Part 1: roadmap

1.1 What *is* the Internet?

1.2 Network edge

- end systems, access networks, links

1.3 Network core

- circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks

1.5 Protocol layers, service models

1.6 Networks under attack: security

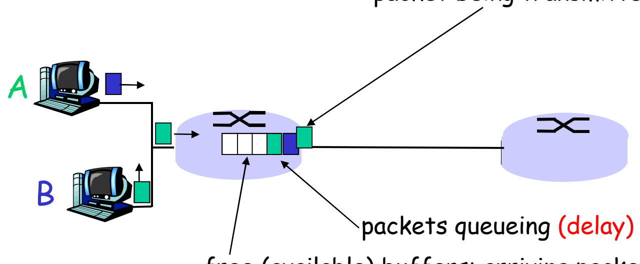
1.7 History

How do loss and delay occur?

packets *queue* in router buffers

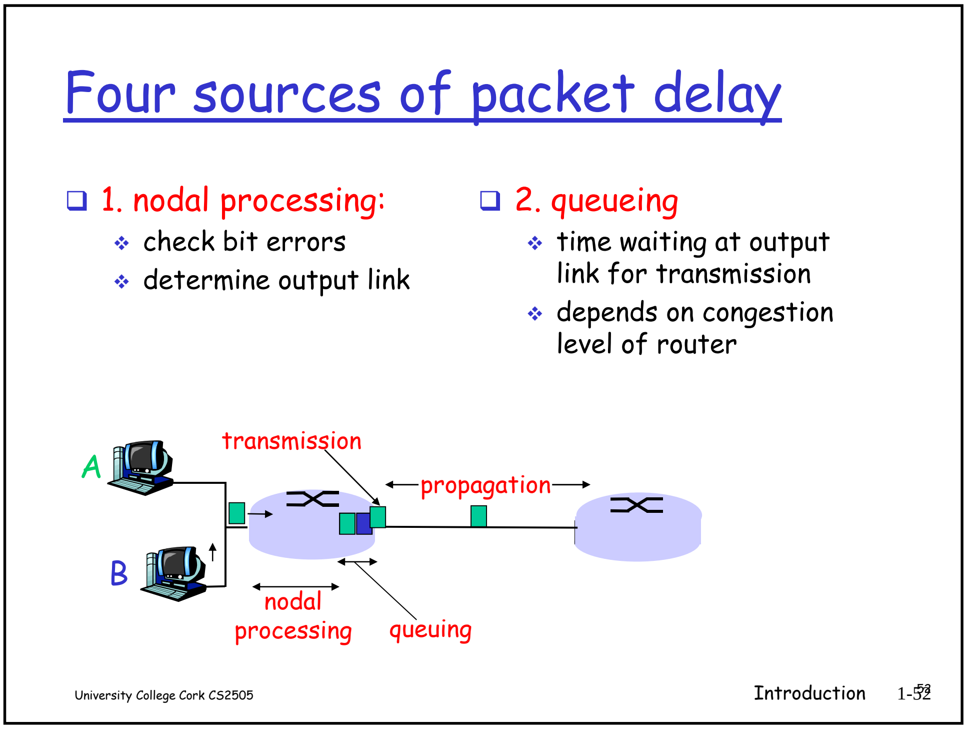
- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn

packet being transmitted (delay)



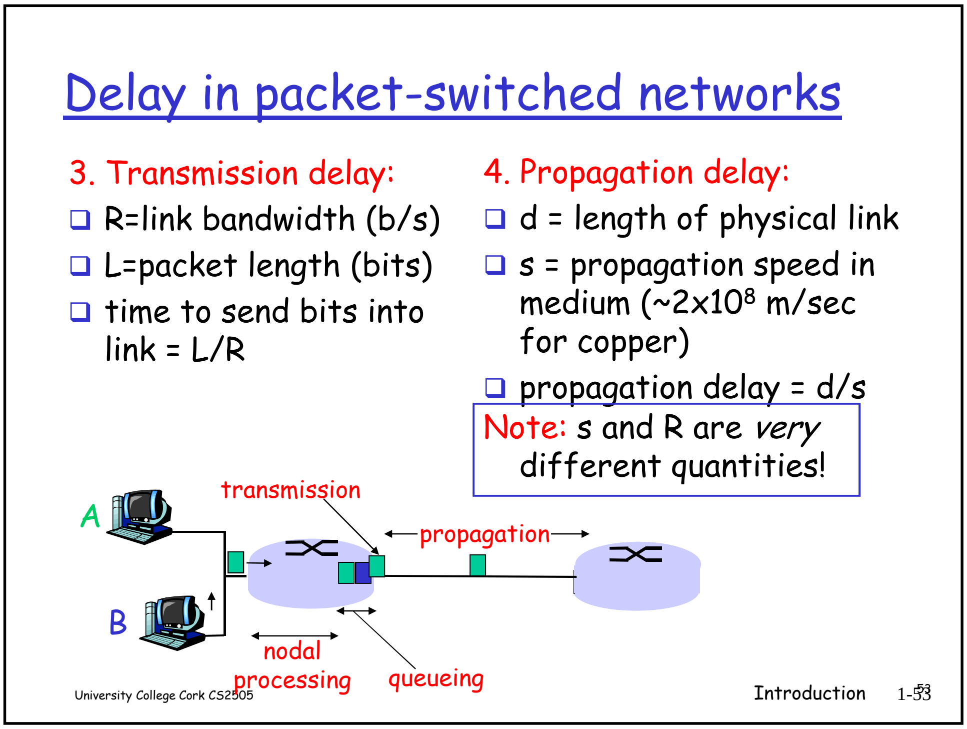
packets queueing (delay)

free (available) buffers: arriving packets dropped (loss) if no free buffers



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:

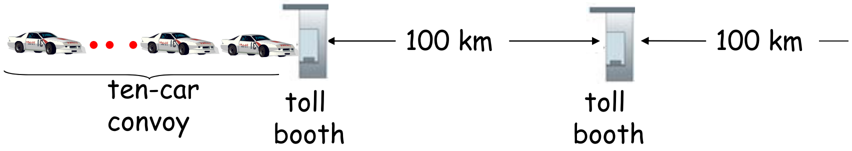
- ❑ R=link bandwidth (b/s)
- ❑ L=packet length (bits)
- ❑ time to send bits into link = L/R

4. Propagation delay:

- ❑ d = length of physical link
- ❑ s = propagation speed in medium (~2x10^8 m/sec for copper)
- ❑ propagation delay = d/s

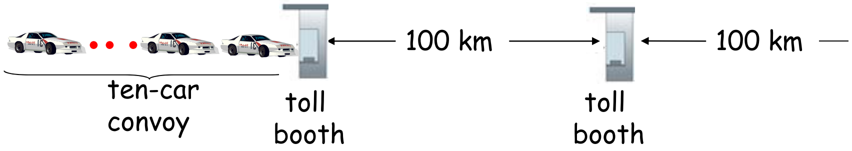
Note: s and R are *very* different quantities!

