ECE - 5577
Wireless Communication

A Report on Multiple Input Multiple Output (MIMO)

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Multiple Input Multiple Output (MIMO)

Introduction:

Multiple Input Multiple Output is a technique that exploits multipath propagation mechanism to achieve higher data rates. Multiple antennas are used at both transmitter and receiver. Parallel data streams are transmitted using multiple channels through multiple antennas at the transmitting side. At the receiving side, original data is extracted from received signal (which consist of original data plus the noise) using various methods.

MU MIMO is a technology that allows communication with multiple devices simultaneously. It is different from SU MIMO (Single user Multiple Input Multiple output) in which only one user is allowed to use the terminals at a time. MU–MIMO is based upon OFDMA (Orthogonal Frequency Divisional Multiple Access) which adds Multiple Access to OFDM technique that is used in SU-MIMO. MU MIMO can be categorized into two:

1. MIMO Broadcast

It represents the downlink case where the transmission occurs from single sender to multiple receivers. For this the channel state information at the transmitter (CSIT) has to be known at the sender in order to increase the throughput and the MIMO broadcast has the advantage over point to point MIMO if the number of transmitter antennas are larger than receiver antennas. The issue in this is Multi User Interference (MUI) where the AP sends the data and the data may interfere with each other.

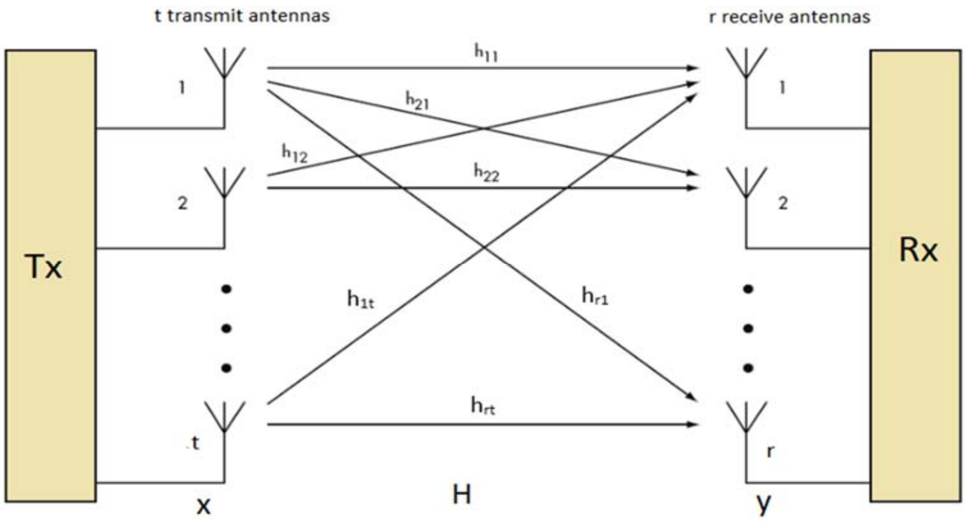
2. MIMO Multiple Access Control(MAC):

It refers to the uplink case in the MU MIMO where the transmission occurs from multiple sender to single receiver. In this case the receiver has to know the channel state information at the receiver (CSIR). It utilizes a lot of resources to know the CSIR information. The Issue in this is Multi User Detection (MUD) in which AP needs to know the Transmitter stations using the Channel State Information (CSIR).

The MU MIMO uses Transmitter Antenna Selection (TAS) to select the transmitter for the Downlink Scheme which uses Maximal Ratio Combining Scheme (MRC) for selecting the antenna based upon the Channel state information. The Pilot Based training sequences estimates the channel at the receiver and based on the feedback the antenna is selected. The Bit Error Rate of MRC system with multiple antennas is carried out as the transmitter antenna selection plays a major role. The error should be minimized in order to get the right antenna as the whole transmission depends on it.

MIMO System Model

The MIMO system consists of multiple antenna at both the transmitting and receiving side. The diagram shown below is the general MIMO system which has $x_1, x_2 \ldots x_t$, transmitting antennas and $y_1, y_2 \ldots y_r$ receiving antennas.



The general equation of t x r MIMO system is given by

$$\overline{y} = \mathrm{H}\,\overline{x} + \overline{n}$$

$$\begin{bmatrix} y_1 \\ \vdots \\ y_r \end{bmatrix} = \begin{bmatrix} h_{11} & \cdots & h_{1t} \\ \vdots & \ddots & \vdots \\ h_{r1} & \cdots & h_{rt} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_t \end{bmatrix} + \begin{bmatrix} n_1 \\ \vdots \\ n_r \end{bmatrix}$$

Where,
H is the Channel matrix (fading channel coefficient)
$\overline{y}$ is the transmitted vector
$\overline{x}$ is the received vector
$\overline{n}$ is the white Gaussian noise vector
$y_1, y_2 \ldots y_r$ receiving antennas.

