Performance Comparison of MIMO Systems over AWGN and Rician Channels using OSTBC3 with Zero Forcing Receivers

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Abstract – Multiple-Input Multiple-Output (MIMO) wireless antenna systems are being recognized as a key technology for future wireless communications. In the present wireless systems, high data rates can be achieved due to the spatial diversity. In this paper, the performance of MIMO system over AWGN and Rician fading channels using OSTBC3 with Zero Forcing (ZF) receiver is analyzed using different antenna configurations. Thus MIMO systems take advantage of spatial diversity by employing multiple antennas at transmitter and receiver and thus the performance can be improved. The Bit Error Rate (BER) is analyzed for M-PSK modulation over AWGN and Rician Channels using OSTBC3 and effects of the antenna selection is also presented in the paper using simulated results.

Keywords – Multiple-Input Multiple-Output (MIMO), Additive White Gaussian Noise (AWGN), Rician, OSTBC3, spatial diversity, Zero Forcing (Zero Forcing), Bit Error Rate (BER), M-ary Phase Shift Keying (M-PSK), fading.

I. INTRODUCTION

In the wireless communications, the high data rates can be achieved by using the MIMO systems. The MIMO system makes use of multiple antennas at the transmitter and receiver. The performance can be improved through diversity compared to single antenna systems [1]. Some future trends of wireless communication which demands for the development of MIMO are mentioned below:

- Need of "high data rate" and "high link quality".
- Limited RF spectrum.
- Need to increase system capacity as transmit power is limited.
- Time and frequency limits.

The multiple antennas offers three potential uses: spatial diversity, beam forming, and space division multiplexing (SDM). A MIMO system utilizes spatial diversity by using spatially separated antennas in a dense multipath scattering environment [2]. The capacity of the system can be increased by introducing additional spatial channels that are exploited by using space-time coding [3]. The MIMO systems are implemented in several ways to obtain a diversity gain so as to combat signal fading or to obtain a capacity gain.

MIMO systems tend to improve the Bit Error Rate (BER) or data rate by using multiple transmitting and receiving antennas. The BER can be improved or high data rate can be achieved by using space-time block coding (STBC) as the core scheme in MIMO system. Here OSTBC3 have been used as space-time coding [4]. The two main functions of STBC: spatial diversity and spatial multiplexing. The improved performance needs tradeoffs between diversity and multiplexing.

In broadband wireless communications, an efficient implementation of space-time block coding (STBC) improves the performance and diversity gains of a space time (ST) coding system through a number of parameters including type of trellis codes and channel fading [5] [6].

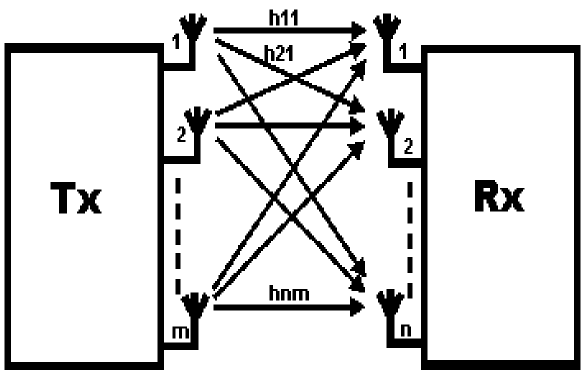

Fig. 1.1: Basic representation of M X N MIMO System

The basic representation of M X N MIMO system is represented in Fig. 1.1. In this paper, the effects of different antenna configurations on the performance of MIMO systems using OSTBC3 over AWGN and Rician channels using Zero Forcing receivers is considered [7]. The data experiences much impairment during transmission, especially noise in the channel or multipath fading.

II. LITERATURE REVIEW

Digital communication using MIMO is a significant technical breakthrough in wireless communications. S. Alamouti [8] presented a simple two-branch transmit diversity scheme. The scheme uses two transmit antennas and one receive antenna. It provides the same diversity order as maximal-ratio receiver combining (MRRC) with one transmit antenna, and two receive antennas.