Vehicle analogy

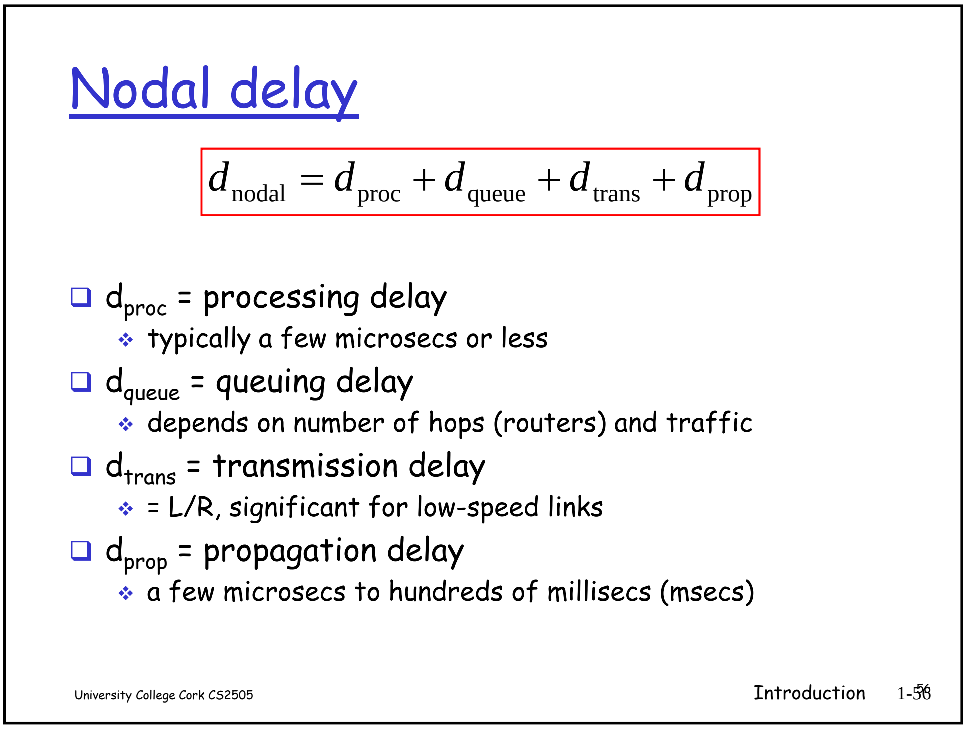


- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (transmission time)
- car~bit; convoy~packet
- Q: How long until cars are lined up before 2nd toll booth?
- Time to "push" all cars through toll booth onto highway = 12*10 = 120 sec
- Time for last car to propagate from 1st to 2nd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

Vehicle analogy (more)



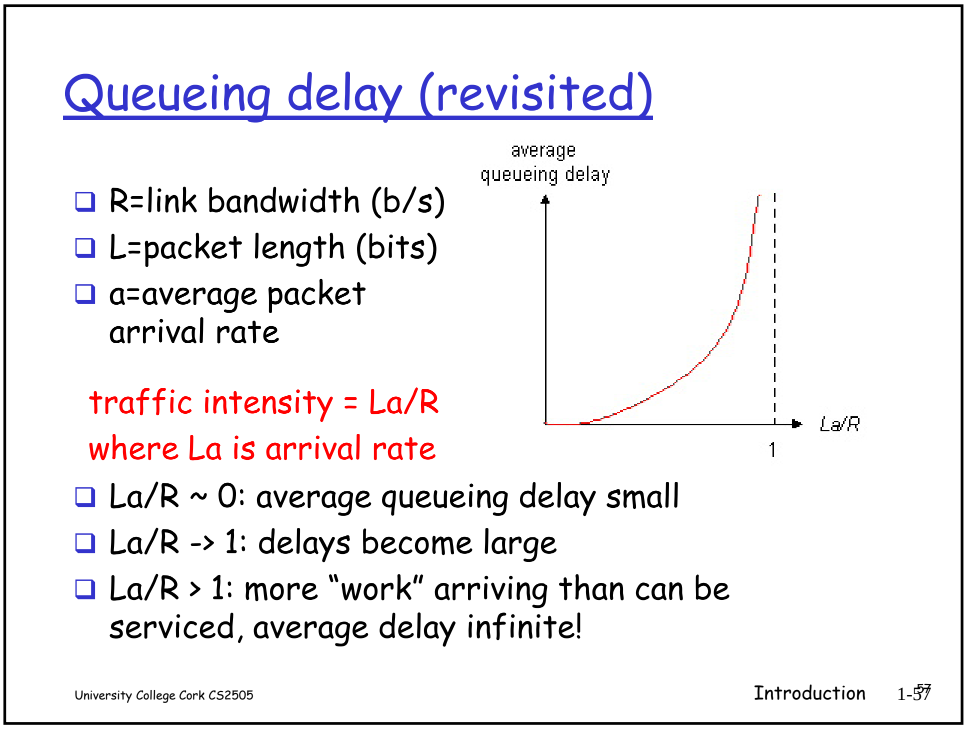
- Cars now "propagate" at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?
- Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!
  - See Ethernet applet at AWL Web site



Nodal delay

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

- ❑ d_{proc} = processing delay
  - ❖ typically a few microsecs or less
- ❑ d_{queue} = queuing delay
  - ❖ depends on number of hops (routers) and traffic
- ❑ d_{trans} = transmission delay
  - ❖ = L/R, significant for low-speed links
- ❑ d_{prop} = propagation delay
  - ❖ a few microsecs to hundreds of millisecs (msecs)



Queueing delay (revisited)

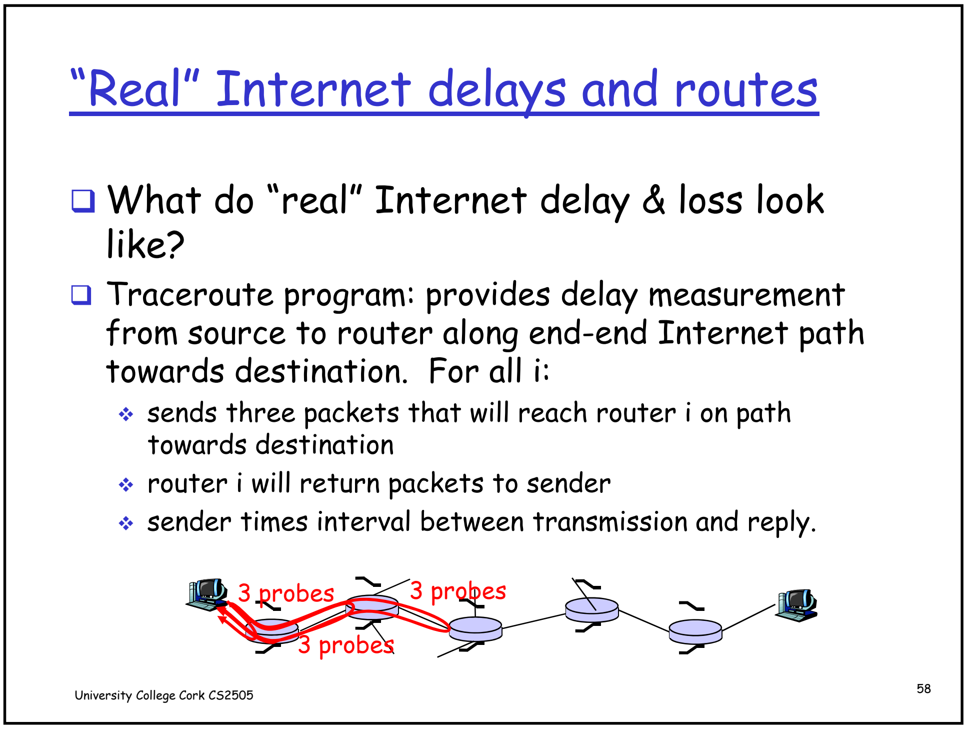
- ❑ R=link bandwidth (b/s)
- ❑ L=packet length (bits)
- ❑ a=average packet arrival rate

