MANIPAL INSTITUTE OF TECHNOLOGY
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INSPIRED BY LIFE

CSE 3124 : Computer Networks [2 1 0 3]

Module 1: Computer Networks & the Internet

our goal:

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

overview:

- what’s the Internet?
- what’s a protocol?
- Network edge; Hosts, Access net, Physical media
- Network core: Packet/Circuit switching, Internet structure
- Performance: Loss, Delay, Throughput
- Protocol layers, Service Models
- History

Computer Network

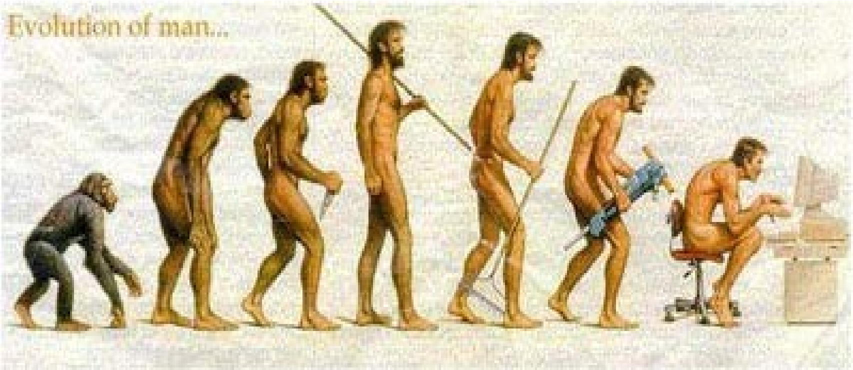
A **computer network** is a group of interconnected devices (such as computers, servers, and routers) that communicate and share resources using wired or wireless connections.

These networks allow data exchange, collaboration, and access to shared resources like printers, files, and the internet.

Networking = “Plumbing”

- Networking is the “plumbing” of computing
- Almost all areas of computing are network-based.
  - Distributed computing
  - Big Data
  - Cloud Computing
  - Internet of Things
  - Smart Cities
- Networking is the backbone of computing.

Internet Age



- Distributed Computing
- Cloud Computing
- Mobile Computing ⍰ Smart Phones
- Streaming Video ⍰ YouTube
- Social Networking ⍰ FaceBook
- Big Data
- Machine Learning ⍰ Artificial Intelligence
- Online Shopping ⍰ Amazon, eBay
- Most fields today – Education, Health, Environment – are advancing simply because of advances in networking.

Current Hot Topics in Networking

1. Internet of Things (IoT)
2. Cybersecurity
3. Cloud Computing
4. Software Defined Networking
5. Wireless Networking
6. Streaming Media

Trend: Smart Everything

Smart Watch

Smart TV

Smart Car

Smart Health

Smart Home

Smart Kegs

Smart Space

Smart Industries

Smart Cities

Trend: Smart to Intelligent

 Intelligent Clock	 Intelligent TV	 Intelligent Car
 Intelligent Health	 Intelligent Home Security	 Intelligent Microwave
 Intelligent Light	Amazon Alexa	Google Assistant

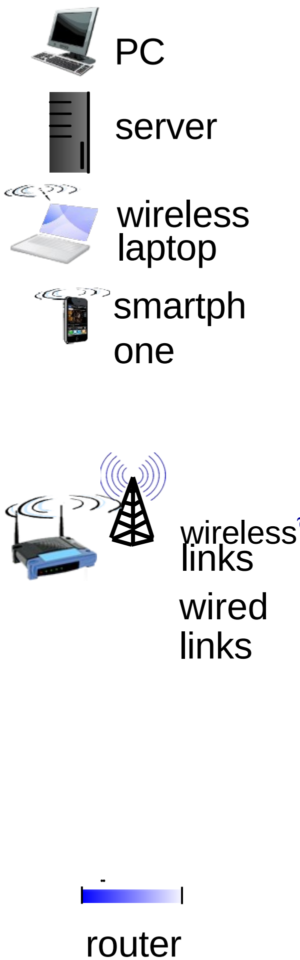
Trend: Security & Cyber Warfare

- Security of computers, companies, smart grid, and nations
- Nation States are penetrating other nations' computers
  5th domain of warfare (after land, sea, air, space)
- In 2010, the US set up US Cyber Command
- UK, China, Russia, Israel, and North Korea have similar centers
- Many cyber wars: North Korea vs. USA, Israel vs. Syria, South Korea vs. lia vs.

Old

New

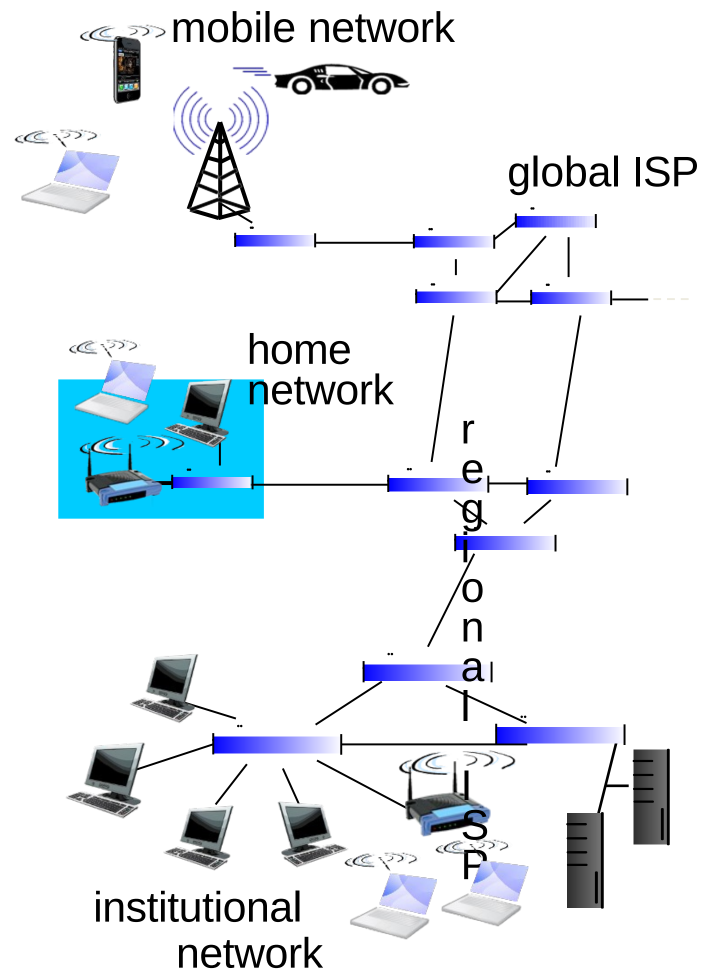
What's the Internet: "nuts and bolts" view



- 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

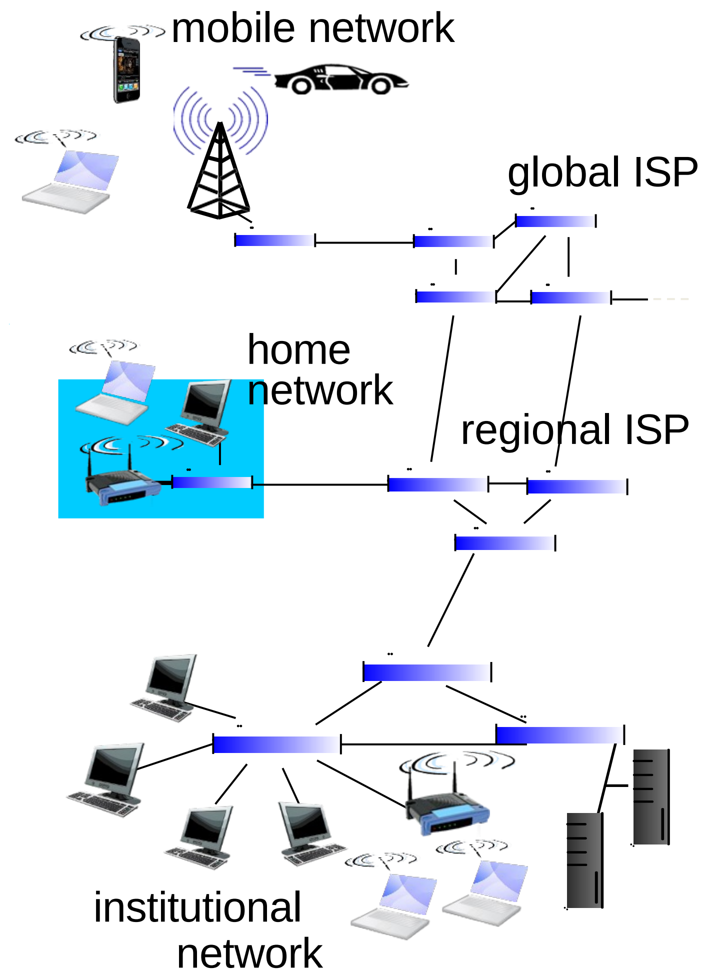
Internet refrigerator

Slingbox: watch, control cable TV remotely

Internet phones

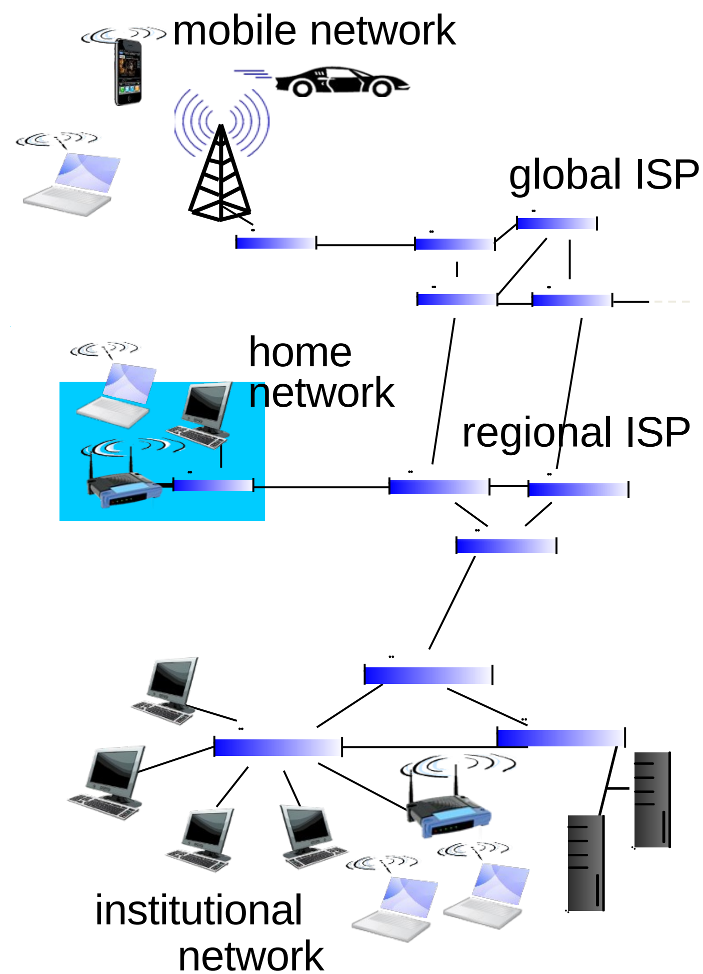
What's the Internet: "nuts and bolts" view

