Network Performance

Objectives: What are the basic aspects (delay, throughput, loss) of end-to-end network performance? Why do they matter for different applications? How are they defined? Introduction of network tools: ping(8) and traceroute(8).

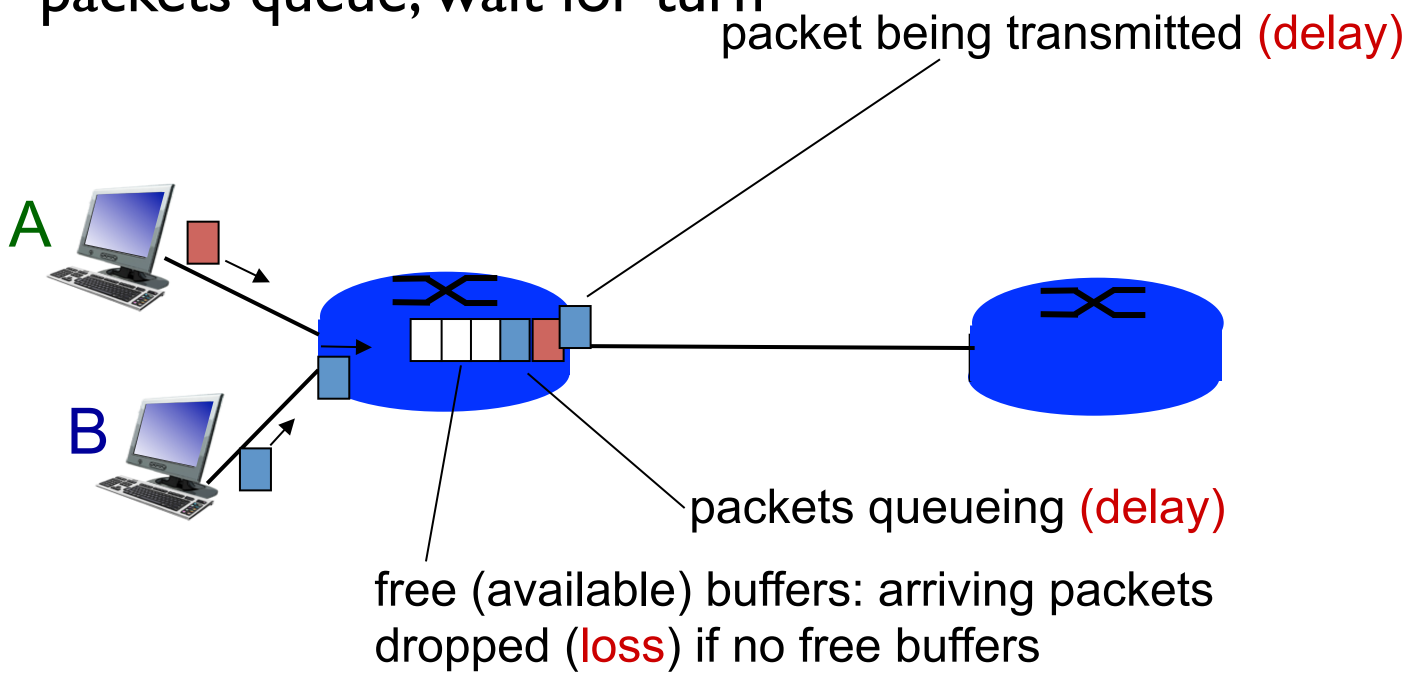
NS2: March 16, 2016

Textbook (K&R): Section 1.4

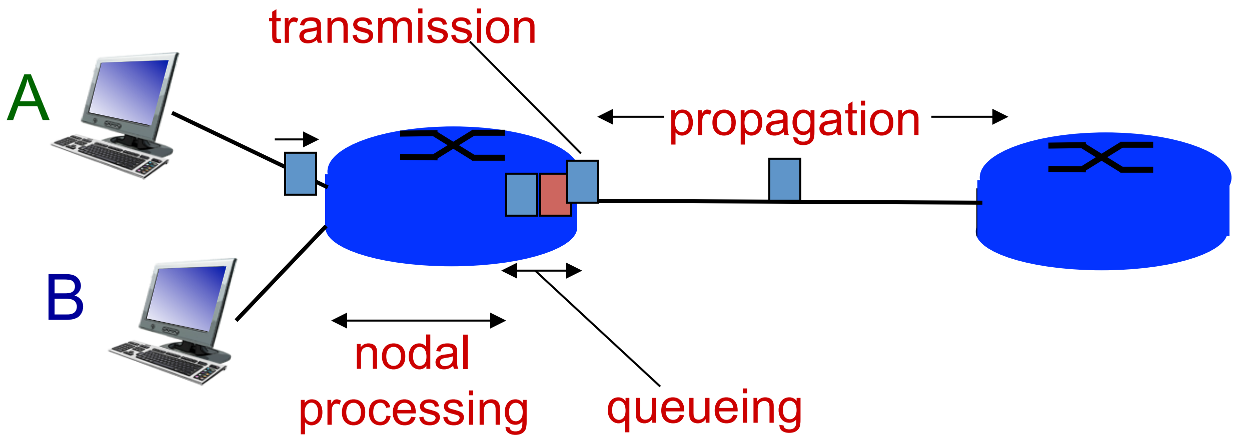
What happens when packet arrives at router?