average queueing delay
La/R
1

traffic intensity = La/R

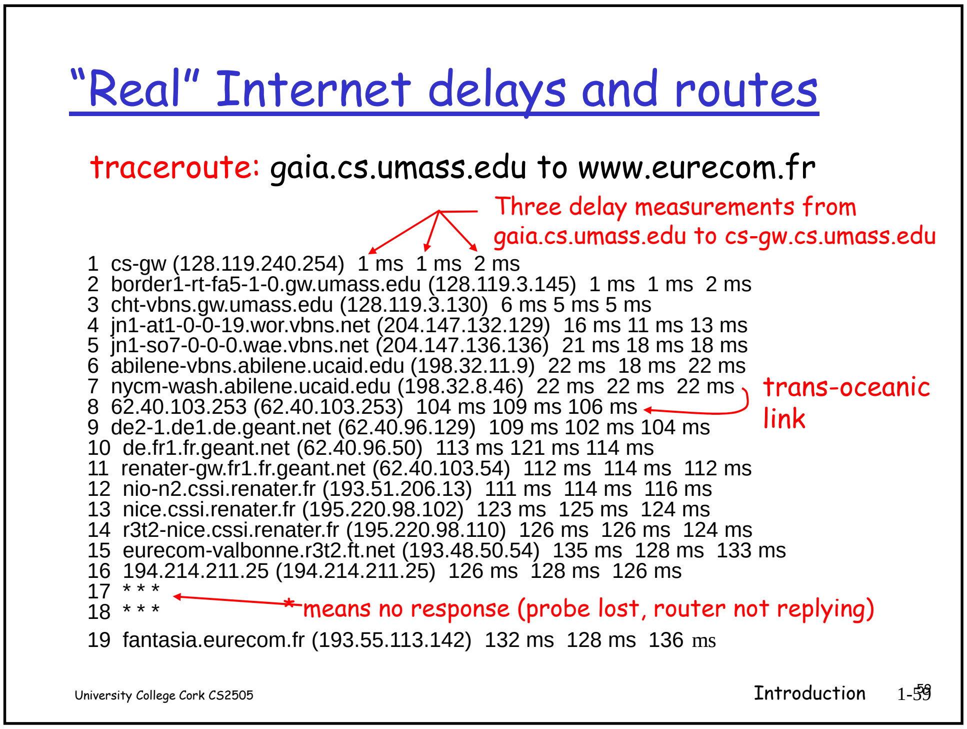
where La is arrival rate

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



“Real” Internet delays and routes

- 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 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

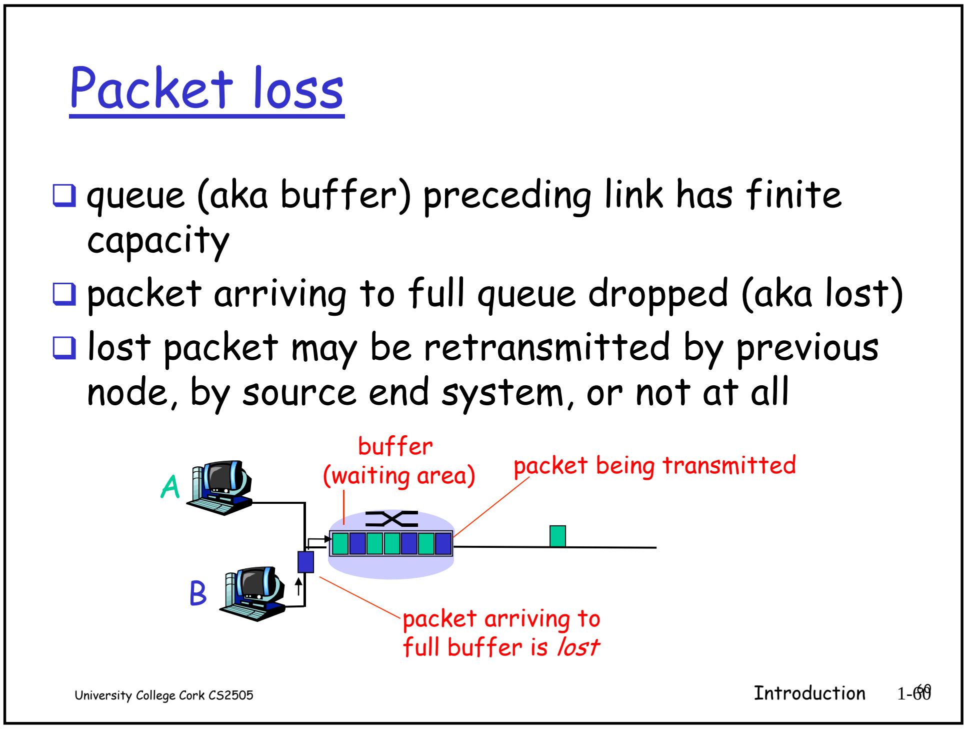
traceroute: gaia.cs.umass.edu to www.eurecom.fr

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)



Packet loss

- queue (aka buffer) preceding link 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

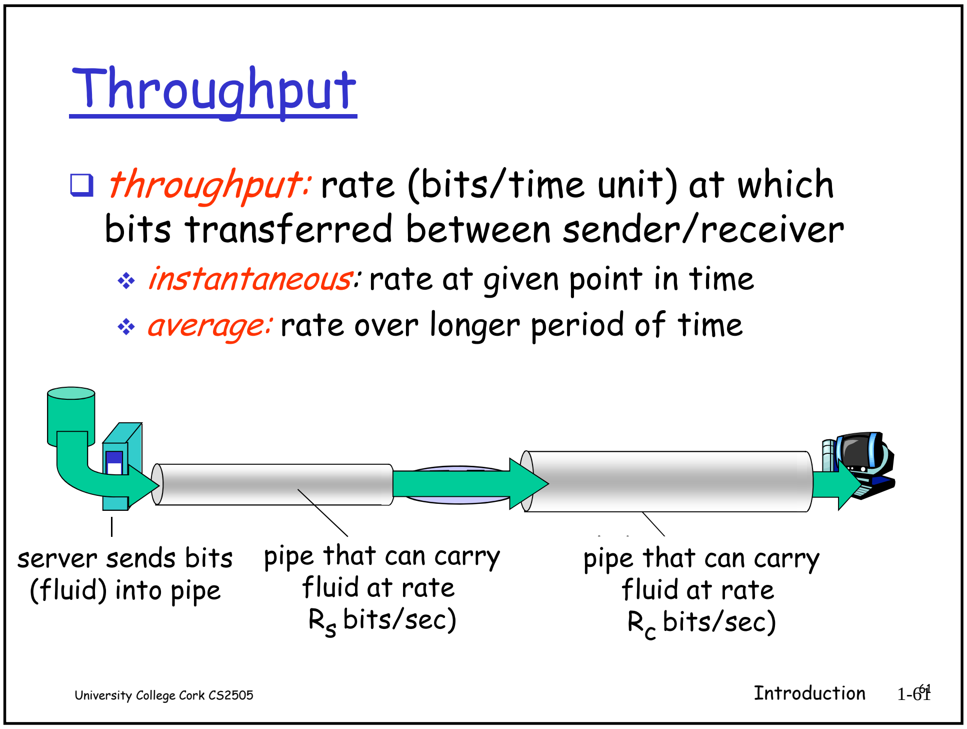
A

B

buffer (waiting area)