- *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*



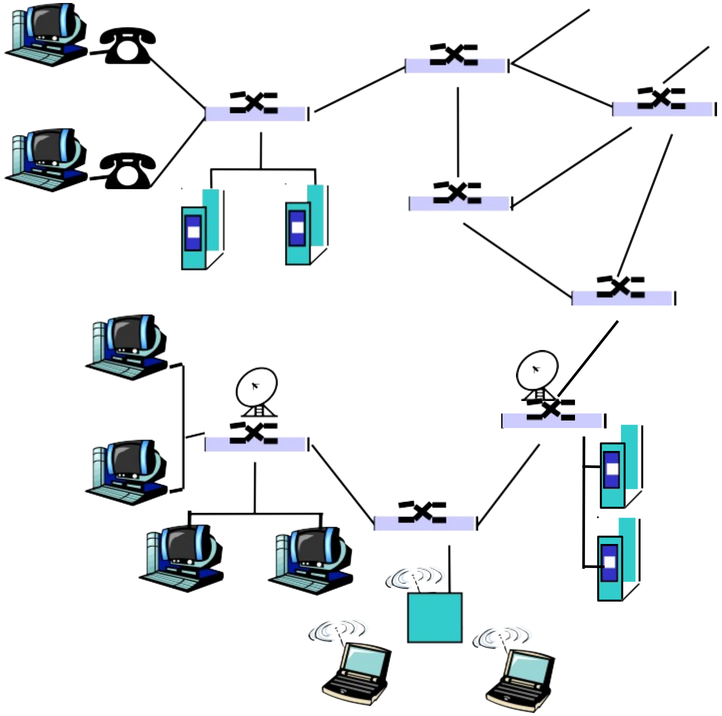
What's the Internet: a service view

- *Infrastructure that provides services to applications:*
  - *Web, VoIP, email, games, e-commerce, social nets, …*
- *provides programming interface to apps*

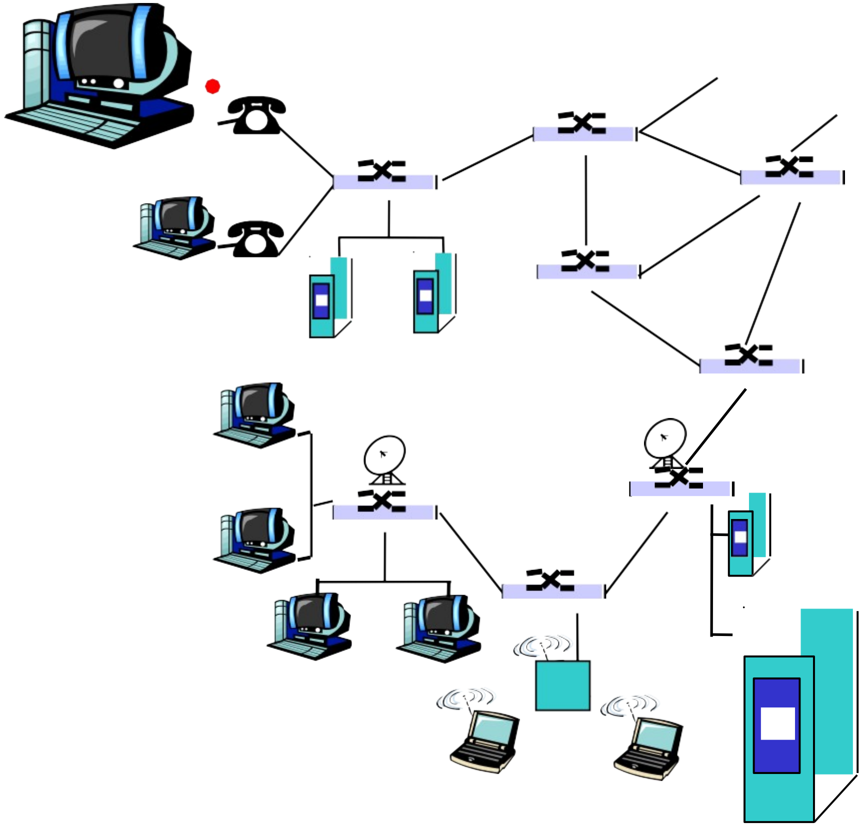


A closer look at network structure:

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



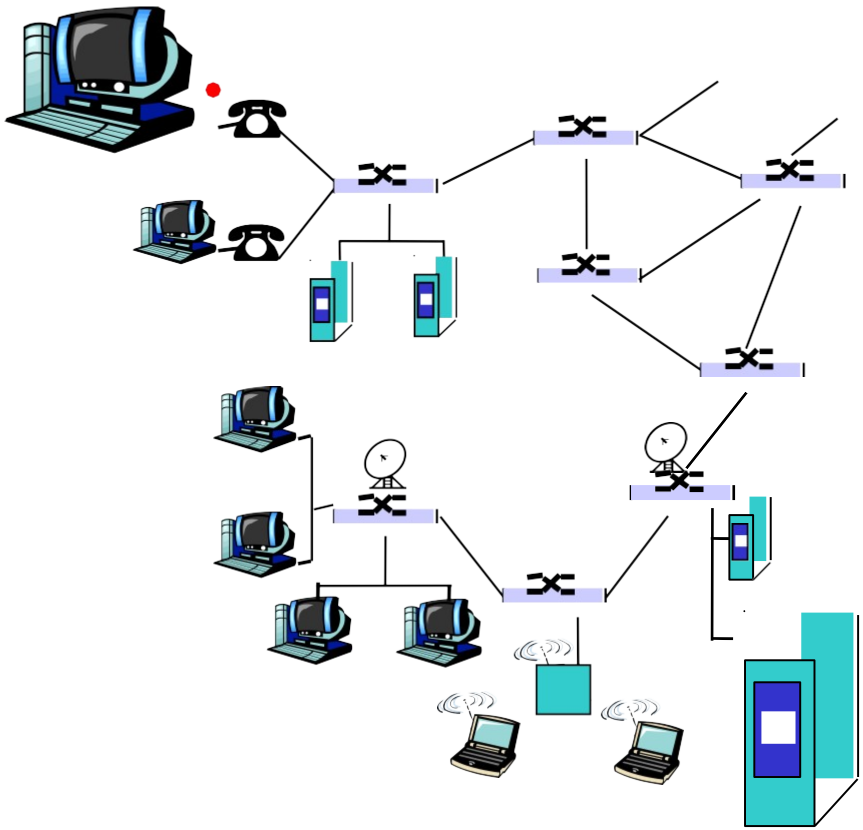
The network edge:



- **end systems (hosts):**
  - run application programs
  - e.g. Web, email
  - at "edge of network"

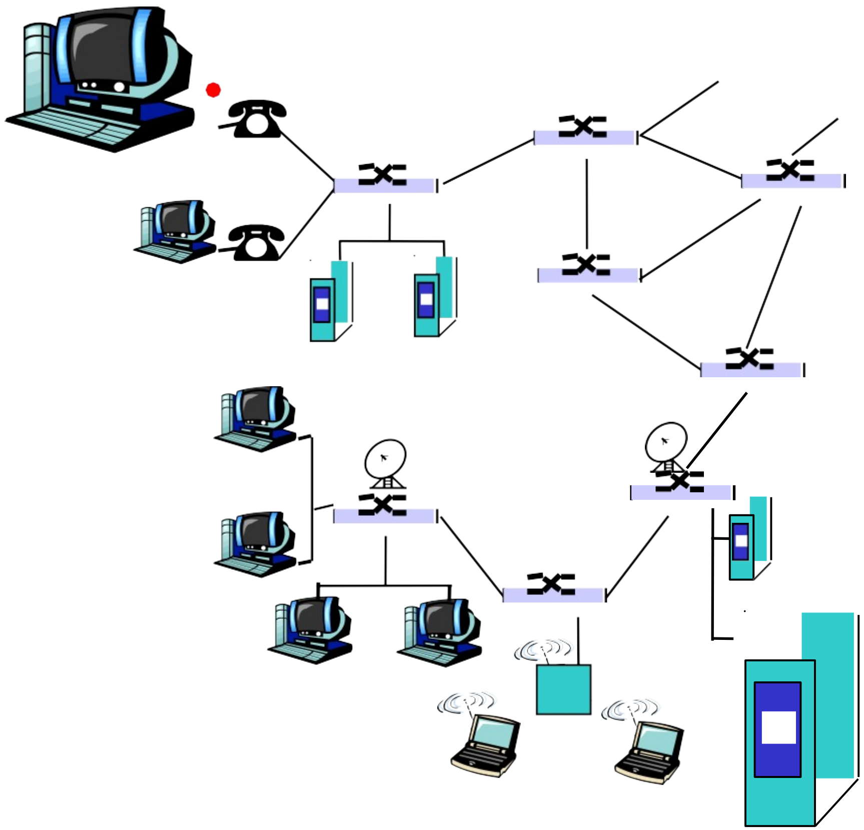
The network edge:

- client/server model
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- why such a popular model?



The network edge:

- *peer-peer model:*
  - *minimal (or no) use of dedicated servers*
    - *e.g. Gnutella, KaZaA*
  - *SETI@home?*



What's a protocol?

human protocols:

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

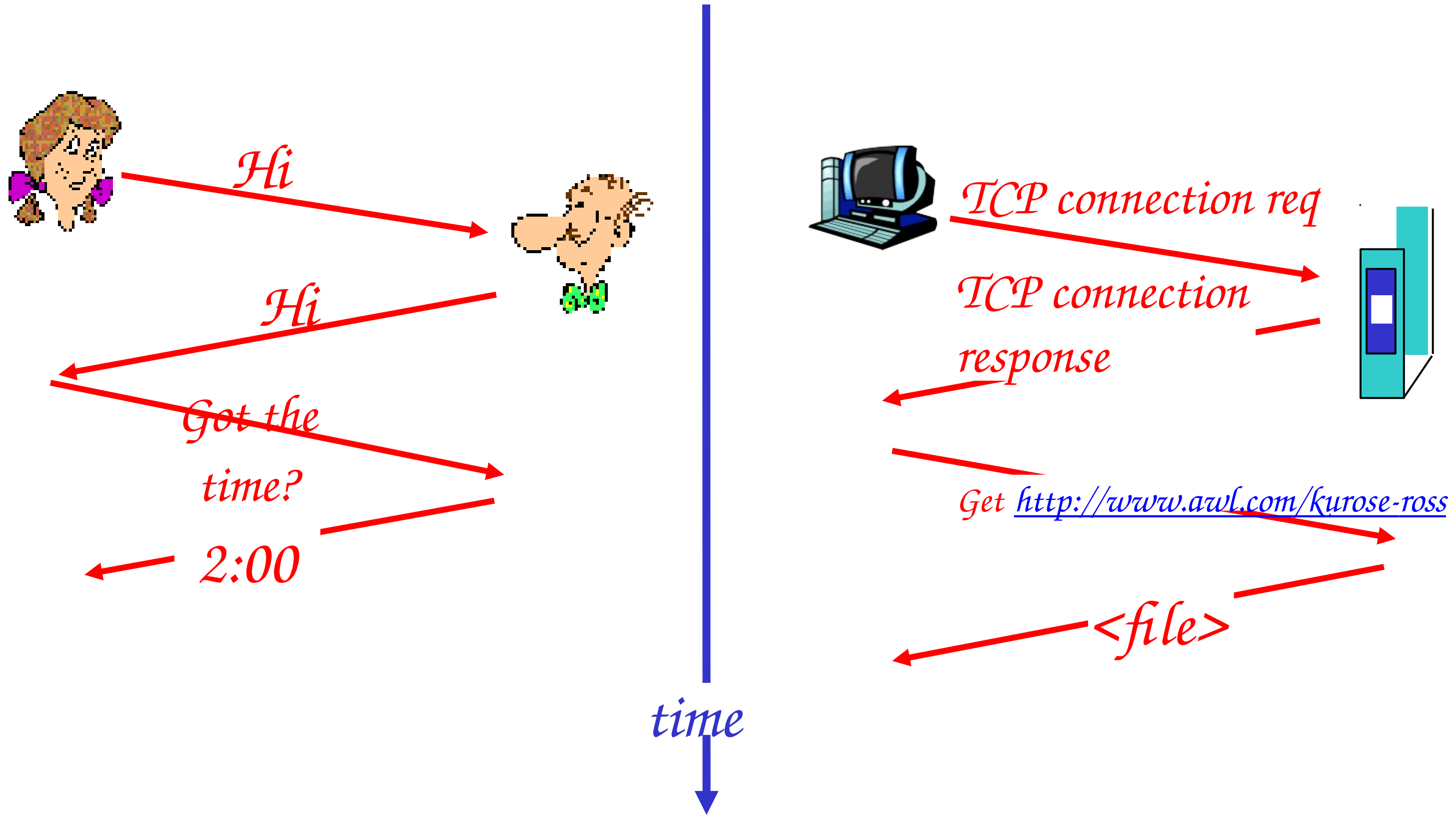
network protocols:

- 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: Why are protocols so important?

