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Performance analysis of different types of decoders for MIMO technique in wireless communication

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Abstract
In Wireless Communication, data transition is done through radio waves. Different standards had developed to improve the signal strength and BER of the signal. So, MIMO has the high demand after the 3G network and used by millions of people in the world for data sending and receiving purpose. Because of higher bandwidth the data transmission is in large amount. In this paper we had studied the MIMO system with different types of decoders. Through alamouti algorithm we had transmitted the signal through multiple antennas in different time instant and with the help of Rayleigh channel noise we had added noise in the signal and with the help of different types of decoders like ZF, MMSE, MRC, ML we had compared the BER of the signal and find out the decoder with better performance the others.

Keywords: BER, STBC, ZF, MMSE, MRC, ML

1. Introduction
In Wireless Communication the data which is transmitted through antenna has a wireless medium. The first technology used for transition of data from one medium to another medium through antenna was 1G technology which was the first technology in 1970s .It was a cellular technology and it is used for analogy cellular telephone. Disadvantage of this system was that as the users increased the signal strength was decreased, cross connection problem was there. After that 2G technology was introduced in 1990s it was GSM technology, it was the advance version of 1G technology. In 1G only Analogy call can be placed, but in 2G digital modulation was used because of which area was covered more, voice quality was improved. 2G network uses digital signal for communication and 64kbps is the data speed. The drawback of 2G network, system are unable to handle complex data such as videos. But 2G also had some limitations the speed of data transition was less so problem facing was if data transmitted was in larger size then it takes time to transmit and error probability was more. So, 3G technology was invented so that user can use the audio, video, data, files for transmitting from one medium to other medium. 3G signal gives the speed of 2Mpbs, and can transmit large file with high speed as compared to 1G, 2G network. But as the users increases the speed get decrease, the quality of signal becomes poor. For this reasons 4G signal was introduced with high speed, better bandwidth and signal strength was comparatively better than other technology. 4G which was invented late 2000s and had speed of 100Mbps-1Gbps. It provide high speed, high capacity, high security and high quality of service. It provide end to end IP solution where data, voice and streamed multimedia can be served to user on an anytime, anywhere Basis at higher data rates than previous generations The technique use in 1G, 2G, 3G technology was only signal antennas was used in transmitter side and at receive side.
But in 4G technology multiple antennas are used on transmitter and receiver side. The transmitter side had n number of antenna to transmit the data and at the receiver side it contains n- number of antenna to receive the data. So this type of transition and receiving system is known as MIMO system. As shown in the figure below.

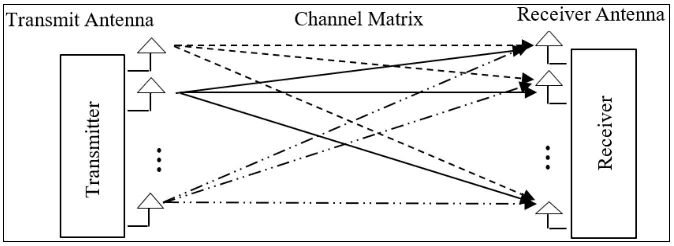

Fig 1. MIMO System for n transmitting and receiving antennas.

At each and every time instance data is transmitted through different antennas and is received. The data is transmitted in small sample through different antennas while transmitting the signal the duplicate data is also transmitted so the utilization of bandwidth is not maximum. MIMO has lager bandwidth is 20MHz per channel, therefore fading in the signal is less. In this paper we had taken different dimension of matrix as an input and transmitted through different antennas through Alamouti code. And by using different decoder we had compared BER of that decoder. By checking the BER we can evaluate the performance of various decoders in MIMO system.

Table 1: 2-Transmiting and 2-Receving Antennas

	T	t+T
Antenna 1	x_1	$-x_2^*$
Antenna 2	x_2	x_1^*

MIMO system is also known as long term evolution which has higher capacity and it provide high bitrate also cost efficient. So to calculate the BER of the signal of different types of decoders we had consider first only for small dimension matrix .i.e. for 3×3 matrix. So the Alamouti code for 3×3 matrix is:

$$\left[\begin{array}{cccc:cccc} x_1 & x_2 & x_3 & x_4 & x_1^* & x_2^* & x_3^* & x_4^* \\ -x_2 & x_1 & -x_4 & x_3 & -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3 & x_4 & x_1 & -x_2 & -x_3^* & x_4^* & x_1^* & -x_2^* \\ -x_4 & -x_3 & x_2 & x_1 & -x_4^* & -x_3^* & x_2^* & x_1^* \end{array}\right]$$

