# Redes de Comunicação 2024/2025

# TP07
# Delay, loss and throughput in packet-switched networks

Jorge Granjal
University of Coimbra

# TP06: Delay, loss and throughput

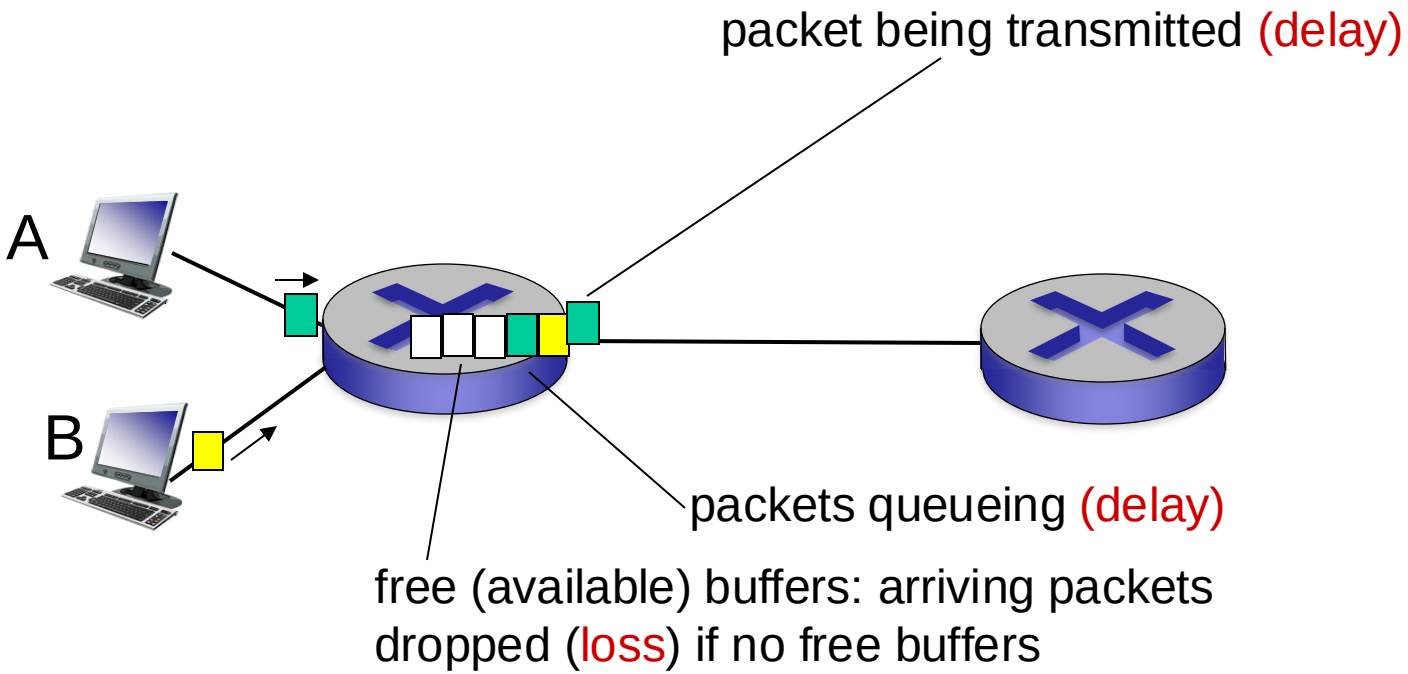
*Overview:*

- 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



# Types of Delay

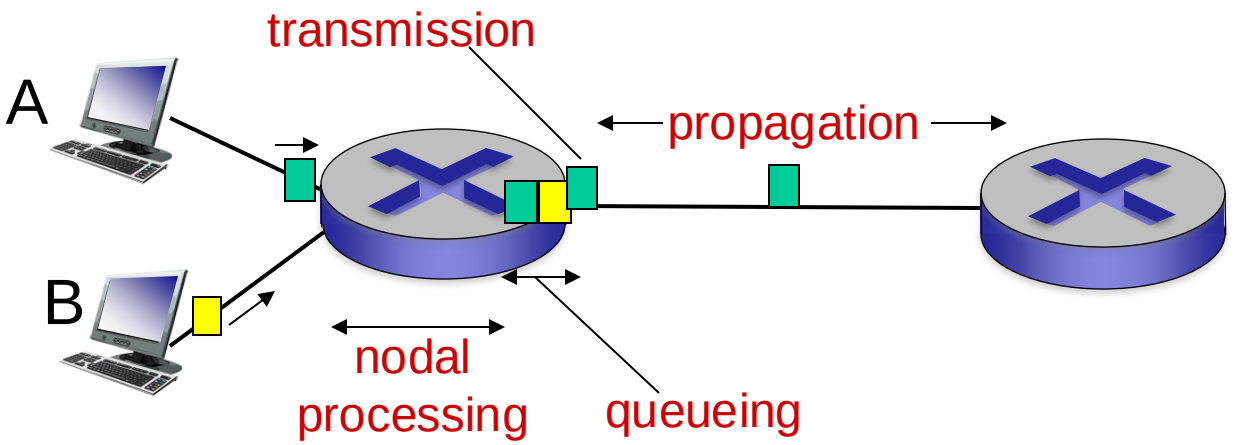
The performance of many applications (search, web browsing, maps, email, etc.) is greatly affected by *network delays*

