IT 304 Computer Networks
Introduction
Week 2-Lecture 2

Recap: Week 2-Lec 1

- Internet
  - Big picture View
  - Service view
- Components of a network
  - Edge, access and core
- Performance metrics

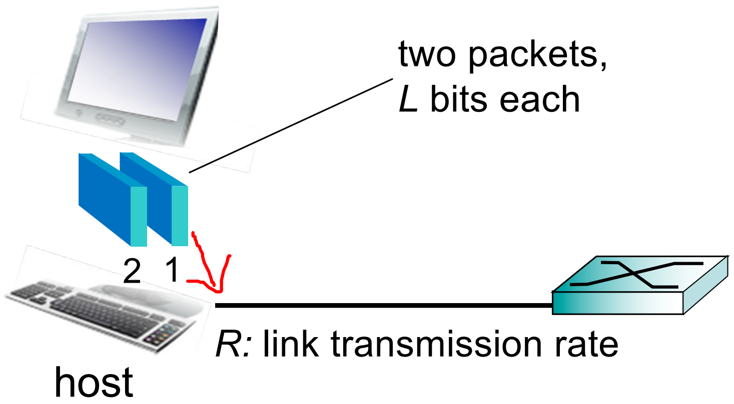
Today’s lecture

- Cont.. performance metrics

Host: sends *packets* of data

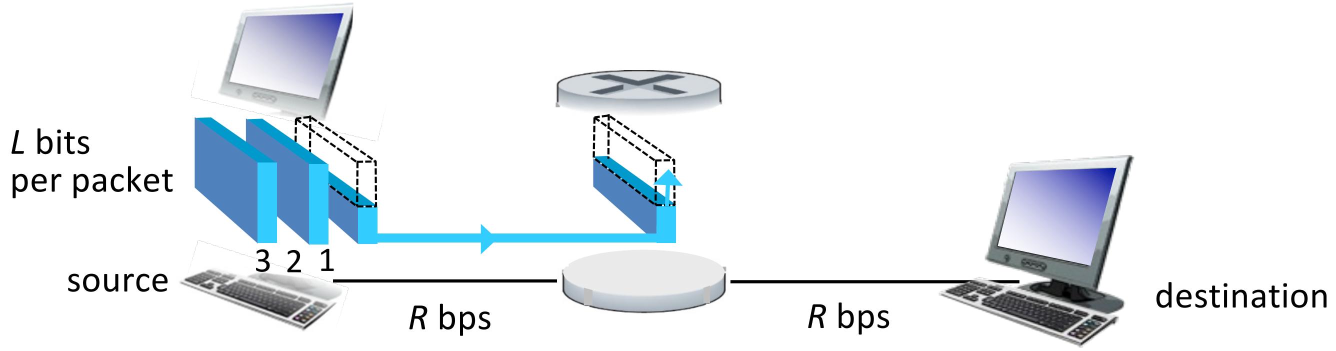
host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length *L* bits
- transmits packet into access network at *transmission rate R*
  - link transmission rate, aka link *capacity, aka link bandwidth*



time needed to transmit *L*-bit packet into link $= \dfrac{L \text{ (bits)}}{R \text{ (bits/sec)}}$

Packet-switching: store-and-forward



- takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- end-end delay = $2L/R$ (assuming zero propagation delay)

