Bandwidth and Propagation Delay Exercises

Lecture 3, Spring 2026

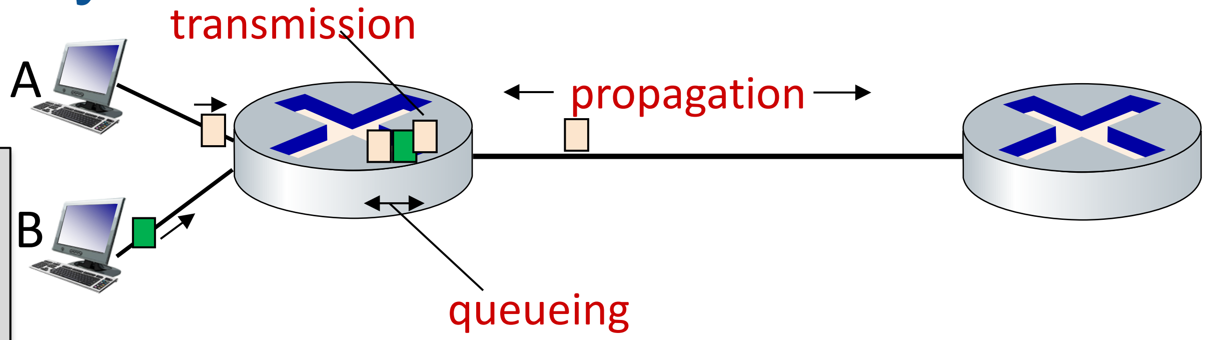
Links

- Bandwidth and Propagation Delay
- Pipe Diagrams
- Overloaded Links

Brief Preview of the Semester

IMPORTANT

Packet delay: four sources



The nodal processing delay (check bit errors, determine output link) is typically very small and can be ignored

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

d_q: queueing delay

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

d_{tx}: transmission delay:

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

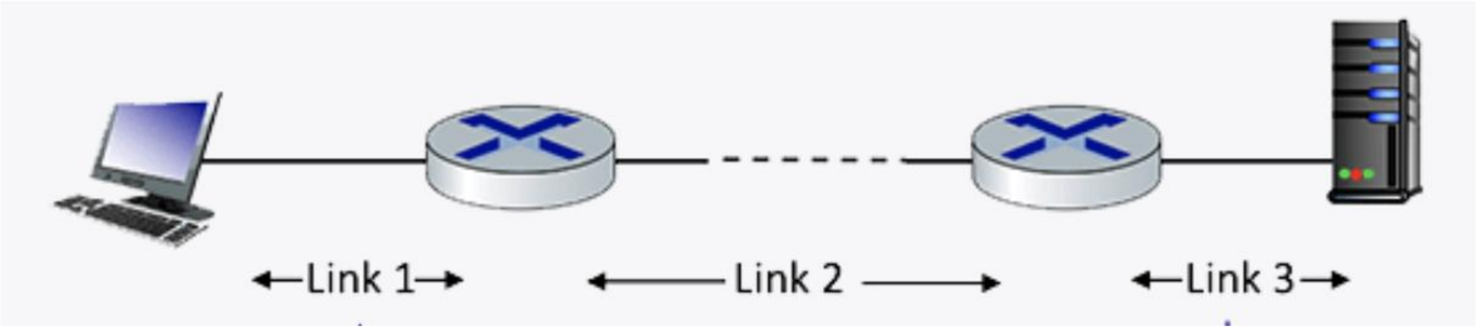
d_{prop}: propagation delay:

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

Q1 End-to-end delay

Consider the network shown in the figure, with three links, each with a transmission rate of 1 Mbps, and a propagation delay of 1 msec per link. Assume the length of a packet is 1000 bits.

- What is the end-end delay of a packet from when it first begins transmission on link 1, until is it received in full by the server at the end of link 3. Assume that queueing delays are zero.



Q2 End-to-end delay

Consider the scenario shown in Figure 1: a server is connected to a router by a 100Mbps link with a 50ms propagation delay. This router is connected to two other routers, each over a 50Mbps link with a 200ms propagation delay. A 1Gbps link connects each client to each of these routers with 0 propagation delay. (Ignore the cache.) All packets in the network are 20,000 bits long.

- What is the end-to-end delay (in ms) from when a packet is transmitted by the server to when it is received by the client? Assume there's no queuing delay at the routers.

