STBC & MIMO Systems

In this project, we want to simulate MIMO systems, STBC Codes and Beamforming. We evaluate and compare their performance (the probability of error) using different decoders such as Maximum Likelihood Decoder (MLD) and Minimum Mean Square Error Decoder (MMSE).

A. System Model

MIMO systems are composed of three main components, namely the transmitter (TX), the channel (H), and the receiver (RX). In this project, N_t is denoted as the number of antenna elements at the transmitter, and N_r is denoted as the number of elements at the receiver. Figure 1 depicts such MIMO system block diagram. It is worth noting that system is described in terms of the channel. For example, the Multiple-Inputs, which are the output signals of the TX, are the inputs of the channel, and similarly, the Multiple-Outputs are the outputs of the channel, which are the input signals of the RX.

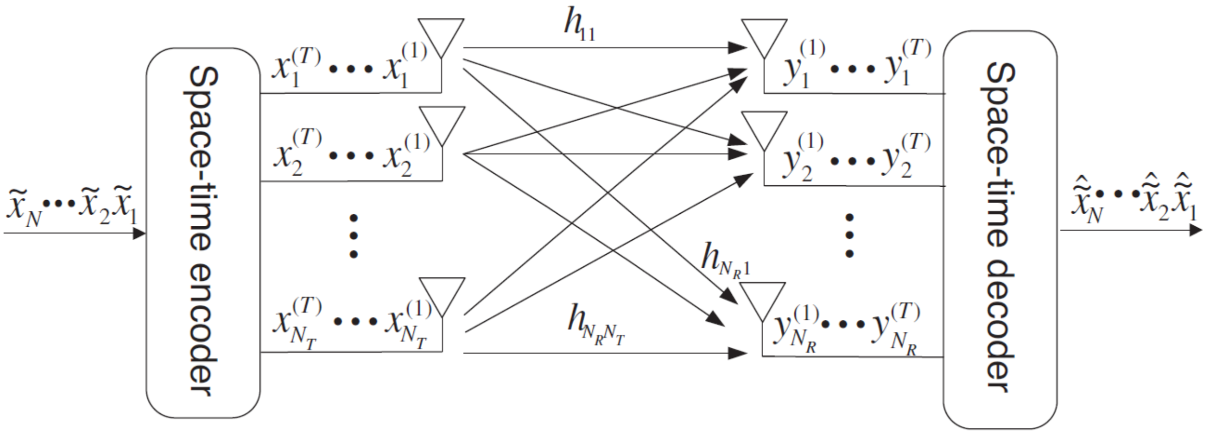

Figure 1. Multiple-Input Multiple-Output system block diagram

The Channel with N_r outputs and N_t inputs is denoted as a $N_r \times N_t$ matrix:

$$\mathbf{H} = \begin{pmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,N_t} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,N_t} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_r,1} & h_{N_r,2} & \cdots & h_{N_r,N_t} \end{pmatrix}$$

Where each entry $h_{i,j}$ denotes the attenuation and phase shift (transfer function) between the j^{th} transmitter and the i^{th} receiver. It is assumed throughout the project that the MIMO channel is modelled as a block flat fading channel. In other words, it behaves in a "quasi-static" fashion, i.e. the channel varies randomly between burst to burst, but fixed within a transmission. This is a reasonable and commonly used assumption as it represents an indoor channel where changes in the channel is negligible during the time of a burst of data.

The MIMO signal model is described as:

$$\underline{\mathbf{y}} = \mathbf{H}\underline{\mathbf{x}} + \underline{\mathbf{n}} \qquad (1)$$

Where $\underline{\mathbf{y}}$ is the received vector of size $N_r \times 1$, $\mathbf{H}$ is the channel matrix of size $N_r \times N_t$, $\underline{\mathbf{x}}$ is the transmitted vector of size $N_t \times 1$, and $\underline{\mathbf{n}}$ is the noise vector of size $N_r \times 1$. Each noise element is typically modeled as independent identically distributed $(i.i.d.)$ white Gaussian distribution. An explanation for this model is as follows. The transmitted signals are mixed in the channel since they use the same carrier frequency. At the receiver side, the received signal is composed of a linear combination of each transmitted signal plus noise. The receiver can solve for the transmitted signals by treating $\underline{\mathbf{y}} = \mathbf{H}\underline{\mathbf{x}}$ as a system of linear equations. If the channel $\mathbf{H}$ has correlated elements, the system of linear equations will have more unknowns than equations. To prevent correlation, the antennas are typically spaced at least $\frac{\lambda}{2}$, where λ is the wavelength of the carrier frequency. Another reason correlation can occur is due to lack of multipath components.

B. Space Time Codes

Space-time coding introduces redundancy in space, though the addition of multiple antennas, and redundancy in time through channel coding. Two prevailing space-time coding techniques are Space Time Block Codes (STBC) and Space Time Trellis Codes (STTC). STBC provide diversity gain, with very low decoding complexity.

This can be achieved by transmitting several replicas of the same information through each antenna. By doing this, the probability of losing the information decreases exponentially. The different replicas sent for exploiting diversity are generated by a space-time encoder which encodes a single stream through space using all the transmit antennas and through time by sending each symbol at different times. This form of coding is called Space-Time Coding (STC).

The most popular form of STCs are space-time block codes (STBC) because of their decoding simplicity.

C. Simulation

Our system is a 4×4 MIMO channel with uncorrelated Rayleigh distributions. We wish to simulate the performance of the system for QPSK and 16-QAM modulated signals in the following configurations:

I. Uncoded system $(r = 4)$

In this scheme, the transmitter sends 4 parallel data streams without any coding. The space-time code of the Uncoded scheme is given by

$$X_1 = (x_1 \quad x_2 \quad x_3 \quad x_4)^T \qquad (2)$$

II. Alamouti's 2×4 STBC $(r = 2)$

This STBC uses four transmit antennas and applies the Alamouti's STBC [2] to each pair of the TX antennas. The space-time code used here is given by

$$X_2 = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \\ x_3 & x_4 \\ -x_4^* & x_3^* \end{pmatrix} \tag{3}$$

III. Quasi OSTBC $(r = 1)$

This is a new STBC that was proposed in [1]. In this STBC, the data transmitted over four time slots, so the rate of this code is 1

$$X_3 = \begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & -x_4^* & x_1^* & x_2^* \\ x_4 & -x_3 & -x_2 & x_1 \end{pmatrix} \tag{4}$$

IV. Beamforming $(r = 1)$

In this system, all transmit antennas send the same symbol in each time slot, also transmitter do not know the channel gains (CSIR) so uniform power will be allocated for all the antennas.
Suppose that Maximum Ratio Combining (MRC) method will be used at the receiver side.

$$X_4 = (x \quad x \quad x \quad x)^T \tag{5}$$

D. Assignments

1- For all above cases, we want to evaluate the performance of the system using Maximum-Likelihood (ML) and Minimum Mean Square Error (MMSE) decoder. Plot BER curve with respect to $\frac{E_b}{N_0}$. Compare different cases and explain their advantages/disadvantages.

2- If the target BER is 10^{-3}, find the required $\frac{E_b}{N_0}$ for all the above cases and plot the results as a Bit-rate vs SNR plot. Explain what you conclude from this plot.

References

[1]. H. Jafarkhani, "A quasi-orthogonal space–time block code," *IEEE Trans. Commun.*, vol. 49, no. 1, pp. 1–4, Jan. 2001.

[2]. S. M. Alamouti, "A simple transmitter diversity scheme for wireless communications," *IEEE J. Select. Areas Commun.*, vol. 16, pp. 1451–1458, Oct. 1998.