Problem 1

(***Circuit Switching and Packet Switching***) 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. Further more, 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?

Hint: Congestion control is a network function at the hosts to control the injected traffic to the network. This is necessary as routers in the backbone network have limited capacity and are shared by a multitude of connections simultaneously. If overwhelming traffic is sent to the network at each host, the backbone network can be heavily congested, resulting in the performance degradation of all hosts. To do the congestion control can be difficult. This is because that the hosts would have no pre-knowledge about the available bandwidth of routers in the backbone network, and, more importantly, the available bandwidth of routers is changing over time due to the random cross traffic, suggesting that the hosts should adaptively adjust the injected traffic to the network from time to time.

Solution:

a) A circuit-switched network would be well suited to the application described, 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 circuit with no significant waste. In addition, we need not worry greatly about the overhead costs of setting up and tearing down a circuit connection, which are amortized over the lengthy duration of a typical application session.

b) Given such generous link capacities, the network needs no congestion control mechanism. In the worst (most potentially congested) case, all the applications simultaneously transmit over one or more particular network links. However, since each link offers sufficient bandwidth to handle the sum of all of the applications' data rates, no congestion (very little queuing) will occur.

Problem 2

(***Statistical Multiplexing***) Consider the discussion of statistical multiplexing in which an example is provided with a 1 Mbps link. Users are generating data at a rate of 100 kbps when busy, but are busy generating data only with probability $p = 0.1$. Suppose that the 1 Mbps link is replaced by a 1 Gbps link.

a. What is N_1, the maximum number of users that can be supported simultaneously under circuit switching?

b. What is N_2, the maximum number of users that can be supported simultaneously by packet switching?

c. Now consider packet switching and a user population of M users. Give a formula (in terms of p, M, N_1) for the probability that more than N_1 users are sending data.

Solution:

a) $N_1 = \frac{\text{Link capacity}}{\text{Rate for each user}} = \frac{\text{1Gbps}}{\text{100Kbps}} = 10,000$

b) $N_2 = \frac{\text{Link capacity}}{\text{Rate for each user}} = \frac{\text{1Gbps}}{100 \times 0.1\text{Kbps}} = 100,000$

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c)

$$P(\text{More than } N_1 \text{ users are sending data}) = \sum_{n=N_1+1}^{M} P(n \text{ users are sending data}) = \sum_{n=N+1}^{M} \binom{M}{n} p^n (1-p)^{M-n} \quad (1)$$

Problem 3

(***Delay***) 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, d_{prop}, in terms of m and s.
b. Determine the transmission time of the packet, d_{trans}, in term 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 $t = d_{trans}$, where is the last bit of the packet?
e. Suppose d_{prop} is greater than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?
f. Suppose d_{prop} is less than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?
g. Suppose $s = 2.5 \times 10^8$, $L = 120$ bits, and $R = 56$ kbps. Find the distance m so that d_{prop} equals d_{trans}.

Solution:
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

$$m = \frac{L}{R}s = \frac{120}{56 \times 10^3}(2.5 \times 10^8) = 536 \text{ km.} \quad (2)$$

Problem 4

(***Segmentation***) In modern packet-switched networks, the source host segments long, application-layer messages (for example, an image or a music file) into smaller packets and sends the packets into the network. The receiver then reassembles the packets back into the original message. We refer to this process as *message segmentation*. Figure 1 illustrates the end-to-end transport of a message with and without message segmentation. Consider a message that is 8×10^6 bits long that is to be sent from source to destination in Figure 1. Suppose each link in the figure is 2 Mbps. Ignore propagation, queuing, and processing delays.
a. Consider sending the message from source to destination without message segmentation. How long does it take to move the message form the source host to the first packet switch? Keeping in mind that each switch uses store-and-forward packet switching, what is the total time to move the message form source host to destination host?
b. Now suppose that the message is segmented into 4,000 packets, with each packet being 2,000 bits long. How long does it take to move the first packet from source host to the first switch? When the first packet is being sent from the first switch to the second switch, the second packet is being sent from the source host to the first switch. At what time will the second packet be fully received at the first switch?

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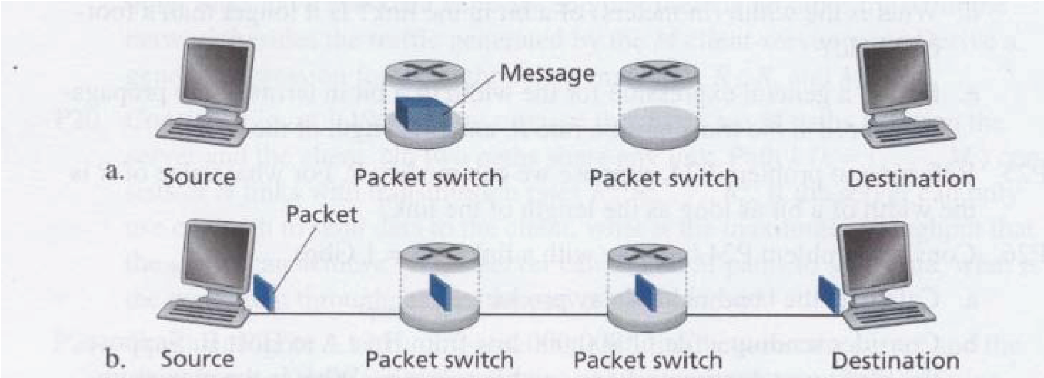

Figure 1: End-to-end message transport: (a)without message segmentation; (b)with message segmentation

c. How long does it take to move the file from source host to destination host when message segmentation is used? Compare this result with your answer in part (a) and comment.
d. Discuss the drawbacks of message segmentation.

Solution:
a) Time to send message from source host to first packet switch = $\frac{8\times10^6}{2\times10^6}$ sec = 4 sec. With store-and-forward switching, the total time to move message from source host to destination host = 4 sec $\times$ 3 hops = 12 sec.
b) Time to send 1^{st} packet from source host to first packet switch = $\frac{2\times10^3}{2\times10^6}$ sec = 1 msec. Time at which 2^{nd} packet is received at the first switch = time at which 1^{st} packet is received at the second switch = 2×1 msec = 2 msec.
c) Time at which 1^{st} packet is received at the destination host = 1 msec $\times$ 3 hops = 3 msec. After this, every 1 msec one packet will be received; thus time at which last (4000^{th}) packet is received = 3 msec + 3999×1 msec = 4.002 sec. It can be seen that delay in using message segmentation is significantly less (almost $1/3^{rd}$).
d) Drawbacks:
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.