Delay in Packet-Switched Networks (cont.)

Example [network delay – one packet, one hop]

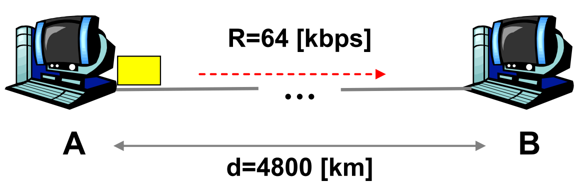
Suppose that a user at one end of Canada sends a L = 1-Mbit file to a remote server on the other end over a data link operating at R = 64 kbps.

Assume that we are using a fiber optic link with a propagation rate of the speed of light, approximately $c = 3 \cdot 10^8$ m/sec, and that the distance is d = 4800 km.

Ignore any processing or queueing delays.

What is the overall network delay, i.e. time to transmit the file?

$$d_{total} = d_{propagation} + d_{transmission}$$



$$d_{propagation} = \frac{d\,[\mathrm{m}]}{s\,[\mathrm{m/sec}]} = \frac{4800 \cdot 10^3\,[\mathrm{m}]}{3 \cdot 10^8\,[\mathrm{m/sec}]} = 0.016\,[\mathrm{sec}]$$

$$\boxed{d_{transmission} = \frac{L\,[\mathrm{bits}]}{R\,[\mathrm{bps}]} = \frac{10^6\,[\mathrm{bits}]}{64 \cdot 10^3\,[\mathrm{bps}]} = 15.625\,[\mathrm{sec}]}$$

transmission delay >> propagation delay

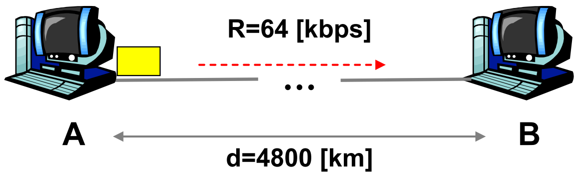
A high-speed channel would reduce the overall delay.

Delay in Packet-Switched Networks (cont.)

Example [network delay – one packet, one hop]

For the same problem, now suppose that we have a R = 1-Gbps link.

What is the overall network delay, i.e. time to transmit the file, in this case?



$$d_{total} = d_{propagation} + d_{transmission}$$

Propagation delay still the same: $d_{propagation} = 0.016\ [sec]$

$$d_{transmission} = \frac{L\ [bits]}{R\ [bps]} = \frac{10^6\ [bits]}{10^9\ [bps]} = 0.001\ [sec]$$

$$d_{total} = 0.017\ [sec]$$

Increasing data rate beyond certain value on a long (e.g satellite) link will not noticeably speed up file delivery.

