CSCE 463/612 Networks and Distributed Processing Fall 2024

Introduction II

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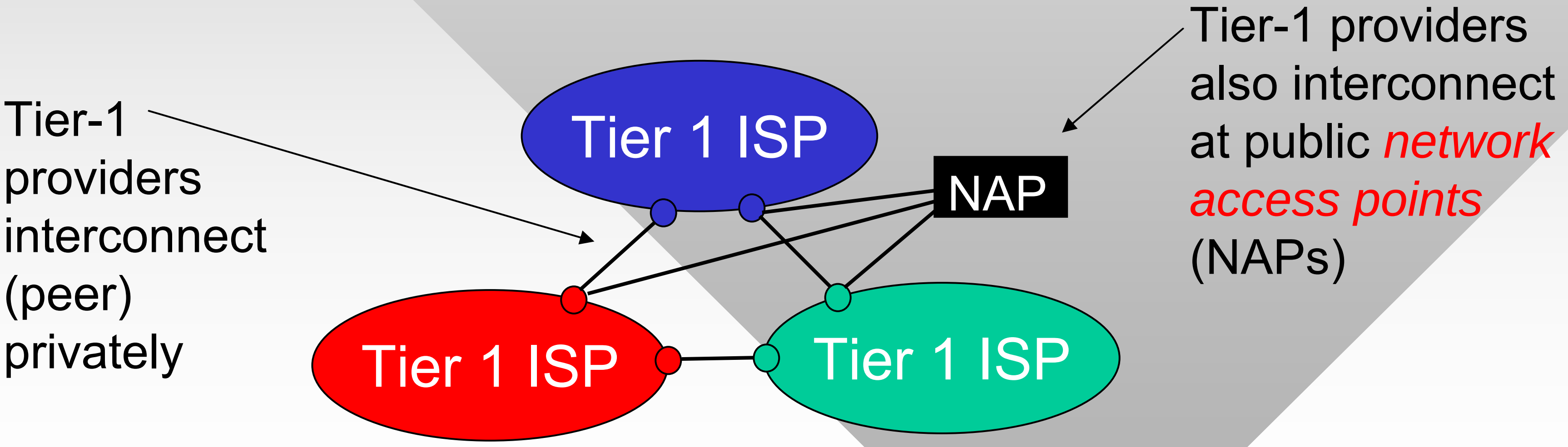
August 29, 2024

Chapter 1: Roadmap

1.1 What *is* the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

Internet: Network of Networks

- Roughly hierarchical
  - In the center: “tier-1” ISPs (e.g., Sprint, AT&T, Verizon), national/international coverage
  - Treat each other as equals, do not pay for upsteam bandwidth
  - Form the backbone of the Internet

