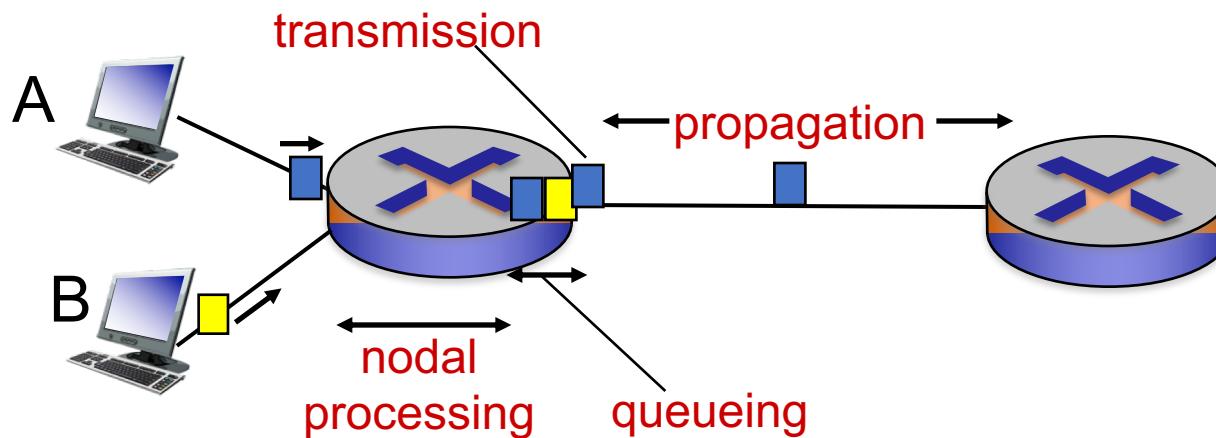


Four sources of packet delay



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

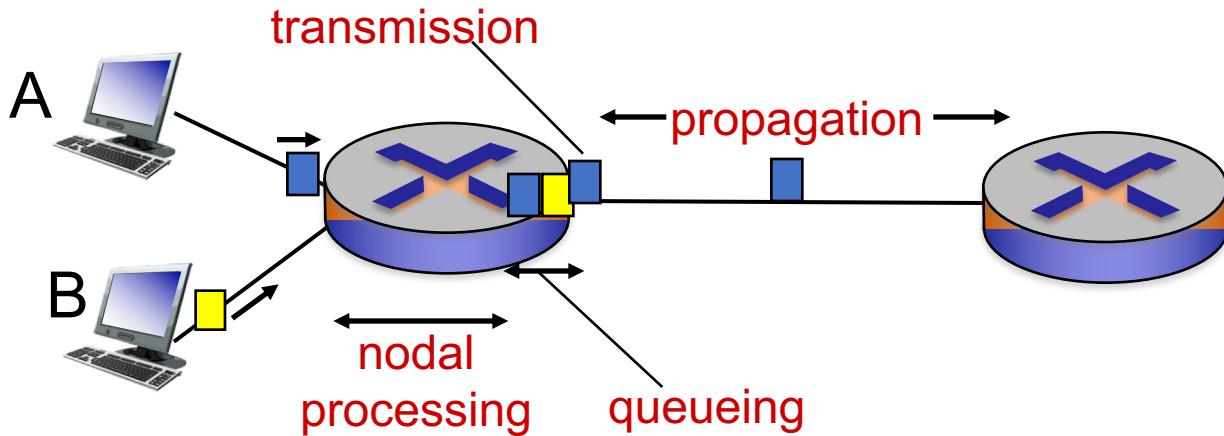
d_{proc} : nodal processing

- 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

Four sources of packet delay



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

d_{trans} : transmission delay:

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

d_{trans} and d_{prop}
very different

d_{prop} : propagation delay:

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

* Check out the [online](#) interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

* Check out the Java applet for an interactive animation on transmission delay vs. propagation delay

How long does it take a packet of length 1,000 bytes to propagate over a link of distance 2,500 km, propagation speed $2.5 \cdot 10^8$ m/s, and transmission rate 2 Mbps? More generally, how long does it take a packet of length L to propagate over a link of distance d , propagation speed s , and transmission rate R bps? Does this delay depend on packet length? Does this delay depend on transmission rate?

Review the car-caravan analogy in Section 1.4. Assume a propagation speed of 100 km/hour.

- a. Suppose the caravan travels 150 km, beginning in front of one tollbooth, passing through a second tollbooth, and finishing just after a third tollbooth. What is the end-to-end delay?
- b. Repeat (a), now assuming that there are eight cars in the caravan instead of ten.

This elementary problem begins to explore propagation delay and transmission delay, two central concepts in data networking. Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link is s meters/sec. Host A is to send a packet of size L bits to Host B.

- a. Express the propagation delay, d_{prop} , in terms of m and s .
- b. Determine the transmission time of the packet, d_{trans} , in terms of L and R .
- c. Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.
- d. Suppose Host A begins to transmit the packet at time $t = 0$. At time $t = d_{\text{trans}}$, where is the last bit of the packet?
- e. Suppose d_{prop} is greater than d_{trans} . At time $t = d_{\text{trans}}$, where is the first bit of the packet?
- f. Suppose d_{prop} is less than d_{trans} . At time $t = d_{\text{trans}}$, where is the first bit of the packet?
- g. Suppose $s = 2.5 \cdot 10^8$, $L = 120$ bits, and $R = 56$ kbps. Find the distance m so that d_{prop} equals d_{trans} .