COMPUTER NETWORKS

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Computer Networks and the Internet

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Performance: Packet Queueing Delay revisited

Unlike other delays (dproc, dtrans, dprop), dqueue is interesting.

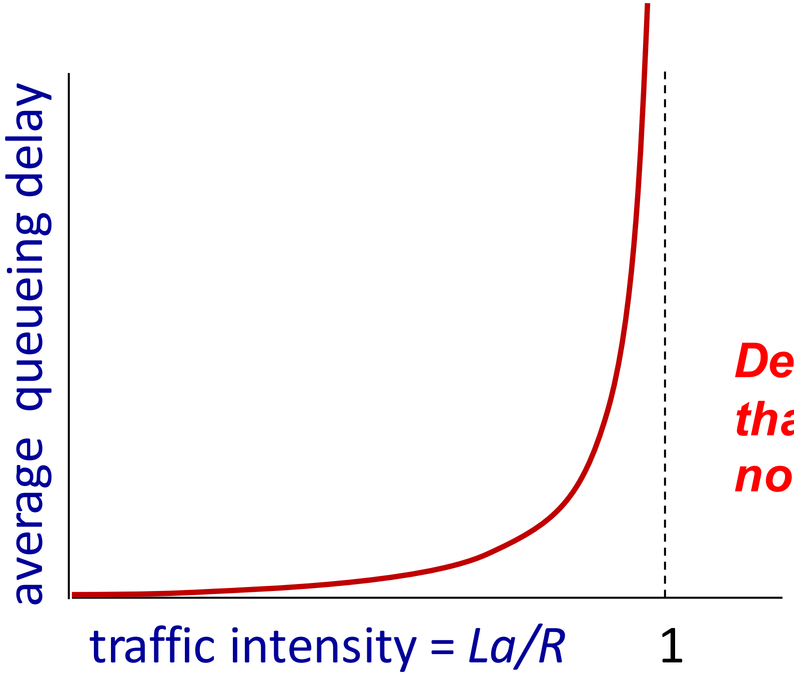
- Can vary from packet to packet.
- Characterize d_{queue} -> average, variance, probability that it exceeds some specified value.

When is the queuing delay large and when is it insignificant?

- Rate at which traffic arrives at the queue,
- Transmission rate of the link,
- Nature of the arriving traffic – periodically or in bursts

Performance: Packet Queueing Delay revisited

- *R:* link bandwidth (bps)
- *L:* packet length (bits)
- *a:* average packet arrival rate (pps)
- La: avg. rate at which bits arrive at the queue



- La/R > 1: more "work" arriving is more than can be serviced - average delay infinite!
- La/R <= 1: nature of arriving traffic
- *La/R* ~ 0: avg. queueing delay small

Design your system so that the traffic intensity is no greater than 1.

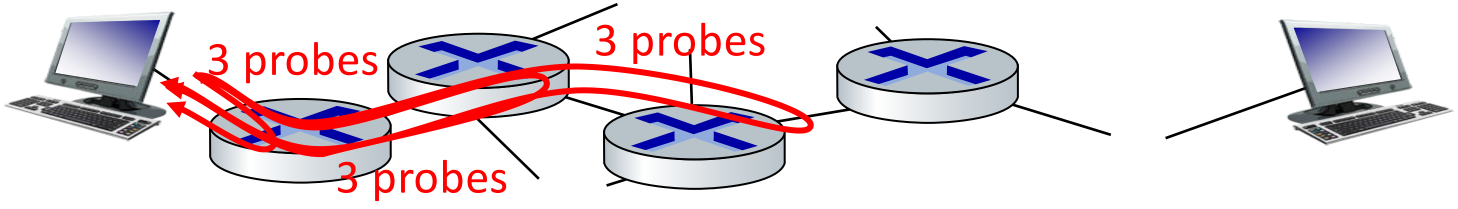
La/R ~ 0

La/R -> 1

La/R > 1: Average rate at which bits arrive at the queue exceeds the rate at which the bits can be transmitted from the queue.