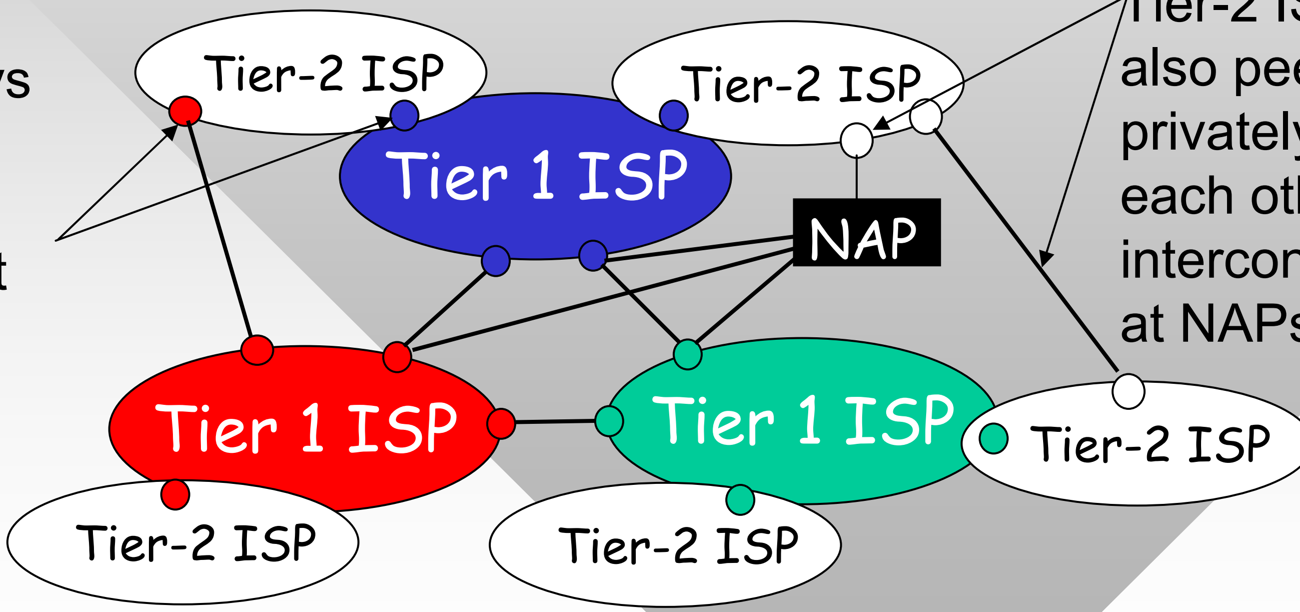


Internet: Network of Networks

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

Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet

Tier-2 ISP is *customer* of tier-1 *provider*

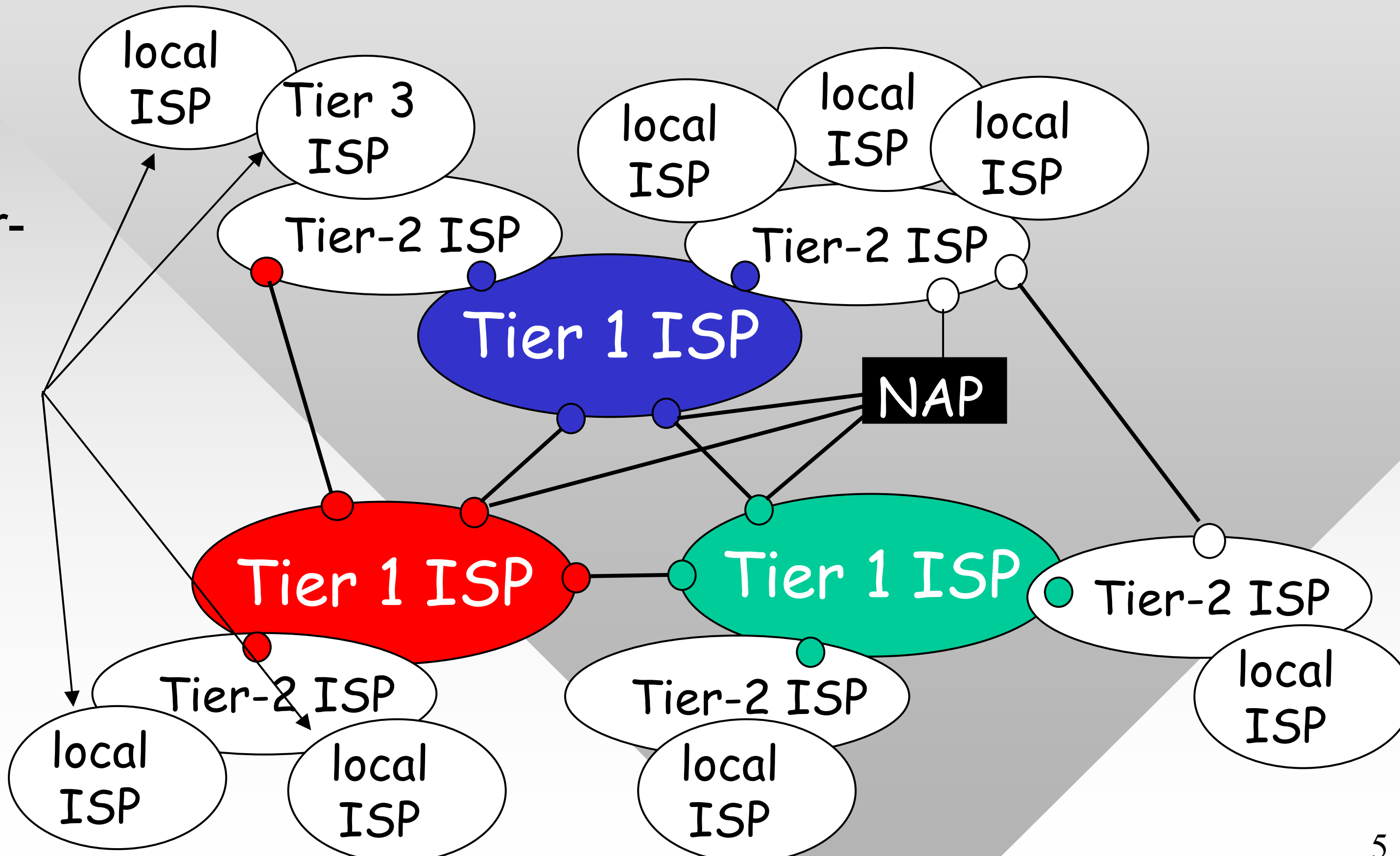