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




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

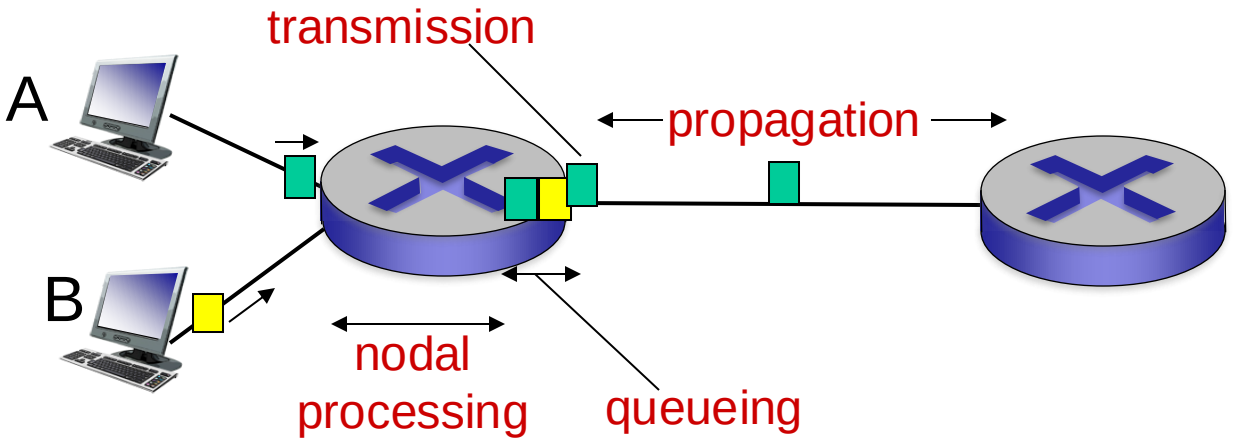
## $d_{proc}$: nodal processing

- 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




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

## $d_{trans}$: 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 (~$2 \times 10^8$ m/sec)
- $d_{prop} = d/s$

# 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

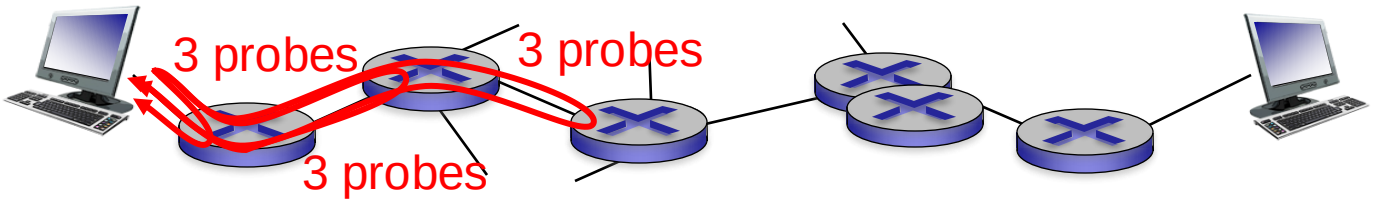
$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

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.