As the dimension of matrix changes, the symbol to be transmitted at each time instance is also changes, so we cannot define any standard format of Alamouti matrix. For 8×8 matrix the Alamouti code is:

$$\left[\begin{array}{cccccccc:cccccccc} x_1 & x_2 & x_3 & x_4 & x_5 & x_6 & x_7 & x_8 & x_1^* & x_2^* & x_3^* & x_4^* & x_5^* & x_6^* & x_7^* & x_8^* \\ -x_2 & x_1 & x_4 & -x_3 & x_6 & -x_5 & -x_8 & x_7 & x_2^* & x_1^* & x_4^* & -x_3^* & x_6^* & -x_5^* & -x_8^* & x_7^* \\ -x_3 & -x_4 & x_1 & x_2 & x_7 & x_8 & -x_5 & -x_6 & -x_3^* & -x_4^* & x_1^* & x_2^* & x_7^* & x_8^* & -x_5^* & -x_6^* \\ -x_4 & x_3 & -x_2 & x_1 & x_8 & -x_7 & x_6 & -x_5 & -x_4^* & x_3^* & -x_2^* & x_1^* & x_8^* & -x_7^* & x_6^* & -x_5^* \\ -x_5 & -x_6 & -x_7 & -x_8 & x_1 & x_2 & x_3 & x_4 & -x_5^* & -x_6^* & -x_7^* & -x_8^* & x_1^* & x_2^* & x_3^* & x_4^* \\ -x_6 & x_5 & -x_8 & x_7 & -x_2 & x_1 & -x_4 & x_3 & -x_6^* & x_5^* & -x_8^* & x_7^* & -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_7 & x_8 & x_5 & -x_6 & -x_3 & x_4 & x_1 & -x_2 & -x_7^* & x_8^* & x_5^* & -x_6^* & -x_3^* & x_4^* & x_1^* & -x_2^* \\ -x_8 & -x_7 & x_6 & x_5 & -x_4 & -x_3 & x_2 & x_1 & -x_8^* & -x_7^* & x_6^* & x_5^* & -x_4^* & -x_3^* & x_2^* & x_1^* \end{array}\right]$$

As at the input we had taken the matrix of different dimension and at the receiver side we have 4 different types of decoder they are ZF, MMSE, MRC, ML by comparing its BER we can analyze the performance of decoders which had received the signal with minimum error and less BER. MMSE had less BER and with less fading in the signal. It minimizes the MSE (mean square error) which is used to measure the average of the square of the error. It considers the estimate value of the signal. ZF decoder is better performer than ML and MRC, it is pseudo inverse which had output exactly inverse of input. ML and MRC had higher BER rate and fading effect is more and can be observed in the output graphs. Maximum Ratio Combining (MRC) can restore a signal to its original shape. Maximum Likelihood Estimation (MLE) is a method of estimating the parameters of a statistical model given observations, by finding the parameter values that maximize the likelihood of making the observations given the parameters.

2. Methology

2.1 For MIMO system (Alamouti code)

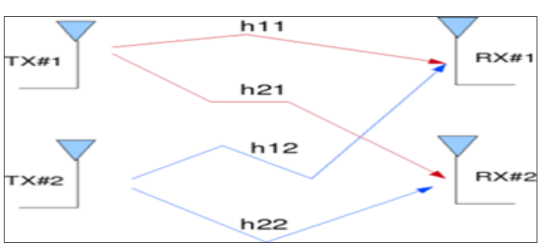

Fig 2: 2 Transmit and 2 Receive (2×2) MIMO system

From the above figure, in the first time slot the received signal on the first receive antenna is,

$$y_1 = h_{11}x_1 + h_{12}x_2 = [h_{11} \;\; h_{12}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \tag{1}$$

And at the second time slot the receiver signal on the second antenna is,

$$y_2 = h_{21}x_1 + h_{22}x_2 = [h_{21} \;\; h_{22}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \tag{2}$$

Where:

y_1 And y_2 are the received symbol on the first and second antenna respectively,

h_{11} Is the channel from 1 transmit antenna to 1 receive antenna,

h_{12} Is the channel from 2 transmit antenna to 1 receive antenna,

h_{21} Is the channel from 1 transmit antenna to 2 receive antenna,

h_{22} Is the channel from 2 transmit antenna to 2 receive antenna,

x_1,x_2 are the transmitted symbols and

n_1 , n_2 is the noise on 1 and 2 receive antennas.