Tier-2 ISPs also peer privately with each other, or interconnect at NAPs

Internet Structure: Network of Networks

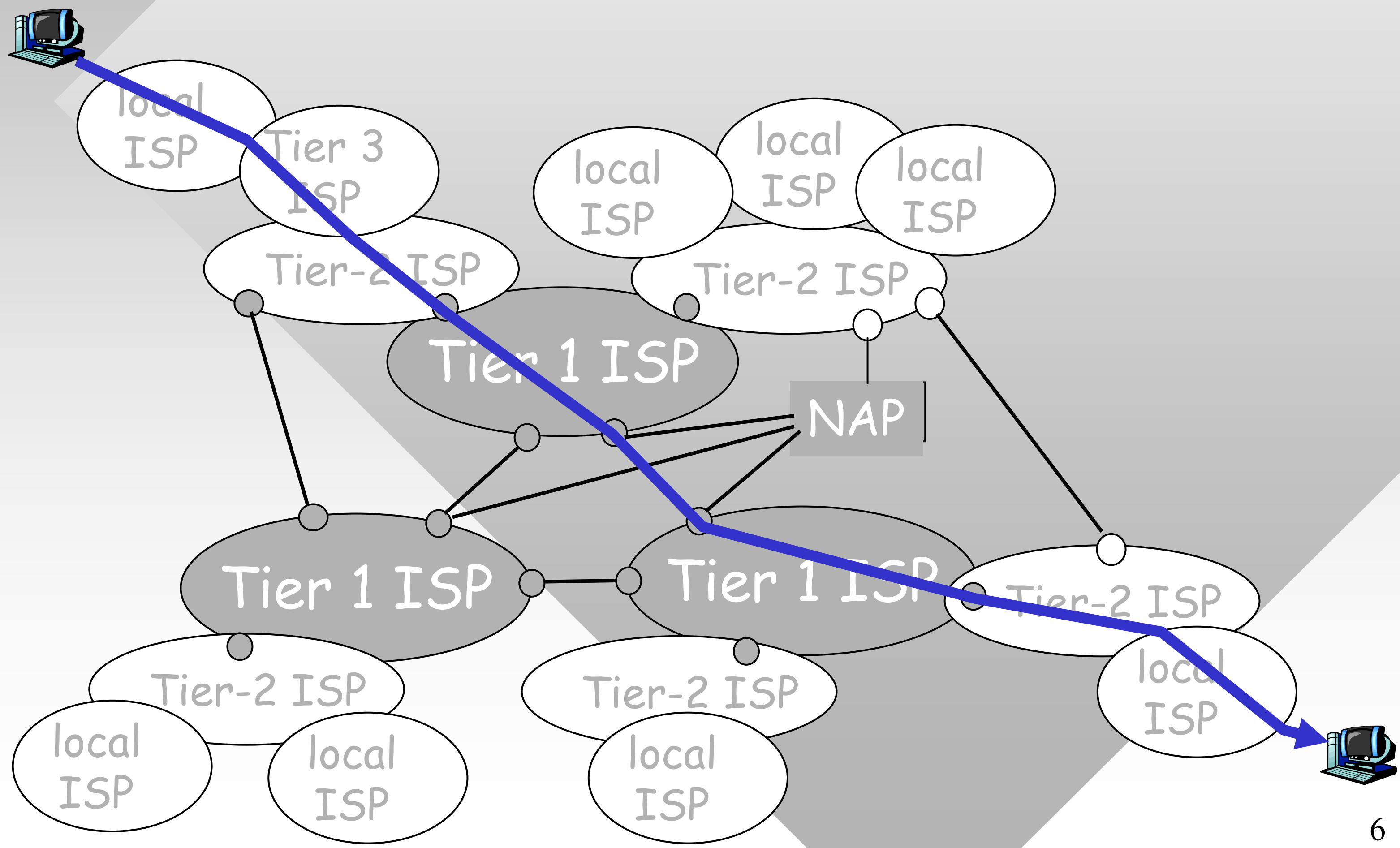
- "Tier-3" ISPs and local ISPs
  - Last hop ("access") network (closest to end systems)