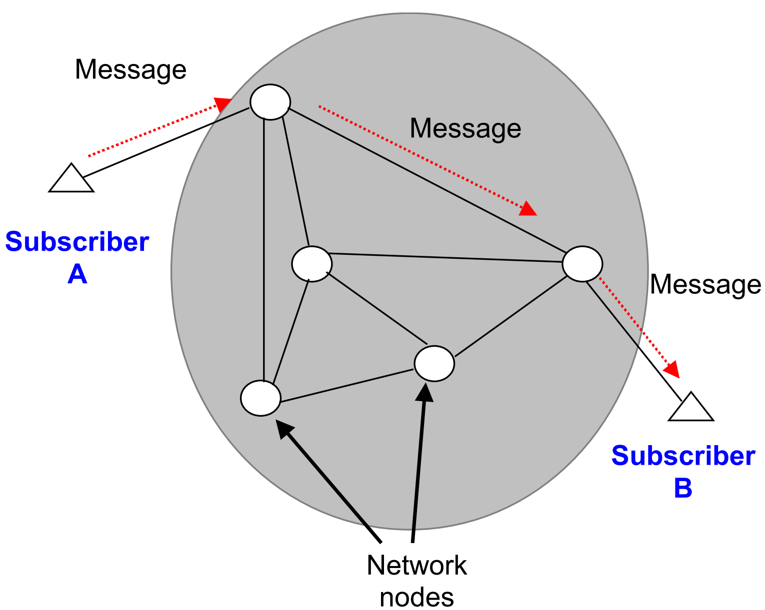
Single Packet Delay

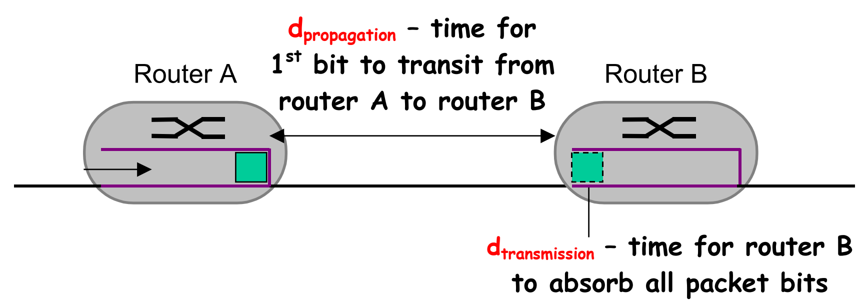
Example [network delay – one packet, multiple hops]

A message needs to be transmitted over a path that involves two intermediate switches. For simplicity assume that the propagation delay and the bit rate of the transmission lines are the same, and ignore any queueing delay.

What is the overall end-to-end message delay in case of datagram packet switching?

Draw corresponding diagrams.



