Chapter 1: roadmap

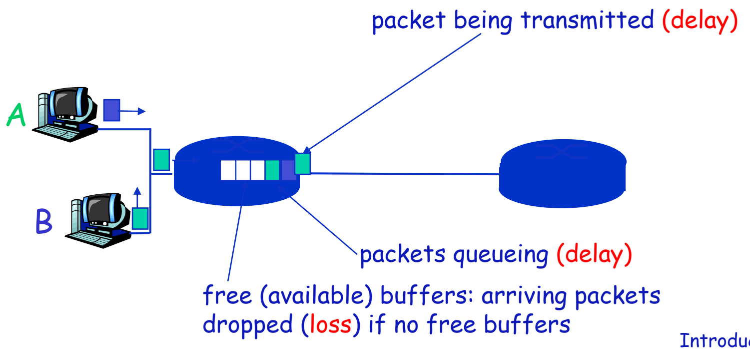
1.1 What **is** the Internet?
1.2 Network edge
- end systems, access networks, links

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

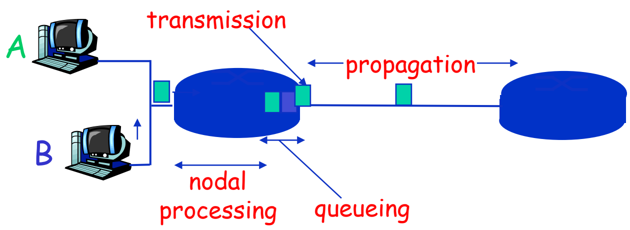
How do loss and delay occur?

packets **queue** in router buffers
- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn



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

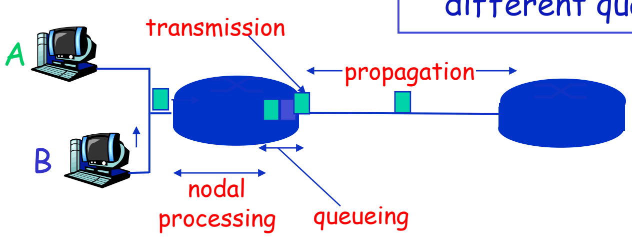
3. Transmission delay:

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

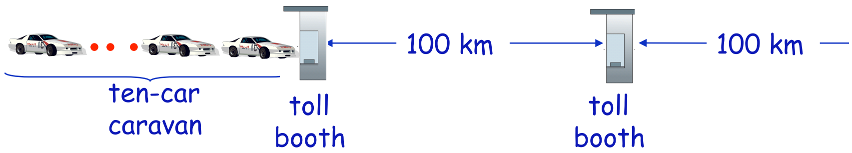
4. Propagation delay:

- 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!

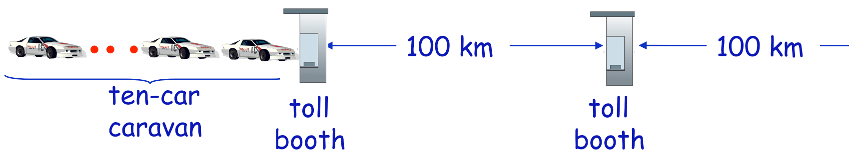


Caravan analogy



- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service 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

Let's analyze it!

- http://media.pearsoncmg.com/aw/aw_kurose_network_2/applets/transmission/delay.html

Nodal delay

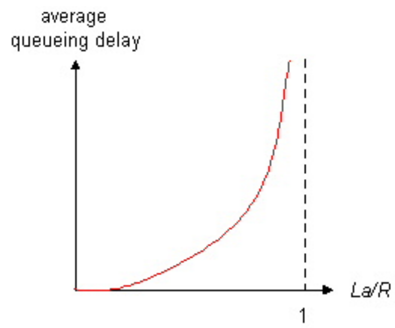
$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

- 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

Queueing delay (revisited)