For 2x2 MIMO system, the above equation becomes

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

$$y_1 = h_{11}x_1 + h_{12}x_2 + n_1$$

$$y_2 = h_{21}x_1 + h_{22}x_2 + n_2$$

n_1, n_2 are the noise received on first and second receive antennas. It is assumed that the receiver knows the Channel State Information (CSI) i.e. h_{11}, h_{12}, h_{21}, h_{22}. The only unknown factor at the receiving side are x_1, x_2.

Let a_1, a_2, $a_3 \ldots a_n$ be the symbols being transmitted. In traditional single antenna system, the symbols a_1 is transmitted in time slot 1 and a_2 in time slot 2 but now the symbol a1 is transmitted using first antenna and a2 using second antenna in same time slot t. so if it took n time slot to transmit data in traditional system but now it will take only n/2. So data rate doubled.

Zero Forcing

From the general equation of MIMO system,

$$\overline{y} = H\,\overline{x} + \overline{n}$$

$$H^{-1}\,\overline{y} = \overline{x} + H^{-1}\,\overline{n}$$

In order to obtain the value of x from above equation H^{-1} must exit. If H^{-1} is a square matrix and non-singular then H^{-1} can be calculated easily. If H^{-1} is not a square matrix, then H^{-1} is replaced with pseudo-inverse (H^{+}). The pseudo-inverse of any non-square matrix is given by

$$H^{+} = (H^{H}\,H)^{-1}\,H^{H}$$

Where, H^{H} is equal to conjugate and transpose of matrix H (i.e. H^{*T}). If the matrix is real then H^{H} is simply H^{T}.

Noise amplification is the major issue in Zero Forcing algorithm. From above equation we see that when the channel response is small, the factor $H^{-1}\,\overline{n}$ increase greatly causing the issue. So another technique MMSE is used.

Minimum Mean Square Error (Bayesian Approach)

Let us consider a linear estimator $W^{T}\,\overline{y} = \overline{x}$. We choose a value W such that E $\{\|\hat{x} - x\|^2\}$ is minimized.

$$E\,\{\|\hat{x} - x\|^2\} = E\,\{(W\,\overline{y} - x)^T(W\,\overline{y} - x)\}$$

To get the minimum value we differentiate the equation with respect to W and equate to zero.

We get $W = R_{yy}^{-1}\,R_{yx}$ which is the linear Minimum Mean Squared Error Estimator for x. R_{yy} is the covariance matrix of y equal to E $\{\overline{y}\,\overline{y}^{\,T}\}$ and R_{yx} is the cross co-variance matrix of x and y equal to E$\{\overline{y}\,\overline{x}^{\,T}\}$. After substituting the value of $\overline{y}$ in E $\{\overline{y\,y}^{\,T}\}$ and E $\{\overline{y\,x}^{\,T}\}$, we find the value of R_{yy}^{-1} R_{yx} as

$$R_{yy}^{-1} = (P_d H H^H + (\sigma_n)^2 I)^{-1}$$

$$R_{yx} = P_d H$$

Hence,

$$\hat{x}_{MMSE} = P_d H^H (P_d H H^H + (\sigma_n)^2 I)^{-1}\overline{y}$$

Where P_d is the transmit power and σ_n is the noise power.

When, $P_d >> (\sigma_n)^2$,

$$\hat{x}_{MMSE} = (HH^H)^{-1} H^H \overline{y}$$

So at high SNR, MMSE is equivalent to ZF receiver.

When, $P_d << (\sigma_n)^2$

$$\hat{x}_{MMSE} = P_d H^H ((\sigma_n)^2)^{-1} \bar{y}$$

So at low SNR, MMSE is equivalent to Matched Filter receiver.

