Consider a stop-and-wait data link control protocol. Let $P$ be the expected transmission time for sending a data frame from node $A$. Let $R$ be the round-trip time, i.e., the propagation time from node $A$ to node $B$ plus the transmission time for the acknowledgment plus the propagation time from node $B$ to node $A$. Let $T$ be the timeout used for retransmitting a data frame when an ACK or NACK is received with errors. Timeout time starts with the data transmission as shown in Figure 1. Acknowledgment frames are transmitted after receiving a frame, with or without errors, but they are not transmitted after a timeout.

Let $p_t$ be the probability of frame error in a data frame and $p_f$ the probability of error in a feedback ACK or NACK frame. Let the probability of a frame loss, either a data frame or an acknowledgment frame, be negligible, i.e., frames are never lost.

A) Find the probability $p_s$ that a data frame is correctly received and acked on a given transmission. [pt. 5]

B) Find the expected number of transmission of a data frame $E[N_T]$ required before the data frame is correctly received and acked. [pt. 20]

C) Find the expected total time $E[T_{tot}]$ as a function of $E[N_T]$. $T_{tot}$ is the total time that it takes for a frame to be successfully transmitted and successfully acknowledged. For example, if no errors happen on both the data and acknowledgment frame transmissions, then $T_{tot}$ is equal to $P + R$. If an error happens on the first data frame transmission and no error happens on the subsequent negative acknowledgment, and no errors happen on both the successive data and acknowledgment frame transmissions then $T_{tot} = P + R + P + R$. [pt. 20]

D) Find the efficiency $\eta$ of the stop-and-wait protocol. [pt. 10]

E) The stop-and-wait protocol is used on a 100 Mb/s link to transmit data frames of 1000 bits each. Given a propagation time $R = 30\mu s$ and probabilities $p_t = p_f = 0.1$, what is the value of timeout time $T$ to have an efficiency of the protocol of $\eta = 0.12$? [pt. 20]
Exercise 2.

In the course, it has been assumed that the population from which the arrivals come (the calling population) is infinite, since the number of arrivals in any time interval is a Poisson random variable with a denumerable infinite sample space. Let us consider now a problem where the calling population is finite, of size \( P \), and thus the arrival rates are function of past behavior. Let assume that \( m \) servers are available.

This problem can be modeled with a queue with \( m \) servers and state dependent arrival rates defined as follows:

\[
\lambda_n = \begin{cases} 
\lambda(P - n) & 0 \leq n < P \\ 
0 & n \geq P.
\end{cases}
\]  

(1)

\( P \) is the size of the finite calling population (\( P \geq m \)).

A) Write the departure rate \( \mu_n \) when there are \( n \) (\( n = 0, 1, \ldots, P \)) customers in the system and sketch the state diagram of the queueing system. [pt. 5]

B) Derive the expression for the steady state probability \( p_n \) (\( n = 0, 1, \ldots, P \)) when \( m = P \) [pt. 20]

Exercise 3.

Suppose that the string “1010” is used as the flag to indicate the end of a frame. A bit stuffing rule is then required to avoid that the string “1010” is mistakenly taken as the flag, when the string “1010” is present in the data.

A) Define the bit stuffing rule that adds a “1” when necessary. [pt. 5]

B) Indicate how the following data string is encoded, including the flag indicating the end of frame 101010111011010011. [pt. 5]

C) Define the de-stuffing rule at the receiver for the stuffing rule defined at point A. [pt. 5]

D) How is the following string decoded? (If multiple strings are decoded, clearly indicate each string) 1011101101100101011011110101. [pt. 5]