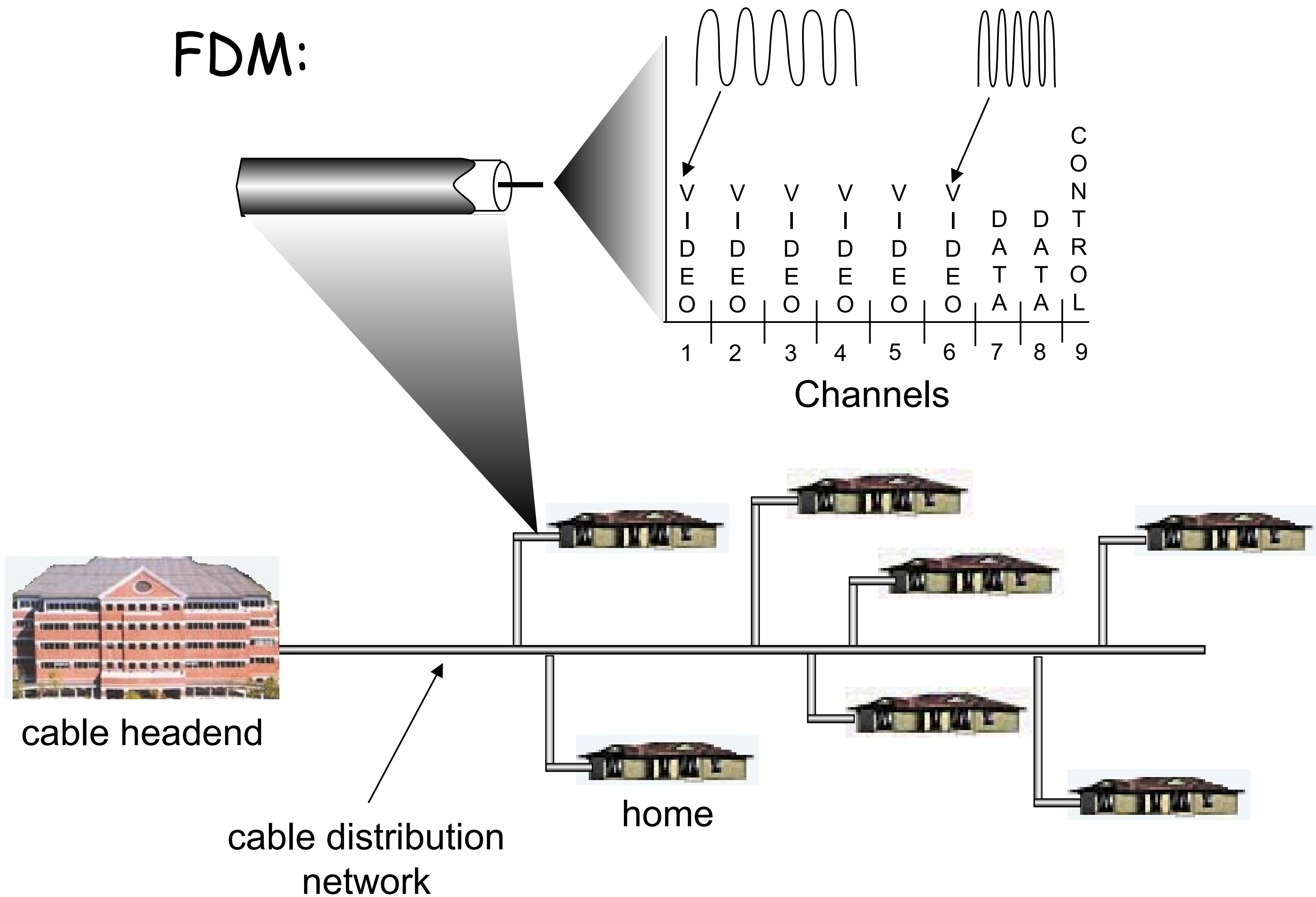


# Cable Network Architecture: Overview



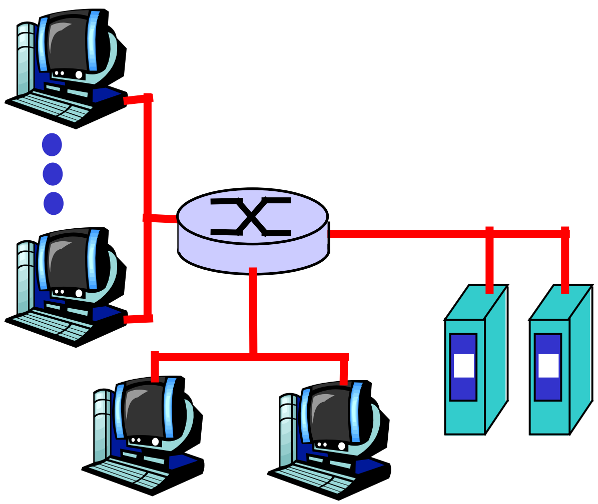
# Cable Network Architecture: Overview

FDM:



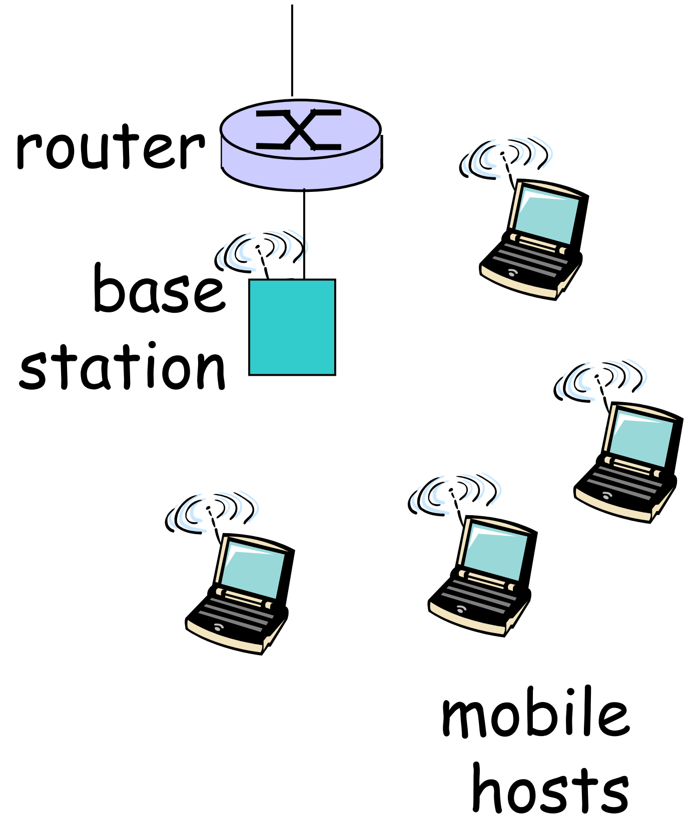
# Company access: local area networks

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



# Wireless access networks

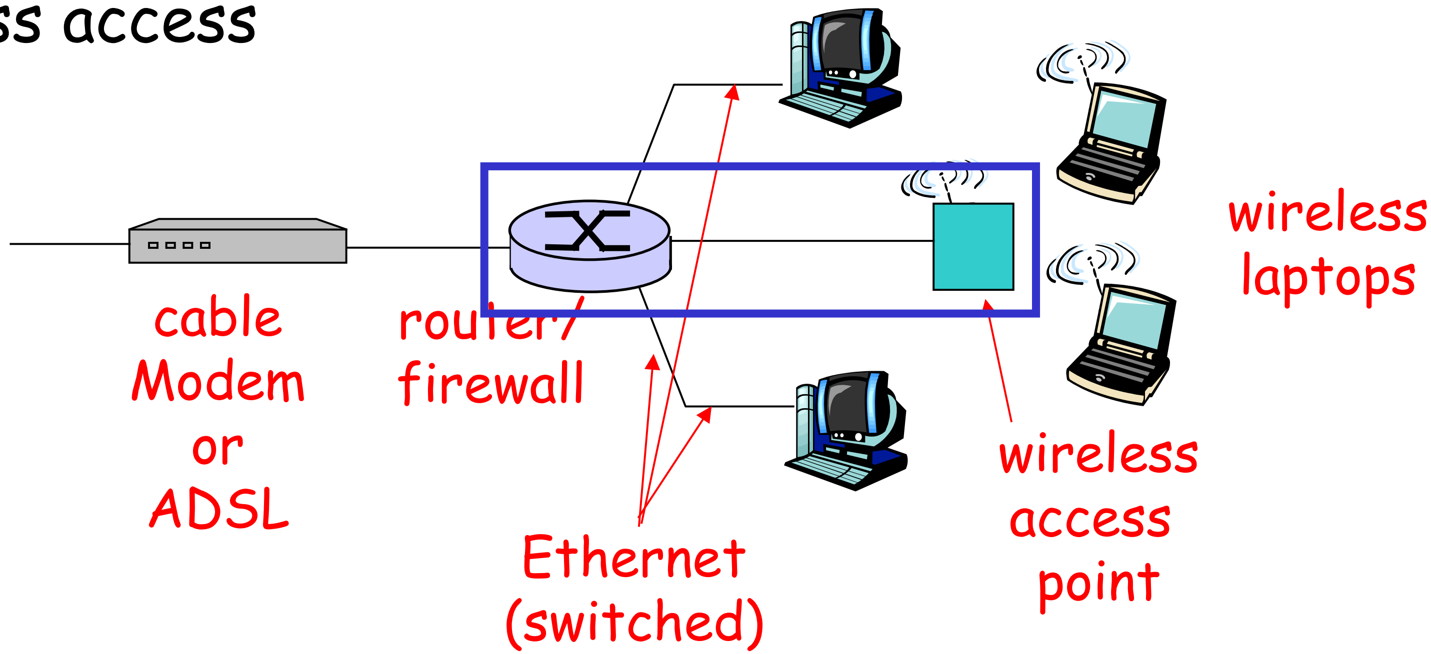
- shared *wireless* access network connects end system to router
  - via base station also known as "access point"
- wireless LANs:
  - 802.11b (WiFi): 11 Mbps
  - 802.11g: 54 Mbps
  - 802.11n: 108 Mbps
- wider-area wireless access
  - provided by telcom operator
  - 3G ~ 384 kbps
    - Will it happen??
  - 4G
  - WAP/GPRS in Europe
  - 802.16a/e (WiMax):



# Home networks

Typical home network components:

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



# 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

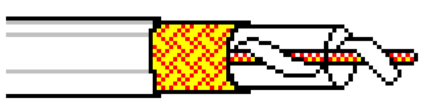
## Twisted Pair (TP)

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

# Physical Media: coax, fiber

**Coaxial cable:**

- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- 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., 5 Gps)
- 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)
  - 2Mbps, 11Mbps, 54Mbps, 108 Mbps
- wide-area (e.g., cellular)
  - e.g. 3G: hundreds of kbps
- satellite
  - up to 50Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low-earth-orbit satellites (LEOS)

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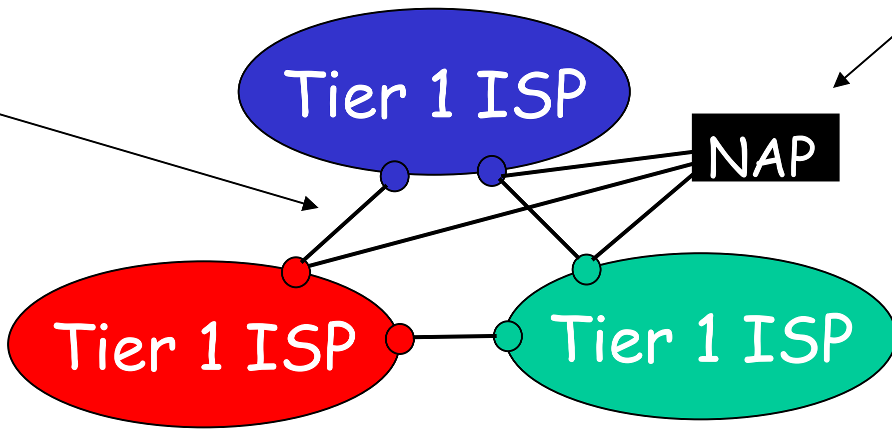
# Internet structure: network of networks

- roughly hierarchical
- at center: "tier-1" ISPs (e.g., UUNet, BBN/Genuity, Sprint, AT&T), national/international coverage
  - treat each other as equals

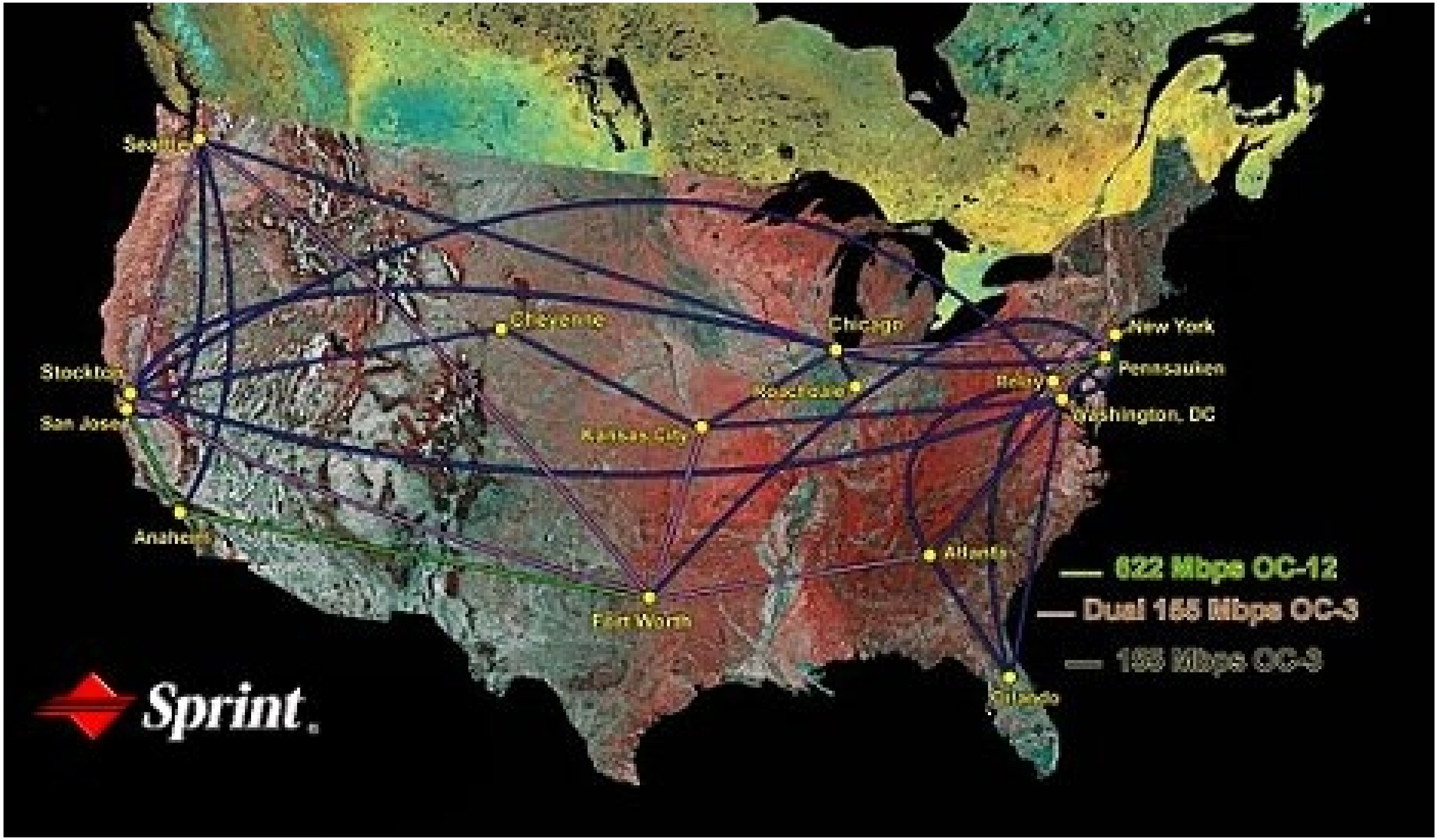
Tier-1 providers interconnect (peer) privately