# "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

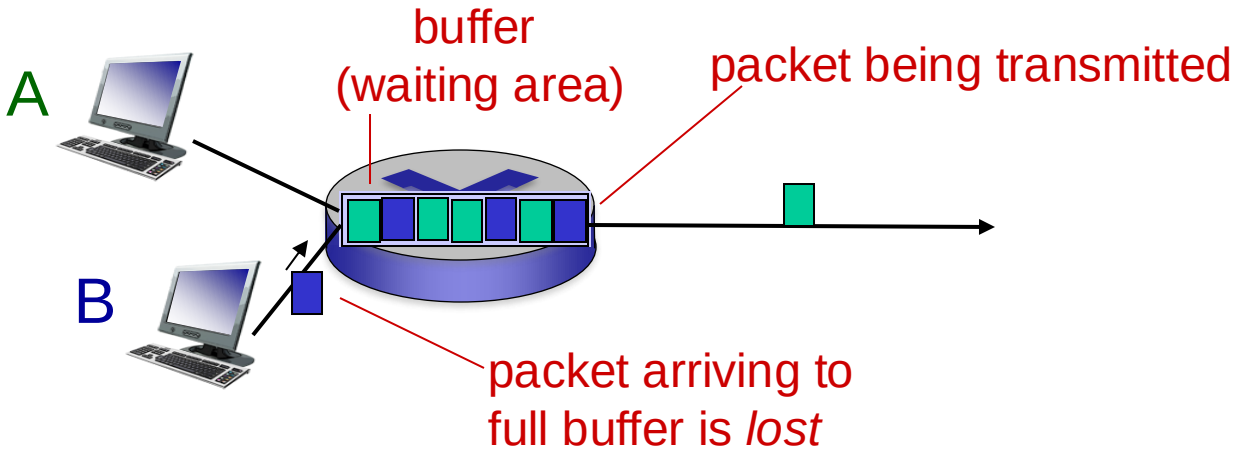
```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 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)

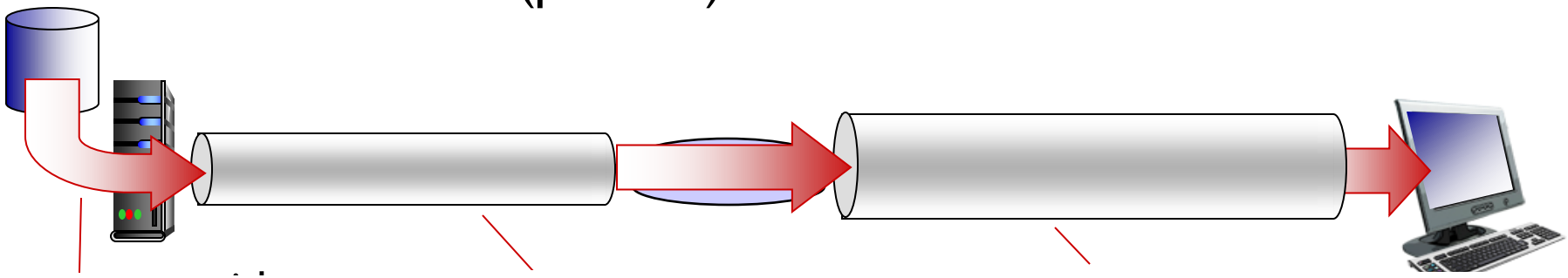
# Packet loss

- 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



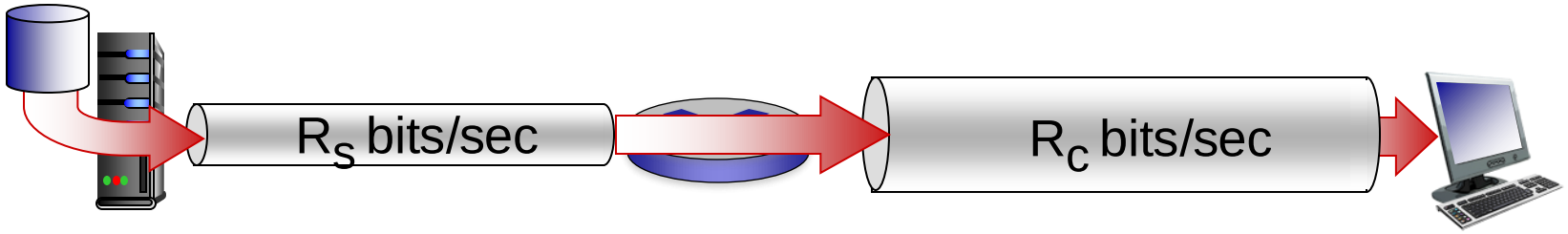
# Throughput

- *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

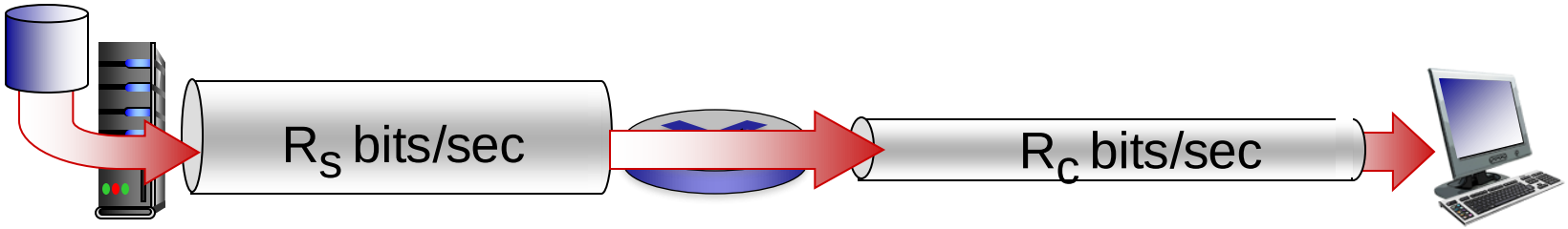


# Throughput (more)

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




