CMSC 332: Computer Networks

Intro (cont.)

Professor Doug Szajda

Chapter 1: roadmap

1.1 What is the Internet?

1.2 Network edge

1.3 Network core

1.4 Delay & loss in packet-switched networks

1.5 Protocol layers and their service models

1.6 Networks Under Attack

1.7 History of Computer Networking and the Internet

1.8 Summary

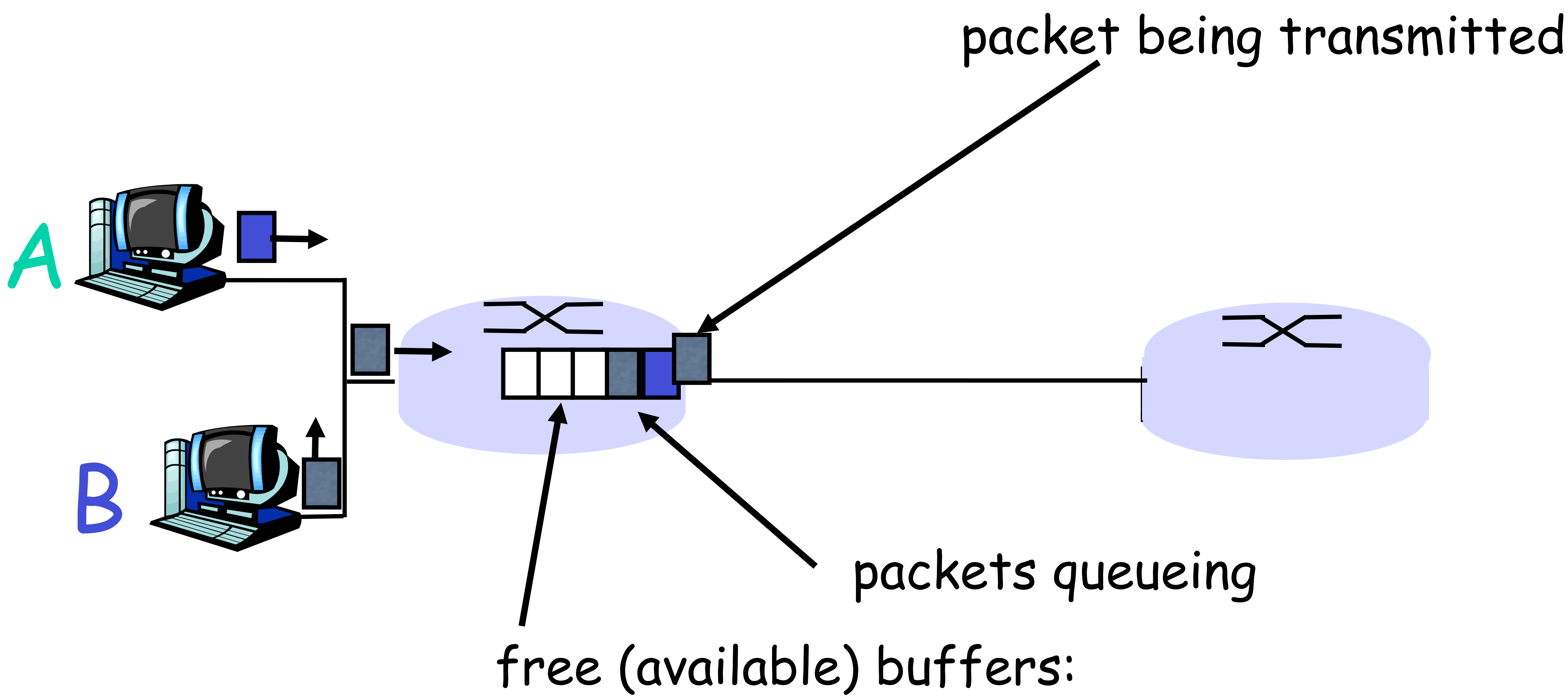
What Took You So Long?

- The time it takes you to get to class depends on a lot of different factors.
  - How congested were the sidewalks? Any construction?
  - Was there a line outside the building? The classroom?
  - Were you carrying more things than usual?
  - Did you drive on congested roads?
- Network traffic is similarly influenced.
  - After all, traffic is not transmitted instantaneously.
  - Why?

How do loss and delay occur?

packets *queue* in router buffers…

- …when packet arrival rate to link exceeds output link capacity
  - which is often
- packets queue, wait for turn

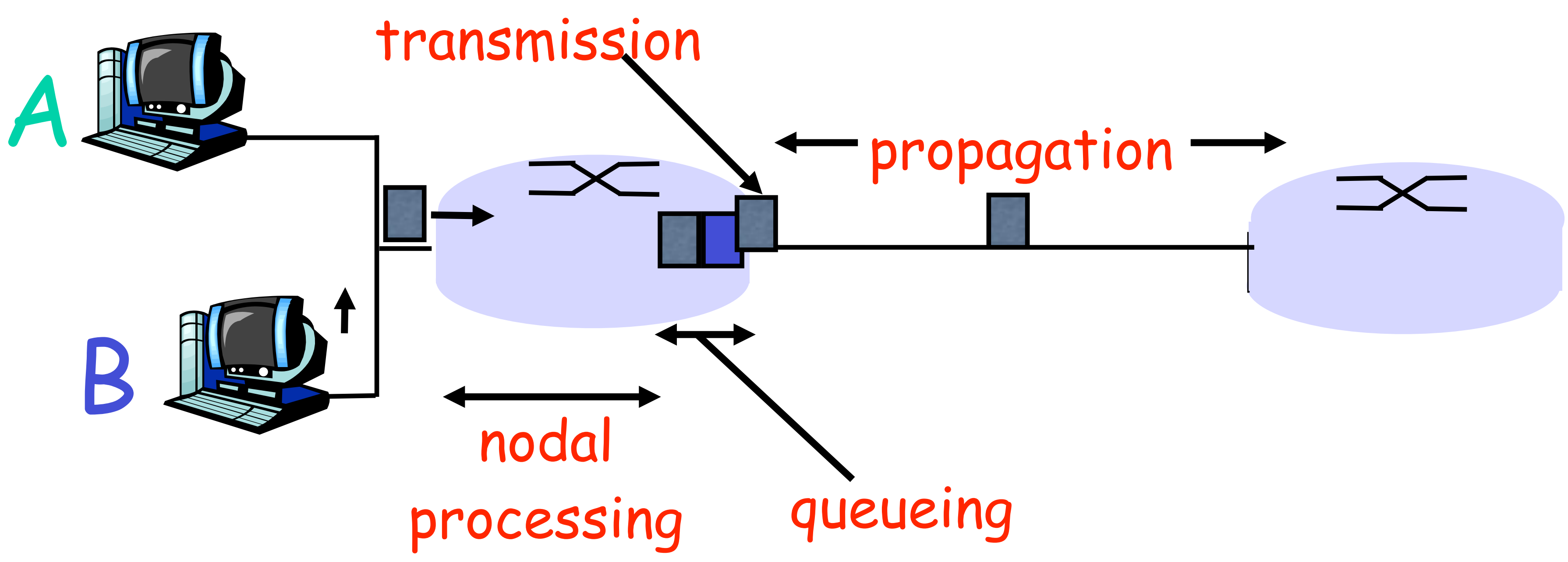


Your task? identify the four sources of packet delay

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

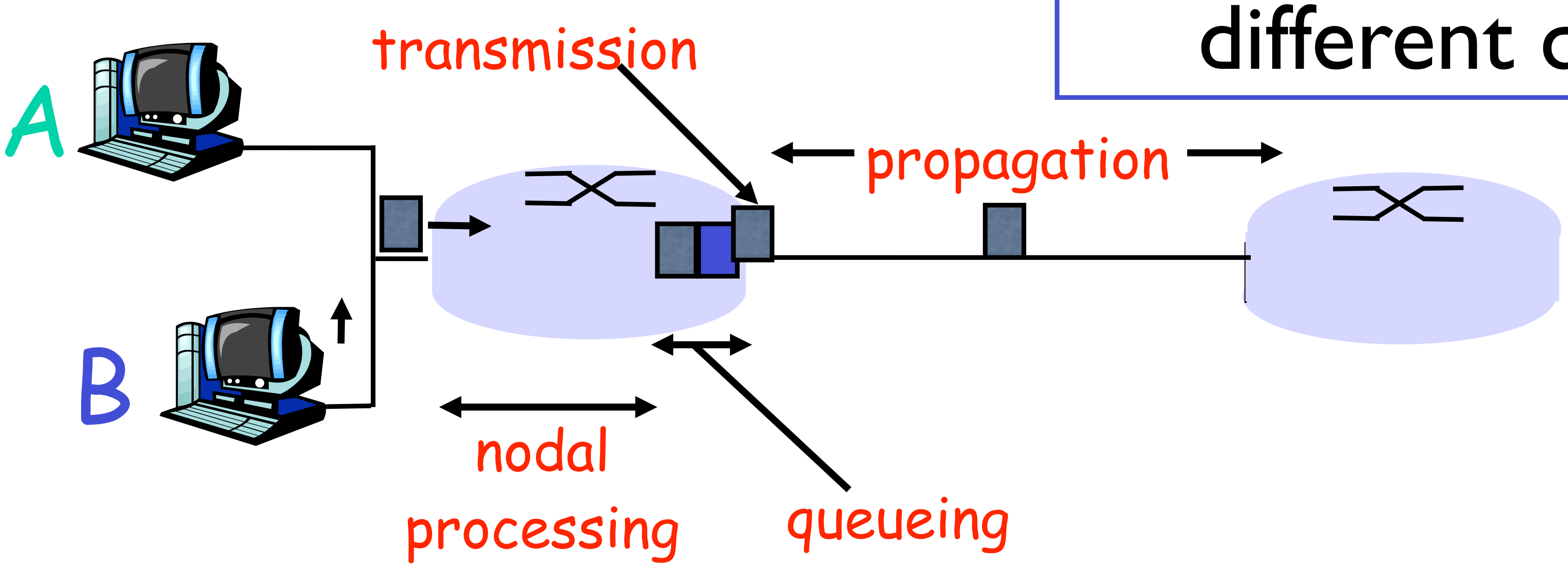
3. Transmission delay:

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

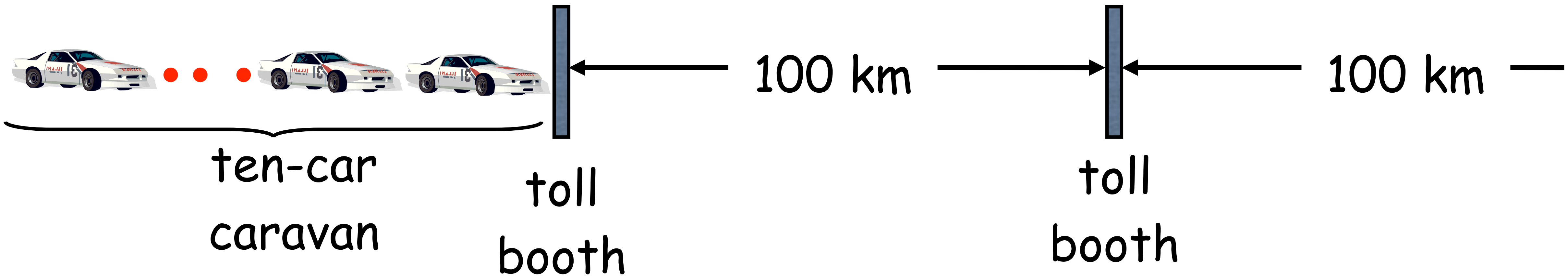
4. Propagation delay:

- 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



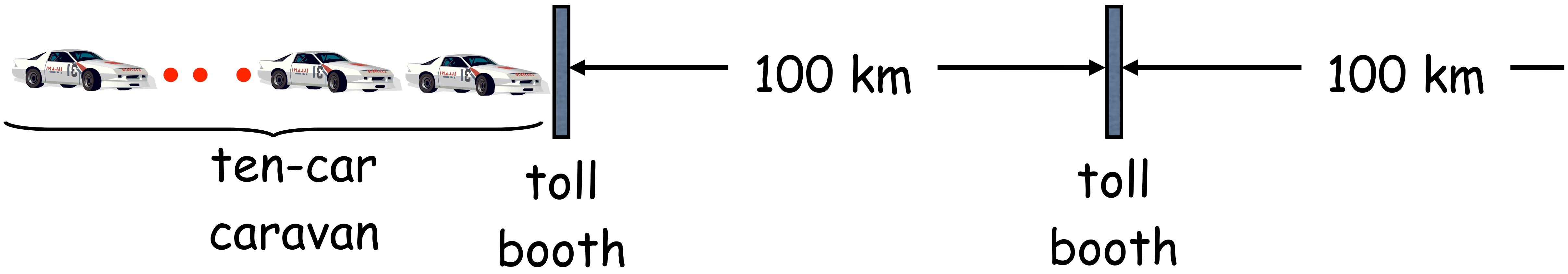
- Cars "propagate" at 100 km/hr
- Toll booth takes 12 sec to service a car (transmission time)
- car~bit; caravan ~ packet
- Q: How long until caravan is lined up before 2nd toll booth?

transmission delay

- 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

propagation delay

Caravan analogy (more)



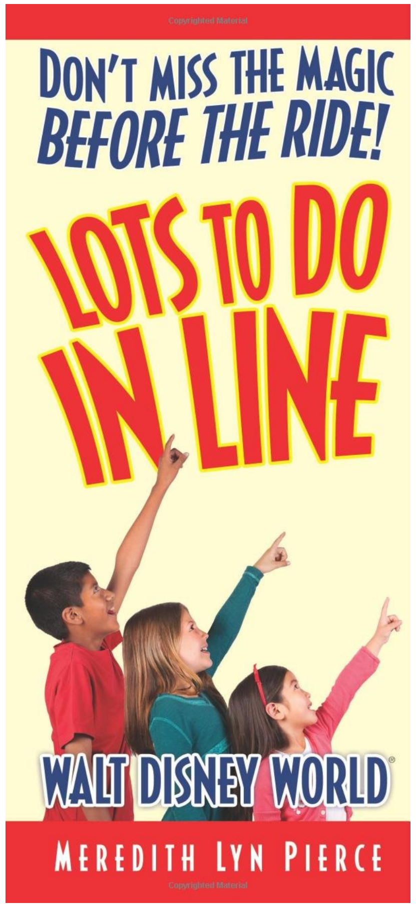
- Cars now "propagate" at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?

- 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!

Nodal delay

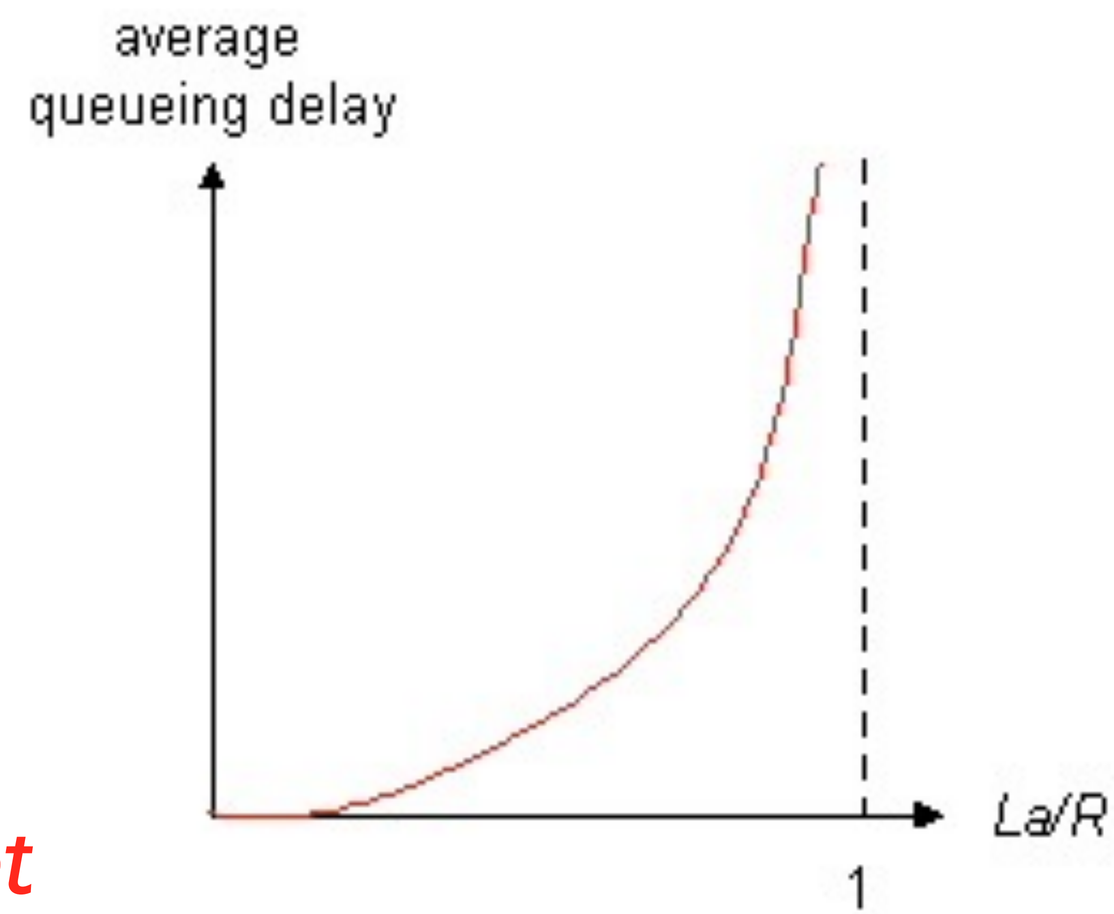
$$\boxed{d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}}$$

- d_{proc} = processing delay
  - typically a few 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= (L/R)a

L/R: seconds to transmit a packet

a: how many packets arrive per second

Traffic intensity is a ratio.
Of what? And what do the values tell us?

