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TP06
Delay, loss and throughput in packet-switched networks

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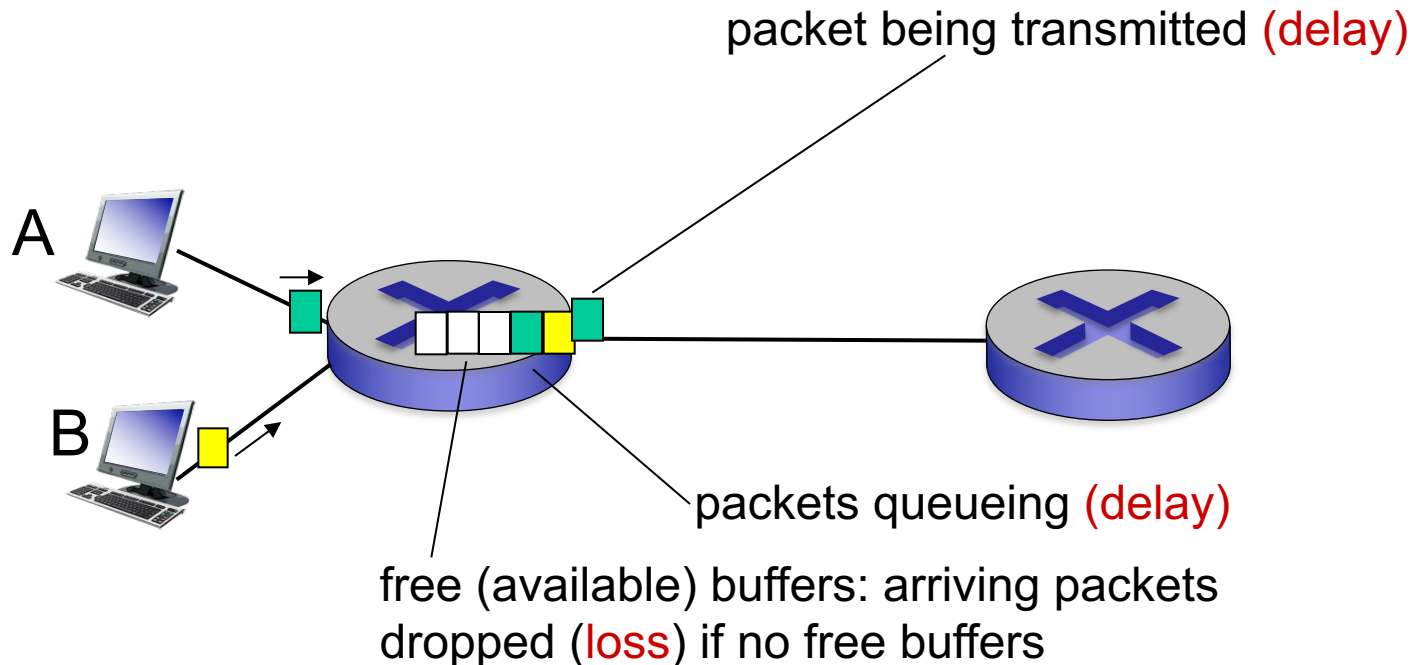University of Coimbra

TP06: Delay, loss and throughput

Overview:

- Types of delay
- Queuing delay and packet loss
- End-to-end delay
- Throughput in computer networks

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

packet being transmitted (delay)

A

B

packets queueing (delay)

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

Types of Delay

The performance of many applications (search, web browsing, maps, email, etc.) is greatly affected by *network delays*

A packet suffers from several types of delays at *each* node along the path from the source to the destination

