BER ANALYSIS OF 2X2 MIMO SPATIAL MULTIPLEXING UNDER AWGN AND RICIAN CHANNELS FOR DIFFERENT MODULATIONS TECHNIQUES

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ABSTRACT

Multiple-input–multiple-output (MIMO) wireless systems use multiple antennas at transmitting and receiving end to offer improved capacity and data rate over single antenna systems in multipath channels. In this paper we have investigated the Spatial Multiplexing technique of MIMO systems. Here different fading channels like AWGN and Rician are used for analysis purpose. Moreover we analyzed the technique using high level modulations (i.e. M-PSK for different values of M). Detection algorithms used are Zero-Forcing and Minimum mean square estimator. Performance is analyzed in terms of BER (bit error rate) vs. SNR (signal to noise ratio).

KEYWORDS

Spatial Multiplexing (SM), Additive White Gaussian Noise (AWGN), Multiple Input Multiple Output (MIMO), Bit error rate (BER).

1. INTRODUCTION

Multiple antenna systems (MIMO) attract significant attention due to their ability of resolving the bottleneck of traffic capacity in wireless networks. MIMO systems are illustrated in Figure 1. The idea behind MIMO is that the signals on the transmitting (Tx) antennas and the receiving (Rx) antennas are combined in such a way that the quality (bit-error rate or BER) or the data rate (bits/sec) of the communication for each MIMO user will be improved. Such an advantage can be used to increase the network's quality of service. In this paper, we focus on the Spatial Multiplexing technique of MIMO systems.

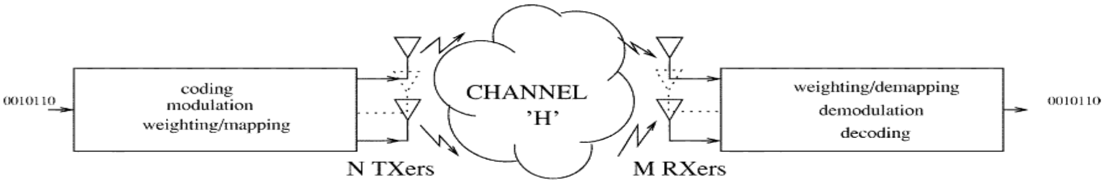

Figure 1.Diagram of MIMO wireless transmission system . Transmitter and receiver are equipped with multiple antennas

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Spatial multiplexing is a transmission technique in MIMO wireless communication system to transmit independent and separately encoded data signals, called as streams, from each of the multiple transmit antennas. Therefore, the space dimension is reused or multiplexed more than one time. If the transmitter and receiver has N_t and N_r antennas respectively, the maximum spatial multiplexing order (the number of streams) is

$$N_S = \min (N_t, N_r) \tag{1}$$

The general concept of spatial multiplexing can be understood using MIMO antenna configuration. In spatial multiplexing, a high data rate signal is divided into multiple low rate data streams and each stream is transmitted from a different transmitting antenna. These signals arrive at the receiver antenna array with different spatial signatures, the receiver can separate these streams into parallel channels thus improving the capacity. Thus spatial multiplexing is a very powerful technique for increasing channel capacity at higher SNR values. The maximum number of spatial streams is limited by the lesser number of antennas at the transmitter or receiver side. Spatial multiplexing can be used with or without transmit channel knowledge.