Tier-1 providers also interconnect at public network access points (NAPs)

# Tier-1 ISP: e.g., Sprint

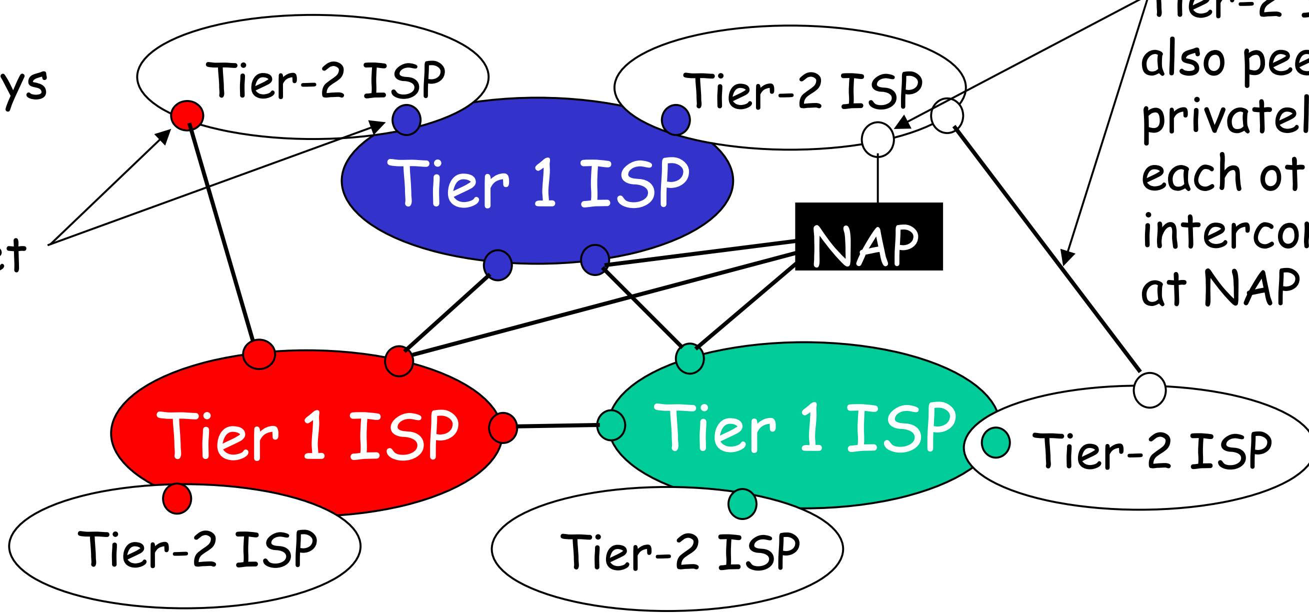
Sprint US backbone network



# Internet structure: network of networks

- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

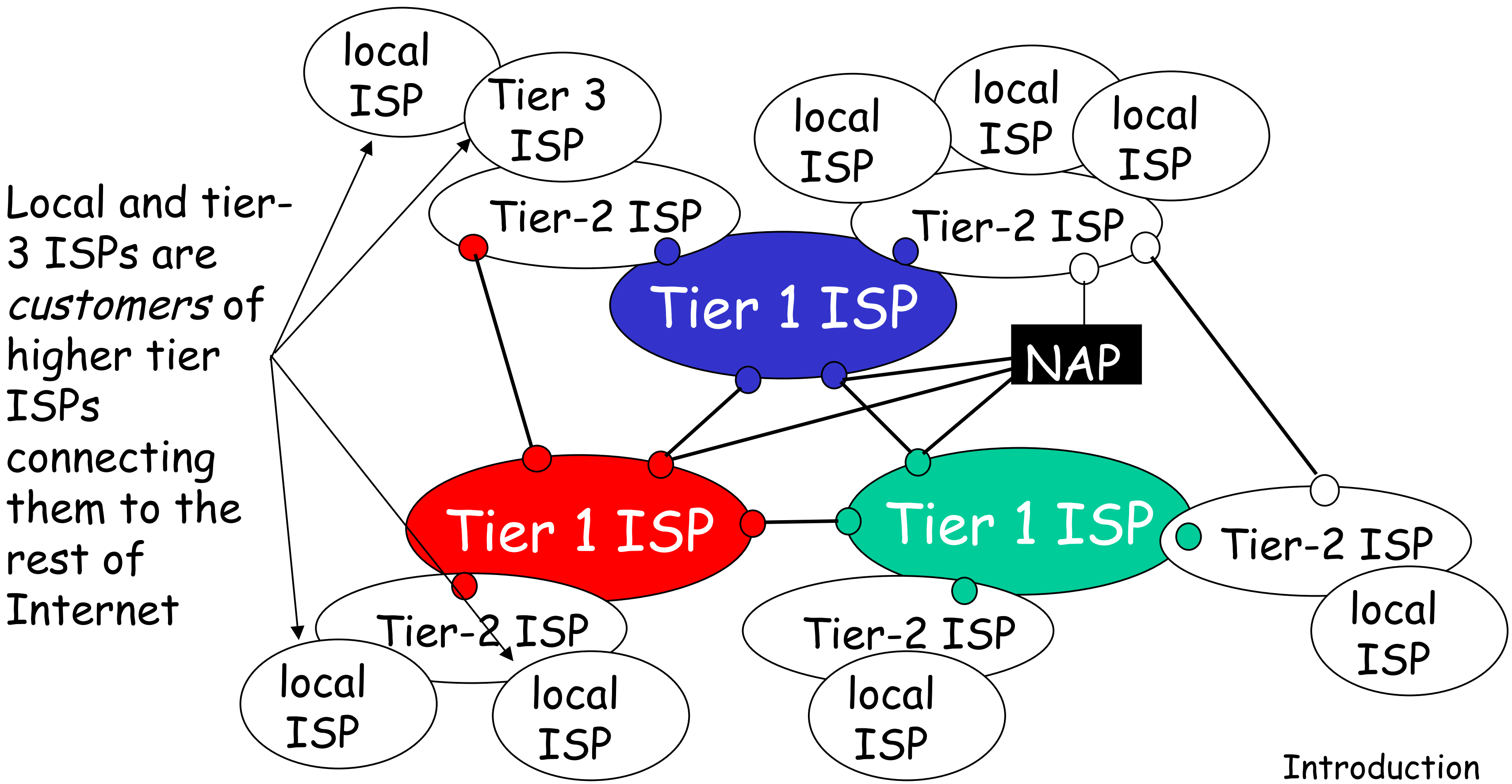
- Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet
- tier-2 ISP is *customer* of tier-1 *provider*