For a SISO system H is scalar (h). Hencc,

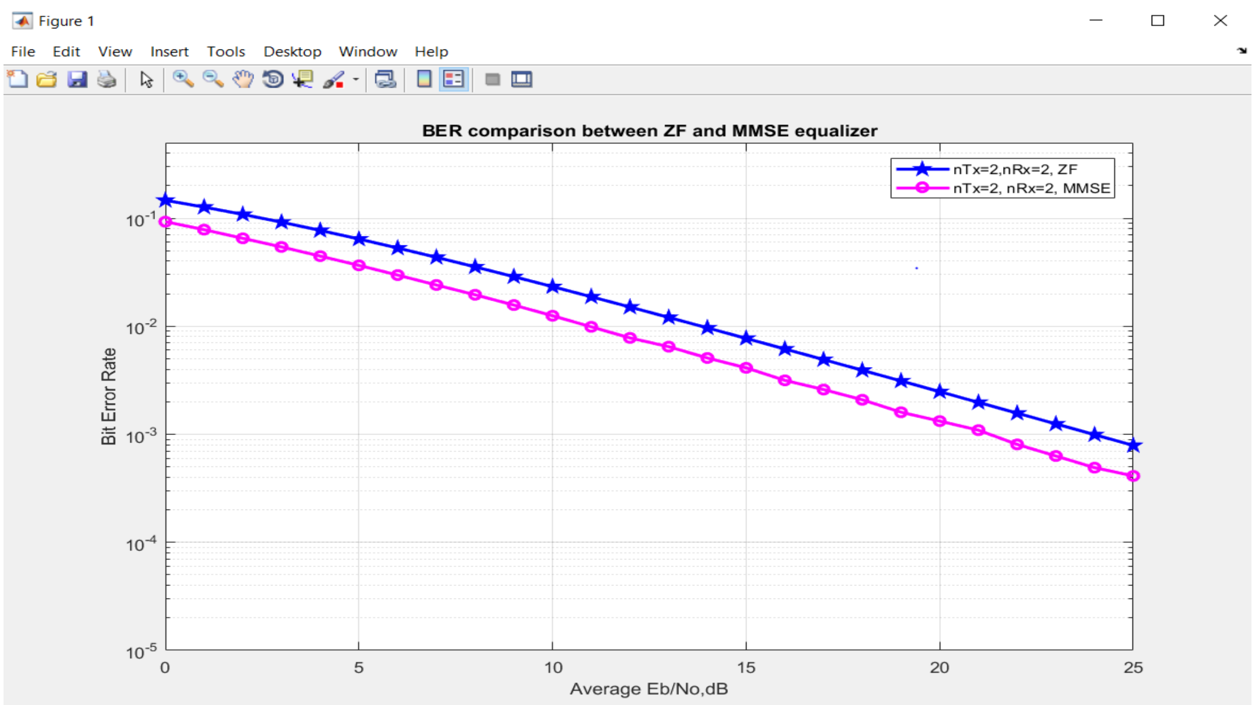
$$\hat{x}_{MMSE} = P_d \left(\frac{h^*}{P_d |h|^2 + (\sigma_n)^2} \right) \bar{y}$$

For a small channel response, $|h|^2$ is negligible.

$$\hat{x}_{MMSE} = P_d \left(\frac{h}{(\sigma_n)^2} \right) \bar{y}$$

Hence, noise amplification is not an issue in MMSE as compared to ZF.

BER comparison between Zero Forcing and MMSE equalizer:



Using Matlab, we compared ZF and MMSE equalizer. We assumed channel to be Rayleigh flat fading channel and modulation is BPSK. Simulation results showed that using MMSE algorithm instead of Zero forcing gave an improvement of 3dB.

Successive Interference Cancellation

SIC is an enhancement to MMSE BER performance. It is basically an algorithm used to manipulate the values by just approximating the values of the estimated power at the Access Point. There are various signals which are flowing through the end of the receiver, amongst which the signal with the maximum power intensity is selected and is detected. This signal is least interfered by others. The selected signal is then subtracted from the mix signals which are carrying relative frequencies. By this process, the following second highest signal is selected. The same process is carried on unless the lowest STA is detected, and the output is shown. It is more accurate than Zero Forcing and MMSE.

Mathematical model is proposed for MU-MIMO system which contains downlink scheme using SIC. We consider a complex lattice matrix for our calculations purpose for SIC proposed model where x and j are vectors and k are the number of users with single antenna at the transmitter end. We take the log of complex matrix function and calculate the x and j vectors depending upon number of users k.

$$\Lambda 1[xk,j\ ] = \log P(xk,j = +1|\boldsymbol{r})\ P(xk,j = -1|\boldsymbol{r})\ ,$$

Using Baye's rule,

$\Lambda 1(xk,j\ )$ can be rewritten as $\Lambda 1[xk,j\ ] = \log P(\boldsymbol{r}|xk,j = +1)\ P(\boldsymbol{r}|xk,j = -1) + \log P(xk,j = +1)\ P(xk,j = -1)$

$$\lambda 1[xk,j\ ] + \lambda p\ 2[xk,j\ ],\ k = 1, . .$$

So if we calculate the value at receiver for highest non disturbed signal when k=1 (number of user) we get,

$$\lambda p\ 2[xk, \mathrm{j}] = \log P\ (xk,=+1)\ P\ (xk,j=-1)$$

This is the MAP decoder by k users which is the highest pure power signal at receiver. The Simulation considers the feedback diversity a decent variety by utilizing various chosen constellation points grouping focuses as the competitors when a past choice is resolved of insignificance.

