1. Consider Figure 1. Assuming TCP Reno is the protocol experiencing the behavior shown below, answer the following questions.

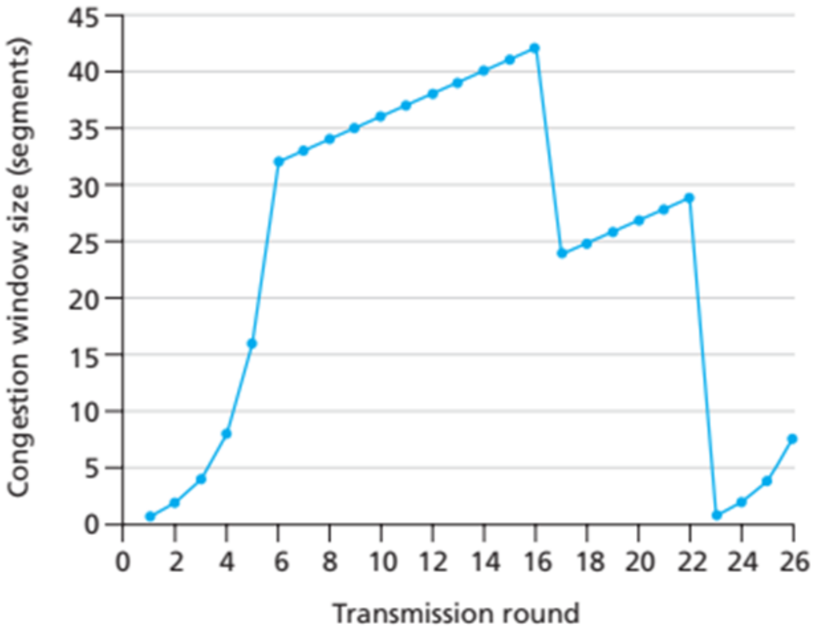

Figure 1: TCP behavior

   (a) Identify the intervals of time when TCP slow start is operating.
   (b) Identify the intervals of time when TCP congestion avoidance is operating.
   (c) After the 16th transmission round, is segment loss detected by a triple duplicate `ACK` or by a timeout?
   (d) After the 22nd transmission round, is segment loss detected by a triple duplicate `ACK` or by a timeout?
   (e) What is the initial value of `ssthresh` at the first transmission round?
   (f) What is the value of `ssthresh` at the 18th transmission round?
   (g) What is the value of `ssthresh` at the 24th transmission round?
   (h) During what transmission round is the 70th segment sent?
   (i) Assuming a packet loss is detected after the 26th round by the receipt of a triple duplicate `ACK`, what will be the values of the congestion window size and of `ssthresh`?

2. Consider a single TCP-Vegas connection over a link with bandwidth 15 Mbps. Assume each packet has a size of 1500 bytes, the round trip time is 80 ms and $\alpha = \beta = 150/T_{pr}$ (T_{pr} is propagation time). Further, we assume packet losses occur when the transmission rate exceeds the link capacity, and no time-out occurs during transmissions. Compute the throughput and queueing delay at the equilibrium point.

3. Let T measured by `RTT` denote the time interval that a TCP connection takes to increase its congestion window size from $W/2$ to W, where W is the maximum congestion window size. Argue that T is a function of TCP's average throughput.

4. Host A and B are directly connected with a 100 Mbps link. There is one TCP connection between the two hosts, and host A is sending to host B an enormous file over this connection. Host A can send its application data into its TCP socket at a rate as high as 120 Mbps

but host B can read out of its TCP RcvBuffer at a maximum rate of 50 Mbps. Describe the effect of TCP flow control and find maximum connection rate over which A can send to B.

5. Consider the TCP procedure for estimating RTT. Let T_n be the most recent sample RTT, let T_{n-1} be the next most recent sample RTT, and so on. We denote the estimate of RTT in terms of n most recent samples as $\hat{T}^{(n)}$, where $\hat{T}^{(2)}(2) = \alpha T_2 + (1-\alpha)\hat{T}^{(1)}(1)$.

   (a) For a given TCP connection, suppose four acknowledgments have been returned with corresponding sample RTTs, (T_4, T_3, T_2, T_1). Express the estimate of RTT as $\hat{T}^{(4)}$ in terms of the four sample RTTs.

   (b) Generalize your formula for n sample RTTs.

   (c) For the formula in part (b) let n approach infinity. Comment on why this averaging procedure is called an exponential moving average.