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

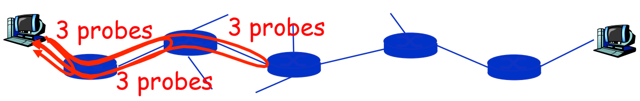
traffic intensity = La/R



- 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

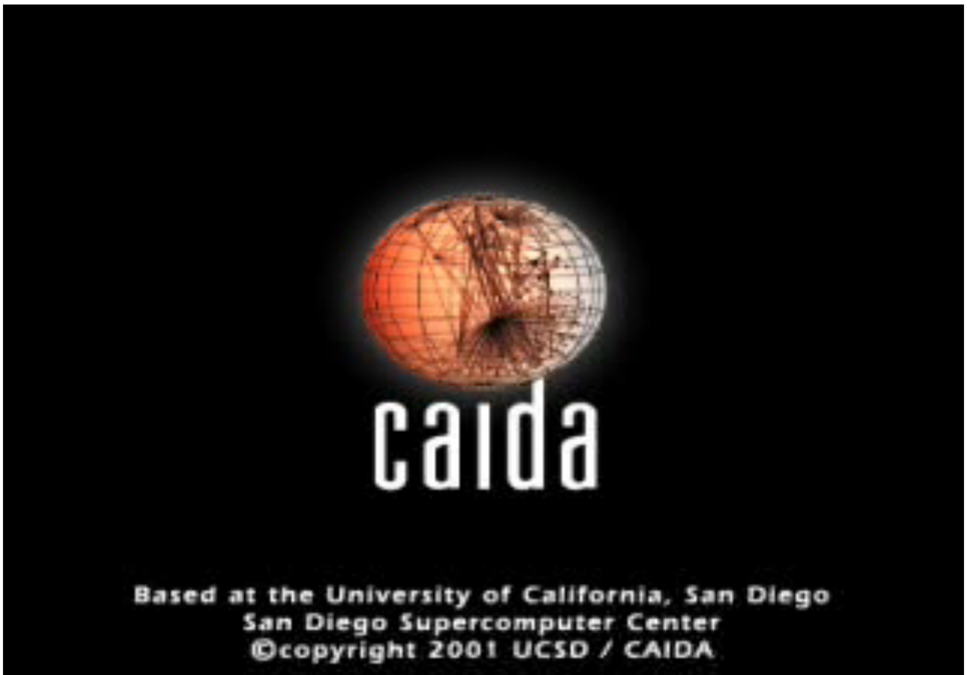
traceroute: gaia.cs.umass.edu to www.eurecom.fr

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 (hop 8)

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



traceroute experiments

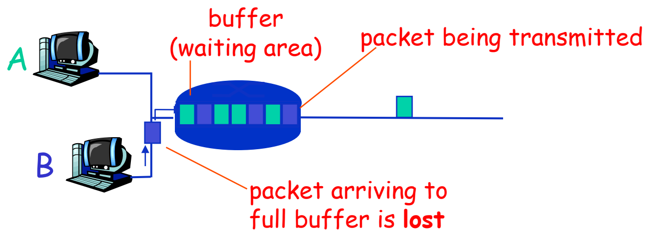
- ...let's try it!
  - starting at your local host...
  - finding an http accessible mirror...
  - trying to find ISP connections...

SUBMIT RESULTS (via elearning platform)

- Using (several) external servers, find out routes to **polo.uminho.pt** (from different continents and places!). **Comment & Submit**
  - http://mirror.sptel.com.au/cgi-bin/trace
  - http://centralops.net/co/
  - http://whatismyipaddress.com/
  - http://visualroute.visualware.com/
  - http://www.yougetsignal.com/tools/visual-tracert/

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

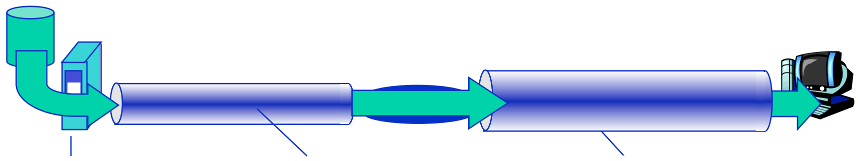


Packet loss

- Let's try it out...
- http://media.pearsoncmg.com/aw/aw_kurose_network_2/applets/queuing/queuing.html
- ... submit your summary analysis via elearning platform!