Keeping in mind the end goal to locate the optimal feedback, a choice algorithm is presented. This algorithm keeps the pursuit space from developing exponentially. The unwavering quality of the past distinguished image is controlled by the SIC, which spares the computational multifaceted nature by keeping away from excess handling.

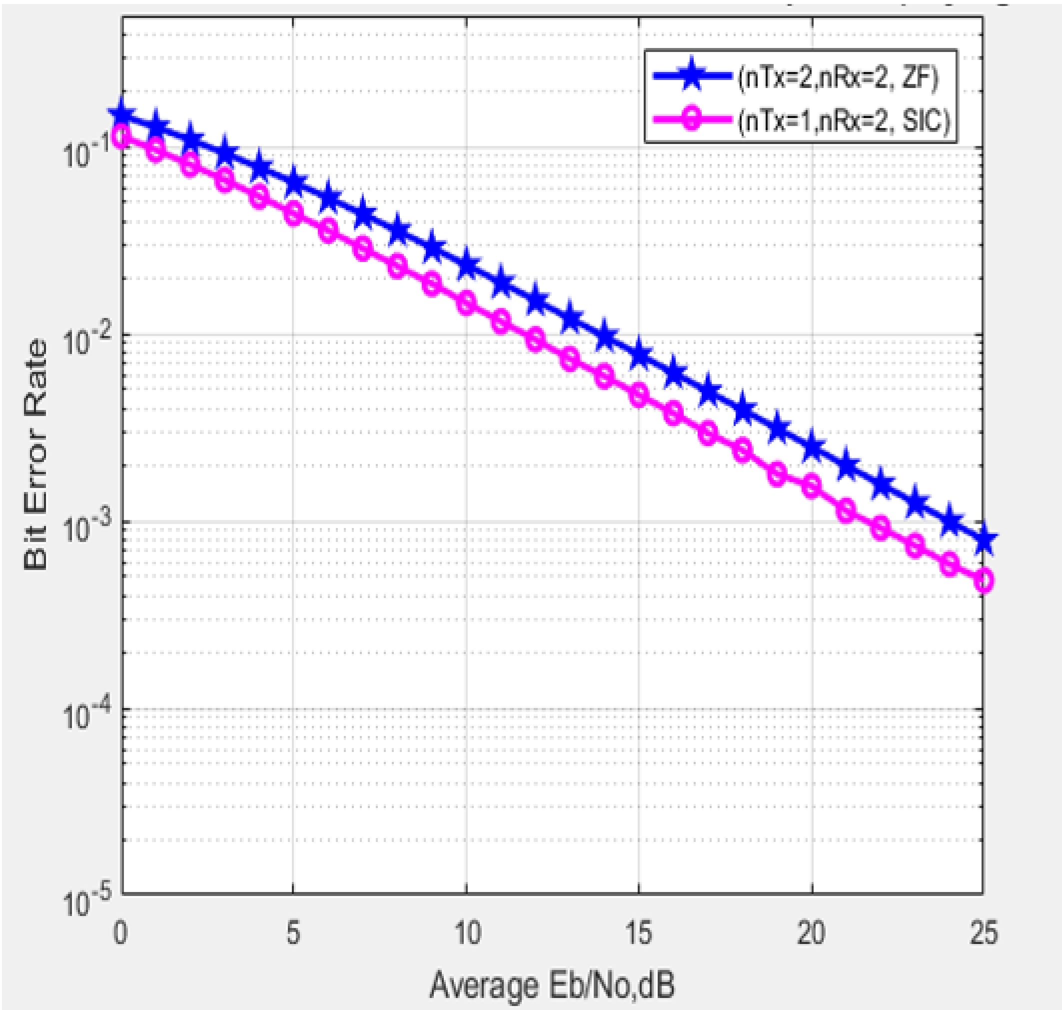


Fig. BER for BPSL modulation with 2x2 MU-MIMO and ZF-SIC equalizer

The output shows better reliability and BER (bit error rate) for SIC as compared to ZF and MMSE. In simulation, there are 2 transmitters and 2 receivers for ZF, whereas for SIC there is 1 transmitter and 2 receivers.