packet being transmitted

packet arriving to full buffer is *lost*



Throughput

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

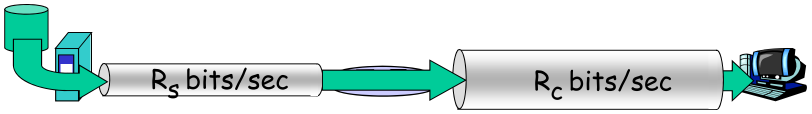
server sends bits (fluid) into pipe

pipe that can carry fluid at rate R_s bits/sec)

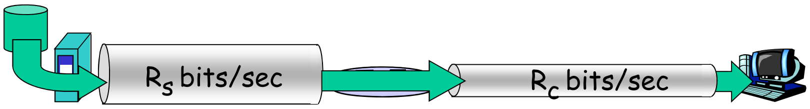
pipe that can carry fluid at rate R_c bits/sec)

Throughput (more)

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



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

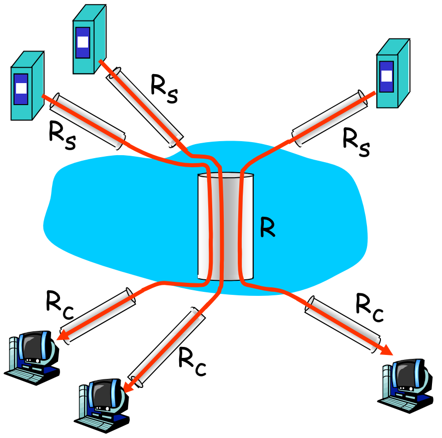


bottleneck link

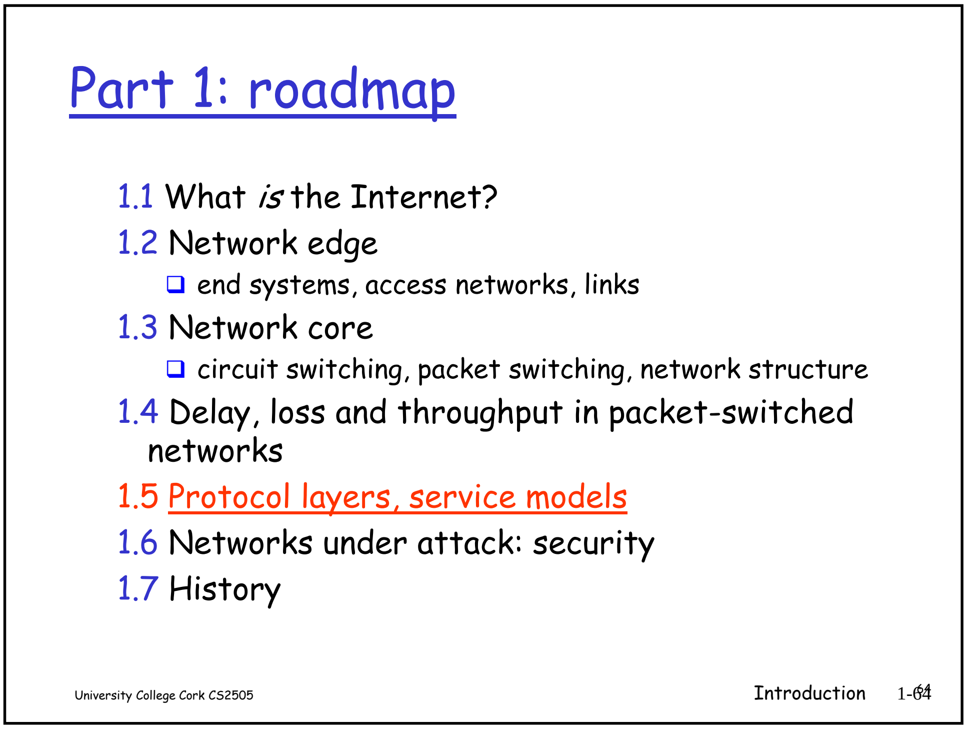
link on end-end path that constrains end-end throughput

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



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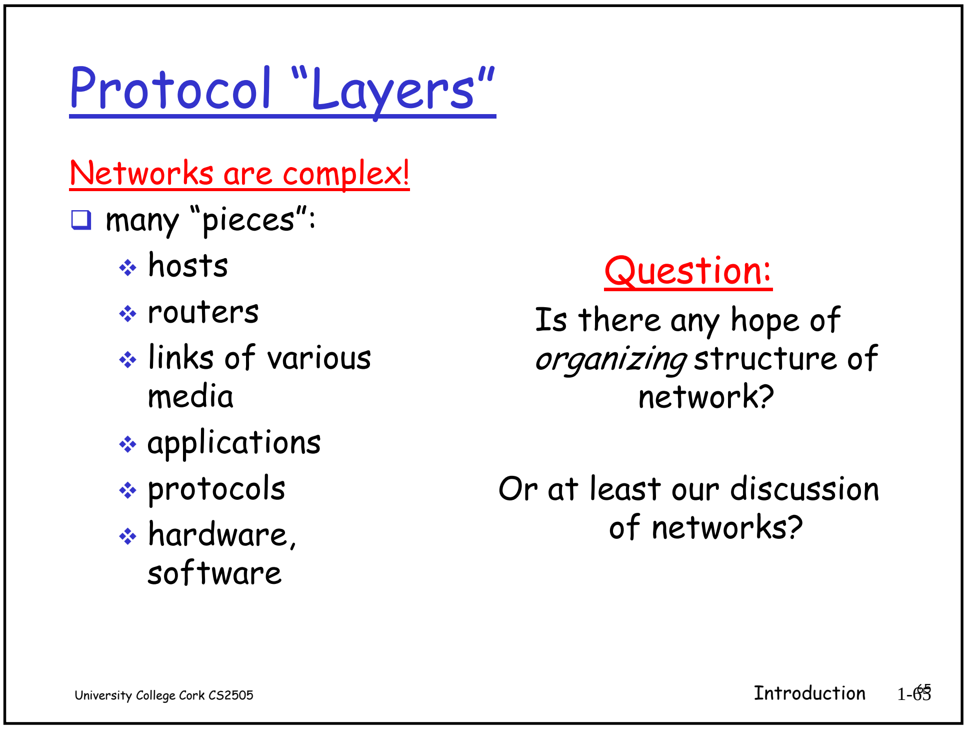


Protocol "Layers"

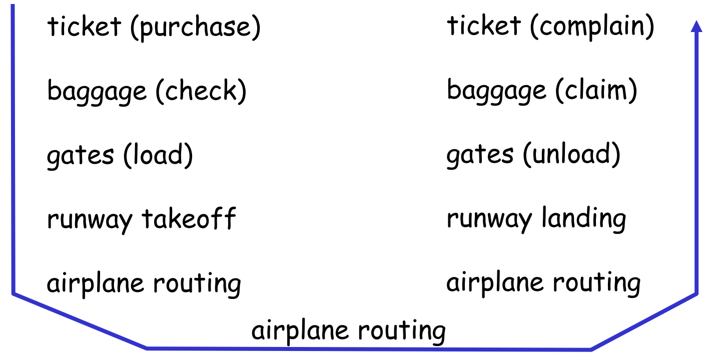
Networks are complex!
- many "pieces":
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

Question:

Is there any hope of *organizing* structure of network?

