Network Performance

- What is throughput?
- Transmission Delay
- Propagation Delay
- Queuing Delay

Network Performance

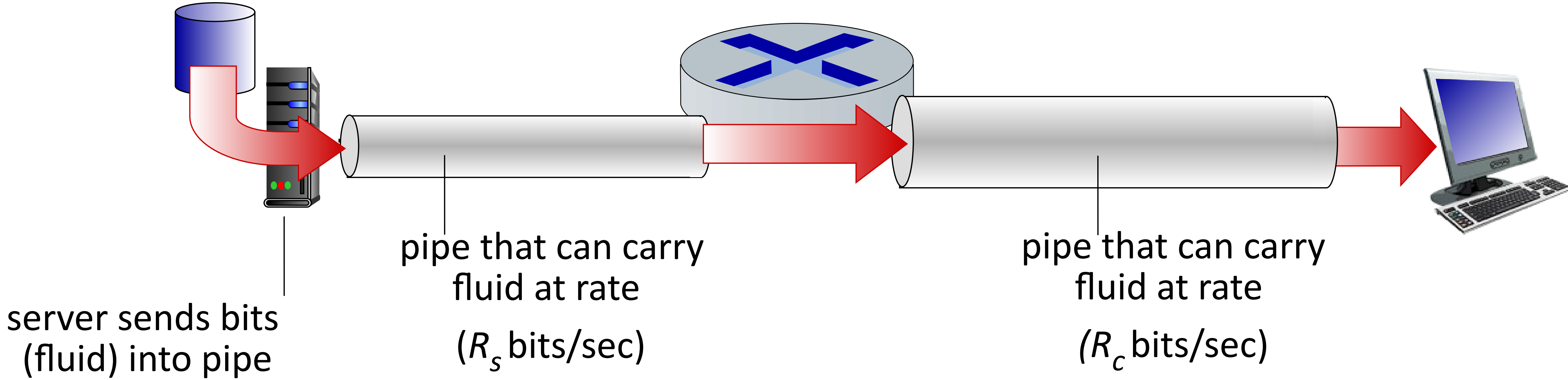
- **Packet length**: size of a packet (units = bits or bytes)
- **Channel speed or bandwidth**: How fast the channel can transmit bits (units = bits/second or Bytes/second or packets/second)
- **Packet transmission time**: amount of time to transmit an entire packet (units = seconds)
- **Propagation delay**: Delay imposed by the properties of the link. Depends on the link’s distance (units = seconds)
- Total transfer time =propagation delay + packet transmission time

Network Performance

- **Bits** are the units used to describe an amount of data in a network
  - 1 kilobit (Kbit) = 1 x 10^3 bits = 1,000 bits
  - 1 megabit (Mbit) = 1 x 10^6 bits = 1,000,000 bits
  - 1 gigabit (Gbit) = 1 x 10^9 bits = 1,000,000,000 bits
- **Seconds** are the units used to measure time
  - 1 millisecond (msec) = 1 x 10^{-3} seconds = 0.001 seconds
  - 1 microsecond (μsec) = 1 x 10^{-6} seconds = 0.000001 seconds
  - 1 nanosecond (nsec) = 1 x 10^{-9} seconds = 0.000000001 seconds
- **Bits per second** are the units used to measure channel capacity/bandwidth and throughput
  - bit per second (bps)
  - kilobits per second (Kbps)
  - megabits per second (Mbps)
- Bytes (8 bits a byte) Mega bytes, Giga bytes, Tera bytes, Peta Bytes, Exa bytes

What is throughput?

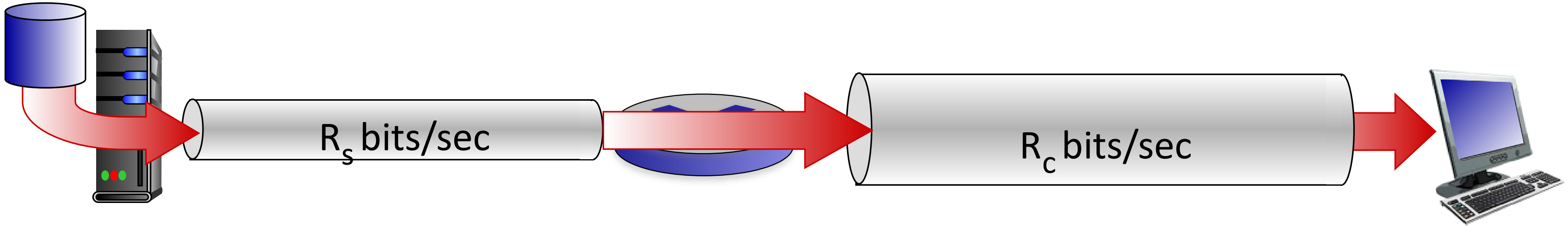
- *throughput:* rate (bits/time unit) at which bits are being sent from sender to rece
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time