- Node processing delay
- Queuing delay
- Transmission delay
- Propagation delay

Together, these delays accumulate to give a *total nodal delay*

Four sources of packet delay

transmission

propagation

A

B

nodal processing
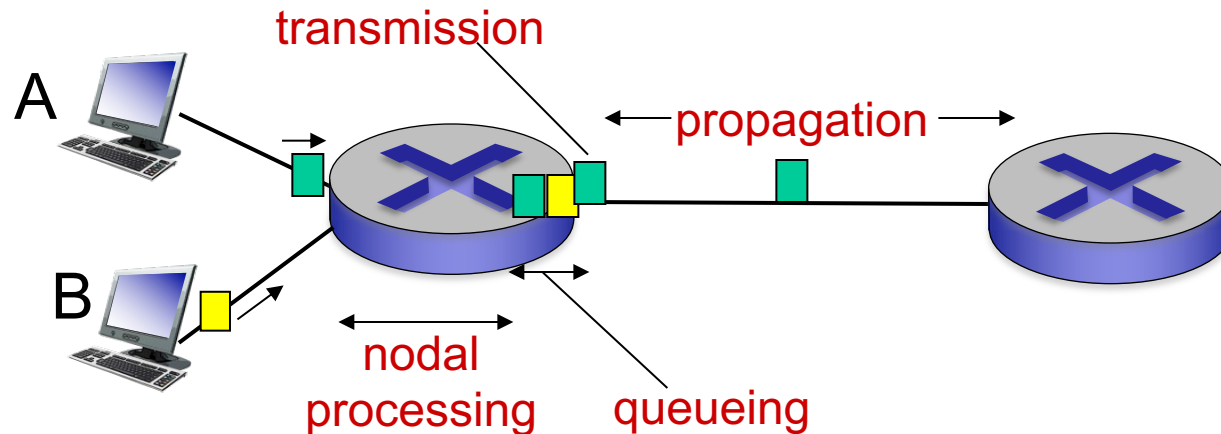
queueing

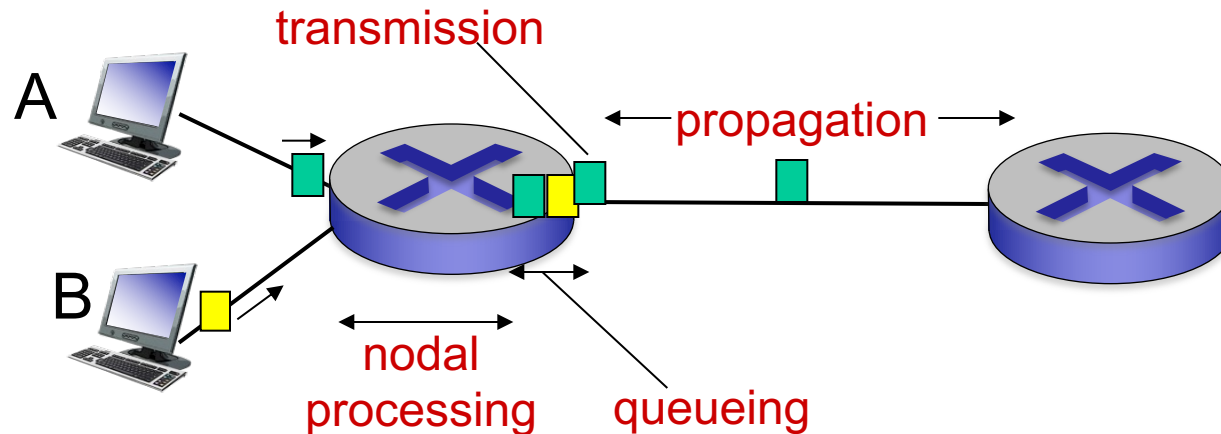$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

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
- Is a function of the intensity and nature of traffic arriving at the queue
- Can vary from packet to packet

Four sources of packet delay

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

d_{trans}: **transmission delay:**
- Time required to transmit the packet's bits into the link
- 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 of the communications link (~2×10^8 m/sec)
- $d_{\text{prop}} = d/s$

Transmission vs. propagation delay

The transmission delay is the amount of time required for the router to push out (transmit) the packet

- It's a function of the packet's length and the transmission rate of the link (bandwidth)
- Has nothing to do with the distance between the two routers

The propagation delay is the time it takes a bit to propagate from one router to the next

- Is a function of the distance between the two routers
- Has nothing to do with the packet's length or the transmission rate of the link

Total nodal delay

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

The contribution of the four delays can vary significantly:

- d_{prop} *can be negligible for a short link connecting two routers, or of hundreds of milliseconds for two routers interconnected by a geostationary satellite link*
- d_{trans} *can be negligible for transmission rates of 10 Mbps or higher, or hundreds of milliseconds for large packets sent over low-speed links (e.g. dial-up modems)*
- d_{proc} *is often negligible, but strongly influences a router's maximum throughput (maximum rate at which it forwards packets)*
- d_{queue} *is the most complicated (and interesting) component*

"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.