DIRTY PAPER CODING

A nonlinear precoding scheme introduced by costa which is used to achieve high performance at the cost of more calculations. The output is a set of infinite code words. The idea is to add a negative value of interference to any of the access point. Access point has to know about the interference beforehand. Through Simulation, as the number of users increase, the BER decreases significantly. In MU-MIMO, base station should perform pre-equalization. Received signal can be simplified by adding Precoding matrix and channel matrix.Whole value multiplied by transmitted symbols.

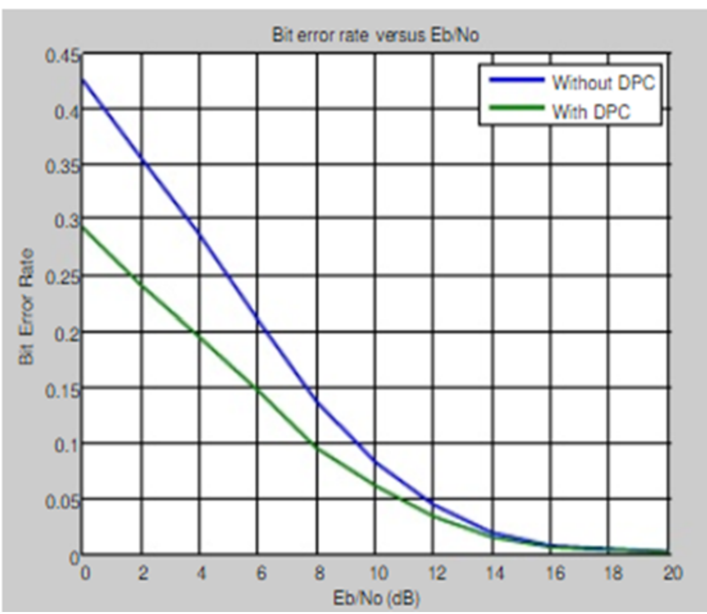
For user1,
$y_1= (h_{11}b_{11}+h_{12}b_{21}+h_{13}b_{31})\ u_1 + (h_{11}b_{12}+h_{12}b_{22}+h_{13}b_{32})\ u_2 + (h_{11}b_{13}+h_{12}b_{23}+h_{13}b_{33})\ u_3.$
Where, h= channel matrix, b=precoding matrix and u= transmitted symbols

DPC performs a scale of inverse matrix which is of lower triangular matrix. This output is obtained from channel gain matrix. It basically increases spectral efficiency.

Following are the steps which can be performed to understand DPC calculations better.

- Choose a codeword for user1.
- Treat the codeword as an interference
- Pick signal for user2 using precoding.
- Now, receiver experiences no interference at all.
- From formula, H=LQ where Q is unitary matrix
- Use LQ-decomposition of channel matrix.

The result is a code of infinite length words with output obtained at simulation.



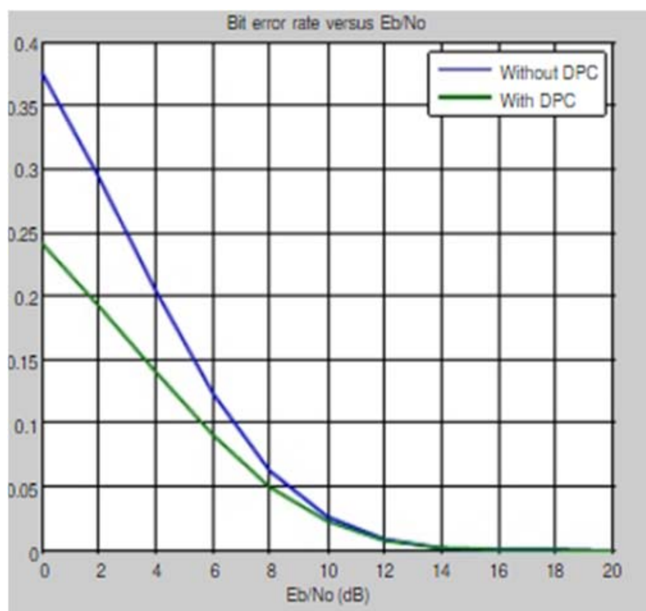


Figure 1 BER rate when number of users is 10

Figure 2 BER rate when number of users is 30

From this output, we can see that DPC is effective for calculating and reducing BER rate as the number of user increases through above calculations and simulations.

References

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