Internetworking: Packet Switching & Performance Metrics

EE4204: Computer Networks
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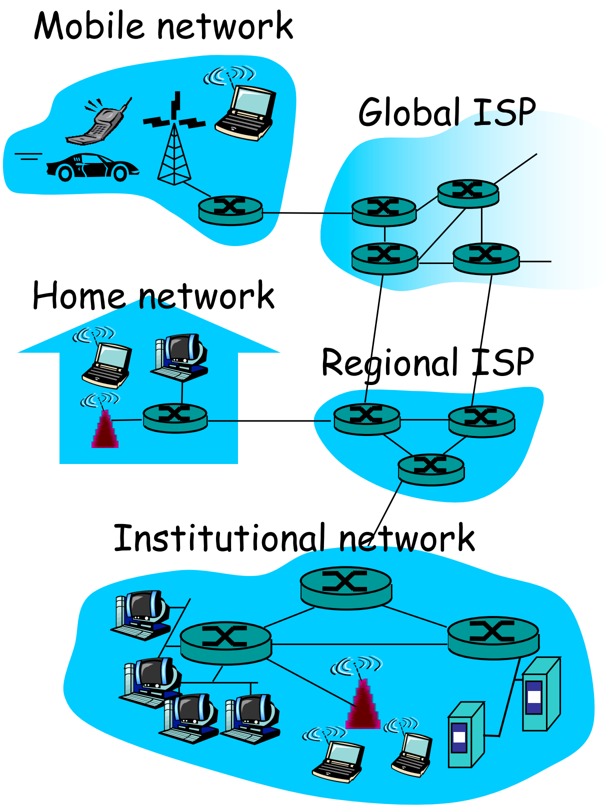
Note: Some slides & graphics adapted from "Computer Networking" by Kurose & Ross

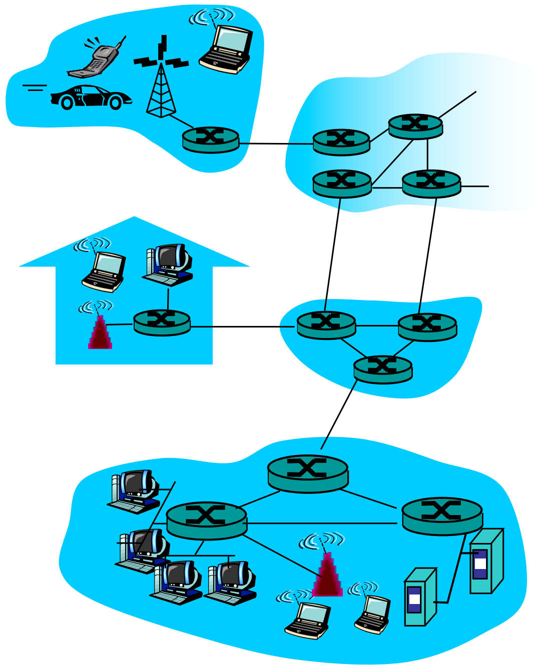
A closer look at network structure

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



The Network Core

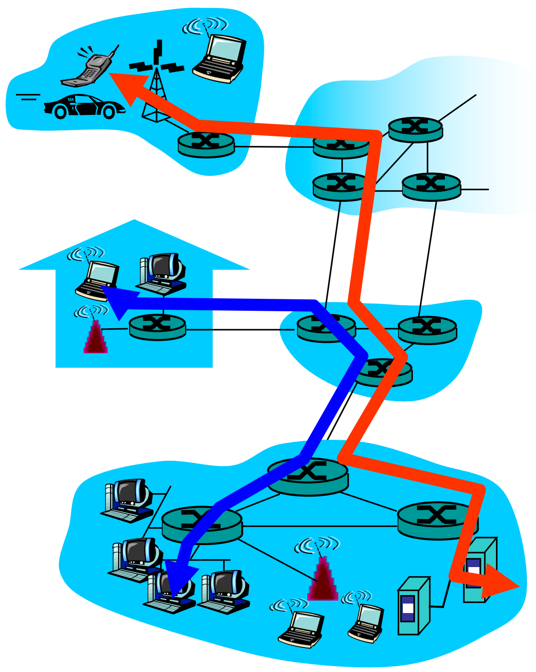
- mesh of interconnected routers
- fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



