Performance Comparison of MIMO Systems over AWGN and Rician Channels using OSTBC4 with Zero Forcing Receivers

Navjot Kaur and Lavish Kansal
Electronics and Communication Engineering Department
Lovely Professional University, Phagwara, India
er.navjot21@gmail.com
lavish.15911@lpu.co.in

***Abstract* – Multiple-input multiple-output (MIMO) are used in wireless communications to achieve high data rates within the limited frequency spectrum. MIMO uses multiple transmitting and receiving antennas so as to utilize the advantages of spatial diversity. The performance analysis of MIMO system over AWGN and Rician fading channels using OSTBC4 as space time coding with Zero Forcing (ZF) receiver is presented. The performance can be improved by using antenna diversity at receiver side as the number of transmitting antennas is four in OSTBC4. In this paper, the Bit Error Rate (BER) analysis for M-PSK modulation using OSTBC4 over AWGN and Rician channels using zero forcing receivers is presented.**

***Index Term*– MIMO, AWGN, Rician, OSTBC4, spatial diversity, antenna diversity, Zero Forcing, Bit Error Rate, M-PSK.**

I. INTRODUCTION

Multiple-Input Multiple-Output (MIMO) technology is a technical breakthrough in the field of wireless communications. Multiple antennas at transmitter and receiver side refer to MIMO and such arrangement can be used to increase data rates or to improve link quality due to spatial diversity [1]. MIMO system uses spatial multiplexing by spatially separated antennas to combat with multipath fading.

This method offers higher capacity to wireless systems and the capacity increases linearly with the number of antennas. The main idea of MIMO is to improve quality (BER) and/or data rate (bits/sec) by using multiple TX/RX antennas [2]. The core scheme of MIMO is space-time coding (STC). The two main functions of STC: spatial diversity and spatial multiplexing. The maximum performance needs tradeoffs between diversity and multiplexing.

There are various categories of MIMO techniques. One of the technique aims to improve the power efficiency by maximizing spatial diversity. Such techniques include delay diversity, STBC [3], [4] and STTC [5]. The second one uses a layered approach to increase capacity. In broadband wireless communications, an efficient implementation of space-time coding (STC) improves the performance and diversity gains of the system [6]. The data experiences much impairment during transmission, especially due to the channel noise.

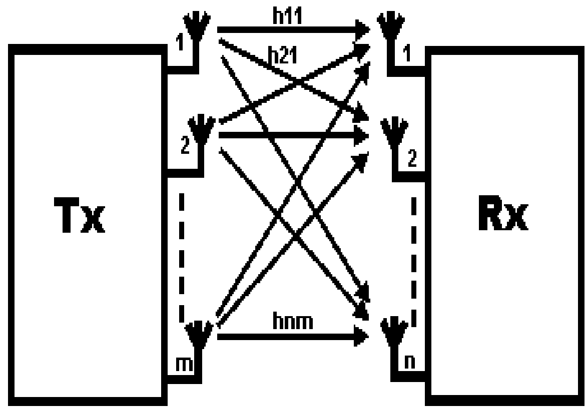


Fig. 1.1. Block Diagram of M X N MIMO System

The block diagram of M X N MIMO system is represented in Fig. 1.1 which consists of M antennas at transmitter side and N antennas at receiver side. In this paper, the effects of using different antenna configuration on the performance of MIMO systems using OSTBC4 over AWGN and Rician channels with Zero Forcing receivers are considered [7].

The impact of antenna selection on the performance of multiple input-multiple output (MIMO) systems over nonlinear communication channels was presented by A. I. Sulyman [8]. The author presented improvement in SNR penalty due to nonlinearity of fading channels for the reduced-complexity system.

S. G. Kim et.al [9] discussed that the MIMO system improves spectral efficiency and enhance link throughput or capacity of the system by comparing MIMO with SISO technology. The authors analyzed BER analysis of M-PSK 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.

A simple two-branch transmit diversity scheme was presented by S. Alamouti [10]. 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 technique to increase the capacity of MIMO systems by employing the spatial multiplexing was discussed by C. Wang [11]. Maximum Likelihood (ML) receiver achieves optimal performance whereas Zero-Forcing (ZF) receiver provides sub-optimal performance but it offers significant computational complexity reduction with tolerable degradation in the performance of system.