3 probes   3 probes

3 probes
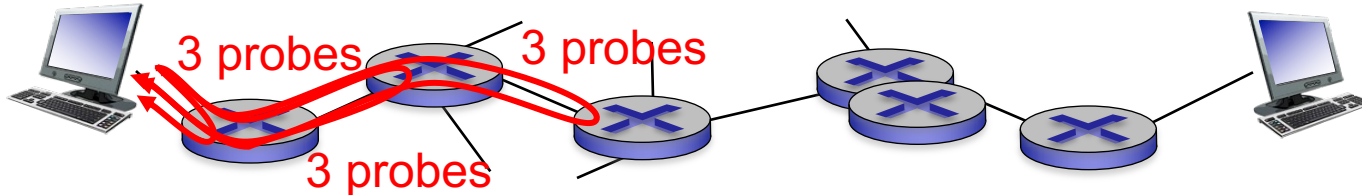
"Real" Internet delays, routes

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

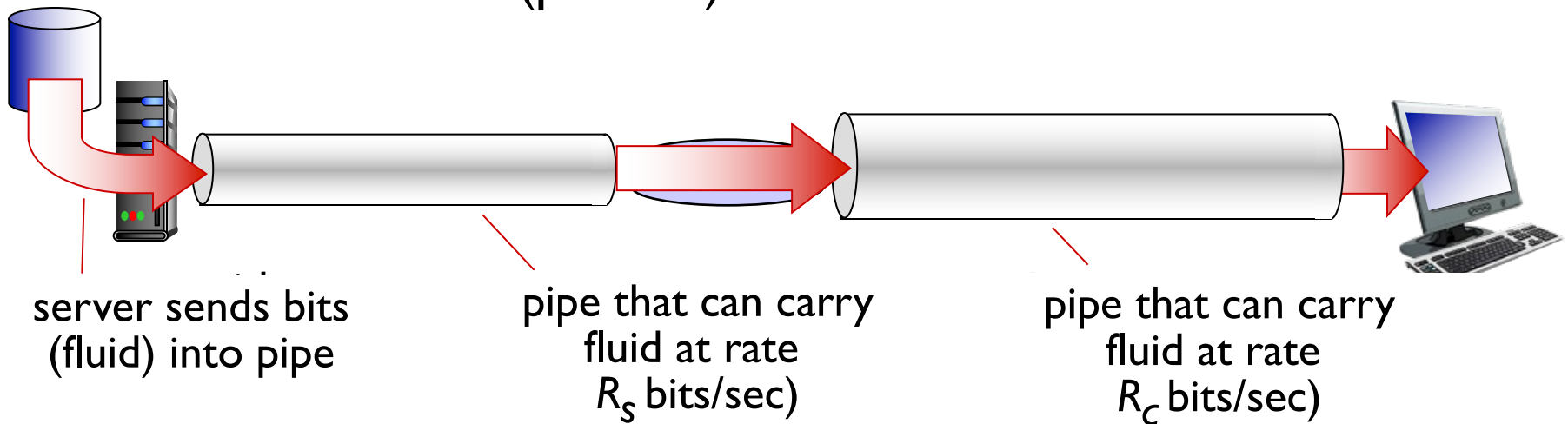* means no response (probe lost, router not replying)

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

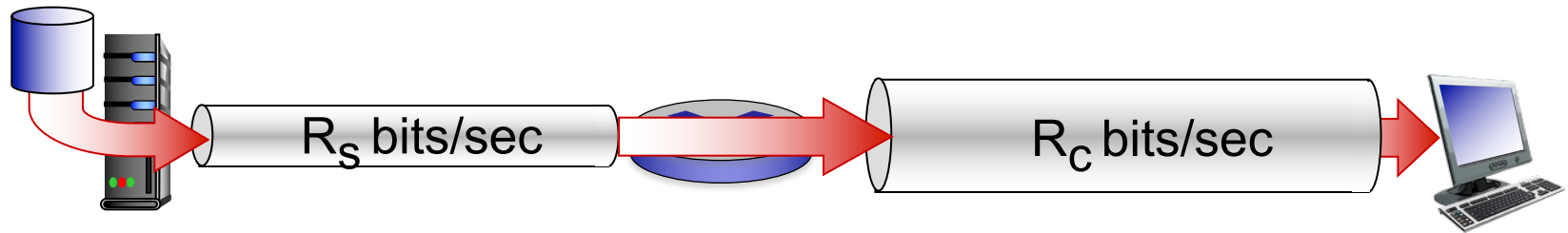- Must be handled by communications protocols