packets *queue* in router buffers

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



Four sources of packet delay



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

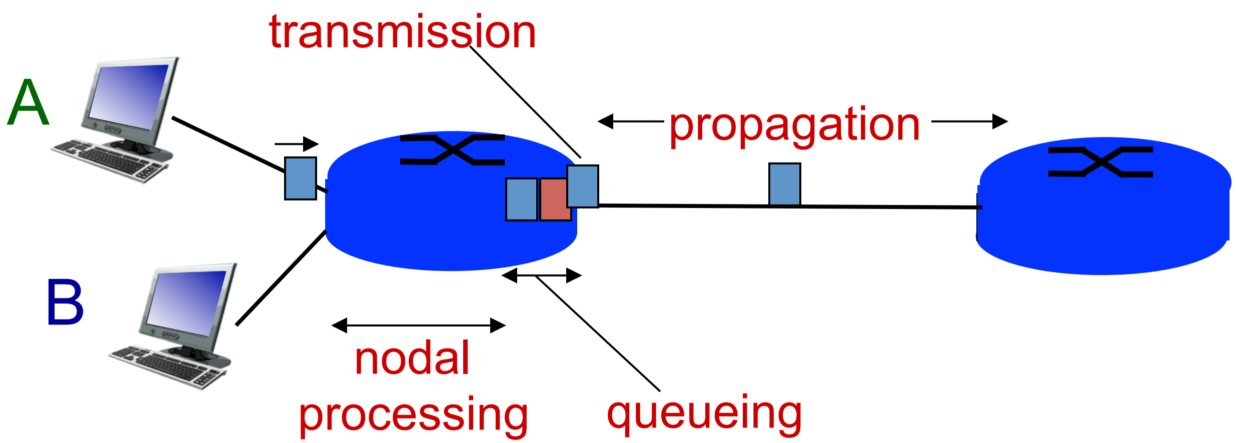
d_{proc}: nodal processing

- 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

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)*
- $d_{trans} = L/R$

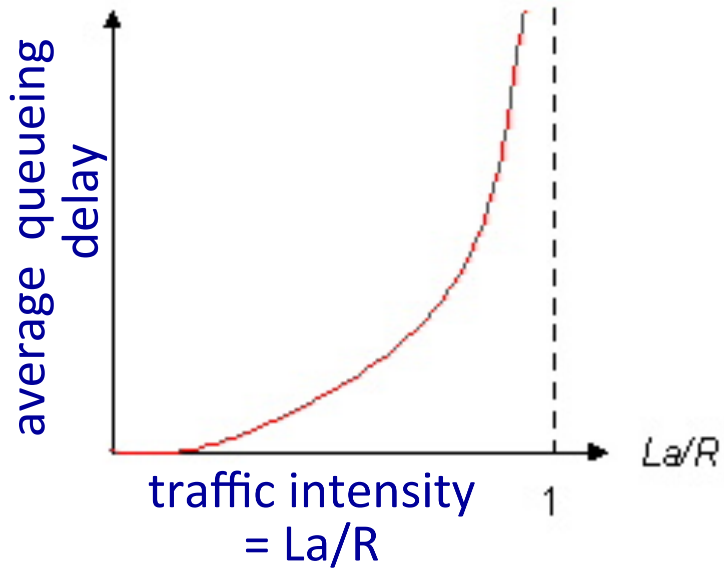
d_{trans} and d_{prop}
very different

d_{prop}: propagation delay:

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

Queueing delay (revisited)

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



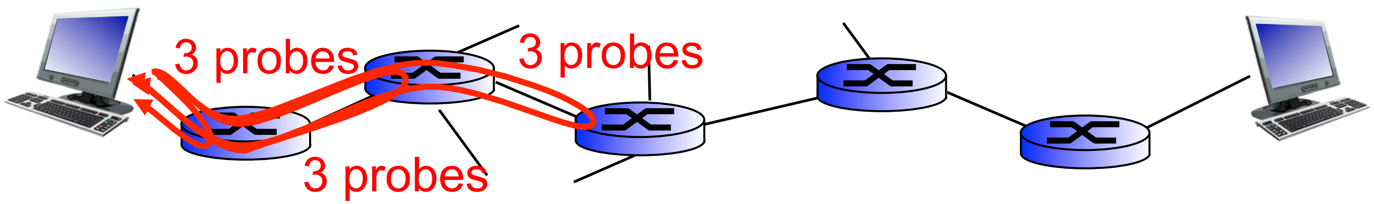
- *La/R* ~ 0: avg. queueing delay small
- *La/R* -> 1: avg. queueing delay large
- *La/R* > 1: more "work" arriving than can be serviced, average delay infinite!


La/R ~ 0


La/R -> 1

"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.



