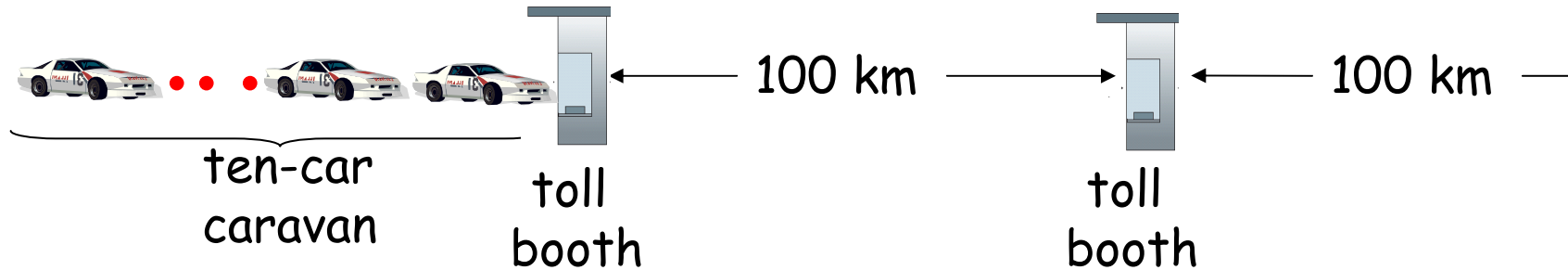


Today

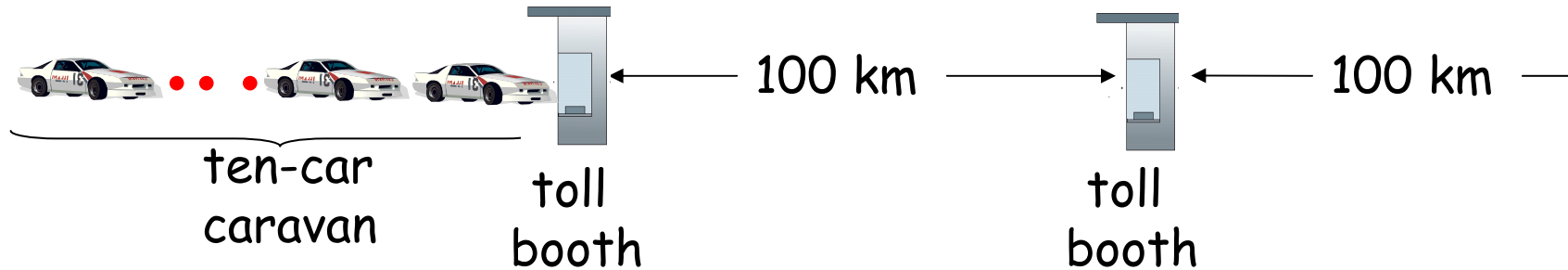
- Finish up 1.4 - performance
- 1.5 - layering
- 1.7 - history (briefly)
- Start Ch. 2 if time

Putting it together: 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 = $12 \times 10 = 120$ sec
- ❑ Time for last car to propagate from 1st to 2nd toll booth: $100\text{km} / (100\text{km/hr}) = 1$ hr
- ❑ **A: 62 minutes**

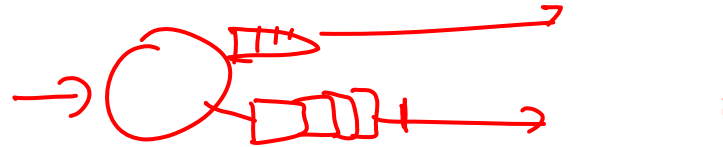
Caravan analogy (more)



- ❑ 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

Nodal delay



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

- 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 microseconds to hundreds of msecs

L - length of packet ^{bits}
 R - transmission rate ^{bits/sec}
 $\frac{\text{bits}}{(\frac{\text{bits}}{\text{sec}})} = \text{sec}$