A

buffer
(waiting area)

packet being transmitted

B

packet arriving to
full buffer is *lost*
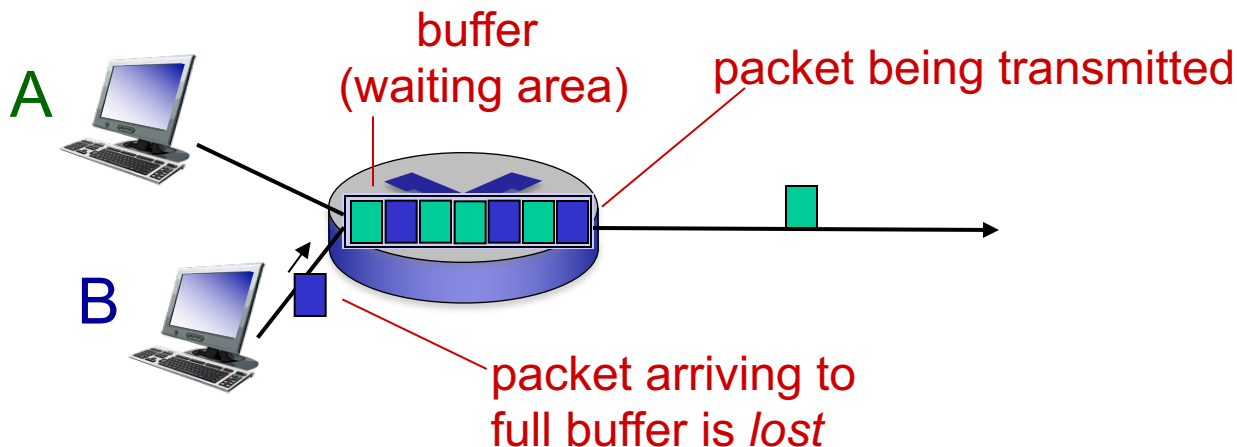
Throughput

- *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
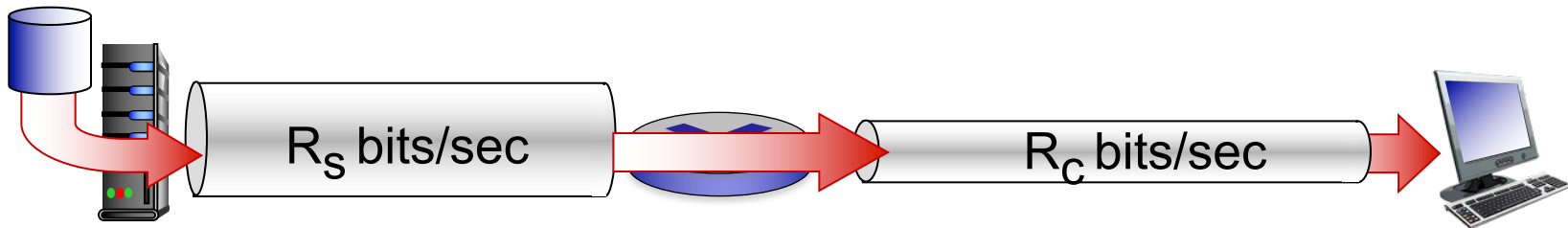 - depends on the transmission rates of the links over which the data (packets) flow

server sends bits
(fluid) into pipe

pipe that can carry
fluid at rate
R_s bits/sec)

pipe that can carry
fluid at rate
R_c bits/sec)