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

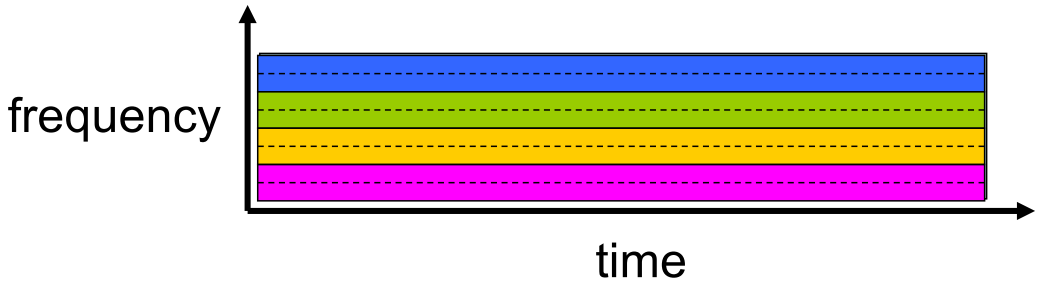


Circuit Switching: FDM and TDM

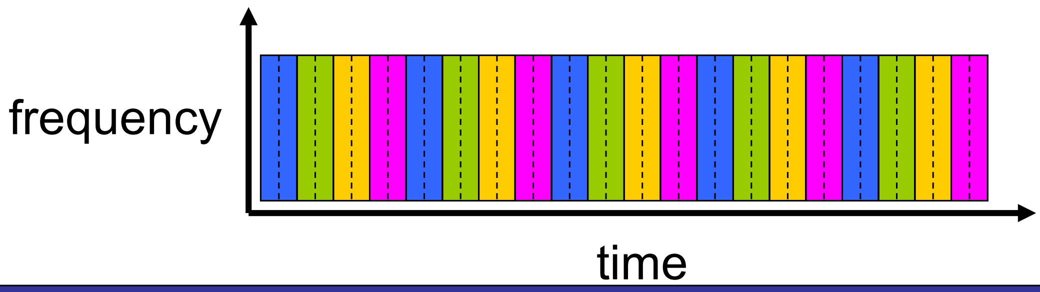
Example:

4 users

FDM



TDM



Network Core: Packet Switching

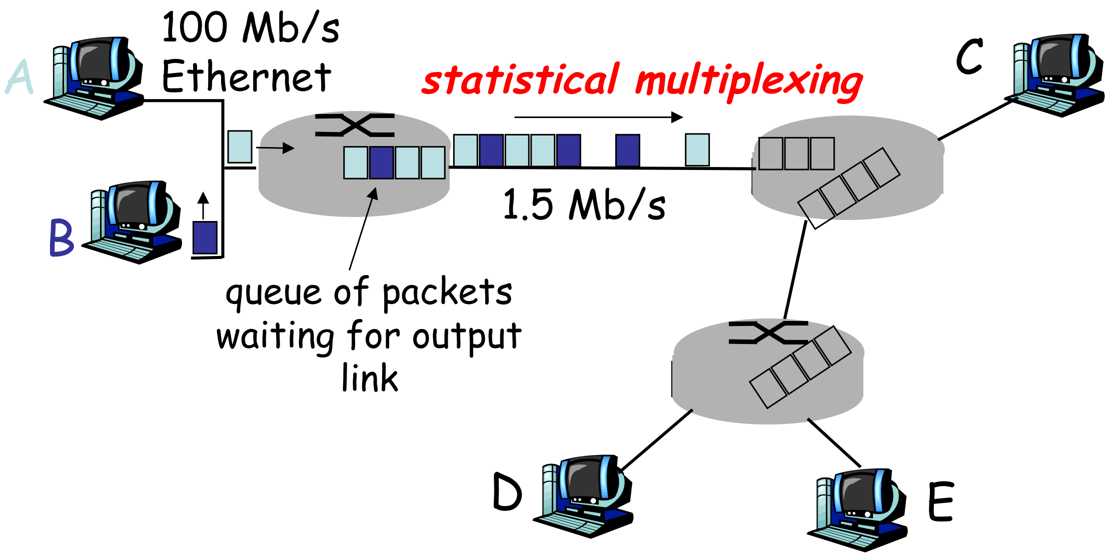
each end-end data stream divided into *packets*