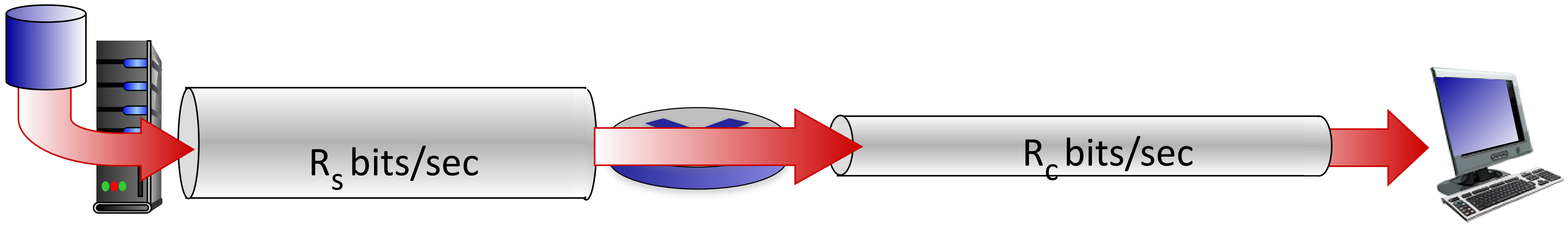
server, with

What is throughput?

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

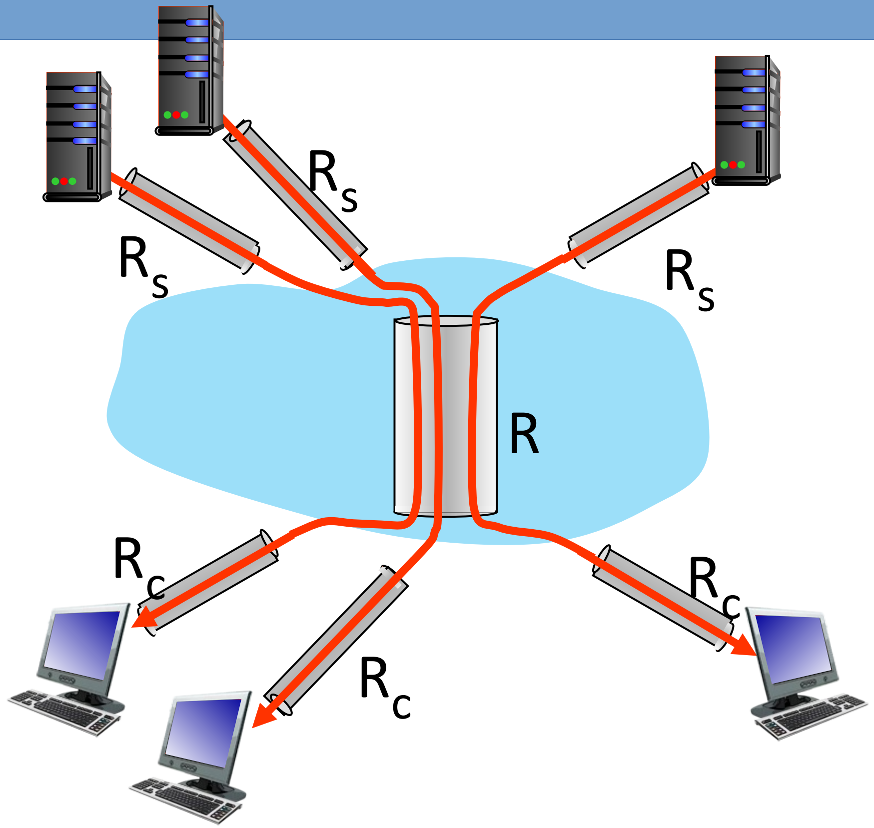


$R_s > R_c$ What is average end-end throughput?



bottleneck link

What is throughput?