Internet Services Models

- Connection-oriented service
- Connectionless service
- Applications
  - FTP, Internet Phone, Web, Internet radio, email

Connection-oriented service

- *Goal:* data transfer between end systems
- handshaking: setup (prepare for) data transfer ahead of time
- *TCP* - Transmission Control Protocol
  - Internet's connection-oriented 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

Connectionless service

Goal: data transfer between end systems

- same as before!

- UDP - User Datagram Protocol [RFC 768]:
  - connectionless
  - unreliable data transfer
  - no flow control
  - no congestion control

- What's it good for?

A Comparison

App's using TCP:

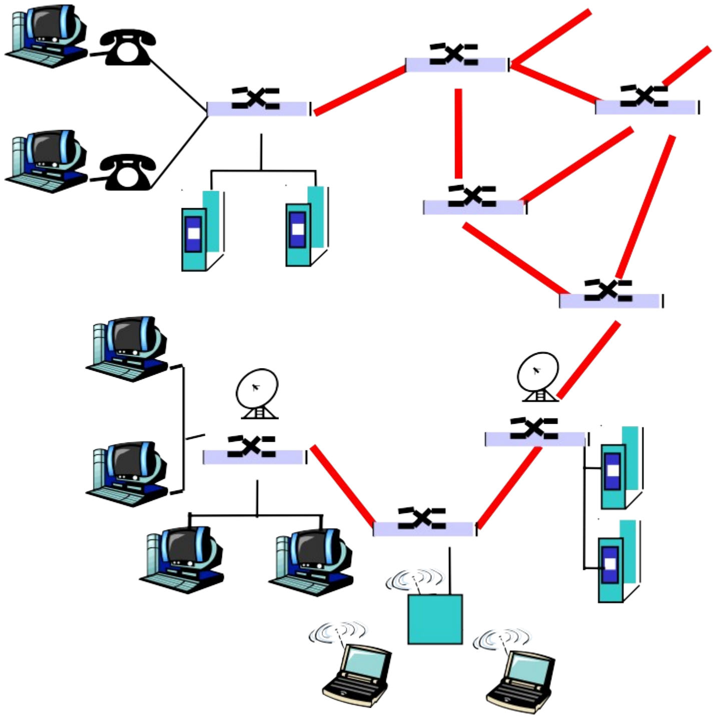
- HTTP (Web), FTP (file transfer), Telnet (remote login), SMTP (email)

App's using UDP:

- streaming media, teleconferencing, DNS, Internet telephony

The Network Core

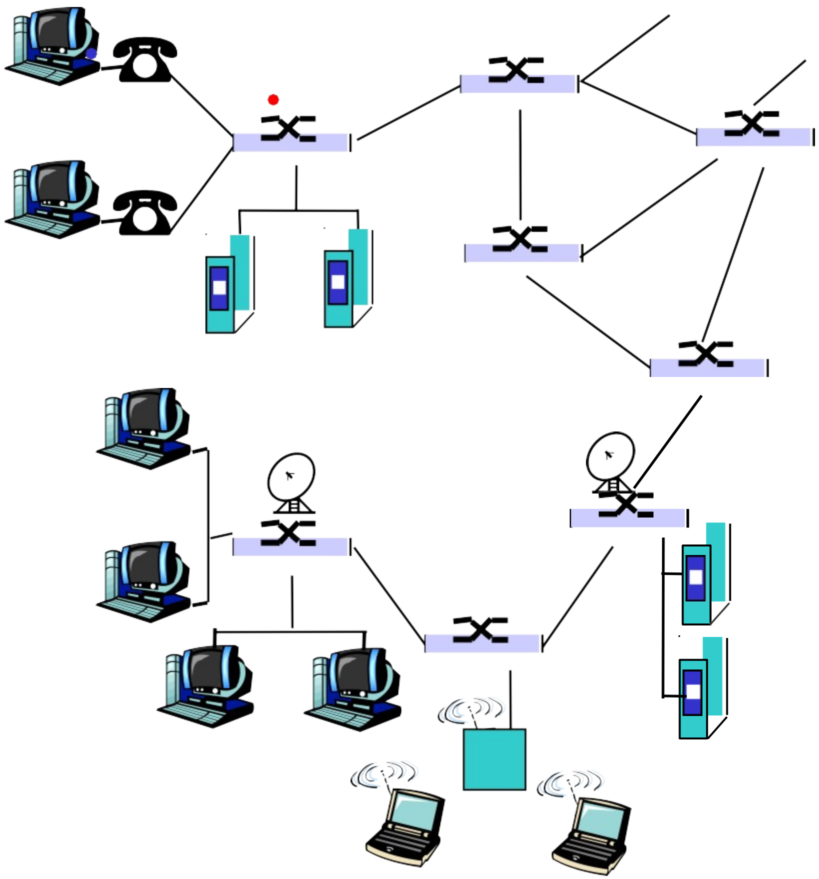
- mesh of interconnected routers
- the fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



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
- must divide link bw into pieces

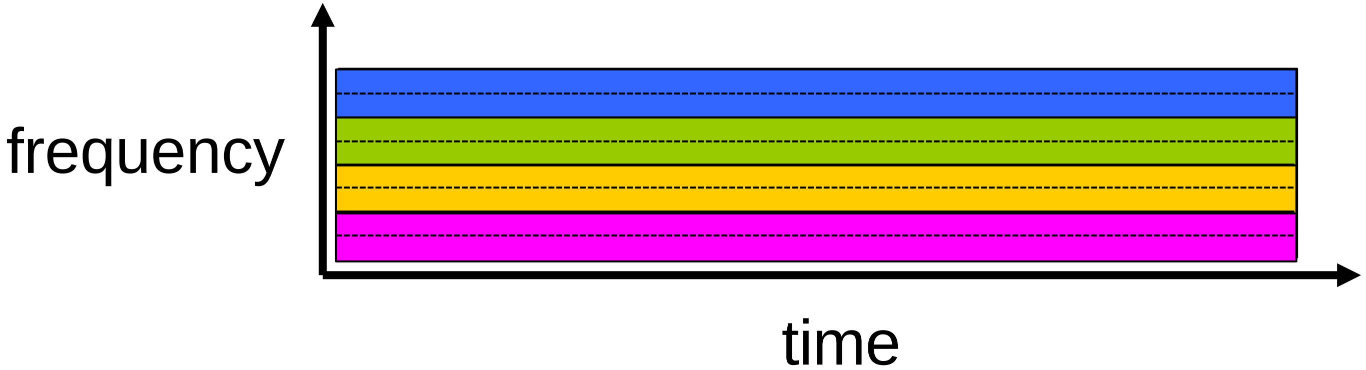


Circuit Switching: FDM and TDM

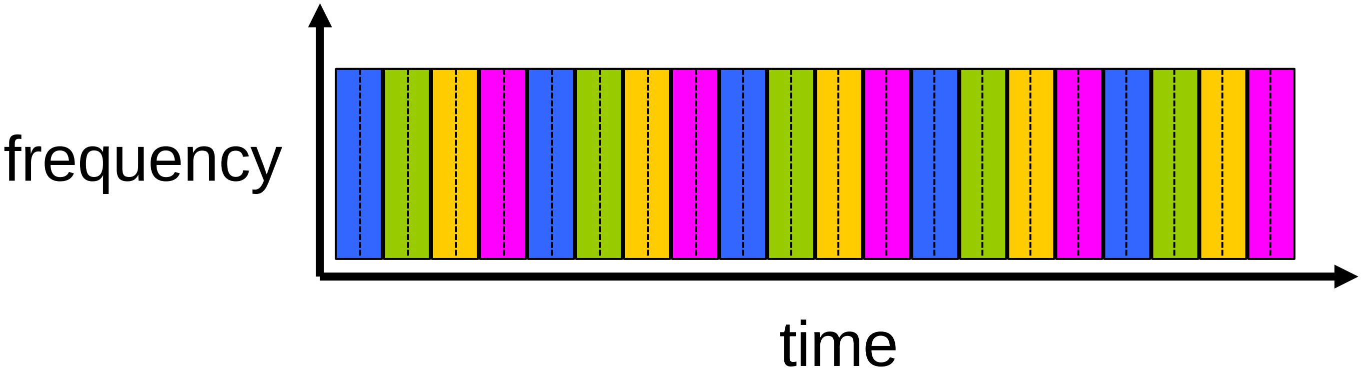
Example:

4 users

FDM



TDM



Circuit Switching: FDM and TDM

TDM (Time Division Multiplexing) *and* ***FDM (Frequency Division Multiplexing)*** *both are multiplexing techniques where TDM is used in both analogue and digital signals.*

Where as FDM used only in analogue signals.

Network Core: Packet Switching

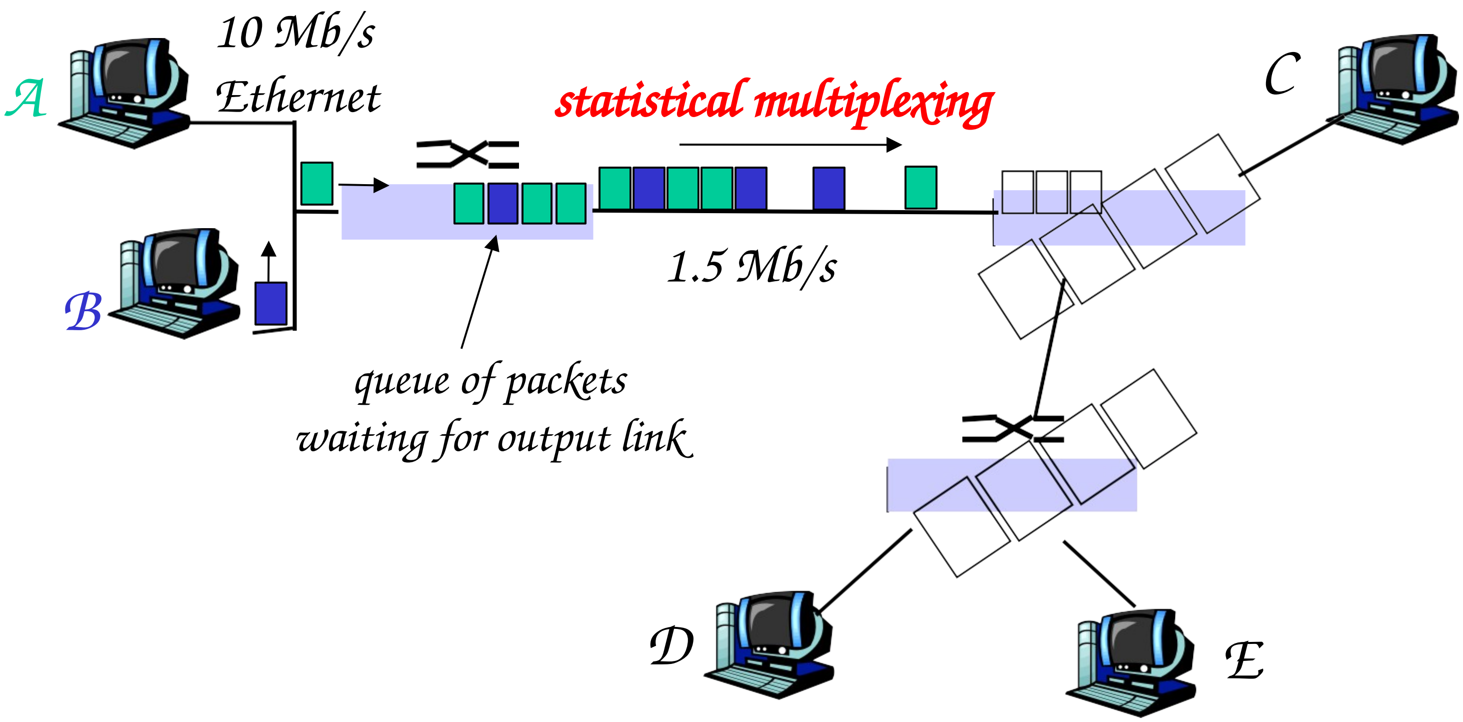
each end-end data stream divided into packets

