COMPUTER NETWORKS

Computer Networks and the Internet

Team Networks
Department of Computer Science and Engineering

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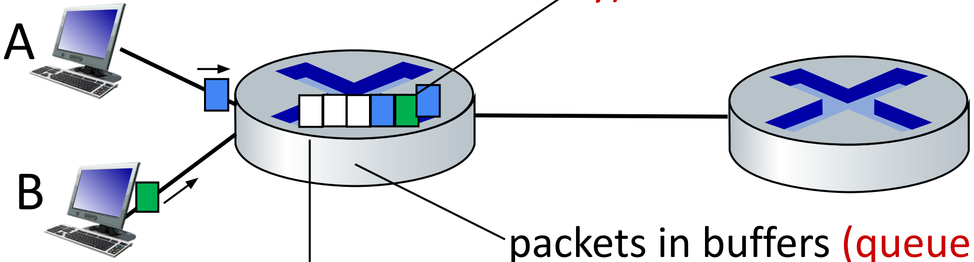
Unit – 1 Computer Networks and the Internet

How do packet loss and delay occurs?

packets *queue* in router buffers

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

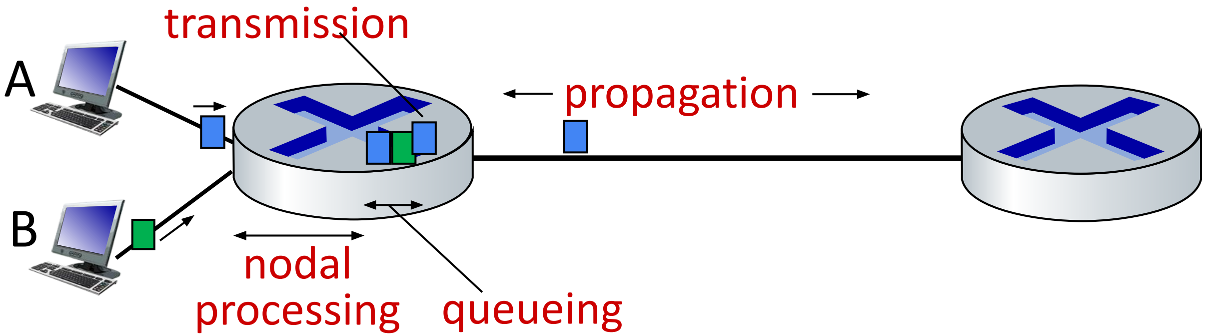
packet being transmitted (transmission delay)



packets in buffers (queueing delay)

free (available) buffers: arriving packets
dropped (loss) if no free buffers

Performance: Packet Delay – 4 Sources

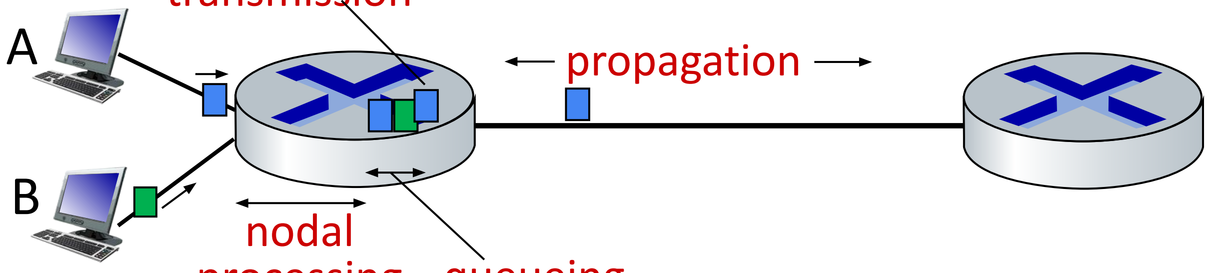


$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

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
- microseconds to milliseconds

Performance: Packet Delay – 4 Sources



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

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

d_{trans}: transmission delay:

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

d_{prop}: propagation delay:

