Experiment # 5

Diversity in Wireless Communications

1 Purpose

This lab will introduce the topic of diversity. Since this experiment encompasses extra material to that given in the theory, you will be encouraged to search for answers by exploring the simulations. These systems intend to show you diversity as one of the three pillars in understanding effective wireless communications over a fading channel. The other two would be delay spread and doppler spread.

You will work with simulations of systems utilizing selection combining, equal gain combining and maximum ratio combining. These are techniques which make use of multiple antennas at the receiving end to improve the received signal. This is done either by selecting the highest signal-to-noise ratio among the signals received or by adding all arriving signals after some correction to maximize SNR at the combiner output.

2 Background Reading and Preparation

Further reading material can be found in [1], [2], [3] or [4], among many others.

This lab will have no preparation.

3 Experiment

This experiment is divided into three parts. All parts will involve simulation in `Simulink`, with models provided to you. You will simulate selection combining, equal gain combining and maximum ratio combining (MRC) as methods to improve the signal-to-noise ratio of the received signal by using spacial (or antenna) diversity.

3.1 Selection Combining

In selection combining, one intends to select the greatest instantaneous signal to noise ratio among the multiple receiving antennas. This can be done by comparing all inputs at every incoming sample or by selecting the strongest at one point and keeping its source as the chosen source unless it falls below an acceptable threshold. The former will be the one presented in this simulation, but the latter makes for a simplified "real" implementation.

Go to `http://www.comm.utoronto.ca/∼bkf/ECE464`, find the Selection Combining model, and save it locally to your machine. This model is comprised of a transmitter, two channel paths and a receiving stage including receiving filters and a decision making subsystem. You run the system and observe the time-domain scope and the eye diagram. If you get an error, that is due to your filters not being set. Read on.

The transmitter block includes a bit source, a Pulse Amplitude Modulation (PAM) stage and a transmitter pulse-shaping filter. This modulation scheme was chosen for simplicity and clarity in displaying results. The model includes a non-connected filter design block, with a filter pre-designed in it. You may have to open the block and export the coefficients of the filter to a variable in the workspace. This is done by selecting `File/Export`. On the GUI, select exporting to workspace, and name the variable "a". Click okay. Note that if you open the block for TX filter (or RX), variable "a" will be called there. You should be able to run the model now.

There are two signal paths, each including some degree of attenuation on the incoming signal, as well as some Gaussian noise. A more realistic model for the channels would include multipath (or an impulse response model of some sort). However, the effect of multipath would have to be mitigated at the receiver with the use of an equalizer, making the demonstration of the point in question (diversity) more intricate. Finally, the receiver stage includes a decision-making subsystem and the appropriate matched filters.

Answer the questions below, based on what you infer from the simulation.

- *Explain what the PAM subsystem is doing. Remember: the original signal is a bit stream.*

- *What is the purpose of the transmitter filter? What is it doing? Why?*

- *At the receiving end, what is the matched filter doing?*

- *Based on what you understood of the PAM subsystem, if you are to extract the original sequence from the received signal, at what point would you take samples of the arriving signal? Hint: base your answer on the eye diagram*

- *While your system is running, open one of the channel paths and modify the gain block which is controlling the amount of noise added. At what point would you* **not** *be able to recover your signal? Hint: base your answer on the eye diagram.*

- *If you added more receiving antennas (and therefore signal paths) would you make things better? Why? If you have worked on the prep: how far appart should they be?*

3.2 Equal Gain Combining

Another technique to account for space diversity is to combine all arriving signals to obtain an increase in signal-to-noise ratio. For the signals to be combined in this fashion, all arriving signals must be in phase. Therefore, it may be necessary to correct the phase prior to adding them up.

With a web-browser, go to `http://www.comm.utoronto.ca/∼bkf/ECE464` and find the link to the Equal Gain Combining Model. Save the model (right-click) locally to your machine. This model presents now three signal paths. Since we have not inserted multipath in this simulation, the signals *are* in phase.

- *Suppose one of the signal paths were very noisy (try it), could adding one more receiving antenna (and therefore signal path) make things better? How?*

- *If the signals were* **not** *in phase, you would need to correct that. Say you have three receiving antennas and you want the three signals in phase. How would you correct that? Key: "out of phase" means "delayed".*

3.3 Maximum Ratio Combining

In Maximum Ratio Combining, the signal received at different antennas is weighted prior to the sum of all the paths. The weight applied is the complex conjugate of the channel between the transmitting antenna and the respective receiving antenna. The result is that the stronger signal is weighted more heavily than the weaker signal. The antennas are considered to be far from one another so that the channels can be considered to be independent from each other.

Go to `http://www.comm.utoronto.ca/~bkf/ECE464` and find the link to the Maximum Ratio Combining Matlab *code*. Save the code (right-click) locally to your machine. The code you will run was presented by [5].

Run the file named `rxvssnr.m`. It simulates effective SNR for number of receivers in a Rayleigh channel. The point of this exercise is for you to note that the greatest benefit in SNR is gained at the steepest slope, which is when one goes from 1 receiver to 2 receivers. Afterwards, an increase in the number of receivers will not reflect similarly on the SNR (it does not saturate, though).

Now run the file named `bersim.m`. This program simulates the Bit Error Rate (BER) versus the Effective bit energy to noise ratio (Eb/No), for a Binary Phase Shift Keying (BPSK) system using MRC in a Rayleigh channel. After you run the program and plot the curves for 1 and 2 receivers, modify the code to increase the number of receivers and see the improvement.

4 Accomplishments

With this final experiment, you would likely have understood the role played by exploring diversity in wireless communication over fading channels.

References

[1] T. Rappaport, *Wireless Communications, Principles and Practice* Prentice Hall, 2002

[2] S. Haykin and M. Moher *Modern Wireless Communications* Pearson-Prentice Hall, 2005

[3] J.W. Mark and W. Zhuang, *Wireless Communications and Networking*. Prentice Hall, 2003.

[4] R. Adve *Course notes on Receive Diversity. http://www.comm.utoronto.ca/ rsadve/Notes/DiversityReceive.pdf*

[5] K.Pillai Scripts for Maximal Ratio Combining *http://www.dsplog.com/2008/09/28/maximal-ratio-combining/*