EE5576: Wireless Communication Systems: Homework Assignment 3

Submission Instructions:
Submit your Matlab files (.m) and your assignment in electronic format (.pdf) directly on Canvas

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Consider a QPSK system with symbol duration $T_s = 2$ ns and carrier frequency $f_c = 1$ GHz. The transmitter uses the in-phase, I, and the quadrature, Q, components to generate the corresponding symbols, where $I = 1, -1$ and $Q = 1, -1$. For the transmitter pulse, consider square pulses with amplitude 1 and duration T_s. Gray encoding is used to define the bits carried by each symbol in the following way:

$$\text{Bits } 11: \quad s_0(t) = \sqrt{2}\cos(2\pi f_c t + \frac{1}{4}\pi) \quad \rightarrow \quad I, Q = 1, 1$$

$$\text{Bits } 01: \quad s_1(t) = \sqrt{2}\cos(2\pi f_c t + \frac{3}{4}\pi) \quad \rightarrow \quad I, Q = -1, 1$$

$$\text{Bits } 00: \quad s_2(t) = \sqrt{2}\cos(2\pi f_c t + \frac{5}{4}\pi) \quad \rightarrow \quad I, Q = -1, -1$$

$$\text{Bits } 10: \quad s_3(t) = \sqrt{2}\cos(2\pi f_c t + \frac{7}{4}\pi) \quad \rightarrow \quad I, Q = 1, -1$$

In this assignment we will consider three different channels. After the propagation delay of the shortest path, the first copy of the signal arrives to the receiver. Ignore this initial delay and consider relative delays to the first copy of the signal, τ, in seconds. Consider that all 3 channels are time invariant, so the impulse response of channel n is given by $h_n(t, \tau) = h_n(\tau)$. The impulse response of these channels are given by:

$$h_1(\tau) = 0.8\delta(\tau)$$
$$h_2(\tau) = 0.8\delta(\tau) + 0.4\delta(\tau - 3 \cdot 10^{-10}) + 0.2\delta(\tau - 4.2 \cdot 10^{-10})$$
$$h_3(\tau) = 0.6\delta(\tau) + 0.3\delta(\tau - 6.4 \cdot 10^{-10}) + 0.4\delta(\tau - 7 \cdot 10^{-10})$$

A random sequence of symbols is sent from the transmitter to the receiver through one of these channels. Consider AWGN at the input of the receiver that results in a SNR=10 dB at the input of the receiver.

At the receiver, the received corrupted symbols are demodulated by using two parallel matched filters (one for the in-phase and the other for the quadrature components) and then the Maximum Likelihood (ML) detector will be used to determine the transmitted bits. For the matched filter we consider the cosine (or sine), the transmitter pulse and a scale factor given that the cosine (sine) do not have unity energy.

Together with this document, you will find 3 Matlab files in the assignment:

- tx_QPSK.m: implements the transmitter with all the specifications described above.

- channel_and_noise.m: implements the signal transmission through a channel with impulse response specified as an input parameter and adds the AWGN noise.

- rx_QPSK.m: implements the receiver with all the specifications described above.

Moreover, you will also find a Matlab file (linfilt.m) that obtains the output signal for a linear filter given the impulse response and the input signal. This function is called by the previous Matlab functions.

In Matlab, the signals must be discrete in time. Consider that the sampling frequency (signal samples per second) is given by $f_s = 50$ GHz. **Consider also that for the Matlab code, frequencies are in MHz, symbol rates are in Mbauds and time is expressed in microseconds**.

Read carefully and understand the functions tx_QPSK, channel_and_noise, rx_QPSK and linfilt in the files attached together with the assignment. All the specifications for the system explained previously are already implemented in these functions. Your first goal is to understand their implementation and understand how to use them. If you are not familiar with some of the Matlab functions called in these functions, use the Matlab help tool. For example, to add AWGN to a signal the function awgn is used. For more information type in Matlab help awgn.

Considering all the previous system information, complete the following tasks:

1. (20 points) Create a M-file for the complete system considering either $h_1(\tau)$, or $h_2(\tau)$, or $h_3(\tau)$ as the impulse response of the channel. For the time (τ) vector used to generate the impulse responses, use a time vector that starts in time 0 and has a longer duration than the impulse response. For example, you can use the same time vector associated to the transmitted signal. Use this file for the next sections.

2. Generate 8 random bits of data.

   (a) (10 points) Plot the transmitted signal. Comment the results.

   (b) (20 points) Consider the channel impulse responses given previously. Generate 8 bits of data and plot the received signals corrupted with noise for the three different channels (plot the signals for each channel in a different figure). Comment the results.

3. Generate 100 bits of data.

   (a) (20 points) Plot the receiver constellation for the values of I and Q at the output of the demodulator for the three possible channels (plot the constellation for each channel in a different figure). Comment the results.

   (b) (20 points) Compare the data sent and the data received for the three cases by obtaining the bit error probability Which is the worst case? Why do you think this happens?

4. (10 points) How would you improve your receiver to reduce the bit error probability? No need to implement your solution, just provide a possible solution and justify your answer.

IMPORTANT: Submit a .pdf document with the answers for each section including figures for each section and comments when requested. For all the figures, generate appropriate labels for the x and the y coordinates. Submit also the M-file you used to obtain your solution.