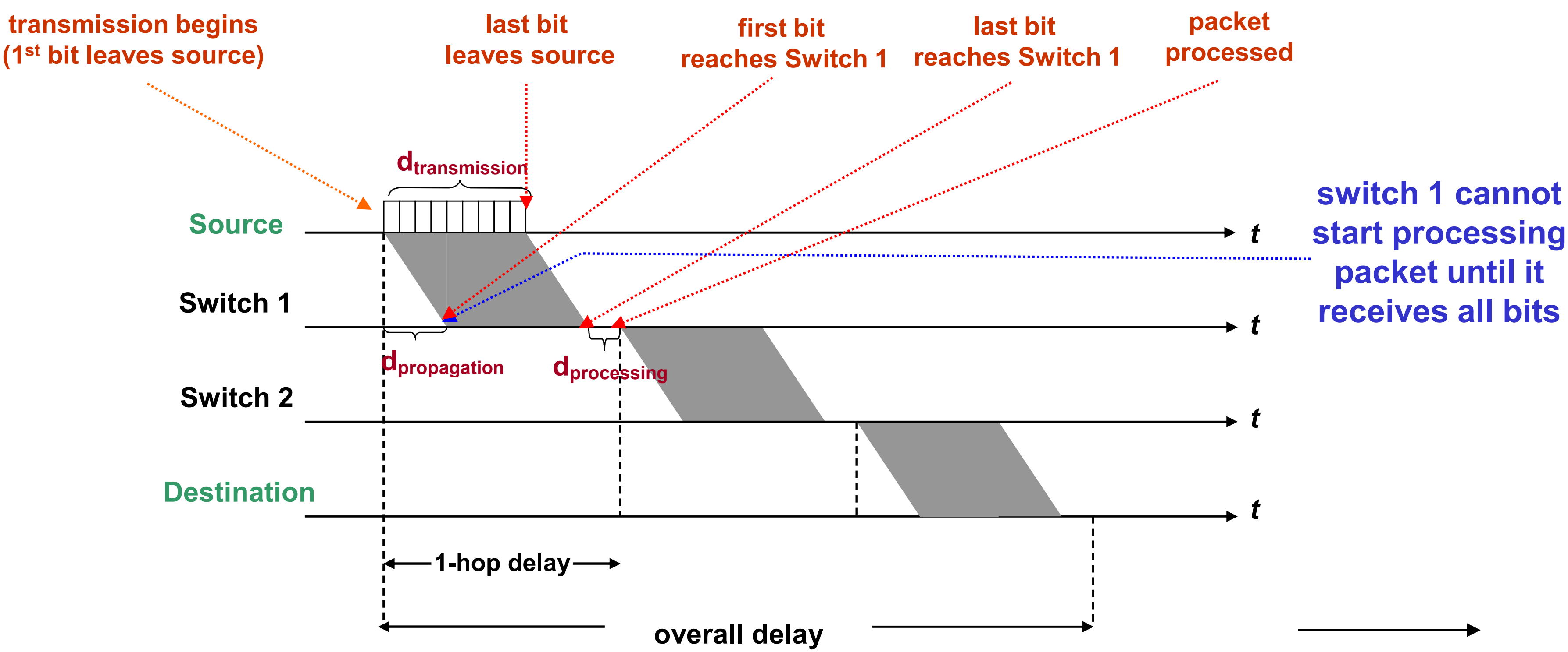


Single Packet Delay (cont.)

(1) delay in case of datagram packet switching

2 intermediate routers ⇒ 3 hops between source and destination

$$d_{total} = 3^*d_{propagation} + 3^*d_{transmission} + 3^*d_{processing}$$



Multiple Packets Delay

Example [network delay – multiple packets, multiple hops]

Assume:

N = number of hops

R = data rate [bps]

H = packet overhead

$d_{propagation}$ = propagation delay per hop [sec]

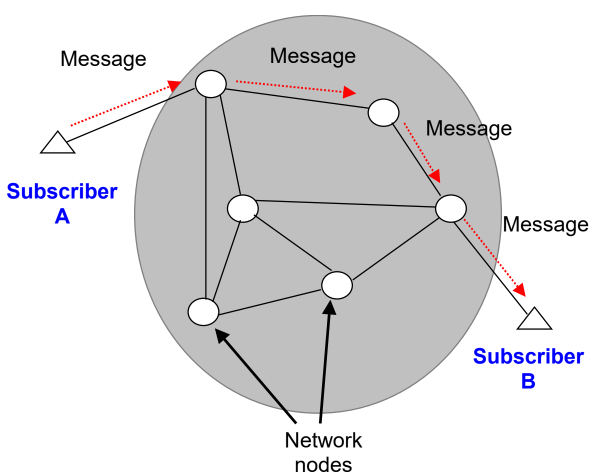
L = message length [bits]

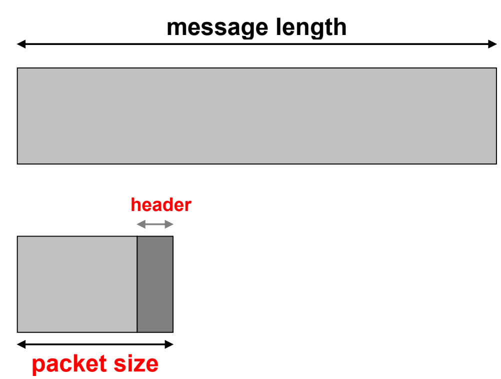
P = packet size [bits] (payload + header)

Compute end-to-end delay for datagram switching, assuming:

N=4, L=3200, R=9600, P=1024, H=16, $d_{propagation}$=0.001.

Ignore any queueing or processing delay.