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

Throughput: Internet scenario

- **per-connection end-end throughput:** $min(R_c, R_s, R/10)$

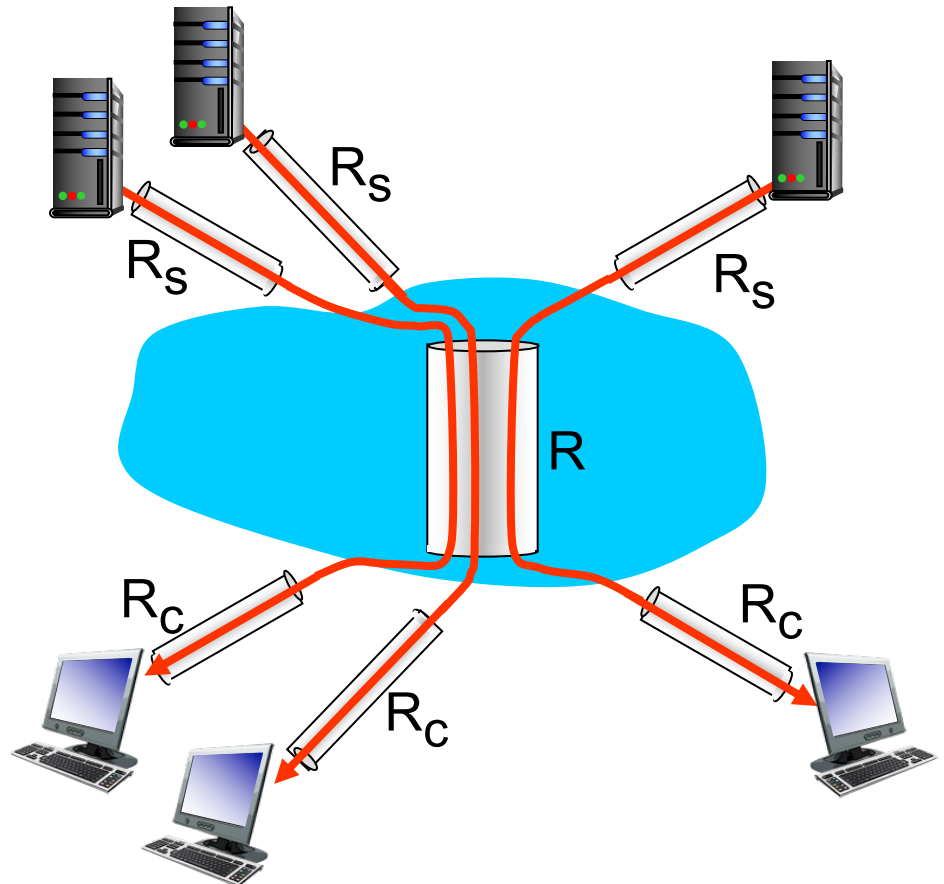- in practice: R_c or R_s (access networks) is often the bottleneck
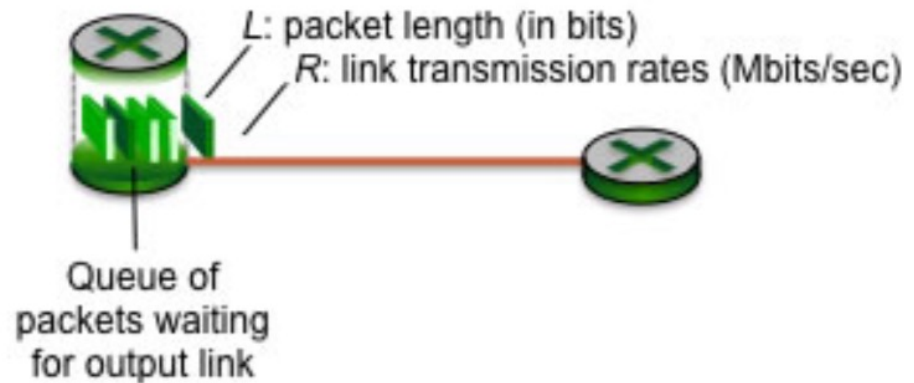
Example:

$R_c = 1\ Mbps$

$R_s = 2\ Mbps$

$R = 5\ Mbps$

Per-connection end-to-end throughput: 500 Kbps

R_s R_s R_s R_s R R_c R_c R_c

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

Exercises (one-hop transmission delay)

Consider the following scenario, in which a single router is transmitting packets of lenght L = 8000 bits, over a single link with transmission rate R = 100 Mbps to another router:

L: packet length (in bits)
R: link transmission rates (Mbits/sec)