- 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
- 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



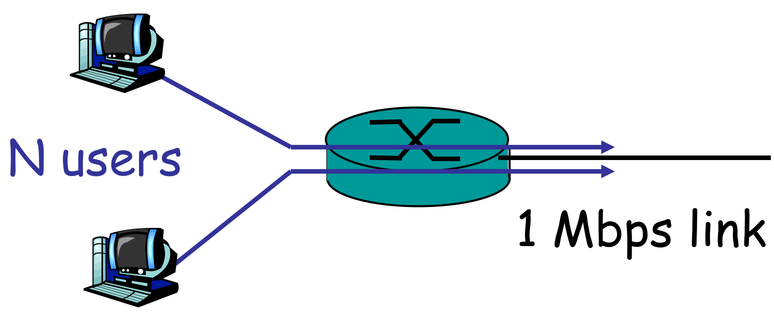
Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand ➡ ***statistical multiplexing***.

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

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 at same time is less than .0005



Q: how did we get value 0.0005?

Packet switching versus circuit switching

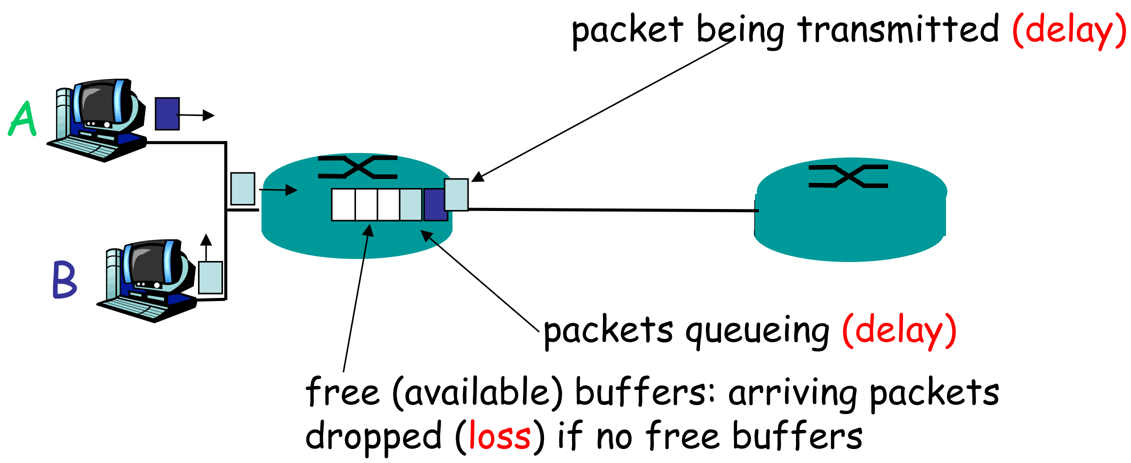
Is packet switching a "slam dunk winner?"

- 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

How do delay and loss occur?

Packets queue in router buffers in network core

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



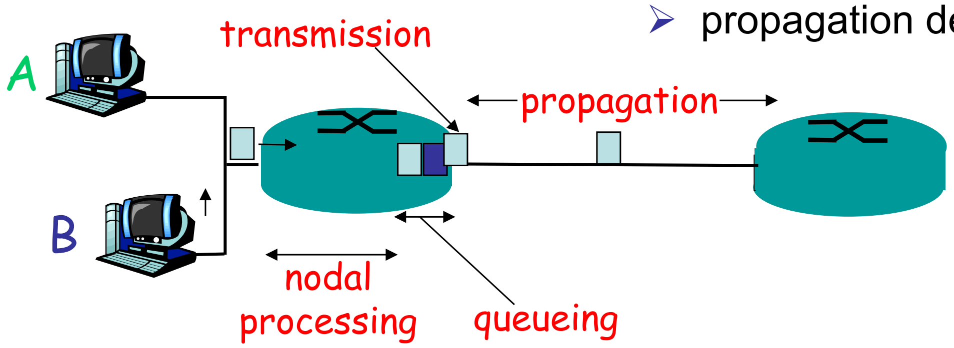
Delay in packet-switched networks

1. nodal processing:
- check bit errors
- determine output link

2. queueing
- time waiting at output link for transmission
- depends on congestion level of router