The comparison of MIMO with SISO technology is discussed by S. G. Kim et.al [9]. The authors explained that the MIMO system not only improve spectral efficiency, but also enhance link throughput or capacity of the system. The authors presented a tight closed form BER approximation of MPSK for MIMO ZF receiver over continuous flat fading channels. The larger the difference between the number of transmit antennas and receive antennas is, the better performance is.

V. Tarokh et.al [10] design a channel codes for improving the high data rate and the reliability of communications over fading channels using multiple transmit antennas. Data is encoded by a channel code and the encoded data is split into multiple streams that are simultaneously transmitted using multiple transmit antennas. The received signal at each receive antenna is a linear superposition of the multiple transmitted signals perturbed by noise.

The impact of antenna selection on the performance of multiple input-multiple output (MIMO) systems over nonlinear communication channels was described by A. I. Sulyman [11]. The author has derived exact analytical expressions for evaluating the PWEP performance of space-time trellis codes over nonlinear MIMO channel.

The approach to increase the capacity of MIMO systems by employing the spatial multiplexing where independent information streams are transmitted from the antennas was explained by C. Wang [12]. These information streams are then separated at the receiver by means of appropriate signal processing techniques such as maximum

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likelihood (ML) which achieves optimal performance or linear receivers like Zero-Forcing (ZF) which provide sub-optimal performance but it also offers significant computational complexity reduction with tolerable performance degradation.

N. S. Kumar et. al [13], investigated about the three types of equalizer for MIMO wireless receivers. The authors made analysis by varying the receiver antenna keeping transmitter antenna constant for a particular type of equalizer based receiver at a particular E_b/N_0 value using BPSK modulation method. The authors discussed about a fixed antenna MIMO antenna configuration and compare the performance with all the three types of equalizer based receiver namely ZF, ML, and MMSE. BER performance of ML Equalizer is superior than zero forcing Equalizer and Minimum Mean Square Equalizers. Based on the mathematical modeling and the simulation result it is inferred that the ML equalizer is the best of the three equalizers.

C. Chen [14] discussed the performance analysis of the low-cost and effective transmission strategy that employs the simple spatial multiplexing at the transmitter and zero-forcing processing at the receiver in multiuser MIMO scheduling systems.

III. MODULATION TECHNIQUE

Modulation and channel coding are fundamental components of a digital communication system. Modulation is the process by which the low frequency signal is mixed with a high frequency carrier to make it transmission possible over a transmitting medium. Modulation is the process of varying the characteristics of carrier signal in accordance to the modulating signal. Phase-shift keying (PSK) is a digital modulation scheme that conveys data by changing, or modulating, the phase of a reference signal (the carrier wave). Phase-shift keying (M-PSK) for which the signal set is:

$$X_i(t) = \frac{\sqrt{2E_s}}{T_s} \cos\left(2\pi * f_{c\tau} + \frac{2(i-1)}{M}\right) \quad i = 1,2,\ldots..M \ \& \ 0 < t < T_s \tag{1}$$

where E_s the signal energy per symbol T_s is the symbol duration and $f_{c\tau}$ is the carrier frequency.

This phase of the carrier takes on one of the M possible values.