Ping: Hi, are you there?

- % ping aranjuez.cs.purdue.edu
- Alive: Yes, I’m here! (w/ RTT)
- No answer ≠ I’m dead
  - Why? Hey, it’s ICMP!
  - % ping www.microsoft.com
- For more details, as always
  - % man ping
  - note arguments + command line options

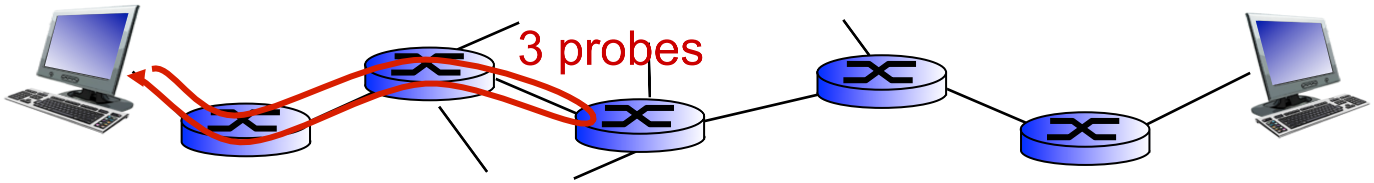
Traceroute and ICMP

- source sends series of UDP segments to dest
  - first set has TTL =1
  - second set has TTL=2, etc.
  - unlikely port number
- when *n*th set of datagrams arrives to nth router:
  - router discards datagrams
  - and sends source ICMP messages (type 11, code 0)
  - ICMP messages includes name of router & IP address

- when ICMP messages arrives, source records RTTs

stopping criteria:

- UDP segment eventually arrives at destination host
- destination returns ICMP "port unreachable" message (type 3, code 3)
- source stops



“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)