Queueing delay (revisited)

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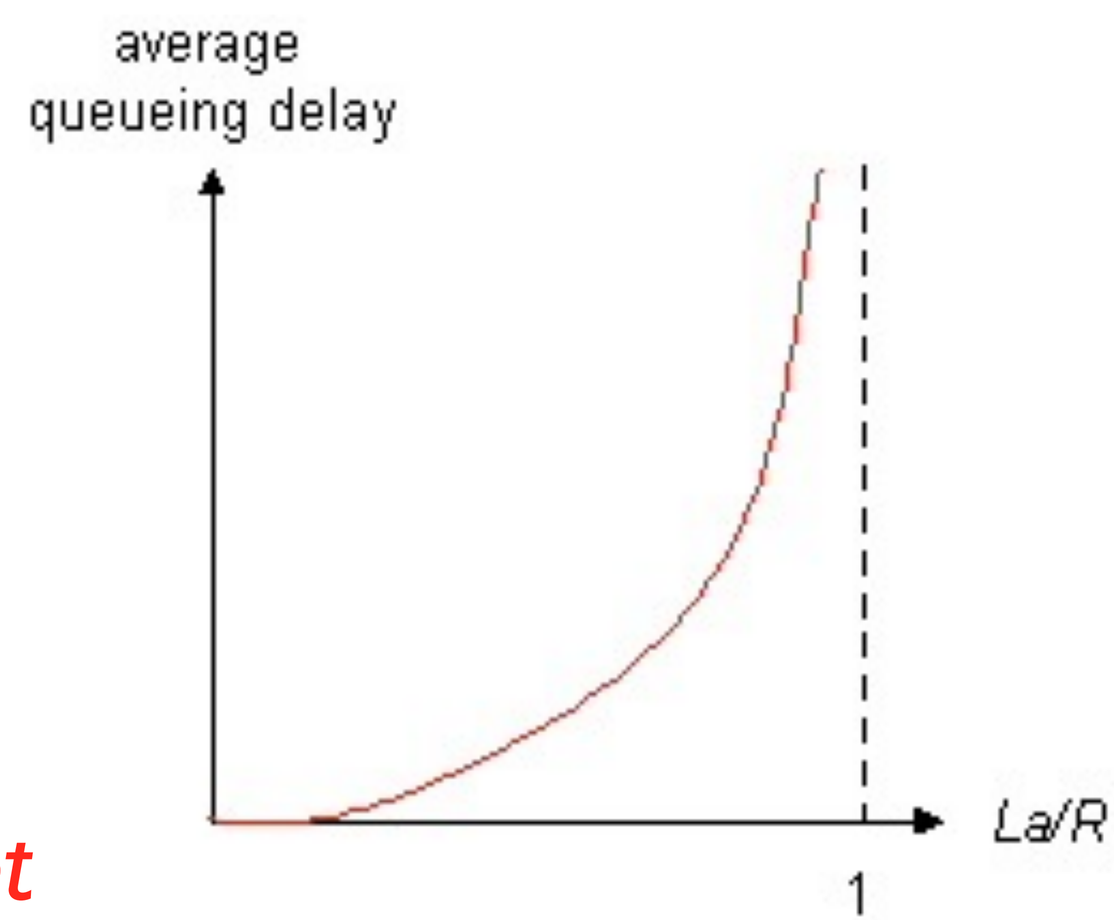

traffic intensity = La/R= (L/R)a

L/R: seconds to transmit a packet

a: how many packets arrive per second

- 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!

Queueing delay (revisited)

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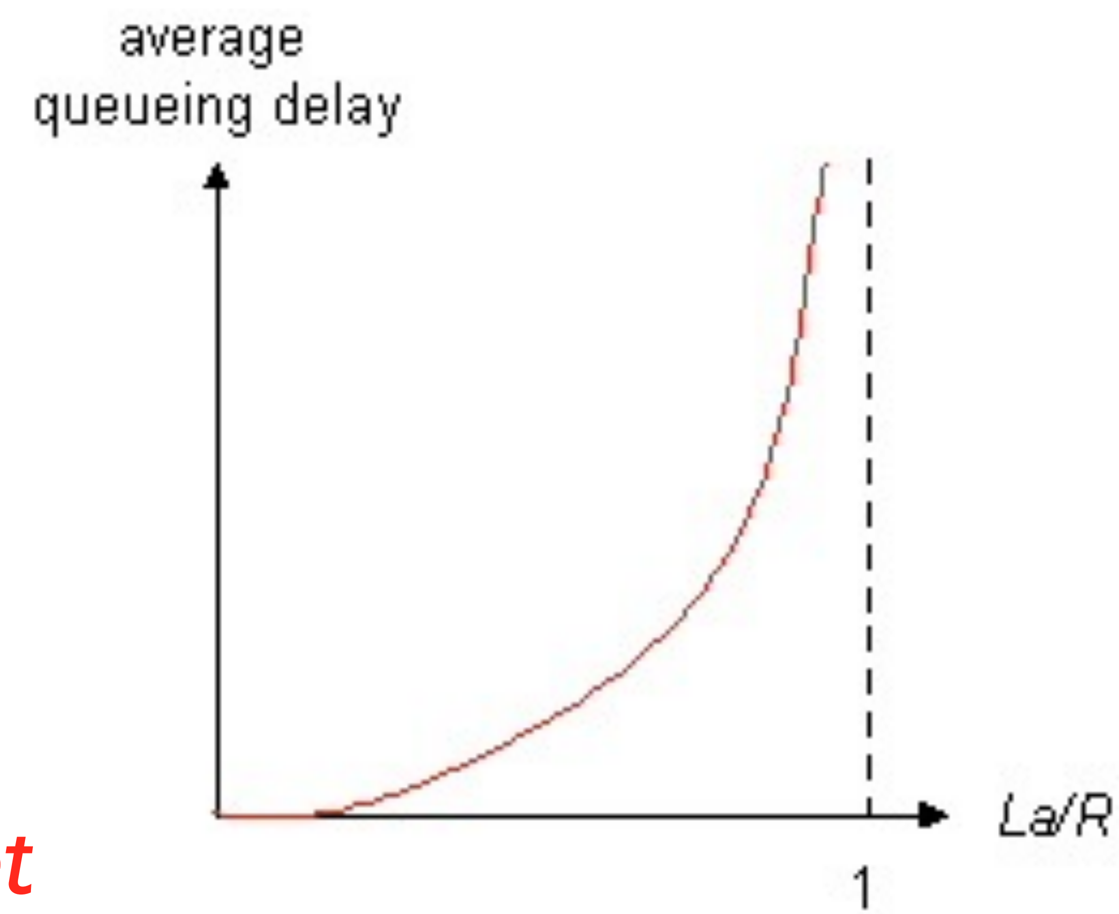

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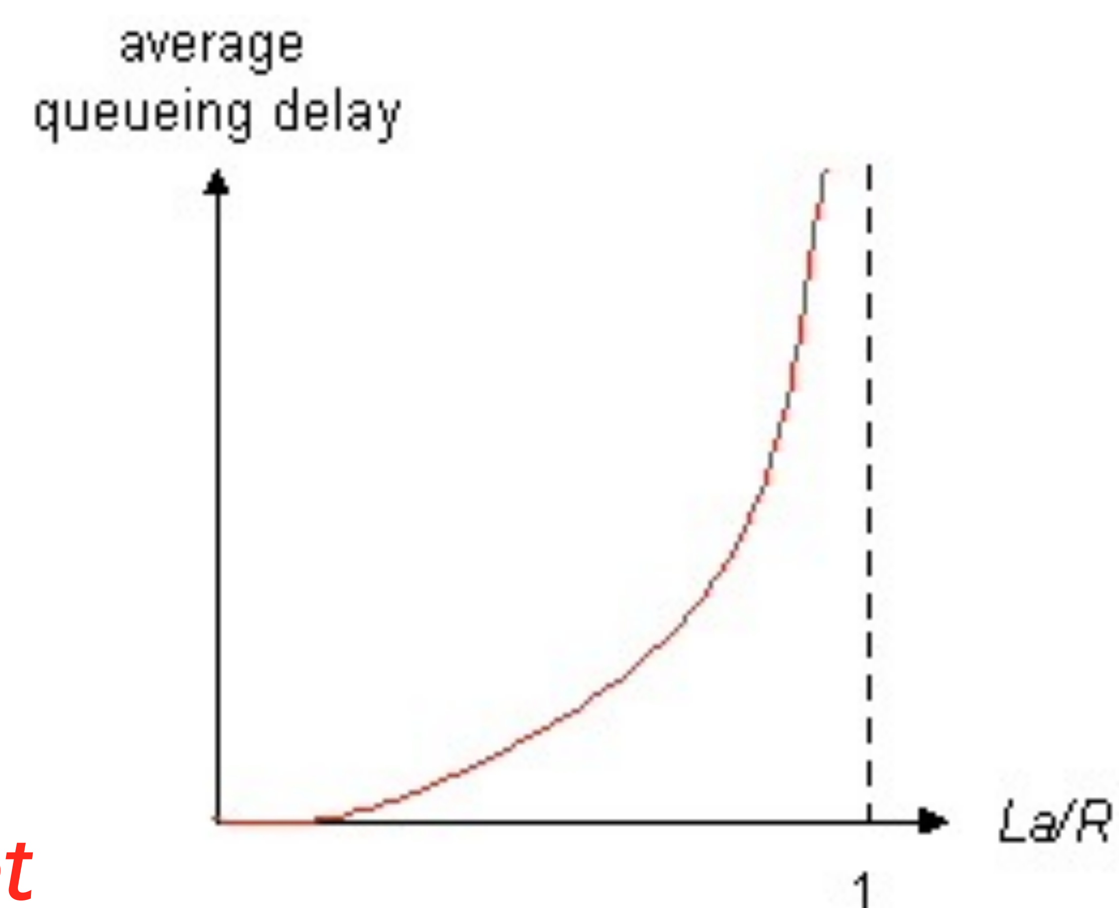

