Note: Provide Detailed solutions and not just final answers. Final Answers only will get a mark of zero.

Problem-1:

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.

Solution-1:

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.

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Problem-2:

Suppose users share a 3 Mbps link. Also suppose each user requires 150 kbps when transmitting, but each user transmits only 10 percent of the time. (See the discussion of packet switching versus circuit switching in Section 1.3.)

a. When circuit switching is used, how many users can be supported?

b. For the remainder of this problem, suppose packet switching is used. Find the probability that a given user is transmitting.

c. Suppose there are 120 users. Find the probability that at any given time, exactly n users are transmitting simultaneously. (*Hint*: Use the binomial distribution.)

d. Find the probability that there are 21 or more users transmitting simultaneously.

Solution-2:

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

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

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

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

$$= 0.997$$

When Z is a standard normal r.v. Thus $P($ "21 or more users" $) \approx 0.003$.

Problem-3:

Consider the network illustrated in Figure 1.16. Assume the two hosts on the left of the figure start transmitting packets of 1500 bytes at the same time towards Router B. Suppose the link rates between the hosts and Router A is 4-Mbps. One link has a 6-ms propagation delay and the other has a 2-ms propagation delay. Will queuing delay occur at Router A?

Solution-3:

To know if queuing delay will occur at router A, we would need to inspect the factors that would cause a queuing delay in router A.

- Both hosts send 1500 bytes in the direction of router B.
- Using link speeds of 4Mbps, the expected arrival times of the packets would be 3ms. (1500 * 8 to turn to bits, divide by 4,000,000 Mb/s to get seconds and then multiply by 1000 to get milliseconds).
- One link has a propagation delay of 6ms and the other has a propagation delay of 2ms.
- This means that the first packets of data arrive after 5ms and the next packets of data arrive after 9ms.
- According to p.64 of the textbook, processing delay typically has values on the order of microseconds or less. Since the difference in time between the two arrival times of the packets of data are of the order of milliseconds and milliseconds are much larger than microseconds, it means that the first set of packets should finish processing well before the second set arrives. Therefore, there will be no queuing delay occurring at router A.

Problem-4:

Suppose two hosts, A and B, are separated by 20,000 kilometers and are connected by a direct link of $R = 2$ Mbps. Suppose the propagation speed over the link is $2.5 \cdot 10^8$ meters/sec.

a. Calculate the bandwidth-delay product, $R \cdot d_{prop}$.

b. Consider sending a file of 800,000 bits from Host A to Host B. Suppose the file is sent continuously as one large message. What is the maximum number of bits that will be in the link at any given time?

c. Provide an interpretation of the bandwidth-delay product.

d. What is the width (in meters) of a bit in the link? Is it longer than a football field?

e. Derive a general expression for the width of a bit in terms of the propagation speed s, the transmission rate R, and the length of the link m.

Solution-4:

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

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Problem-5:

Consider sending a large file of F bits from Host A to Host B. There are three links (and two switches) between A and B, and the links are uncongested (that is, no queuing delays). Host A segments the file into segments of S bits each and adds 80 bits of header to each segment, forming packets of $L = 80 + S$ bits. Each link has a transmission rate of R bps. Find the value of S that minimizes the delay of moving the file from Host A to Host B. Disregard propagation delay.

Solution-5:

- There are F/S packets. Each packet is S=80 bits.
- Time at which the last packet is received at the first router is $\frac{S+80}{R} \times \frac{F}{S}$ sec.
- At this time:
  - The first F/S-2 packets are at the destination, and
  - The F/S-1 packet is at the second router.
  - The last packet must then be transmitted by the first router and the second router, with each transmission taking $\frac{S+80}{R}$ sec.
  - Thus delay in sending the whole file is $delay = \frac{S+80}{R} \times (\frac{F}{S} + 2)$
- To calculate the value of S which leads to the minimum delay, $\frac{d}{dS} delay = 0 \Rightarrow S = \sqrt{40F}$