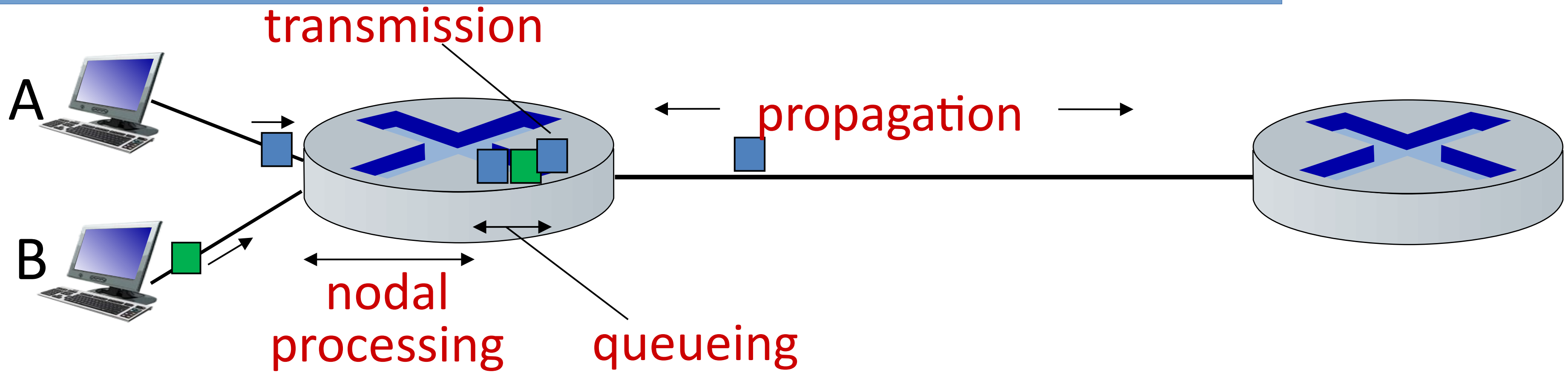
10 connections (fairly) share backbone bottleneck link *R* bits/sec

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

• Transmission Delay vs Propagation Delay

- Time for the first box = time to travel the length of the belt
  - Propagation delay
- Time for successive boxes (1/rate at which boxes are put on the belt)
- Transmission time = number of boxes /rate
- For packets the units are bits/sec, Bytes/sec or packets/sec
- Total transfer time= Transmission time + Propagation delay

• Transmission Delay vs Propagation Delay



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

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 (~2x10^8 m/sec)
- $d_{prop} = d/s$

• Propagation Delay

-Often a function of the speed of light
-2 times Propagation delay often referred to as RTT (Round Trip Time)

1. How long does it take a single bit to travel on the link from A to B of length 500 m with a prop. delay factor = 5 **μsec**/km ?

Another way to ask this question:
If it takes a signal 5 μsec to travel 1 kilometer, then how long does it take a signal to travel 500 meters?