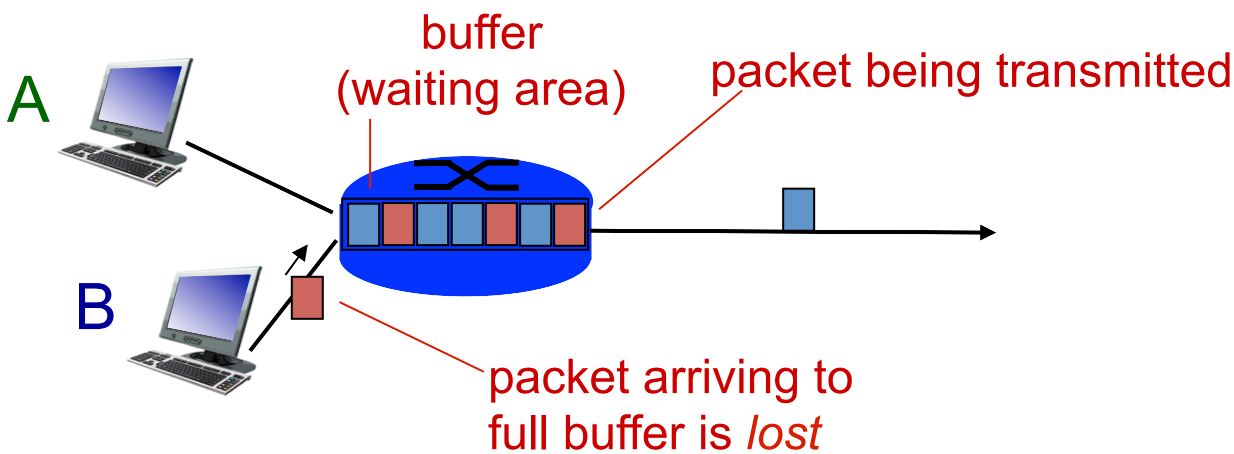
* Do some traceroutes from exotic countries at www.traceroute.org

More on ICMP

- Runs at both end hosts and routers
  - Traceroute: ICMP TTL Exceeded, ICMP port unreachable (no app is interested in the packet)
  - Ping: ICMP echo request/reply
- Mostly FYI: information about interesting events in the network
- Not critical for normal operation
- Hence, not unusual for it to be
  - Disabled
  - Misconfigured
  - Buggy (see "man –s 8 traceroute" for examples)

Packet loss

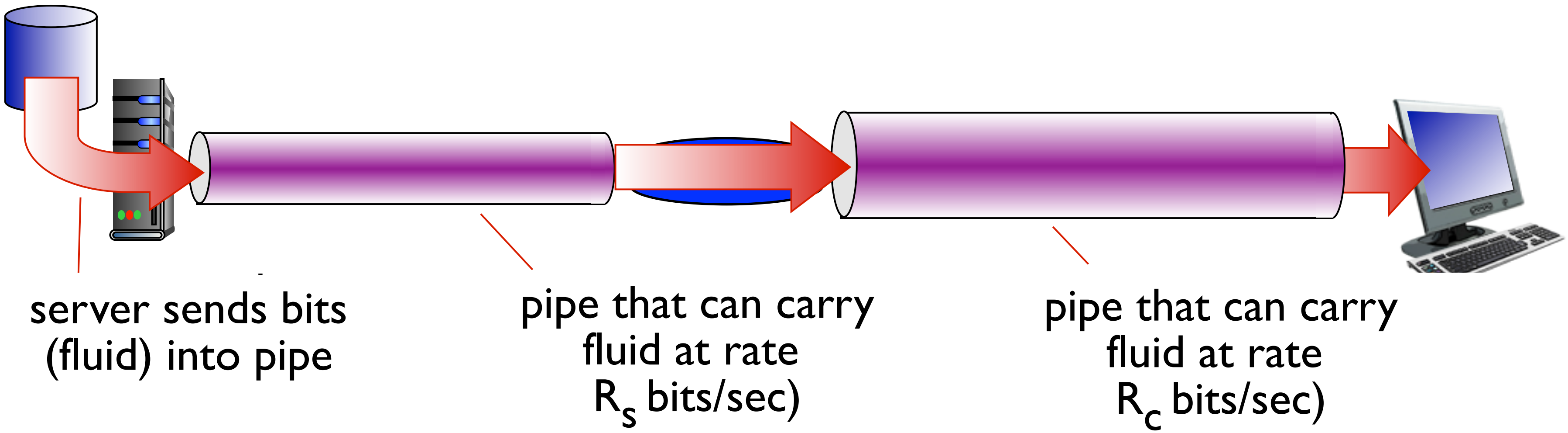
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