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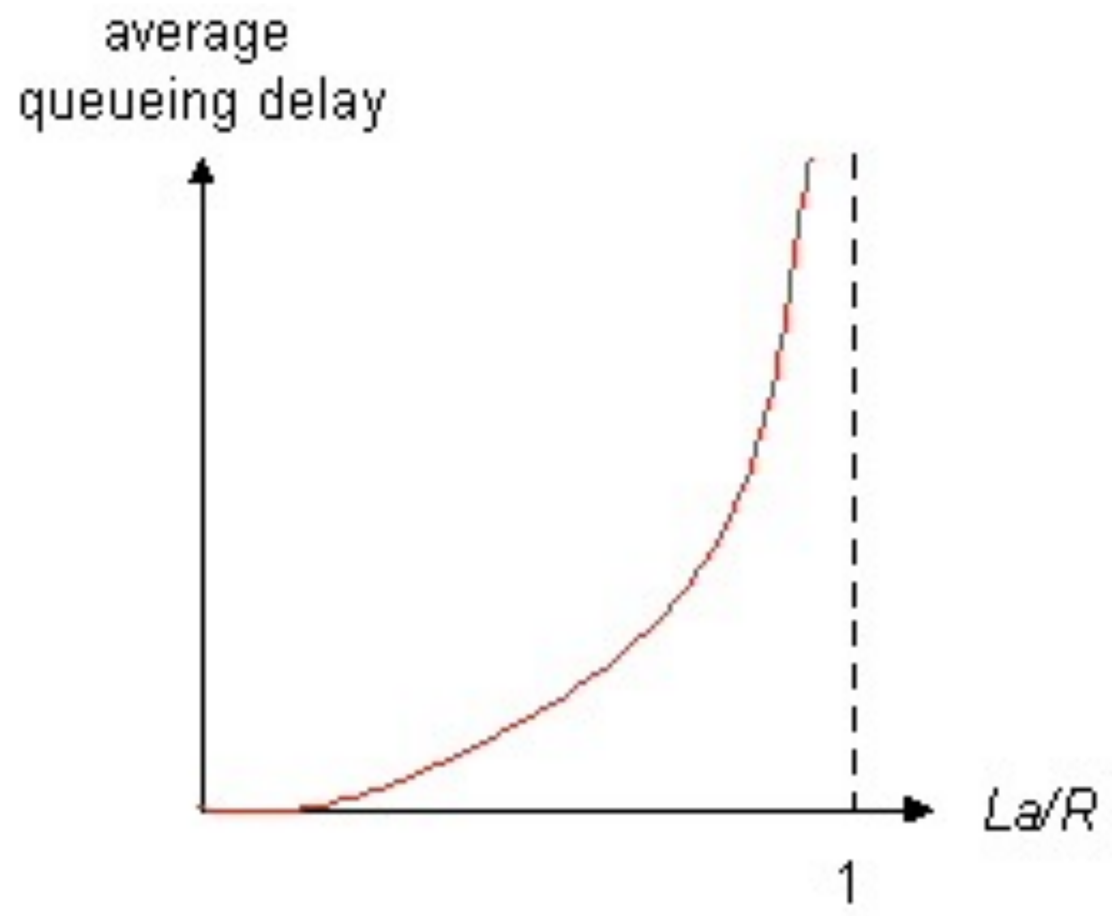
But we're not: bursty!

Queueing delay (revisited)



If one packet arrives every L/R secs (a = R/L), we should be good. But we're not: bursty!

Your task: Explain why this curve looks like it does. Especially as La/R gets close to one from below.

Think of it this way…

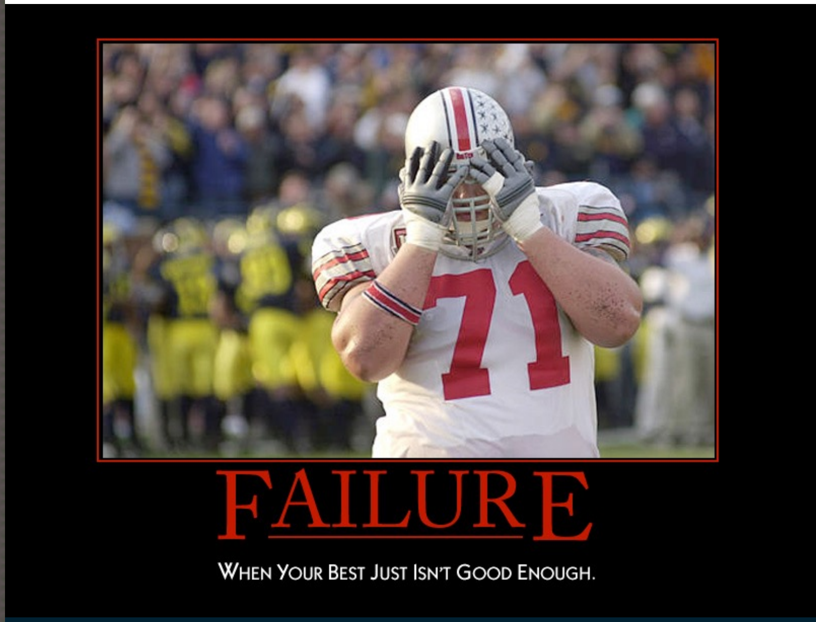
L/R is time (in seconds) to transmit a single packet (dimensional analysis helps with units here). Now, if (L/R)a = 1, then a = 1 / (L/R). Which means packets arrive at exact rate at which they can be transmitted.

(Ex. If packet transmission time is 5 sec, and La/R = 1, then a = 1/5 packets/sec. Which means getting one packet on average every 5 seconds. So incoming exactly matches outgoing.)

But of course a is avg. arrival time, not instantaneous arrival time. Since actual arrival times will have some variance from avg. arrival time, we end up getting delays during "bursts".

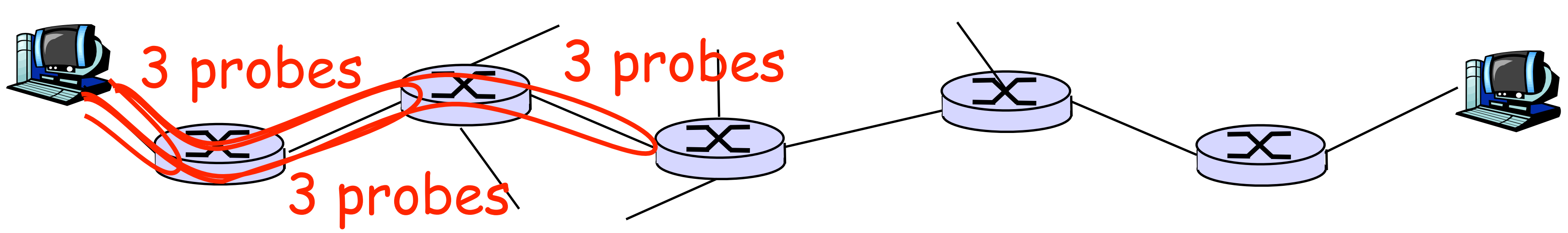
Packet loss

- queue (aka buffer) preceding link has finite capacity
- when packet arrives to full queue, packet is dropped (a.k.a. lost)
- lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all



"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 (how do we know this?)

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

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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

ticket (purchase) ticket (complain)

baggage (check) baggage (claim)

gates (load) gates (unload)

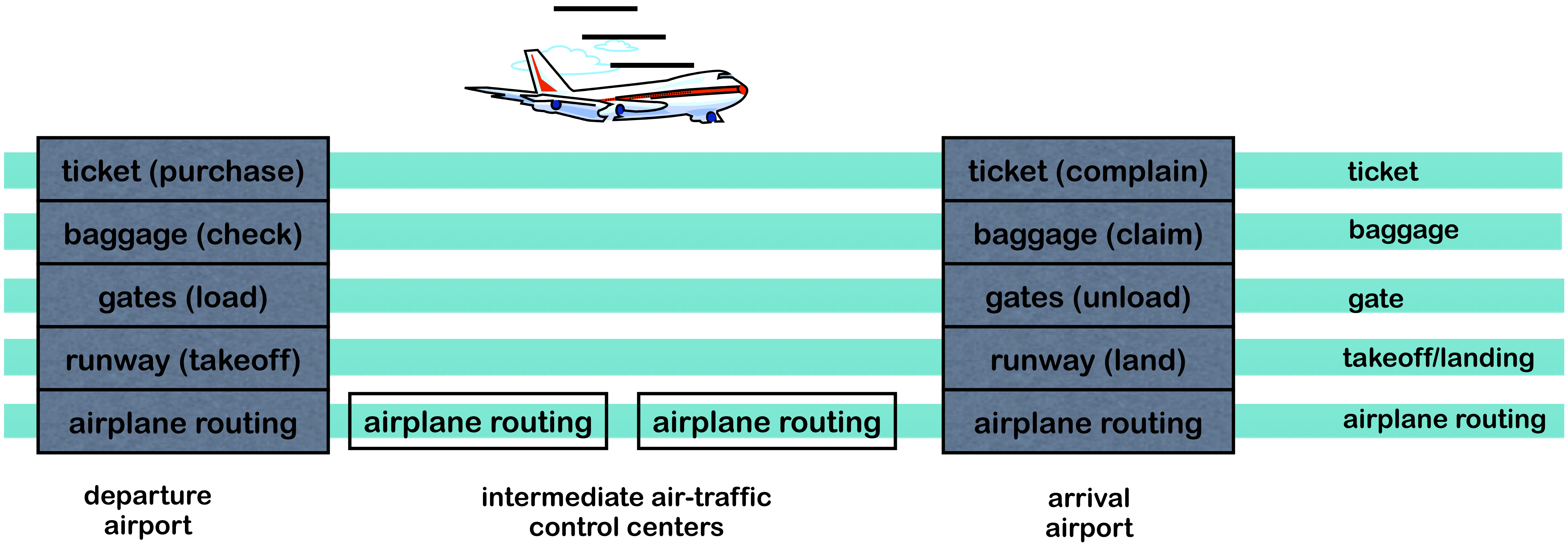
runway takeoff runway landing

airplane routing airplane routing

airplane routing

- 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? Thought experiment: why might layering be considered harmful (in CS, there is no free lunch — anything you do involves tradeoffs).

