TELCOM 2310 – Computer Networks
Fall Term 00-1

Homework 1 Solutions

1 Problem 1

A typical packet faces a propagation time of 15 ms plus the delays in the 10 nodes. First, let us analyze the delay through the nodes neglecting the propagation delay. Assume that a packet arrives at the first node at time $t = 0$. The last bit of the packet leaves that node after 6 packets have been transmitted: the 5 packets in the queue + the packet itself. Therefore, the packet will be completely received at time: $t = 6 * 1000/56000 \approx 107.14ms$. To go through 10 nodes, the packet takes: $107.14ms * 10 \approx 1.07sec.$ of transmission time. Adding the propagation deay: $t = 1.07 + 0.015 =$ **1.085 sec**. When a packet is transmitted as expedited data, it must wait for the current packet transmission to be completed. Therefore, in average, the packet will wait for the transmission of half of a packet. The delay is: $t = 10 * 1.5 * 1000/56000 + 0.015 \approx$ **0.283 sec**.

2 Problem 2

The transmission time of a packet (datagram) is: $T = (400 + 10 * 8 + 2 * 8)\_bits/56000bps \approx 8.86ms$. The store-and-forward transmission of a packet will take: $(N + 10) * T$. This is because during the first T seconds, the first packet is sent to node 1; during the second T seconds, the first packet is sent to node 2 from node 1 and the second packet is sent to node1. During the 11^{th} time unit T, the first packet is sent out of node 10. The second packet leaves the node 10 during 12^{th} time interval. Finally, after the $(N + 10) * T$ time units, the N^{th} packet leaves node 10. In the case of virtual circuit, in order to calculate the total time, we need to include the setup time: $(N + 10) * T + T_{setup}$, where time unit $T = (400 + 5 * 8 + 2 * 8bits)/56000bps \approx 8.15ms$. Using two formulas above we can calculate N for which $T_{vc} < T_d : (N+10) * T_d > (N+10) * T_{vc} + 0.4sec. \Rightarrow N > 550$ packets.

3 Problem 3

When packets of 1000 bits arrive in pairs every second at 56 Kbps transmitter, the successive pairs find the buffer empty, because the interarrival time for packet pairs is more than the transmission time for every pair. The first packet faces a delay equal the transmission time: $t = 1000/56000 \approx 17.9ms$. The second packet faces a delay equal twice the transmission time $= 2 * t$. Therefore, the average delay is $1.5 * t \approx 26.8ms$. If the packets arrive in pairs every 0.5 seconds at 112 Kbps trasmitter *(Note: problem states* 122 *Kbps transmitter)*, the delays of the two packets become $t/2$ and t, so that the average delay is $0.75 * t \approx 13.4ms$. The gain achieved is the half of the packets transmission time.

This model is simplistic. To show this, consider a batch of 2k packets of P bits, that arrive at transmitter with rate $2R$. The average delay per packet is: $D_1 = (2k+1) * P/4 * R$. Assume that the channel with rate $2R$ is divided into two channels with rate R each (i.e. using TDM). Each batch is divided into two batches of k packets that are sent to the channel. The average delay per packet is: $D_2 = (k+1) * P/2 * R$. The differecnce $D_2 - D_1 = P/4R$, and statistical multiplexing reduces the dealy only by a quarter of a packet transmission time.

4 Problem 4

Every time a packet arrives, P bits are added to the buffers of the node. The bits are "consumed" at the rate R. Let D_i be the delay suffered by packet i. $D_1 = P/R$, as the first packet does not have to wait. The buffer occupancy is dipicted in Figure 1.

To compute D_2, we observe that P_2 may have to wait the residual time of packet 1. This, however, only happens if P_2 arrives between T_1 and $T_1 + D_1$. Therefore: $D_2 = max\{D_1 - (T_2 - T_1), 0\} + P/R$. The queuing delay is equal to 0 if $D_1 - (T_2 - T_1) < 0$.

In general, the following holds:

$$D_{n+1} = max\{D_n - (T_{n+1} - T_n), 0\} + \frac{P}{R}, \text{and} \tag{1}$$

$$Queuing\ \ delay = 0 \ \text{ if } \ D_n - (T_{n+1} - T_n) < 0. \tag{2}$$

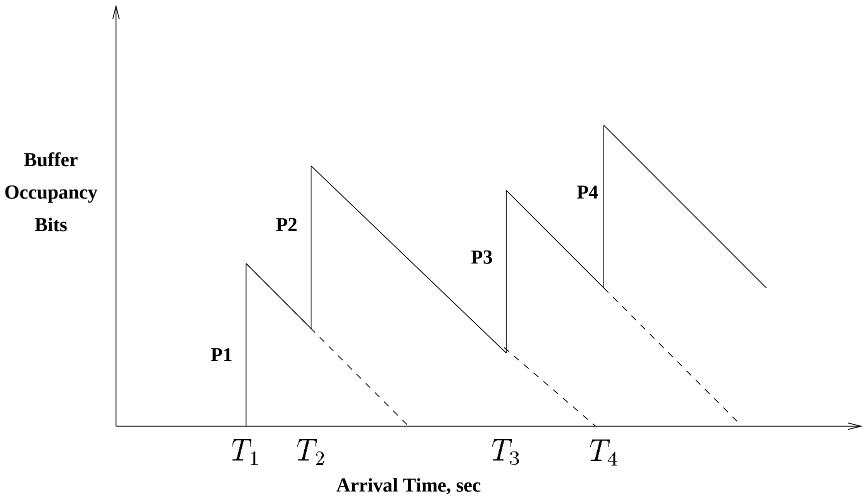

Figure 1: Number of bits in buffer as a function of time.

To show that large delays can occur even if we have low arrival rate, consider the following scenario:

- packets arrive by batches of k packets every T seconds.
- let T be larger than $k * P/R$, so that successive batches find buffer empty.
- the first packet of the batch suffers $D_1 = P/R$ delay.
- the second packet of the batch suffers $D_2 = 2 * P/R$ delay, and the k^{th} packet suffers $D_k = k * P/R$ delay.
- Therefore, the average delay is $(D_1 + D_2 + ... + D_k) = (k+1) * P/2R$. Choosing k large we make delay $\rightarrow \infty$ even if T is so large that the average packet arrival rate k/T is small.