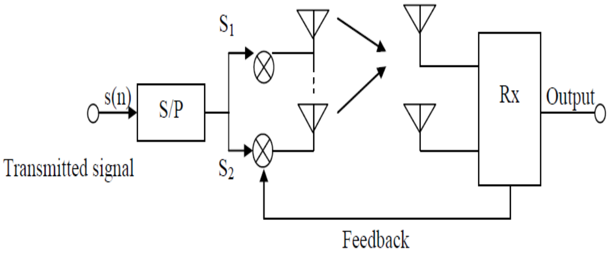

Figure 2.Spatial Multiplexing Concept

MIMO spatial multiplexing achieves high throughput by utilizing the multiple paths and effectively using them as additional channels to carry data such that receiver receives multiple data at the same time. The tenet in spatial multiplexing is to transmit different symbols from each antenna and the receiver discriminates these symbols by taking advantage of the fact that, due to spatial selectivity, each transmit antenna has a different spatial signature at the receiver . This allows an increased number of information symbols per MIMO symbol. In any case for MIMO spatial multiplexing, the number of receiving antennas must be equal to or greater than the number of transmit antennas such that data can be transmitted over different antennas. Therefore the space dimension is reused or multiplexed more than one time. The data streams can be separated by equalizers if the fading processes of the spatial channels are nearly independent. Spatial multiplexing requires no bandwidth expansion and provides additional data bandwidth in multipath radio scenarios [2].

2. MIMO SYSTEM

In MIMO system we use multiple antennas at transmitter and receiver side, they are extension of developments in antenna array communication. There are three categories of MIMO techniques. The first aims to improve the reliability by decreasing the fading through multiple spatial paths. Such technique includes STBC and STTC. The second class uses a layered approach to increase capacity. One popular example of such a system is V-BLAST suggested by Foschini et al. [2].

Finally, the third type exploits the knowledge of channel at the transmitter. It decomposes the channel coefficient matrix using SVD and uses these decomposed unitary matrices as pre- and post-filters at the transmitter and the receiver to achieve near capacity [3].

2.1. Benefits of MIMO system

MIMO channels provide a number of advantages over conventional Single Input Single Output (SISO) channels such as the array gain, the diversity gain, and the multiplexing gain. While the array and diversity gains are not exclusive of MIMO channels and also exist in single-input multiple-output (SIMO) and multiple-input single-output (MISO) channels, the multiplexing gain is a unique characteristic of MIMO channels. These gains are described in brief below:

2.2.1 Array Gain

Array gain is the average increase in the SNR at the receiver that arises from the coherent combining effect of multiple antennas at the receiver or transmitter or both. Basically, multiple antenna systems require perfect channel knowledge either at the transmitter or receiver or both to achieve this array gain.

2.2.2 Spatial Diversity Gain

Multipath fading is a significant problem in communications. In a fading channel, signal experiences fade (i.e they fluctuate in their strength) and we get faded signal at the receiver end. This gives rise to high BER. We resort to diversity to combat fading. This involves providing replicas of the transmitted signal over time, frequency, or space.

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2.2.3 Spatial Multiplexing Gain

Spatial multiplexing offers a linear (in the number of transmit-receive antenna pairs or min (MR, MT) increase in the transmission rate for the same bandwidth and with no additional power expenditure. It is only possible in MIMO channels. Consider the cases of two transmit and two receive antennas. The stream is split into two half-rate bit streams, modulated and transmitted simultaneously from both the antennas. The receiver, having complete knowledge of the channel, recovers these individual bit streams and combines them so as to recover the original bit stream. Since the receiver has knowledge of the channel it provides receive diversity, but the system has no transmit diversity since the bit streams are completely different from each other in that they carry totally different data. Thus spatial multiplexing increases the transmission rates proportionally with the number of transmit-receive antenna pairs.

2.3 Modulation

Modulation is the process of mapping the digital information to analog form so it can be transmitted over the channel. Modulation of a signal changes binary bits into an analog waveform. Modulation can be done by changing the amplitude, phase, and frequency of a sinusoidal carrier. Every digital communication system has a modulator that performs this task. Similarly we have a demodulator at the receiver that performs inverse of modulation. There are several digital modulation techniques used for data transmission.