Tier-2 ISPs also peer privately with each other, interconnect at NAP

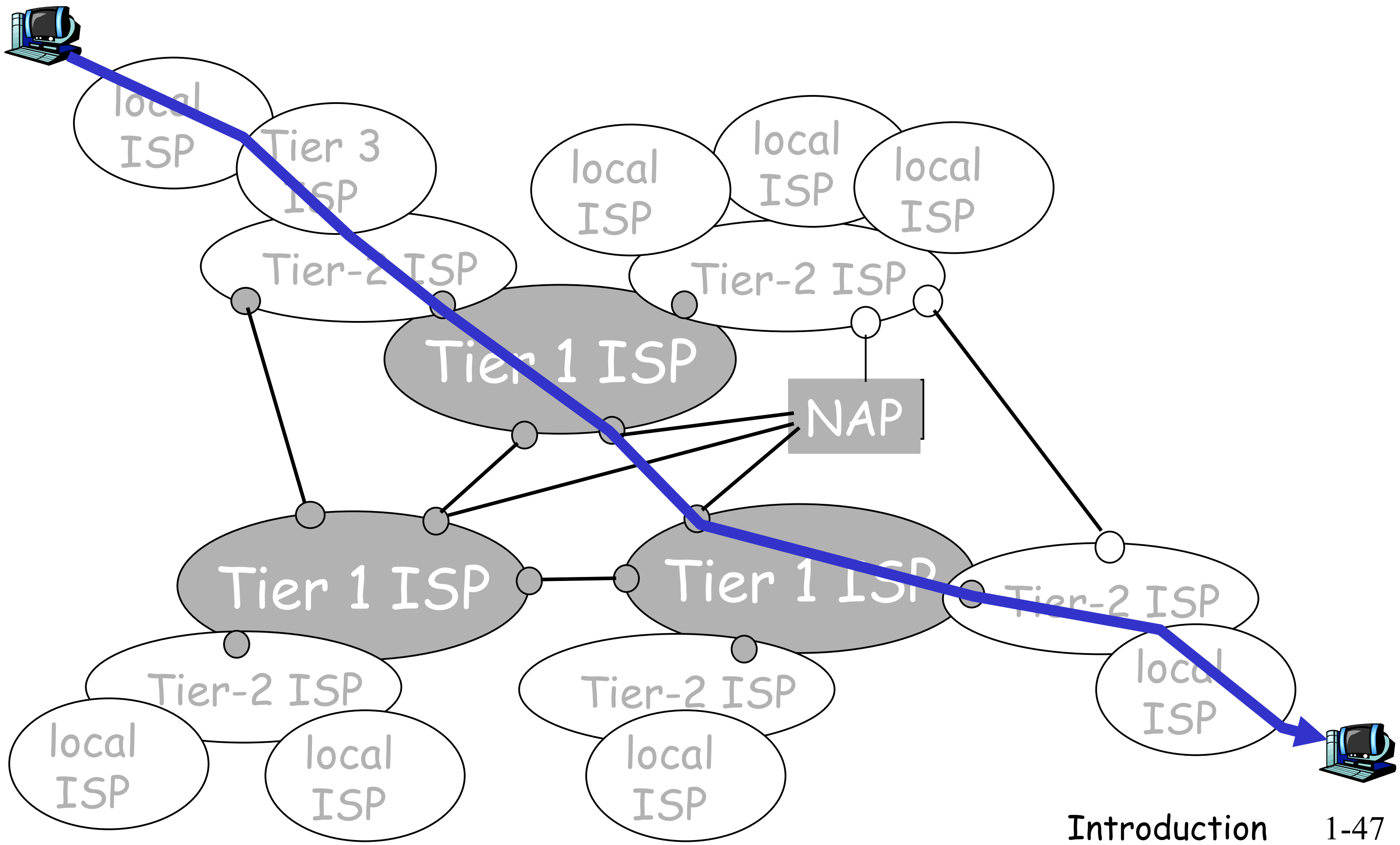
# Internet structure: network of networks

- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)



# Internet structure: network of networks

- a packet passes through many networks!



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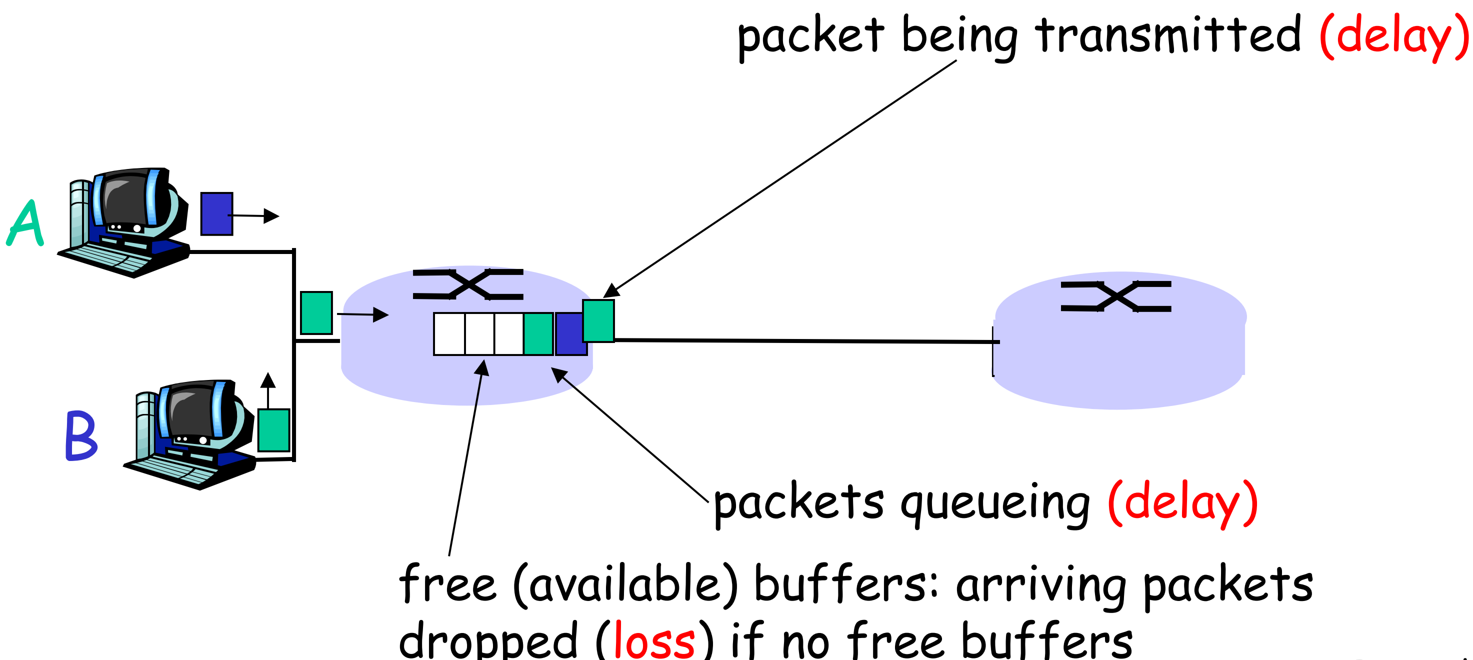
# How do loss and delay occur?

