1. (a) A channel has a data rate of 4 kbps and a propagation delay of 20 ms. For what range of frame sizes does stop and wait give an efficiency of at least 50%?

(b) Consider the use of 1000-bit frames on a 1-Mbps satellite channel with a 270-ms delay. What is the maximum link utilisation for:
   (i) Stop-and-wait flow control?
   (ii) Sliding-window flow control with W = 127?
   (iii) Sliding-window flow control with W = 255?
   (iv) Sliding-window flow control with W = 511?

2. A channel has a data rate of $R$ bps and a propagation delay of $t$ sec/km. The distance between the sending and receiving nodes is $L$ km. Nodes exchange fixed-size frames of $B$ bits. Find a formula that gives the minimum sequence field size in bits of the frame as a function of $R$, $t$, $B$ and $L$. Assume that ACK frames are negligible in size, the processing at the nodes is instantaneous, and that maximum utilisation is required.

3. (a) With a k-bit sequence number field the maximum window should be $2^k$. Why is the maximum allowable window $2^k - 1$?

(b) Two stations communicate via a 1-Mbps satellite link with a propagation delay of 270 ms. The satellite serves merely to retransmit data received from one station to another, with negligible switching delay. Using HDLC frames of 1024 bits with 3-bit sequence numbers, what is the maximum possible data throughput (not counting the 48 overhead bits per frame)?

4. Consider a satellite system with a bit error probability $p$. The data rate is $R$ bps, the average frame length is $L$ bits, $L_h$ is the length of the frame header and RTT is the round-trip-time for the shortest time an acknowledgment can be returned after a frame has been transmitted.
   (a) Derive an expression for the maximum normalised data rate of a go-back-N ARQ scheme.

   (b) Hence explain why for a 48 kbps satellite system with an RTT of 700 msec and $p = 10^{-5}$ the size of the HDLC frame is 2250 bits. Assume a 48-bit frame header.

5. To improve network throughput and efficiency in a cost-effective manner, what would you do first?
   (i) Double the bandwidth of the communication channel.
   (ii) Improve the routing algorithm to reduce the processing and queuing delays.
   (iii) Increase the window size of the flow control algorithm.
   What would you do next? Assume a sliding-window protocol is being used.