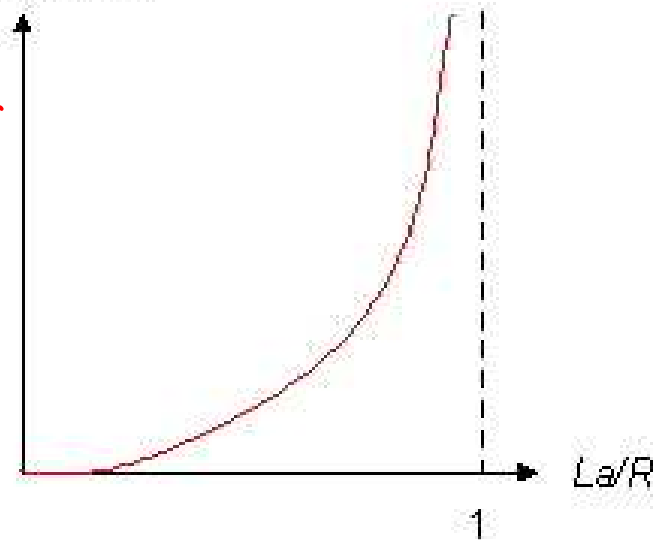
Important

Queueing delay (revisited)

$$\frac{\frac{\text{bits}}{\text{packet}} \cdot \frac{\text{packets}}{\text{sec}}}{\frac{\text{bits}}{\text{sec}}} = 1$$

- R=link bandwidth (bps) *b/s*
- L=packet length (bits) *bits/packet*
- a=average packet arrival rate *bits/sec* *packets/sec*

average queueing delay



traffic intensity = La/R
link utilization

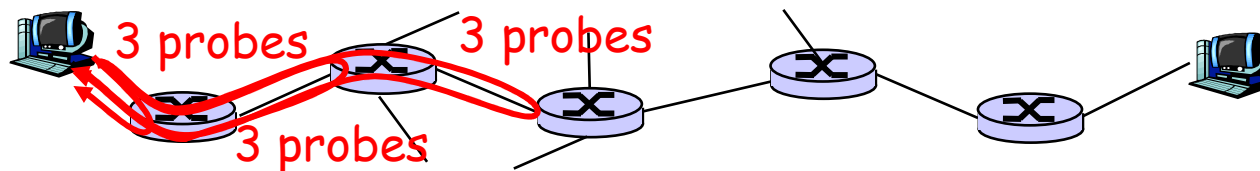
- $La/R \sim 0$: average queueing delay small
- $La/R \rightarrow 1$: delays become large
- $La/R > 1$: more "work" arriving than can be serviced, average delay infinite!
- La/R is the **average offered load** for a link (check the units!)

$La/R < 1$
 $La/R \geq 1$

"Real" Internet delays and routes

tracert

- ❑ 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

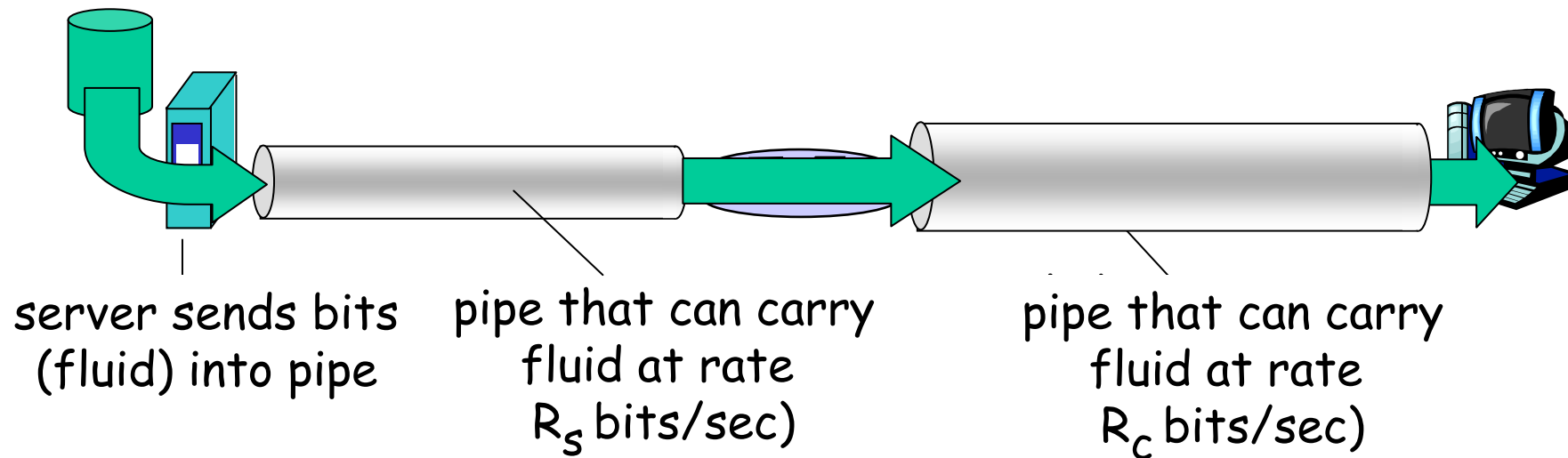
1	cs-gw (128.119.240.254)	1 ms	1 ms	2 ms
2	border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)	1 ms	1 ms	2 ms
3	cht-vbns.gw.umass.edu (128.119.3.130)	6 ms	5 ms	5 ms
4	jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)	16 ms	11 ms	13 ms
5	jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)	21 ms	18 ms	18 ms
6	abilene-vbns.abilene.ucaid.edu (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)