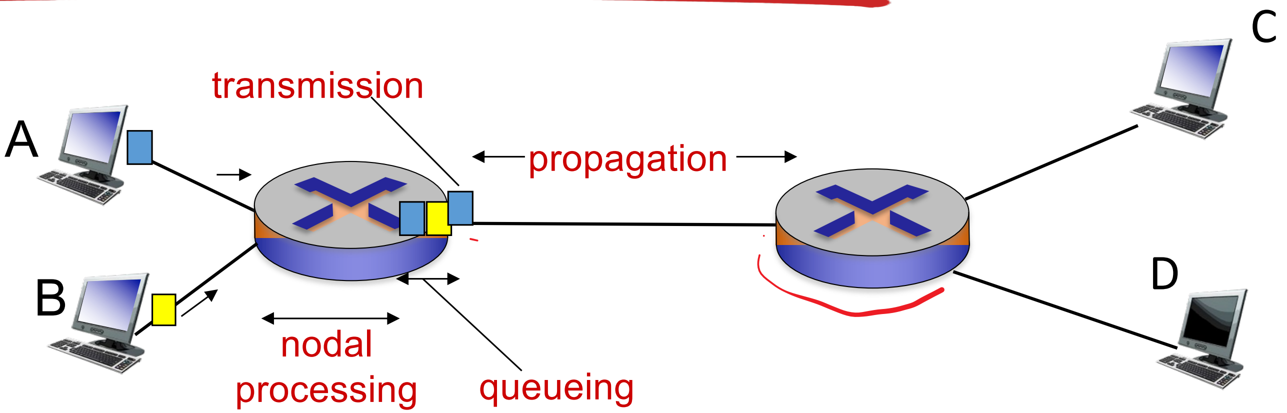
one-hop numerical example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- one-hop transmission delay = 5 sec

more on delay shortly …

What are the main components of delay when we use packet switching?
→ *Processing delay*
→ *queuing delay*
→ *transmission delay*
→ *propagation delay*

Four sources of packet delay



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

d_{trans}: transmission delay: func(L, R)

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

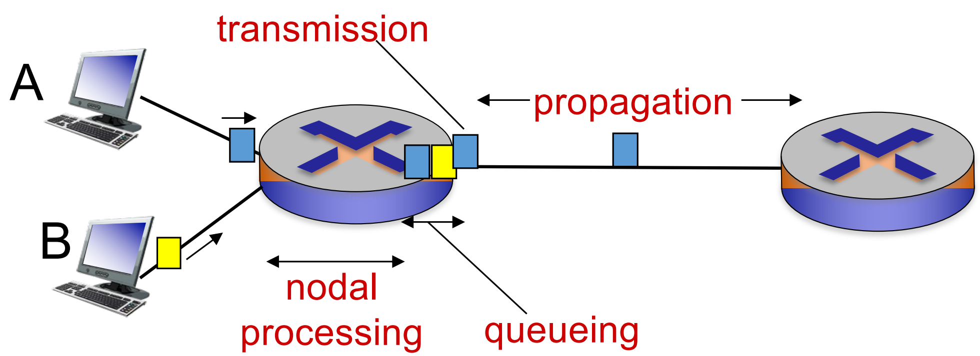
d_{trans} and d_{prop} *very* different

d_{prop}: propagation delay: func(d)

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

* Check out the online [interactive exercises]for more examples:

Four sources of packet delay



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

d_{proc}: nodal processing

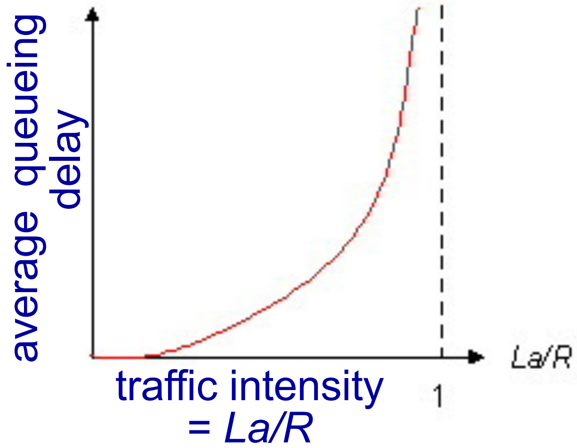
- check bit errors
- determine output link
- typically < msec

d_{queue}: queueing delay

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

Queueing delay

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



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

La/R ~ 0

La/R -> 1

* Check online interactive animation on queuing and loss

Delay factor contributions to Total Delay

- d_{prop}
  - for a link connecting two routers on the same university campus → negligible
  - for two routers interconnected by a satellite link(100s km) → 100+ milliseconds
- d_{trans}
  - > bandwidths (10 Mbps and higher) → negligible [more bits/sec]
  - If large Internet packets sent over low-speed dial-up modem links → hundreds of milliseconds
  - .
- d_{proc} is often negligible
  - Super fast routers

Propagation delay is defined as the time taken for bits in a packet to go over a transmission link.