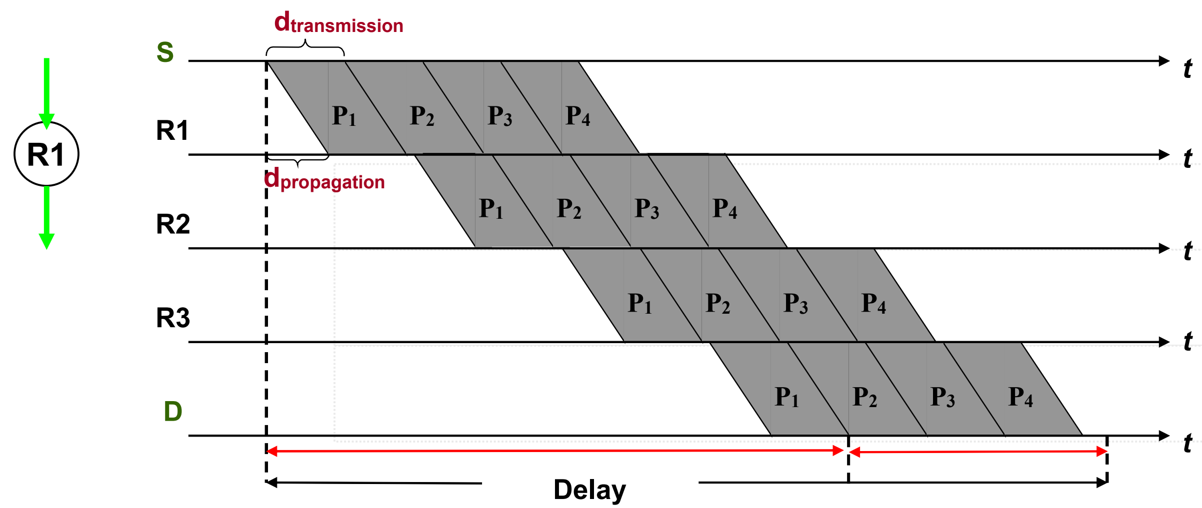




Multiple Packets Delay (cont.)

(2) delay in case of datagram packet switching

There are P – H = 1024 – 16 = 1008 data bits per packet.
A message of 3200 bits require four packets: Np = ceiling(3200 / 1008) = 4.
(3200 bits/1008 bits/packet = 3.17 packets which we round up to 4 packets.)



d = D1 + D2 + D3 + D4, where

D1 = Time to transmit entire 1st packet <u>over all hops</u>

D2 = Time to transmit entire 2nd packet

D3 = Time to transmit entire 3rd packet

D4 = Time to transmit entire 4th packet

time to absorb the rest of the message

Multiple Packets Delay (cont.)

Let:

T = transmission time for one packet = P/R

$$D1 = N*d_{propagation} + N*T =$$
$$= 4*d_{propagation} + 4*P/R =$$
$$= 4 \times 0.001 + 4*1024/9600 =$$
$$= 0.427$$

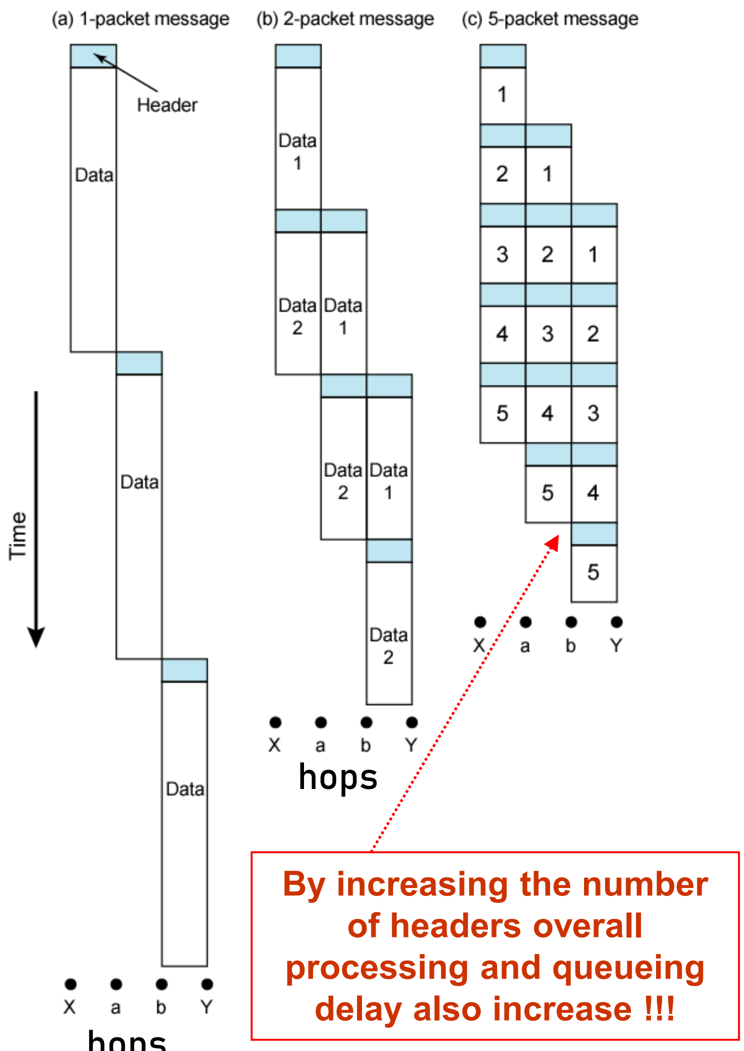
We are assuming here that all packets are of the same size!!!