Impact on applications: Email? Banking? Images? Video?

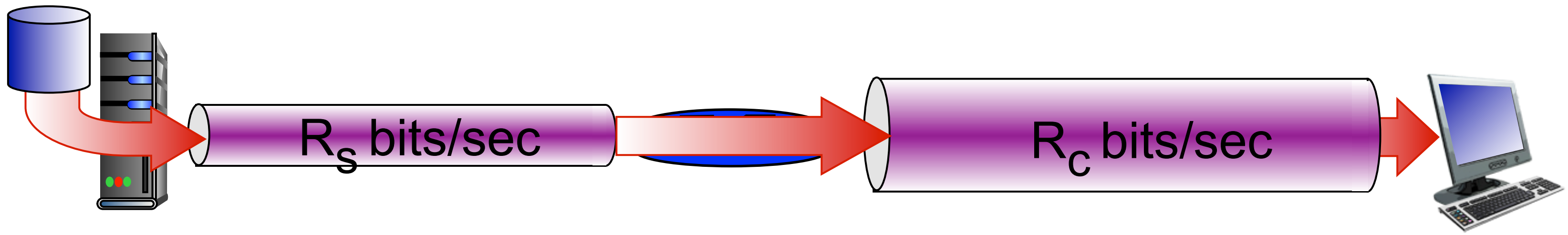
Throughput

- *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
- Some link "speeds" (throughput): T1 line (1.5Mbps); Fast Ethernet (100Mb/s); T3 line (43Mbps); Gigabit Ethernet (1Gb/s); OC48 (2.5Gbps); OC192 (9.95Gbps)



Throughput (more)

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



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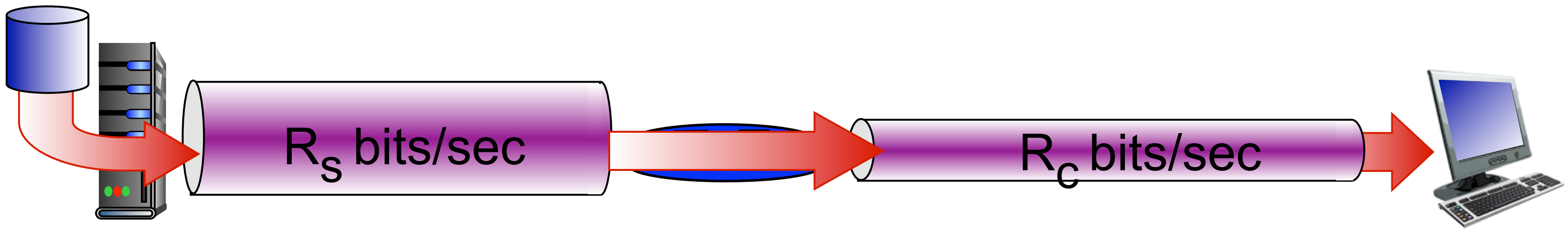