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

resource contention:

- aggregate resource demand can exceed amount available
  - what happens if bandwidth is not available?
- congestion: packets queue, wait for link use
- store and forward: packets move one hop at a time
  - Node receives complete packet before forwarding

Packet Switching: Statistical Multiplexing



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

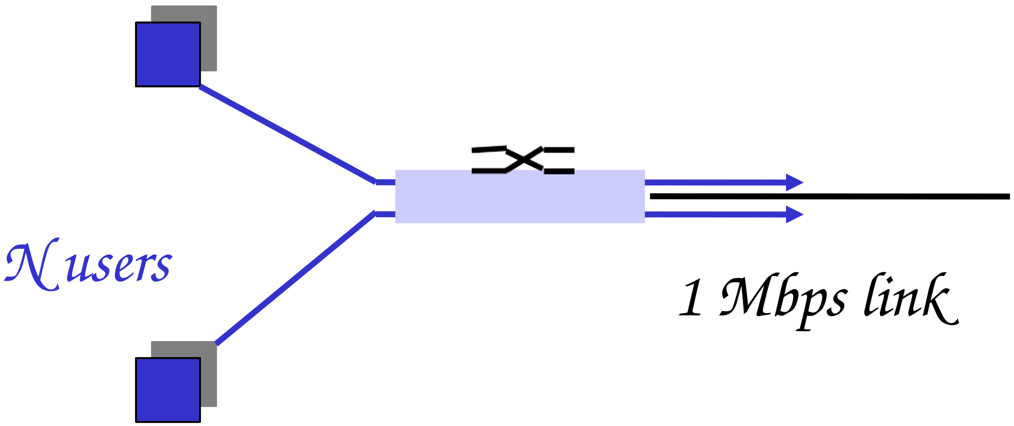
Packet Switching: Statistical Multiplexing

- *In statistical multiplexing, packets from sources A and B are sent based on demand.*
- *The sequence of packets (A, B, A, A, B, etc.) does not follow a fixed pattern—this is what makes it statistical.*

Packet switching versus circuit switching

Packet switching allows more users to use network!

- 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 less than .0004

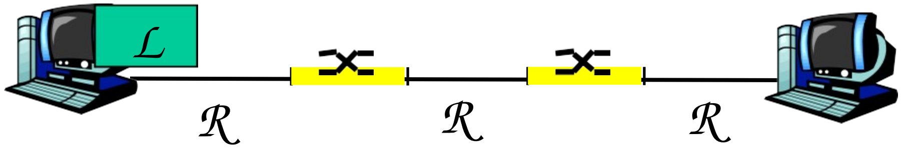


Packet switching versus circuit switching

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*
- *Circuit Switching = Guaranteed behavior*
  - *good for which apps?*

Packet-switching: store-and-forward



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

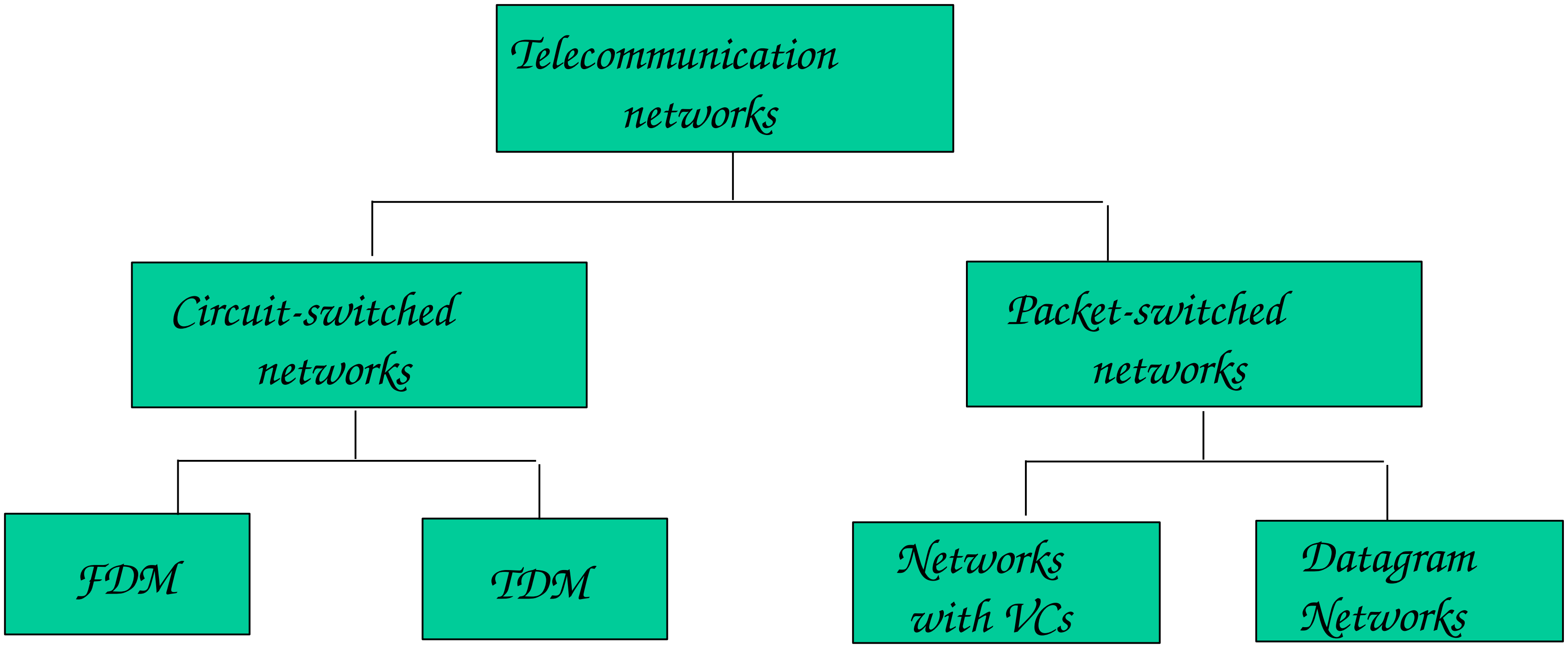
Example:

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

Packet-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.

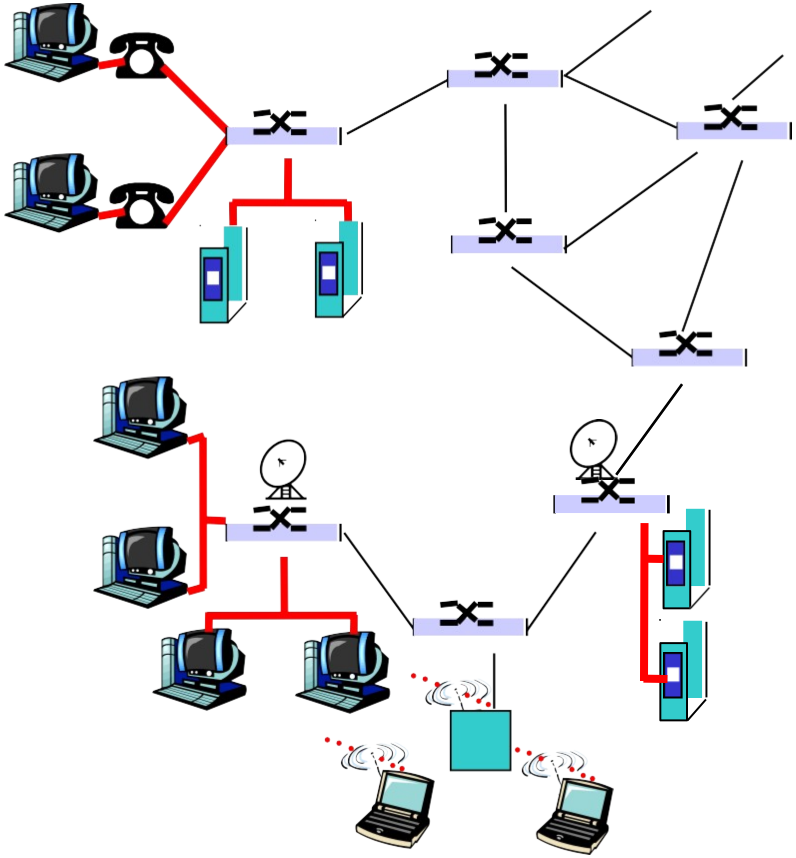
Access networks and physical media

Q: How to connect end systems to edge router?

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

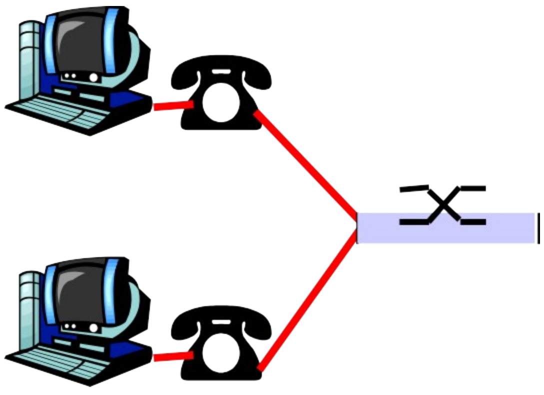
Keep in mind:

- 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"

