Computer Networks I

Some Performance Metrics

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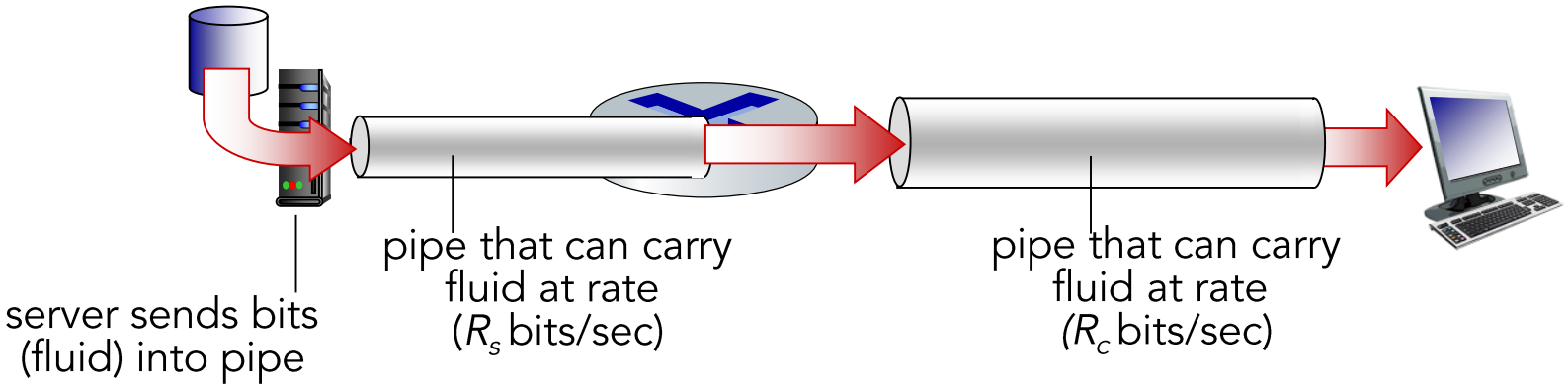
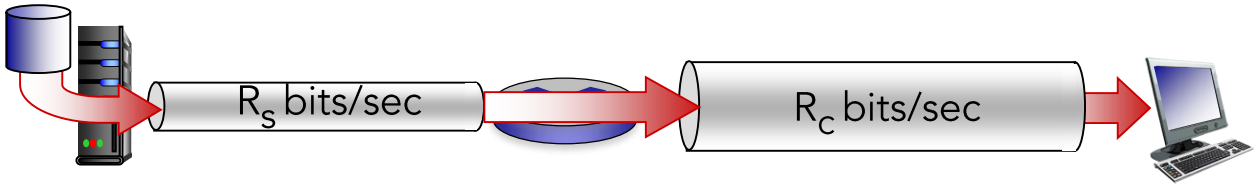
Throughput

- *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



Throughput

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



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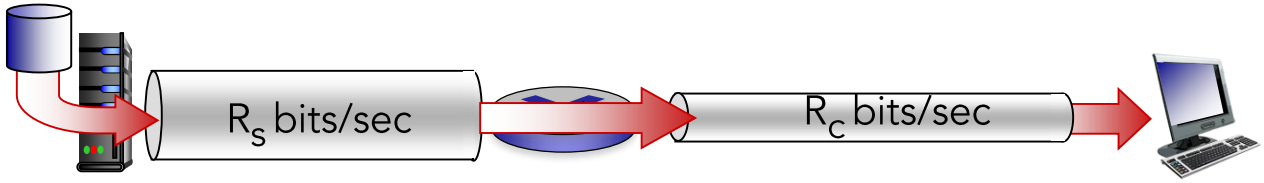


bottleneck link

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

Related Terminologies/Metrics

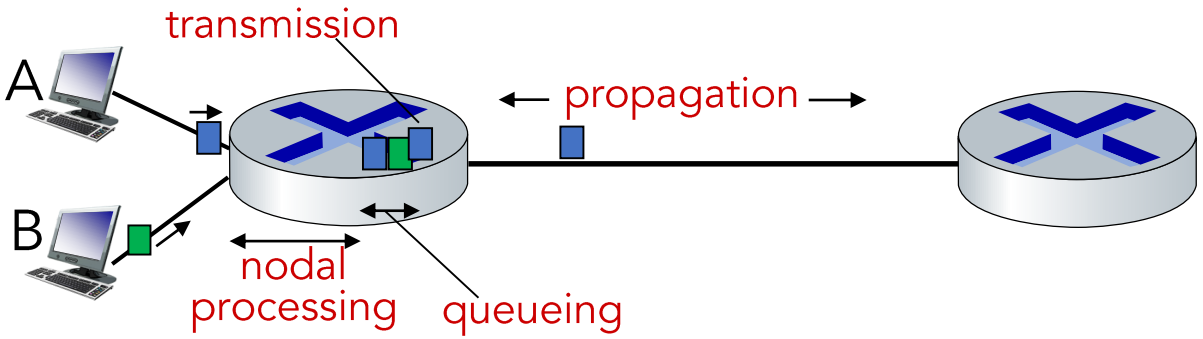
- *Datarate/Bitrate:* Rate (bits/time unit) at which bits are being sent/received at the physical layer

