P3

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.

P6

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

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

c) $d_{end\text{-}to\text{-}end} = (m / s + L / R)$ 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) We want $m = \frac{L}{R}s = \frac{1500\times 8}{10\times 10^6}(2.5 \times 10^8) = 3 \times 10^5 = 300$ km.

P7

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

The time required to transmit the packet is $\frac{56\times 8}{10\times 10^6} sec = 44.8 \mu sec$.

Propagation delay = 10 msec.

The delay until decoding is 7m + 44.8µ + 10m = 17.0448 msec.

A similar analysis shows that all bits experience a delay of 17.0448 msec.

P8

a) 50 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("51 or more users") = $1 - P\left(\sum_{j=1}^{120} X_j < 51\right)$

$P\left(\sum_{j=1}^{120} X_j < 51\right) = P\left(\frac{\sum_{j=1}^{120} X_j - 12}{\sqrt{120 \times 0.1 \times 0.9}}\right) \approx P\left(Z \le \frac{9}{3.286}\right) = P(Z \le 2.74) = 0.997$

When Z is a standard normal r.v. Thus P("51 or more users") $\approx$ 0.003.

P10

The first end system requires L/R_1 to transmit the packet onto the first link; the packet propagates over the first link in d_1/s_1; the packet switch adds a processing delay of d_{proc}; after receiving the entire packet, the packet switch connecting the first and the second link requires L/R_2 to transmit the packet onto the second link; the packet propagates over the second link in d_2/s_2. Similarly, we can find the delay caused by the second switch and the third link: L/R_3, d_{proc}, and d_3/s_3.

Adding these five delays gives

$$d_{end\text{-}end} = L/R_1 + L/R_2 + L/R_3 + d_1/s_1 + d_2/s_2 + d_3/s_3 + d_{proc} + d_{proc}$$

To answer the second question, we simply plug the values into the equation to get 4.8 + 4.8 + 4.8 + 20 + 16 + 4 + 3 + 3 = 60.4 msec.

P13

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:

$(L/R + 2L/R + \ldots\ldots. + (N-1)L/R)/N$

$= L/(RN) * (1 + 2 + \ldots.. + (N-1))$

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

$= LN(N-1)/(2RN)$

$= (N-1)L/(2R)$

Note that here we used the well-known fact:

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

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., $(N-1)L/2R$.

P25

a) 400,000 bits

b) 400,000 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

P31

a) Time to send message from source host to first packet switch = $\frac{10^6}{5\times 10^6} = 0.2$ sec. With store-and-forward switching, the total time to move message from source host to destination host = $0.2 \text{ sec} \times 3 \text{ hops} = 0.6$ sec.

b) Time to send 1st packet from source host to first packet switch = $\frac{1\times 10^4}{2\times 10^6}$ sec = 5 msec. Time at which 2nd packet is received at the first switch = time at which 1st packet is received at the second switch = 2 × 5 msec = 10 msec.

c) Time at which 1st packet is received at the destination host = 5 msec × 3 hops = 15 msec. After this, every 5 msec one packet will be received; thus time at which last (800th) packet is received = 15 msec + 799 × 5 msec = 4.01 sec. It can be seen that delay in using message segmentation is significantly less (almost 1/3rd).

d)

i. Without message segmentation, if bit errors are not tolerated, if there is a single bit error, the whole message has to be retransmitted (rather than a single packet).

ii. Without message segmentation, huge packets (containing HD videos, for example) are sent into the network. Routers have to accommodate these huge packets. Smaller packets have to queue behind enormous packets and suffer unfair delays.

e)

i. Packets have to be put in sequence at the destination.

ii. Message segmentation results in many smaller packets. Since header size is usually the same for all packets regardless of their size, with message segmentation the total amount of header bytes is more.