MACQUARIE University SYDNEY·AUSTRALIA

TELE4081/8081 FINAL PROJECT

Due: Week 13

INSTRUCTIONS

This final TELE4081/8081 project consists of **8 questions**. The questions are intended to guide your thinking to approach the design problem in a structured way. There will be a ***final oral examination (Viva)*** during the workshop hours in Week 13. The Viva will mainly focus on your work in this project as well as other fundamental concepts introduced in the unit such as modulation, pulse shaping and bandwidth. Please make sure that you can explain your design in this project clearly as well as articulating your responses to the questions clearly.

The assessment will be based on the acquired skills you demonstrate during the oral examination such as the use of Matlab/Simulink, understanding of digital communications system design and layers, articulation of observed performance results/tradeoffs and analytical thinking to solve a communications problem. You are allowed to use the lecture notes and any other open source to complete the final project. However, you are **NOT** allowed to discuss your solution/approach with other students taking the unit and to receive any help from someone within or outside the unit to complete the final project. Due to the open-ended system design nature of the assessment, different students are expected to have different statements detailing their approach, logical reasoning behind the proposed design and interpretation of observed results. Please read the honour pledge given below before starting to work on the project.

Honor Pledge: By completing the project in this final assessment task, you accept to obey to the following Honor Pledge:

"I have neither given nor received aid, nor have I used unauthorized resources, on this examination.".

FADING CHANNEL DESCRIPTION

In this final project, you will develop ***your*** fading channel model in Simulink and measure the symbol error rate (SER) and bit error rate (BER) performance of a typical digital communications system over fading channels using the developed model. The model you will develop will be simple but still be useful to characterise some common communications environments. It is important to note that Simulink has built-in fading channel blocks called Rayleigh SISO and Rayleigh MIMO, however you will not use them in this project. Rather, you will develop your own model from first principles.

In the workshops, our main focus was the additive white Gaussian noise (AWGN) as a major channel impairment corrupting transmitted symbols. AWGN channel model is useful to understand transmission dynamics in wireline communications. However, this model cannot describe the random effects frequently observed in wireless digital communications systems. In addition to additive noise, *fading* is an important source of randomness in wireless communications causing distortion to the transmitted symbols in the form of amplitude scaling and rotation as discussed in the lectures. You will develop a frequently used fading channel model and data decoding algorithm in this final project.

A common fading model often used to characterise digital communications system performance is the *Rayleigh flat fading* model. The *flat fading* is an appropriate model for channel fading when the transmission bandwidth is smaller than the channel coherence bandwidth. The *Rayleigh* distribution is a good statistical fit for the channel amplitude gains in richly scattering urban environments such as Sydney CBD area. In this channel model, the input-output relationship between transmitted and received symbols is given by a *simple* relationship, which can be expressed as

$$Y = H \cdot X + N, \tag{1}$$

where

- X is the transmitted symbol chosen from a given constellation (i.e., recall that the choice of constellation was M-QAM in the workshops).
- Y is the received symbol at the receiver. The receiver observes a particular realisation of Y, say $Y = y$, and attempts to estimate the most likely transmitted symbol X leading to observation $Y = y$.
- H is the Rayleigh flat fading coefficient scaling the transmitted symbol. Since transmitted symbols are complex numbers represented by in-phase and quadrature components (i.e., recall the Simulink models developed in the Workshops), H is also a complex number in Eqn. (1), which can be represented as

  $$H = H_{\mathrm{re}} + jH_{\mathrm{im}}. \tag{2}$$

  The name "Rayleigh" comes from the statistical structure characterising the distribution of the amplitude of H, which is denoted by $|H|$ and defined to be

  $$|H| \triangleq \sqrt{H_{\mathrm{re}}^2 + H_{\mathrm{im}}^2}. \tag{3}$$

QUESTION 1

The power of fading coefficient H is defined as the expected value of its squared amplitude. Describe how you should generate H_{re} and H_{im} in Eqn. (2) to have a Rayleigh fading channel model with power σ^2.

QUESTION 2

Modify the 16-QAM AWGN Simulink model you developed in Workshops 3 and 4 to obtain a Rayleigh fading channel model having average power 1 [Watts]. Here, you will need to develop your own Simulink block and integrate it with the 16-QAM AWGN Simulink model to emulate the Rayleigh fading channel environment. Describe your work, approach and logical reasoning behind your model.

QUESTION 3

Data decoding in the presence of fading is more involved than that for AWGN channel models studied in the workshops. We are required to track and estimate the channel before starting the decoding process for having reliable data decoding algorithms. In this question, you will develop your data decoder to decode transmitted symbols over Rayleigh fading channels.

