Computer Networks COL 334/672

Measuring Internet Performance

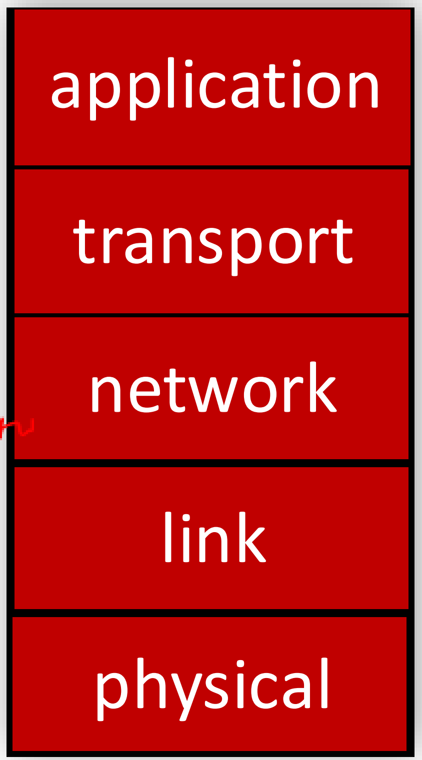
Sem 1, 2025-26

Recap

① Proc to proc
② Reliability
③ In-order delivery
④ Congestion control

Protocols are one implementation of layers

- Internet design philosophy
  - Network of networks – any network can connect
  - Packet switching for cost-effective resource sharing
  - End-to-end principle: dumb network, intelligent end-hosts
- 5-layered Internet Protocol (IP) stack



- **This class: How do we measure the performance of a network?**

Why? ***you can't improve what you can't measure***

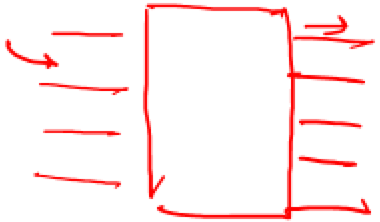
How would you characterize a network performance?

- Latency or delay
- Throughput
- Loss

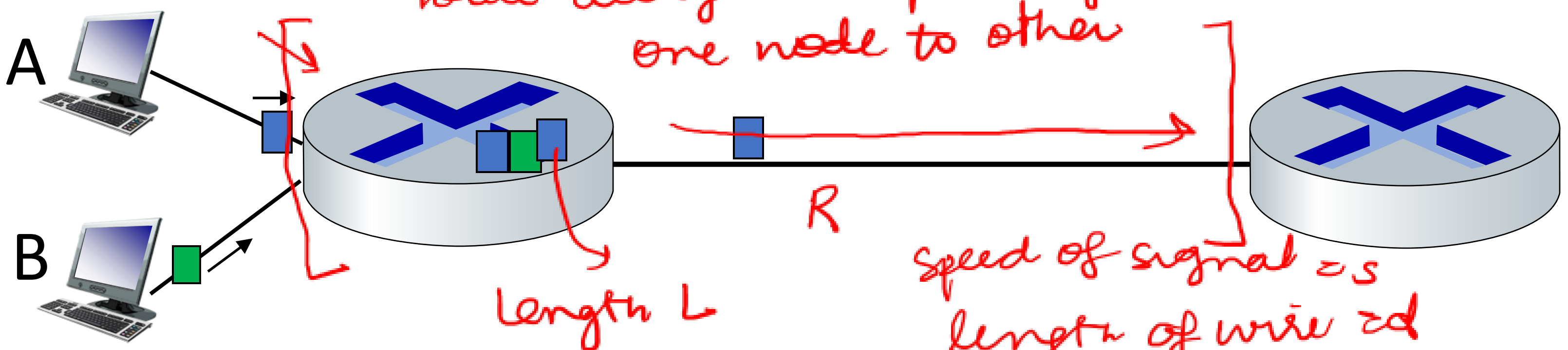
Sources of packet delay

d_{nodal} =

Total delay corresponding to ~~a node~~ sending a pkt from one node to other



switching



R

length L

speed of signal = s

length of wire = d

$d_{propagation}$:

time it takes to traverse over the link

$= d/s$

$d_{nodal} = d_{processing\ delay} + d_{queuing\ delay} + d_{transmission} + d_{propagation}$

