CS 455/555 / Spring 2013
Intro to Networks and Communications

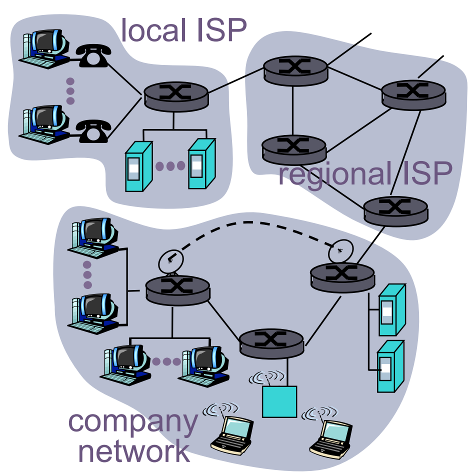
Whirlwind Introduction to the Internet (part 2)

Dr. Michele C. Weigle

http://www.cs.odu.edu/~mweigle/CS455-S13/

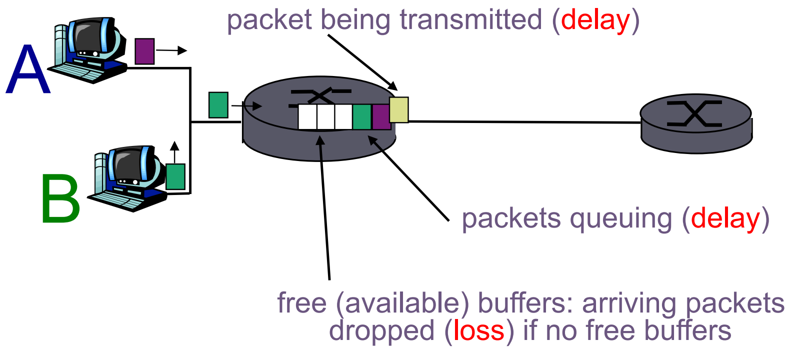
A Whirlwind Introduction to the Internet
Overview

- What's the Internet (KR 1.1)
- Network Edge (KR 1.2)
- Network Core (KR 1.3)
- Performance: Loss and Delay (KR 1.4)
- Protocol Layering (KR 1.5)
- Networks Under Attack (KR 1.6)
- History (KR 1.7)



Performance: Loss and Delay

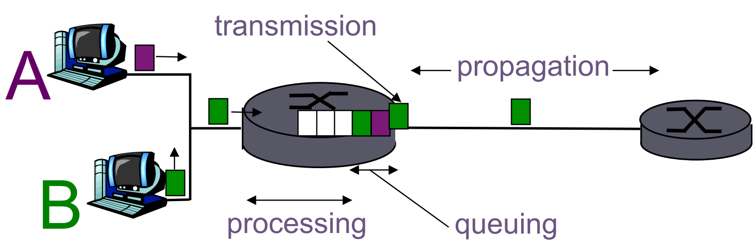
How do delay and loss occur?



- Packets queue in router buffers
  - packet arrival rate to link (temporarily) exceeds output link capacity
  - packets queue, wait for turn
- If queue is full, packets are not admitted (dropped)

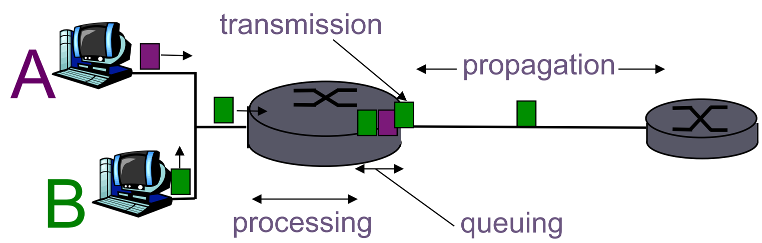
Performance: Loss and Delay

Delay in packet-switched networks



- Packets experience variable delays along the path from source to destination
- Four sources of delay at each hop
  - Processing
    - Check for bit errors
    - Determine the output interface to forward packet on
  - Queuing
    - Time spent waiting at outbound interface for transmission
    - Duration depends on the level of congestion at the interface
  - Transmission
  - Propagation

Performance: Loss and Delay
Delay in packet-switched networks



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

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

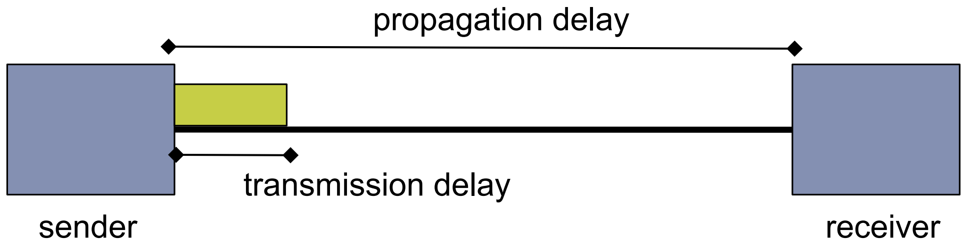
- Transmission delay = time to "put bits onto the link" = L/R
  - R = link bandwidth (bps)
  - L = packet length (bits)
- Propagation delay = d/s
  - d = length of physical link
  - s = signal propagation speed in medium (~2×10^8 m/s)

Delay in Packet-Switched Networks
Transmission & Propagation Delay

- propagation delay
  - time it takes a *bit* to travel (propagate) the length of a wire
  - depends upon the length of the wire and the *propagation speed* of the physical medium (coaxial cable, fiber optics, air, etc.)
  - tells you when the first bit will reach the other end of the wire
- transmission delay
  - time it takes to put (transmit) a *packet* on the wire
  - depends on the length (size) of the packet and the *transmission speed* (or link speed or bandwidth)
  - tells you when the last bit of the packet is transmitted (leave the sender)

