Problem 2

At time N*(L/R) the first packet has reached the destination, the second packet is stored in the last router, the third packet is stored in the next-to-last router, etc. At time N*(L/R) + L/R, the second packet has reached the destination, the third packet is stored in the last router, etc. Continuing with this logic, we see that at time N*(L/R) + (P-1)*(L/R) = (N+P-1)*(L/R) all packets have reached the destination.

Problem 3

a) A circuit-switched network would be well suited to the application, because the application involves long sessions with predictable smooth bandwidth requirements. Since the transmission rate is known and not bursty, bandwidth can be reserved for each application session without significant waste. In addition, the overhead costs of setting up and tearing down connections are amortized over the lengthy duration of a typical application session.

b) In the worst case, all the applications simultaneously transmit over one or more network links. However, since each link has sufficient bandwidth to handle the sum of all of the applications' data rates, no congestion (very little queuing) will occur. Given such generous link capacities, the network does not need congestion control mechanisms.

Problem 4

a) Between the switch in the upper left and the switch in the upper right we can have 4 connections. Similarly we can have four connections between each of the 3 other pairs of adjacent switches. Thus, this network can support up to 16 connections.

b) We can *4* connections passing through the switch in the upper-right-hand corner and another *4* connections passing through the switch in the lower-left-hand corner, giving a total of *8* connections.

c) Yes. For the connections between A and C, we route two connections through B and two connections through D. For the connections between B and D, we route two connections through A and two connections through C. In this manner, there are at most 4 connections passing through any link.

Problem 5

Tollbooths are 75 km apart, and the cars propagate at 100km/hr. A tollbooth services a car at a rate of one car every 12 seconds.

a) There are ten cars. It takes 120 seconds, or 2 minutes, for the first tollbooth to service the 10 cars. Each of these cars has a propagation delay of 45 minutes (travel 75 km) before arriving at the second tollbooth. Thus, all the cars are lined up before the second tollbooth after 47 minutes. The whole process repeats itself for traveling between the second and third tollbooths. It also takes 2 minutes for the third tollbooth to service the 10 cars. Thus the total delay is 96 minutes.

b) Delay between tollbooths is 8*12 seconds plus 45 minutes, i.e., 46 minutes and 36 seconds. The total delay is twice this amount plus 8*12 seconds, i.e., 94 minutes and 48 seconds.

Problem 6

a) $d_{prop} = m/s$ seconds.

b) $d_{trans} = L/R$ seconds.

c) $d_{end-to-end} = (m/s + L/R)$ seconds.

d) The 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) Want

$$m = \frac{L}{R}s = \frac{120}{56 \times 10^3}\left(2.5 \times 10^8\right) = 536\,\text{km}.$$

Problem 7

Consider the first bit in a packet. Before this bit can be transmitted, all of the bits in the packet must be generated. This requires

$$\frac{56 \cdot 8}{64 \times 10^3}\text{ sec=7msec.}$$

The time required to transmit the packet is

$$\frac{56 \cdot 8}{2 \times 10^6}\text{ sec= } 224\mu\text{ sec.}$$

Propagation delay = 10 msec.

The delay until decoding is

7msec + 224μ sec + 10msec = 17.224msec

A similar analysis shows that all bits experience a delay of 17.224 msec.

Problem 8

a) 20 users can be supported.
b) $p = 0.1$.
c) $\binom{120}{n} p^n (1-p)^{120-n}$.
d) $1 - \sum_{n=0}^{20} \binom{120}{n} p^n (1-p)^{120-n}$.

We use the central limit theorem to approximate this probability. Let X_j be independent random variables such that $P(X_j = 1) = p$.

$$P(\text{ “21 or more users” }) = 1 - P\left(\sum_{j=1}^{120} X_j \le 21 \right)$$

$$P\left(\sum_{j=1}^{120} X_j \le 21 \right) = P\left(\frac{\sum_{j=1}^{120} X_j - 12}{\sqrt{120 \cdot 0.1 \cdot 0.9}} \le \frac{9}{\sqrt{120 \cdot 0.1 \cdot 0.9}} \right)$$

$$\approx P\left(Z \le \frac{9}{3.286} \right) = P(Z \le 2.74)$$

$$= 0.997$$

when Z is a standard normal r.v. Thus $P(\text{ “21 or more users” }) \approx 0.003$.

Problem 12

The arriving packet must first wait for the link to transmit 4.5 *1,500 bytes = 6,750 bytes or 54,000 bits. Since these bits are transmitted at 2 Mbps, the queuing delay is 27 msec. Generally, the queuing delay is (nL + (L - x))/R.

Problem 13

a) The queuing delay is 0 for the first transmitted packet, *L/R* for the second transmitted packet, and generally, *(n-1)L/R* for the n^{th} transmitted packet. Thus, the average delay for the *N* packets is:

(L/R + 2L/R + ... + (N-1)L/R)/N
*= L/(RN) * (1 + 2 + ... + (N-1))*

$= L/(RN) * N(N-1)/2$
$= LN(N-1)/(2RN)$
$= (N-1)L/(2R)$

Note that here we used the well-known fact:

$1 + 2 + ... + N = N(N+1)/2$

b) It takes LN/R seconds to transmit the N packets. Thus, the buffer is empty when a each batch of N packets arrive. Thus, the average delay of a packet across all batches is the average delay within one batch, i.e., $(N\text{-}1)L/2R$.

Problem 25

a) 160,000 bits
b) 160,000 bits
c) The bandwidth-delay product of a link is the maximum number of bits that can be in the link.
d) the width of a bit = length of link / bandwidth-delay product, so 1 bit is 125 meters long, which is longer than a football field
e) s/R