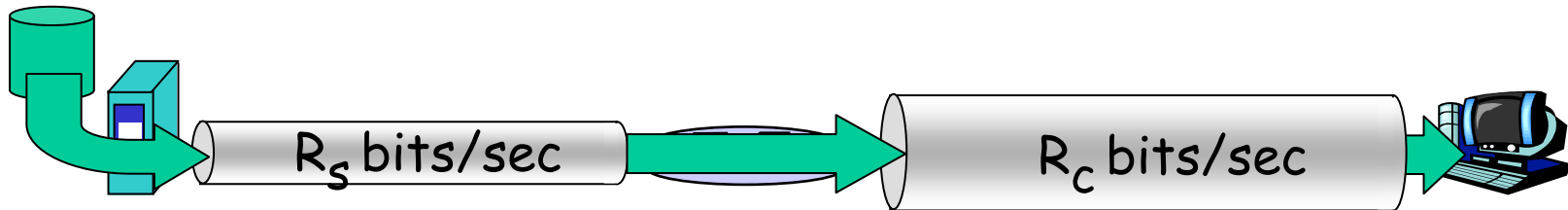
Throughput : measurement of a rate : bandwidth \sim throughput

- *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

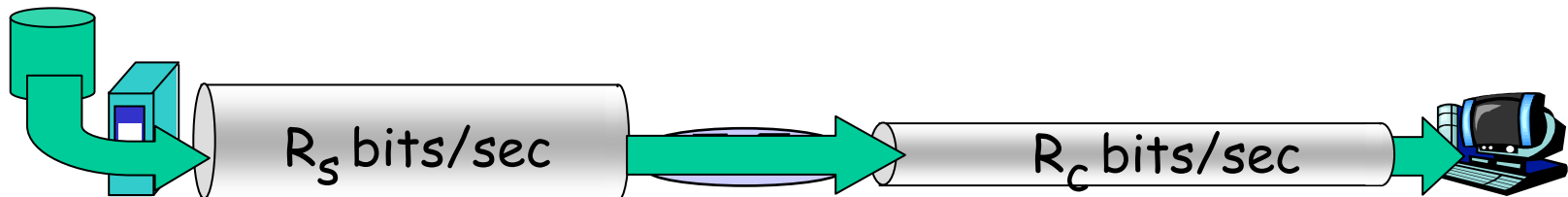


Throughput (more)