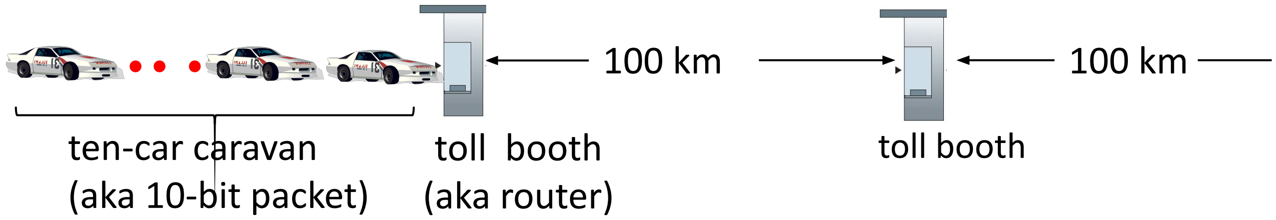
- d: length of physical link
- s: propagation speed (~2×10^8 m/sec)
- $d_{\text{prop}} = d/s$

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

Transmission Delay vs Propagation Delay

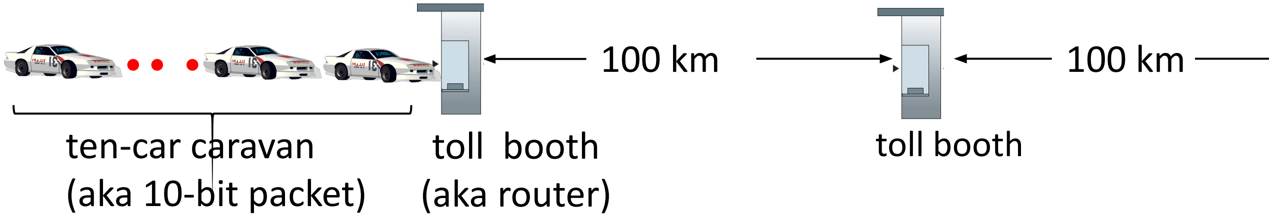
Transmission Delay	Propagation Delay
Time required for the router to push out the packet.	Time it takes a bit to propagate from one router to the next.
A function of the **packet's length** and the **transmission rate** of the link.	A function of the **distance** between the two routers.
$d_{trans} = L/R$	$d_{prop} = d/s$
Nothing to do with the distance between the two routers.	Nothing to do with the packet's length or the transmission rate of the link.

Performance: Delay – 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

Performance: Delay – 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, first car arrives at second booth; three cars still at first booth

Performance: Packet Queueing Delay revisited

Unlike other delays (d_{proc}, d_{trans}, d_{prop}), d_{queue} is interesting.

- Can vary from packet to packet.
- Characterize $\boldsymbol{d}_{\mathbf{queue}}$ -> average, variance, probability that it exceeds some specified value.

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

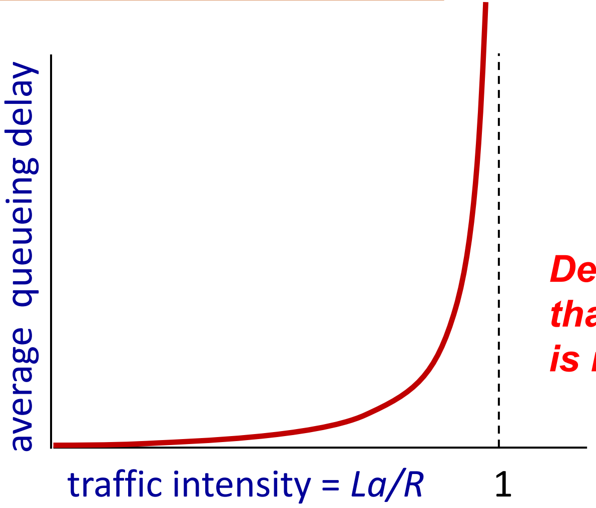
- Rate at which traffic arrives at the queue,
- Transmission rate of the link,
- Nature of the arriving traffic – periodically or in bursts

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

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.



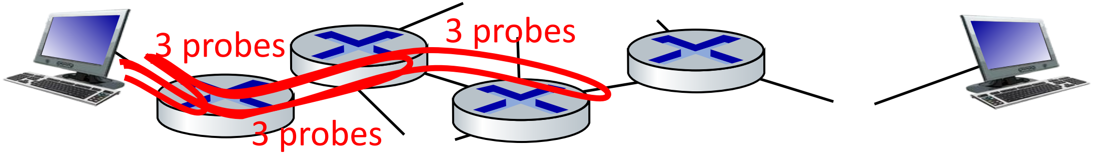
Design your system so that the traffic intensity is no greater than 1.

