Week2

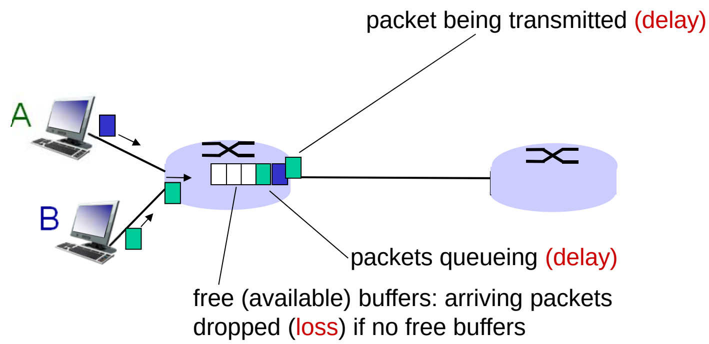
Delay, loss, and throughput in networks

Addresses

How do loss and delay occur?

packets *queue* in router buffers

- packet arrival rate to link (temporarily) exceeds output link capacity
- packets queue, wait for turn



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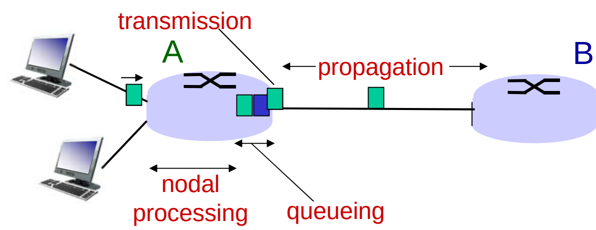
Four sources of packet delay



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

d_{proc}: nodal processing
- check bit errors
- determine output link
- typically < msec

d_{queue}: queueing delay
- time waiting at output link for transmission
- depends on congestion level of router

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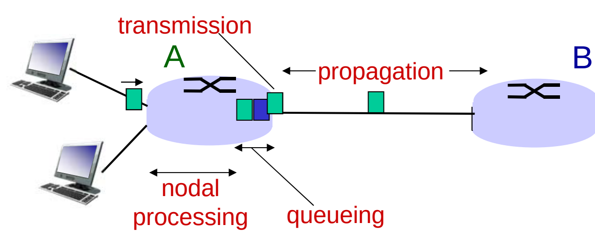
Four sources of packet delay



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

d_{trans}: transmission delay:
- *L*: packet length (bits)
- *R*: link *bandwidth (bps)*
- $d_{trans} = L/R$

d_{trans} and d_{prop} *very* different

d_{prop}: propagation delay:
- *d*: length of physical link
- *s*: propagation speed in medium (~2×10^8 m/sec)
- $d_{prop} = d/s$

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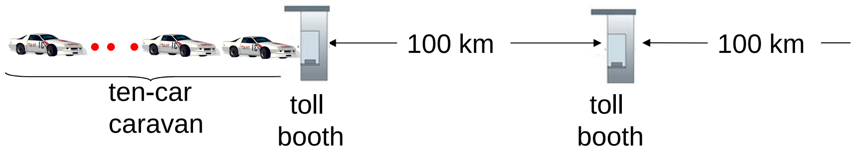
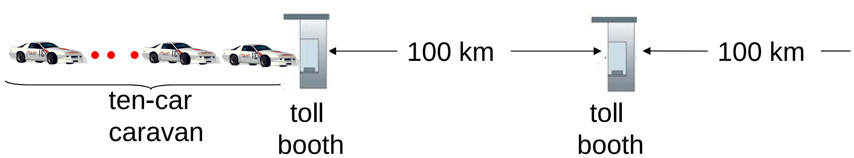
Caravan analogy



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



- suppose cars now "propagate" at 1000 km/hr
- and suppose toll booth now takes one min to service a car
- *Q:* Will cars arrive to 2nd booth before all cars serviced at first booth?
  - *A: Yes!* after 7 min, 1st car arrives at second booth; three cars still at 1st booth.

Exercise

Consider two hosts, A and B, are separated by 5,000 kilometers and are directly connected by a link with transmission rate R=10Mbps. The propagation speed over the link is $2.5*10^8$ meters/sec.

- What is the propagation delay of the link?
- Solution:

  propagation delay

  = link length / propagation speed

  = 5,000,000 m / $2.5*10^8$ meters/sec

  = 0.02 sec

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Exercise

Consider two hosts, A and B, are separated by 5,000 kilometers and are directly connected by a link with transmission rate R=10Mbps. The propagation speed over the link is $2.5*10^8$ meters/sec.

- Consider only one file of 50,000 bits from Host A to Host B. What is the transmission delay?
- Solution:

  transmission delay

  = file size / transmission rate

  = 50,000 bits / $10*10^6$ bits/s

  = 0.005 sec

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Exercise

Consider two hosts, A and B, are separated by 5,000 kilometers and are directly connected by a link with transmission rate R=10Mbps. The propagation speed over the link is $2.5*10^8$ meters/sec.

- How to interpret the bandwidth –propagation delay product?
- Solution:

  bandwidth-propagation delay product

  = $10*10^6$ bits/s * 0.02 sec

  = $2*10^5$ bits

  The amount of data that could be in transit in the link.

Exercise

Consider two hosts, A and B, are separated by 5,000 kilometers and are directly connected by a link with transmission rate R=10Mbps. The propagation speed over the link is $2.5*10^8$ meters/sec.

- What is the width (in meters) of a bit in the link?
- Solution:

  width = propagation speed * transmission time for one bit

  = propagation speed / transmission rate

  = $2.5*10^8$ meters/sec / $10*10^6$ bits/sec

  = 25 meters/bit

Exercise

Consider two hosts, A and B, are separated by 5,000 kilometers and are directly connected by a link with transmission rate R=10Mbps. The propagation speed over the link is $2.5*10^8$ meters/sec.