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{3}$$

$$y = H\,x + n \tag{4}$$

2.2 For Zero Forcing Decoder (ZF)

The Zero Forcing equalizer is the pseudo inverse of the channel matrix. Hence, the zero forcing equalizer is purely a function of the channel state or the channel matrix from figure 3.

$$W = \min ||y - Hx||^2 \tag{5}$$

Let W be the received signal vector,

$$W = (y - Hx)^H \, (y - Hx)$$

By multiplying the above equations we get,\

$$W = \bar{y}\bar{y}^H - \bar{x}^H H^H \bar{y} - \bar{y}^H H\bar{x} + \bar{x}^H H^H H\bar{x}$$

Where,

$$\bar{y}\bar{y}^H = 0$$

$$H^H\bar{y} = constant$$

$$W = 0 - H^H\bar{y} - H^H\bar{y} + H^H H\bar{x} + H^H H\bar{x}$$

$$W = -2(H^H\bar{y} + H^H H\bar{x})$$

So, differentiating each component with x, we get

$$\frac{d||\bar{y}-H\bar{x}||^2}{d\bar{x}} = -2H^H\bar{y} + 2H^H H\bar{x}$$

$$-2H^H\bar{y} + 2H^H H\bar{x} = 0$$

$$H^H H\bar{x} = H^H\bar{y}$$

$$\bar{x} = (H^H H)^{-1} H^H \bar{y}$$

.i.e.

$$\bar{x} = (H^H H)^{-1} H^H \bar{y} \quad (6)$$

This is the estimate of H. This is not the exact solution but the approximate solution. $\bar{x}$ is the approximate solution that minimizes the least square error.

So, the above equation is known as the zero forcing receiver,

$$W = (H^H H)^{-1} H^H \quad (7)$$

2.3 For Minimum Mean Square Error (MMSE)

The MMSE criterion is formulated as shown in equation below -

$$\min[E\{|W_{mmse}\, y - x|\}]$$

$$\min[E\{(Wy - x)(Wy - x)^H\}]$$

$$\min[E(Wy - x)(W^H y^H - x^H)]$$

$$\min[E\{Wyy^H W^H - Wyx^H - xy^H W^H + xx^H\}]$$

$$\min(WR_{yy}W^H - WR_{yx} - R_{xy}W^H + R_{xx})$$

R_{yy} and R_{xx} represents the auto-correlation of the x and y, respectively. R_{xy} and R_{yx} are cross-correlation of the x and y, respectively. The minima of a function with respect to a variable can be found by partial differential of the function set to zero.

$$\frac{\partial\,(WR_{yy}W^H - WR_{yx} - R_{xy}W^H + R_{xx})}{\partial W} = 0$$

$$\frac{\partial T^H V T}{\partial T} = V^H T + VT$$

Using above equation,

$$W = R_{yy}^{-1} R_{xy}$$

$$R_{yy} = E\{yy^H\}$$

$$R_{yy} = E\{(HX + N)(HX + N)^H\}$$

$$R_{yy} = (HH^H + N_0 I)$$

$$R_{xy} = E(xy^H)$$

$$R_{xy} = E(x(HX + N)^H)$$

$$R_{xy} = H^H$$

$$W = (HH^H + N_0 I)^{-1} H^H$$

So, the coefficient W which minimize the criteria,

$$W = [H^H H + N_0 I]^{-1} H^H \quad (8)$$

Where:

I= Identity Matrices

$$I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \begin{pmatrix} 1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{pmatrix}$$

$$N_0 = \frac{1}{SNR}$$

2.4 For Maximum Ratio Combining (MRC)

From equation 3-

For the i^{th} receive antenna, the receive signal is,

$$y_i = H_i\, x + n_i$$

Where,

y_i is the received symbol on the i^{th} receive antenna,
H_i is the channel on the i^{th} receive antenna,
x is the transmitted symbol
n_i is the noise on i^{th} receive antenna.