Local and tier-3 ISPs are *customers* of higher tier ISPs connecting them to rest of Internet



Internet Structure: Network of Networks

- A packet passes through many networks!



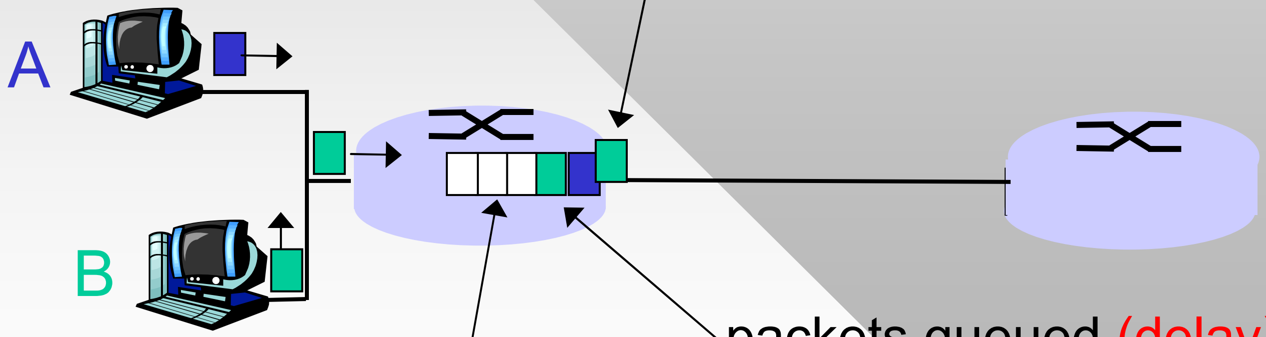
Chapter 1: Roadmap

How Do Loss and Delay Occur?

Packets *queue* in router buffers (typically FIFO queues)

- If packet arrival rate exceeds output link capacity:
  - Packets queue, wait for their turn
  - Analogy: 5 lanes of traffic merge into 1

packet being transmitted (delay)



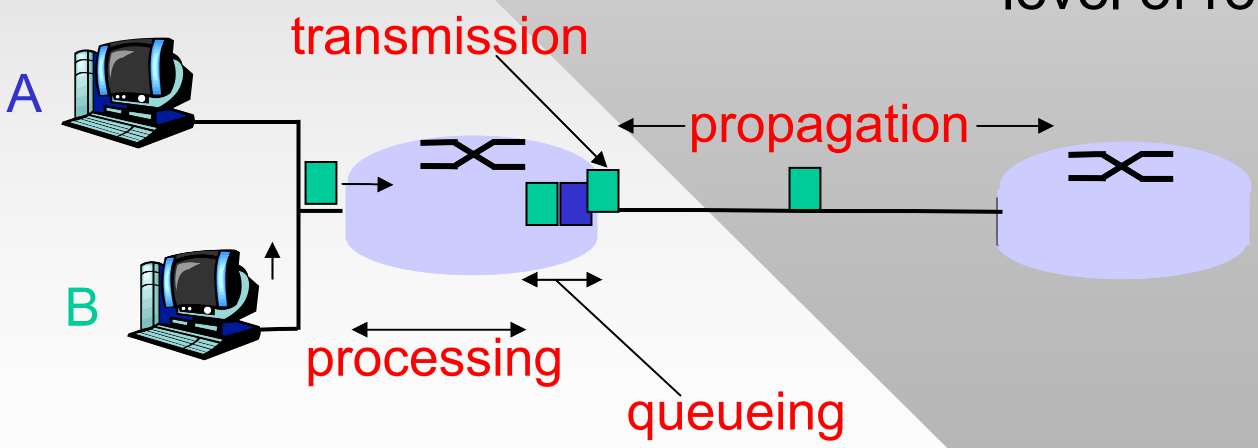
packets queued (delay)