$$D2 = D3 = D4 = T =$$
$$= (P/R) =$$
$$= (\boxed{1024}/9600) =$$
$$= 0.107$$

$$d = 0.427 + 3*0.107 =$$
$$= 0.748 \text{ sec}$$

Multiple Packets Delay (cont.)

Relationship between Packet Size and Transmission Time



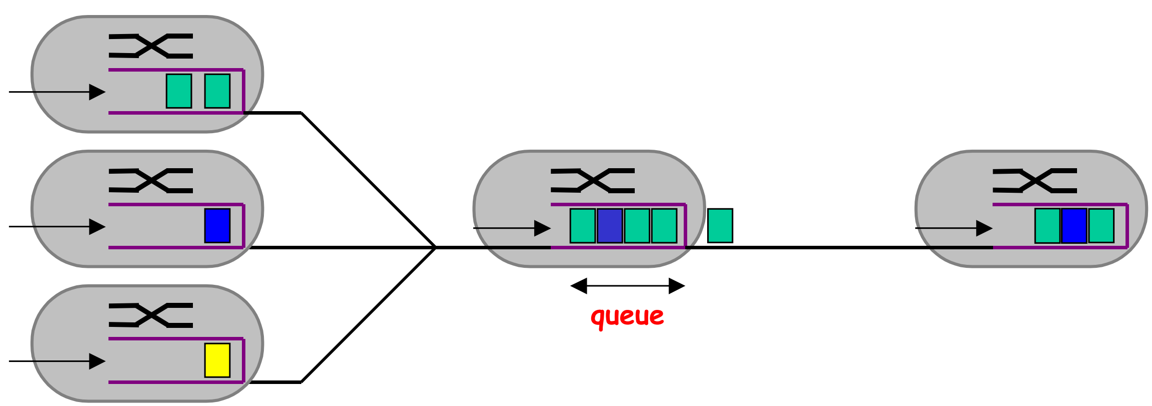
– by breaking message into smaller packets, nodes can begin transmitting 1st packet as soon as it has arrived, without waiting for 2nd packet

- this overlap in packet transmission can result in considerably shorter overall delay – smaller packet will sooner be received / absorbed at the destination
- however, process of using more and smaller packets eventually results in increased rather than reduced delay, since each packet must contain a header (more overhead)
- in contrast to transmission delay, processing and queueing delays always increase as # of packets increases
- packet-switched network designers must consider all factors when attempting to find an optimum packet size

Queueing Delay and Packet Loss

Queueing Delay – most complex component of network delay

- unlike the other tree delays ($d_{processing}$, $d_{transmission}$, $d_{propagation}$) queueing delay can vary from packet to packet!
- example: 10 packets arrive at an empty queue at the same time ⇒ 1st packet transmitted will suffer no queue. delay, last packet transmitted will suffer relatively large queueing delay
- when characterizing queueing delay, one typically uses probabilistic and statistical measures, such as: average queueing delay, average queue size, probability that queue exceeds some specific size, etc.



Calculation of queueing delay (for known λ and w) discussed earlier!!!

Queueing Delay and Packet Loss (cont.)