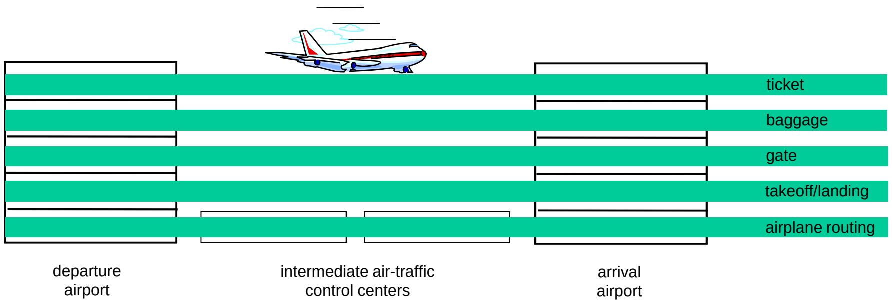
Or at least our discussion of networks?

Organization of air travel



- ❑ 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

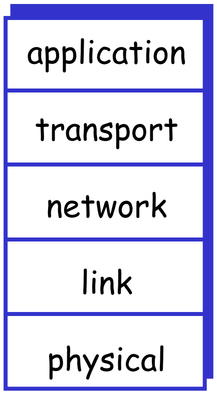
Why layering?

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
- layering considered harmful?

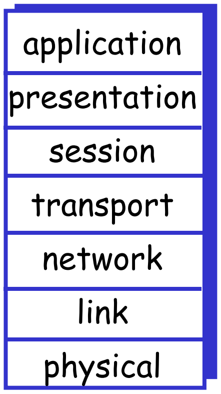
Internet protocol stack

- application: supporting network applications
  - FTP, SMTP, HTTP
- transport: process-process 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"

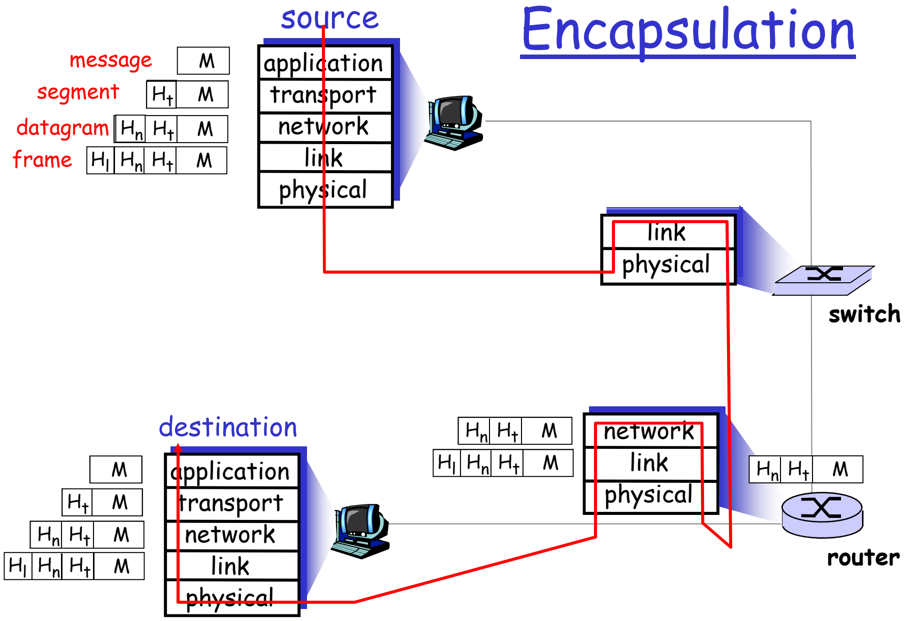


ISO/OSI reference model

- presentation: allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed,* must be implemented in application
  - needed?



Encapsulation



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Network Security

- ❑ The field of network security is about:
  - ❖ how bad guys can attack computer networks
  - ❖ how we can defend networks against attacks
  - ❖ how to design architectures that are immune to attacks
- ❑ 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!

Bad guys can put malware into hosts via Internet

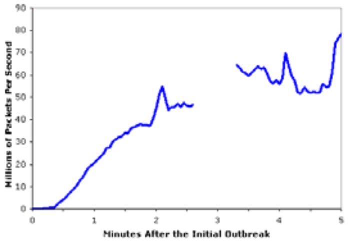
- ❑ Malware can get in host from a virus, worm, or trojan horse.
- ❑ Spyware malware can record keystrokes, web sites visited, upload info to collection site.
- ❑ Infected host can be enrolled in a botnet, used for spam and DDoS attacks.
- ❑ Malware is often self-replicating: from an infected host, seeks entry into other hosts

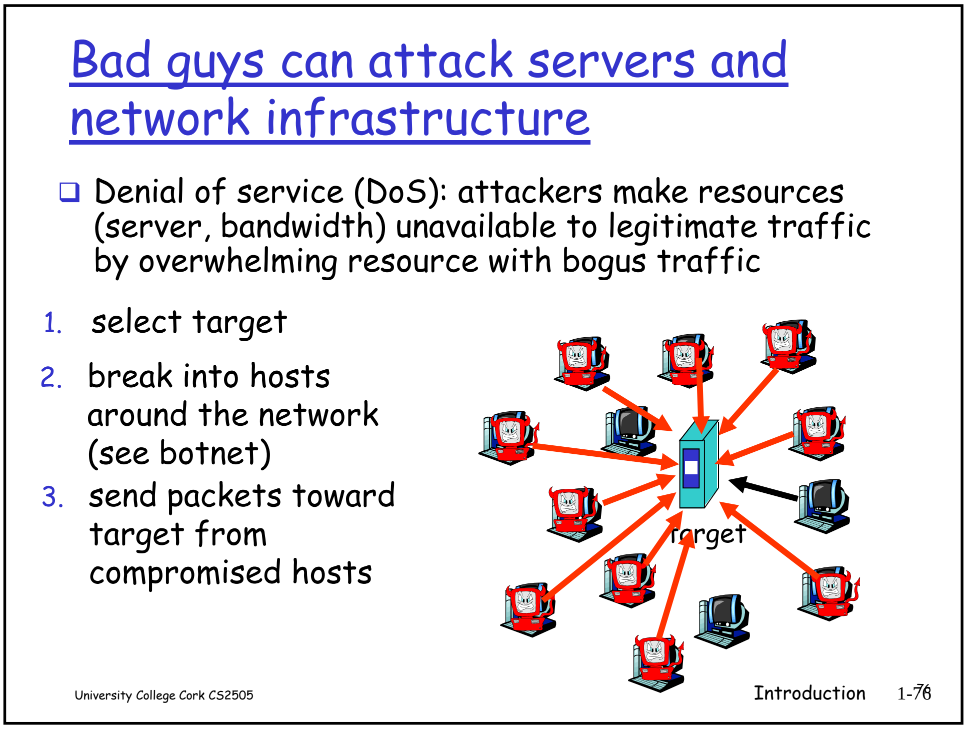
Bad guys can put malware into hosts via Internet