2.3.1 Phase Shift Keying

Phase-shift keying (PSK) is a digital modulation scheme that conveys data by modulating, the phase of a reference signal (the carrier wave). In M-ary PSK modulation, the amplitude of the transmitted signals is constrained to remain constant, thereby yielding a circular constellation. Modulation equation of M-PSK signal is:

$$s_i(t) = \sqrt{\frac{2E_S}{T}}\cos\left(2\pi f_c t + \frac{2\pi i}{M}\right) \qquad \text{i=0,1....,M} \tag{2}$$

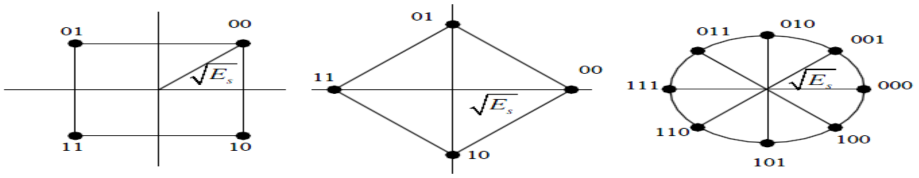


Figure 3.Constellation Diagrams of M-PSK
(a) QPSK (b) QPSK (c) 8-PSK

2.4 Channels

Channel is transmission medium between transmitter and receiver. Channel can be wired or wireless. In wireless transmission we use air or space as medium and it is not as smooth as wired transmission since the received signal is not only coming directly from the transmitter, but the combination of reflected, diffracted, and scattered copies of the transmitted signal. These signals are called multipath components. AWGN and Rician channels are taken into consideration for the analysis.

2.4.1 AWGN Channel

AWGN channel is universal channel model for analyzing modulation schemes. In this model, a white Gaussian noise is added to the signal passing through it. Fading does not exist. The only distortion is introduced by the AWGN. AWGN channel is a theoretical channel used for analysis purpose only. The received signal is simplified to:

$$y(t)=x(t)+n(t) \tag{3}$$

where n(t) is the additive white Gaussian noise.
y(t) is the received signal
x(t) is the input signal

2.4.2 Rician Channel

The direct path component is the strongest component that goes into deep fades compared to multipath components when there is line of sight. Such signal is approximated with the help of Rician distribution. The received signal can be simplified to:

$$y(t)=x(t)*h(t)+n(t) \tag{4}$$

where h(t) is the random channel matrix having Rician distribution and n(t) is the additive white Gaussian noise.

The Rician distribution is given by:

$$P(r) = \frac{r^2}{\sigma^2} e^{\left(-\frac{r^2+A^2}{\sigma^2}\right)} I_0\left(\frac{A_r}{\sigma^2}\right) \quad \text{for } (A \geq 0, r \geq 0) \tag{5}$$

where A denotes the peak amplitude of the dominant signal and $I_O[.]$ is the modified Bessel function of the first kind and zero-order.

2.5 Detection Techniques

There are numerous detection techniques available with combination of linear and non-linear detectors. The most common detection techniques are ZF, MMSE and ML detection technique. The generalized block diagram of MIMO detection technique is shown in Figure 4.

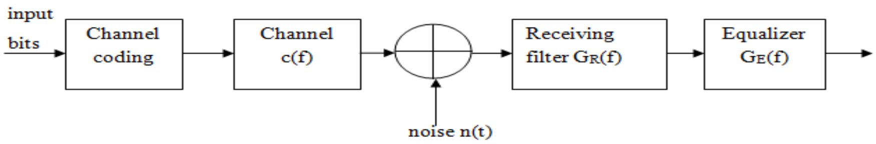


Fig. 4 Block Diagram of system with equalizer

2.5.1 Zero Forcing (ZF) Detection

The ZF is a linear estimation technique, which inverse the frequency response of received signal, the inverse is taken for the restoration of signal after the channel. The estimation of strongest transmitted signal is obtained by nulling out the weaker transmit signal. The strongest signal has been subtracted from received signal and proceeds to decode strong signal from the remaining transmitted signal. ZF equalizer ignores the additive noise and may significantly amplify noise for channel.