Traffic Intensity (Router Utilization) – **plays critical role in estimating extent of queueing delay**

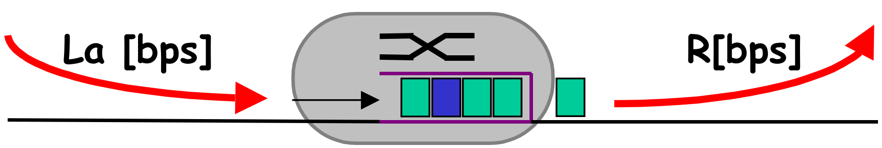
$$\text{traffic intensity} = \rho = \frac{La}{R}$$

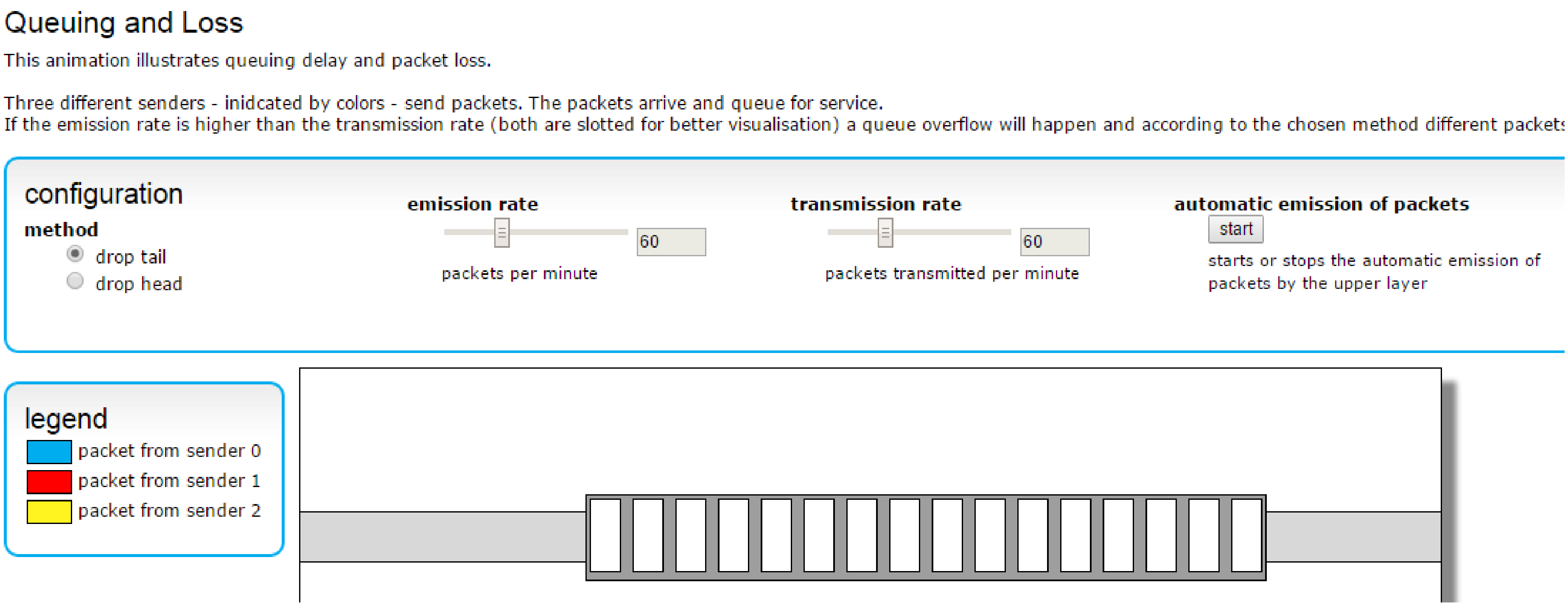
aka router/server utilization

L = packet size [bits/packet]
a = <u>average</u> packet arrival rate [packet/sec]
R = output transmission rate [bps]

arrival bit rate - λ
departure bit rate - μ

- ρ = La/R $\approx$ 0: average queueing delay small
- ρ = La/R $\rightarrow$ 1: delay becomes large
- ρ = La/R > 1: average rate at which bits arrive exceeds the rate at which bits can be transmitted
  - (a) infinite queue $\Rightarrow$ qeueing delay $\rightarrow \infty$
  - (b) finite queue $\Rightarrow$ router drops packets





http://www.ccs-labs.org/teaching/rn/animations/queue/index.htm

Queueing Delay and Packet Loss (cont.)