Layering Considered Harmful?

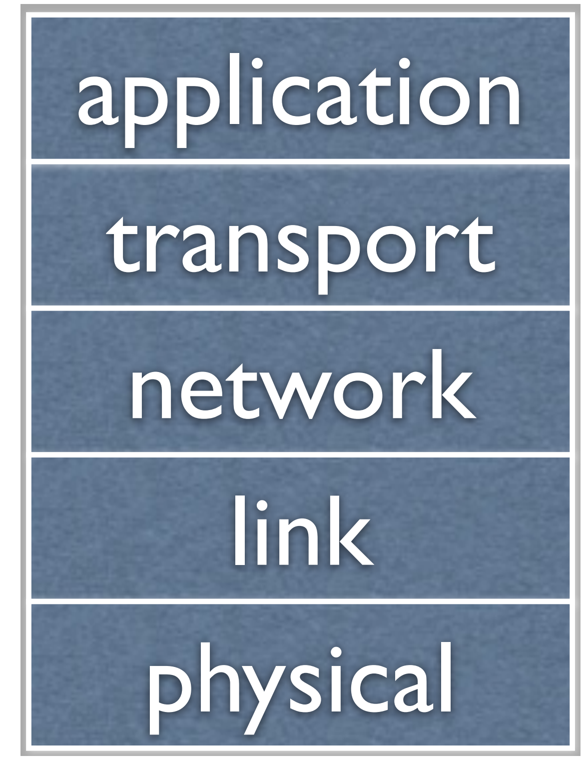
Why may layering be considered harmful?

Well, duplication of functionality. If, for example, there is error recovery on an end-to-end basis and also on a link-by-link basis, this is redundant and (in some cases) wasteful. Also, there is the issue of separation of functionality (keeping clean layer boundaries): one layer should not need to use information specific to another layer. This can be difficult to achieve!

On the whole, however, it works well!

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"

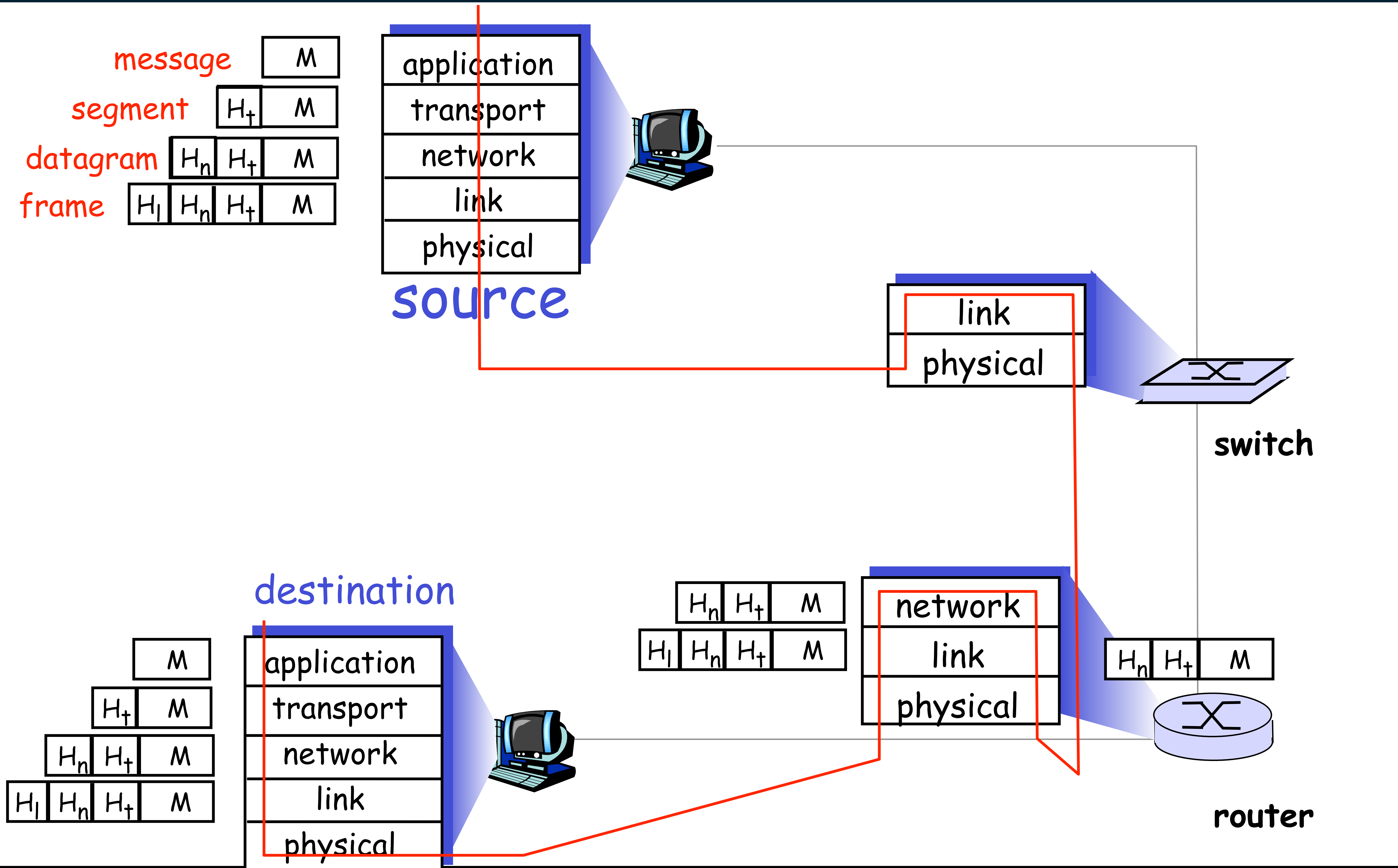


OSI Reference Model

- The Open Systems Interconnection (OSI) model has two additional layers: Session and Presentation.
- Session Layer: Manages sessions between applications
  - (e.g., SSH, RTCP, RPC, NFS)
- Presentation Layer: Delivery and formatting of messages.
  - (e.g., RDP, ASCII)

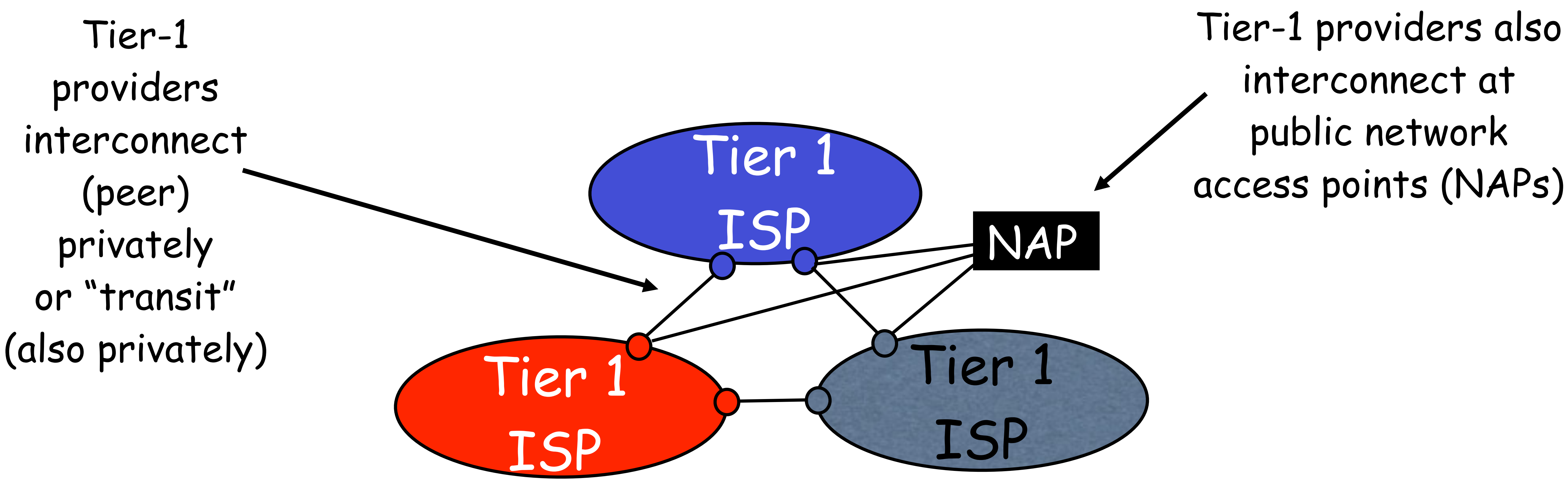
Been a while since anyone has used this model.
Really part of the application layer in current thought.