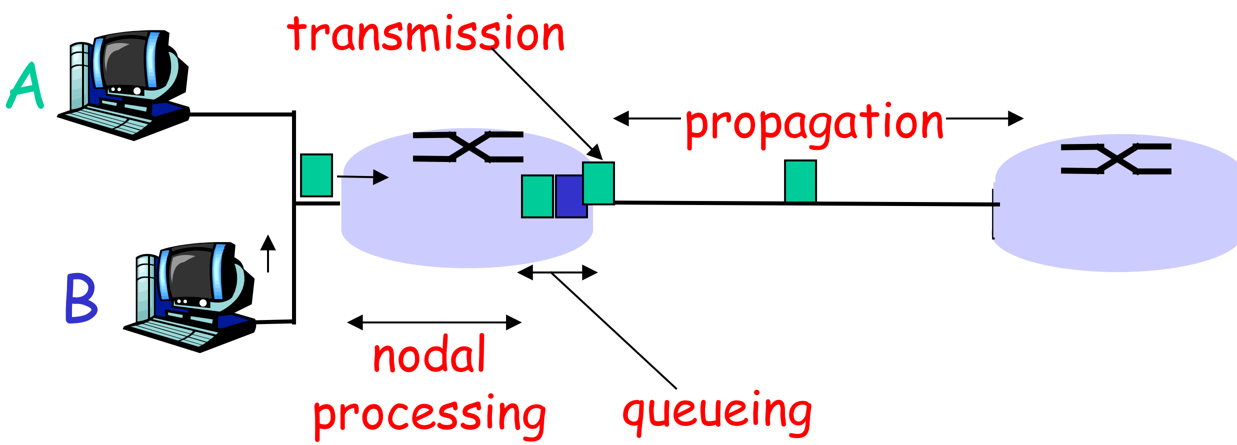
packets *queue* in router buffers

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



# Four sources of packet delay

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



# Delay in packet-switched networks

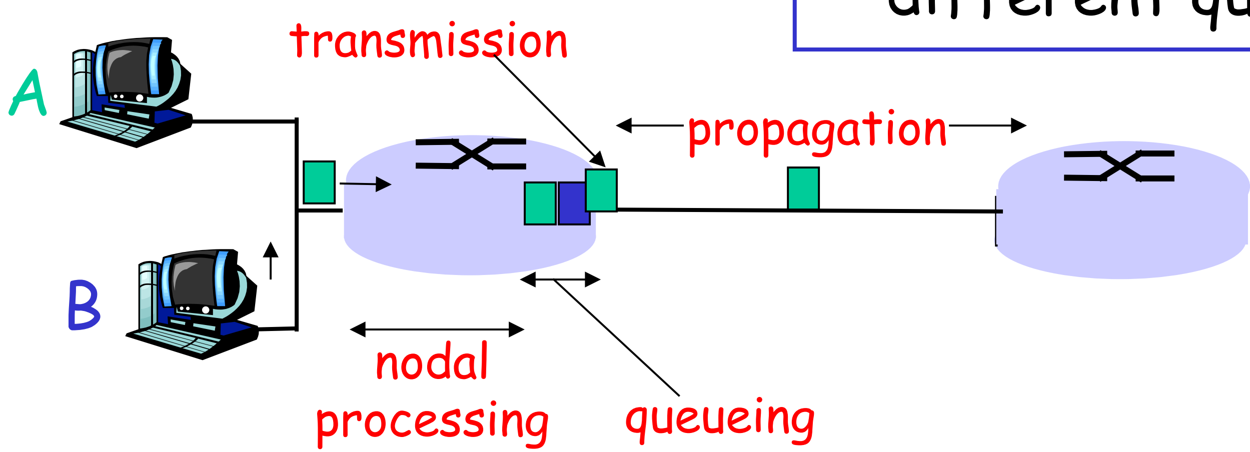
3. Transmission delay:

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

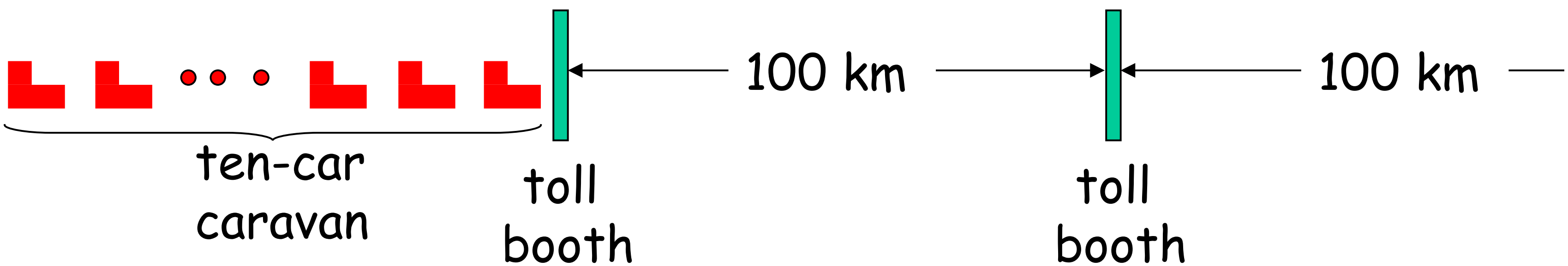
4. Propagation delay:

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

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

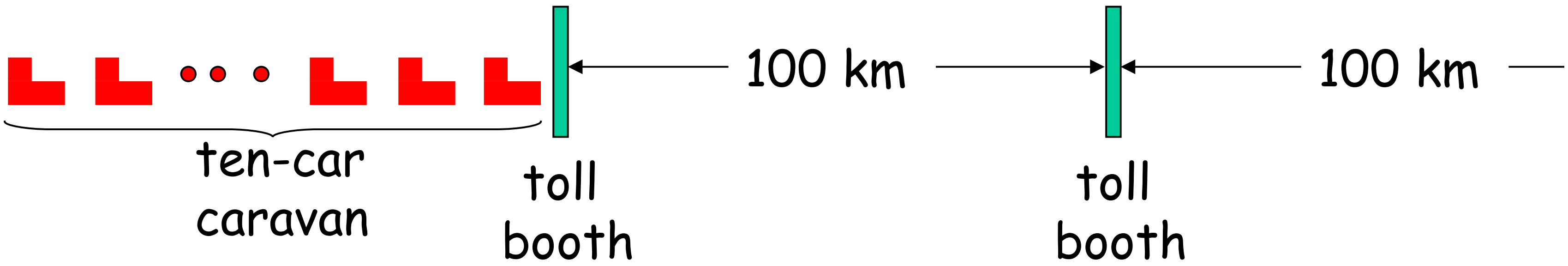


# Caravan analogy




- Cars "propagate" at 100 km/hr
- Toll booth takes 12 sec to service a car (transmission time)
- car~bit; caravan ~ packet
- Q: How long until caravan is lined up before 2nd toll booth?
- Time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec
- Time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
- A: 62 minutes

# Caravan analogy (more)




- Cars now "propagate" at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?

- Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!
  - See Ethernet applet at AWL Web site

# Nodal delay

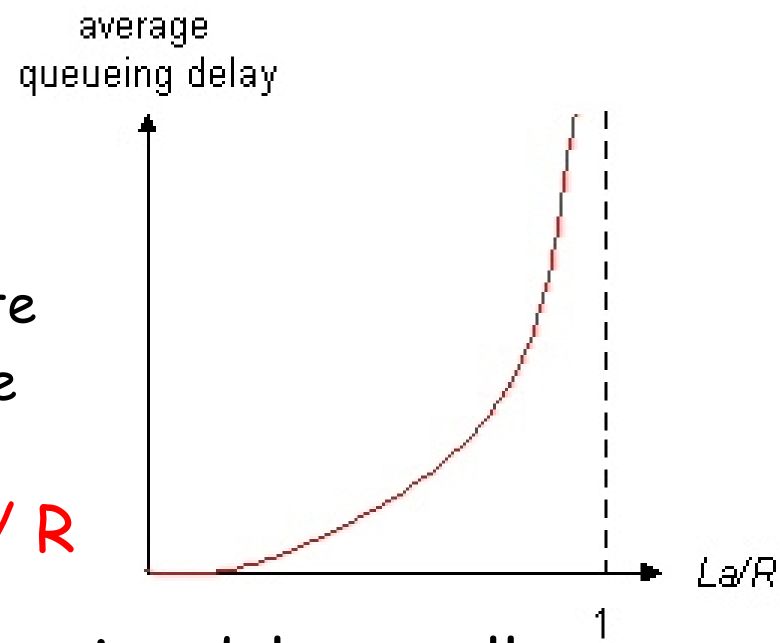
$$\boxed{d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}}$$

- $d_{proc}$ = processing delay
  - typically a few microsecs or less
- $d_{queue}$ = queuing delay
  - depends on congestion
- $d_{trans}$ = transmission delay
  - = L/R, significant for low-speed links
- $d_{prop}$ = propagation delay
  - a few microsecs to hundreds of msecs