$d_{processing}$

↳ Figuring out the output port

↳ Error detection

$d_{queuing}$

↳ Amount of time packet spends in the router buffer

$d_{transmission}$

↳ time taken to transmit packet

L/R

Caravan analogy

Transmission vs propagation

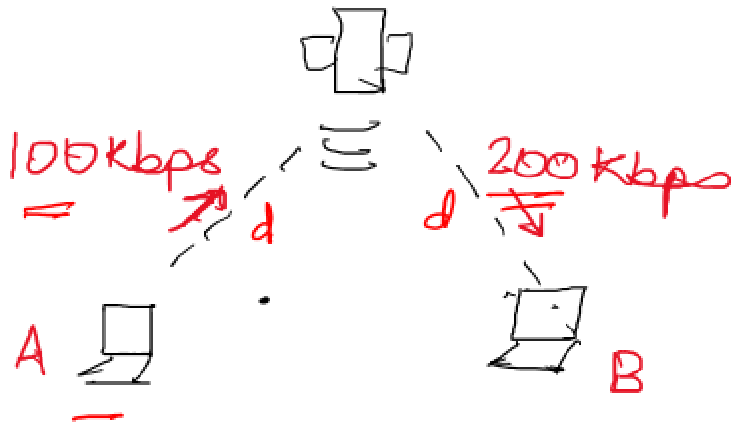
$d_{\text{Toll booth}}$ = 2 minutes

$d_{\text{propagation}}$ = 60 mins

d_{total} = 62 mins

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

Problem



$d = 30{,}000$ km

packet size $= 1000$ bits

signal speed $= 3 \times 10^8$ m/s

Q: How long does it take to send a packet from A to B?

$$d_{propagation} = d/s = 2 \times \frac{3 \times 10^7}{3 \times 10^8} = 200\,ms$$

$$d_{transmission} = \frac{L}{r_1} + \frac{L}{r_2} = 1000\left(\frac{1}{10^5} + \frac{1}{2 \times 10^5}\right)$$

$$= 10\,ms + 5\,ms$$

$$= 15\,ms$$

$= 215\,ms$

M/M/1 queue

M/D/1 queue

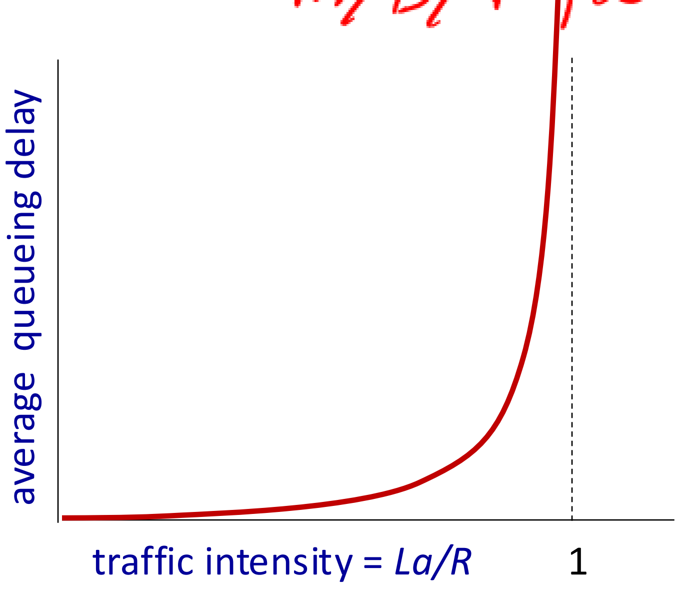
Packet queueing delay (revisited)

avg queuing delay $= \dfrac{\lambda}{\mu(\lambda - \mu)}$

- *a:* average packet arrival rate
- *L:* packet length (bits)
- *R:* link bandwidth (bit transmission rate)

$\lambda = L \cdot a$, $\mu = R$

$$\frac{L \cdot a}{R} : \frac{\text{arrival rate of bits}}{\text{service rate of bits}} \quad \text{“traffic intensity”}$$



- *La/R* ~ 0: avg. queueing delay small
- *La/R* -> 1: avg. queueing delay large
- *La/R* > 1: more “work” arriving is more than can be serviced - average delay infinite!