Encapsulation

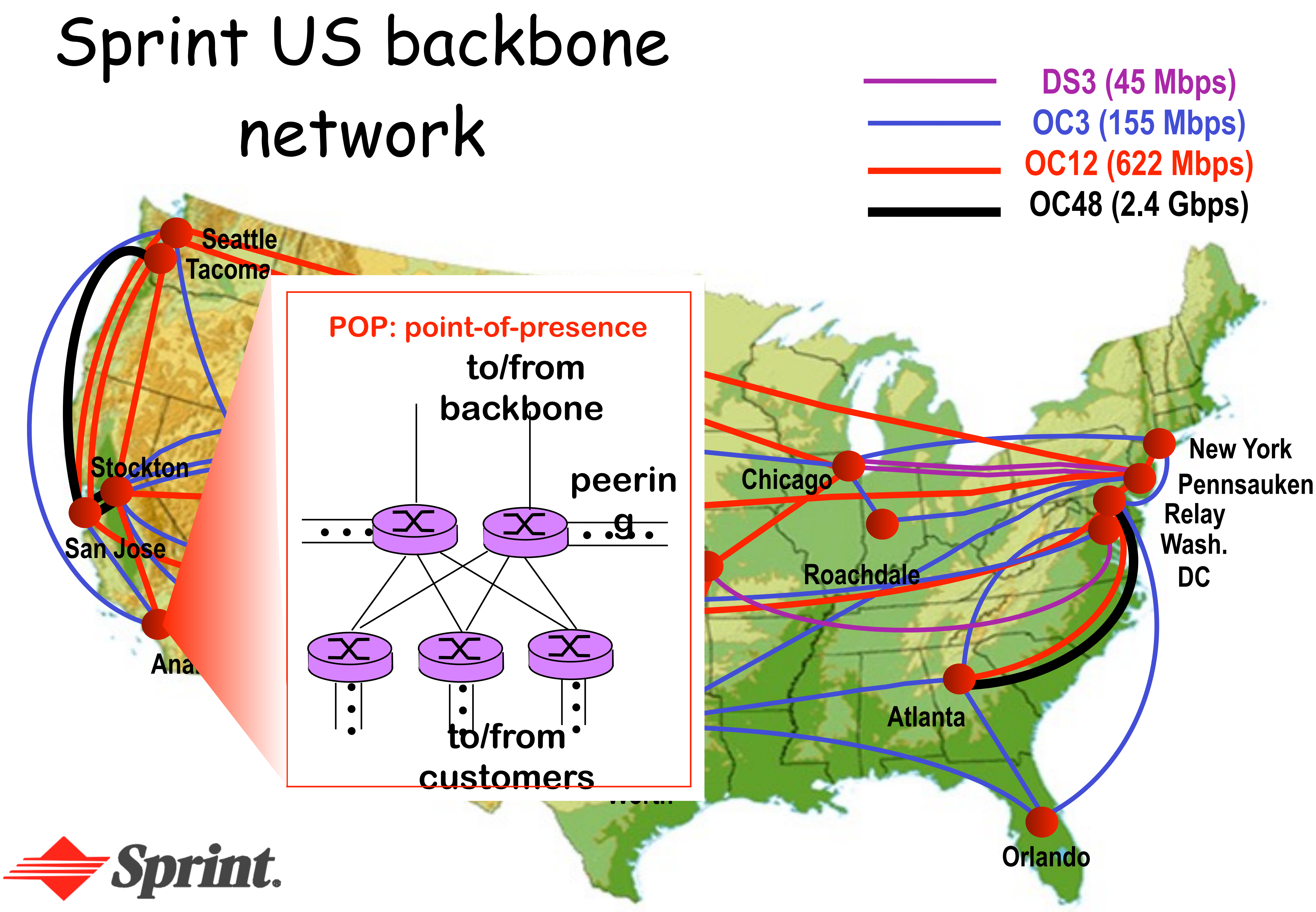


Internet structure: network of networks

- roughly hierarchical
- at center: "tier-1" ISPs (e.g., Verizon, Sprint, AT&T, Cable and Wireless), national/international coverage
  - treat each other as equals