- ❑ Trojan horse
  - ❖ Hidden part of some otherwise useful software
  - ❖ Today often on a Web page (Active-X, plugin)
- ❑ Virus
  - ❖ infection by receiving object (e.g., e-mail attachment), actively executing
  - ❖ self-replicating: propagate itself to other hosts, users

- ❑ Worm:
  - ❖ infection by passively receiving object that gets itself executed
  - ❖ self- replicating: propagates to other hosts, users

Sapphire Worm: aggregate scans/sec
in first 5 minutes of outbreak (CAIDA, UWisc data)

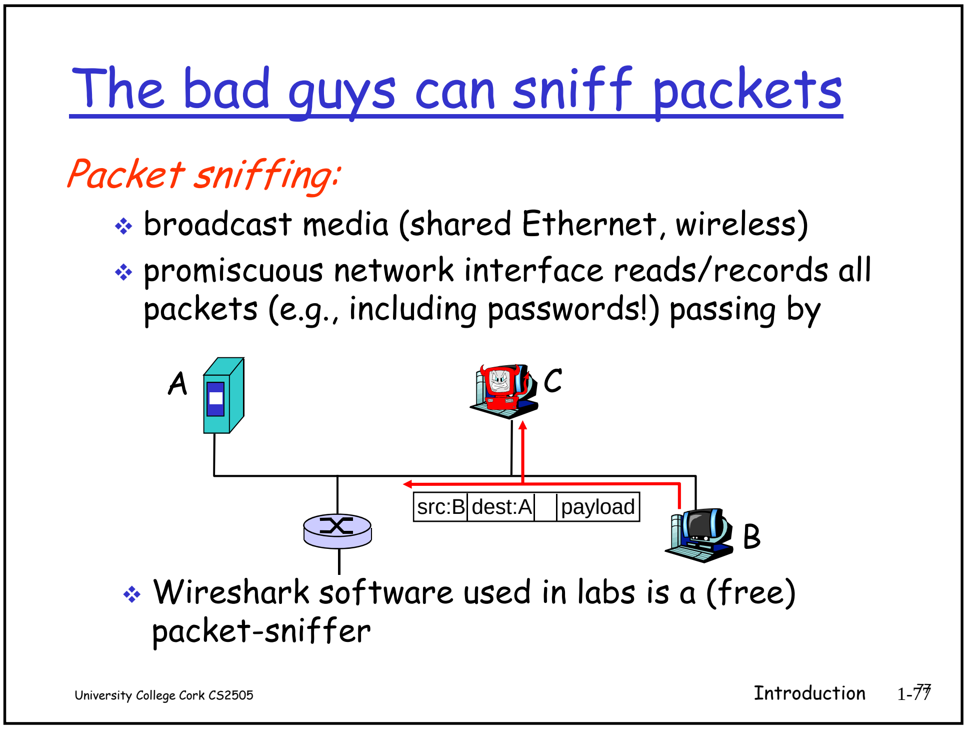




Bad guys can attack servers and network infrastructure

- ❑ Denial of service (DoS): attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

1. select target
2. break into hosts around the network (see botnet)
3. send packets toward target from compromised hosts



The bad guys can sniff packets

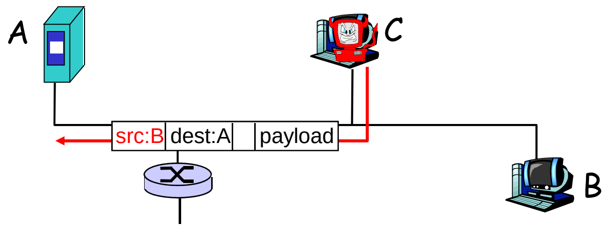
Packet sniffing:

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

- Wireshark software used in labs is a (free) packet-sniffer

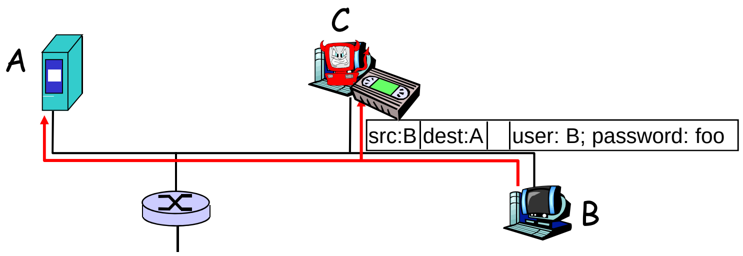
The bad guys can use false source addresses

- *IP spoofing:* send packet with false source address



The bad guys can record and playback

- *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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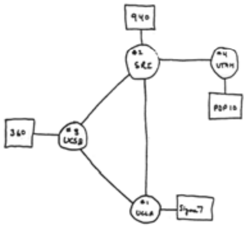
Internet History

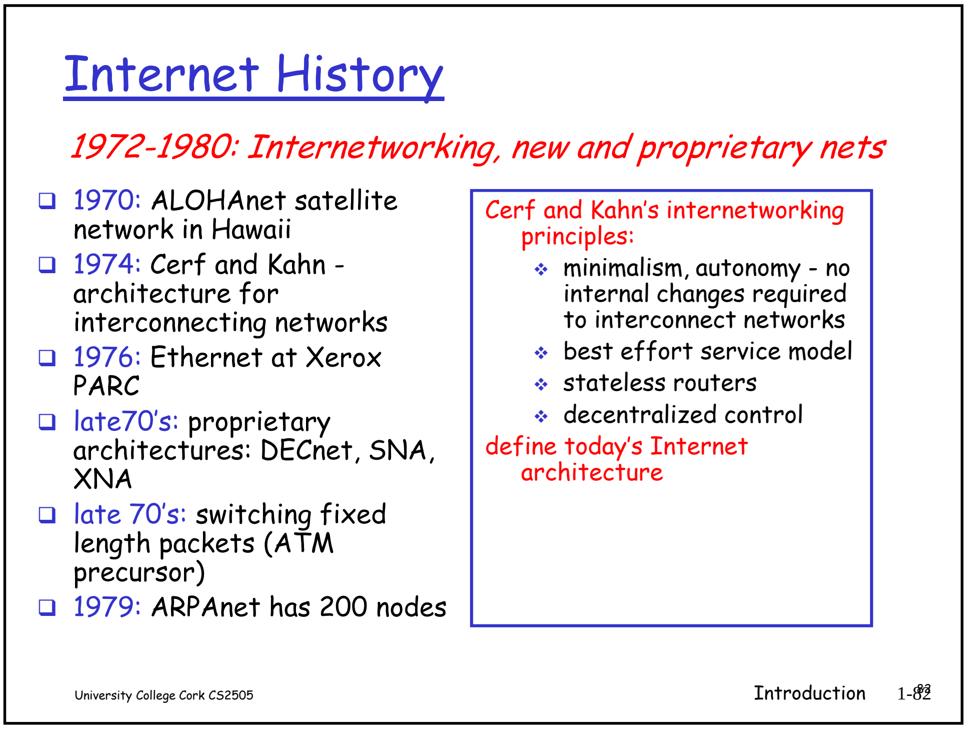
1961-1972: Early packet-switching principles