$$\frac{5\ \mu\text{sec}}{1000\ \text{m}} = \frac{t}{500\ \text{m}}$$

Solving for t…
$t = 2.5\ \mu\text{sec}$

Transmission Delay

A function of the length of the packet and speed of the link

2. How long does it take A to transmit an entire packet onto the link?

Relevant information: packet length = 1500 bytes
channel speed = 10 Mbps

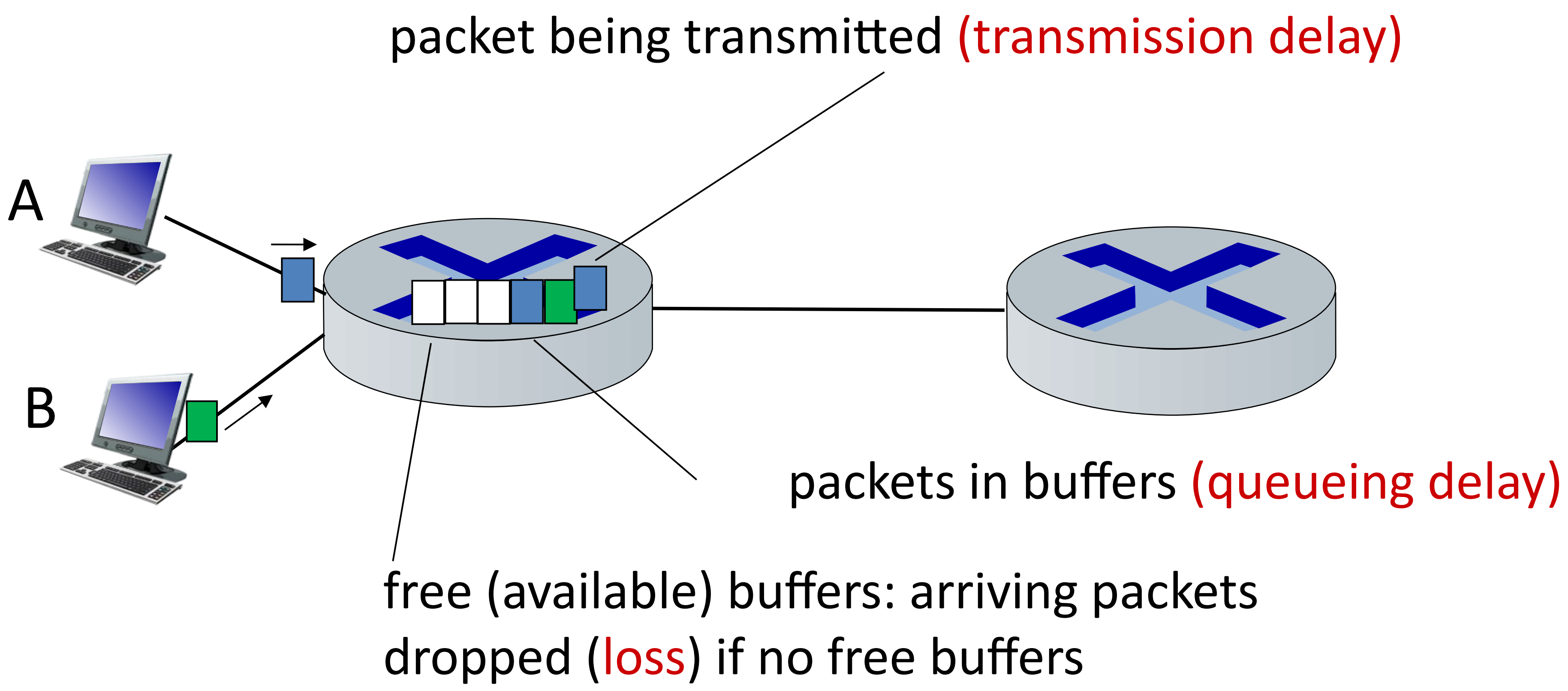
Another way to ask this question:
If the link can transmit 10 million bits in a second, how many seconds does it take to transmit 1500 bytes (8x1500 bits)?

$$\frac{10 \text{ Mbits}}{1 \text{ sec}} = \frac{1500 \text{ x } 8 \text{ bits}}{t}$$

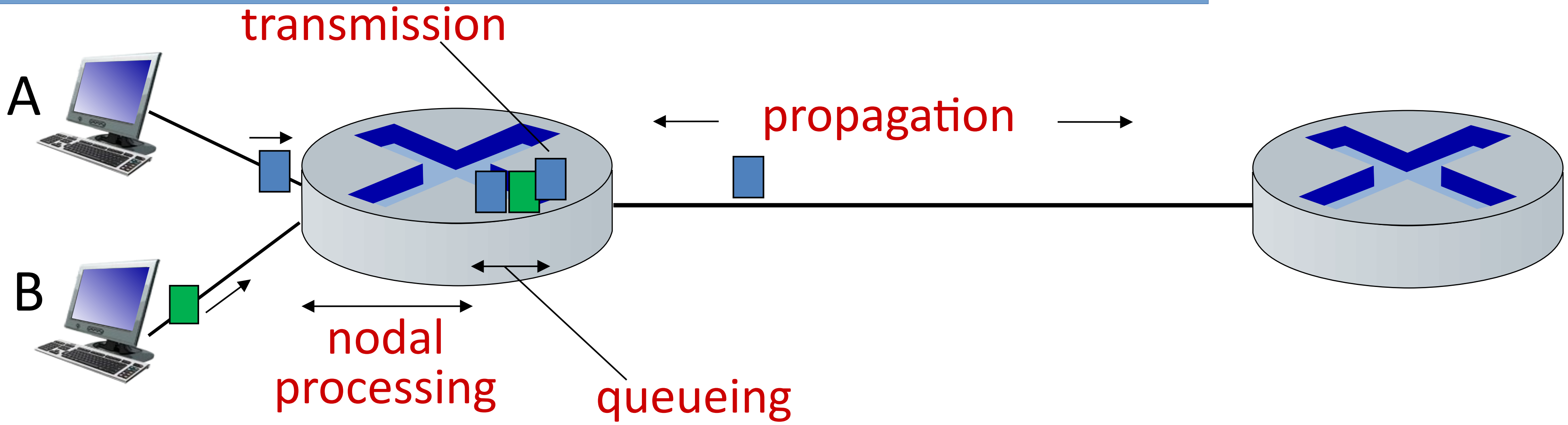
Solving for t…
t = 0.0012 sec (or 1.2 msec)

