Problem 1

Suppose users share a 100 Mbps link. Also suppose each user requires 10 Mbps when transmitting, but each user transmits only 25% of the time.

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

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

(c) Suppose there are 100 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.

(a) $N = \frac{\text{Total bandwidth}}{\text{Bandwidth per user}} = \frac{\text{100 Mbps}}{\text{10 Mbps/user}} = 10$ users;

(b) $Pr(1) = 0.25$;

(c) $Pr(n) = \binom{100}{n}(0.25)^n(1-0.25)^{100-n}$;

(d)

$$Pr(n \geq 21) = 1 - Pr(0 \leq n \leq 20) = 1 - \sum_{n=0}^{20} \binom{100}{n} (0.25)^n (1-0.25)^{100-n} \approx 0.85$$

Note: (d) only needs formula; numerical results not required.

Problem 2

Queuing delay.

(a) Suppose N packets arrive simultaneously to a link at which no packets are currently being transmitted or queued. Each packet is of length L and the link has transmission rate R. What is the average queuing delay for the N packets?

(b) Now suppose that N such packets arrive to the link every $\frac{LN}{R}$ seconds. What is the average queuing delay of a packet?

(a) The queuing delay for the 1^{st} packet is 0; for the 2^{nd} packet is $\frac{L}{R}$; and $\frac{2L}{R}$ for the 3^{rd} packet, and so on. So the average queuing delay for N packets is

$$d_{queuing,avg} = \frac{1}{N}\left(0 + \frac{L}{R} + \frac{2L}{R} + \cdots + \frac{(N-1)L}{R}\right) = \frac{(N-1)L}{2R};$$

(b) It takes $\frac{LN}{R}$ seconds to transmit N packets. Because these N packets arrive the link every $\frac{LN}{R}$ seconds, the buffer is empty when each batch of N packets arrive. Therefore, the average queuing delay of a packet equals to the average delay for N packets, which is $\frac{(N-1)L}{2R}$.

Problem 3

Review the car-caravan analogy in lecture #1 slides (for Chapter 1). Assume a propagation speed of 100 km/h.

(a) Suppose the caravan (10 cars) travels 100 km, beginning in front of one tollbooth, passing through a second tollbooth, and finishing just after a third tollbooth. The distance between two tollbooths is 50 km. Each car takes 12 sec to serve. What is the end-to-end delay?

(b) Repeat (a), now assuming that there are 8 cars in the caravan instead of 10.

(a) Since the caravan travels 100 km and passes three tollbooths, the distance between adjacent tollbooths is 50 km. So, propagation delay between each tollbooth is

$$d_{prop} = \frac{50 \text{ km}}{100 \text{ km/h}} = 30 \text{ min;}$$

Each car taking 12 sec to serve, so the processing delay at each tollbooth is:

$$d_{proc} = 10 \times 12 \text{ sec} = 2 \text{ min;}$$

Therefore, the total delay equals:

$$d_{total} = 2 \times d_{prop} + 3 \times d_{proc} = 66 \text{ min.}$$

(b) Change car number to eight, the propagation delay is still the same; the new processing delay changes to

$$d'_{proc} = 8 \times 12 \text{ sec} = 96 \text{ sec;}$$

Therefore the new total delay is:

$$d'_{total} = 2 \times d_{prop} + 3 \times d'_{proc} = 64 \text{ min } 48 \text{ sec.}(64.8\ min)$$

Problem 4

In this problem, we consider sending real-time voice from Host A to Host B over a packet-switched network (VoIP). Host A converts analog voice to a digital 64 Kbps bit stream on the fly. Host A then groups the bits into 56-byte packets. There is one link between Hosts A and B; its transmission rate is 2 Mbps and its propagation delay is 10 msec. As soon as Host A gathers a packet, it sends it to Host B. As soon as Host B receives an entire packet, it converts the packet's bits to an analog signal. How much time elapses from the time a bit is created (from the original analog signal at Host A) until the bit is decoded (as part of the analog signal at Host B)?

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
$\frac{56\times 8}{64\times 10^3}$ sec = 7 msec.
The time required to transmit the packet is
$\frac{56\times 8}{2\times 10^6}$ sec = 224 μsec.
Propagation delay = 10 msec. The delay until decoding is
7 msec + 224 μsec + 10 msec = 17.224 msec
A similar analysis shows that all bits experience a delay of 17.224 msec.

Problem 5

Suppose you would like to urgently deliver 50 terabytes data from Boston to Los Angeles. You have available a 1 Gbps dedicated link for date transfer. Would you prefer to transmit the data via this link or to use FedEx overnight delivery instead? Explain your choice.

Using the dedicated link to deliver the data would take

$$T_{net} = (50 \text{ TB})/(1 \text{ Gbps}) = (4 \times 10^{14} \text{ bits})/(1 \times 10^{9} \text{ bits/sec}) = 400,000 \text{ sec} \approx 4.6 \text{ days}.$$

It would be better to use FedEx overnight delivery which takes only one day.
Note that, students may confuse Byte with Bit in the calculation. If they did so, their results would likely to be 0.57 days for data transmission.