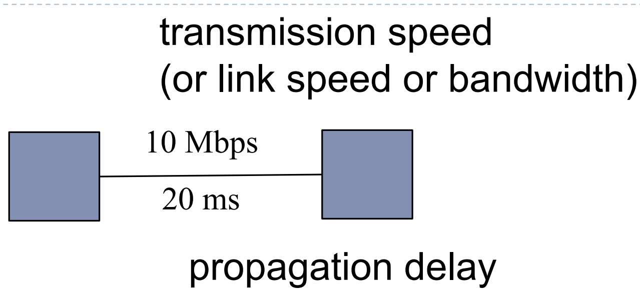
See Java applet

Delay in Packet-Switched Networks
Calculating Transmission & Propagation Delay



- propagation delay ($d_{prop} = m / s$)
  - divide the length of the wire (m) by the propagation speed (s) (typically 2.5 x 10^8 meters/second)
  - end result is a time, so units should be seconds or milliseconds
- transmission delay ($d_{trans} = L / R$)
  - divide the size of the packet (L) by the transmission speed (R)
  - end result is a time, so units should be seconds or milliseconds

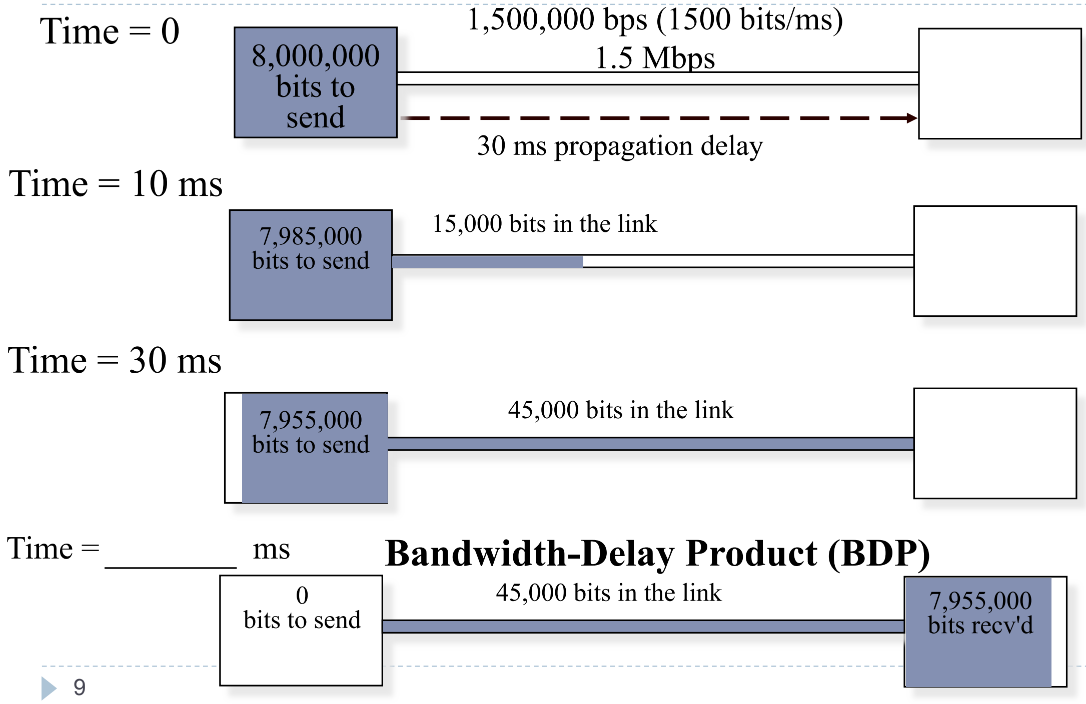
Delay in Packet-Switched Networks
Transmission & Propagation Delay



- end-to-end delay
  - time it takes for the entire packet to reach the receiver (i.e., when does the last bit of the packet reach the receiver?)
  - transmission delay + propagation delay

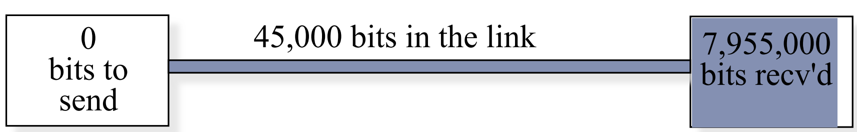
Transmission & Propagation Example

Transmission on a "slow" link



Delay in Packet-Switched Networks

Bandwidth Delay Product (BDP)

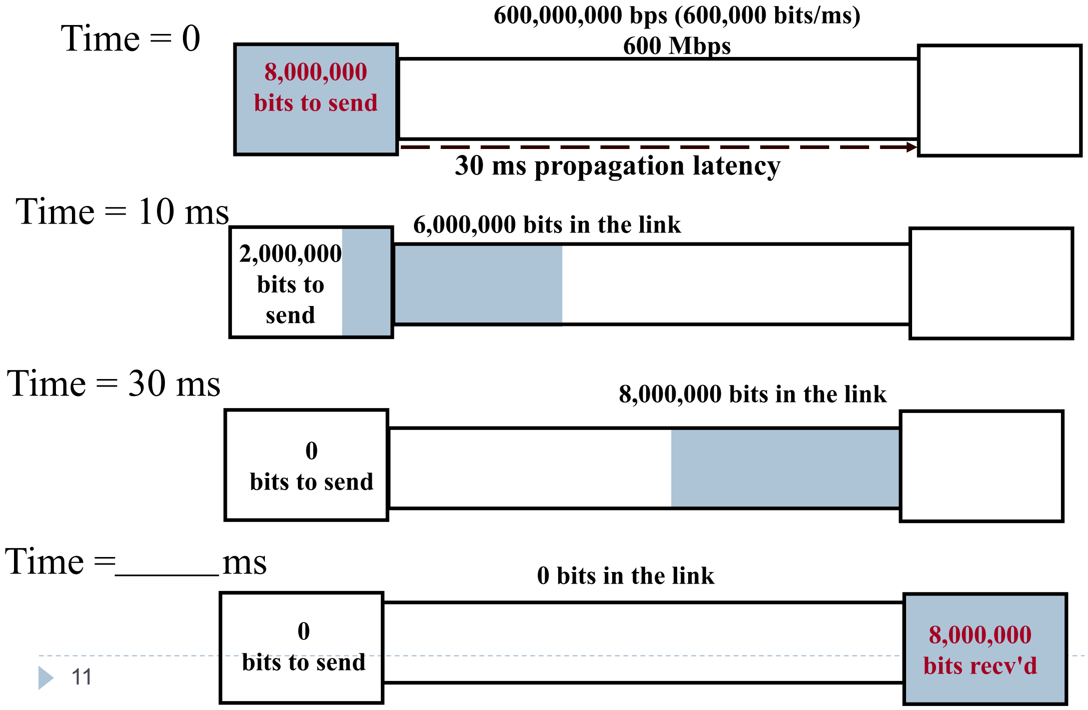


- *R * dprop*
- Three ways to think about it:
  - If you are sending continuously, how much can you send before the first bit is received?
  - Max amount of data that can be in the link at one time.
  - What size packet would you need so that $d_{trans} = d_{prop}$?