A. True

B. False

Propagation delay is a function of

A. Distance

B. Bandwidth

C. Packet size

D. Speed of light in a medium

Tranmission delay is a function of

A. Distance

B. Speed of light in a medium

C. Bandwidth

D. Packet size

Total delay =

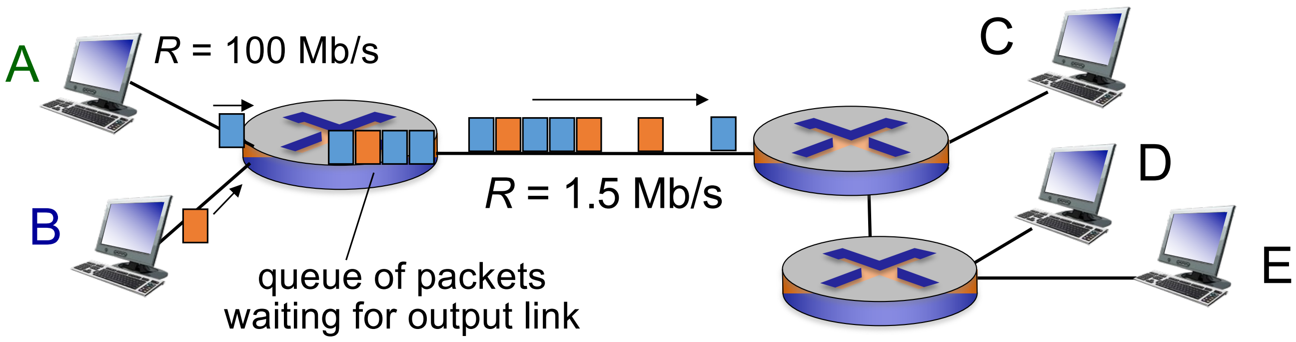
# dtrans	#dprop

Total delay =

# dtrans	#dprop

$$\boxed{d_{End\text{-}End} = N(d_{\mathrm{proc}} + d_{\mathrm{queue}} + d_{\mathrm{trans}} + d_{\mathrm{prop}})}$$

Packet Switching: queueing delay, loss



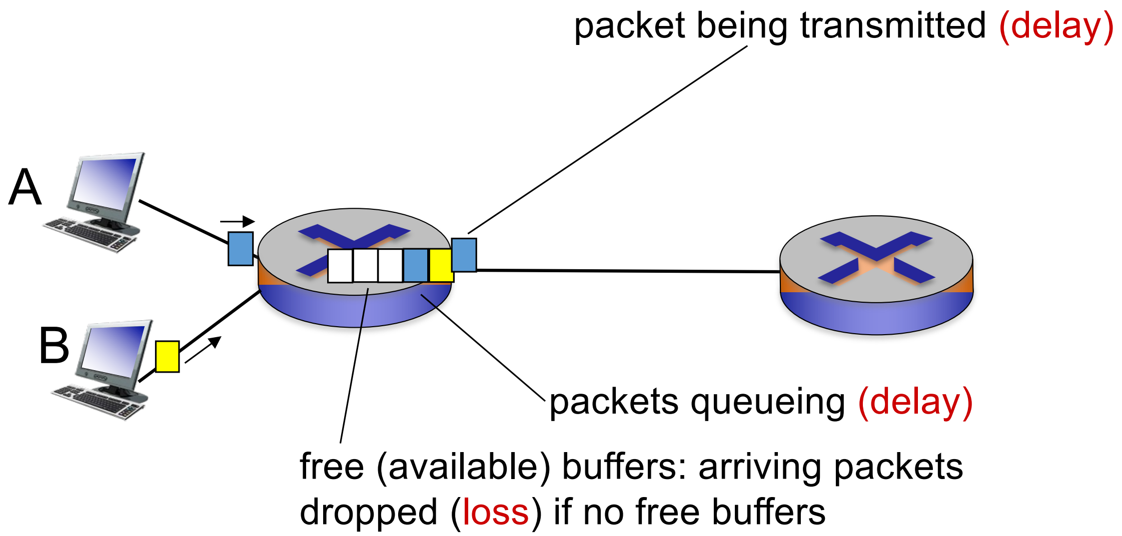
queuing and loss:

- if arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

How do loss and delay occur?

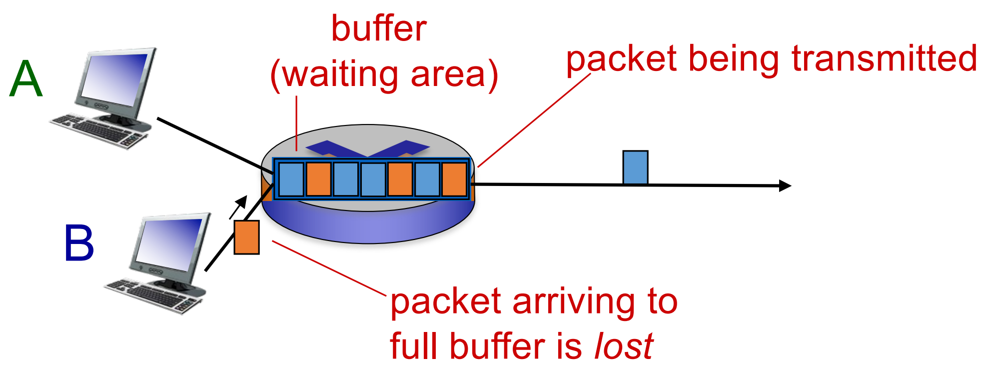
packets *queue* in router buffers

- packet arrival rate to link (temporarily) exceeds output link capacity
- packets queue, wait for turn



Packet loss

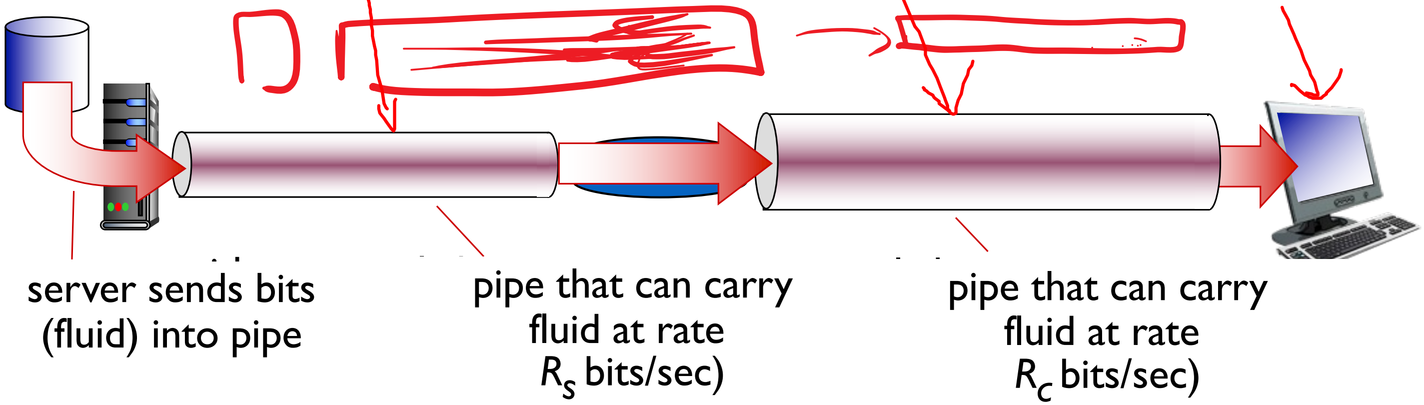
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