Queue of packets waiting for output link

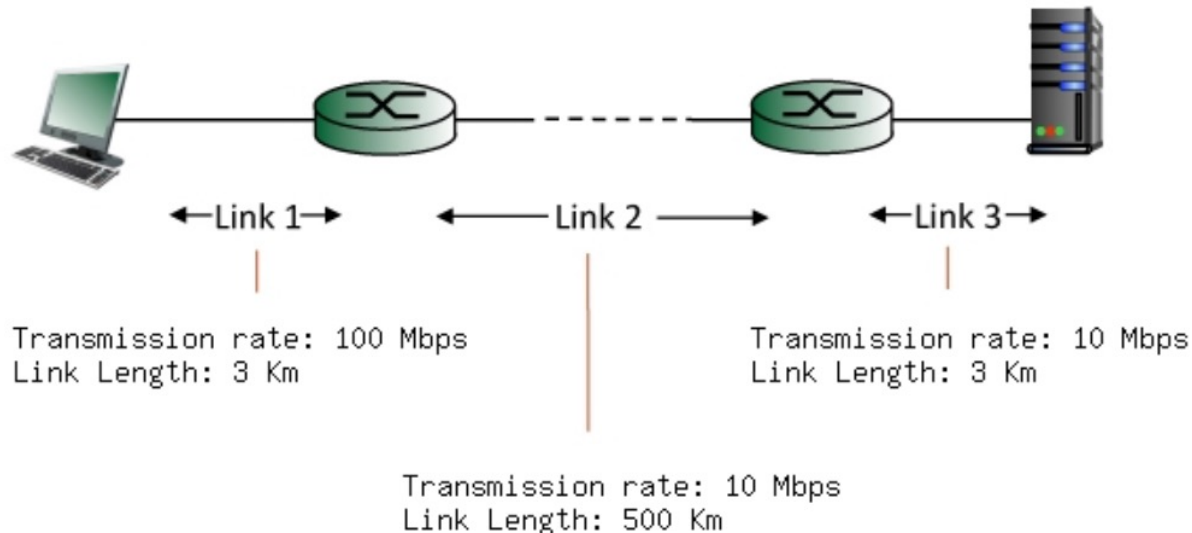1) What is the transmission delay (the time needed to transmit all of a packet's bits into the link)?

L/R = 8000 bits / 100 Mbps = 0,08 msec

2) What is the maximum number of packets per second that can be transmitted by the link?

100 Mbps / 8000 bits = 12500 packets/sec

Exercises (end-to-end delay)

Considering the scenario below, find the end-to-end delay considering the transmission delays and propagation delays on each of the three links, but *ignoring queueing delays and processing delays*. The speed of light propagation delay on each link is 3x10**8 m/sec, assume a packet length of 8000 bits.

←Link 1→   ←—— Link 2 ——→   ←Link 3→

Transmission rate: 100 Mbps   Transmission rate: 10 Mbps
Link Length: 3 Km   Link Length: 3 Km

Transmission rate: 10 Mbps
Link Length: 500 Km

Link 1 transmission delay = L/R = 8000 bits / 100 Mbps = 0.080000 msec.
Link 1 propagation delay = d/s = 3 Km / 3*10**8 m/sec = 0.010000 msec.
Link 2 transmission delay = L/R = 8000 bits / 10 Mbps = 0.800000 msec.
Link 2 propagation delay = d/s = 500 Km / 3*10**8 m/sec = 1.666667 msec.
Link 3 transmission delay = L/R = 8000 bits / 10 Mbps = 0.800000 msec.
Link 3 propagation delay = d/s = 3 Km / 3*10**8 m/sec = 0.010000 msec.

Thus, the total end-to-end delay is the sum of these six delays: 3.366667 msecs.

Exercises (throughput)

server   client

R_s = 2 Mbps R_n = 1000 Mbps R_c = 1 Mbps
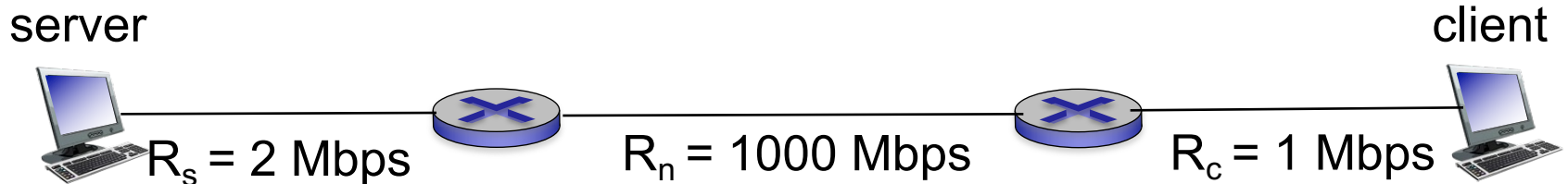
Consider the network scenario above, and that you need to download a file of 32 million bits from the server to the client:

    1. Assuming no other traffic in the network, what is the end-to-end throughput for the file transfer?

      1 Mbps (transmission rate of the bottleneck link)

    2. What is the time needed to transfer the file (ignoring any end-to-end delays)?

      32 Mbits / 1 Mbps = 32 sec

TP06: Summary

What we have covered here?

- Types of delay in computer networks

- Queuing delay and packet loss

- End-to-end delay

- Throughput in computer networks