$$\frac{L}{R} = \frac{m}{s} \Rightarrow L = R\left(\frac{m}{s}\right) \Rightarrow L = R * d_{prop}$$

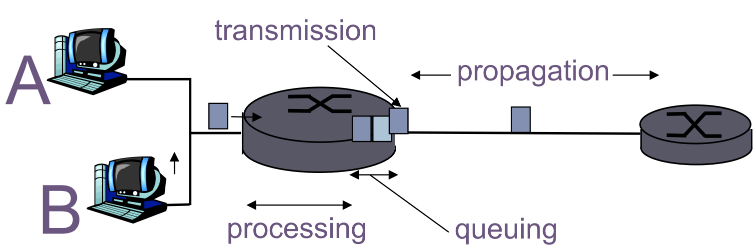
Transmission & Propagation Example

Transmission on a "fast" link



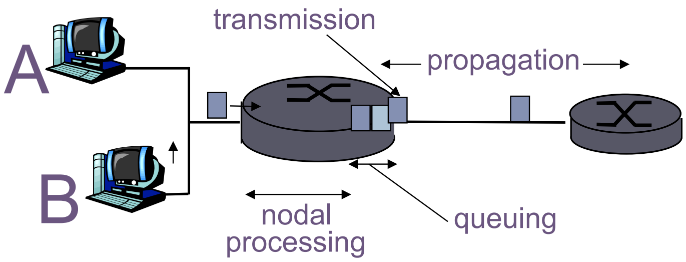
Performance: Loss and Delay

Delay in packet-switched networks



- Typical transmission delay:
  - L/R (significant for low-speed links)
  - 120 µs (for 1,500 byte packet on a 100 Mbps Ethernet)
- Typical propagation delay:
  - ≤ 1 µs on a small campus
  - ≈ 25 ms to the West coast
- Typical processing delay:
  - a few microsecs or less
- Typical queuing delay:
  - depends on congestion

Performance: Loss and Delay
Delay in packet-switched networks



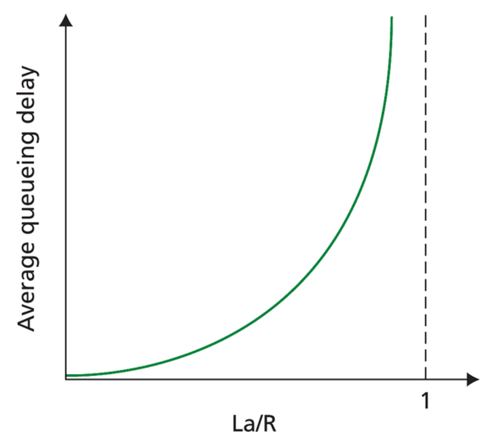
Transmission delay = 120 μs
Propagation delay = 10 μs
Queuing delay = k x 120 μs
Processing delay = 100 μs

What is k?

- What dominates end-to-end delay?
- Note that processing, transmission, and queuing delays are encountered at each hop
  - End-to-end delay is largely a function of the number of routers encountered along the path from source to destination

Delay in Packet-Switched Networks
Queuing Delay

- What affects queuing delay?
  - traffic arrival rate (La)
  - speed of outgoing link (R)
  - nature of arriving traffic (uniform or bursty)
    - hard to quantify
- Represent queuing delay with statistical measures
  - average queuing delay
  - variance of queuing delay
  - probability that queuing delay exceeds some value
- Traffic intensity (La/R)
  - $La/R \sim 0$ - avg queuing delay small
  - $La/R \rightarrow 1$ - avg queuing delay large
  - $La/R > 1$ - more "work" arriving than can be serviced, avg delay infinite!



La/R ~ 0

La/R -> 1

See Java applet

Questions

- What is the transmission delay for a 2000-byte packet over a 1 Mbps link?
- Where is the last bit of the packet after the transmission delay has passed?
- What is the transmission delay for a 250,000-bit packet over a 1 Mbps link?

Questions

- What are the four types of delay that are (potentially) encountered at every router/hop? Which one may not be encountered?
- What is the difference between transmission delay and propagation delay?
- What two things affect the duration of queuing delay for a particular packet?

Delay in Packet-Switched Networks
Effect of Store and Forward

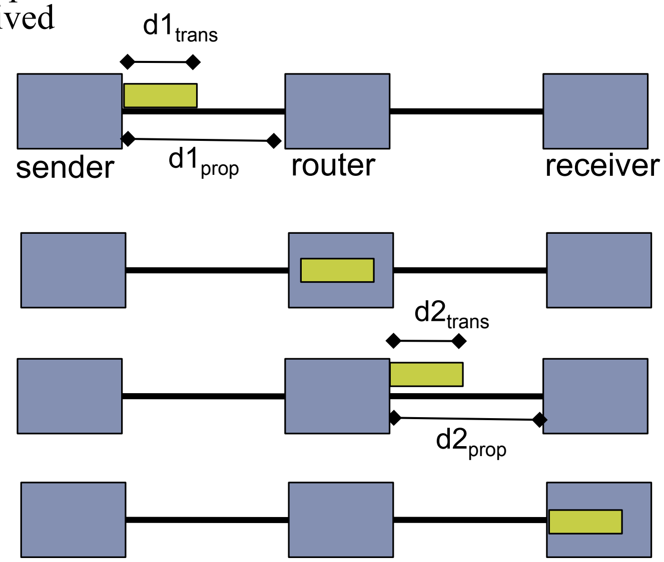
- Can't begin transmitting a packet over the next link until the entire packet has first been received

time = $d1_{trans}$

time = $d1_{trans} + d1_{prop}$

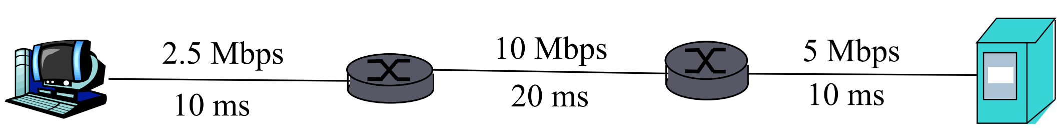
time = $d1_{trans} + d1_{prop} + d2_{trans}$

time = $d1_{trans} + d1_{prop} + d2_{trans} + d2_{prop}$



Question

- How long would it take a 5000-bit packet to travel from source to destination over the following network?