The basic Zero force equalizer of 2x2 MIMO channel can be modelled by taking received signal y_1 during first slot at receiver antenna as:

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = [h_{1,1} \quad h_{1,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \tag{6}$$

The received signal y_2 at the second slot receiver antenna is:

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = [h_{2,1} \quad h_{2,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \tag{7}$$

Where i=1, 2 in x_i is the transmitted symbol and i=1, 2 in $h_{i,j}$ is correlated matrix of fading channel, with j represented transmitted antenna and i represented receiver antenna, is the noise of first and second receiver antenna. The ZF equalizer is given by:

$$W_{ZF} = \left(H^H\right)^{-1} H^H \tag{8}$$

Where W_{ZF} is equalization matrix and H is a channel matrix. Assuming $M_R \geq M_T$ and H has full rank, the result of ZF equalization before quantization is written as:

$$y_{ZF} = \left(H^H H\right)^{-1} H^H y \tag{9}$$

2.5.2. Minimum Mean Square Estimator (MMSE)

Minimum mean square error equalizer minimizes the mean –square error between the output of the equalizer and the transmitted symbol, which is a stochastic gradient algorithm with low complexity. Most of the finite tap equalizers are designed to minimize the mean square error performance metric but MMSE directly minimizes the bit error rate. The channel model for MMSE is same as ZF [13],[14]. The MMSE equalization is

$$W_{MMSE} = \arg_G^{\min} E_{x,n}[\|x - x^{\wedge}\|^2] \tag{10}$$

Where is W_{MMSE} equalization matrix, H channel correlated matrix and n is channel noise

$$y_{MMSE} = H^H(HH^H + n_o I_n)^{-1} y \tag{11}$$

3. Results and Discussions

This paper analyzes the Spatial Multiplexing(SM) technique for 2x2 antenna configuration under different modulation techniques for different fading channels i.e. AWGN and Rician channels. Results are shown in the term of BER vs SNR plots.

3.1 Using ZF detection

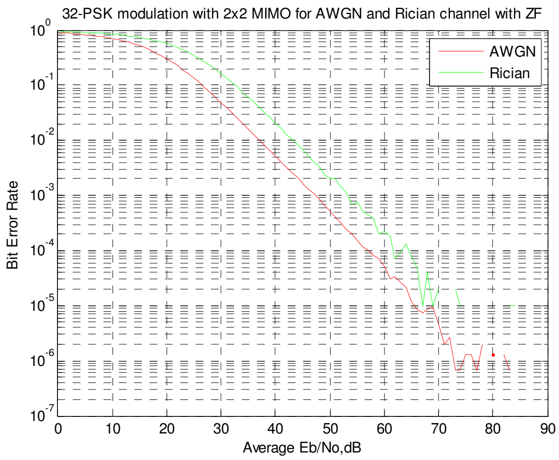


Figure 5(a).

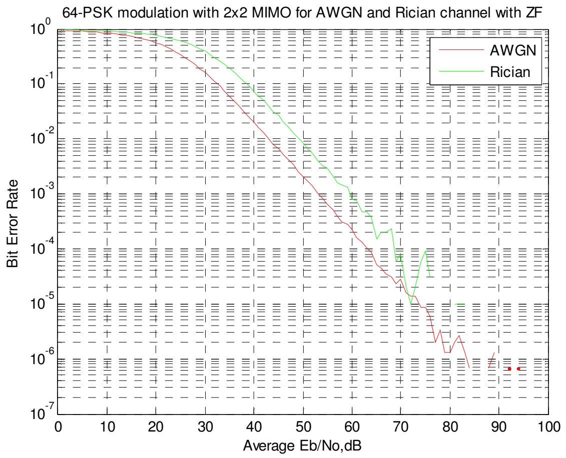
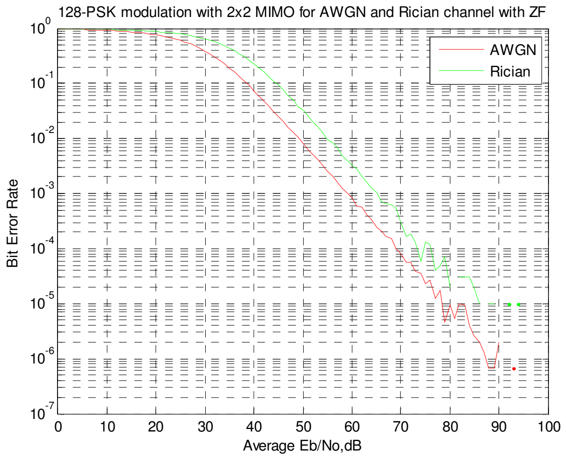


Figure 5(b).