# Queueing delay (revisited)

- R = link bandwidth (bps)
- L = packet length (bits)
- a = average packet arrival rate
- L · a = average bit arrival rate

traffic intensity = (L · a) / R



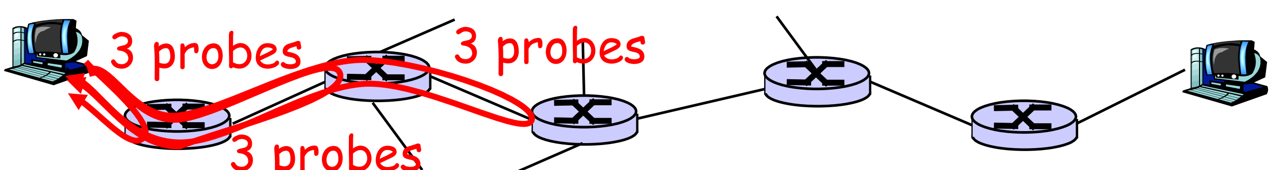

- (L · a)/R ~ 0: average queueing delay small
- (L · a)/R -> 1: delays become large
- (L · a)/R > 1: more "work" arriving than can be serviced, average delay infinite! (infinite queue length) -- or packet loss! (finite queue length)

# "Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- Traceroute program: provides delay measurement from source to router along end-end Internet path towards destination.

For *i = 1,2,3,…*

- sends three packets that will reach router *i* on path towards destination
- router *i* will return packets to sender
- sender times interval between transmission and reply.



# “Real” Internet delays and routes

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

Three delay measements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

1 cs-gw (128.119.240.254) 1 ms 1 ms 2 ms
2 border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145) 1 ms 1 ms 2 ms
3 cht-vbns.gw.umass.edu (128.119.3.130) 6 ms 5 ms 5 ms
4 jn1-at1-0-0-19.wor.vbns.net (204.147.132.129) 16 ms 11 ms 13 ms
5 jn1-so7-0-0-0.wae.vbns.net (204.147.136.136) 21 ms 18 ms 18 ms
6 abilene-vbns.abilene.ucaid.edu (198.32.11.9) 22 ms 18 ms 22 ms
7 nycm-wash.abilene.ucaid.edu (198.32.8.46) 22 ms 22 ms 22 ms
8 62.40.103.253 (62.40.103.253) 104 ms 109 ms 106 ms
9 de2-1.de1.de.geant.net (62.40.96.129) 109 ms 102 ms 104 ms
10 de.fr1.fr.geant.net (62.40.96.50) 113 ms 121 ms 114 ms
11 renater-gw.fr1.fr.geant.net (62.40.103.54) 112 ms 114 ms 112 ms
12 nio-n2.cssi.renater.fr (193.51.206.13) 111 ms 114 ms 116 ms
13 nice.cssi.renater.fr (195.220.98.102) 123 ms 125 ms 124 ms
14 r3t2-nice.cssi.renater.fr (195.220.98.110) 126 ms 126 ms 124 ms
15 eurecom-valbonne.r3t2.ft.net (193.48.50.54) 135 ms 128 ms 133 ms
16 194.214.211.25 (194.214.211.25) 126 ms 128 ms 126 ms
17 * * *
18 * * *
19 fantasia.eurecom.fr (193.55.113.142) 132 ms 128 ms 136 ms

trans-oceanic link

* means no reponse (probe lost, router not replying)

# Packet loss

- queue (also known as buffer) preceding link in buffer has finite capacity
- when packet arrives to full queue, packet is dropped (also known as lost)
- lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all

# Chapter 1: roadmap

# 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?

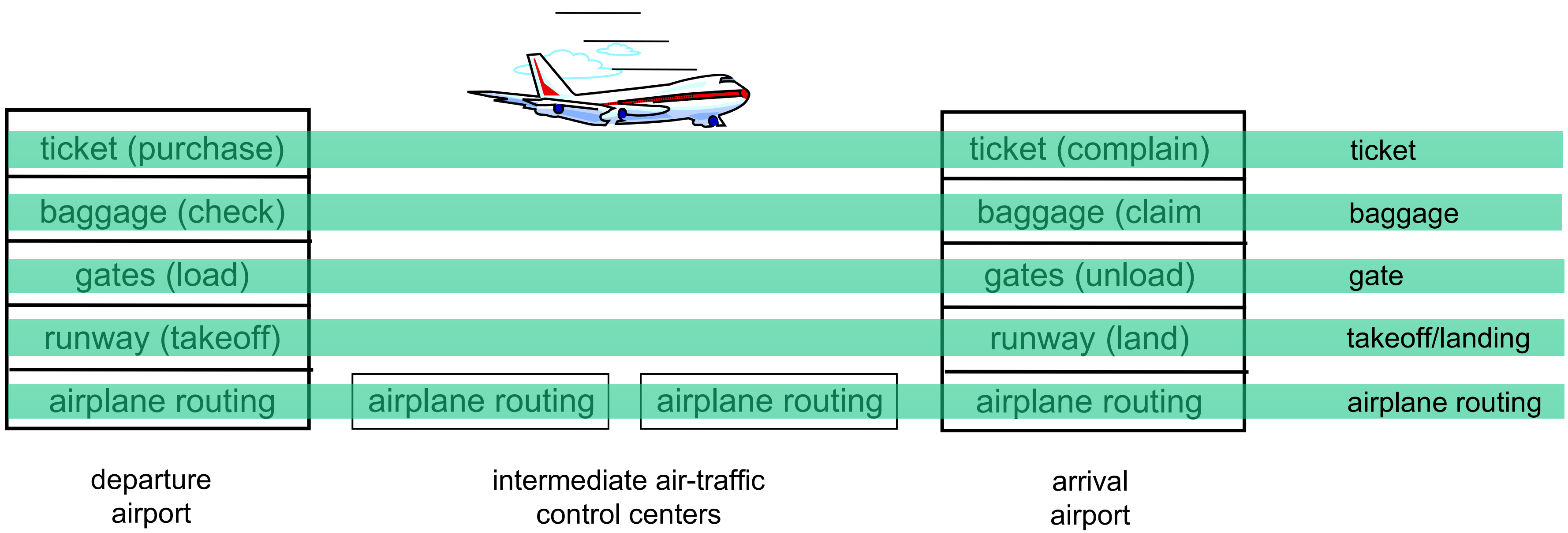
# Organization of air travel

| | |
|---|---|
| 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

# Layering of airline functionality




Layers: each layer implements a service

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

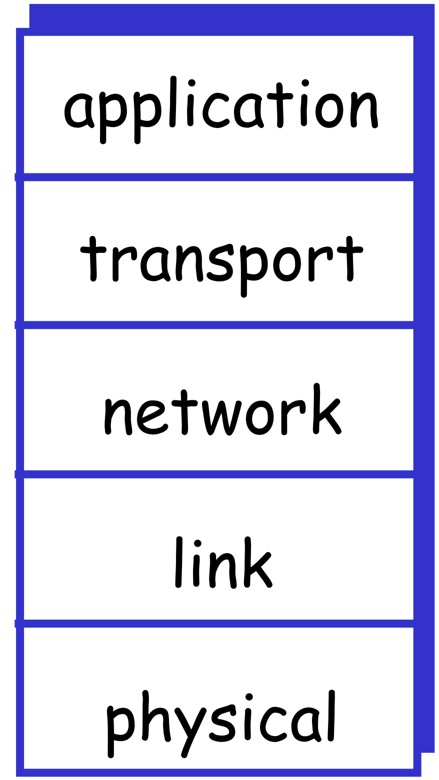
# Why layering?