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



THE ARPA NETWORK



Internet History

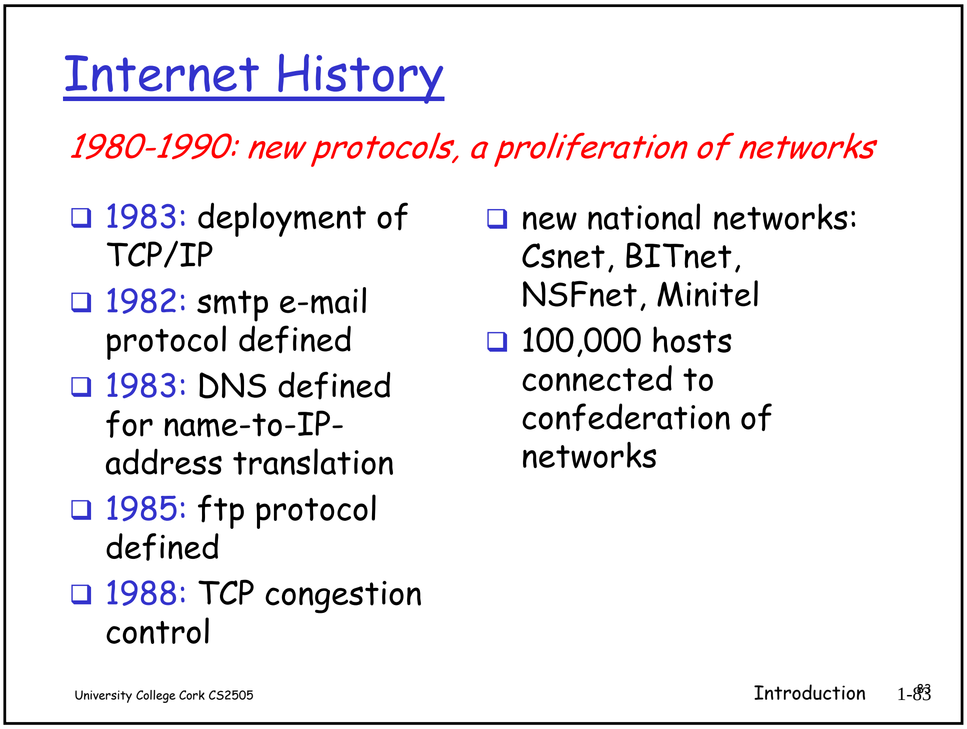
1972-1980: Internetworking, new and proprietary nets

- ❑ 1970: ALOHAnet satellite network in Hawaii
- ❑ 1974: Cerf and Kahn - architecture for interconnecting networks
- ❑ 1976: Ethernet at Xerox PARC
- ❑ 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

