Due at BEGINNING of class, Thursday, November 7. Where indicated, you must show your work to receive credit. Also, numerical problems must have a final answer, not just a formula. You must do your work on THESE sheets and submit.

(10 pts) Write your name at the top of this sheet and on the BACK of the last sheet.

1. (6 points) In class we developed a reliable protocol by removing, one at a time, assumptions about the state of the two endpoints and the behavior of the network. Assuming errors can be detected, what problem did we encounter if we numbered data packets but not acknowledgments?

2. (8 pts) In class we considered a stop-and-wait (a.k.a. Automatic Repeat reQuest – ARQ) protocol executed on 1 Gbps link from New York to California, with a 15 msec one-way delay and a packet size of 8000 bits. Assume no errors.

   (a) (3 pts) Ignoring headers and the transmission time for ACKs, and assuming there are no errors, what is the maximum utilization if we instead used a sliding window protocol with a maximum send window size of 100 packets? Show your work.

   (b) (5 pts) If the maximum send window size is 100 packets, how large must packets be (in bits) to achieve utilization of 0.5? Assume no errors.
3. (4 pts) Does TCP use piggybacked ACKs? Explain your answer.

4. (4 pts) What do we mean when we say ACKs are cumulative? Give your answer in the context of TCP.

5. (12 pts) Consider the “packet based” sliding window protocols we discussed in class, where we number packets/frames instead of bytes. Assume $n = 6$, that is, we have $2^6 = 64$ sequence numbers.
   (a) (3 pts) If we implement a Go-Back-N protocol, what is the maximum send window size? Briefly explain your answer.
   (b) (3 pts) If we implement a Go-Back-N protocol, what is the maximum receive window size? Briefly explain your answer.
   (c) (3 pts) If we implement a Selective Repeat protocol, what is the maximum send window size? Briefly explain your answer.
   (d) (3 pts) If we implement a Selective Repeat protocol, what is the receive window size? Briefly explain your answer.
6. (16 pts) Consider a fiber-optic channel from Chicago, Illinois, to Madison, Wisconsin. The distance is 234 km and the bit rate is 100 Mbps. Frames contain 1400 bytes of data and 100 bytes of header. ACKs are 100 bytes long. Signals propagate at the speed of light, $3 \times 10^8$ m/s.

(a) (4 pts) If a stop-and-wait protocol is implemented, what is the maximum channel utilization in the absence of errors? Do not ignore headers and transmission time for ACKs.

(b) (4 pts) If a sliding window protocol is implemented with a maximum send window of 8, what is the maximum channel utilization in the absence of errors? Do not ignore headers and transmission time for ACKs.

(c) (4 pts) A stop-and-wait protocol is used. However, the probability that a frame requires retransmission is 0.2. That is, $L = 0.2$. If the timeout value is 5 milliseconds, what is the maximum utilization of the channel?

(d) (4 pts) If a selective repeat sliding window protocol is implemented with a maximum send window of 8, what is the maximum channel utilization if the probability that a frame requires retransmission is 0.2? That is, $L = 0.2$. Do not ignore headers and transmission time for ACKs.
7. (6 pts) Consider demultiplexing of arriving transport-level packets to the appropriate socket.
   (a) (3 pts) What information in a UDP datagram is used to demultiplex the datagram?

   (b) (3 pts) What information in a TCP segment is used to demultiplex the segment?

8. (4 points) What is the purpose of the Receive Window field in the TCP header? Be specific.

9. (4 points) Consider a TCP connection in which endpoint A connects to an endpoint B. Consider all the TCP segments transmitted in setting up and using the TCP connection. In which segments is the Ack (A) bit set, and in which is it not set?

10. (5 pts) Describe how the TCP timeout value is related to the measured round trip time of the connection. Be specific.

11. (4 pts) Why does TCP retransmit a segment after receiving three duplicate ACKs?
12. (6 pts) In TCP, the send window for a given connection is the minimum of the receive window and the congestion window. Briefly describe these windows and why the minimum is used.

13. (6 pts) Consider a TCP connection from A to B in slow start phase, no packets or acknowledgments are lost. Assume the MSS is 1500 bytes and A has just received an acknowledgment for the 7th segment sent in the slow start phase. At this point, what is the size of the send window, assuming the receive window and congestion window do not yet limit sending? Briefly explain your answer.

14. (8 pts) We observe a queue on a router. Packet interarrival times are exponentially distributed, with $\lambda = 800$ pps. All packets are the same size, 1500 bytes. The channel bit rate is 10 Mbps.

(a) (4 pts) What is the probability that exactly 3 packets will arrive in a period of 5 msec? Show your work.

(b) (4 pts) On average, a packet waits in the queue for 2 msec before being transmitted. What is the average number of packets in this queueing system? Show your work.
15. (16 points total) Packets queue on a router before being transmitted on a 100 Mbps link. Let us make the following assumptions: the number of buffers in the queue is infinite; packet lengths are exponentially distributed about a mean of 12,500 bits, and arrivals are Poisson with a mean rate of 5,000 packets per second.

(a) (2 points) This queue can be modeled as an M/M/1 queueing system. What are the values of $\lambda$ and $\mu$?

(b) (3 points) On average, how long does a packet spend in the system (both in the queue and being transmitted). Show your work.

(c) (3 points) On average, what is the number of packets in the system? Show your work.

(d) (3 points) What is the probability that exactly 3 packets are in the queueing system? Show your work.

(e) (5 points) Assume that the router has just finished transmitting a packet and that the queue currently holds 3 packets. What is the probability that exactly two of these packets will be transmitted completely in a period of 50 microseconds? Show your work.