Performance: Loss and Delay
Example: What was the delay from my house?

- I live in Larchmont (less than 1 mile from campus)

```
% ping www.odu.edu
PING www.odu.edu (128.82.111.39): 56 data bytes
64 bytes from 128.82.111.39: icmp_seq=0 ttl=116 time=13.851 ms
64 bytes from 128.82.111.39: icmp_seq=1 ttl=116 time=13.596 ms
64 bytes from 128.82.111.39: icmp_seq=2 ttl=116 time=13.139 ms
64 bytes from 128.82.111.39: icmp_seq=3 ttl=116 time=19.433 ms
^C
--- www.odu.edu ping statistics ---
4 packets transmitted, 4 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 13.139/15.005/19.433/2.569 ms
```

Round trip time: time between sending data and the response returning, roughly equal to 2 * propagation delay

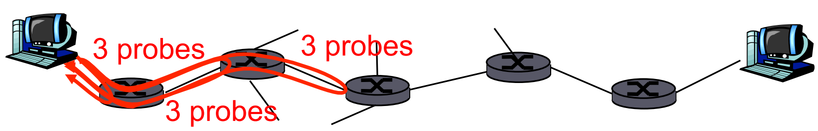
Performance: Loss and Delay
Example: What was the path from my house?

```
1  wrt54g.weigle.home                 my cable modem router
2  10.11.184.1                        Cox Cable default router
3  68.10.14.137
4  nrfkdsrj01-ge0705.rd.hr.cox.net    Cox network - Hampton Roads
5  12.118.122.77                      What's this?
6  tbr1-p010401.wswdc.ip.att.net      AT&T network - Rockville, MD
7  ar5-p3110.wswdc.ip.att.net
8  att-gw.dc.sprint.net               AT&T Gateway - Sprint network - DC
9  sl-st22-ash-15-0.sprintlink.net    Sprint network - Ashburn, VA
10 sl-bb24-rly-8-0.sprintlink.net     Sprint network - Relay, MD
11 sl-gw21-rly-9-0.sprintlink.net
12 sl-vwan-9-0.sprintlink.net         ODU's Sprint default router
13 128.82.254.198                     ODU's campus router
```

Note: This capture is from a couple years ago. ODU now has a Cox interface, so the traceroute is not as interesting now.

Performance: Loss and Delay
Traceroute

- Traceroute program: provides delay measurement from source to router along end-end Internet path towards destination.
- For all *i*:
  - 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



Performance: Loss and Delay
Example: What was the route from my house?

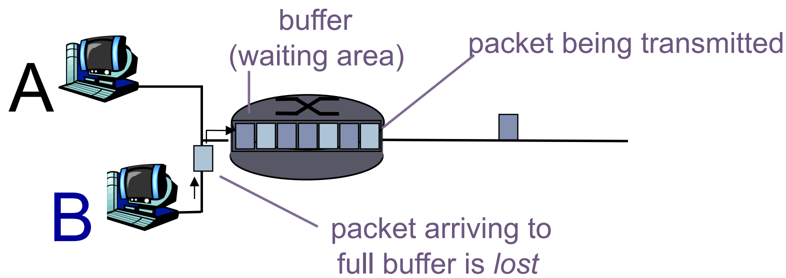
```
% traceroute fast.cs.odu.edu

Tracing route to fast.cs.odu.edu [128.82.4.4]
over a maximum of 30 hops:

  1     1 ms    <1 ms    <1 ms  wrt54g.weigle.home [192.168.2.127]
  2    29 ms     8 ms     8 ms  10.11.184.1
  3    13 ms    13 ms     7 ms  68.10.14.137
  4     9 ms     9 ms    23 ms  nrfkdsrj01-ge0705.rd.hr.cox.net [68.10.14.25]
  5    17 ms    15 ms    14 ms  12.118.122.77
  6    34 ms    16 ms    14 ms  tbr1-p010401.wswdc.ip.att.net [12.123.8.26]
  7    13 ms    15 ms    13 ms  ar5-p3110.wswdc.ip.att.net [12.123.8.129]
  8    18 ms    15 ms    19 ms  att-gw.dc.sprint.net [192.205.32.166]
  9    15 ms    27 ms    22 ms  sl-st22-ash-15-0.sprintlink.net [144.232.29.207]
 10     *       27 ms    37 ms  sl-bb24-rly-8-0.sprintlink.net [144.232.20.154]
 11    18 ms    18 ms    18 ms  sl-gw21-rly-9-0.sprintlink.net [144.232.14.54]
 12    21 ms    22 ms    19 ms  sl-vwan-9-0.sprintlink.net [160.81.98.58]
 13    33 ms    50 ms    24 ms  128.82.254.198
```

