Multi-Channel Communications

Mini-Project #1

The MIMO Channel

Due September 6, 2022

Note: You may use outside references including books and notes and may discuss the project with your classmates in general terms. However, you may not obtain code or direct assistance from another person.

PLEASE MAKE SURE YOU ANSWER ALL PARTS OF EACH PROBLEM AND CLEARLY MARK YOUR FINAL ANSWERS. YOUR ANSWERS SHOULD BE AS COMPLETE AND CLEAR AS POSSIBLE – NOT JUST A LISTING OF THE ANSWER. MATLAB CODE SHOULD BE CLEARLY DOCUMENTED AND SUBMITTED SEPARATELY FROM YOUR REPORT IN A ZIP FILE PER THE INSTRUCTIONS IN LECTURE #1.

I pledge that I have neither given nor received any unauthorized assistance on this project.

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(signed)

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Name (print) Student Number

1 Mini-Project Overview

The first project you are going to accomplish is the design and implementation of a space-time channel simulator in Matlab. This simulator will be used and enhanced later in the course. You will turn in two primary components: (1) Matlab code (uploaded to Canvas as a zip file) and (2) A report validating your design (uploaded to Canvas as a pdf file and a hard copy submitted in class).

2 Detailed Description

You will create a Matlab function titled channel.m. The function creates a narrowband MIMO wireless channel. The function should use a spatial Clarke's (sum-of-sinusoids) model which introduces both spatial and temporal correlation. The function should accept a single structure which includes all of the parameters needed to defined the channel (e.g., N_t, M_r, angle spread, angle distribution, mean angle of arrival, antenna spacing, Ricean K-factor, etc.) and output a $M_r \times N_t \times N_s$ array where M_r is the number of receive antennas, N_t is the number of transmit antennas, and N_s is the number of time samples. The channel samples are assumed to be in complex baseband. *Note that the channel function should result in unit average gain between any transmit antenna and any receive antenna.*

Once you have completed the function, you should create a short report detailing your work and validating its performance. The report should have the following sections:

1. Introduction - this section briefly outlines the goals of the project.
2. Description - this section outlines the basic theory behind the implementation and briefly describes the created function.
3. Validation - this section provides validation that the created function works properly by meeting the theoretical expectations. The required validations are listed below.
4. Conclusion - this section concludes the report and outlines any issues experienced.

3 Required Validation

You will create a report describing your function briefly and providing validation plots. **IMPORTANT: Please read the directions below carefully. Full credit will only be given if the directions are followed exactly.** Specifically, you must validate the channel functions by providing the following plots/analyses:

1. **Temporal Behavior**

   (a) Example time domain plots of the signal magnitude (envelope) for two received signals for a one-antenna transmitter and two-antenna receiver. Plot the channel amplitude for 0.1 seconds when sampled at $f_s = 1$kHz. The antenna spacing and angle spread should be chosen so that the channels are essentially independent (i.e., very low correlation) with a maximum Doppler spread of $f_d = 100$Hz and a Ricean K-factor of $K = 0$ (i.e., Nakagami m parameter of $m = 1$). Thus, there should be two received signals plotted over 0.1 seconds. **Clearly label all axes and plots**. *Also, use a semilog plot with the y-axis (10^{-4} to 10^{1}) using a log scale and the x-axis (0 to 0.1s) using a linear scale.*

   (b) Verify the average received power per antenna (measured over at least 10s).

   (c) Measure the temporal auto-correlation and compare to theory in a plot extending from a delay of 0 to 0.1s. The measurement should be averaged over at least 10s, although the delays examined need only range from 0 to 0.1s.

   (d) Repeat the above three validations for a lower Doppler spread of $f_d = 15$Hz.

2. **Spatial Behavior Part I**: Find the correlation between the two signals from part 1a when measured over 100 seconds. Compare with theory.

3. **Frequency Behavior**: Plot the measured Doppler spectrum of the received signals from part 1a and compare to the theoretical distribution when maximum Doppler spread is 100Hz. Provide a mathematical description of the theoretical Doppler spectrum. Repeat for a maximum Doppler spread of 15Hz.

4. **Statistical Distributions**:

   (a) Plot the histogram of the envelope of one of the received signals from part 1a and compare with theory (i.e., the theoretical pdf). Note that the theoretical pdf should be plotted on top of the histogram for a direct comparison. This can be accomplished by properly normalizing both plots. The number of bins in the histogram should be chosen so that a reasonable match can be seen. Using 100 bins is typically sufficient.

   (b) Repeat part 4a when $K = 15$.

   (c) Create a channel with four nearly independent (or nearly independent) channels at the receiver. Coherently combine the received channels using maximal ratio combining on the four antennas (with $K = 0$ or $m = 1$). Measure and compare the distribution (i.e., histogram) of the resulting power (i.e., $\sum_i |h_i|^2$) with theory. Again, use a histogram with at least 100 bins. **Derive the theoretical distribution for the comparison.**

5. **Spatial Behavior Part II**:

   (a) Add spatial correlation to the received signals from part 4c (by reducing angle spread at the receiver) and show that the histogram changes accordingly. Again, compare with theory.

   (b) Create a 2×2 channel. Examine three cases (through the appropriate choice of antenna spacing and angle spread): (a) when the correlation between two transmit antennas is 0.1 and the correlation between the two receive antennas is approximately 0; (b) when the correlation value at the transmitter side is 0.8, and the correlation between the two receive antennas is approximately 0; and (c) when both correlation values at the transmitter and receiver are approximately 0.8. Compare the histograms (again, please use a sufficient number of bins) of the max eigenvalue of $\mathbf{H}\mathbf{H}^H$ for sample matrices for each of the three cases. Compare cases (a) and (b) with theory (you may have to do a little research to find the theoretical distribution). Note that the eigenvalues should be measured using samples of the matrix channel that are spaced larger than the coherence time of the channel so as to create independent eigenvalues for the histogram.

6. **Capacity**: Calculate the capacity of the three 2×2 channels created in part 5b as well as the capacity of channel in the 1a (a 1×2 channel). Assume that the average SNR per channel $\gamma = 10$dB. Specifically, for the comparison plot the cumulative histogram (empirical estimate of the cdf) of the four cases. How do they compare? Do the relative plots make sense? Explain.