$$\theta = 2(i-1)^{\pi/M} \quad i = 1,2,\ldots..M \tag{2}$$

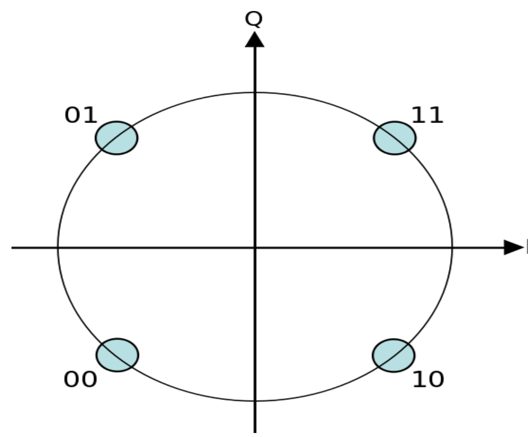


Fig. 1.2: Signal Constellation Diagram for 4-PSK

The circular constellation diagram for M-ary PSK modulation is as shown in Fig. 1.2. The main constraint was to keep the amplitude of the transmitted signals be constant. In PSK, the constellation points chosen are usually positioned with uniform angular spacing around a circle. This gives maximum phase-separation between adjacent points and thus the best immunity to corruption. They are positioned on a circle so that they can all be transmitted with the same energy.

IV. CHANNELS

Communication channels can be classified as fast and slow fading channels. A channel is fast fading if the impulse response changes approximately at the symbol rate of the communication system, whereas a slow fading channel stays unchanged for several symbols. Channel impairments ultimately cause loss of signal and bit transmission errors. Noise is the most common culprit in bit errors. Dropped or changed bits introduce serious transmission errors that may make communications unreliable. As such, the BER is used to indicate the quality of a transmission channel. In this paper, the focus will be on BER analysis of MIMO system over AWGN channel and Rician channels using OSTBC3 code structure.

(A) AWGN CHANNEL

AWGN is a universal channel model used for analyzing modulation schemes. It adds a white Gaussian noise to the signal passing through it. This implies that the channel's amplitude frequency response is flat and phase frequency response is linear for all frequencies so that modulated signals pass through it without any amplitude loss and phase distortion of frequency components. Fading does not exist but the only distortion is introduced by the AWGN. The received signal is simplified to

$$r(t) = x(t) + n(t) \qquad (3)$$

where n(t) is the additive white Gaussian noise.

The whiteness of n(t) implies that it is a stationary random process with a flat power spectral density (PSD) for all frequencies. It is a convention to assume its PSD as

$$N(f) = No/2, -\infty < f < \infty \qquad (4)$$

This implies that a white process has infinite power. This of course is a mathematical idealization. According to the Wiener-Khinchine theorem, the autocorrelation function of the AWGN is

$$R(\tau) = No/2\,\delta(\tau) \qquad (5)$$

where $\delta(\tau)$ is the Dirac delta function.

(B) RICIAN CHANNEL

Rician fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself. Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution. Rayleigh fading is the specialized model for stochastic fading when there is no line of sight signal, and is sometimes considered as a special case of the more generalized concept of Rician fading.

When there is line of sight, direct path is normally the strongest component goes into deeper fade compared to the multipath components. This kind of signal is approximated by Rician distribution. As the dominating component run into more fade the signal characteristic goes from Rician to Rayleigh distribution.

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{(r^2+A^2)}{2\sigma^2}} I_0\left(\frac{Ar}{\sigma^2}\right) \quad \text{for } (A \geq 0, r \geq 0) \qquad (6)$$

where A denotes the peak amplitude of the dominant signal and I0[.] is the modified Bessel function of the first kind and zero-order.

V. MIMO CHANNEL

The 2X2 MIMO channel with an antenna array with 2 elements at the transmitter and an antenna array with 2 elements at the receiver is presented in Fig. 1.3. The input-output notation of the MIMO system can now be expressed by the equation:

$$y(t) = H(\tau, t) \otimes s(t) + u(t) \qquad (7)$$

where $\otimes$ denotes convolution, s(t) is a n_t X 1 vector corresponding to the n_t transmitted signals, y(t) is a n_r X 1 vector corresponding to the n_r and u(t) is the additive white noise.