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

# Internet protocol stack

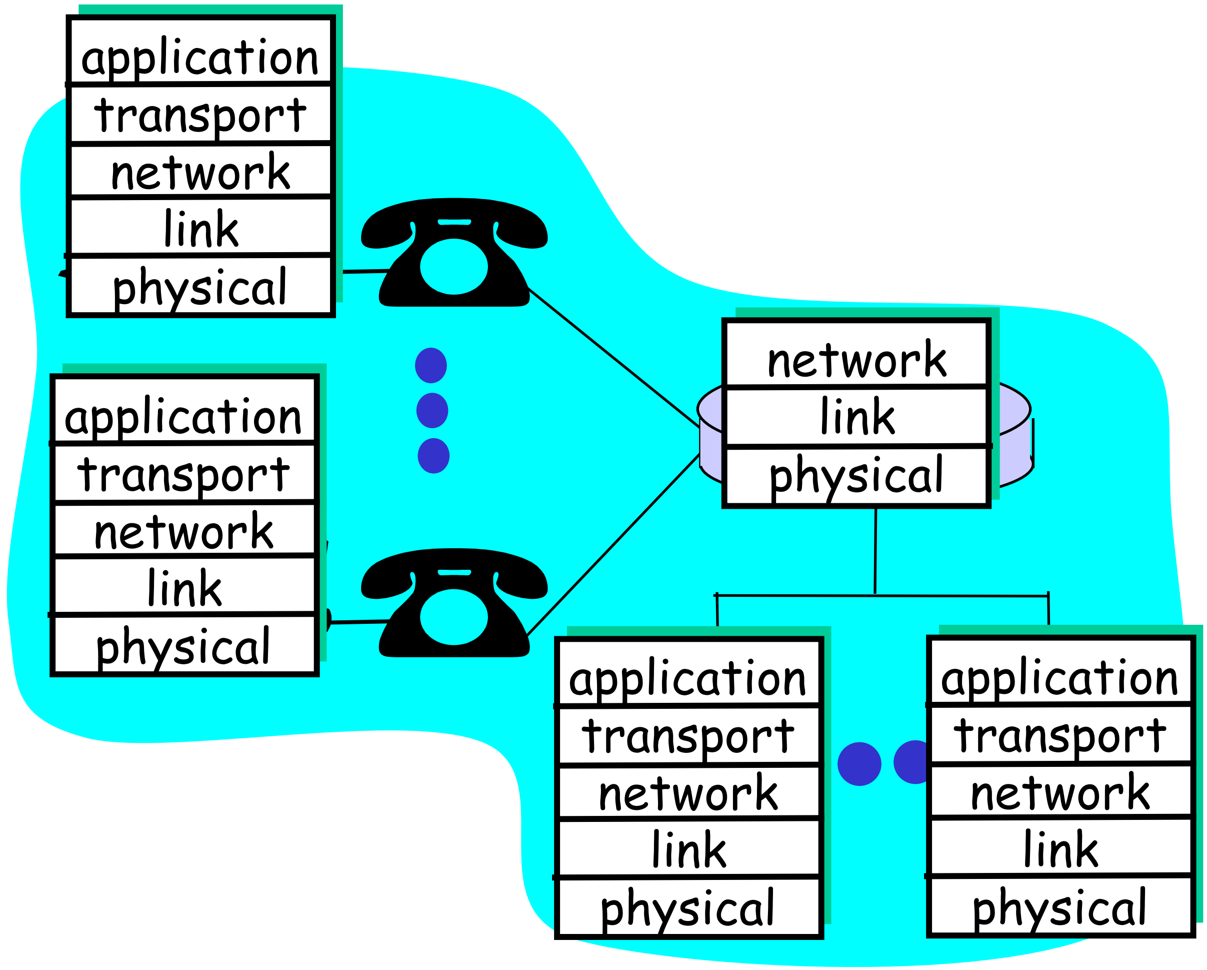
- application: supporting network applications
  - FTP, SMTP, HTTP
- transport: host-host data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - PPP, Ethernet
- physical: bits "on the wire"



# Layering: logical communication

Each layer:

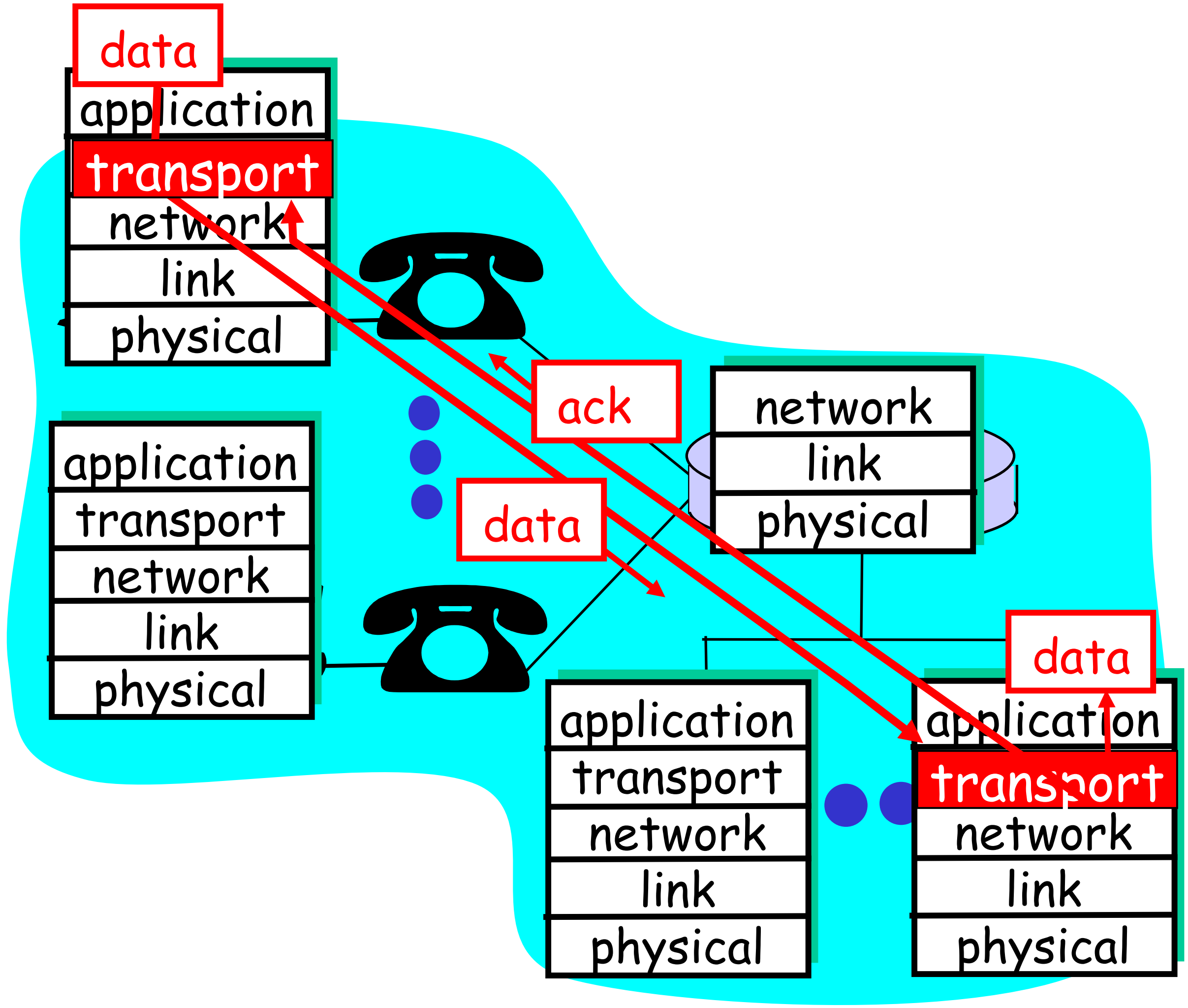
- distributed "entities" implement layer functions at each node
- entities perform actions, exchange messages with peers