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



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

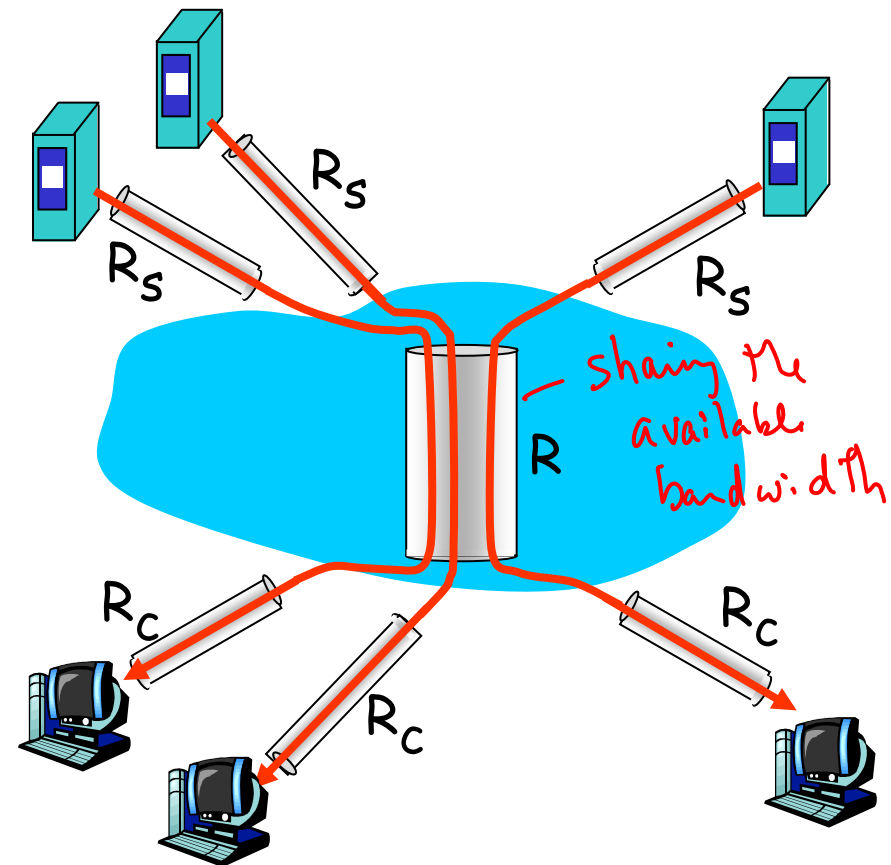


bottleneck link

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

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

Protocol "Layers"

Networks are complex!

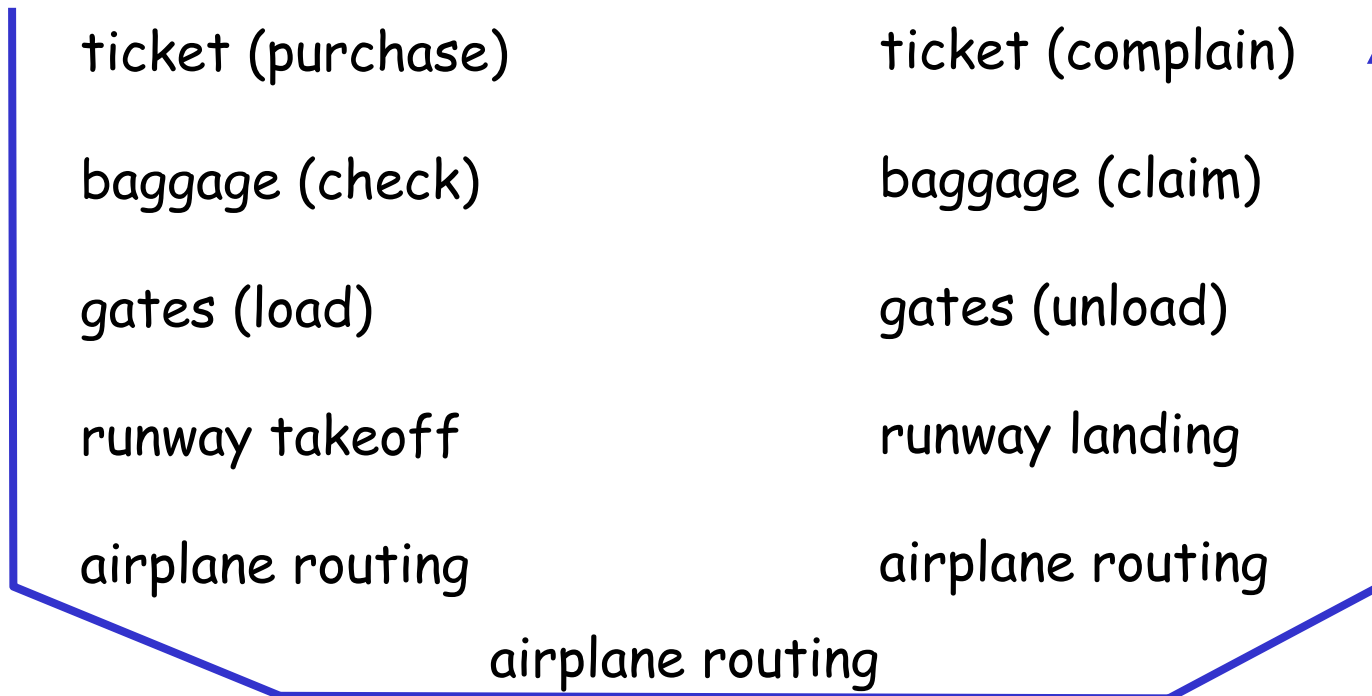
- many "pieces":
 - ❖ hosts
 - ❖ routers
 - ❖ links of various media
 - ❖ applications
 - ❖ protocols
 - ❖ hardware, software