- *Throughput:* Rate (bits/time unit) at the network layer to measure the end-to-end performance
  - A related terminology that used is goodput

- *Difference between throughput and goodput:*
  - *Throughput:* Number of bits received per unit time
  - *Goodput:* Number of useful bits received per unit time

Packet delay: four sources

- *Delay/Latency:* Time taken by the packet to reach the destination



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

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

Packet delay: four sources

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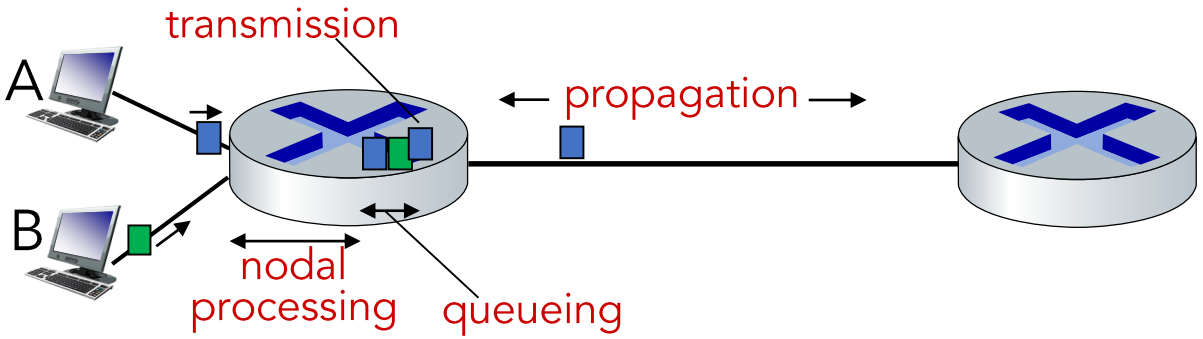


$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{trans}: transmission delay:

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

d_{prop}: propagation delay:

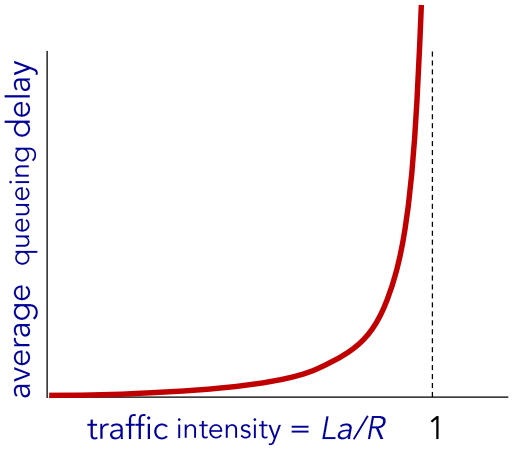
- *d:* length of physical link
- *s:* propagation speed (~2×10^8 m/sec)
- $d_{prop} = d/s$

Packet queueing delay

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

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

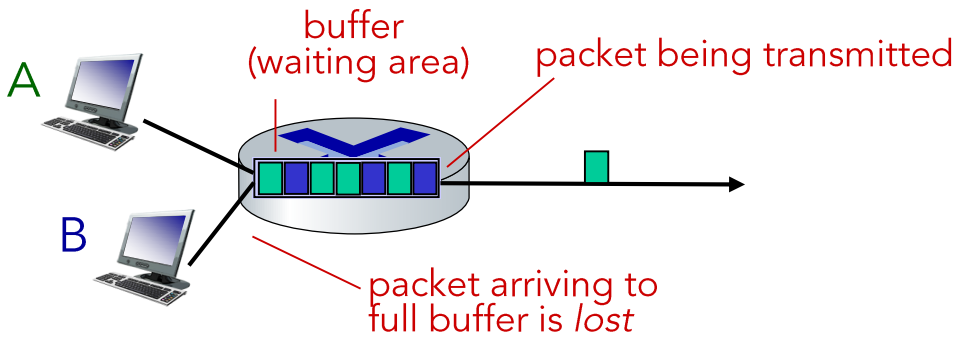
"traffic intensity"



- *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!