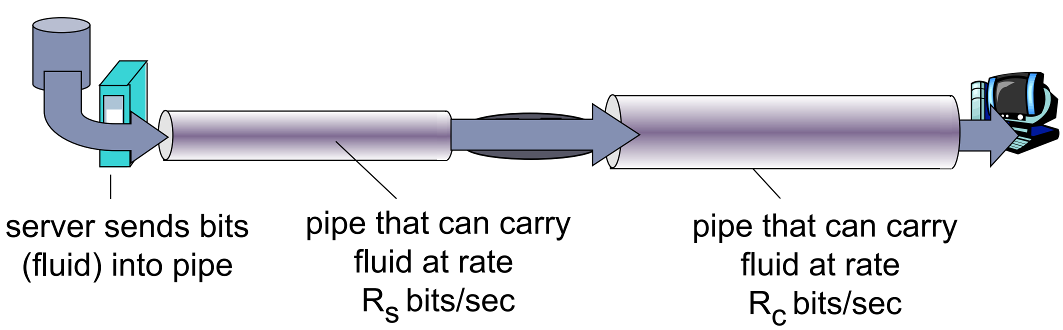
Performance: Loss and Delay
Packet Loss

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



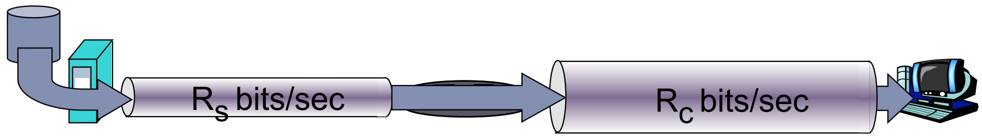
Performance: Loss and Delay
Throughput

- *throughput*: rate (bits/time unit) at which bits transferred between sender/receiver
  - *instantaneous*: rate at given point in time
  - *average*: rate over long(er) period of time

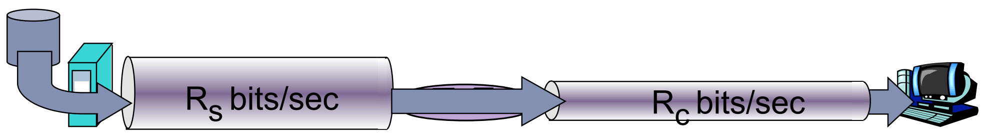


Performance: Loss and Delay
Throughput

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



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

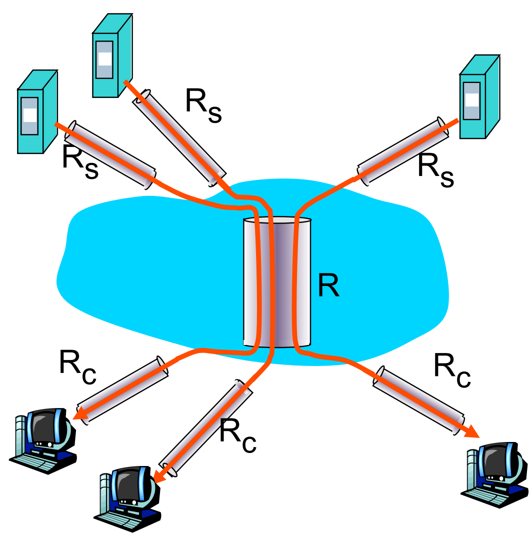


bottleneck link

link on end-end path that constrains end-end throughput

Performance: Loss and Delay
Throughput: Internet Scenario

- Per-connection end-to-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

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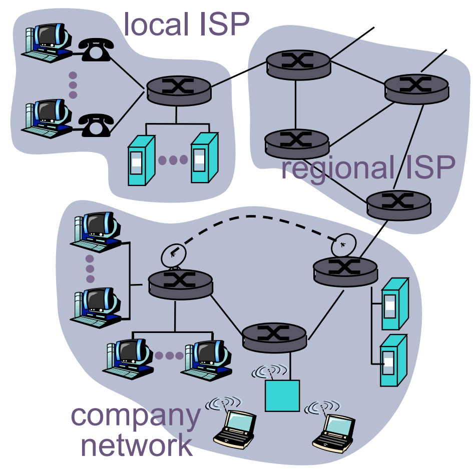
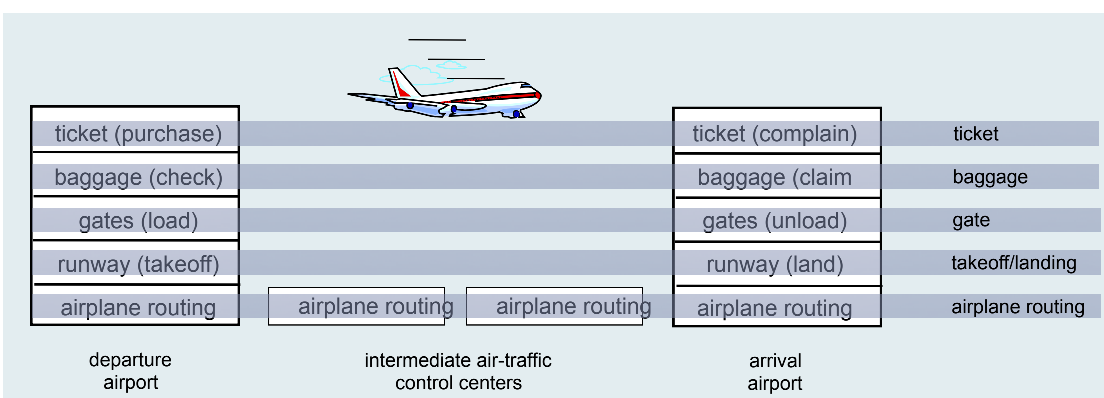


Protocol Layering in the Internet
Airline Example

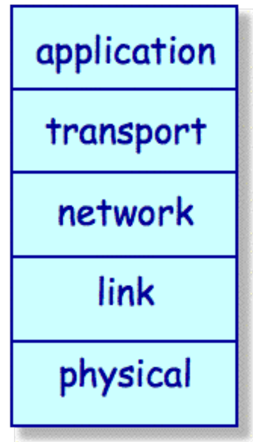
- Layers: each layer implements a service
  - via its own internal-layer actions
  - relying on services provided by layer below



Protocol Layering in the Internet

Internet protocol layers ("stack")

- Application layer
  - Supporting network applications
    - FTP, SMTP, HTTP
- Transport layer
  - Host-host data transfer
    - TCP, UDP
- Network layer
  - Routing of packets from source to destination
    - IP, routing protocols
- Link layer
  - Data transfer between directly connected network elements
    - Ethernet, 802.11, SONET, …
- Physical layer
  - The insertion of individual bits "on the wire"
    - Manchester encoding