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

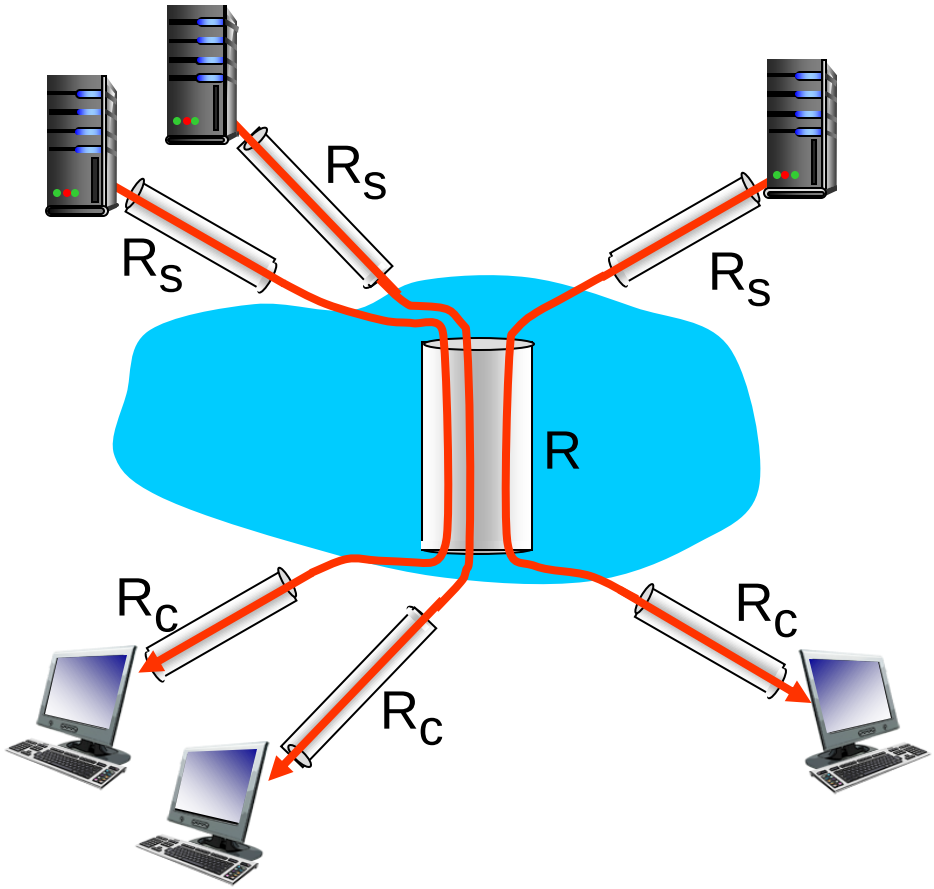



*bottleneck link*

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




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

Example:

*$R_c$ = 1 Mbps*

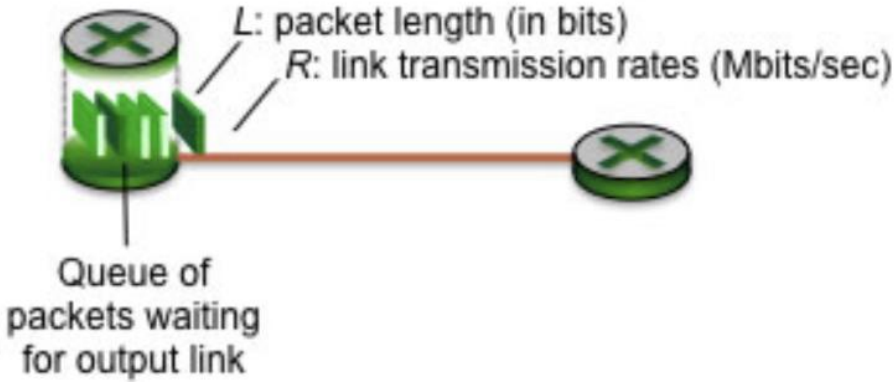
*$R_s$ = 2 Mbps*

*R = 5 Mbps*

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

# 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:




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

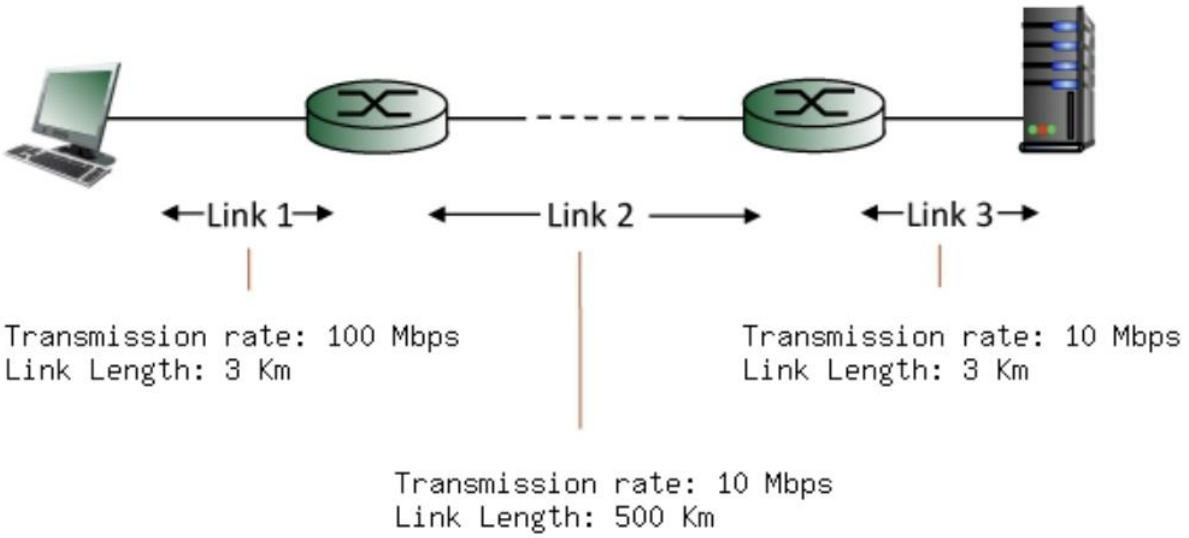