Queuing Delay

- packets *queue* in router buffers, waiting for turn for transmission
  - queue length grows when arrival rate to link (temporarily) exceeds output link capacity
- packet *loss* occurs when memory to hold queued packets fills up



Queuing Delay



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

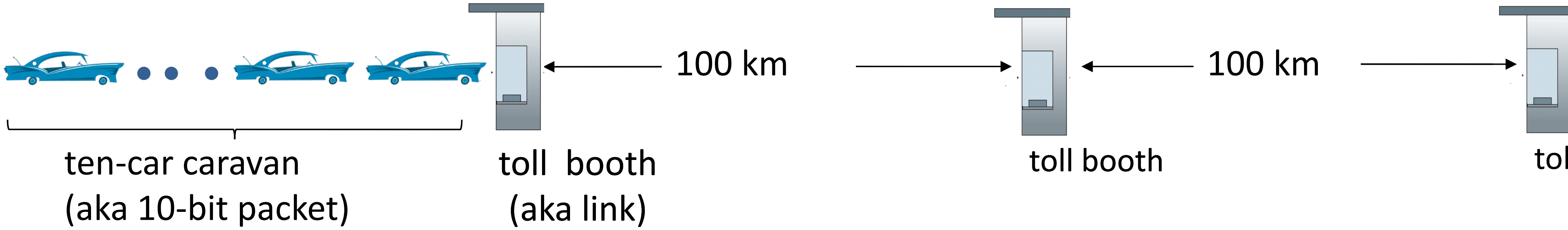
d_{proc}: nodal processing

- check bit errors
- determine output link
- typically < microsecs

d_{queue}: queueing delay

- time waiting at output link for transmission
- depends on congestion level of router

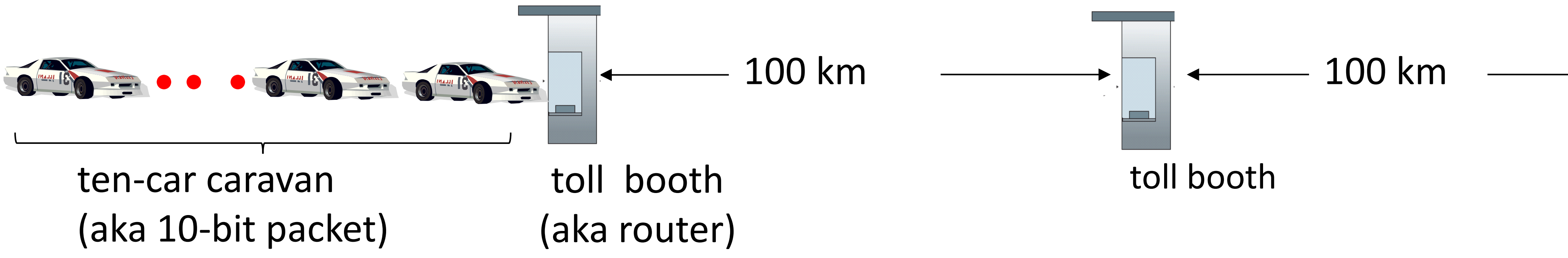
Queuing Delay



- car ~ bit; caravan ~ packet; toll service ~ link transmission
- toll booth takes 12 sec to service car (bit transmission time)
- “propagate” at 100 km/hr
- *Q:* How long until caravan is lined up before 2nd toll booth?