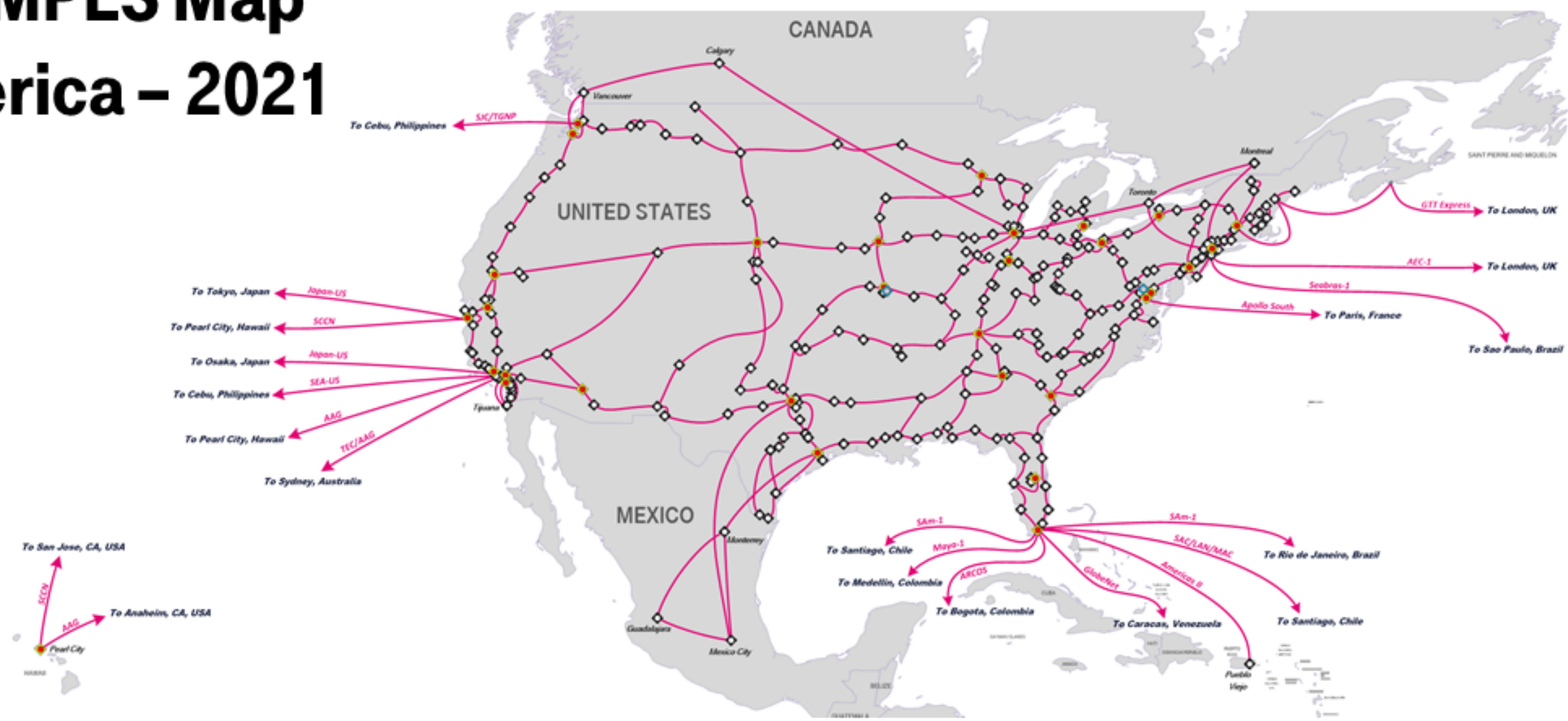
Tier-1 ISP: e.g., Sprint



Updated Sprint (Well, now T-Mobile) Network

T-MOBILE FOR BUSINESS

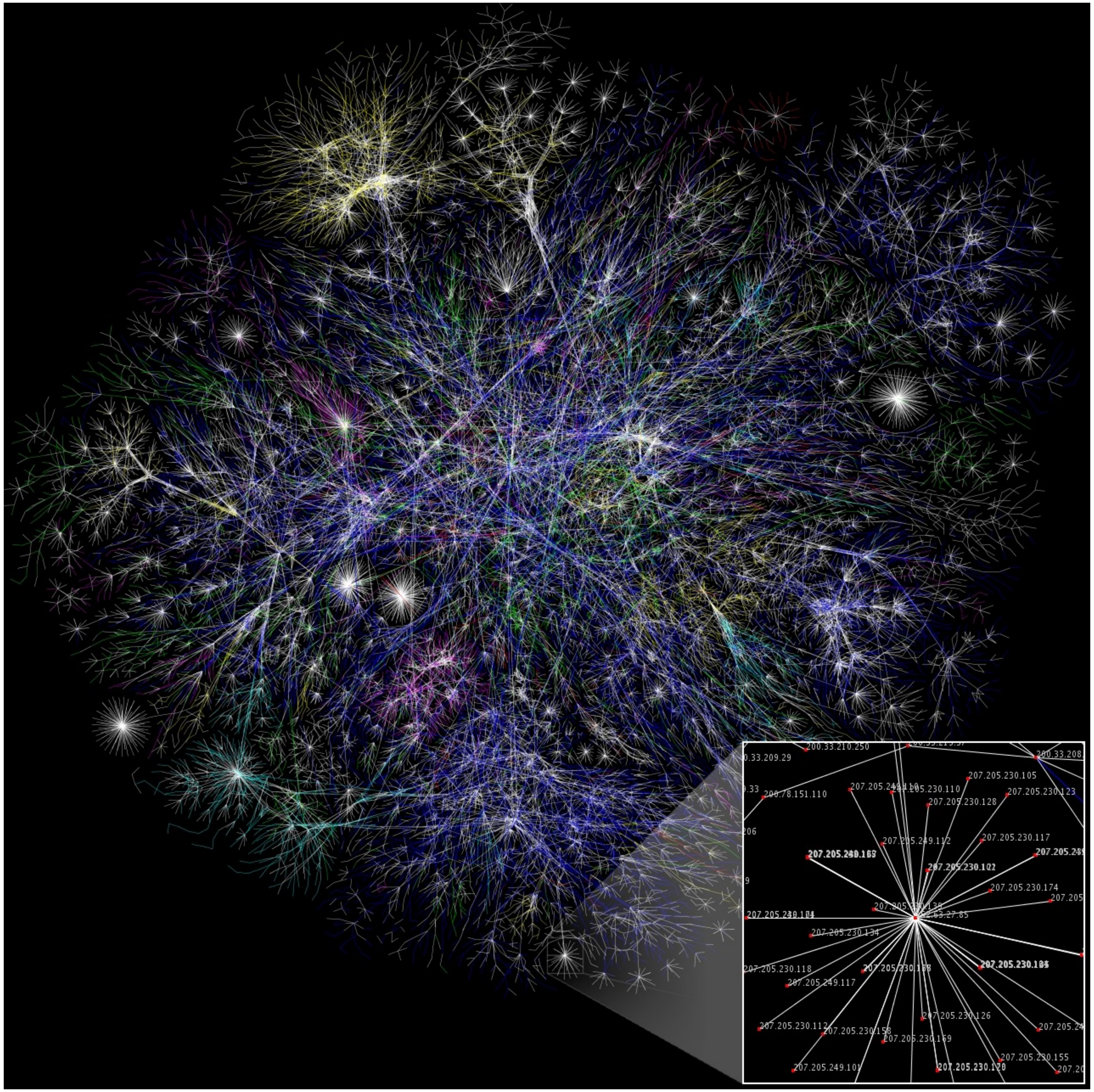
Global IP/MPLS Map North America – 2021



- T-Mobile Node
- T-Mobile Core
- T-Mobile NOC
- T-Mobile Ethernet POP or T-Mobile Virtual POP
- Landing Station
- T-Mobile Network Backbone

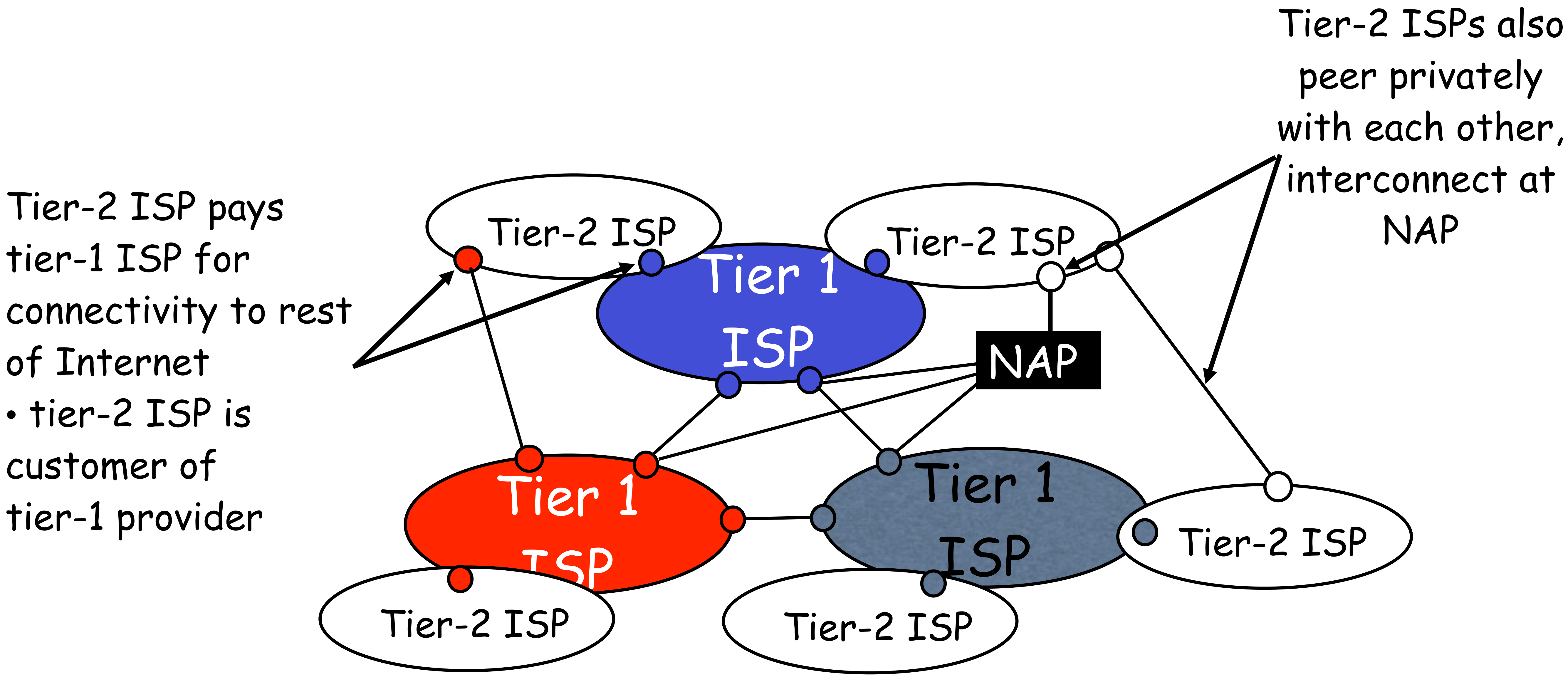
Restrictions and conditions apply in some countries; not available in all areas.