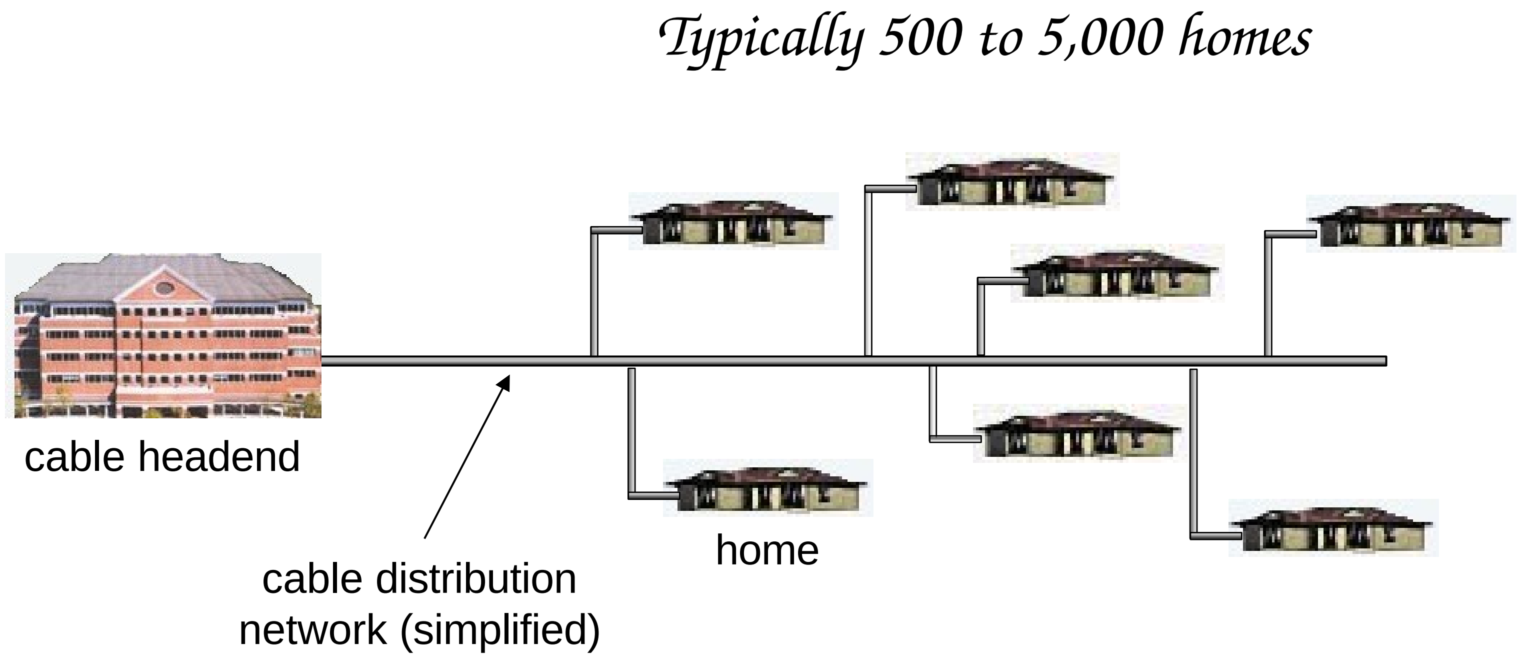


- ADSL: asymmetric digital subscriber line
  - up to 1 Mbps upstream (today typically < 256 kbps)
  - up to 8 Mbps downstream (today typically < 1 Mbps)
  - FDM: 50 kHz - 1 MHz for

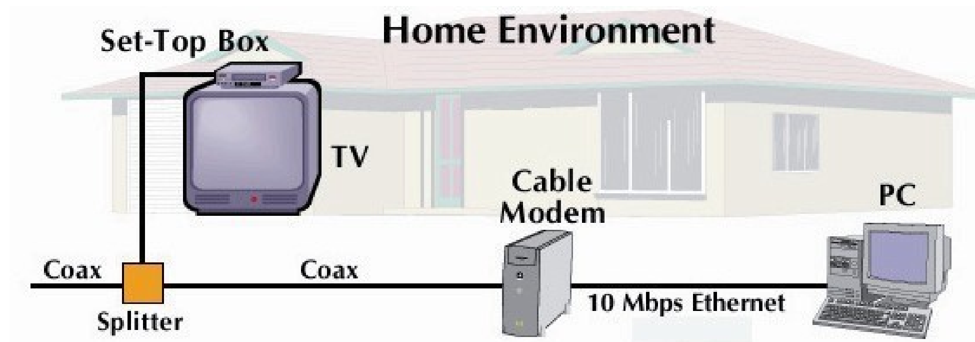
Residential access: cable modems

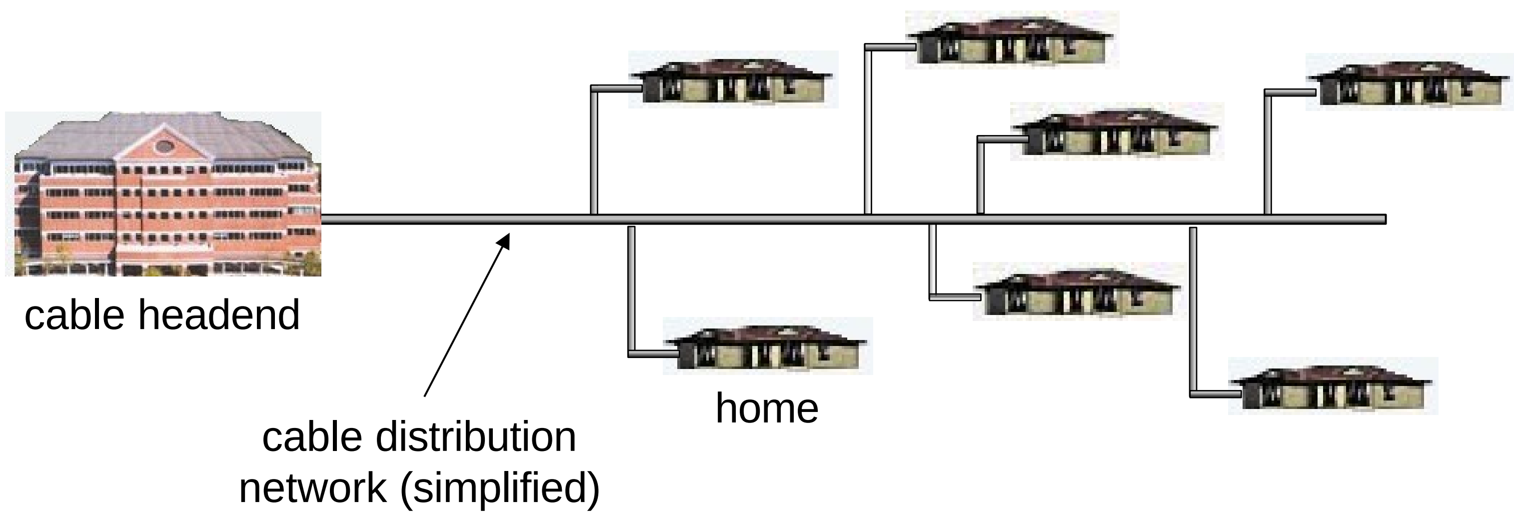
- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- network of cable and fiber attaches homes to ISP router
  - homes share access to router
- deployment: available via cable TV companies

Cable Network Architecture: Overview



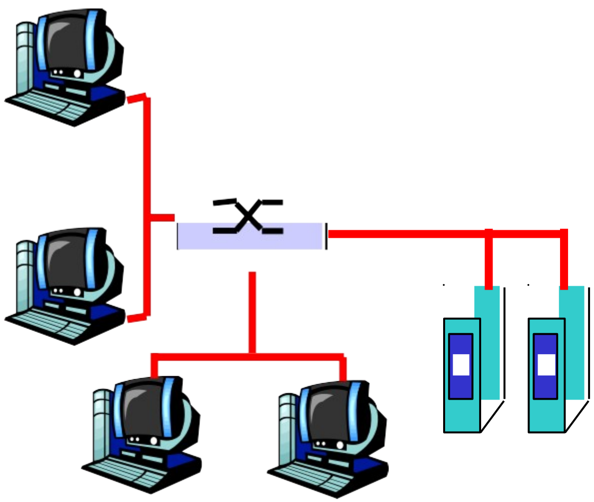
Cable Network Architecture: Overview





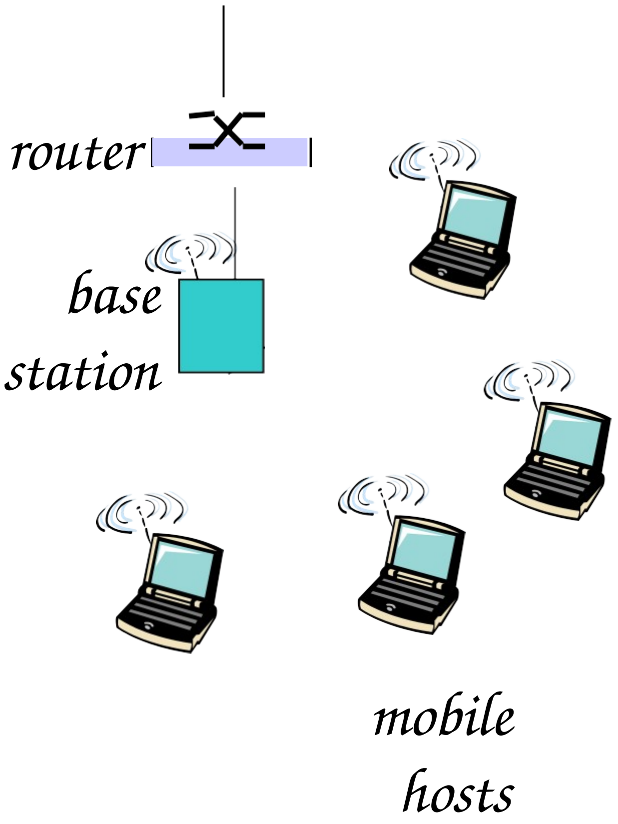
Company access: local area networks

- company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - shared or dedicated link connects end system and router
  - 10 Mbps, 100Mbps, Gigabit Ethernet
- LANs: chapter 5



Wireless access networks

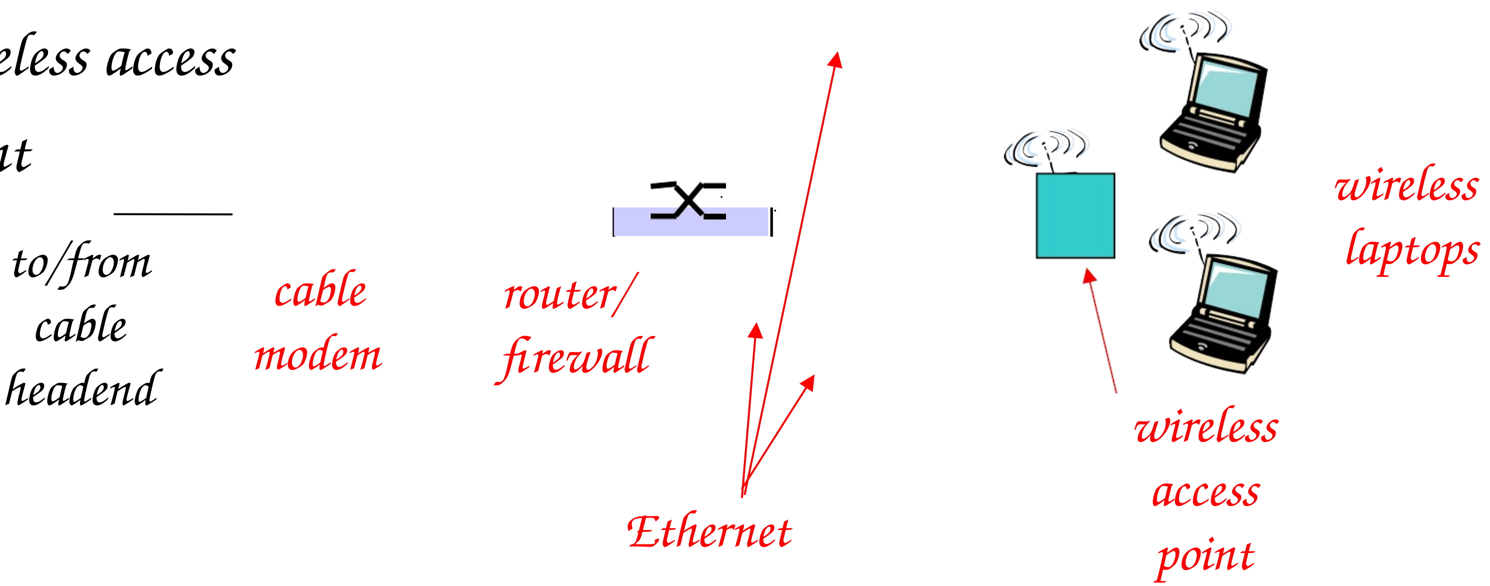
- shared wireless access network connects end system to router
  - via base station aka "access point"
- wireless LANs:
  - 802.11b (WiFi): 11 Mbps
- wider-area wireless access
  - provided by telco operator
  - 3G ~ 384 kbps
    - Will it happen??
  - WAP/GPRS in Europe