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 (~2×10^8 m/sec)
- propagation delay = d/s



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

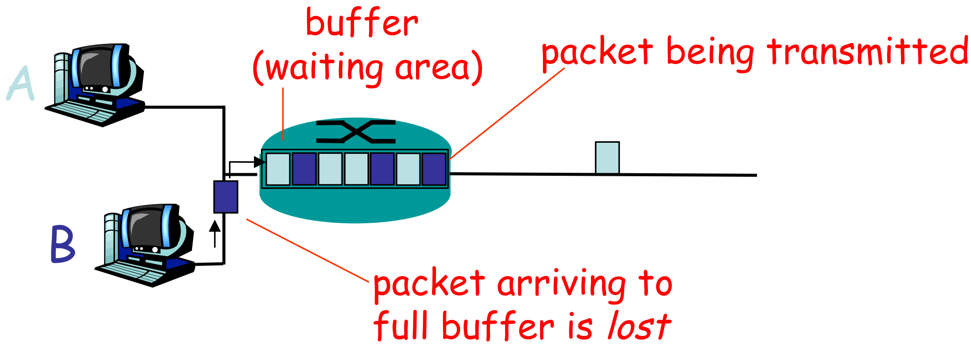
Nodal delay

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

- d_{proc} = processing delay
  - typically a few microseconds 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

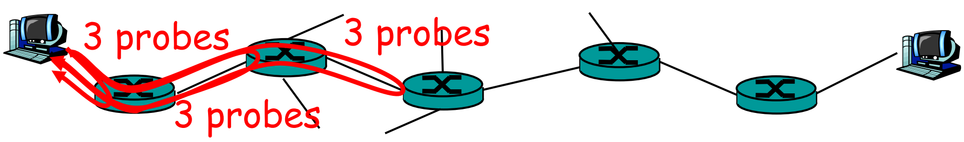
Packet loss

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



"Real" Internet delays and routes

- **Ping** program: hello message to remote host, gives delay and loss rate
- **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.



"Real" Internet delays and routes

```
[frogg:~ motani$ ping www.yahoo.com
PING atsv2-fp-shed.wg1.b.yahoo.com (106.10.250.10): 56 data bytes
64 bytes from 106.10.250.10: icmp_seq=0 ttl=55 time=6.971 ms
64 bytes from 106.10.250.10: icmp_seq=1 ttl=55 time=9.234 ms
64 bytes from 106.10.250.10: icmp_seq=2 ttl=55 time=9.456 ms
64 bytes from 106.10.250.10: icmp_seq=3 ttl=55 time=16.526 ms
64 bytes from 106.10.250.10: icmp_seq=4 ttl=55 time=10.097 ms
64 bytes from 106.10.250.10: icmp_seq=5 ttl=55 time=9.866 ms
64 bytes from 106.10.250.10: icmp_seq=6 ttl=55 time=6.971 ms
64 bytes from 106.10.250.10: icmp_seq=7 ttl=55 time=9.301 ms
64 bytes from 106.10.250.10: icmp_seq=8 ttl=55 time=18.473 ms
64 bytes from 106.10.250.10: icmp_seq=9 ttl=55 time=49.639 ms
64 bytes from 106.10.250.10: icmp_seq=10 ttl=55 time=8.990 ms
64 bytes from 106.10.250.10: icmp_seq=11 ttl=55 time=9.174 ms
64 bytes from 106.10.250.10: icmp_seq=12 ttl=55 time=9.903 ms
64 bytes from 106.10.250.10: icmp_seq=13 ttl=55 time=27.054 ms
64 bytes from 106.10.250.10: icmp_seq=14 ttl=55 time=30.060 ms
64 bytes from 106.10.250.10: icmp_seq=15 ttl=55 time=9.538 ms
64 bytes from 106.10.250.10: icmp_seq=16 ttl=55 time=9.555 ms
64 bytes from 106.10.250.10: icmp_seq=17 ttl=55 time=9.547 ms
64 bytes from 106.10.250.10: icmp_seq=18 ttl=55 time=16.386 ms
^C
--- atsv2-fp-shed.wg1.b.yahoo.com ping statistics ---
19 packets transmitted, 19 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 6.971/14.565/49.639/10.376 ms
frogg:~ motani$
```