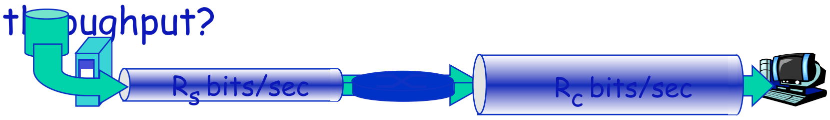
Throughput

- **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

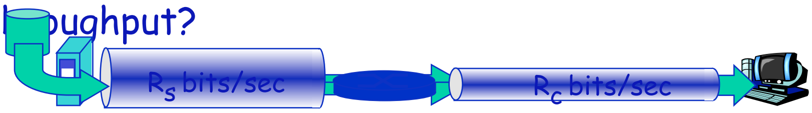


Throughput (more)

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



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

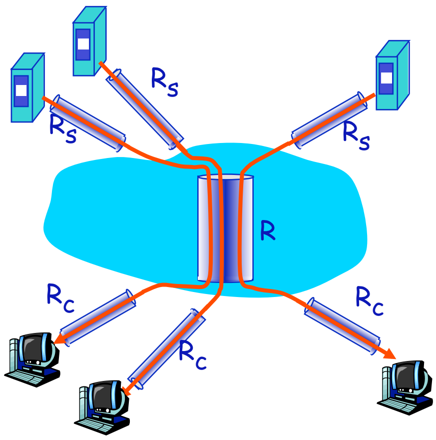


bottleneck link

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

Problems to solve...

- In the following problems, we are sending a **30 Mbit** MP3 file from a source host to a destination host. **All links** in the path between source and destination **have a transmission rate of 10 Mbps**. Assume that the **propagation speed** is **2 * 10^8 m/sec**, and the **distance** between **source** and **destination** is **10,000 km**.

Problems to solve…

- In the following problems, we are sending a 30 Mbit MP3 file from a source host to a destination host. All links in the path between source and destination have a transmission rate of 10 Mbps. Assume that the propagation speed is 2 * 10^8 meters/sec, and the distance between source and destination is 10,000 km.

1 Initially suppose there is only one link between source and destination. Also suppose that the entire MP3 file is sent as one packet. The transmission delay is:
- 3.05 seconds
- 3 seconds ←
- 50 milliseconds
- none of the above.

Problems to solve…

2 Referring to the above question, the end-to-end delay (transmission delay plus propagation delay) is
- 3.05 seconds ←
- 3 seconds
- 6 seconds
- none of the above

3 Referring to the above question, how many bits will the source have transmitted when the first bit arrives at the destination.
- 1 bit
- 30,000,000 bits
- 500,000 bits ←
- none of the above

Problems to solve...

4 Now suppose there are two links between source and destination, with one router connecting the two links. Each link is 5,000 km long. Again suppose the MP3 file is sent as one packet. Suppose there is no congestion, so that the packet is transmitted onto the second link as soon as the router receives the entire packet. The end-to-end delay is

- ❑ 3.05 seconds
- ❑ 6.05 seconds
- ❑ 6.1 seconds
- ❑ none of the above

5 Now suppose that the MP3 file is broken into 3 packets, each of 10 Mbits. Ignore headers that may be added to these packets. Also ignore router processing delays. Assuming store and forward packet switching at the router, the total delay is

- ❑ 3.05 seconds
- ❑ 4.05 seconds
- ❑ 6.05 seconds
- ❑ none of the above

Problems to solve...

6 Now suppose there is only one link between source and destination, and there are 10 TDM channels in the link. The MP3 file is sent over one of the channels. The end-to-end delay is

- ❑ 30.05 seconds
- ❑ 30 seconds
- ❑ 300 microseconds
- ❑ none of the above

7 Now suppose there is only one link between source and destination, and there are 10 FDM channels in the link. The MP3 file is sent over one of the channels. The end-to-end delay is

- ❑ 30.05 seconds
- ❑ 3 seconds
- ❑ 300 microseconds
- ❑ none of the above

Problems to solve…

8 Suppose there are two links between a source and a destination. The first link has transmission rate 100 Mbps and the second link has transmission rate 10 Mbps. Assuming that the only traffic in the network comes from the source, what is the throughput for a large file transfer?

- 1 Gbps
- 110 Mbps
- 100 Mbps
- 10 Mbps ←

Chapter 1: roadmap

Protocol "Layers"

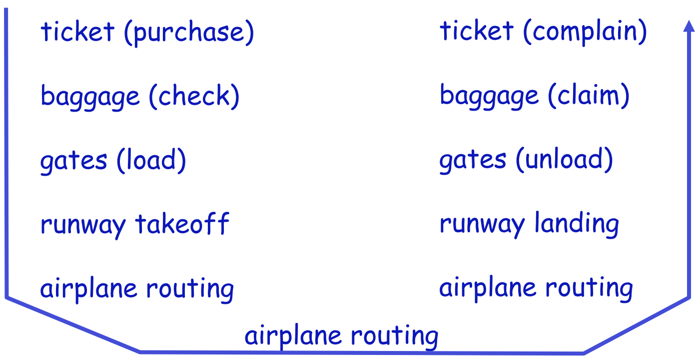
Networks are complex!