bottleneck link

link on end-end path that constrains end-end throughput

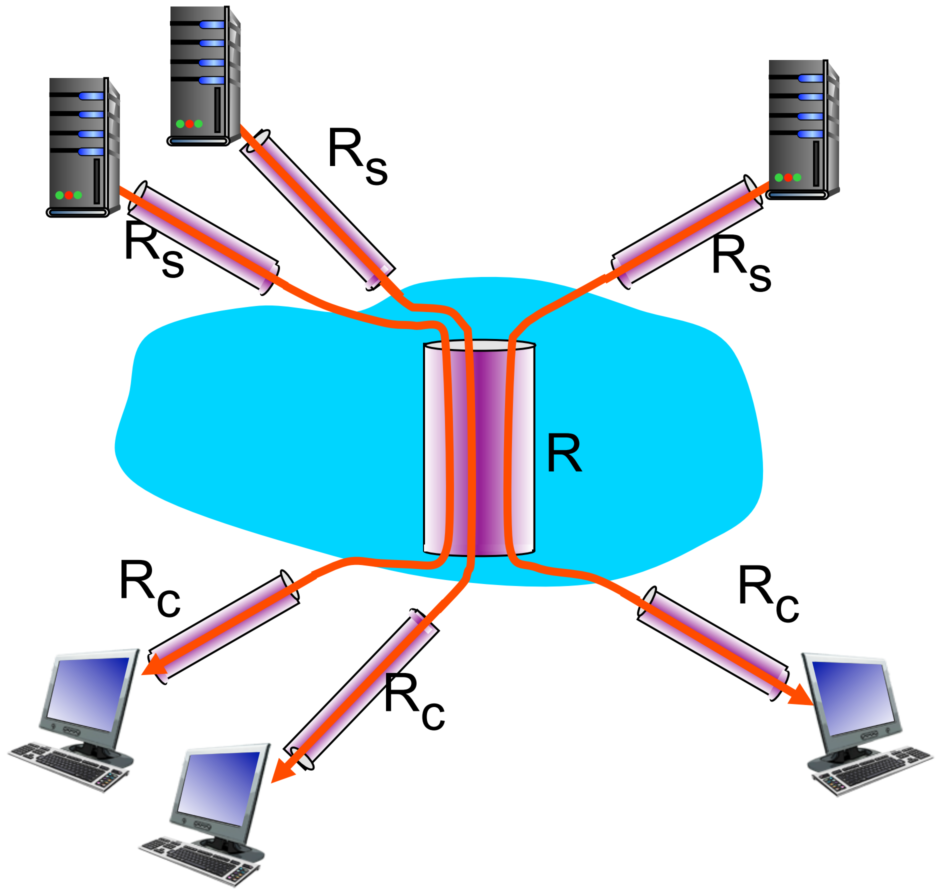
Activity 2.1

- An end-to-end network path *P* consists of three links 1, 2, 3.
- Link 1: delay 2ms, throughput 100Mb/s, loss rate: 5%; Link 2: 60ms, 1Gb/s, 10%; Link 3: 5ms, 10Mb/s, 10%
- What are *P*'s delay, throughput, and loss rate?
  – Assume that losses are independent

NB: Strictly speaking, 1k=1024, 1M=1024^2, etc. **But** in your calculations, use **1k=1000, 1M=10^6**, etc, whenever doing so simplifies your life.

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

Activity 2.2

- Give an example A of an Internet application that transfers lots of data (bulk data) in one direction.
- Give an example B of an Internet application that does mainly a sequence smaller message transfers over long distances in both directions.
- Ignoring resource contention due to sharing, what performance metrics mainly impact A vs. B?
- If we upgrade the network core from T3 links to OC48 links, which application (A or B) will likely benefit more?
- What will limit the performance gain for B fundamentally?
- How does loss rate interact with delay (e.g., tradeoff?)?
  - Without retransmission?
  - With retransmission?

Visualize by Space-Time Diagram

U.S. coast-to-coast transfer (5000 km) of L=10 Mbits on a link of "speed" (throughput) R Mb/s

Gigabit Ethernet: R=1000 (i.e., 1Gb/s)
E2e transfer time: 0.035s

Fast Ethernet link: R=100 (Mb/s)
E2e transfer time: 0.125s