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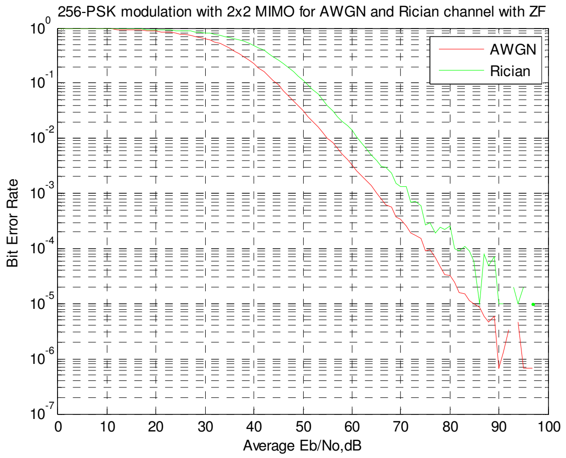

Figure 5(d).

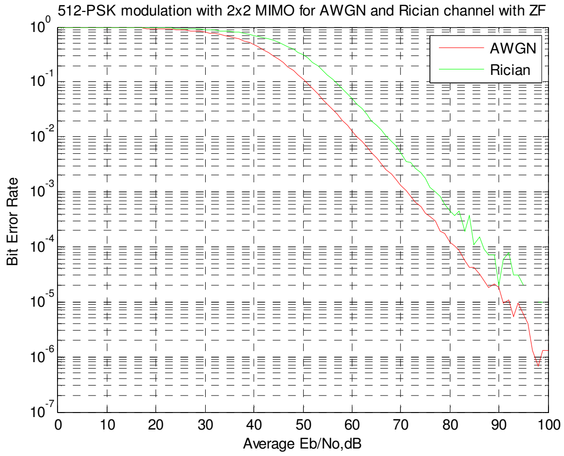

Figure 5(e).

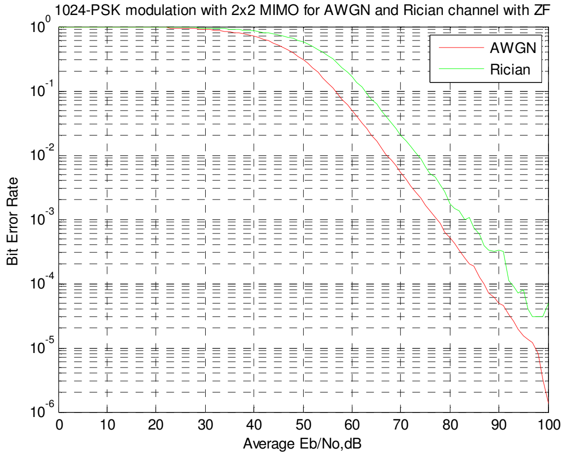

Figure 5(f).

Figure 5. BER vs. SNR plots over AWGN & Rician channel for SM technique using 2x2 MIMO System using ZF Equalization

a)32 PSK b) 64 PSK c) 128 PSK d) 256 PSK e) 512 PSK
f) 1024 PSK

Table 1. Comparison of different Modulation Techniques for Rician& AWGN Channel for 2x2 MIMO Spatial Multiplexing using ZF Equalization

Modulations	**Rician channel**	**AWGN channel**	**Improvement**
32-PSK	62dB	57dB	5dB
64-PSK	63dB	69db	6dB

128-PSK	74dB	69dB	5dB
256-PSK	81dB	75dB	6dB
512-PSK	86dB	81dB	5dB
1024-PSK	93dB	87dB	6dB

From table we depict that at 32-PSK, 128-PSK, 512-PSK there is difference of 5dB between channels and there is difference of 6dB at 64-PSK, 128-PSK and 1024-PSK at BER of 10^{-4}. Table shows the improvement in terms of decibels shown by proposed system employing SM technique for 2x2 MIMO system for different modulation schemes over different channels.