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

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

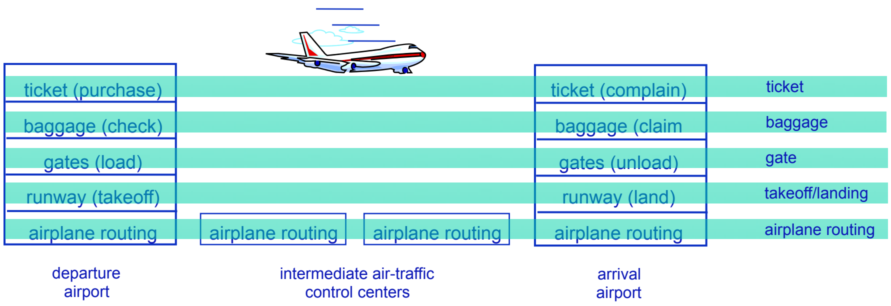
Or at least our discussion of networks?

Organization of air travel



- a series of steps

Layering of airline functionality



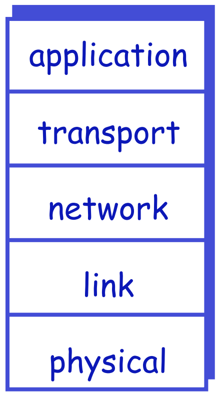
Layers: each layer implements a service
- via its own internal-layer actions
- relying on services provided by layer below

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?

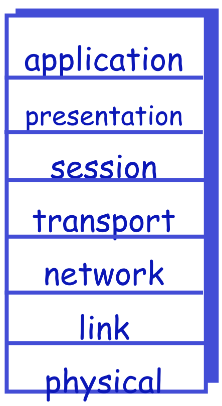
Internet protocol stack

- 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"

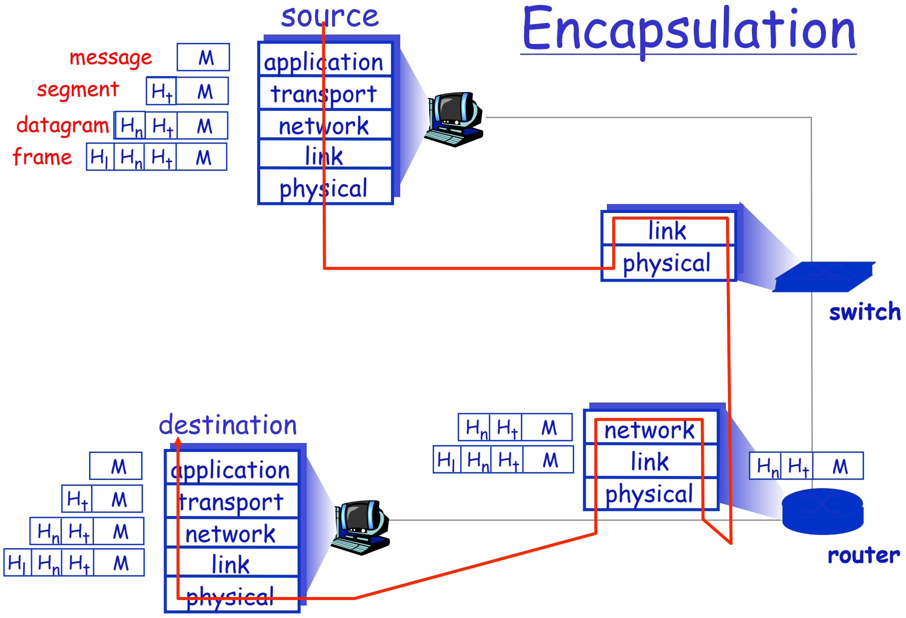


ISO/OSI reference model

- 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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1.6 Networks under attack: security

1.7 History

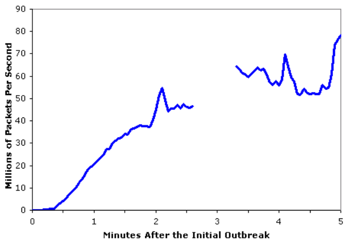
Network Security

- 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?