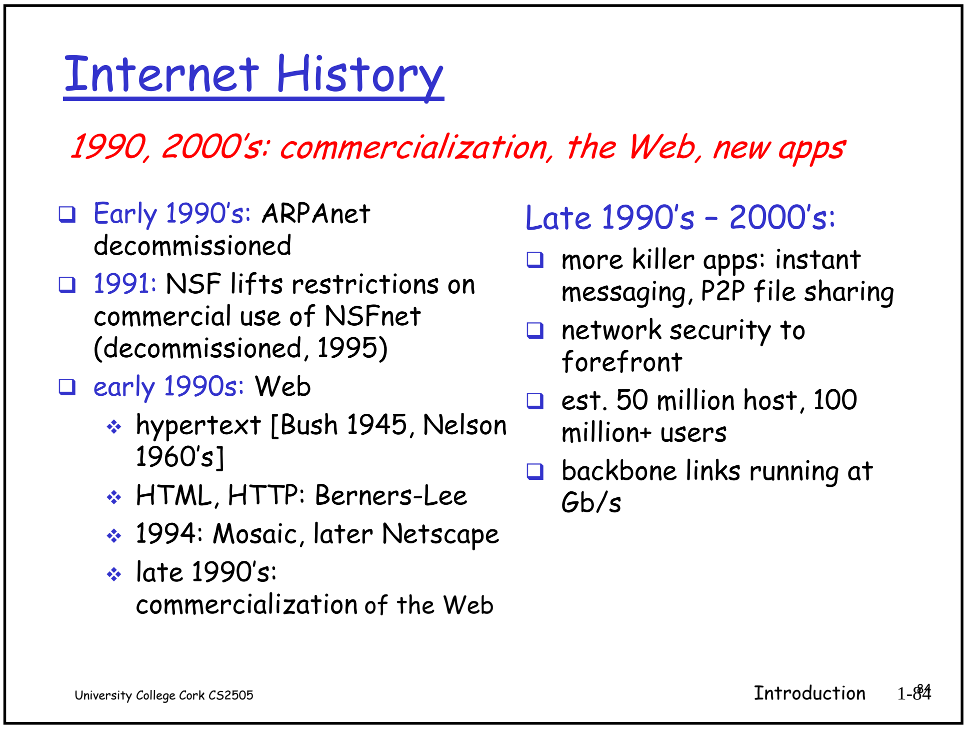
define today's Internet architecture



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



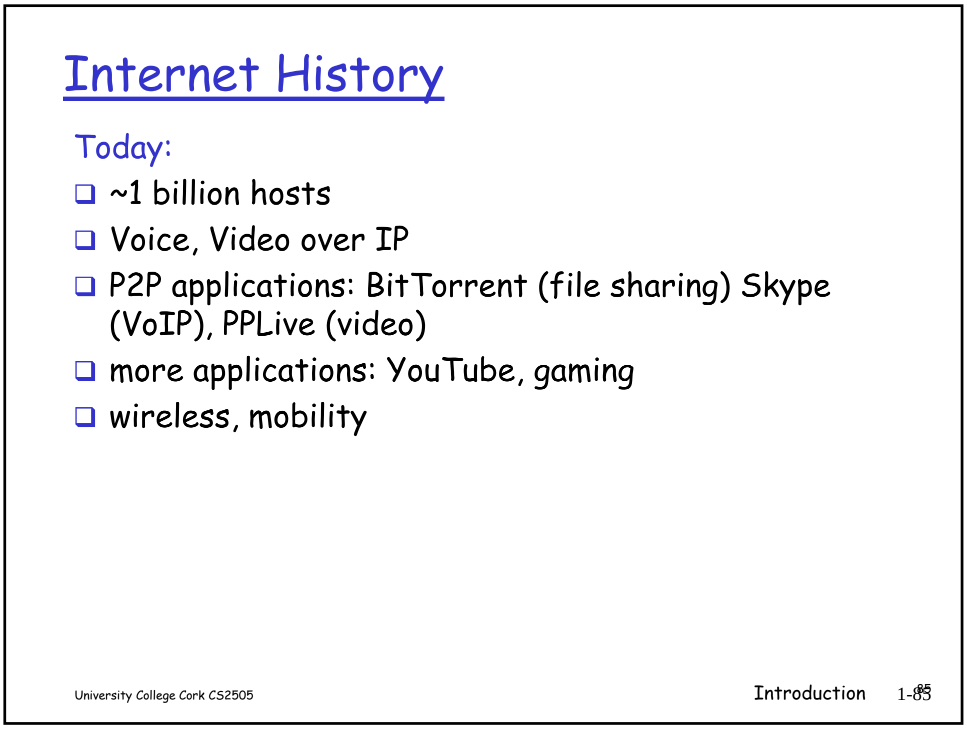
Internet History

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, P2P file sharing
- ❑ network security to forefront
- ❑ est. 50 million host, 100 million+ users
- ❑ backbone links running at Gb/s

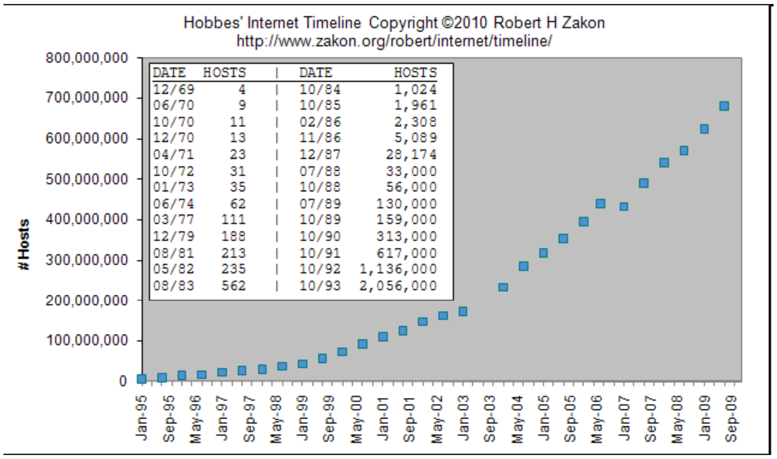


Internet History

Today:

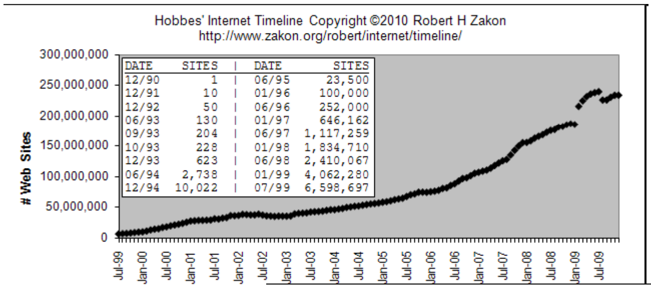
- ❑ ~1 billion hosts
- ❑ Voice, Video over IP
- ❑ P2P applications: BitTorrent (file sharing) Skype (VoIP), PPLive (video)
- ❑ more applications: YouTube, gaming
- ❑ wireless, mobility

Internet Statistics



DATE	HOSTS	DATE	HOSTS
12/69	4	10/84	1,024
06/70	9	10/85	1,961
10/70	11	02/86	2,308
12/70	13	11/86	5,089
04/71	23	12/87	28,174
10/72	31	07/88	33,000
01/73	35	10/88	56,000
06/74	62	07/89	130,000
03/77	111	10/89	159,000
12/79	188	10/90	313,000
08/81	213	10/91	617,000
05/82	235	10/92	1,136,000
08/83	562	10/93	2,056,000

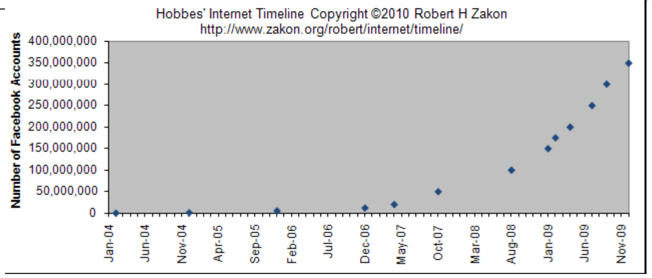
Internet Statistics

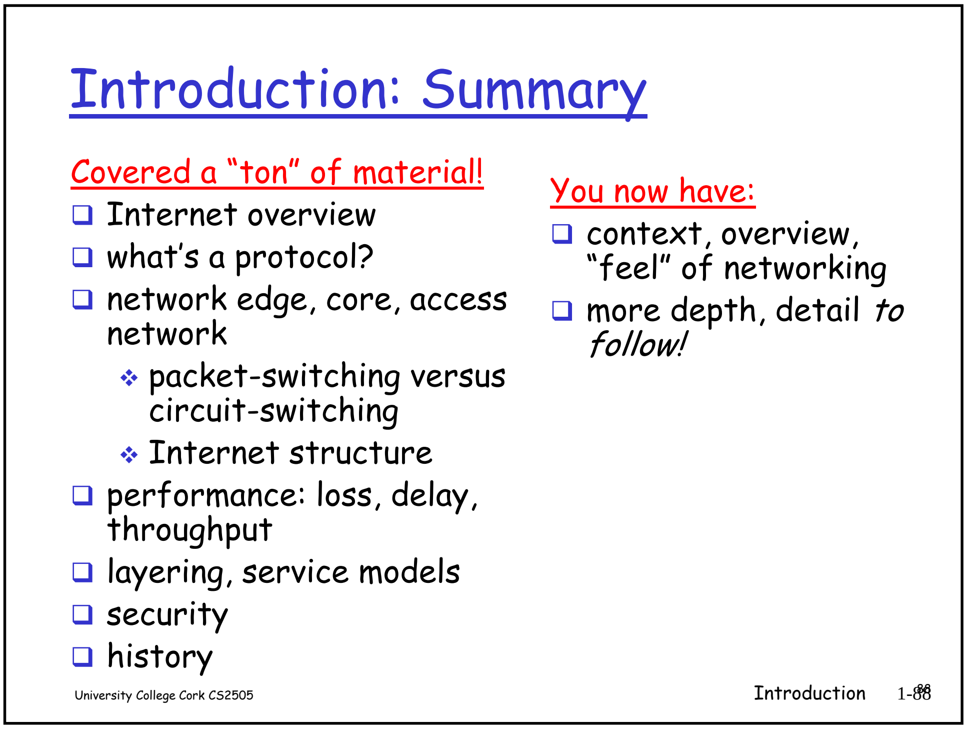


DATE	SITES	DATE	SITES
12/90	1	06/95	23,500
12/91	10	01/96	100,000
12/92	50	06/96	252,000
06/93	130	01/97	646,162
09/93	204	06/97	1,117,259
10/93	228	01/98	1,834,710
12/93	623	06/98	2,410,067
06/94	2,738	01/99	4,062,280
12/94	10,022	07/99	6,598,697

www

facebook





Introduction: Summary

Covered a "ton" of material!

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

You now have:

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