P2. 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.

end-to-end delay = N(L/R)
P packet delay = P*N(L/R)

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?

a. A circuit-switched network would be more appropriate for this application. Because the application involved fixed bandwidth and long sessions.
b. No congestion control needed, since the sum of the application data rates is less than the capacities of each and every link. For the worst case, the bandwidth is still enough for all applications transmitting data in the same time over one or more network links, thus congestion is not needed.

P5. Review the car-caravan analogy in Section 1.4. Assume a propagation speed of 100 km/hour.
a. Suppose the caravan travels 175 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.

a. travel time = 175 km / 100 km/h = 1.75 h = 105 mins
   time for taken by 3 tollbooths to reach 10 cars= 2 * 3=6 mins
   end-to-end delay = 105 + 6 = 111 mins
b. time for taken by 3 tollbooths to reach 8 cars = 12 * 8 * 3 = 288 s = 4.8 mins
   end-to-end delay = 105 + 4.8 = 109.8 mins

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 end-to-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 * 10^8 , L = 1500 bytes, and R = 10 Mbps. Find the distance m so that dprop equals dtrans.

a. dprop = m/s seconds
b. dtrans = L/R seconds
c. end-to-end delay = (L/R + m/s) seconds
d. The last bit is just leaving Host A.
e. The first bit is in the link and has not reached Host B.
f. The first bit has reached Host B.
g. m = L/R * s = 1500/(10^7) * (2.5 * 10^8) = 37500 m

P10. Consider a packet of length L that begins at end system A and travels over three links to a destination end system. These three links are connected by two packet switches. Let di, si, and Ri denote the length, propagation speed, and the transmission rate of link i, for i = 1, 2, 3. The packet switch delays each packet by dproc. Assuming no queuing delays, in terms of di , si , Ri, (i = 1, 2, 3), and L, what is the total end-to-end delay for the packet? Suppose now the packet is 1,500 bytes, the propagation speed on all three links is 2.5 * 10^8 m/s, the transmission rates of all three links are 2.5 Mbps, the packet switch processing delay is 3 msec, the length of the first link is 5,000 km, the length of the second link is 4,000 km, and the length of the last link is 1,000 km. For these values, what is the end-to-end delay?

end-to-end delay = L/R1 + L/R2 + L/R3 + d1/s1 + d2/s2 + d3/s3 + dproc +dproc
= (1500 * 8)/(2.5 * 10^6) * 3 + (5000 * 10^3)/(2.5 * 10^8) + (4000 * 10^3)/(2.5 * 10^8) + (1000 * 10^3)/(2.5 * 10^8) + 0.003 + 0.003
= 0.0048 * 3 + 0.02 + 0.016 + 0.004 + 0.006
= 0.0604 sec