Multi-Channel Communications

Final Project

MIMO OFDM

Due December 14, 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 ANSWERS BY PUTTING A BOX AROUND EACH ANSWER. 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.

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 Final Project Overview

In your final project you will combine several aspects of your previous projects by developing a full MIMO-OFDM transceiver. 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 combine your previously designed MIMO and OFDM transmitters and receivers. The transmit function should include options for both spatial multiplexing and space-time block coding. Additionally, the transceiver should include an option for transmitting a MIMO-OFDM signal with varying modulation/coding on each sub-carrier (or group of sub-carriers) and each stream (when spatial multiplexing is enabled). Note that the transmitter code should take three inputs: a block of N_b input data bits, a feedback message (needed for modulation and coding choices or channel feedback) and an object/struct named "parameters" which provides the input parameters defining the modulation scheme (or adaptation scheme in this case), MIMO scheme and any other needed parameters (you will have hopefully already included various items to the Parameters struct including the number of subcarriers, the pilot locations, etc.). The receiver function should take two inputs: the complex received samples (after going through a channel function) and a parameters object/structure that has the necessary details concerning the OFDM scheme, MIMO scheme, the modulation scheme used, etc. The receiver function should output the data and the feedback bits. The receiver should operate in two different modes: (1) synchronized mode which assumes frequency and time synchronization has already taken place; and (2) (EXTRA CREDIT) unsynchronized mode in which the receiver must perform timing and frequency synchronization.

3 Required Validation

You will create a report describing your function briefly and providing validation plots. Specifically, you must validate the channel function by providing the following plots/analyses:

1. MIMO-OFDM Channel

   (a) Implement a 2×2 MIMO channel with an angle spread of 360^o at the receiver and 5^o at the transmitter, Doppler spread of $f_d = 100$Hz and an rms delay spread of $\tau_{rms} = 1\mu s$ (resolvable multipath follows an exponential decay). Assume a sampling rate of 1MHz. Plot the time-domain channels for the first resolvable multipath between all transmit and receive antennas (i.e., all four channels). Plot the magnitude using a log-scale for the y-axis. Calculate the correlation between the four channels. Plot the frequency domain channel for between all antennas at a specific time.

   (b) Change the delay spread and Doppler spread used in the previous validation (1a) to $10\mu s$ and 10Hz respectively and repeat. How are the plots affected?

2. MIMO-OFDM

(a) Assume the use of $N = 128$ sub-carriers, $T_{eff} = 0.5ms$ and two transmit and two receive antennas. Use the same antenna spacing and channel parameters as in (1a). Also assume the use of QPSK on all subcarriers and a half rate error correction code of your choice. Encode 256 bits into a 512-bit coded block which is mapped to two consecutive OFDM symbols (2 bits / sub-carrier x 128 subcarriers x 2 OFDM symbols). Use your knowledge of the transmitted bits to determine if a block is received correctly or not (in real life a CRC check would be used, but here we can use ideal knowledge). Measure the block error rate and the associated throughput for an average SNR ranging from 0-30dB in 2dB increments. Assume the use of STBC (or SFBC - i.e., using frequency/sub-carrier instead of time for the 2-antenna block code), perfect channel knowledge and perfect synchronization.

(b) Repeat 2a using spatial multiplexing instead of STBC. How does the throughput compare?

(c) Implement either LS/MLE or MMSE channel estimation based on known pilots and pilot locations. Using the set of physical layer and wireless channel parameters from 2b show the performance of QPSK modulation with a chosen number of pilots for an average SNR ranging from 0-30dB in 2dB increments. How does channel estimation impact throughput? Is there an optimal number of pilots to maximize throughput? Assume perfect synchronization.

3. Bit Loading / Adaptive Modulation

   (a) Repeat 2c but with adaptive modulation (i.e., bit loading). Include BPSK, QPSK, 8-PSK, 16-QAM, 32-QAM and 64-QAM. How is throughput affected?

4. Synchronization (EXTRA CREDIT)

   (a) Repeat 3a but also implement a time/frequency synchronization technique and examine the impact of synchronization on performance for random (uniformly distributed) delay offsets (prior to synchronization) of 1-100 samples and random frequency offsets uniformly distributed from $0.1N$ to $0.5N$.