This is a closed book (and notes) examination. Answer all questions on the exam itself. Take the number of points assigned to each problem and the amount of space provided for your answer as a measure of the length and difficulty of the expected solution. The exam totals 100 points.

Potentially useful formulas:

- Nyquist rule for a noiseless channel:
  \[ \text{max data rate} = 2H \log_2 V \text{ bps} \text{ where } H \text{ is the bandwidth and } V \text{ is the number of states encoded}. \]

- Shannon’s theorem for channels with noise:
  \[ \text{max data rate} = H \log_2 (1 + S/N) \text{ where noise is measured in decibels (db) and } \]
  \[ \text{db} = 10 \log_{10} \frac{S}{N} \]
1. (10 points) Television channels are 6MHz wide. How many bits/sec can be sent if four-level digital signals are used? Would this data rate change if a channel had a signal-to-noise ratio of 30 dB? If so, indicate the maximum data rate for this noisy channel.

2. (8 points) Queueing analysis often models a server in a system as being M/M/1, where the M represents an exponential probability density.

(a) Draw a graph showing the probability density function for an exponential distribution.

(b) What property of this distribution makes it desirable to use in queueing models?

(c) Using Little’s Law, the total wait time \( T \) for a request arriving to the server can be expressed as \( T = 1/(\mu - \lambda) \). What are \( \mu \) and \( \lambda \)? What relationship must they satisfy for the queueing model to be stable?
3. (10 points) Assume we are constructing a reliable, in-order delivery sliding window protocol using 4-bit sequence numbers. If a Go Back N protocol is used, what are the window sizes for the sender and receiver? If a Selective Repeat protocol is used, what are the window sizes for the sender and receiver? What property concerning sending and receiving window sizes must hold for any sliding window protocol using 4-bit sequence numbers?

4. (8 points) Cyclic Redundancy Codes (CRC) is a method for (indicate the correct answer(s) and explain):

   (a) Correcting some errors.
   (b) Correcting all errors.
   (c) Detecting some errors.
   (d) Detecting all errors.
   (e) Reducing the bit error rate.
5. (12 points) If a sender wants to transmit any one of four distinct values to a receiver then a simple approach is to construct a code with codewords of two bits: 00, 01, 10 and 11.

(a) What is the Hamming distance of this code?

(b) What is the Hamming distance needed for a code to detect a single-bit error?

(c) Specify a code of four distinct values that allows a receiver to detect a single-bit error (each value should contain as few bits as possible).

(d) What is the Hamming distance needed for a code to correct a single-bit error?

(e) Specify a code of four distinct values that allows a receiver to correct a single-bit error (each value should contain as few bits as possible).
6. (8 points) *Pulse Code Modulation (PCM)* is used to convert analog input (such as voice) for transmission as a digital signal. Briefly explain how it works. Name, and briefly explain, an alternative to PCM that reduces the amount of data sent.

7. (12 points) Assume the data link layer handles transmission errors by requesting damaged frames to be retransmitted using a stop-and-wait protocol with a large time-out. Assume the probability of a frame being damaged is $p$, $0 \leq p < 1$, in which case no acknowledgement is sent. Assume the probability of an acknowledgement being damaged is $q$, $0 \leq q < 1$.

(a) What is the probability that the first transmitted frame will be successfully sent, irrespective of what happens to the acknowledgement?

(b) What is the probability that the first transmitted frame will be both successfully sent and successfully acknowledged?

(c) What is the probability that a frame will need to be transmitted more than once?

(d) What is the probability that two transmissions will be needed for successful reception and acknowledgement of a frame?
8. (10 points) An important function of the Data Link Layer is framing. Briefly describe and state the relative advantage and disadvantage of each of the following approaches to framing.

(a) a character count at the beginning of the frame,

(b) special bit (or character) delimiters at the beginning and end of a frame along with bit (or character) stuffing, or

(c) encoding violations to indicate beginning and end of a frame.
9. (10 points)

(a) What is the maximum channel utilization for an $x$-bit frame sent over a $b$ bps channel with a propagation delay of $p$ seconds using a stop-and-wait protocol where the ACK of the frame is of negligible size?

(b) What is the maximum utilization for this channel using a sliding window protocol with an $n$-bit sequence number? You may assume that the propagation delay is much larger than the time to send a frame.
10. (12 points) Rather than providing reliable, in order delivery service to the network layer, assume the data link layer should provide acknowledged delivery service. Acknowledged delivery service guarantees that each frame sent by the sender is reliably received by the receiver and delivered to its network layer. However, frames are not guaranteed to be delivered in the same order they are sent. Assume a 3-bit sequence number is used. Outline changes to a standard sliding window protocol needed to better handle these delivery semantics. Be sure and indicate the window sizes for the sender and receiver.