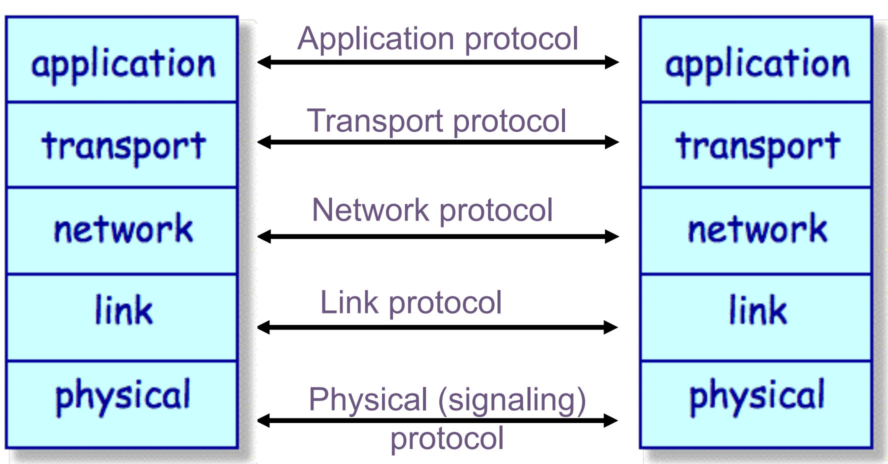


Different services specified at each layer interface

Protocol Layering in the Internet

Internet protocol layers ("stack")

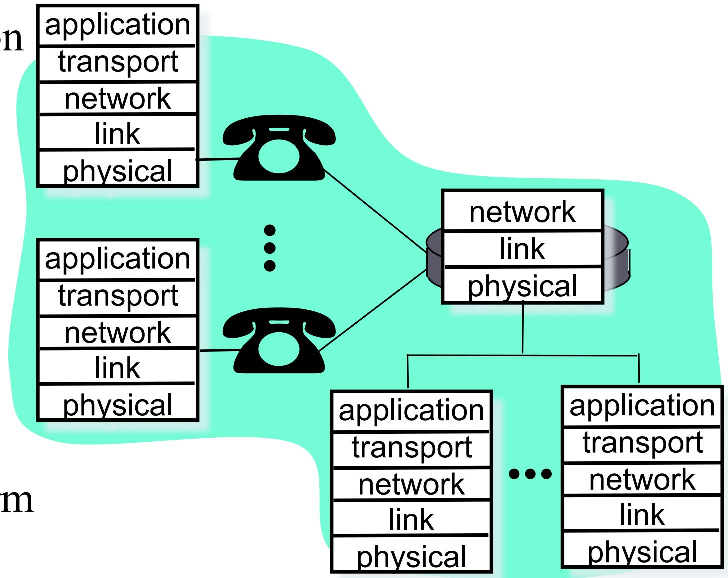
- Each layer implements a protocol with its peer layer in a distributed system



End system A End system B

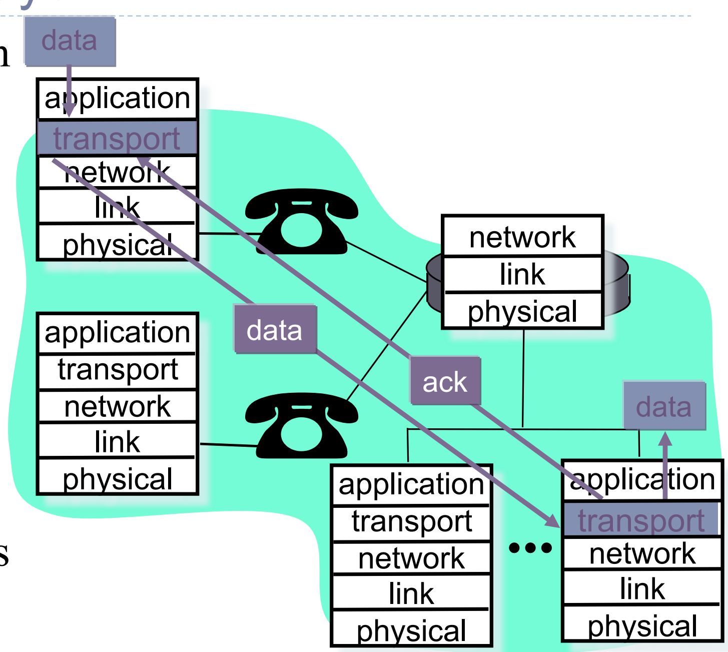
Protocol Layering in the Internet
Logical communication

- The implementation of each layer is distributed throughout the network
  - Some layers just distributed on the end-systems
- The distributed components perform actions, exchange messages with peers

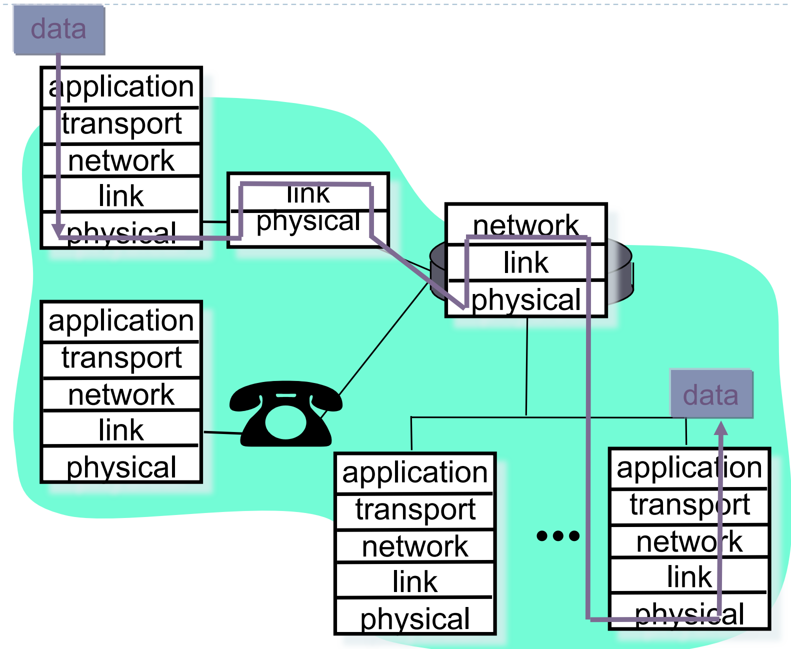


Logical Communication Example
The transport layer

- Receive data from application
- Add transport-layer protocol information
- Send to peer transport layer
- Wait for peer transport layer to respond
- Peer transport delivers data to its application layer

