Problem 1  FEC vs. ARQ

In this problem you will compare the required overhead of forward error correction with the overhead required by error detection and retransmission in an idealized setting. By overhead, we mean the number of extra bits that must be transmitted in addition to the bits in the packets generated by the network layer.

Suppose that each packet from the network layer contains 1000 bits. Suppose that at most one bit error occurs in a packet and assume that each packet contains an error independently with probability $p$.

1. How many bits of redundancy are needed to correct all single bit errors in a packet using Hamming code? (This is the overhead per packet required for forward error correction)

2. How many bits of redundancy are needed to detect all single bit errors in a packet?

3. Define the overhead per packet required for detection and retransmission to be the answer to part (2) plus (the expected number of times a packet needs to be retransmitted) $\times$ (the number of bits per packet, including redundancy). Give an expression for this quantity as a function of $p$.

4. For what values of $p$ will the overhead required by retransmission be less than the overhead required by forward error correction.

Problem 2  Parallel ARQ

Suppose that instead of Go-Back-N ARQ, $N$ simultaneous Stop-and-Wait ARQ processes are run in parallel over the same transmission channel. Each frame is assigned to one of the $N$ processes that is currently idle. The processes that have frames to send take turns transmitting in round-robin fashion. The frames carry the binary send sequence number as well as an ID identifying which ARQ process it belongs to. Acknowledgments for all ARQ processes are piggybacked onto every frame.

1. Qualitatively, compare the relative performance of this protocol with Go-Back-N ARQ and with Stop-and-Wait ARQ.
   
   [Hint: for simplicity, you may look at a sequence of $N$ consecutive frames passing through the system, and compare different behaviors under these two protocols.]

2. How does the service offered by this protocol differ from that of Go-Back-N ARQ?
**Problem 3  Finite State Machine**

Consider the state transition diagram for Stop-and-Wait ARQ in Figure 1. Let $P_f$ be the probability of frame error in going from station A to station B and let $P_a$ be the probability of ACK error in going from B to A. Suppose that information frames are two units long, ACK frames are one unit long, and propagation and processing delays are negligible.

1. What is the average time that it takes to go from state $(0,0)$ to state $(0,1)$?

2. What is the average time that it then takes to go from state $(0,1)$ to state $(1,1)$?

3. What is the throughput of the system in information frames/second.

**Problem 4  Selective Repeat ARQ**

Consider a bidirectional link that uses Selective Repeat ARQ with a window size of $N = 4$. Suppose that all frames are one unit long and use a time-out value of 4. Assume that the one-way propagation delay is 0.5 time unit, the processing times are negligible, and the ACK timer is one unit long. Assuming station A and B begin with their sequence numbers set to zero, show the pattern of transmissions and associated state transitions for the following sequences of events: Station A sends six frames in a row, starting at $t = 0$. All frames are received correctly, except frame 3 is lost.

[Hint: Consult the following example for the slightly simpler case: Station A sends six frames in a row, starting at $t = 0$. All frames are received correctly. Let the timeout value be 2. The diagram is shown in Figure 2. You may answer Problem Problem 4 by plotting a similar diagram.]

**Problem 5  ALOHA**

Suppose that the ALOHA protocol is used to share a 56 kbps satellite channel. Suppose that frames are 1000 bits long. Find the maximum throughput of the system in frames/second.
Problem 6  3-node ALOHA

This problem helps you understand the analysis of ALOHA.

Suppose three active nodes, referred to as nodes A, B, and C, are competing for access to a channel using slotted ALOHA. Assume each node has an infinite backlog of packets to send. Each node attempts to transmit in each slot with probability $p$. The first slot is numbered slot 1, the second slot is numbered slot 2, and so on.

1. What is the probability that node A succeeds for the first time in slot 4?
2. What is the probability that some node (either A, B, or C) succeeds in slot 2?
3. What is the probability that the first success occurs in slot 4?
4. What is the efficiency of this 3-node system as a function of $p$? Plot this function. (Hand drawn figure is fine but it must show the important features.)