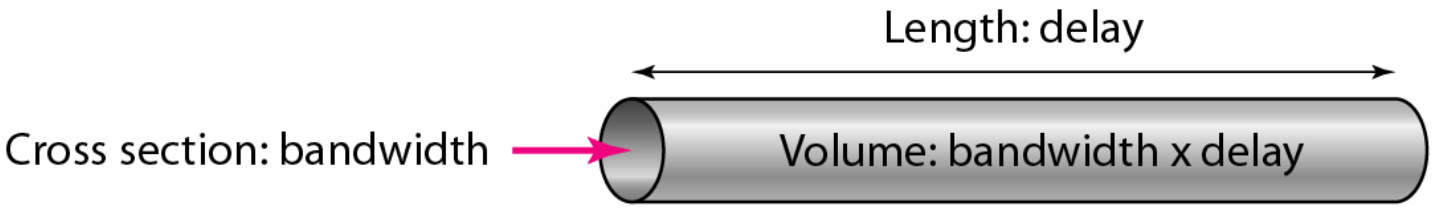
How do packet delay and loss occur?

- 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

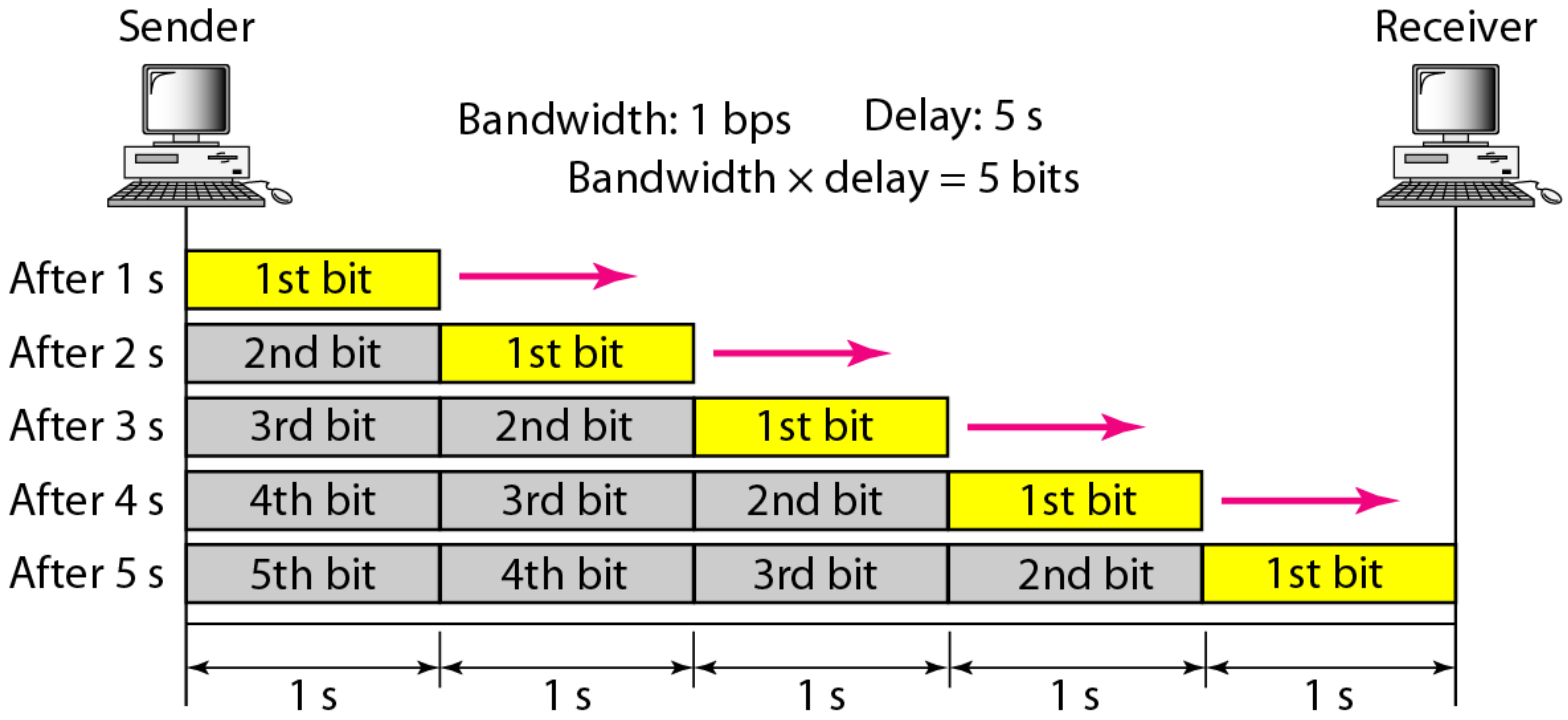


Bandwidth-Delay Product

- The bandwidth-delay product defines the number of bits that can fill the link
  - Think about the link between two points as a pipe
  - The cross section of the pipe represents the bandwidth
  - The length of the pipe represents the delay
- We can say the volume of the pipe defines the bandwidth-delay product



Bandwidth-Delay Product



Bandwidth-Delay Product