V. Tarokh et.al [12] design a channel codes for improving the high data rate and the reliability of communications over fading channels using multiple transmit antennas. The received signal at each receive antenna is a linear superposition of the multiple transmitted signals perturbed by noise.

N. S. Kumar et. al [13], compared the three types of equalizers for MIMO wireless receivers. The authors explained a fixed antenna MIMO configuration and compare the performance with all the three types of equalizer based receiver namely Zero Forcing, Maximum Likelihood, and Minimum Mean Square Equalizers. BER performance of ML Equalizer is superior among the three types of equalizers. Based on the mathematical modeling and the simulation results, Maximum Likelihood equalizer is the best of the three equalizers.

II. MODULATION TECHNIQUE

Modulation and channel coding are fundamental components of a digital communication system. Modulation is the process of superimposing information on some form of carrier signal. Modulation can be analog and digital type. Modulation is the process of varying the characteristics of carrier signal in accordance to the modulating signal. These characteristics can be amplitude, frequency or phase. A modulator performs modulation (conversion of analog carrier signals into digital information) and a demodulator performs demodulation, the inverse operation of modulation (decoding the transmitted information).

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). M-ary Phase-shift keying (M-PSK) for which the signal set is:

$$X_i(t) = \frac{\sqrt{2E_s}}{T_s}\cos\left(2\pi * f_{c\tau} + \frac{2(i-1)}{M}\right) \quad i = 1,2,\ldots..M \;\; \& \; 0 < t < T_s \tag{1.1}$$

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.

$$\theta = 2(i-1)^{\pi/M} \qquad i = 1,2,\ldots..M \tag{1.2}$$

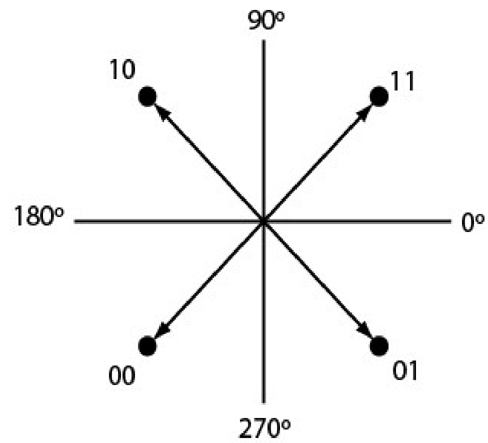


Fig. 1.2. Constellation Diagram for 4-PSK Signal

The M-ary PSK modulation yields a circular constellation as shown in Fig. 1.2. The main constraint was to keep the amplitude of the transmitted signals be constant.

III. CHANNELS

In wireless communications, channel is a physical transmission medium such as a wire, or to a logical connection over a multiplexed medium such as a radio channel. A channel is used to convey an information signal, from transmitter to receiver. 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. In this paper, the focus will be on performance analysis of MIMO system over AWGN channel and Rician channels using OSTBC4 code structure.

(A) AWGN CHANNEL

AWGN is a channel model used for analyzing modulation schemes. It adds a white Gaussian noise to the signal passing through it. 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

$$r(t) = x(t) + n(t) \tag{1.3}$$

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

$$N(f) = No/2, -\infty < f < \infty \tag{1.4}$$

(B) RICIAN CHANNEL

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.

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

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

IV. MIMO CHANNEL

The M X N MIMO channel with an antenna array with M elements at the transmitter and an antenna array with N 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:

$$y(t) = H(\tau,t) \otimes s(t) + u(t) \qquad (1.6)$$

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.

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:

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

(1.7)

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.

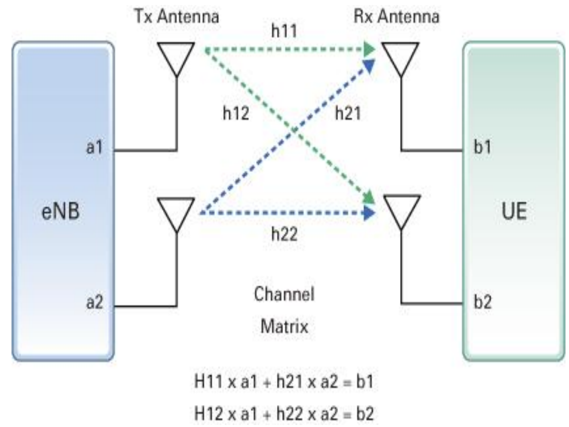


Fig. 1.3. MIMO Channel

Space time block coding (STBC) 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. Here we have used OSTBC4 as space-time block coding. The given matrix gives the only way to achieve orthogonality. 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.

