5 Problems, 80 Minutes, 60 Points
Must show related work and/or provide explanation for all answers

1. (6 points) Uncompressed digitized voice produced by a pulse code modulation (PCM) system is nominally rated at 64000 bps (bits per second). Identify the three major steps in the PCM process and briefly explain how these steps yield a 64000 bps data rate for digitized voice.

2. An error detecting code is applied to the information message 100. What is the channel word that is transmitted if:
   a) (2 points) Even parity is applied?
   b) (3 points) Cyclic redundancy check (CRC) with generator polynomial \( g(x) = x^2 + 1 \) is applied?
   List the received word sequences that would contain undetectable bit errors for the information message 100 when (need also to provide some brief justification):
   c) (4 points) Even parity is applied.
   d) (6 points) CRC with \( g(x) = x^2 + 1 \) is applied (Hint: Consider what happens if \( g(x) \) is a factor of the polynomial, \( e(x) \), corresponding to the sequence of channel bit errors.)

3. The M/M/m/m queue arises in circuit switching applications where Poisson call arrivals are served by a maximum of \( m \) exponentially distributed servers. The arrival and service rates are given by \( \lambda_n = \lambda \quad (n = 0,1,...,m-1) \) and \( \mu_n = n \cdot \mu \quad (n = 1,2,...,m) \):
   a) (3 points) Sketch the related state transition diagram showing states 0, 1, 2, \( m-1 \) and \( m \).
   b) (9 points) Derive the steady-state probability distribution \( (P_n) \) for the number of active calls in the system.
   c) (2 points) What is the blocking probability \( (P_b) \)?

4. Expedited (priority class 1) and normal (priority class 2) data packets are served from an M/G/1 buffer. The average arrival rates are \( \lambda_1 = 1 \) and \( \lambda_2 = 2 \). The average service rates are \( \mu_1 = 10 \) and \( \mu_2 = 5 \). The service times \( (X_k) \) are deterministic (i.e., \( X_k = X_k^k \equiv E[X_k] \)).
   a) (3 points) What is the average system utilization \( (\rho) \)?
   Compute \( W_2 \equiv E[W_2] \) (the average waiting time for priority class 2 packets) in the following cases:
   b) (6 points) Non-preemptive priority service.
   c) (6 points) Non-priority service.

M/G/1 expected waiting time with \( n \) priority classes: \( W_k = \frac{\sum_{j=1}^{n} \lambda_j \cdot X_j^j}{2 \cdot (1 - \sum_{j=1}^{k-1} \rho_j) \cdot (1 - \sum_{j=1}^{k} \rho_j)} \) where \( W_k \equiv E[W_k] \) and \( X_j^j \equiv E[X_j^j] \). \( E[\theta] \equiv \) The average value of some function or process, \( \theta \).

5. (10 points) Suppose that a go-back-N sliding window algorithm is in operation for a point-to-point serial link with a sender window size \( W = 4 \). Information frames are numbered in sequence over the range \( \{0,1,...,s\} \), wrapping around back to 0 after frame number \( s \). Find the smallest permissible value \( (s_{\text{MIN}}) \) for \( s \) that allows correct operation. Give an example to demonstrate that \( s = s_{\text{MIN}} - 1 \) is not sufficient and that \( s = s_{\text{MIN}} \) does support correct operation (use frame transmission diagrams showing information frames and ACK frames).