$$W = H^H y$$

So, the Maximum ratio combining (MRC) estimator is given as,

$$W = H^H(Hx + n) = H^H Hx + H^H n \quad (9)$$

2.5 Maximum likelihood Estimator (ML)

From equation 3,

$$y = Hx + n$$

So, the maximum likelihood estimator is given as,

$$W = \min ||y - Hx||^2 \quad (10)$$

Where,

Y is the received symbol for the received antenna
x is the transmitted symbol for the transmit antenna
H is the channel matrix

From equation 10, we get

$$W = x^H G x - 2Re(yHx) + ||y||^2 \quad (11)$$

Where,

$$G = H^H H$$

3. Result

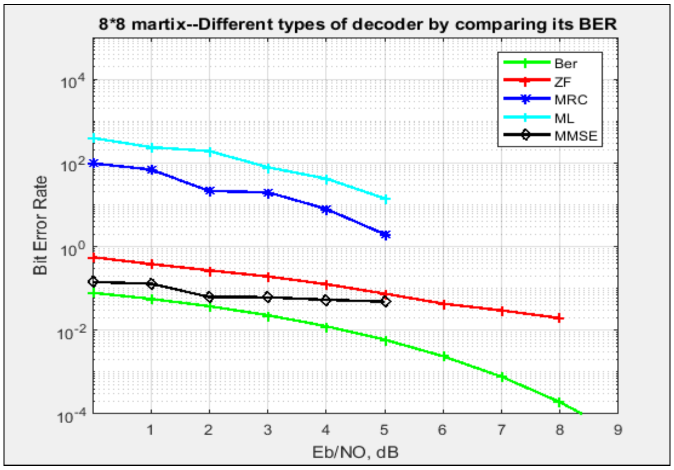

Fig 3

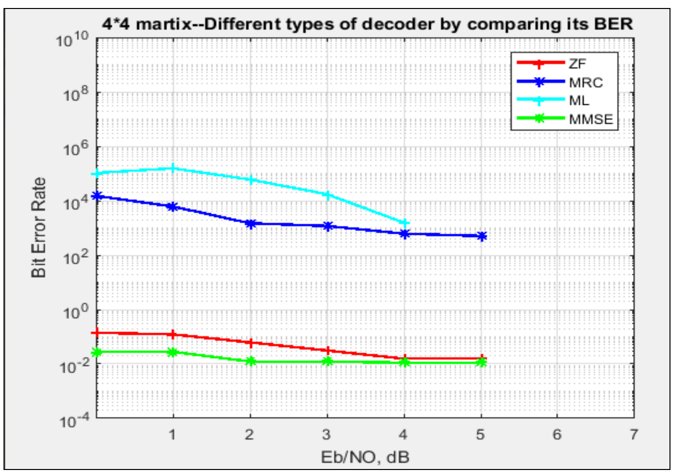

Fig 4

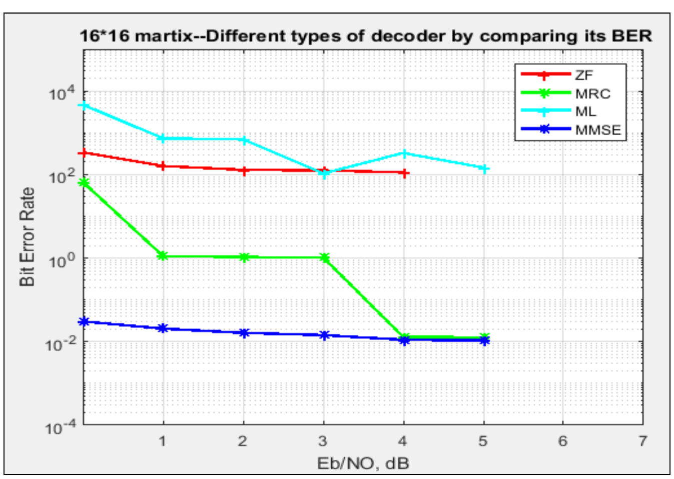

Fig 5

4. Conclusion

In this paper we have performed the analysis of different types of decoder by measuring its BER, by Alamouti approach. By analyzing the result of different matrix dimension we had concluded that the performance of MMSE decoder is better than ZF and ML and MRC Decoder is the worst performer than all the decoder by analyzing BER. MRC is worst because of high BER and fading in the signal.

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