La/R ~ 0

La/R ->

“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

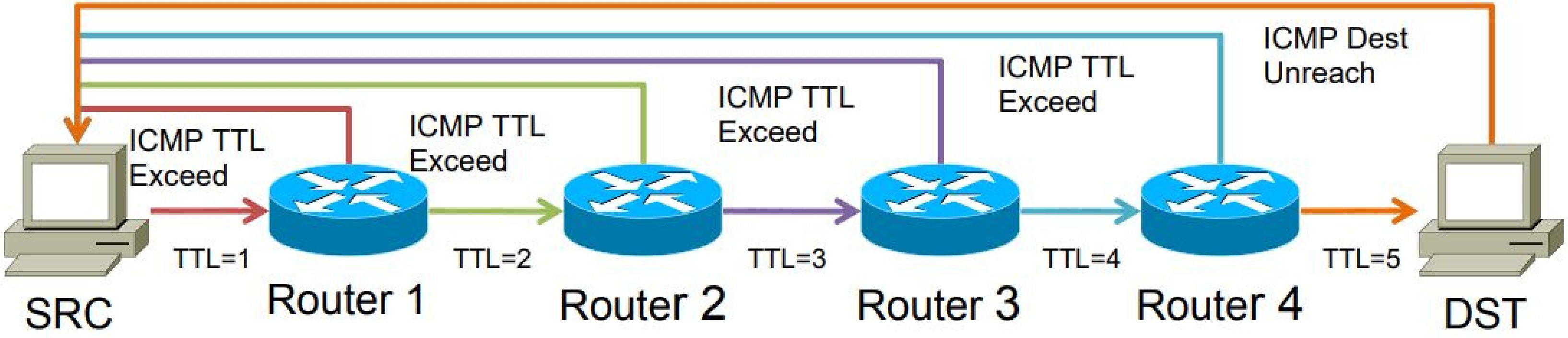
trans-oceanic link

looks like delays *decrease*! Why?

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

* Do some traceroutes from exotic countries at

How Traceroute works?

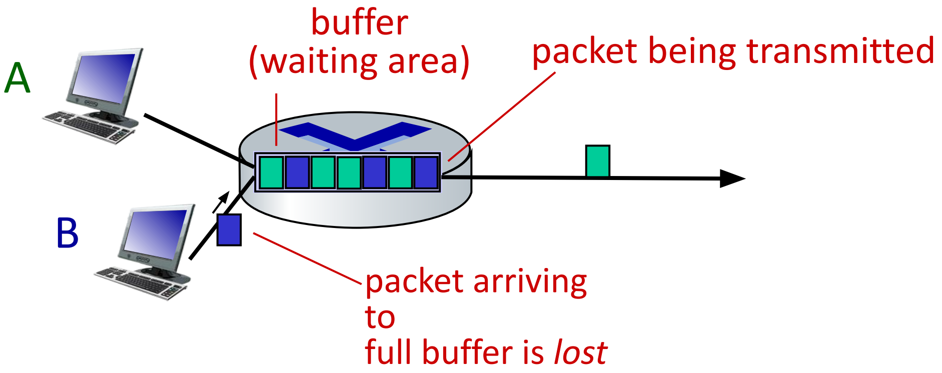


Refer RFC 1393, **Traceroute Using an IP Option**

Don't Trust Traceroute (Completely)

Performance: Packet loss

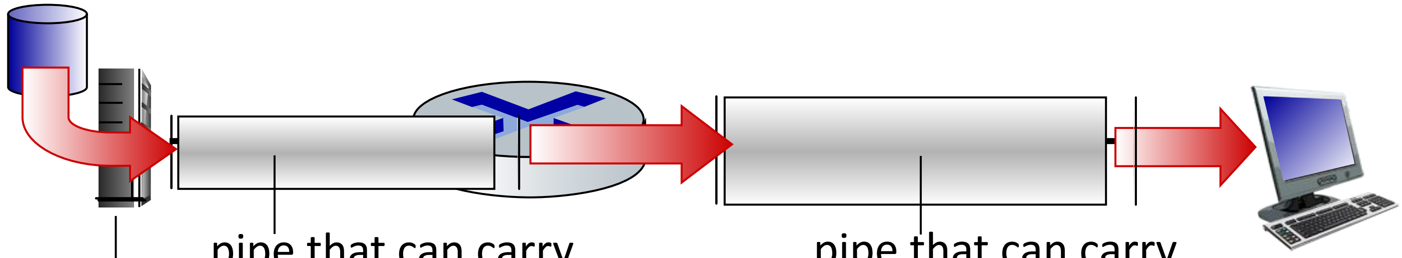
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