* Check out the Java applet for an interactive animation on queuing and loss

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

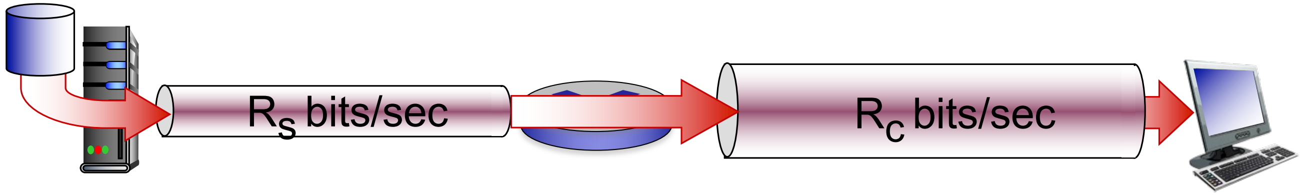


If four routers are separated by 10km, but with different capacity optical fibre cables, which delay component will be constant and which one will vary?

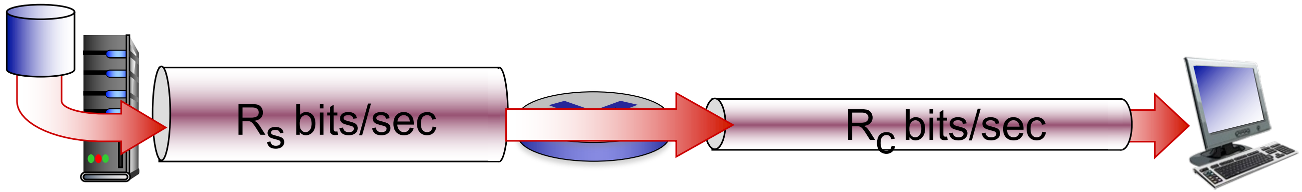
A. d_{prop} constant, d_{trans} varying
B. d_{prop} varying, d_{trans} varying
C. d_{prop} varying, d_{trans} constant
D. d_{prop} constant, d_{trans} constant

Throughput (more)

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



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

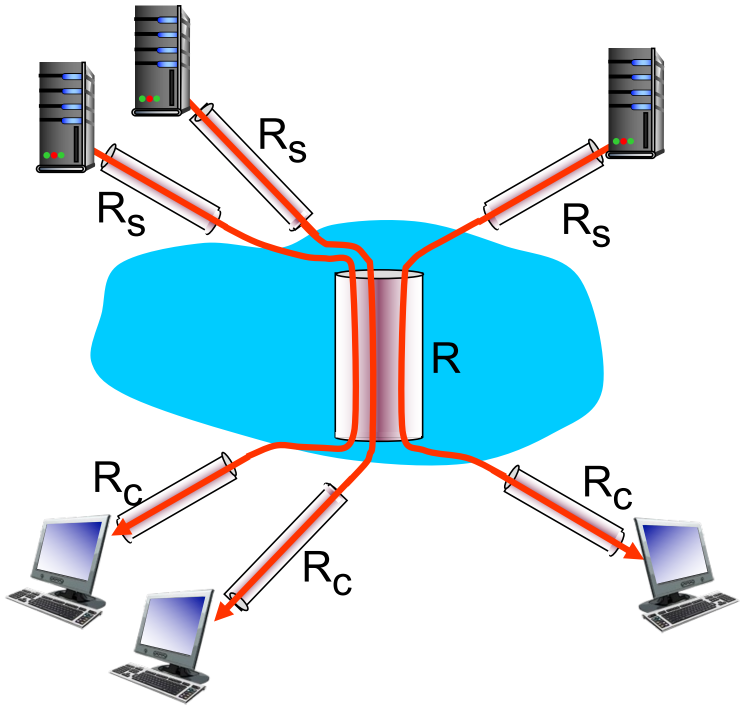


bottleneck link

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 is often bottleneck



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

"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.