- time to “push” entire cara through toll booth onto h 12*10 = 120 sec
- time for last car to propag 1st to 2nd toll both: 100km/(100km/hr) = 1 hr
- *A:* 62 minutes

Queuing Delay



- 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?*

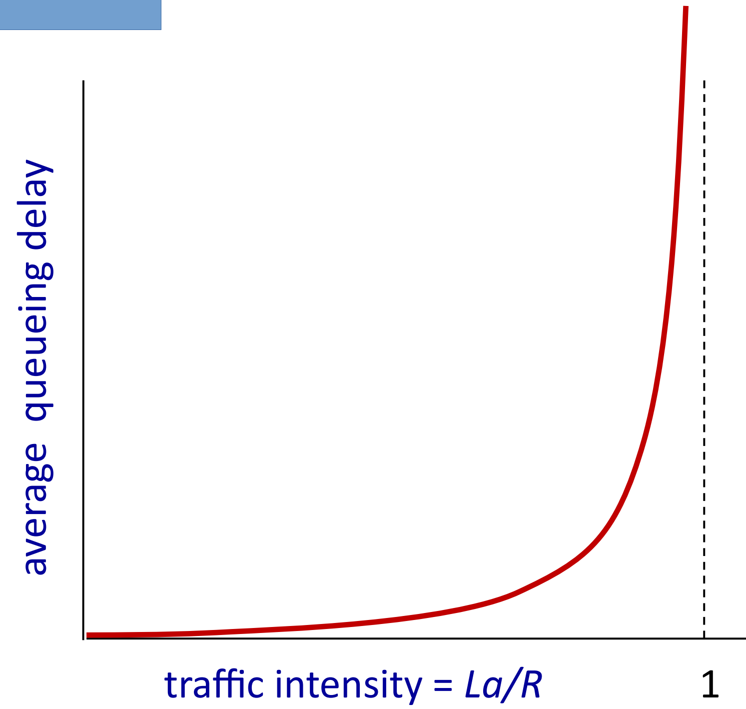
A: Yes! after 7 min, first car arrives at second booth; three cars still at first b

Queuing Delay

- *a:* average packet arrival rate
- *L:* packet length (bits)
- *R:* link bandwidth (bit transmission rate)

$$\frac{L \cdot a}{R} : \quad \frac{\text{arrival rate of bits}}{\text{service rate of bits}}$$

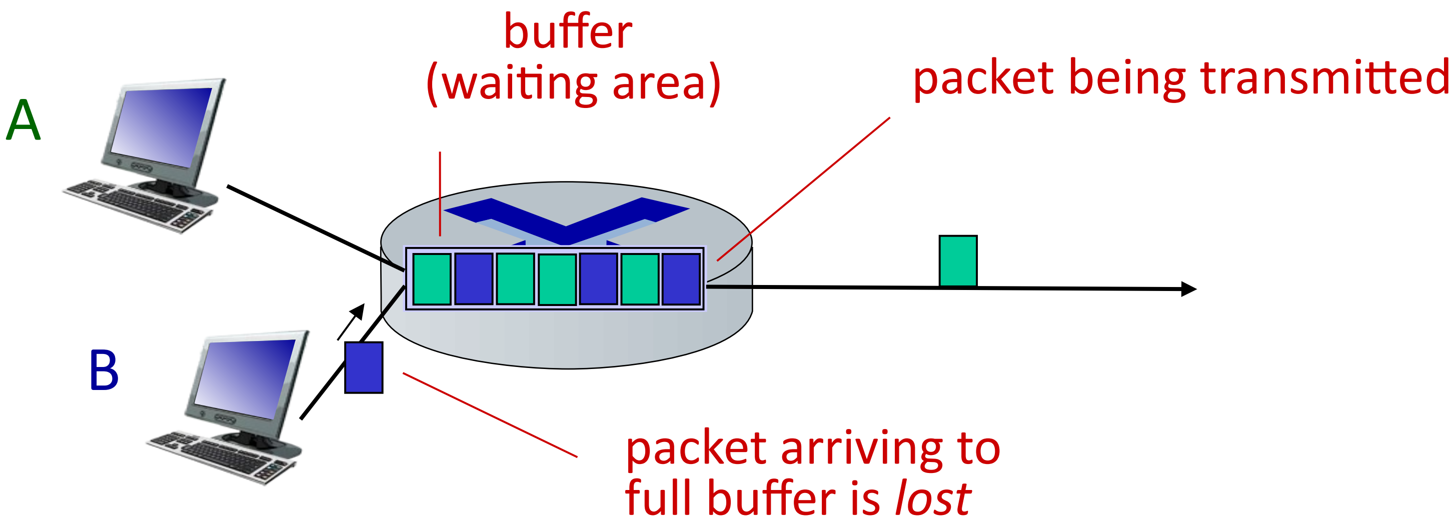
"traffic intensity"