"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 (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: 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
```

3 delay measurements to border1-rt-fa5-1-0.gw.umass.edu

trans-oceanic link

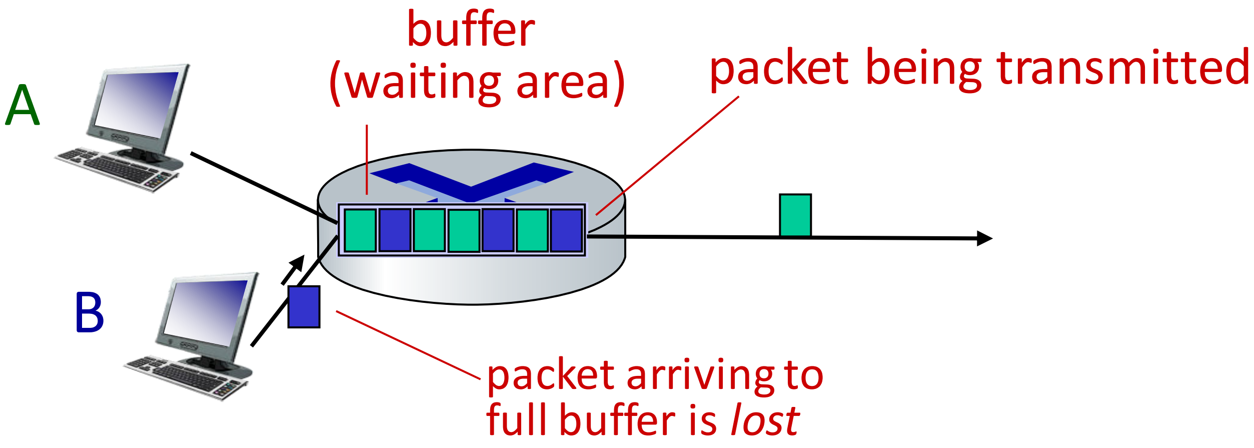
looks like delays *decrease*! Why?

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

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

Performance: Packet loss

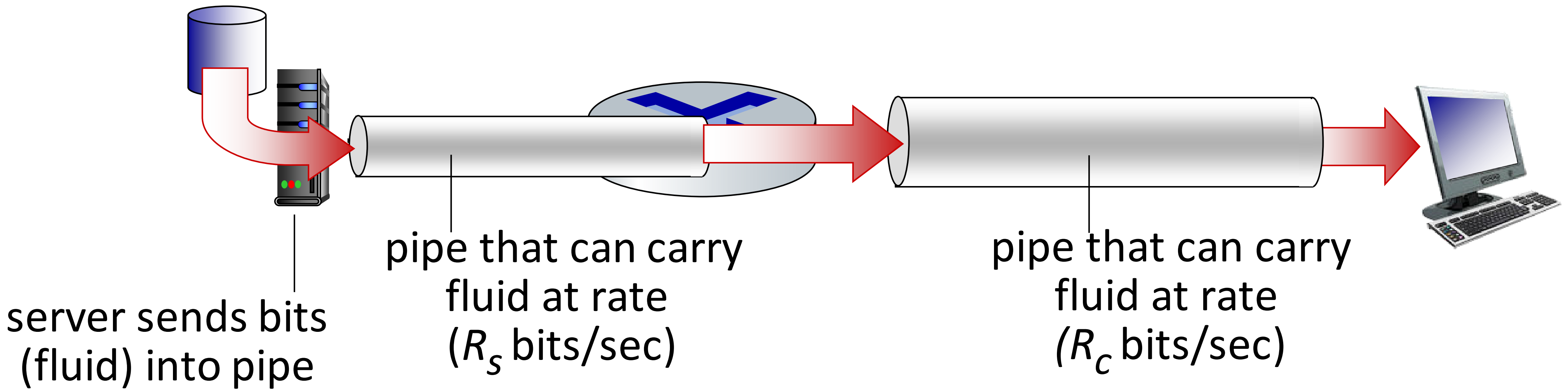
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



* Check out the Java applet for an interactive animation on queuing and loss

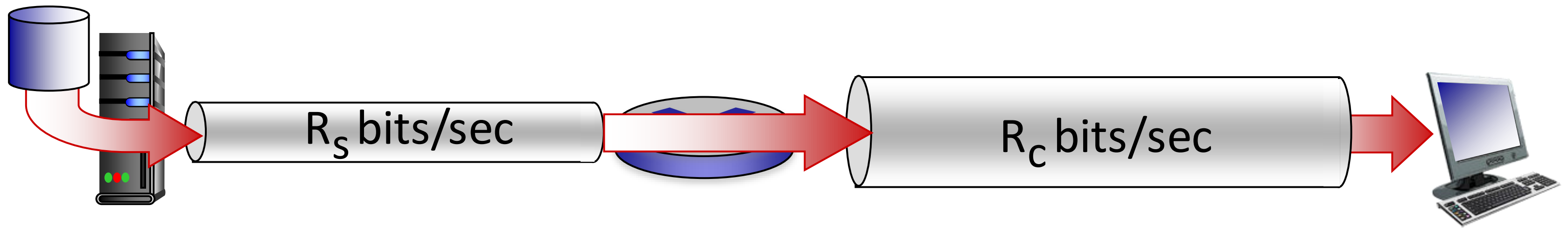
Performance: Throughput

- *throughput:* rate (bits/time unit) at which bits are being sent from sender to receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time