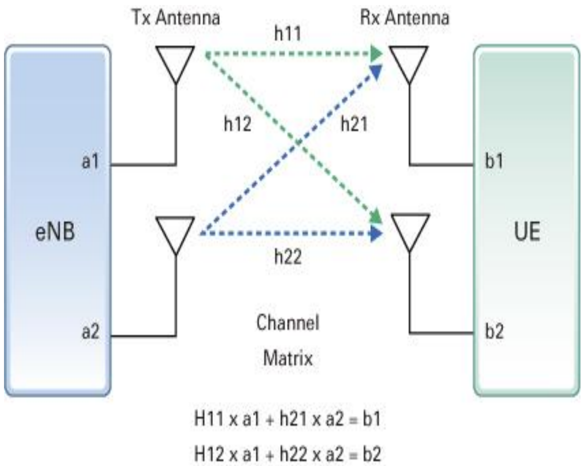


Fig. 1.3: 2X2 MIMO Channel

The impulse response of the channel between the j^{th} transmitter element and the i^{th} receiver element is denoted as $h_{ij}(\tau,t)$. The MIMO channel can then be described by the n_r X n_t $H(\tau,t)$ matrix:

$$H(\tau,t) = \begin{bmatrix} h_{1,1}(\tau,t) & h_{1,2}(\tau,t) & \cdots & h_{1,n_t}(\tau,t) \\ h_{2,1}(\tau,t) & h_{2,2}(\tau,t) & \cdots & h_{2,n_t}(\tau,t) \\ \vdots & \vdots & & \vdots \\ h_{n_r,n_1}(\tau,t) & h_{n_r,n_2}(\tau,t) & & h_{n_r,n_t}(\tau,t) \end{bmatrix} \quad (8)$$

The matrix elements are complex numbers that correspond to the attenuation and phase shift that the wireless channel introduces to the signal reaching the receiver with delay τ.

Space–time block coding is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. The fact that the transmitted signal must traverse a potentially difficult environment with scattering, reflection, refraction and so on and may then be further corrupted by thermal noise in the receiver means that some of the received copies of the data will be 'better' than others. This redundancy results in a higher chance of being able to use one or more of the received copies to correctly decode the received signal. In fact, space–time coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible. Here we have used OSTBC3 as space-time block coding.

STBCs as originally introduced are orthogonal. STBC is designed such that the vectors represents any pair of columns taken from the coding matrix is orthogonal. The result of this is simple, linear, optimal decoding at the receiver. Its most serious disadvantage is that all but one of the codes that satisfy this criterion must sacrifice some proportion of their data rate. Moreover, there exist quasi-orthogonal STBCs that achieve higher data rates at the cost of inter-symbol interference (ISI). Thus, the STBCs provide ISI free transmissions due to orthogonality.

$$C_{3,1/2} = \begin{bmatrix} c_1 & c_2 & c_3 \\ -c_2 & c_1 & -c_4 \\ -c_3 & c_4 & c_1 \\ -c_4 & -c_3 & c_2 \\ c_1^* & c_2^* & c_3^* \\ -c_2^* & c_1^* & -c_4^* \\ -c_3^* & c_4^* & c_1^* \\ -c_4^* & -c_3^* & c_2^* \end{bmatrix} \quad (9)$$

These codes achieve rate-1/2. The given matrix gives the only way to achieve orthogonality.

VI. ZERO FORCING EQUALIZER

The Zero Forcing Equalizer is a linear equalization algorithm used in communication systems that applies the inverse of the frequency response of the channel. This equalizer was first proposed by Robert Lucky.

For a channel with frequency response F(f) the zero forcing equalizer C(f) is constructed by C(f) = 1 / F(f).. Thus the combination of channel and equalizer gives a flat frequency response and linear phase F(f)C(f) = 1. If the channel response (or channel transfer function) for a particular channel is H(s) then the input signal is multiplied by the reciprocal of it.

This is intended to remove the effect of channel from the received signal, in particular the inter symbol interference (ISI). This will be useful when ISI is significant compared to noise. The zero-forcing equalizer removes all ISI, and is ideal when the channel is noiseless.