arriving packets dropped if no free buffers (packet loss)

Four Sources of Packet Delay

1. Router processing delay:
   - Check bit errors
   - Determine output link
   - Place packet in buffer

2. Queueing delay
   - Time waiting at output link for transmission
   - Depends on congestion level of router



Delay in Packet-Switched Networks

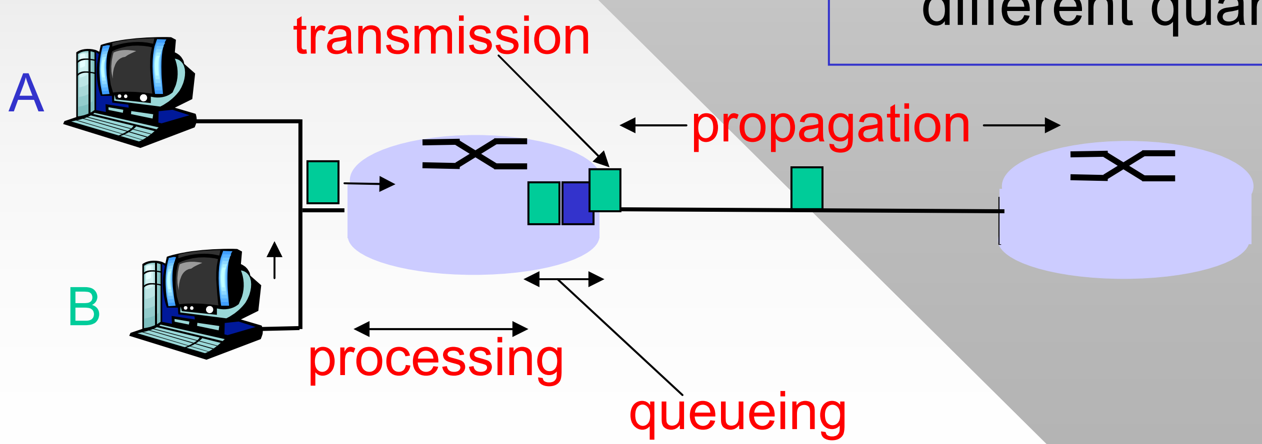
3. Transmission delay:

- $R =$ link rate (bps)
- $L =$ packet length (bits)
- Time to send bits into link $= L/R$

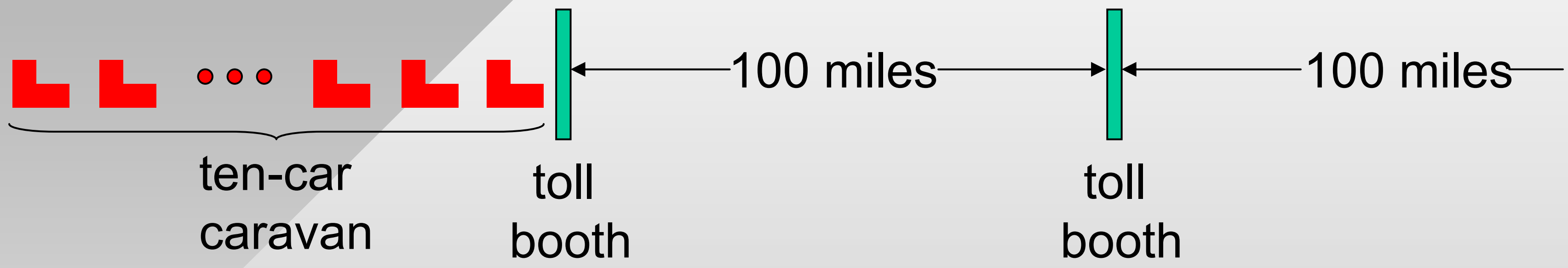
4. Propagation delay:

- $d =$ length of link (m)
- $s =$ propagation speed in medium ($\approx 2 \times 10^8$ m/sec)
- Propagation delay $= d/s$

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

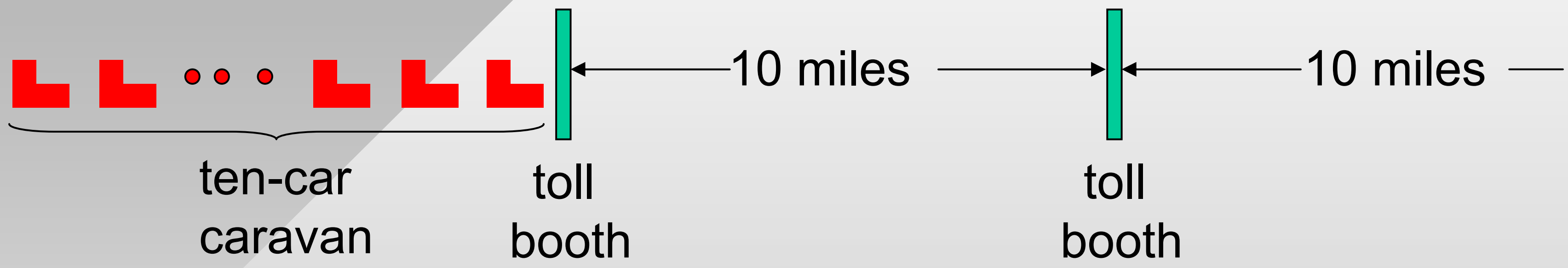


Caravan Analogy



- Car ~ bit; caravan ~ packet
- Cars "propagate" at 100 mph
- Toll booth takes 12 sec to service a car (transmission time of a bit)
- Q: How long until caravan is lined up before the 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: 100 miles / (100 mph) = 1 hr
- A: 62 minutes

Caravan Analogy (more)



- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars are 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 from 1st router!
- Can a packet be at 3 routers simultaneously?

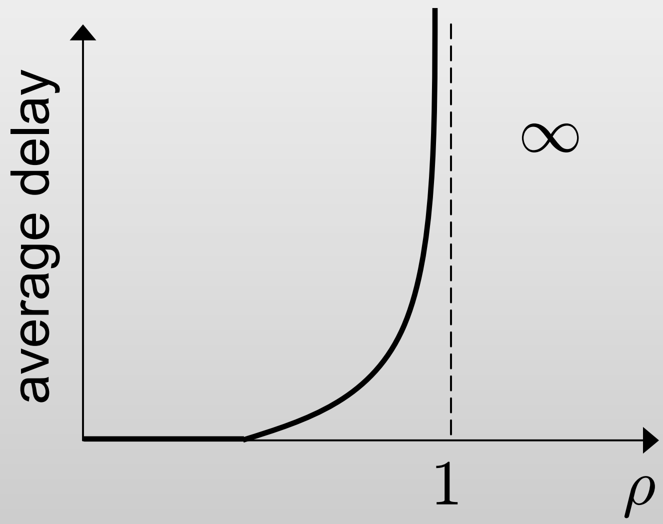
Nodal (Per-Router) Delay

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

- $d_{proc} =$ processing delay
  - A few microsecs or less, usually fixed for all packets
- $d_{queue} =$ queuing delay
  - Depends on congestion, randomly varies between packets
- $d_{trans} =$ transmission delay
  - Equals L/R, high for low-speed links, depends on packet size
- $d_{prop} =$ propagation delay
  - A few microsecs to hundreds of msecs, depends on physical length of the link

Queueing Delay (Revisited)

- $R =$ link bandwidth (bps)
- $L =$ packet length (bits)
- $a =$ average packet arrival rate (pkts/sec)
- Infinite buffer space