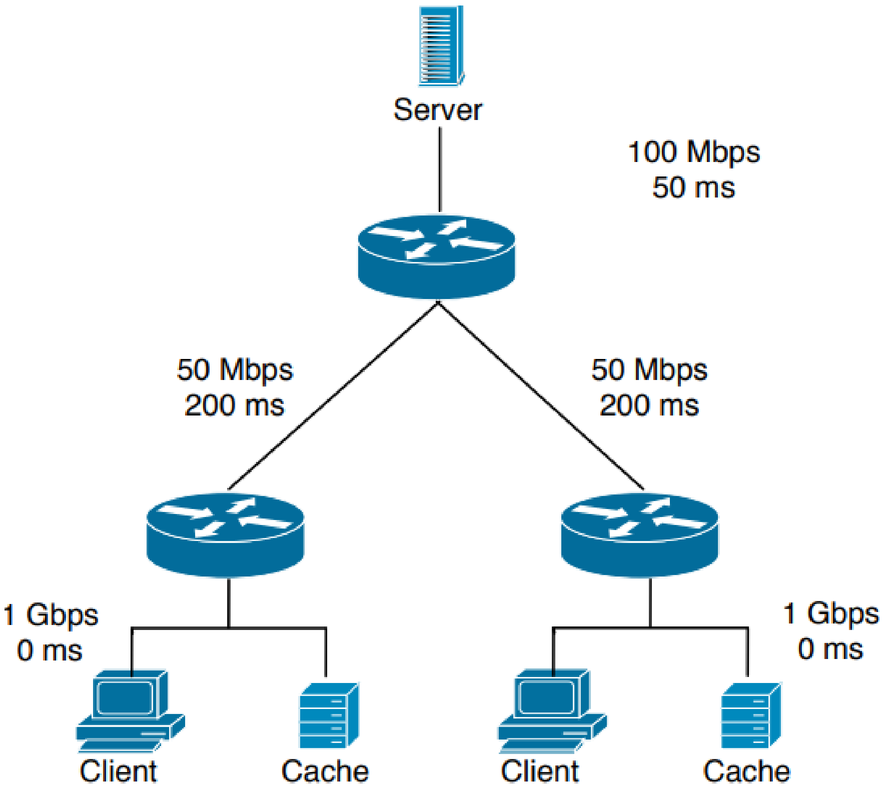
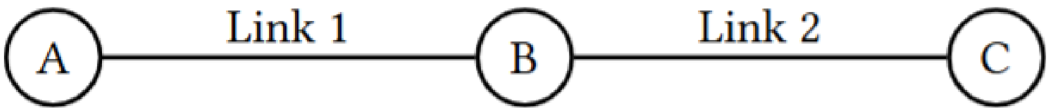


Figure 1

Q3.1 End-to-end delay

- In the diagram below, we have two different links, each with different physical properties.
  - Suppose T_1 = 10000, L_1 = 100000, and $S_1 = 2.5 \times 10^8$. How long does it take to send a 500-byte packet from Node A to Node B?



	Link 1	**Link 2**
Physical length of link	L_1 meters	L_2 meters
Speed of data propagation	S_1 meters/sec	S_2 meters/sec
Bandwidth of link	T_1 bits/sec	T_2 bits/sec

Q3.2 End-to-end delay

- The RTT (Round Trip Time) is the time it takes to send a packet (from source to destination) and receive a response (from destination to source). Count from the time the source transmits the first byte, to the time the source receives the last byte of the response.
- Node A sends a x-byte packet to Node C. Then, Node C sends an x-byte response back to Node A. What is the RTT for this exchange?
- Note: Since there is only one packet, there is no queuing delays. We assume processing delay is negligible, so Node C starts transmitting the response immediately after it receives the last byte of the packet.

Q3.3 End-to-end delay

- Node A sends two packets: Packet P_1 of size D_1 bytes. Packet P_2 of size D_2 bytes. Node A starts sending packet P_1 at t = 0. Node A immediately starts sending packet P_2 after it finishes transmitting all the bits of P_1.
- When will Node C receive the last bit of packet P_2?

Q3.4 End-to-end delay

- Find the variable relations that need to be satisfied in order to have no queuing delays for part (c).

Q4. Statistical Multiplexing

- Consider three flows F_1, F_2, F_3 sending packets over a single link. The sending pattern of each flow is described by how many packets it sends within each one-second interval; the table below shows these numbers for the first ten intervals. A perfectly smooth (i.e., non-bursty) flow would send the same number of packets in each interval, but our three flows are very bursty, with highly varying numbers of packets in each interval:
- 1) What is the peak rate of each flow? What is the sum of the peak rates?
- 2) Now consider all packets to be in the same aggregate flow. What is the peak rate of this aggregate flow?
- 3) Which is higher - the sum of the peaks, or the peak of the aggregate?

Time (s)	1	2	3	4	5	6	7	8	9	10
F_1	1	8	3	15	2	1	1	34	3	4
F_2	6	2	5	5	7	40	21	3	34	5
F_3	45	34	15	5	7	9	21	5	3	34