Q1 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 · 108 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?

Q2 Suppose Host A wants to send a large file to Host B. The path from Host A to Host B has three links, of rates R1 = 500 kbps, R2 = 2 Mbps, and R3 = 1 Mbps.

a. Assuming no other traffic in the network, what is the throughput for the file transfer?

b. Suppose the file is 4 million bytes. Dividing the file size by the throughput, roughly how long will it take to transfer the file to Host B?

c. Repeat (a) and (b), but now with R2 reduced to 100 kbps.

Q3 Suppose end system A wants to send a large file to end system B. At a very high level, describe how end system A creates packets from the file. When one of these packets arrives to a packet switch, what information in the packet does the switch use to determine the link onto which the packet is forwarded? Why is packet switching in the Internet analogous to driving from one city to another and asking directions along the way?

. Equation 1.1 gives a formula for the end-to-end delay of sending one packet of length L over N links of transmission rate R. Generalize this formula for sending P such packets back-to-back over the N links.

P3. Consider an application that transmits data at a steady rate (for example, the sender generates an N-bit unit of data every k time units, where k is small and fixed). Also, when such an application starts, it will continue running for a relatively long period of time. Answer the following questions, briefly justifying your answer: a. Would a packet-switched network or a circuit-switched network be more appropriate for this application? Why? b. Suppose that a packet-switched network is used and the only traffic in this network comes from such applications as described above. Furthermore, assume that the sum of the application data rates is less than the capacities of each and every link. Is some form of congestion control needed? Why?

P4. Consider the circuit-switched network in Figure 1.13. Recall that there are 4 circuits on each link. Label the four switches A, B, C and D, going in the clockwise direction. a. What is the maximum number of simultaneous connections that can be in progress at any one time in this network? b. Suppose that all connections are between switches A and C. What is the maximum number of simultaneous connections that can be in progress? c. Suppose we want to make four connections between switches A and C, and another four connections between switches B and D. Can we route these calls through the four links to accommodate all eight connections?

P5. 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.

P6 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, dprop, in terms of m and s. b. Determine the transmission time of the packet, dtrans, in terms of L and R. c. Ignoring processing and queuing delays, obtain an expression for the endto-end delay. d. Suppose Host A begins to transmit the packet at time t = 0. At time t = dtrans, where is the last bit of the packet? e. Suppose dprop is greater than dtrans. At time t = dtrans, where is the first bit of the packet? f. Suppose dprop is less than dtrans. At time t = dtrans, where is the first bit of the packet? g. Suppose s = 2.5 · 108, L = 120 bits, and R = 56 kbps. Find the distance m so that dprop equals dtrans.