- Suppose a 5000bits file is sent continuously as one big message. What is the maximum number of bits that will be in the link at any given time?
- Solution:

link distance / bit width

= 5,000,000 m / 25 meters/bit

= $2*10^5$ bits > 5000 bits, so the solution is 5000 bits.

propagation delay * transmission rate

= 0.02 sec * $10*10^6$ bits/sec

= $2*10^5$ bits > 5000 bits, so the solution is 5000 bits.

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Exercise

Consider two hosts, A and B, are separated by 5,000 kilometers and are directly connected by a link with transmission rate R=10Mbps. The propagation speed over the link is $2.5*10^8$ meters/sec.

- Let x denote the size of the file, what is the minimum value of x for the link to be continuously transmitting?
- solution

link distance / bit width

= 5,000,000 m / 25 meters/bit

= $2*10^5$ bits

propagation delay * transmission rate

= 0.02 sec * $10*10^6$ bits/sec

= $2*10^5$ bits

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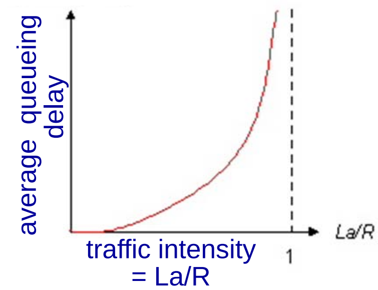
Queuing delay

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



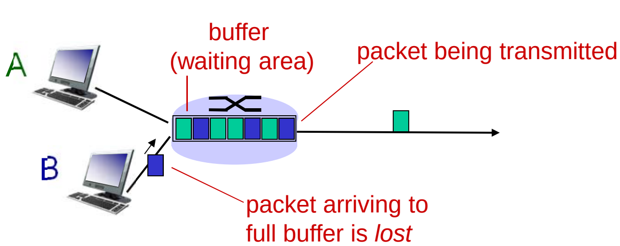
- *La/R* ~ 0: avg. queueing delay small
- *La/R* -> 1: avg. queueing delay large
- *La/R* > 1: more "work" arriving than can be serviced, average delay infinite!

La/R ~ 0

La/R -> 1

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



End-to-End Delay

- Suppose there are N-1 routers between the source and the destination

$$\boxed{D_{\text{end-end}} = N\,(d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}})}$$

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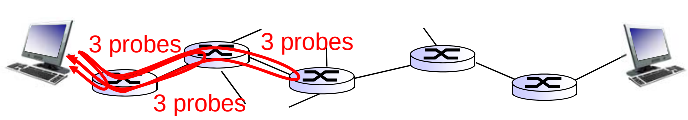
"Real" Internet delays and routes

- 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.



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"Real" Internet delays, routes

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

3 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)

* Do some traceroutes from exotic countries at www.traceroute.org

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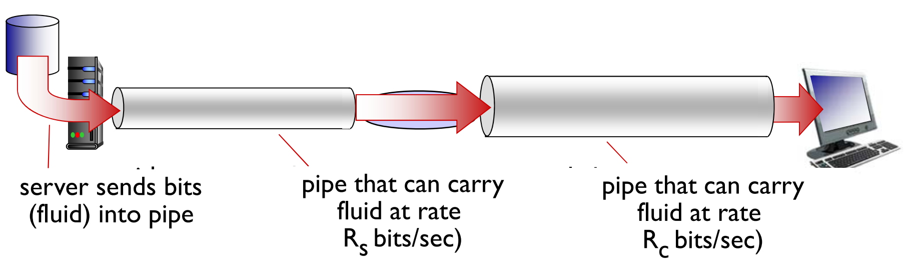
Throughput

- *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



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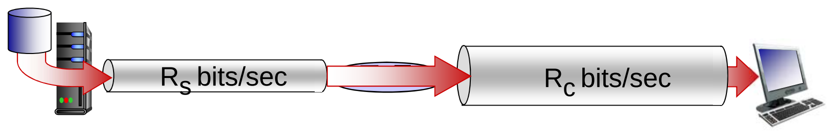
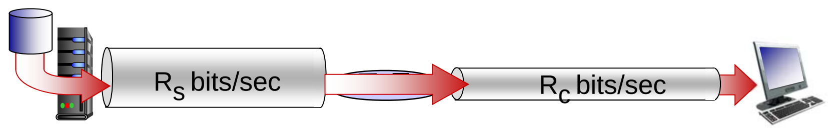
Throughput (more)

- $R_s < R_c$ 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

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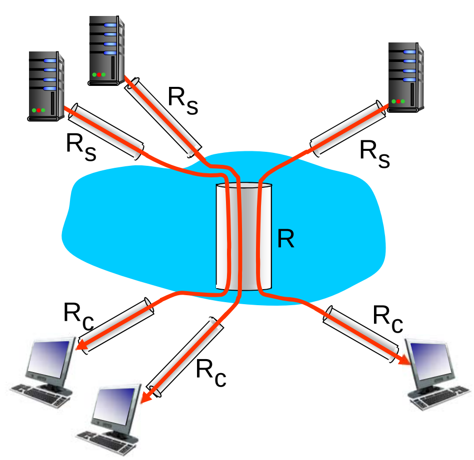
Throughput: Internet scenario

- 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

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Addressing

- Physical address (aka link address)
  - E.g.: 07:01:02:01:2C:4B
- Logical address: IP
  - No two publicly addressed and visible hosts on the Internet can have the same IP
  - ARP/RARP: physical address ←→ IP address
- Port address
  - E.g.: 80 web port
- Others: URL, easy to remember
  - DNS: URL→IP