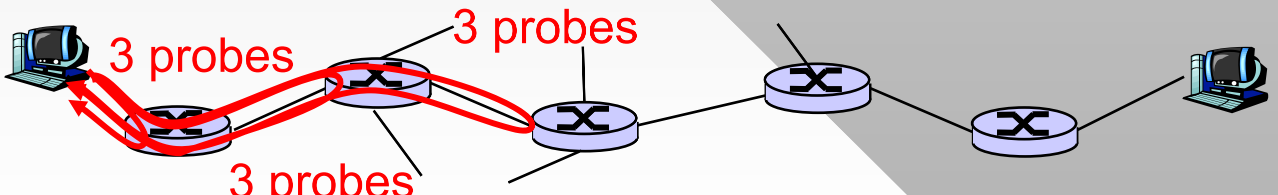


Traffic intensity $\rho = La/R$

- $\rho \approx 0$: average queueing delay is small
- $\rho \geq 1$: more "work" arriving than can be serviced, average delay is infinite
- $\rho \to 1$: delay quickly shoots up

“Real” Internet Delays and Routes

- What do “real” Internet delay & loss look like?
- Traceroute (tracert in Windows): provides delay measurement from source to all routers along end-end Internet path towards destination. For all i:
  - Sends three packets that reach router i on path towards destination
  - Router i returns a response 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 at first hop

```
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
```

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

Packet Loss

- Queues have finite capacity
- When packets arrive to a full buffer, they are dropped (aka lost) – drop-tail queuing
- Lost packet may be retransmitted by previous router, by the source (end system), or not at all
- Loss rate: average fraction of data lost over a long period of time
- Example: link capacity $R = 10$ Mbps and total arrival rate of traffic is 11 Mbps
  - Q: What's the average loss rate on the link?
  - A: About 9%

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Protocol "Layers"

Networks are complex!

- Many "pieces"
  - Hosts
  - Routers
  - Links of various media
  - Applications
  - Protocols
- Some type of modular organization is desirable

Solution: Layered structure

- Same host: each layer interacts only with adjacent (upper/lower) layers
- Remote host: each layer talks to identical layer on the other end-host