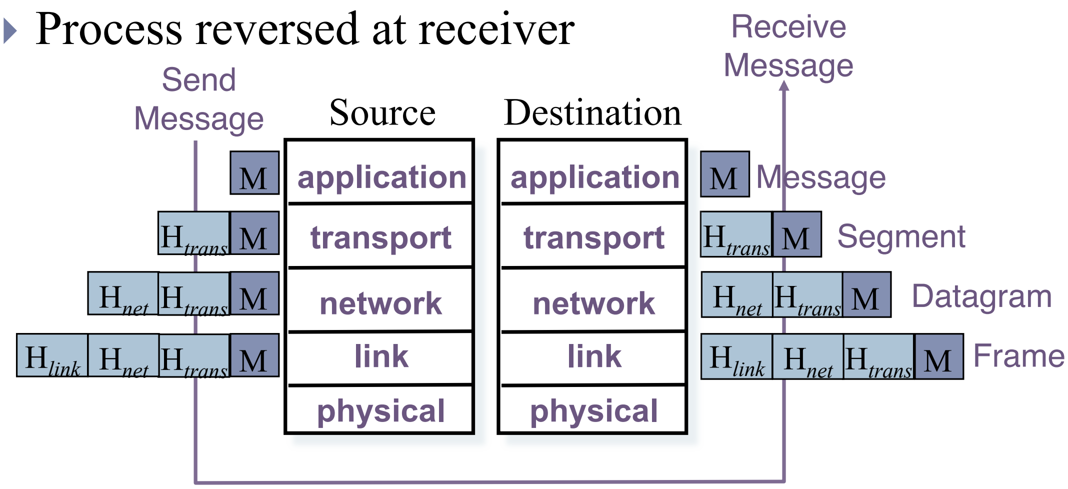


Protocol Layering in the Internet
Data flow through protocol layers



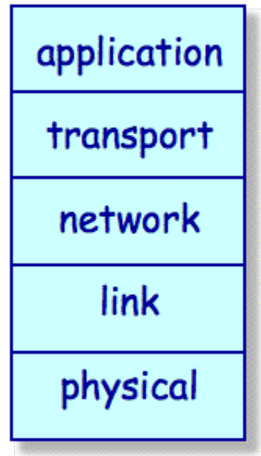
Protocol Layering in the Internet
Protocol layering and data formats

- At sender, each layer takes data from above
  - Adds header information to create new data unit
  - Passes new data unit to layer below
- Process reversed at receiver



Protocol Layering in the Internet
Common logical functions in most layers

- Error control
  - Make the logical channel between layers reliable (or simply more reliable)
- Flow control
  - Avoid overwhelming a peer with data
- Segmentation and reassembly
  - Partitioning large messages into smaller ones at the sender and reassembling them at the receiver
- Multiplexing
  - Allowing several higher-level sessions to share a single lower-level connection
- Connection setup
  - Handshaking with a peer



Questions

- What are the five network protocol layers?
- Which layers do end systems use?
- Which layers do routers use?

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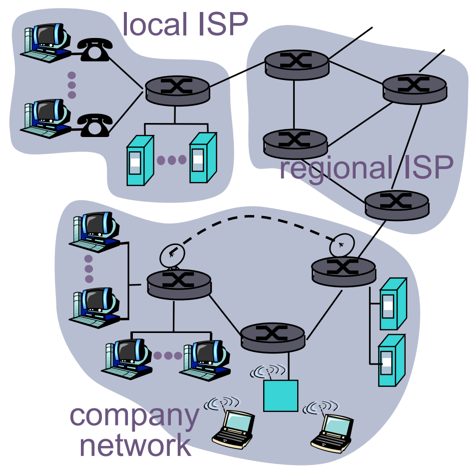


Networks Under Attack

- Attacks on Internet infrastructure:
  - infecting/attacking hosts: malware, spyware, worms, unauthorized access (data stealing, user accounts)
  - denial of service: deny access to resources (servers, link bandwidth)
- Internet not originally designed with (much) security in mind
  - original vision: "a group of mutually trusting users attached to a transparent network" ☺
  - Internet protocol designers playing "catch-up"
  - Security considerations in all layers!

What Can Bad Guys Do?
Malware

- malware can get in host from:
  - *virus*: self-replicating infection by receiving/ executing object (e.g., e-mail attachment)
  - *worm:* self-replicating infection by passively receiving object that gets itself executed

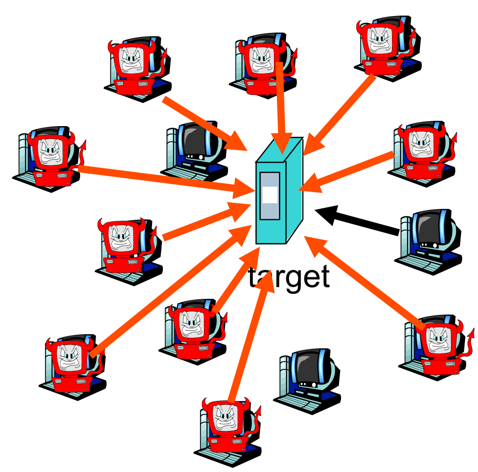
- *spyware* can record keystrokes, web sites visited, upload info to collection site

- infected host can be enrolled in *botnet*, used for spam, DDoS attacks

What Can Bad Guys Do?
Denial of service (DoS) attacks

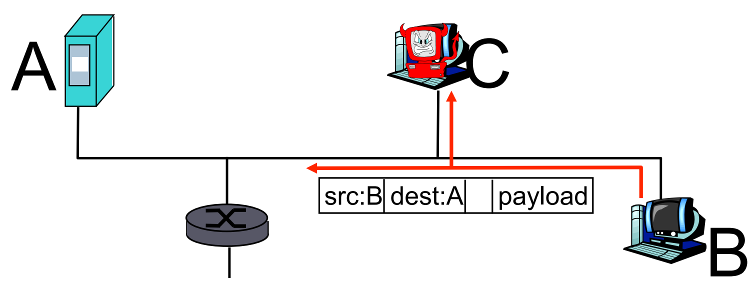
- Attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