Example [average queueing delay]

Typically, arrivals do not follow any pattern and packets are spaced apart by random amount of time ⇒ La/R is not usually sufficient to fully characterize delay statistics !

packet transmission time

Assume La/R=1 (average arrival bit rate = average departure bit rate). Determine the average queueing delay in the following two cases:

(a) Packets arrive periodically – one packet of size L every L/R seconds.

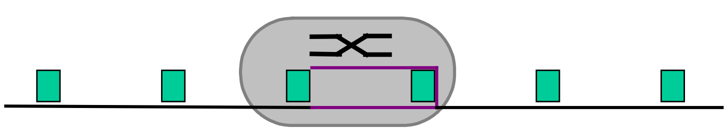
(b) Packets arrive in bursts, but periodically – N packet every (L/R)*N seconds.

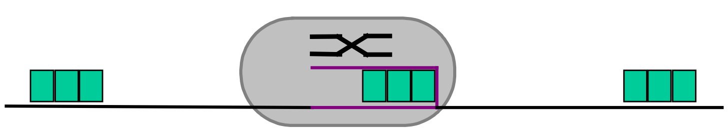
(a) Every packet will arrive at an empty queue ⇒ no queueing delay.

(b)

1^{st} packet:	no queueing delay
2^{nd} packet:	delay = L/R [sec]
3^{rd} packet:	delay = 2*L/R [sec]
…	
N^{th} packet:	delay = (N-1)*L/R [sec]

average delay = ???





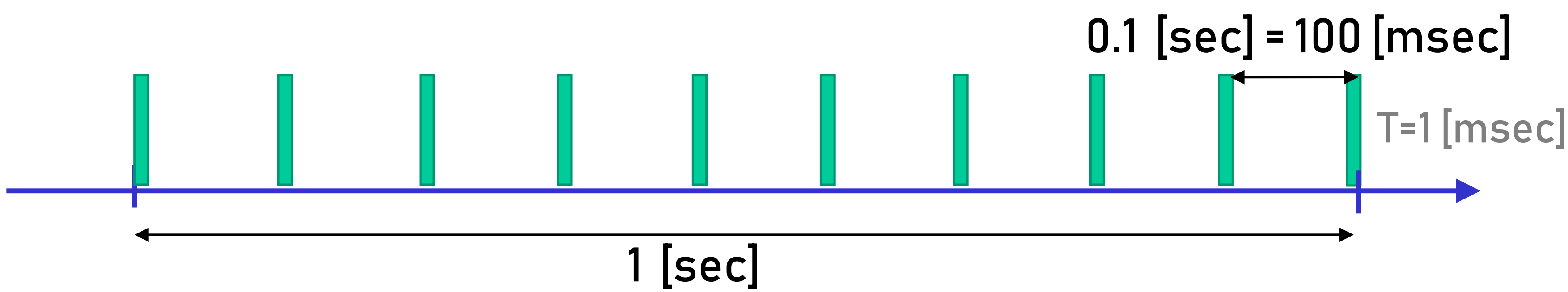
Queueing Delay and Packet Loss (cont.)