Question:

Is there any hope of
organizing structure of
network?

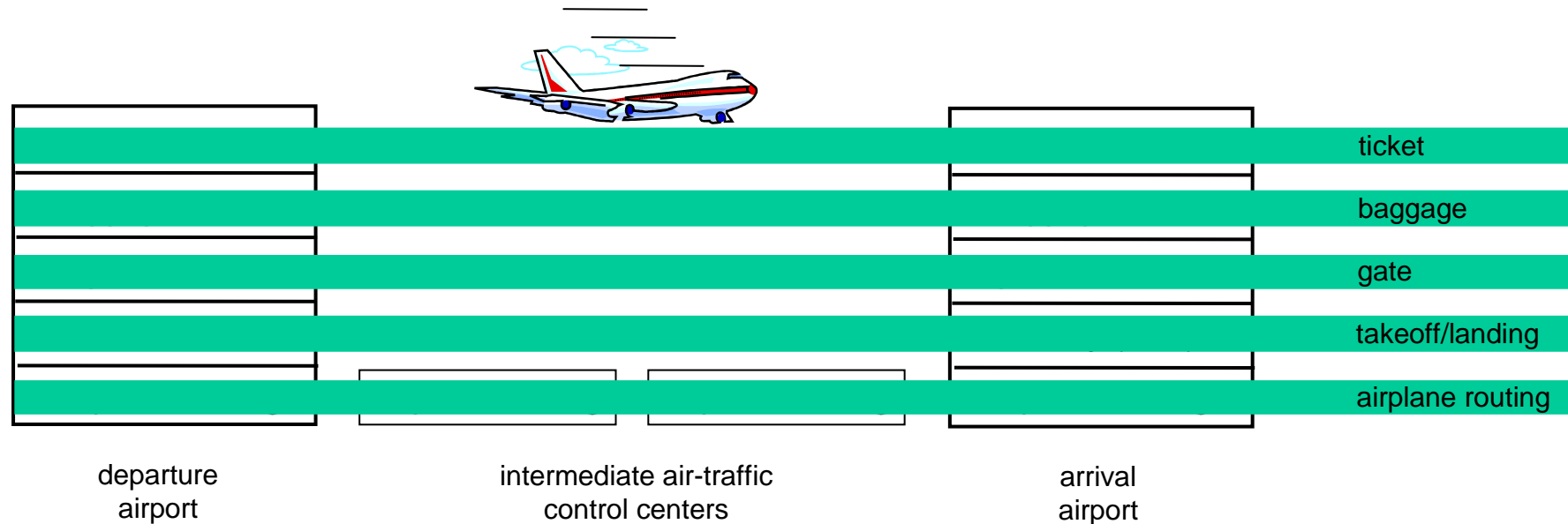
Or at least our discussion
of networks?