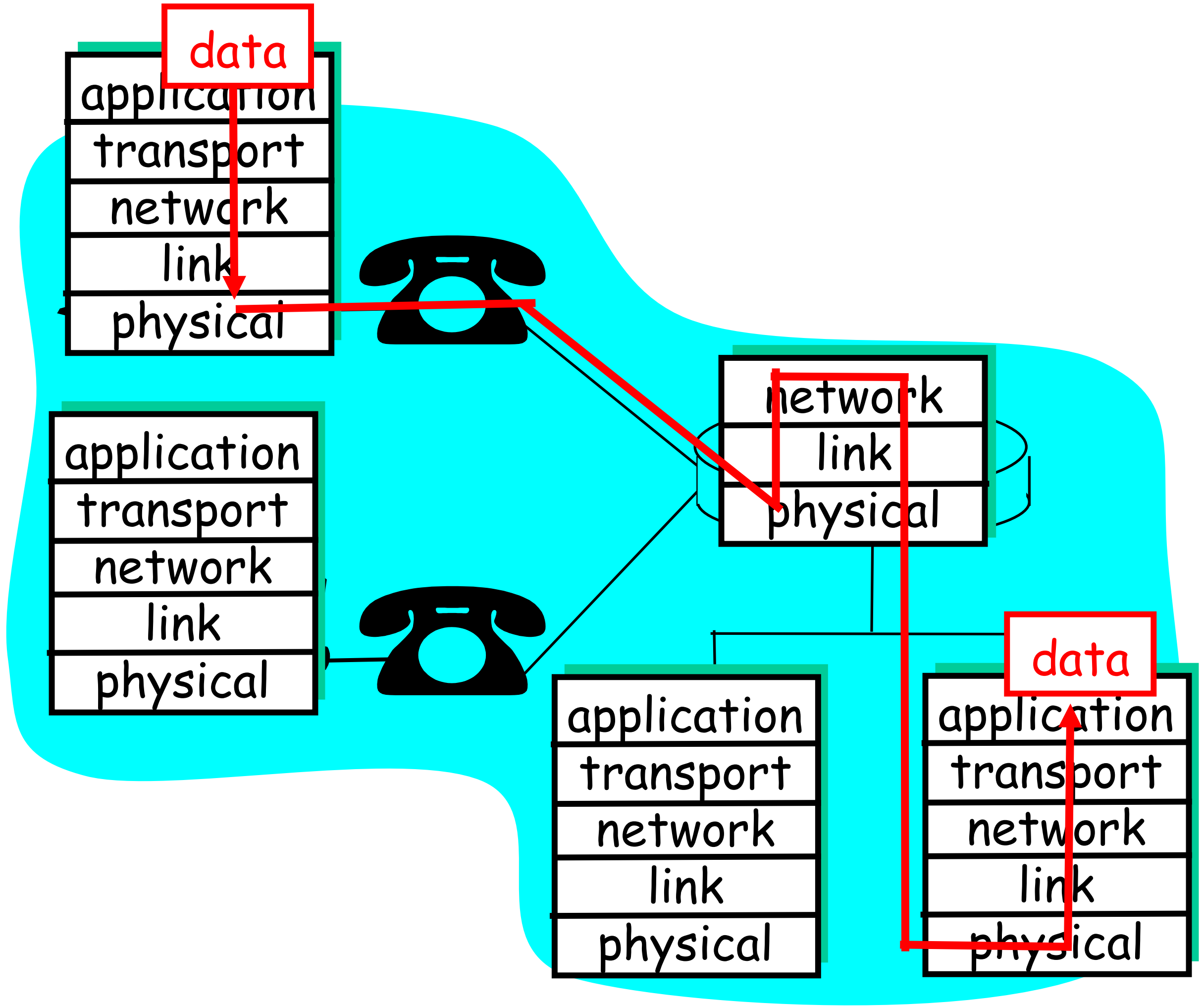
# Layering: *logical* communication

E.g.: transport

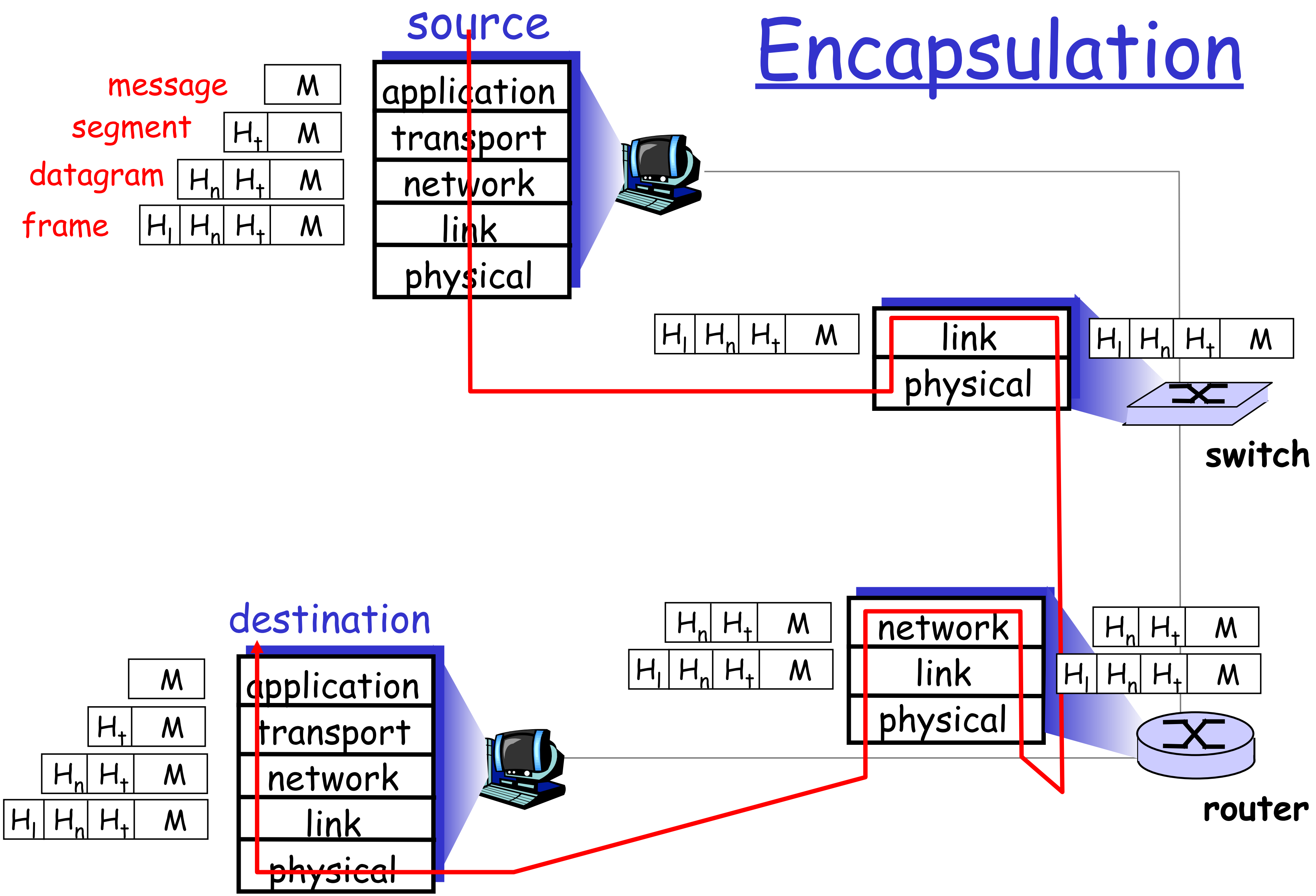
- take data from app
- add addressing, reliability check info to form "datagram"
- send datagram to peer
- wait for peer to ack receipt
- analogy: post office



# Layering: physical communication



# Encapsulation



# Chapter 1: roadmap

# Internet History

*1961-1972: Early packet-switching principles*

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1972:
  - ARPAnet 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 (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, peer2peer file sharing (e.g., Naptser)
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

# Introduction: Summary

Covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
- Internet/ISP structure
- performance: loss, delay
- layering and service models
- history

You now have:

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