"Real" Internet delays and routes

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

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

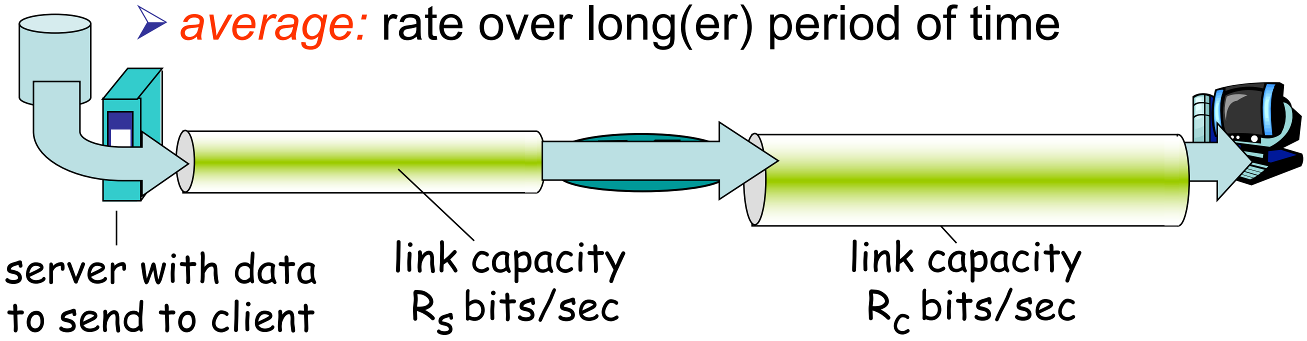
```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 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 response (probe lost, router not replying)

Throughput

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

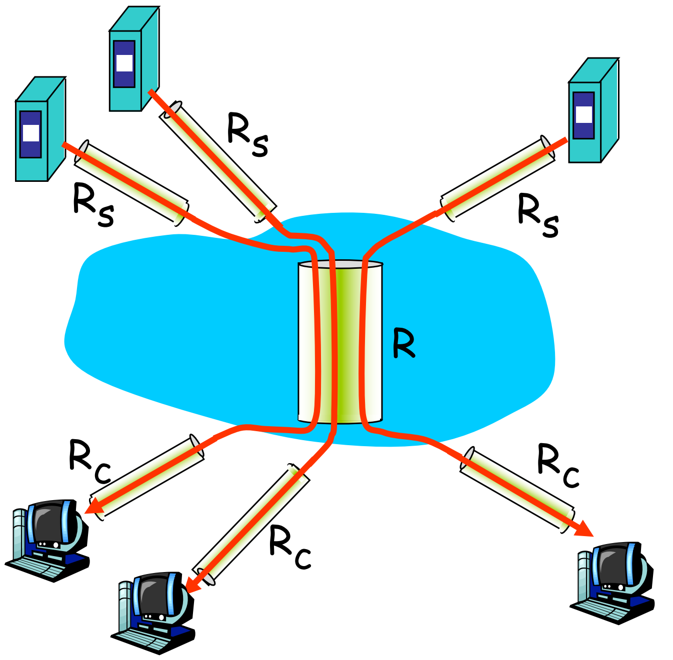


bottleneck link

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

Throughput: Internet scenario

- per-connection end-end throughput: $\min(R_c,R_s,R/10)$
- in practice: R_c or R_s is often bottleneck



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

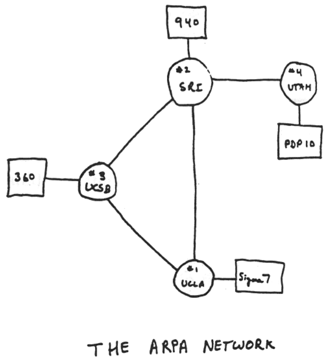
Internet History

http://edgalaxy.com/history/2010/9/16/the-history-of-the-internet.html

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

1972-1980: Internetworking, proprietary networks

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- ate70'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 and new 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: Internet explosion, web 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

2010 & beyond: rebirth of the web

- Over 1 billion hosts
- Voice, Video over IP
- P2P applications: BitTorrent (file sharing) Skype (VoIP), PPLive (video)
- Rich content & applications: Gaming, YouTube, Facebook, Twitter, Google
- Mobile wireless broadband
- Web 2.0, Internet 2.0
- Clean slate Internet – a complete redesign?