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

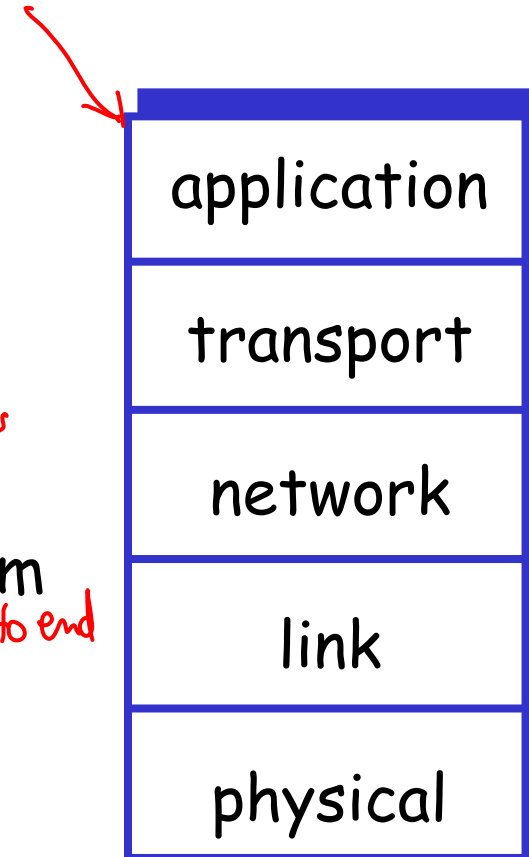
Why layering?

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

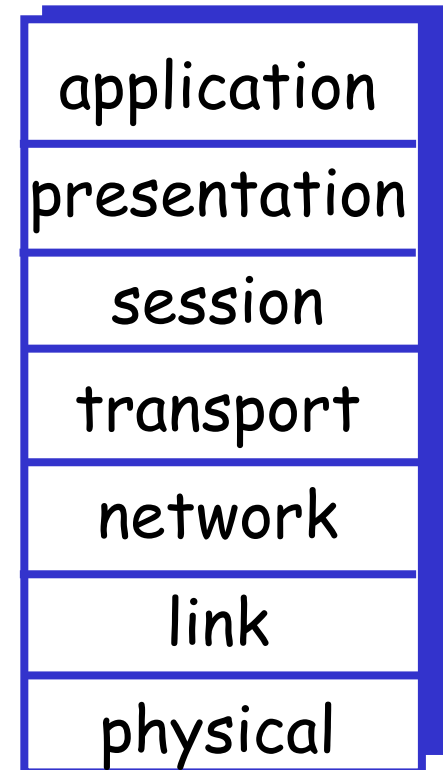
- **application:** supporting network applications
 - ❖ FTP, SMTP, HTTP
- **transport:** process-process data transfer
 - ❖ TCP, UDP
 - reliability*
delivery to particular applications
- **network:** routing of datagrams from source to destination
 - ❖ IP, routing protocols
 - host-to-host* | *end to end*
data transfer
- **link:** data transfer between neighboring network elements
 - ❖ PPP, Ethernet
 - single-hop*
- **physical:** ~~bits~~ "on the wire"
 - electrons or photons*