- Spyware:
  - infection by downloading web page with spyware
  - records keystrokes, web sites visited, upload info to collection site
- 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

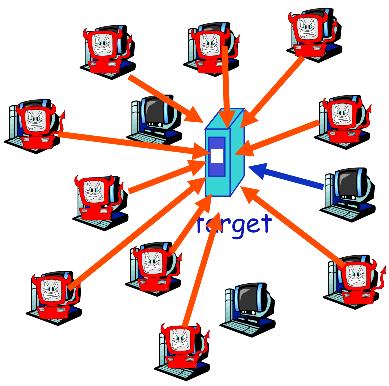
Sapphire Worm: aggregate scans/sec in first 5 minutes of outbreak (CAIDA, UWisc data)



Denial of service attacks

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

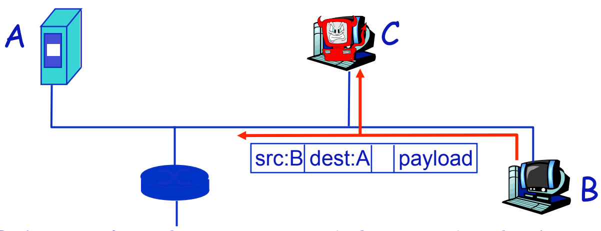
1. select target
2. break into hosts around the network (see malware)
3. send packets toward target from compromised hosts



Sniff, modify, delete your packets

Packet sniffing:

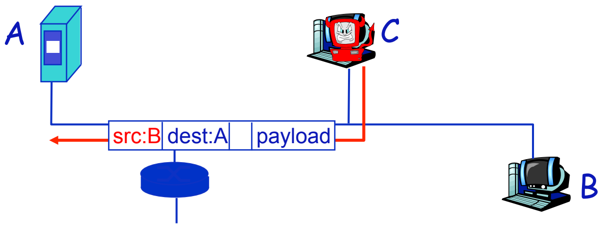
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



- Ethereal software used for end-of-chapter labs is a (free) packet-sniffer
- more on modification, deletion later

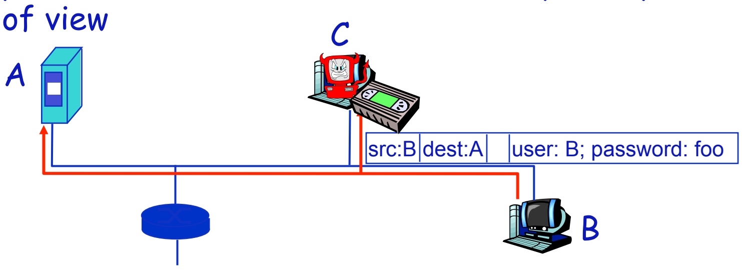
Masquerade as you

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



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



Masquerade as you

- **IP spoofing:** send packet with false source address
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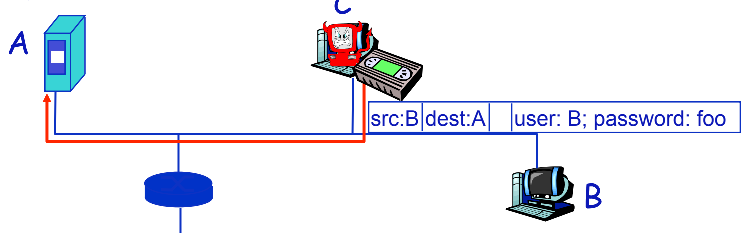
  - password holder **is** that user from system point of view **later** …..



Network Security

- more throughout this course
- chapter 8: focus on security
- crypographic techniques: obvious uses and not so obvious uses

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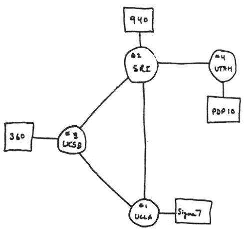
Internet History

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
- 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, 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 Gbps

Internet History

2007:

- ~500 million hosts
- Voice, Video over IP
- P2P applications: BitTorrent (file sharing) Skype (VoIP), PPLive (video)
- more applications: YouTube, gaming
- wireless, mobility

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!**