3.2 Using MMSE detection

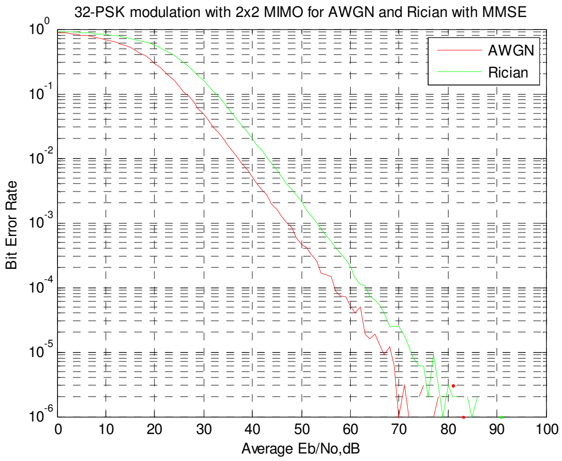

Figure 6(a).

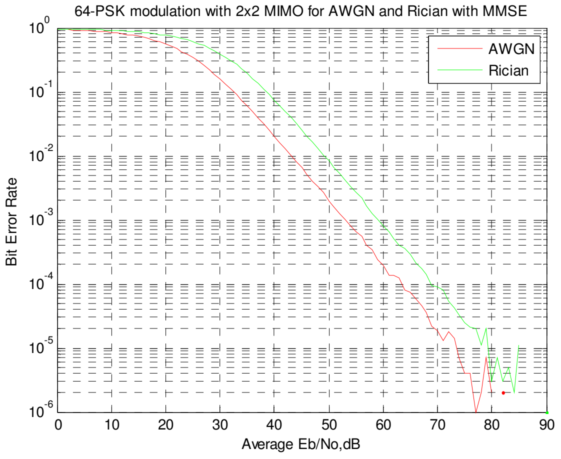

Figure 6(b).

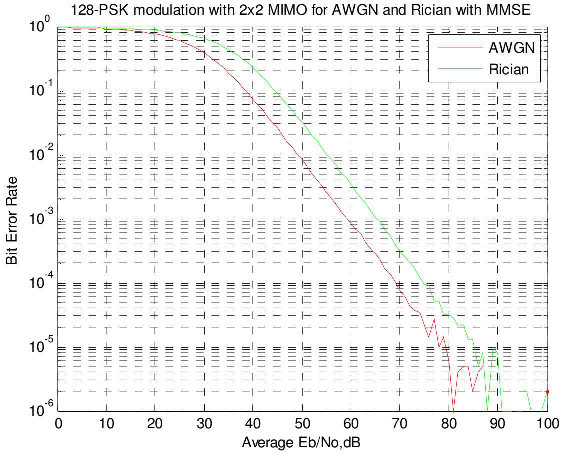

Figure 6(c).

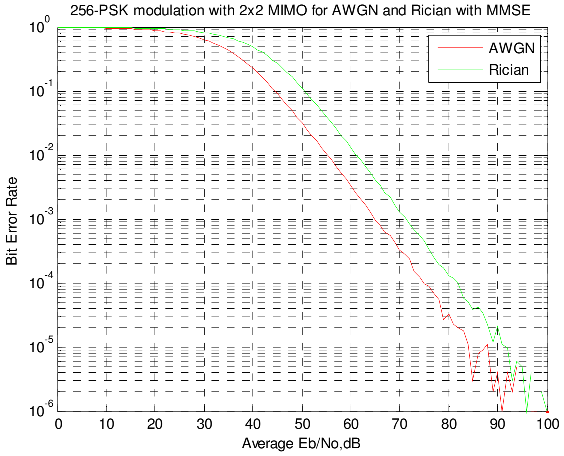

Figure 6(d).