The received vector can be represented by using the linear model as:

$$y = Hx + n \tag{10}$$

For a 2x2 MIMO channel, the channel is modeled as,

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix} \tag{11}$$

where

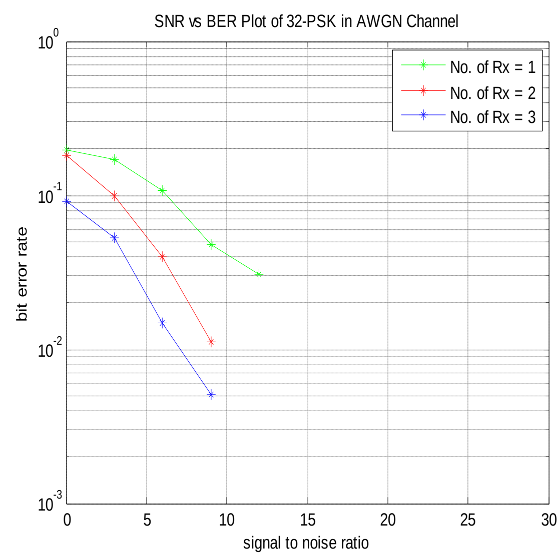
y_1,y_2 are the received symbol on the first and second antenna respectively,
$h_{1,1}$ is the channel from 1st transmit antenna to the 1st receive antenna,
$h_{1,2}$ is the channel from 2nd transmit antenna to the 1st receive antenna,
$h_{2,1}$ is the channel from 1st transmit antenna to the 2nd receive antenna,
$h_{2,2}$ is the channel from 2nd transmit antenna to the 2nd receive antenna,
x_1, x_2 are the transmitted symbols and n_1, n_2 are the noise on 1st and 2nd receive antennas.

The Zero-Forcing Equalizer applies the inverse of the channel frequency response to the received signal, to restore the signal after the channel. It has many useful applications. It is mostly used for IEEE 802.11n (MIMO) where knowing the channel allows recovery of the two or more streams which will be received on top of each other on each antenna.

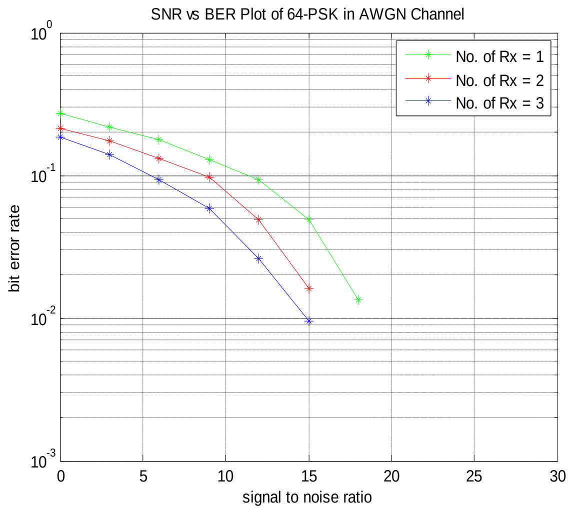
VI. SIMULATED RESULTS

In this section, the performance analysis of MIMO system over AWGN and Rician channels using OSTBC3 code structure with zero forcing receivers is done for M-PSK Modulation. The BER is used as the parameter to indicate the quality of a transmission channel. The BER analysis of MIMO system is done for M-PSK over AWGN and Rician fading channels where M can be 32, 64, 128, 256, 512 and 1024 for different antenna configurations. Here we have used receiving antennas ranging from NR = 1 to NR = 3.