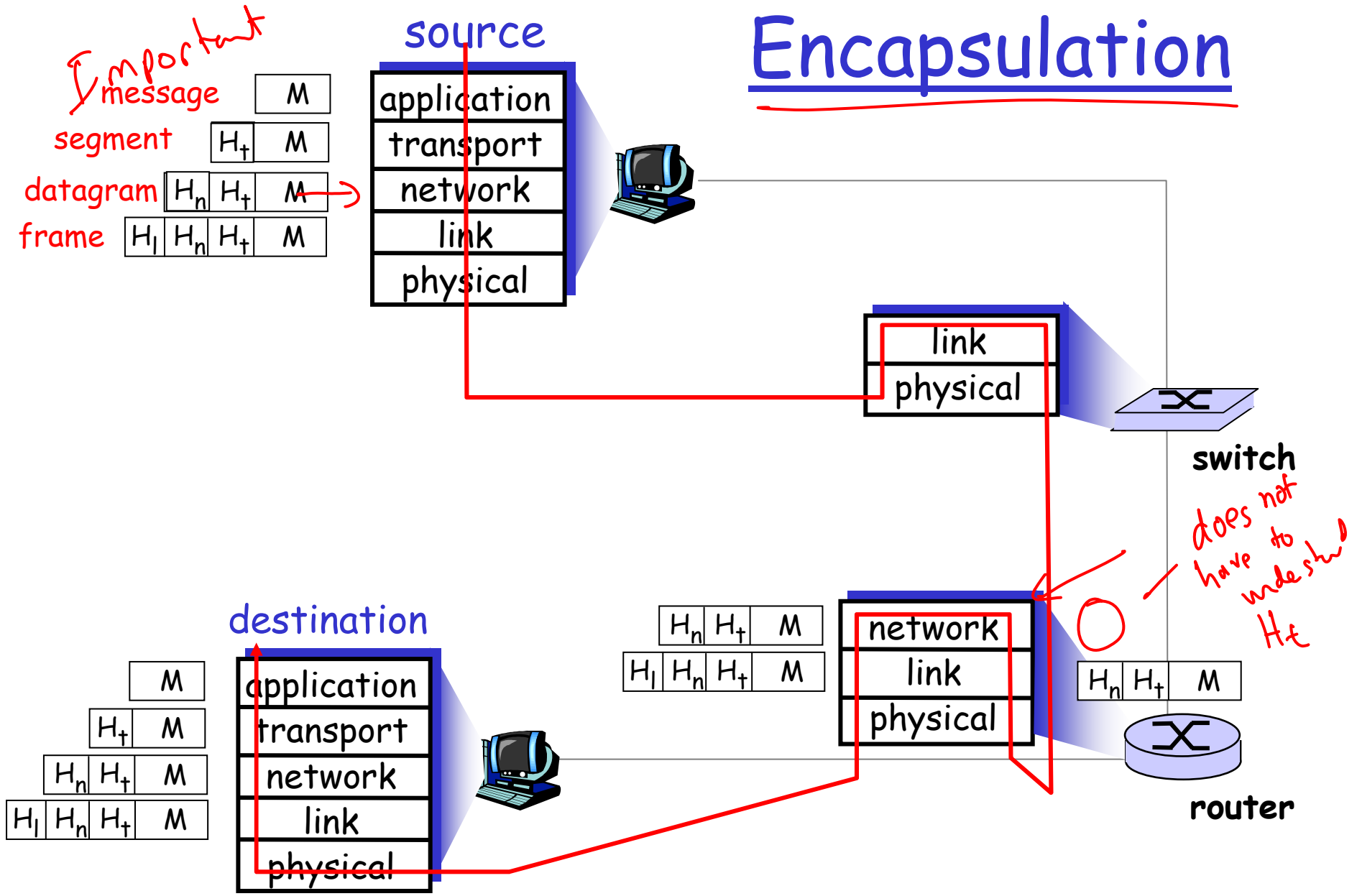
ISO/OSI reference model

- **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?

COORBA



Encapsulation



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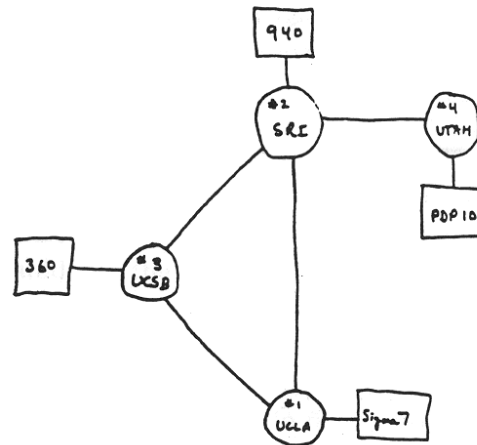
1.6 Networks under attack: security

1.7 History

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
- ❑ 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

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: Csnnet, 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

1990

Late 1990's - 2000's:

- ❑ more killer apps: instant messaging, P2P file sharing
- ❑ network security to forefront
- ❑ est. 50 million host, 100 million+ users *500M:11m*
- ❑ 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!*