Backbone Snapshot



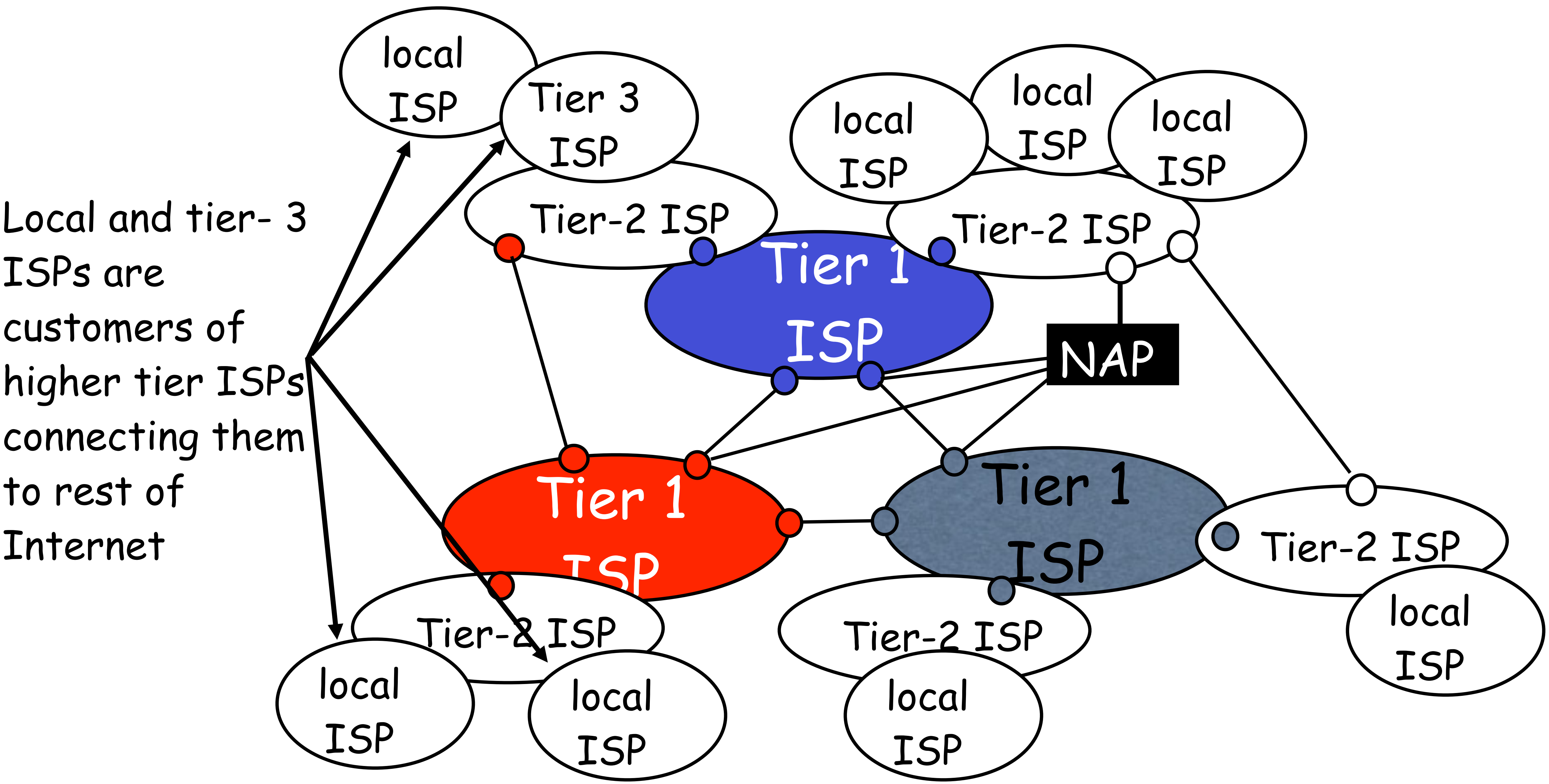
Internet structure: network of networks

- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs



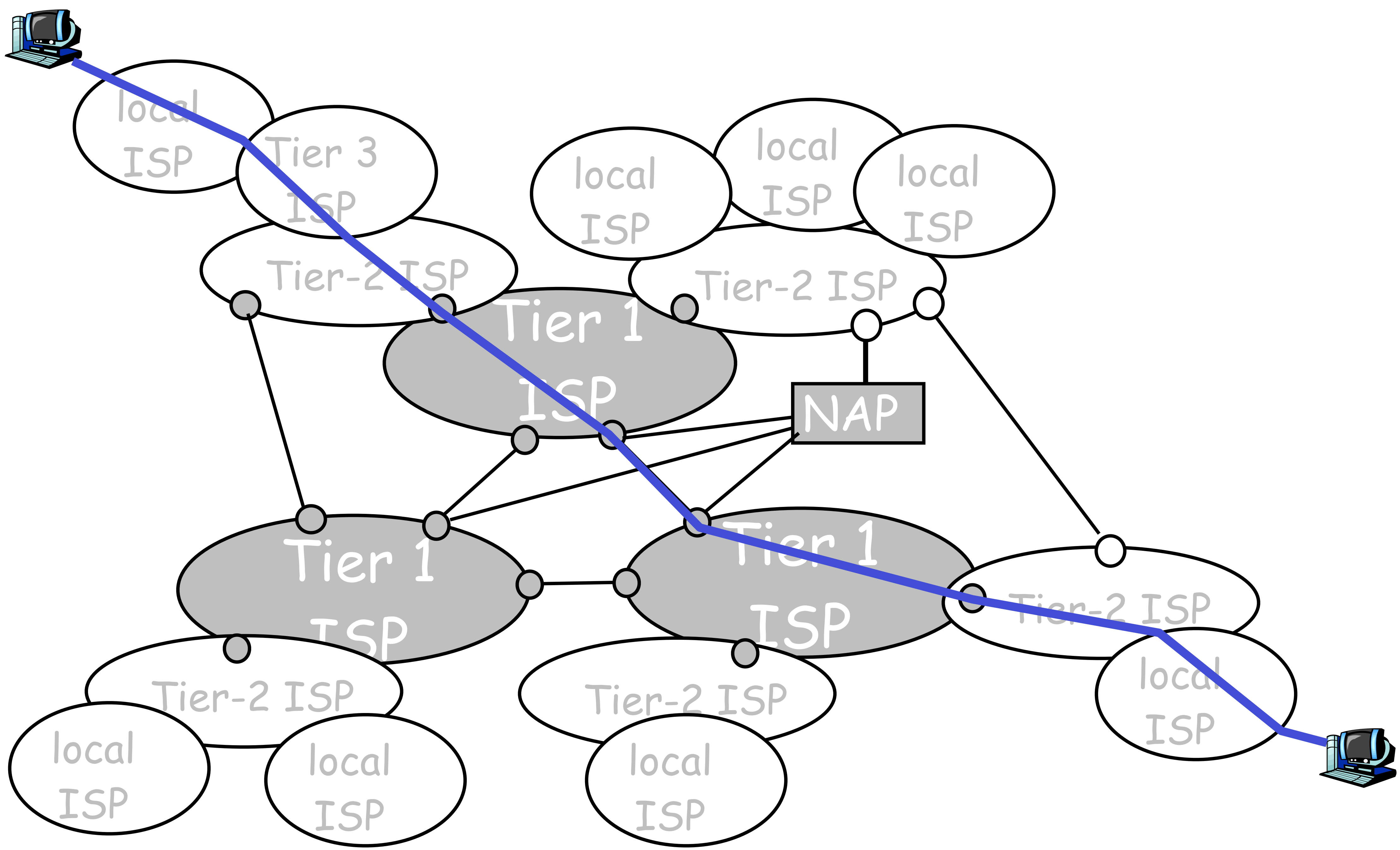
Internet structure: network of networks

- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)



Internet structure: network of networks

- a packet passes through many networks!



Chapter 1: roadmap

Back to the Silk Road

- When the Mongol Empire collapsed around 1400, most of the trade routes became too dangerous.
  - Columbus tried to avoid all of that.

- Any system in which huge amounts of money and information are exchanged will always be of interest to criminals.
  - The Internet is no different.

- What sorts of threats are out there?

Malware

- Malicious software is generically known as *malware*.
  - (e.g., Virus, worm, botnet, trojan horse)

- The distinction between these is often due to:
  - ...how they propagate...
  - ...what they control...
  - ...their usefulness to you...
- Anyone here ever been infected?
- Anyone think they haven't?

Attacking Availability

- An adversary may try to shut you down with a *Denial of Service* (DoS) attack.
- The book considers three categorizations, but the community has generally settled on two:
  - Flooding: Simply overwhelming your servers with more traffic than they can handle.
  - Logical: Exploiting a limited resource or known vulnerability.

Packet Manipulation

- If the Internet is a network of networks, who says that someone in the middle can't mess with your packets?
- Assume that everything sent over the Internet is read or *sniffed* by someone/thing.
- Anyone with control of the wire can also arbitrarily drop or modify your packets.
  - When might this be a problem?
  - Does it happen?

Authenticity

- How do you know who you are talking to?
  - In real life? On the web?

- Pretending to be someone else is easier than you think.

- An adversary can *spoof* identity in any number of ways...
  - Has this ever happened to you?

"On the Internet, nobody knows you're a dog."

Security

- Security is, in general, a hard problem.
  - Even picking a good definition is difficult.

- As we move through this semester, ask yourself a few questions about the topics we study:
  - Did the designer consider malicious behavior?
  - How would I break this?
  - How would I fix this?

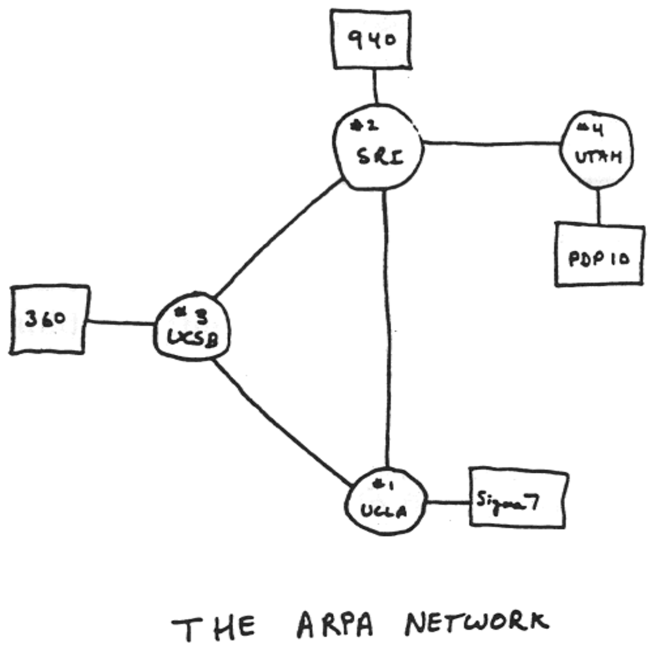
Chapter 1: roadmap

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



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

Question: Why these principles?

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
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- stateless routers
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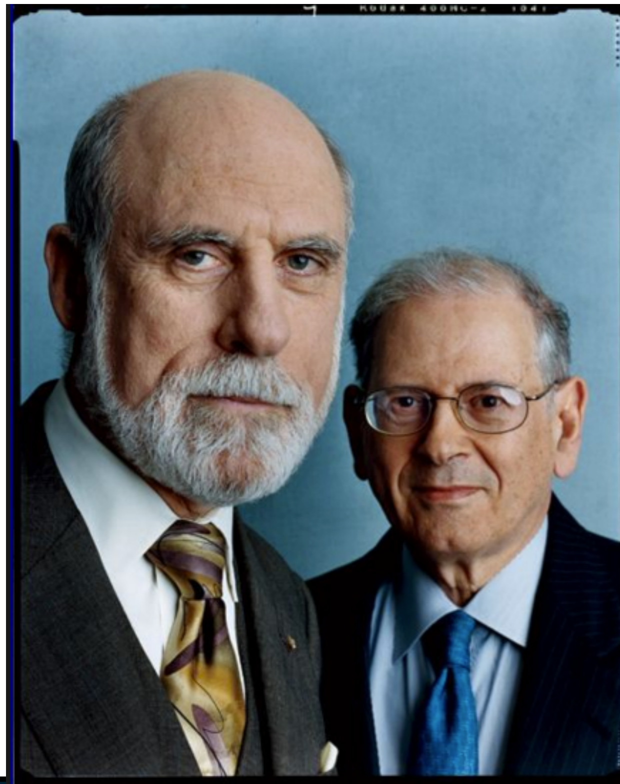
define today's Internet architecture

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, KaZaA
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Internet History

2021:

- As of January of this year, 4.66 billion active internet users worldwide - 59.5 percent of the global population. Of this total, 92.6 percent (4.32 billion) accessed the internet via mobile devices. (Thanks: https://www.statista.com/statistics/617136/digital-population-worldwide/)
- In 2019, over a billion hosts (also thanks to statista)

Internet History

2025:

- As of July of this year, 5.65 billion active internet users worldwide - 68.7 percent of the global population. Of this total, 95.9 percent of Internet users access via mobile devices at some point. Mobile traffic now accounts for roughly 63% of the world's web traffic.
  Thanks: https://datareportal.com/global-digital-overview)
- 6 hours 36 minutes the average amount of time a person spends online

Introduction: Summary

Covered a "ton" of material!

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

You now have:

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