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

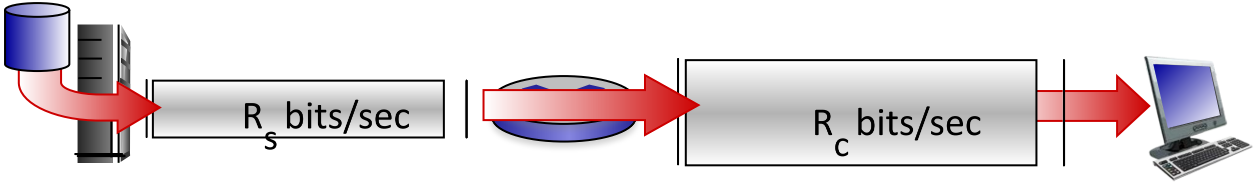
Performance: Throughput

- *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



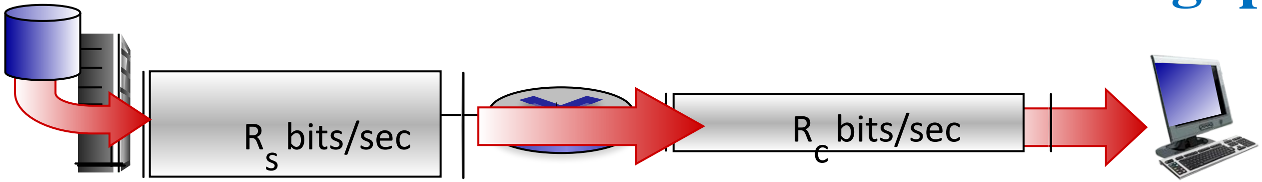
Performance: Throughput (more)

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



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

Throughput = min{R_s, R_c}



bottleneck link

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

Throughput – Numerical Example

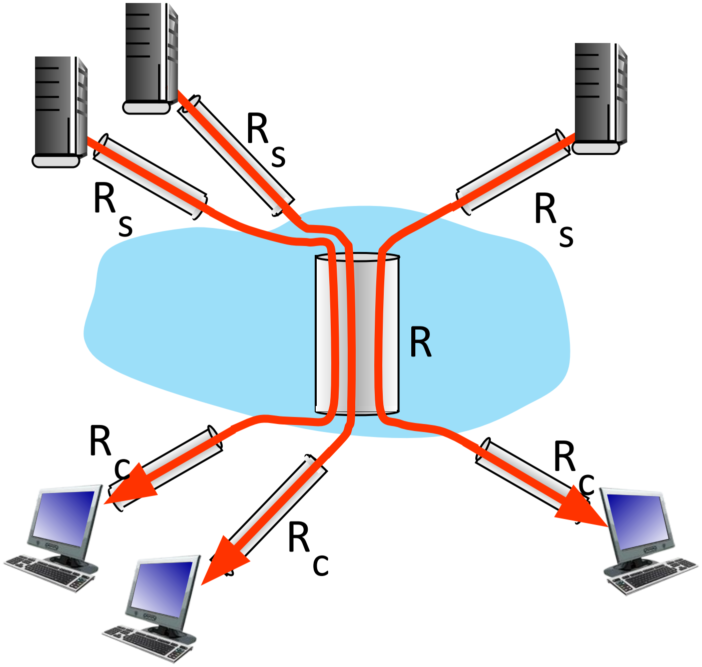
- Suppose you are downloading an MP3 file of F = 32 million bits.
- The server has a transmission rate of R_s = 2 Mbps and you have an access link of R_c = 1 Mbps.
- What is the time needed to transfer the file?

Let's work it out!

Solution:

- 32 seconds!

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.

THANK YOU

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