1. A 64,240-byte file is to be transmitted over a three-hop path (i.e., source-router1-router2-destination). Each hop is a 500-km long fiber optics link; the speed of light in fiber is approximately 200,000,000 m/s. Each packet has a 40-byte header. The network limits packet size to 1,500 bytes, including the header. Links support DS-3 data rates (44.736 Mbits/sec). No other traffic contends for the links. Ignore processing delays.

(a) What is the propagation delay between source and destination?

(b) If the source starts transmitting the first packet at time t = 0 sec, at what time does the destination finish receiving that packet?

(c ) How many packets are required for the transmission of the file?

(d) If the source starts transmitting the file at time t = 0 sec, at what time does the destination finish receiving the file?

2. This problem considers the response time of HTTP. Your browser wants to download a 10 Kbyte (81,920 bits) HTML page. This page references 10 images, each 5 Kbytes (40,960 bits) in size. The HTML file and all referenced images are stored in the same server, which has a 300 ms round-trip time (RTT) from your host. We will abstract the path between your host and the web server as a 1 Mbps link. Assume that GET messages are short enough that their *transmission* time is negligible (note that the transmission time for the HTML page and images is *not* negligible). Also ignore transmission time for TCP/IP headers. The time to set up a TCP connection is 600 ms. Assume the IP address of the web server is cached locally (i.e., ignore DNS lookup time).
Determine the response time, i.e. the time from when the user requests the web page to the time when the page and associated images are displayed by the browser, under the following conditions.

(a) Non-persistent HTTP, with no parallel TCP connections between the host and the web server.

(b) Non-persistent HTTP, with the browser able to open as many parallel connections with the web server as it wants.

(c) Persistent HTTP, without pipelining.

(d) Persistent HTTP, with pipelining.

3. Using TCP Reno, a TCP connection has been established between hosts A and B. Assume the value of the timeout timer is very large as compared to the times shown below. Consider the following exchange of packets. Assume none of the segments sent by A is a retransmission.

At t = 0, Host A sends a TCP segment with sequence number 102560 to host B
At t = 1, Host A receives an ACK with sequence number 100512 from host B
At t = 2, Host A sends a TCP segment with sequence number 103072 to host B
At t = 3, Host A receives an ACK with sequence number 100512 from host B
At t = 4, Host A sends a TCP segment with sequence number 103584 to host B
At t = 5, Host A receives an ACK with sequence number 100512 from host B
At t = 6, Host A receives an ACK with sequence number 100512 from host B

(a) What is the length (in bytes) of the segment sent by host A at t = 0?
(b) Does the receipt of repeated ACKs with sequence number 100512 imply that host B has

not received the TCP segment with sequence number 102560? Why or why not?
(c) [After t = 6, what is the likely sequence number of the next segment sent by host A to host B? Explain.

(d) [5 pts.] After t = 6, will the connection go into slow start or congestion avoidance? If the congestion window just prior to that time is W, what will it be after t = 5? Explain.

4. Suppose you are designing a sliding window protocol for a 1-Mbps point-to-point link to a stationary satellite revolving around the Earth at 3 x 104 km altitude. Assume each frame carries 8,000 bits of data. The speed of light is 3 x 108 m/s. Acknowledgements are small enough that their transmission time can be neglected. The window size is specified in number of frames.

(a) How large must the window size be to enable continuous transmission until the first acknowledgment returns, given that no frames are received in error?

(b) If a Go-Back-N protocol is used, what is the minimum feasible window size (expressed in number of frames)?

(c) If a Selective-Repeat protocol is used, what is the minimum feasible window size (expressed in number of frames)?