Assuming that the receiver can perfectly estimate the channel, describe how you should modify the 16-QAM AWGN Simulink model to obtain a data decoder to decode the transmitted symbols. Develop a Simulink block for your data decoder and integrate it with the 16-QAM AWGN Simulink model. Describe your work, approach and logical reasoning behind your model.

QUESTION 4

In this question, you will characterise the SER performance of your decoder to decode data over Rayleigh fading channels. To this end, simulate the system you designed to obtain numerical SER values for a range of SNR parameters varying from 0 [dB] to 50 [dB] and measured in terms of the bit-energy-to-noise-PSD-height ratio.

Due to its dynamic range, it is more insightful to plot the variations in SER as a function of SNR by using the logarithmic scale in both x and y axes. Plot the SER as a function of SNR with logarithmic scale in both axes. In the same figure, plot also the SER as a function of SNR for AWGN channels.

A useful metric to understand the telecommunications reliability in the high SNR-regime is the ratio $\frac{\log(\mathsf{SER})}{\log(\mathsf{SNR})}$. Plot this ratio for both Rayleigh fading and AWGN channels, showing both in the same figure as a function of SNR.

Describe your observations in both figures and provide a detailed discussion explaining the difference between the SER plots in the Rayleigh fading and AWGN channel cases. One may speculate that the distortion due to fading can be compensated at the receiver when the channel can be perfectly estimated at the receiver. Do you agree with this argument or not based on your observations? If you do not agree with it, what may be going wrong at the receiver even with perfect channel estimation?

QUESTION 5

In this question, you will investigate the effect of channel estimation errors on the system SER performance. One way to study this effect is to model the estimated channel coefficient $\tilde{H}$ as

$$\tilde{H} = H + \epsilon, \tag{4}$$

where $\epsilon = \epsilon_{\mathrm{re}} + j\epsilon_{\mathrm{im}}$ with ϵ_{re} and ϵ_{im} being independent Gaussian random variables with mean zero and variance $\delta \geq 0$.

Modify the Rayleigh fading model developed in the previous questions to model the channel estimation errors as described in Eqn. (4). Set the δ parameter to $0, 0.05, 0.1$ and 0.5 to investigate the effect of channel estimation errors on the data decoding performance over Rayleigh fading channels. Provide the SER plots as a function of SNR in the same figure for these values of δ. Describe your observations and provide a discussion about the effect of channel estimation errors observed in the figure.

QUESTION 6

In the previous question, you analysed the effect of channel estimation errors on SER. In this question, you will investigate a fundamental tradeoff between time-to-estimate the channel and the system reliability. For the sake of obtaining some high-level insights, we will simplify the problem by ignoring the change in the fading process over time below.

The channel estimation becomes more accurate if you have a larger time window to collect more data about the channel during the channel estimation phase. Assume you have performed a large set of measurements indicating that the SER you achieve becomes equal to $p(\alpha)$ when you spend $\alpha \in [0, 1]$ fraction of time for channel estimation. To put the discussion into perspective, observe that $\alpha = 0$ corresponds to the case where you do not spend any time to estimate the channel and try to decode the data without any knowledge of the channel. On the other hand, $\alpha = 1$ corresponds to the case where you spend all the time for channel estimation without any time left for the actual data communications. These are the two extreme situations, both of which are not favourable to operate in as you may have already guessed.

In the first case, no channel information is available at the receiver and the data decoding will resemble to random selection of data symbols as the fading will rotate and shift the symbols in your constellation diagram. In the second case, you spend excessive amount of time to estimate the channel and do not essentially transmit any data to the receiver.

How would you set the parameter α to obtain the maximum "*goodput*" over a fading channel? We define the goodput in data communications as the number of useful bits delivered to the receiver per unit time. For what values of parameter α, we obtain a higher goodput than random guessing in the case of 16-QAM transmissions? This question aims to test your analytical thinking to solve a telecommunications problem in an abstract situation. Hence, clearly describe your work, approach and logical reasoning for how you set the parameter α to obtain the maximum goodput and to determine the range resulting in better performance than random guessing.

QUESTION 7

Repeat Questions 3 and 4 to calculate the BER performance of your decoder over Rayleigh fading channels. Clearly describe your work, approach and logical reasoning for the changes you make in your model to measure the BER in stead of SER.

QUESTION 8

In Workshops 3 and 4, you compared

- total number of symbol errors

with

- total number of bit errors

and

- SER

with

- BER

over AWGN channels. Perform a similar comparison over Rayleigh fading channels. Which quantity is bigger than the other and explain your reasons for this behaviour? Here, you are focusing on a different communications environment with Rayleigh flat fading than the AWGN one you analysed in the workshops. Do you think that comparison of these quantities and their relative "bigness" with respect to each other change for data communications over fading channels? Clearly describe your work, approach and logical reasoning behind your answers.