

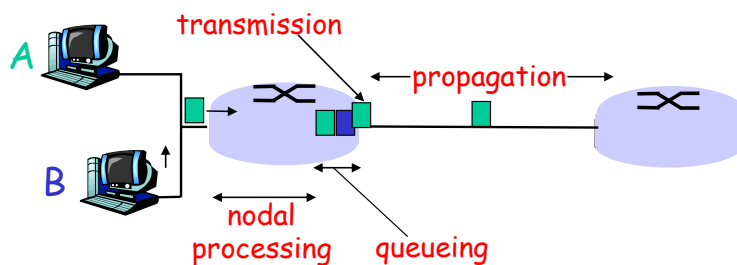
Four sources of packet delay

1. nodal processing:

- check bit errors
- determine output link

2. queueing

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



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Delay in packet-switched networks

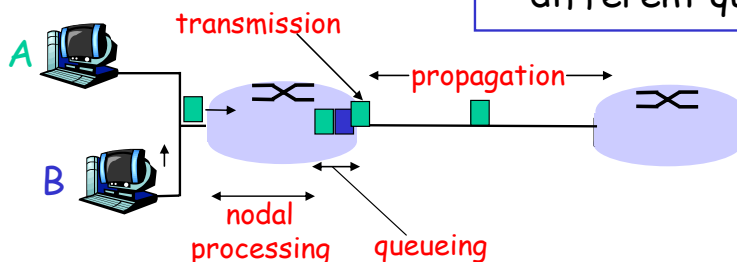
3. Transmission delay:

- R = link bandwidth (bps)
- L = packet length (bits)
- time to send bits into link = L/R

4. Propagation delay:

- d = length of physical link
- s = propagation speed in medium ($\sim 2 \times 10^8$ m/sec)
- propagation delay = d/s

Note: s and R are very different quantities!



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Nodal delay

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

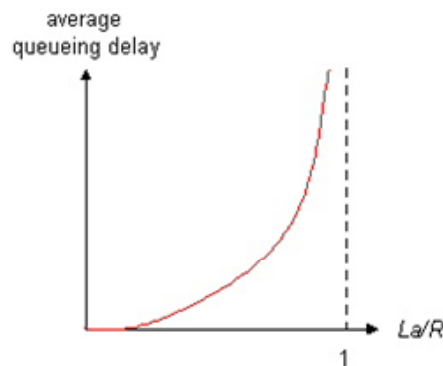
- d_{proc} = processing delay
 - typically a few microsecs or less
- d_{queue} = queuing delay
 - depends on congestion
- d_{trans} = transmission delay
 - $= L/R$, significant for low-speed links
- d_{prop} = propagation delay
 - a few microsecs to hundreds of msecs

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Queueing delay (revisited)

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

traffic intensity = La/R



- $La/R \sim 0$: average queueing delay small
- $La/R \rightarrow 1$: delays become large
- $La/R > 1$: more "work" arriving than can be serviced, average delay infinite!

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