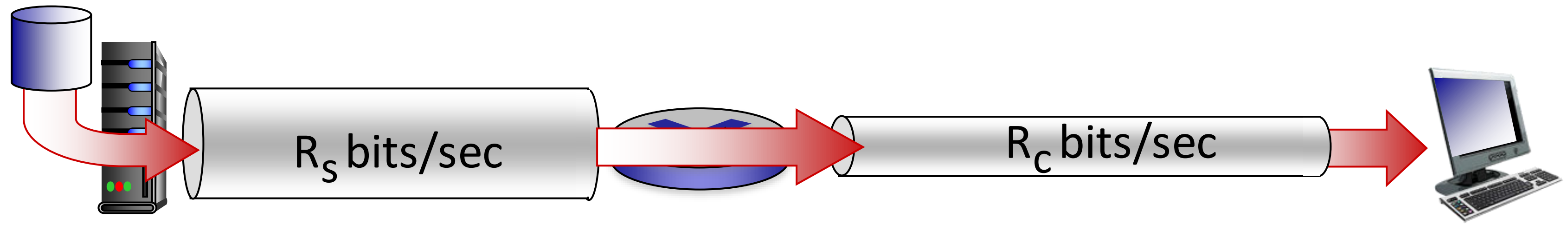


Performance: Throughput (more)

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



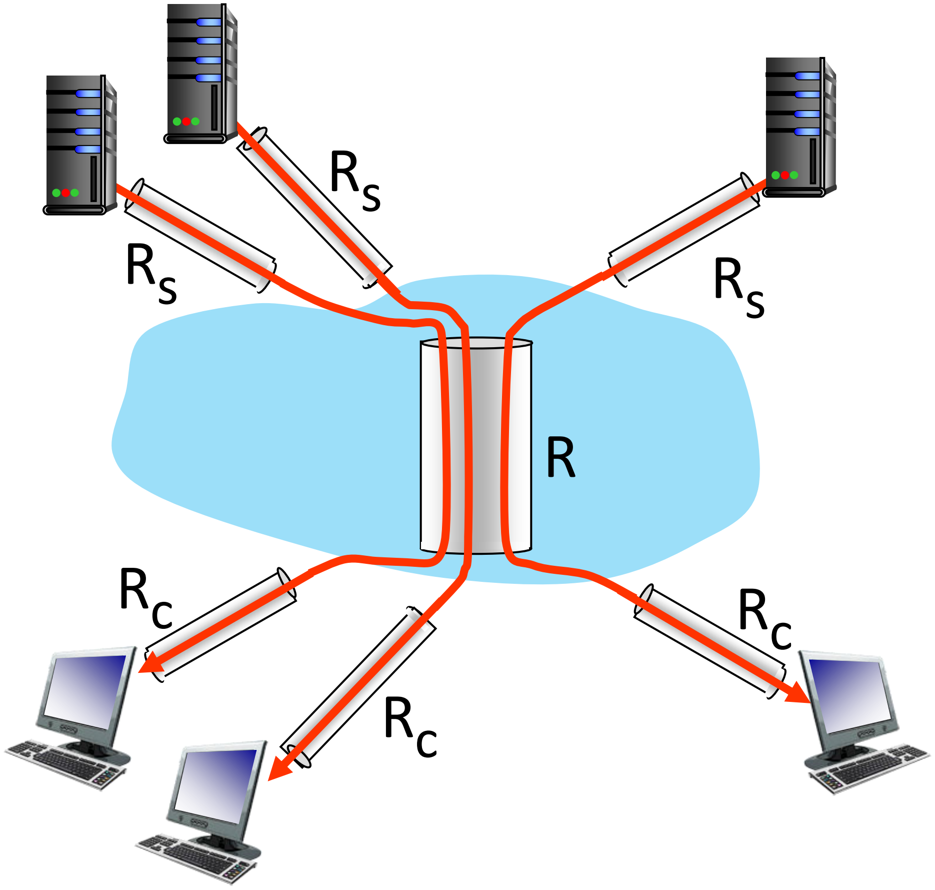
$R_s > R_c$ What is average end-end throughput?



bottleneck link

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

Performance: Throughput – Network Scenario



10 connections (fairly) share backbone bottleneck link *R* bits/sec

- per-connection end-end throughput: *min(R_c,R_s,R/10)*
- in practice: R_c or R_s is often bottleneck

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/

- Suppose Rs = 2 Mbps, Rc = 1 Mbps, R = 5 Mbps
- 10 clients from 10 servers = 10 downloads

End-to-end throughput for each download is now reduced to 500 kbps.

Queries

Thank You
For Your Attention

Q&A

THANK YOU

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