Home networks

Typical home network components:

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



Physical Media

- **Bit:** propagates between transmitter/rcvr 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

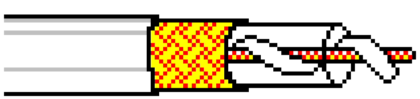
Twisted Pair (TP)

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

Physical Media: coax, fiber

Coaxial cable:

- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
  - multiple channel on cable HFC
- broadband:
  -



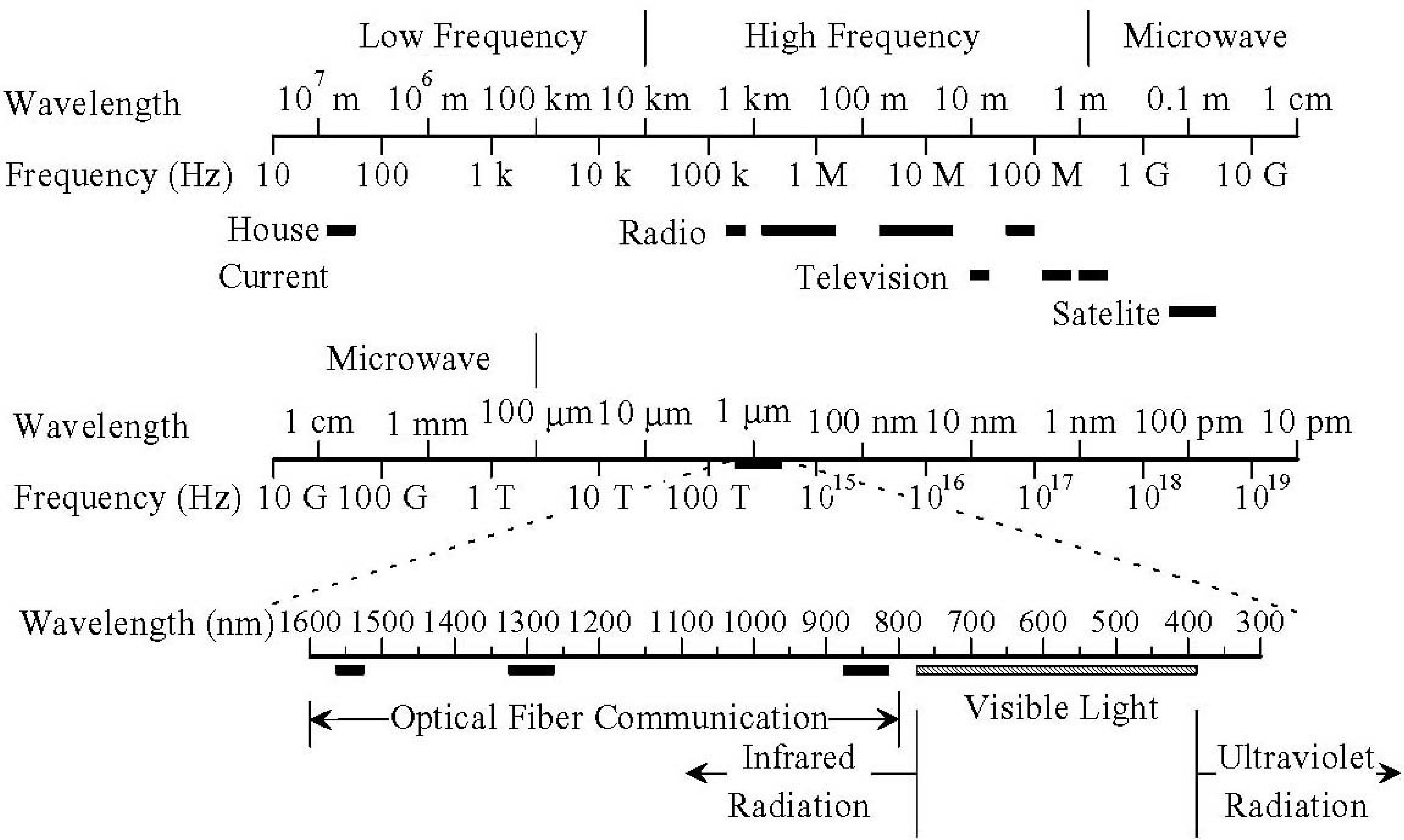
Fiber optic cable:

- 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: coax, fiber

Feature	**Fiber Optic Cable**	**Copper Coaxial Cable**
Speed / Bandwidth	Much **higher bandwidth** (10 Gbps and beyond)	Lower bandwidth; suitable for limited-speed usage
Distance	Transmits over **longer distances** without signal loss	Signal degrades faster, needs frequent amplifiers
Interference	**Immune to electromagnetic interference**	Susceptible to EMI and radio frequency interference
Signal Quality	Very **low loss** and **high-quality** signal	More signal attenuation over distance
Security	Difficult to tap without detection (more secure)	Easier to tap into (less secure)
Size and Weight	**Lighter and thinner**	Thicker and heavier
Cost (initial)	**Higher** installation cost	Cheaper initially

Electromagnetic Spectrum



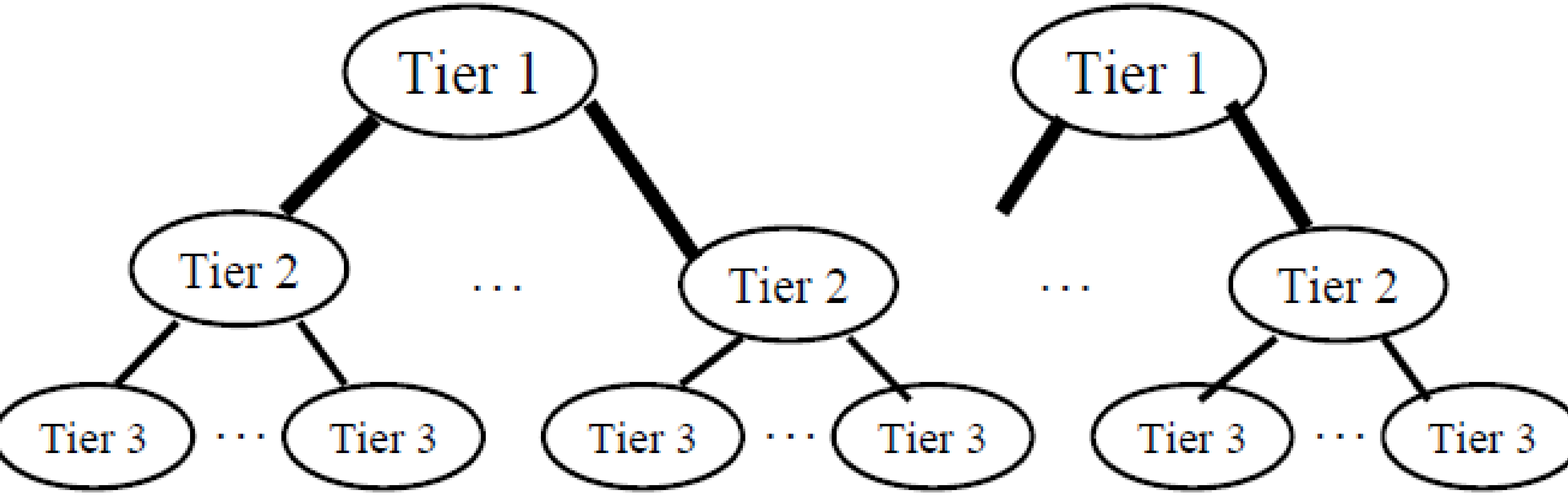
Physical media: radio

- 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
- 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 altitude