La/R ~ 0

La/R -> 1

Packet queueing delay (revisited)

- *a:* average packet arrival rate
- *L:* packet length (bits)
- *R:* link bandwidth (bit tra

$$\frac{L \cdot a}{R} \quad : \quad \frac{\text{arrival rate of bi}}{\text{service rate of b}}$$

$La/R < 1$

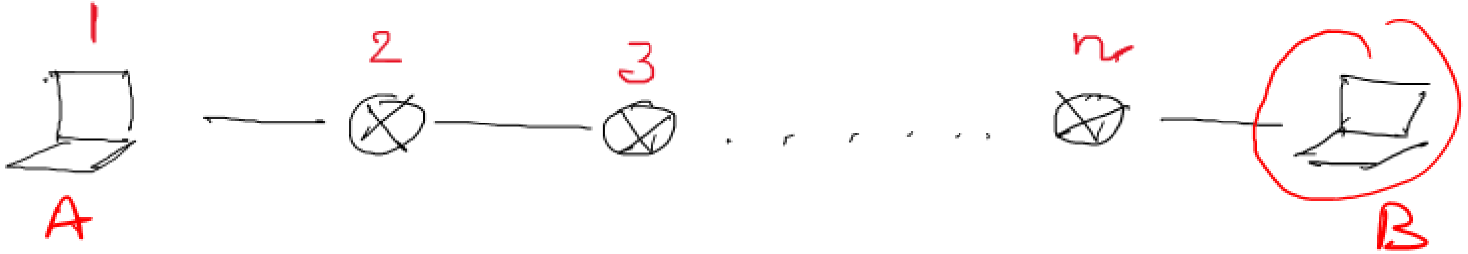
- La/R ~ 0: avg. queuei
- La/R -> 1: avg. queue
- La/R > 1: more "work more than can be se delay infinite!

Balaji Prabhakar: Can digital incentives help alleviate traffic?

Researchers are reducing traffic congestion and commute times using networks that gently nudge people toward better travel habits.

He calls it "nudging," and says that small shifts in commute times — just 20 minutes earlier or later — can make a considerable impact on the day's congestion in highly trafficked urban areas, like San Francisco.

End-to-end delay



- What is end-to-end delay?

$$d_{end\text{-}to\text{-}end} = \sum_{i=1}^{n} d^{i}_{nodal}$$

$$= \sum_{i=1}^{n} \left(\underline{d^{i}_{prop} + d^{i}_{trans} + d^{i}_{proc}} + d^{i}_{queuing} \right)$$

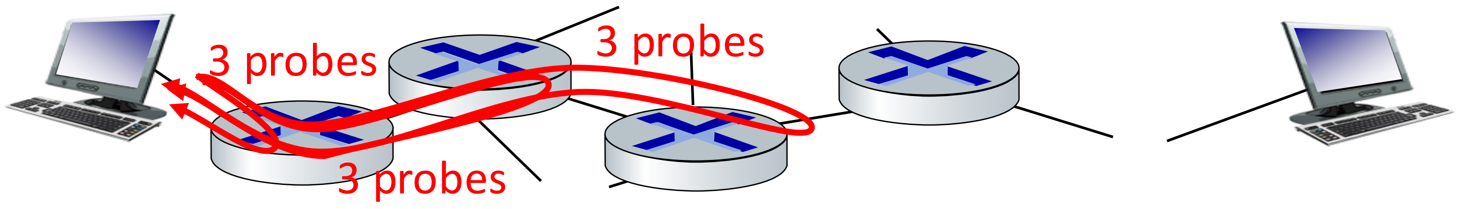
One-way delay : source to destination : clock synchronization

round-trip time : ping

delay jitter

How do you measure delay on network?

- **Network operator:** directly query each router in the network (e.g., using SNMP protocol)
- **End user:** various utilities
  - **ping**
  - **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 (with time-to-live field value of *i*)
    - router *i* will return packets to sender
    - sender measures time interval between transmission and reply



Real Internet delays and routes

traceroute: airtel network to 1.1.1.1

```
traceroute to 1.1.1.1 (1.1.1.1), 64 hops max, 40 byte packets
 1  192.168.1.1 (192.168.1.1)  11.500 ms  8.883 ms  8.043 ms
 2  abts-mh-dynamic-001.34.169.122.airtelbroadband.in (122.169.34.1)  6.331 ms  9.668 ms  9.866 ms
 3  182.78.219.37 (182.78.219.37)  9.468 ms
    182.78.219.41 (182.78.219.41)  6.546 ms
    182.78.219.37 (182.78.219.37)  8.043 ms
 4  116.119.55.232 (116.119.55.232)  15.910 ms
    116.119.109.77 (116.119.109.77)  9.001 ms
    116.119.73.221 (116.119.73.221)  8.572 ms
 5  * 182.79.223.5 (182.79.223.5)  31.429 ms  24.942 ms
 6  104.23.231.5 (104.23.231.5)  9.569 ms  11.494 ms  9.524 ms
 7  one.one.one (1.1.1.1)  14.574 ms  9.953 ms  8.987 ms
```