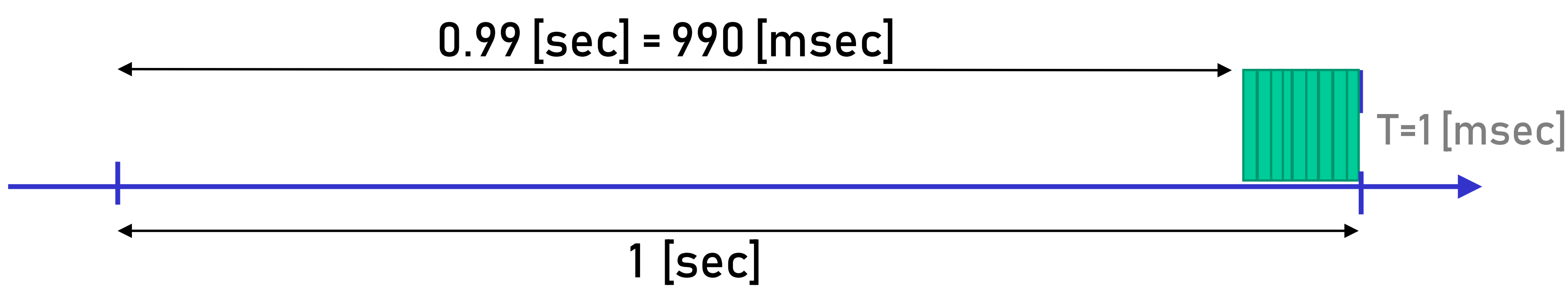
L = 1,000 [bits / packet]
$a_{average}$ = 10 [packet / sec]
R = 1,000,000 [bps]

Server utilization =0.01 !
Server is busy only 1% of time.
Queue will not grow!

Does that mean
$d_{queueing}$ = 0 ???

$L*a = 10^4$ [bps] << $R = 10^6$ [bps]





Assume a packet switching router with a 'single input / single output queue', as shown in the figure below. Furthermore, assume that packets of size P=1000 [bits] arrive to the router's **input queue**

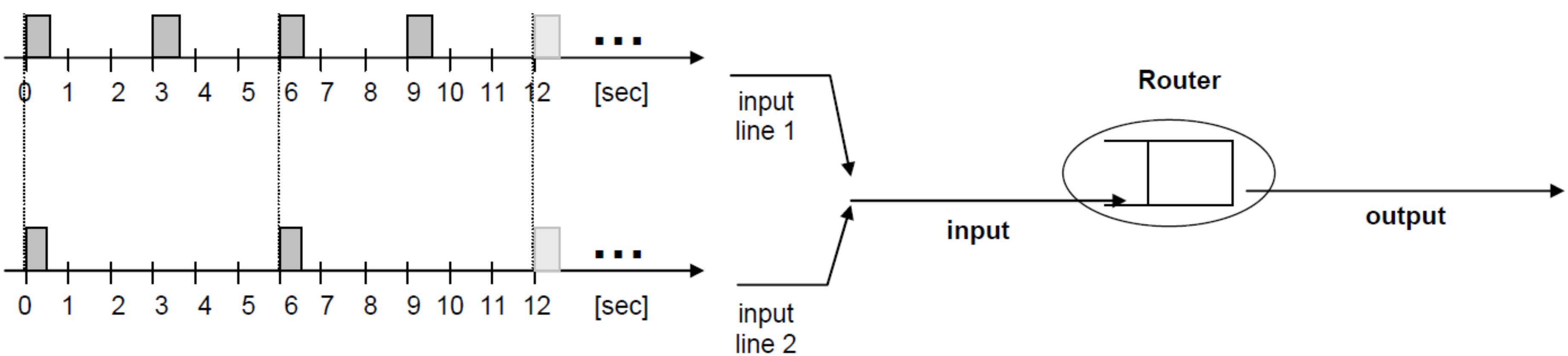
- through *input line 1*, in regular intervals of 3 [sec], and
- through *input line 2*, in regular intervals of 6 [sec],

as illustrated in the figure.

The average bit departure (i.e. service) rate at the router is R=1000 [bps].

a) [1.5 points] What is the average waiting delay that packets experience in the queue?

b) [1 point] What is the router (i.e. server) utilization calculated from the given data?



a) $$d_{average} = \frac{d_1 + d_2 + d_3}{3} = \frac{0 + 1 + 0\,[\text{sec}]}{3} = \frac{1}{3}[\text{sec}]$$

b) $$\rho = \frac{\lambda}{\mu} = \frac{\frac{3\ packets}{6\ seconds}}{1000\ [bps]} = \frac{\frac{3000\ bits}{6\ seconds}}{1000\ [bps]} = \frac{3}{6} = 0.5$$