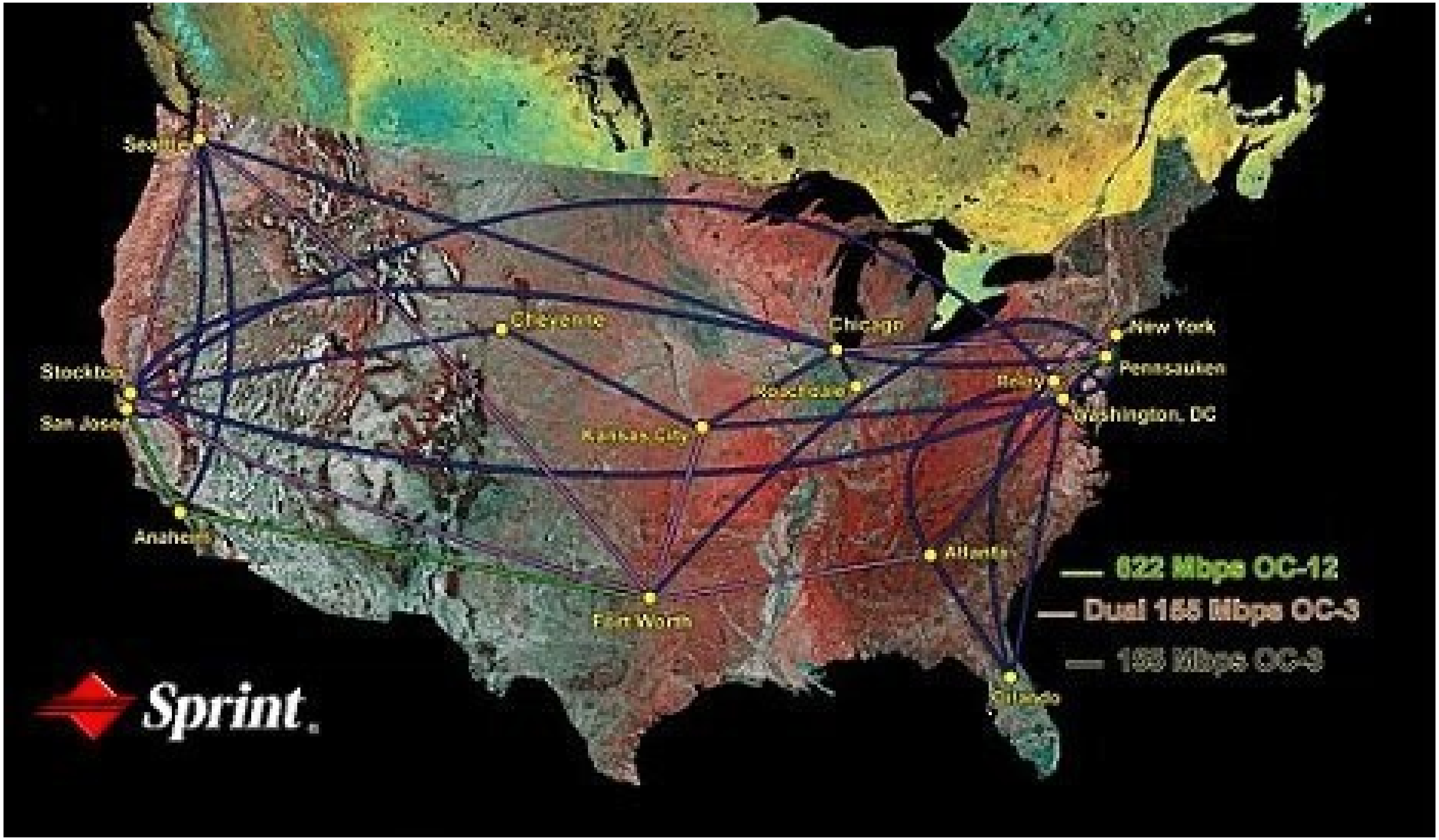
Types of ISPs



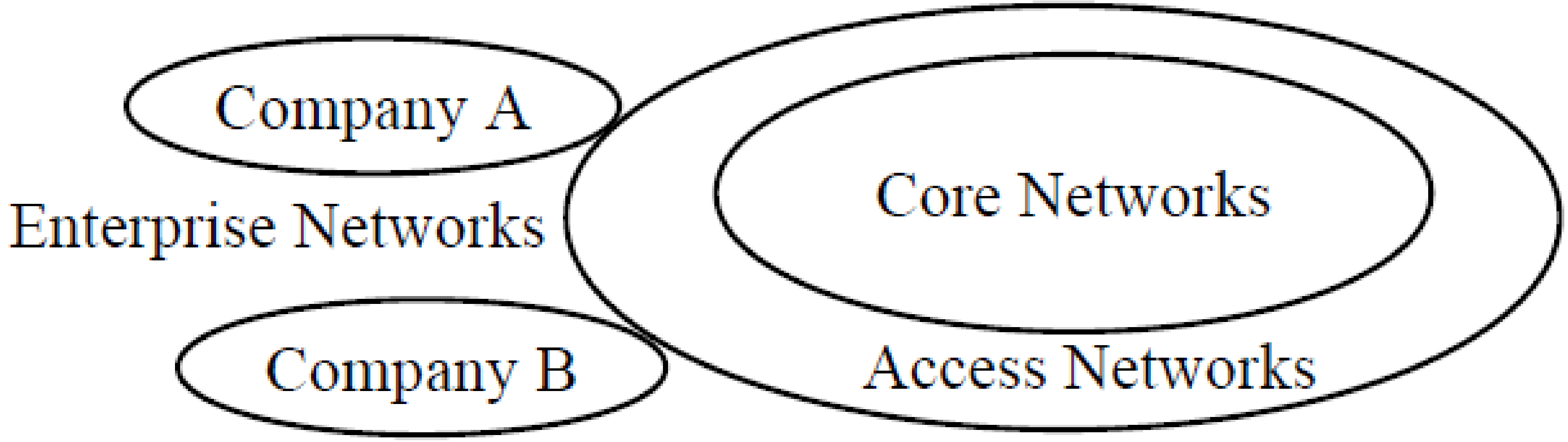
- Tier 1: Global or National, e.g., AT&T
- Tier 2: Regional
- Tier 3: Local

ISP: e.g., Sprint

Sprint US backbone network



Structure of the Internet

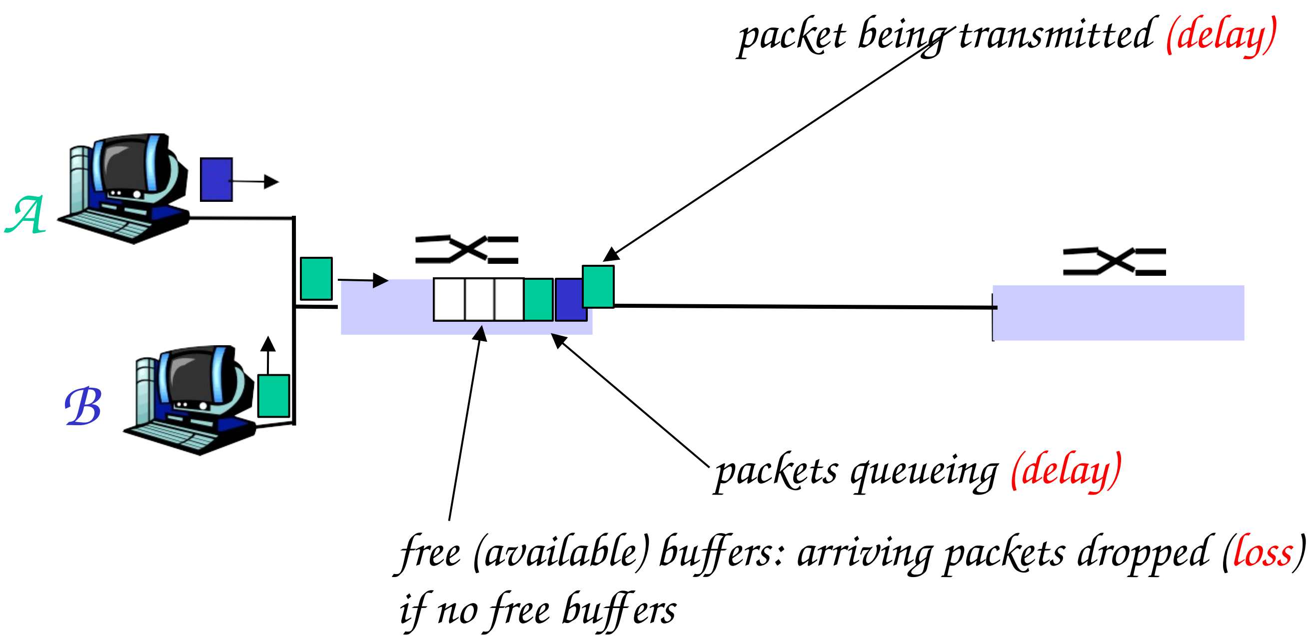


- Enterprise/Home Networks: Stub Networks.
  Privately owned ⇒ Not owned by ISP
  e.g., WUSTL network: Ethernet and WiFi
- Access Network: Enterprise/Users to ISP (in the city)
  WiFi, 3G/4G, DSL
- Core Network: ISP's network (between city): Optical Fiber

How do loss and delay occur?

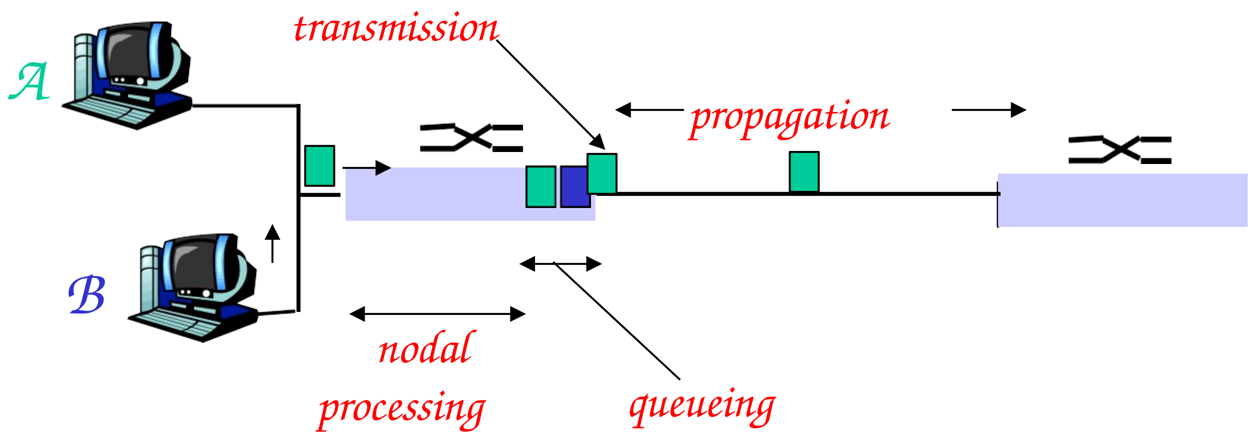
packets queue in router buffers

- 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

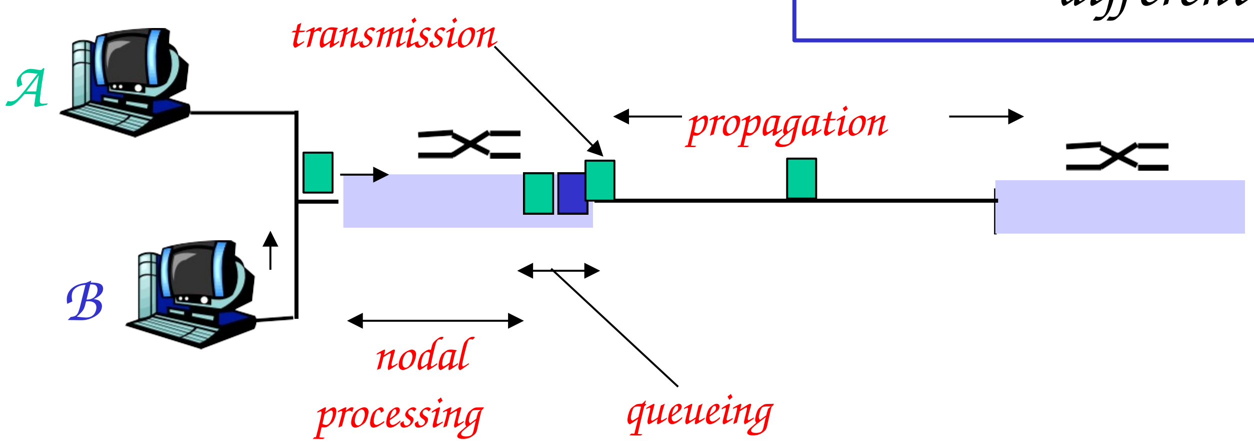
3. Transmission delay:

- 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 (~2x10^8 m/sec)
- propagation delay = d/s

Note: s and R are very different quantities!



Nodal delay

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

- 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*

Packet loss

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

Throughput

- Measured in Bits/Sec
- Capacity: Nominal Throughput
- Throughput: Realistic
- Bottleneck determines the end-to-end throughput

Net end-to-end capacity = 10 Mbps

Actual throughput will be less due to sharing and overhead.

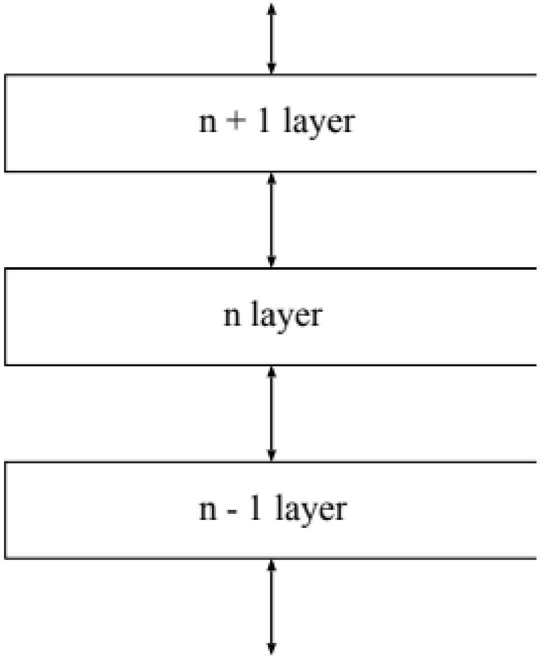
Network System Modularity

Like software modularity, but:

- Implementation is distributed across many machines (routers and hosts)
- Must decide:
  - How to break system into modules
    - **Layering**
  - Where modules are implemented
    - **End-to-End Principle**
  - Where state is stored
    - **Fate-sharing**

Layering Concept

- A restricted form of abstraction: system functions are divided into layers, one built upon another
- Often called a *stack*; but **not** a data structure!