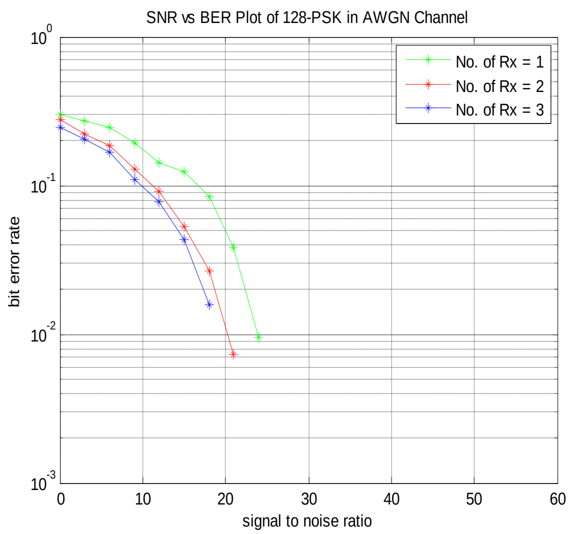
(A) M-PSK over AWGN Channel



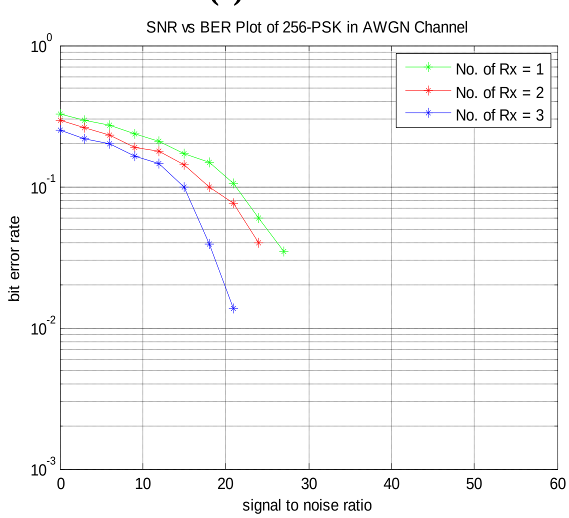
(a) 32-PSK



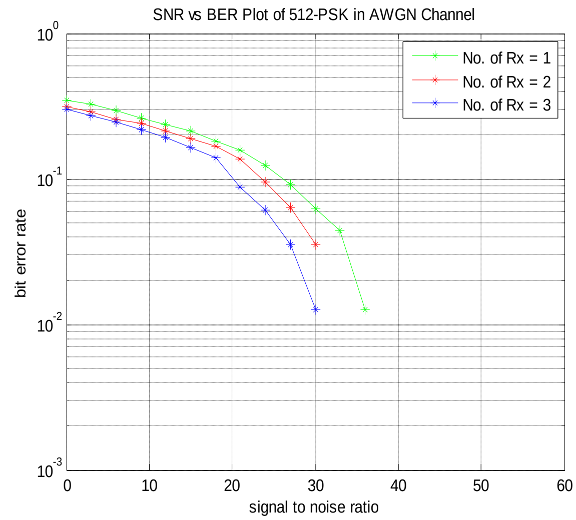
(b) 64-PSK



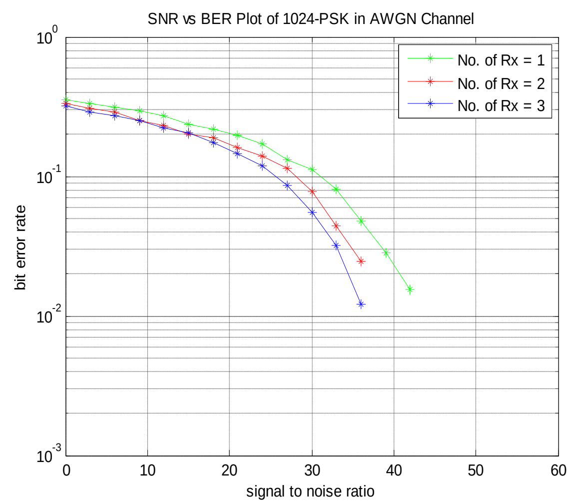
(c) 128-PSK



(d) 256-PSK



(e) 512-PSK

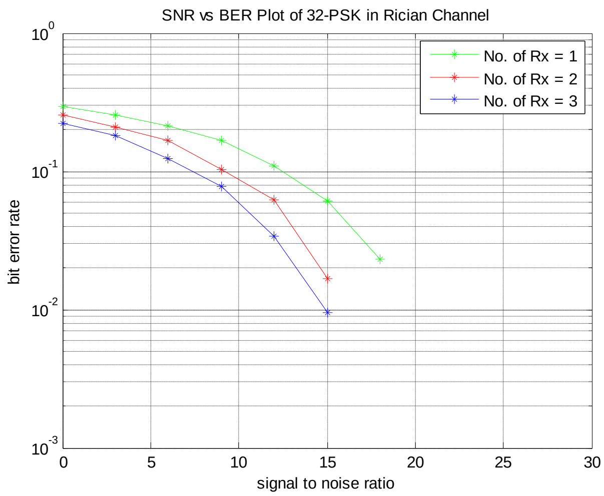


(f) 1024-PSK

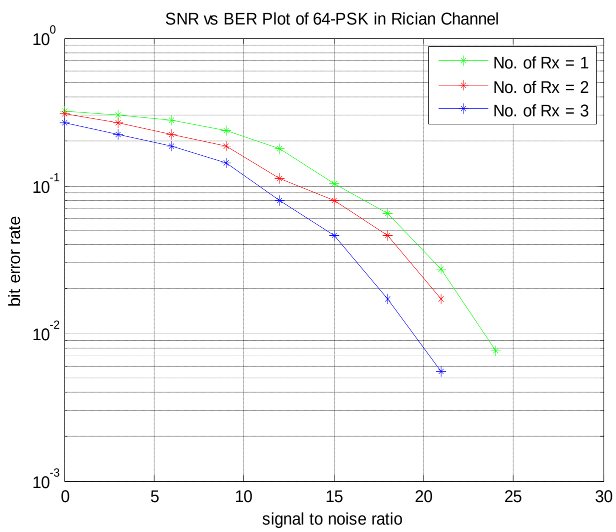
Fig. 1.4: SNR vs BER plots for M-PSK over AWGN channel

Fig. 1.4 (a) – (f) presents SNR vs. BER plots for M-PSK over AWGN channel for MIMO system with different antenna configurations using OSTBC3 with zero forcing receivers. Here the graph depicts that in MIMO system as we goes on increasing the number of receiving antennas, the BER keeps on decreasing due to space diversity and thus the proposed system provide better BER performance as compared to the other antenna configurations.