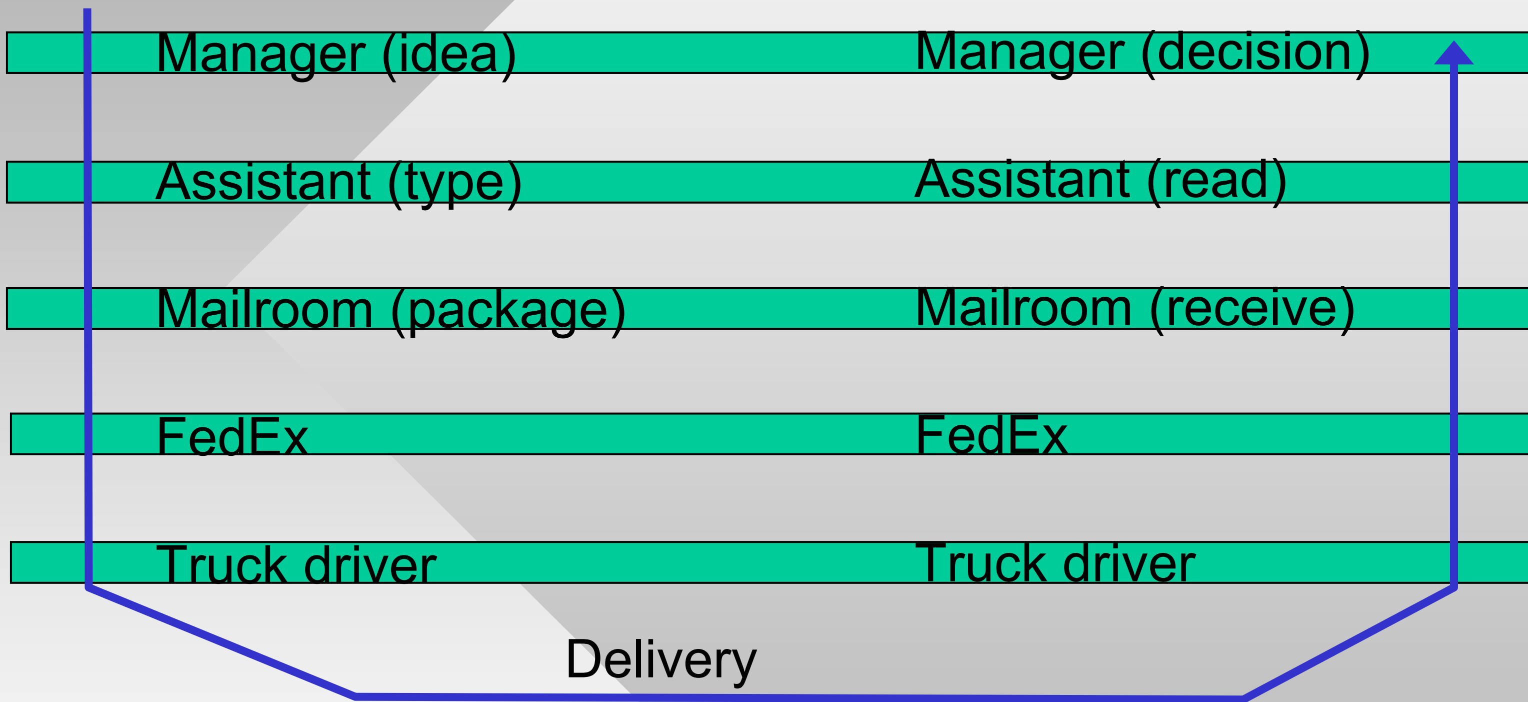
Layering

New York	Los Angeles
Manager (idea)	Manager (decision)
Assistant (type)	Assistant (read)
Mailroom (package)	Mailroom (receive)
FedEx	FedEx
Truck driver	Truck driver

Delivery

- Information travels down the protocol stack on the sender side and up on the receiver side

Layering



Layers: each layer implements a service

- Via its own internal-layer actions
- Relying on services provided by the layer below
- Talks to same layer on the other host

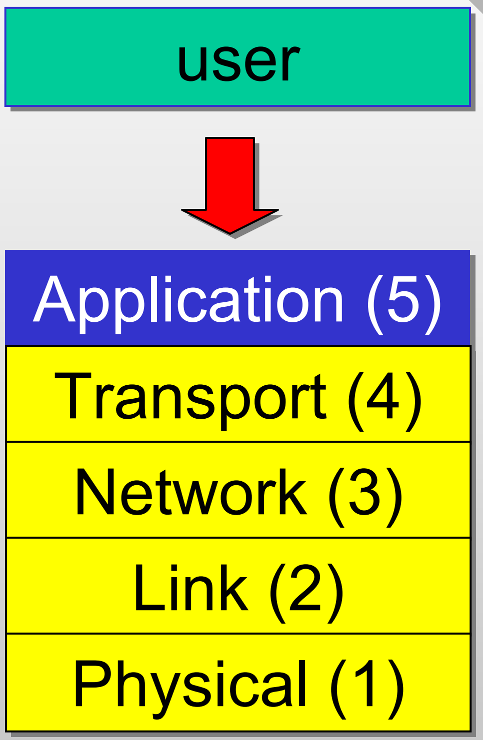
Why Layering?

Benefits of layered organization:

- Sufficient to specify only the relationship between the system's pieces
  - Instead of defining one big protocol that does everything
  - Complexity reduced by separately standardizing individual components
- Modularization eases maintenance and upgrade
  - Change of implementation of layer's service transparent to the rest of system
  - For example, change in FedEx truck routing doesn't affect other layers

Internet Protocol Stack

- Application: interacts with user and supports network applications
  - FTP, SMTP, HTTP (ch 2)
- Transport: inter-process data transfer
  - TCP, UDP (ch 3)
- Network: routing of datagrams from source to destination host
  - IP, routing protocols (ch 4)
- Link: data transfer between neighboring network elements
  - 802.11b, Ethernet (ch 5)
- Physical: bits “on the wire”
  - Not covered in this class



Encapsulation