Layers and Communications

- Interaction only between adjacent layers
- *layer n* uses services provided by *layer n-1*
- *layer n* provides service to *layer n+1*
- Bottom layer is physical media
- Top layer is application

Entities and Peers

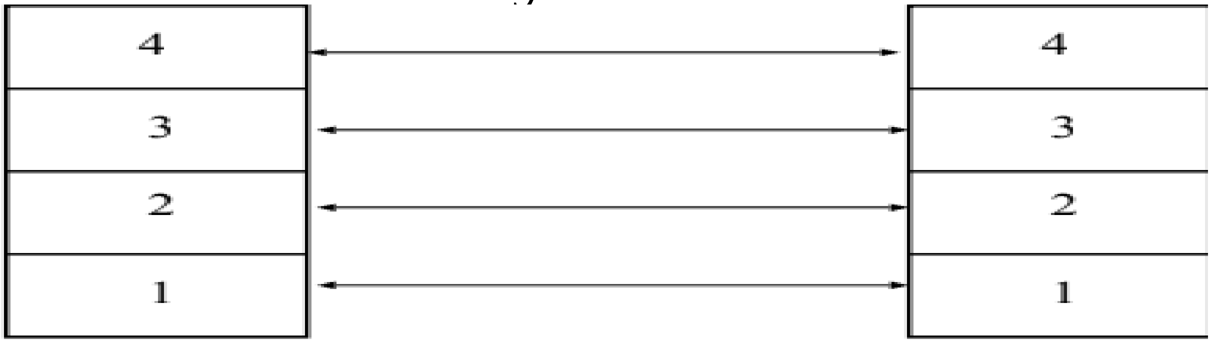
Entity – a *thing* (an independent existence)

Entities *interact* with the layers above and below

Entities *communicate* with *peer* entities

– same level but different place (eg different person, different box, different host)

Communications between peers is supported by entities at the lower layers



Entities and Peers

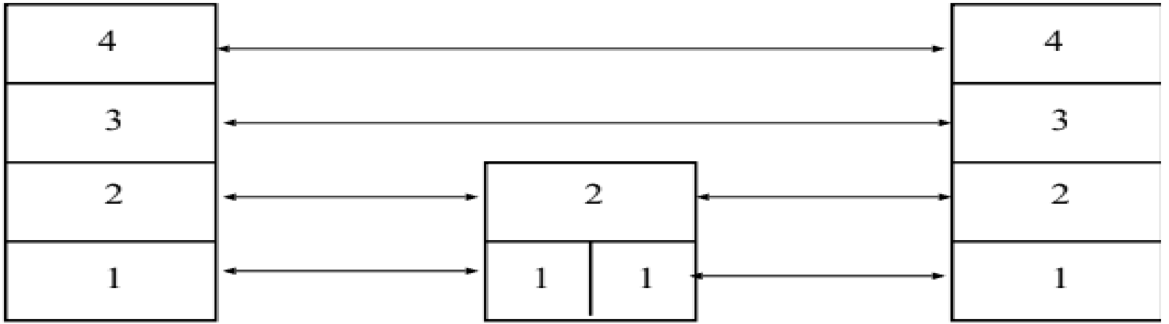
Entities usually do something useful

- Encryption – Error correction – Reliable Delivery
- Nothing at all is also reasonable

Not all communications is end-to-end

Examples for things in the middle

- IP Router – Mobile Phone Cell Tower
- Person translating French to English



Protocol "Layers"

Networks are complex!

- many "pieces":
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

Organization of air travel

- ticket (purchase) ticket (complain)

baggage (check) gates baggage (claim)

(load) gates (unload)

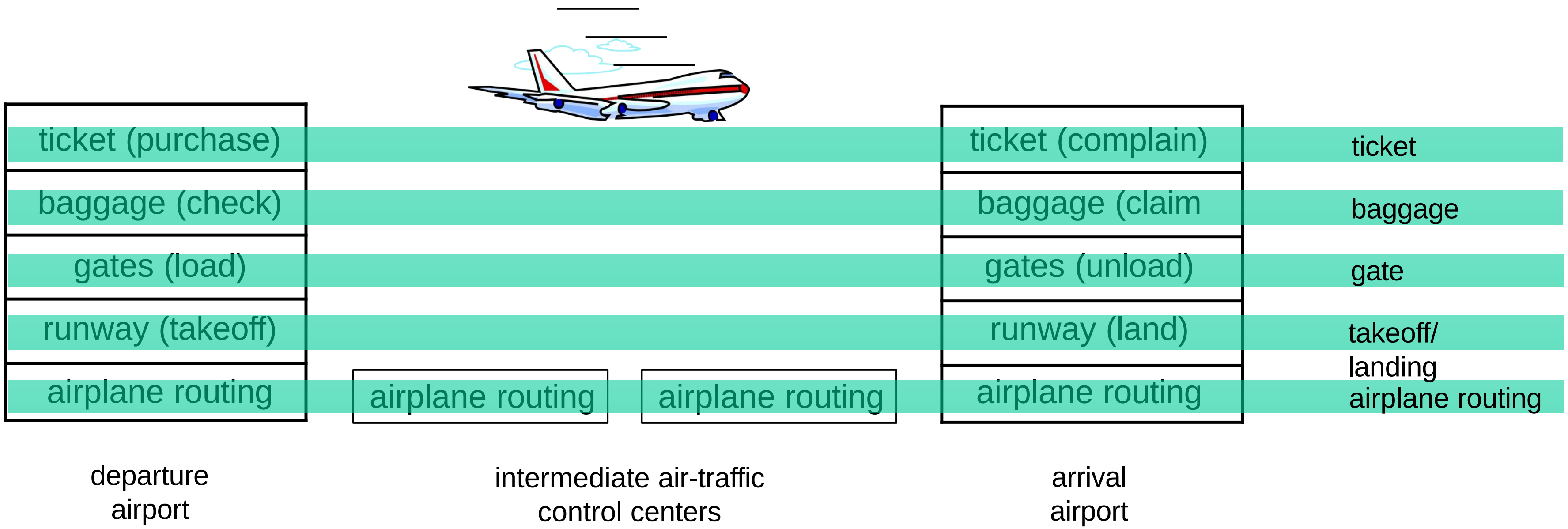
runway takeoff runway landing

airplane routing airplane routing

airplane routing

- a series of steps

Layering of airline functionality



Layers: *each layer implements a service*

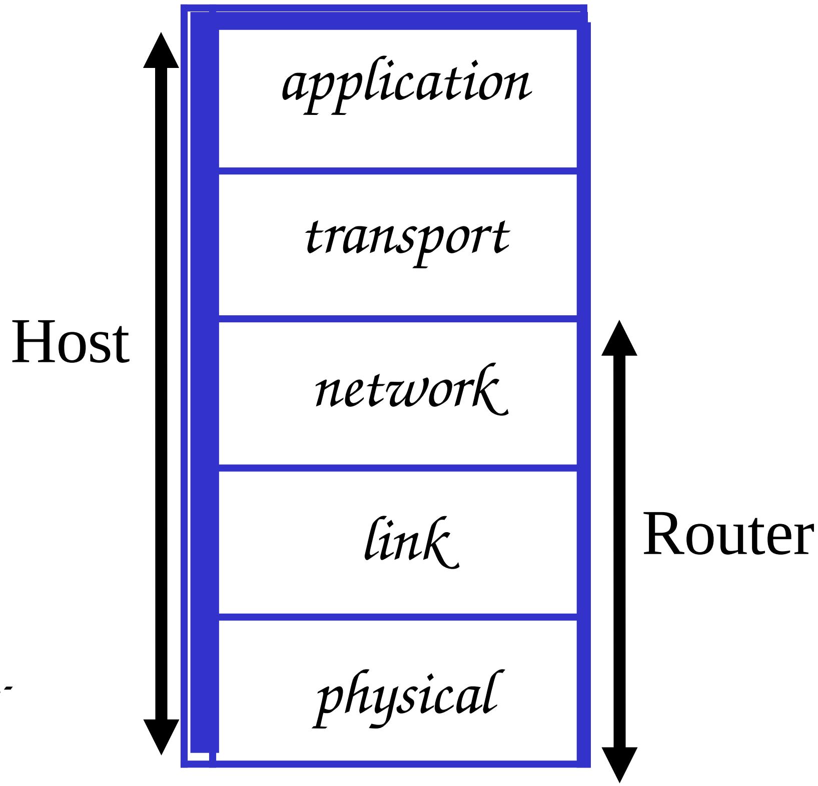
- *via its own internal-layer actions*
- *relying on services provided by layer below*

Why layering?

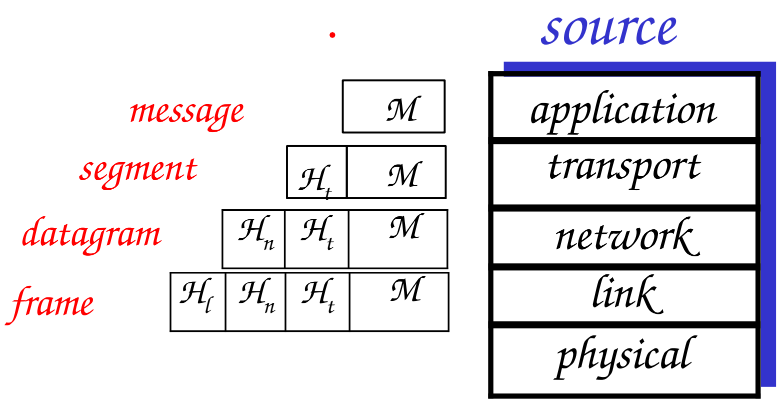
- ***Layering*** *is a design approach that divides the complex process of communication into* ***simpler, well-defined steps*** *(layers), where* ***each layer performs a specific task.***

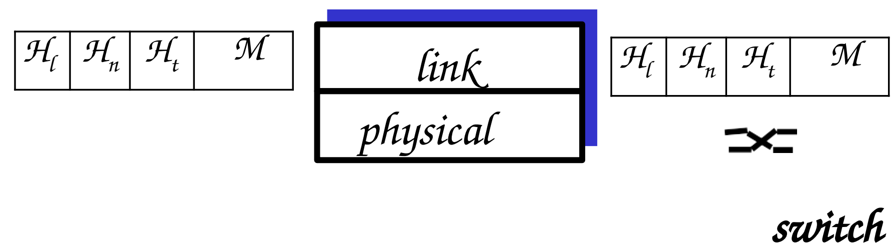
Internet protocol stack

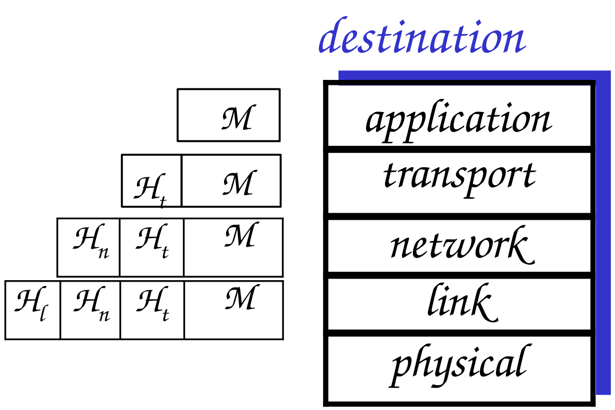
- *application:* supporting network applications
  - ftp, smtp, http
- *transport:* host-host data transfer
  - tcp, udp
- *network:* routing of datagrams from source to destination
  - ip, routing protocols
- *link:* data transfer between neighboring network elements
  - ppp, ethernet
- *physical:* bits "on the wire", modulation scheme, line-coding format, electrical & physical specifications, etc.
- Routers in the network operate only up to the Network Layer

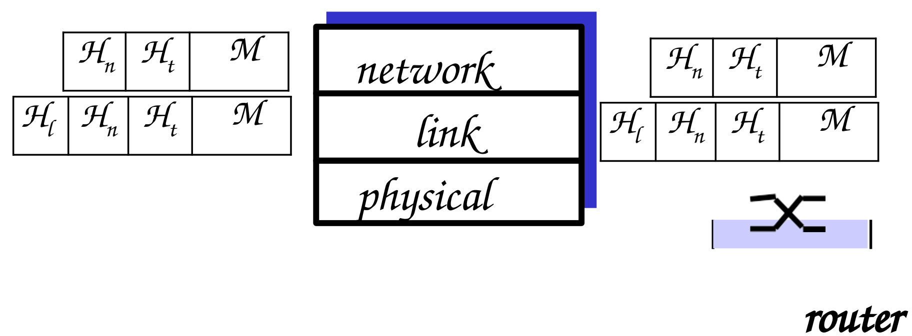


Encapsulation









1.9 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'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*

Late 1990's & 2000's:

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

You now hopefully have:

- context, overview, "feel" of networking
- more depth, detail *later* in course