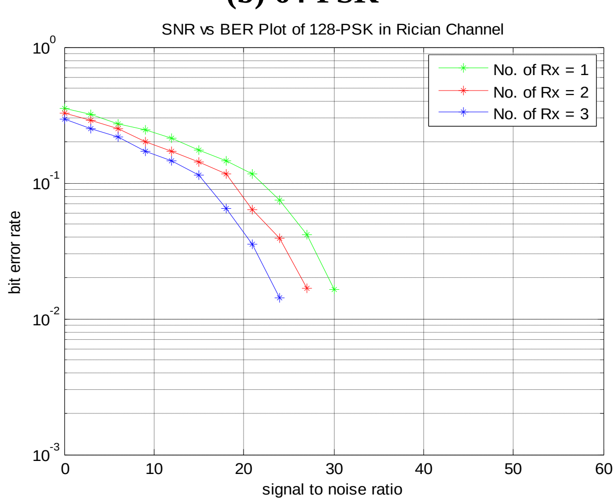
(B) M-PSK over Rician Channel



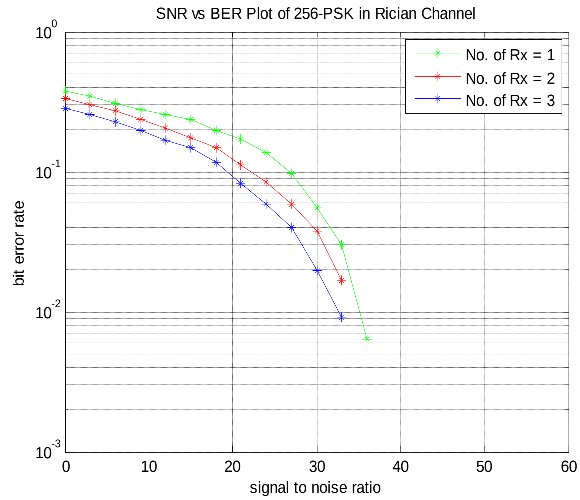
(a) 32-PSK



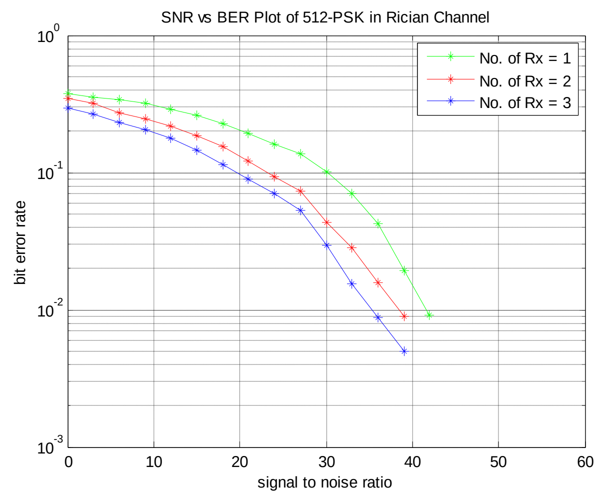
(b) 64-PSK



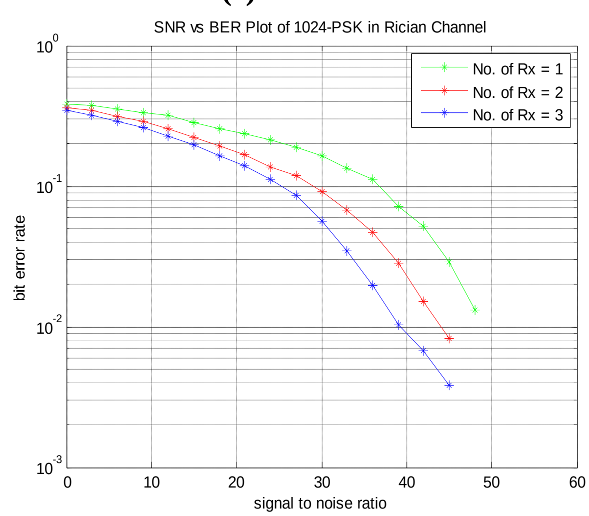
(c) 128-PSK



(d) 256-PSK



(e) 512-PSK



(f) 1024-PSK

Fig. 1.5: SNR vs BER plots for M-PSK over Rician channel

In Fig. 1.5 (a) – (f), SNR vs. BER plots for M-PSK over Rician channel for MIMO system with different antenna configurations using OSTBC3 with zero forcing receivers are presented. It can be concluded from the graphs that as we goes on increasing the number of receiving antennas in the MIMO system, the BER keeps on decreasing due to the space diversity. Thus the system provides better BER performance.

VII. CONCLUSION

In this paper, the performance analysis of MIMO system over AWGN and Rician fading channels employing different antenna configurations using OSTBC3 is presented. It can be depicted from the graphs that the BER keeps on decreasing in MIMO system due to space diversity as we goes on increasing the number of receiving antennas. It can also be concluded that the BER of Rician channel is higher than that of the AWGN channel. Thus the multiple transmitting and receiving antennas are used to combat multipath fading and thus improving the Signal-to Noise ratio (SNR).

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