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

Queuing Delay

- 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, at all



Switching

- Circuit Switching
- Message Switching
- Packet Switching

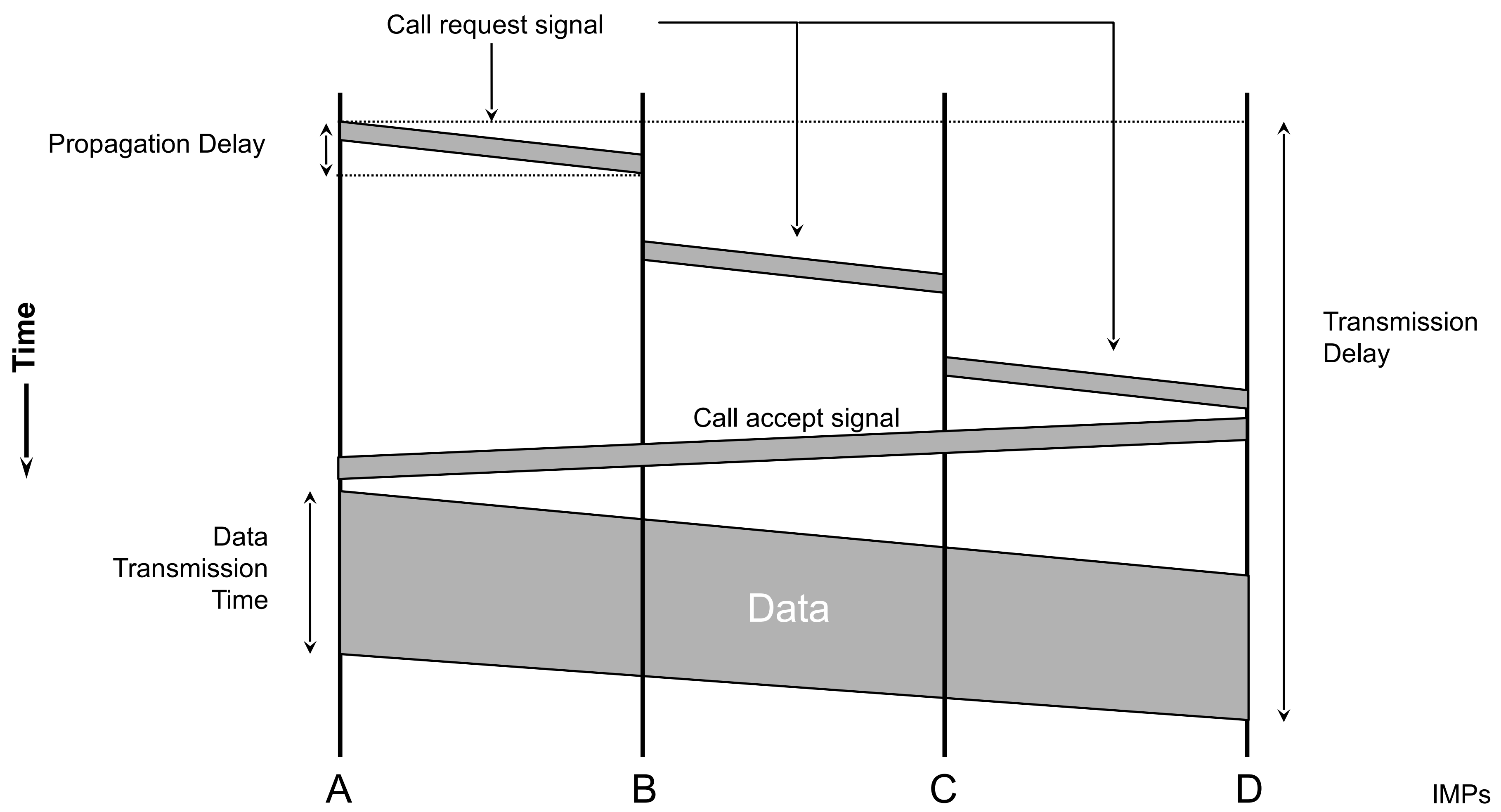
Circuit Switching

- Provides service by setting up the total path of connected lines from the origin to the destination
- Example: Telephone network

Circuit Switching

1. Control message sets up a path from origin to destination
2. Return signal informs source that data transmission may proceed
3. Data transmission begins
4. Entire path remains allocated to the transmission (whether used or not)
5. When transmission is complete, source releases the circuit