- Distributed DoS
  - select target
  - break into hosts around the network (see malware)
  - send packets toward target from compromised hosts



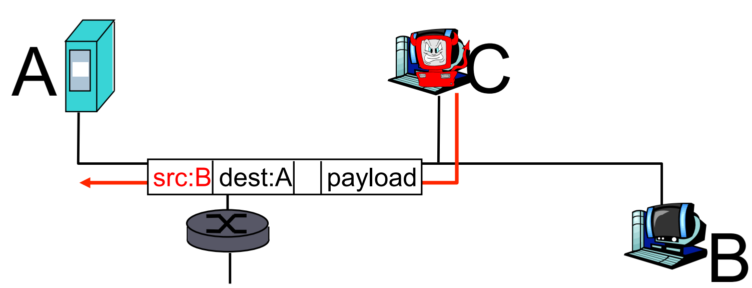
What Can Bad Guys Do?
Sniff, modify, delete your packets

- Packet sniffing:
  - broadcast media (shared Ethernet, wireless)
  - promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



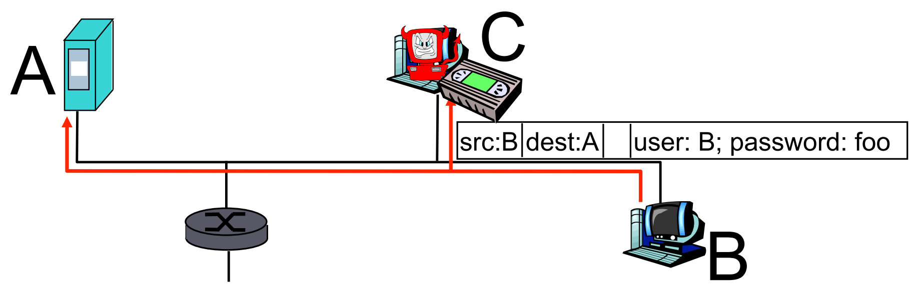
What Can Bad Guys Do?
Masquerade as you

- IP spoofing: send packet with false source address



What Can Bad Guys Do?
Masquerade as you

- IP spoofing: send packet with false source address
- Record-and-playback: sniff sensitive info (e.g., password), and use later
  - password holder is that user from system point of view



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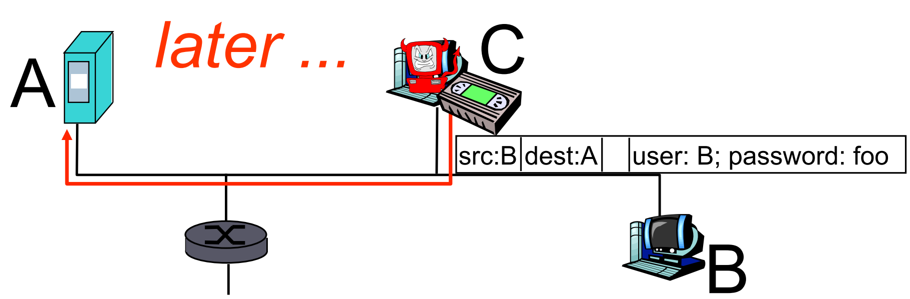
  - password holder is that user from system point of view

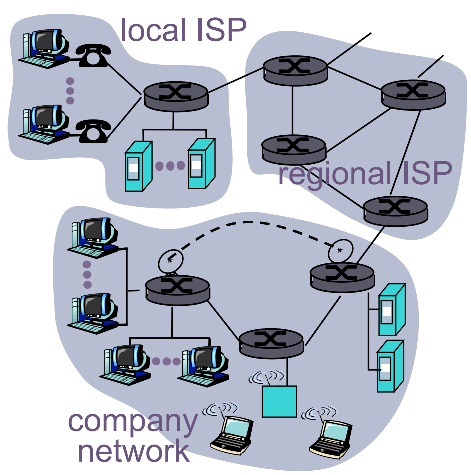


Networks Under Attack!
More on this later

- Security will be scattered throughout the rest of the course
- Chapter 8 focuses on security

A Whirlwind Introduction to the Internet
Overview

- What's the Internet (KR 1.1)
- Network Edge (KR 1.2)
- Network Core (KR 1.3)
- Performance: Loss and Delay (KR 1.4)
- Protocol Layering (KR 1.5)
- Networks Under Attack (KR 1.6)
- History (KR 1.7)



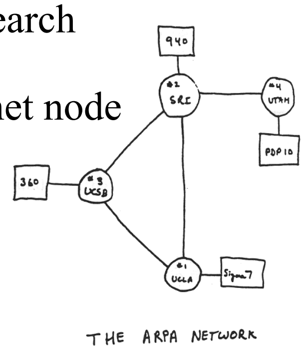
Internet History Lesson

- 1961-1972: Early packet-switching principles
- 1972-1980: Internetworking, new and proprietary nets
- 1980-1990: New protocols, a proliferation of networks
- 1990-today: commercialization, the Web, new apps

Internet History Lesson

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 demonstration
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

Internet History Lesson

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
- late 70'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

Internet History Lesson

1980-1990: new protocols, a proliferation of networks

- 1982: SMTP e-mail protocol defined
- 1983: deployment of TCP/IP
- 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 Lesson
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 Lesson
2005-Present

- ~850 million hosts
  - smartphones, 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)

A Whirlwind Introduction to the Internet
Summary

- Covered a "ton" of material
  - Internet overview
  - What's a protocol?
  - Network edge, core, access network
  - Performance: loss, delay
  - Layering and service models
  - Backbones, NAPs, ISPs
  - Network security
  - History
- You now hopefully have:
  - Context, overview, "feel" of networking
  - More depth, detail later in course
- Something dangerous to mumble at parties!