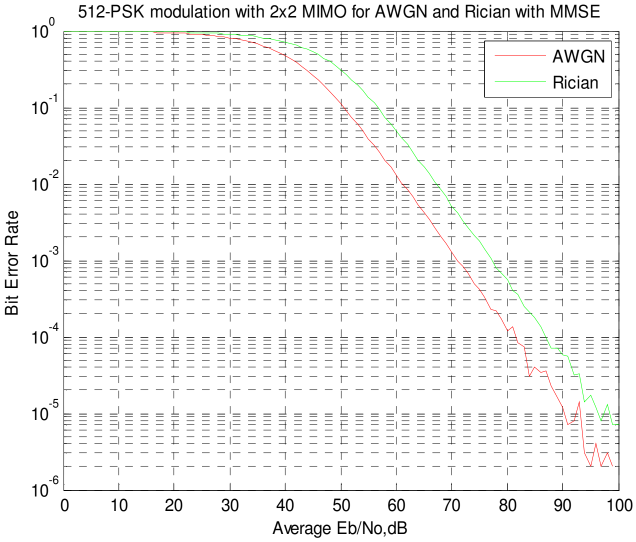

Figure 6(e)

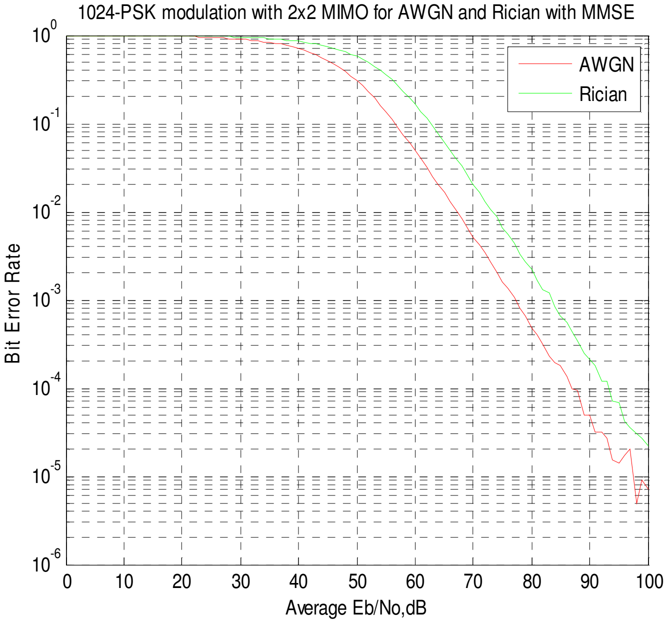

Figure 6(f)

Fig. 6 BER vs. SNR plots over AWGN & Rician channel for SM technique using 3x3 MIMO using MMSE Equalization

a) 32 PSK b) 64 PSK c) 128 PSK d) 256 PSK e) 512 PSK f) 1024 PSK

Table 2. Comparison of different Modulation Techniques for Rician &AWGN Channel for 2x2 MIMO Spatial Multiplexing using MMSE Equalization

Modulations	**Rician channel**	**AWGN channel**	**Improvement**
32-PSK	63dB	57dB	6dB
64-PSK	70dB	63dB	7dB
128-PSK	75dB	69dB	6dB
256-PSK	82dB	76dB	6dB
512-PSK	86dB	82dB	4dB
1024-PSK	93dB	87dB	6dB

It can be seen from table that at 32-PSK, 128-PSK, 256-PSK and 1024-PSK there is an improvement of 6dB. At 64-PSK and 512-PSK there is difference of 7dB and 4dB at BER of 10^{-4}. Table shows the improvement in terms of decibels shown by proposed system employing SM technique for 2x2 MIMO system for different modulation schemes over different channels.

4. CONCLUSIONS

In this paper, an idea about the performance of the MIMO-SM technique at higher modulation levels is presented. We implemented 2x2 antenna configuration and used different signal detection technique at receiver end. It can be concluded BER is greater in Rician channel as compared to AWGN channel.

Also BER (bit error rate) increases as the order of the modulation order i.e. M increases. This increase is due to the fact that as the value of M increases distances between constellation points decreases which in turn makes the detection of the signal corresponding to the constellation point much tougher The solution to this problem is to increase the value of the SNR so, that the effect of the distortions introduced by the channel will also goes on decreasing, as a result of this, the BER will also decreases at higher values of the SNR for high order modulations.

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