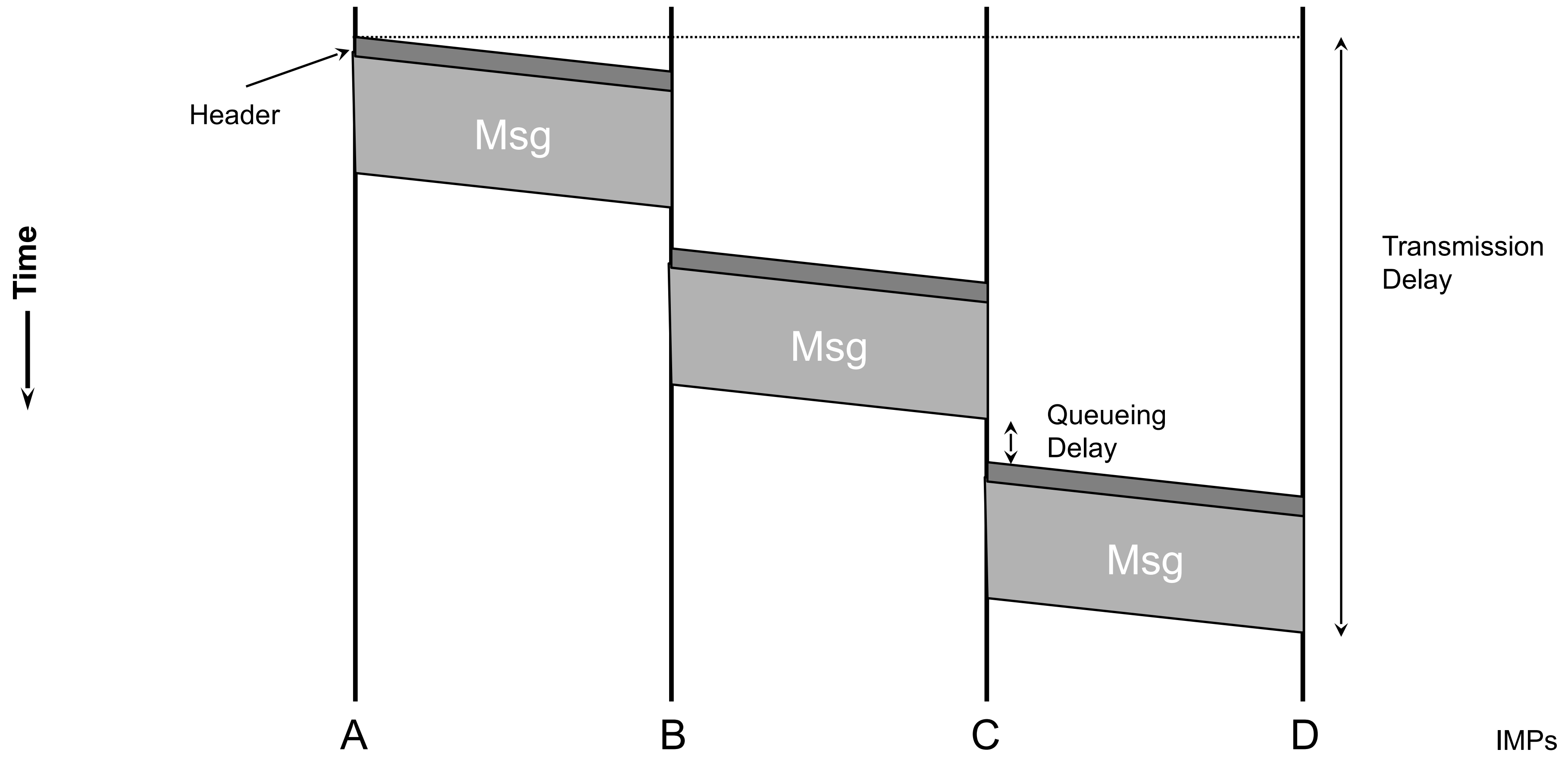
Circuit Switching



Message Switching

- Each message is addressed to a destination
- When the entire message is received at a router, the next step in its journey is selected; if this selected channel is busy, the message waits in a queue until the channel becomes free
- Thus, the message “hops” from node to node through a network while allocating only one channel at a time
- Analogy: Postal service

Message Switching



Packet Switching

- Messages are split into smaller pieces called **packets**
- These packets are numbered and addressed and sent through the network one at a time
- Pipelining

Packet Switching