L/R = 8000 bits / 100 Mbps = 0,08 msec

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)

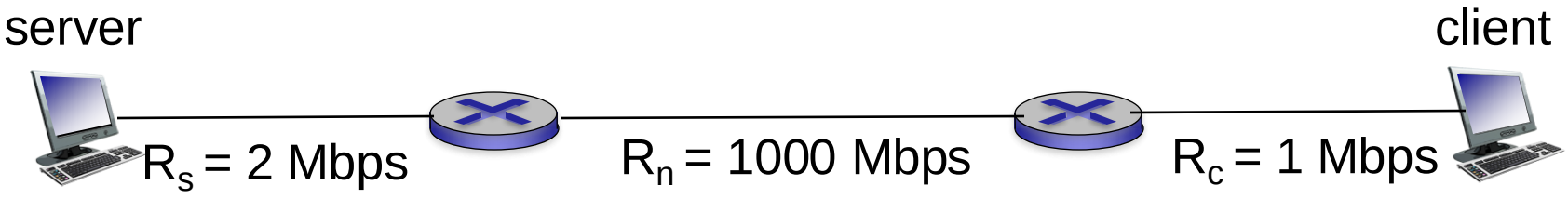
Considering the scenario below, find the end-to-end delay considering the transmission delays and propagation delays on each of the three links, but *ignoring queueing delays and processing delays*. The speed of light propagation delay on each link is 3x10**8 m/sec, assume a packet length of 8000 bits.




Link 1 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)




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