Tarokh et.al [12] discovered a set of STBCs that are particularly straightforward, and coined the scheme's name. No code for more than 2 transmit antennas could achieve full-rate. They also demonstrated the simple, linear decoding scheme that goes with their codes under perfect channel state information assumption.

$$C_{4,1/2} = \begin{bmatrix} c_1 & c_2 & c_3 & c_4 \\ -c_2 & c_1 & -c_4 & c_3 \\ -c_3 & c_4 & c_1 & -c_2 \\ -c_4 & -c_3 & c_2 & c_1 \\ c_1^* & c_2^* & c_3^* & c_4^* \\ -c_2^* & c_1^* & -c_4^* & c_3^* \\ -c_3^* & c_4^* & c_1^* & -c_2^* \\ -c_4^* & -c_3^* & c_2^* & c_1^* \end{bmatrix}$$

(1.8)

V. ZERO FORCING EQUALIZER

Zero Forcing Equalizer is a linear equalization algorithm used in communication systems, which inverts the frequency response of the channel. This equalizer was first proposed by Robert Lucky. The Zero-Forcing Equalizer applies the inverse of the channel to the received signal, to restore the signal before the channel. The name Zero Forcing corresponds to bringing down the ISI to zero in a noise free case. For a channel with frequency response F(f) the zero forcing equalizer C(f) is constructed such that C(f) = 1 / F(f). If the channel response for a particular channel is H(s) then the input signal is multiplied by the reciprocal of this. This is intended to remove the effect of channel from the received signal particularly the Inter symbol Interference (ISI).

By using the linear model, the received vector can be represented as:

$$y = Hx + n \qquad (1.9)$$

The equation can be represented in matrix notation as follows:

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix} \qquad (1.10)$$

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,

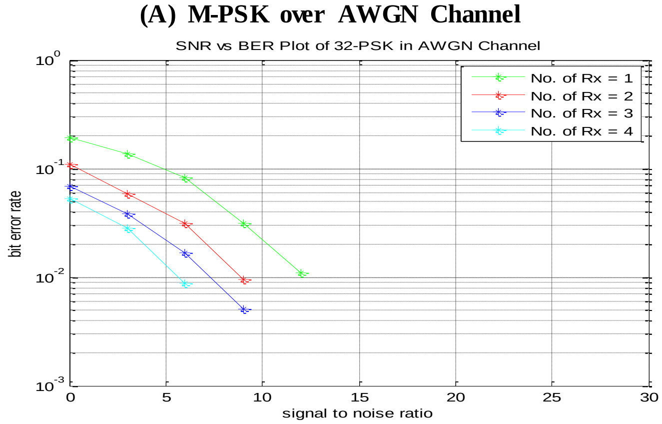
$h_{2,2}$ is the channel from 2nd transmit antenna to the 2nd receive antenna,

x_1, x_2 are the transmitted symbols and n_1, n_2 are the noise on 1st and 2nd receive antennas.

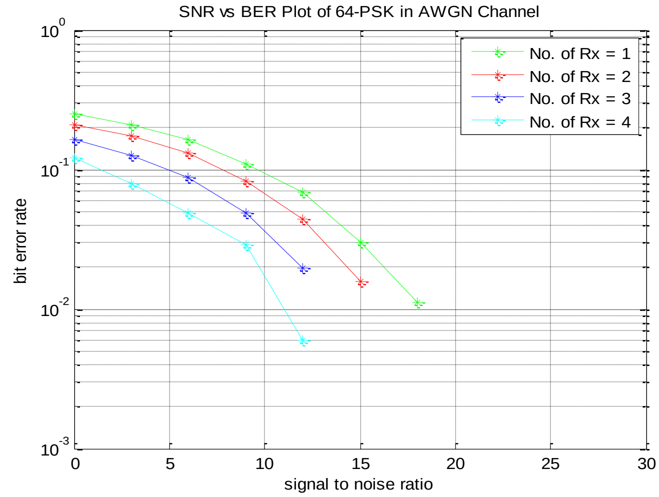
VI. SIMULATED RESULTS

In this section, the Bit Error Rate analysis of MIMO system over AWGN and Rician channels using OSTBC4 code structure with zero forcing receivers is done for M-PSK Modulation. 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 = 4.

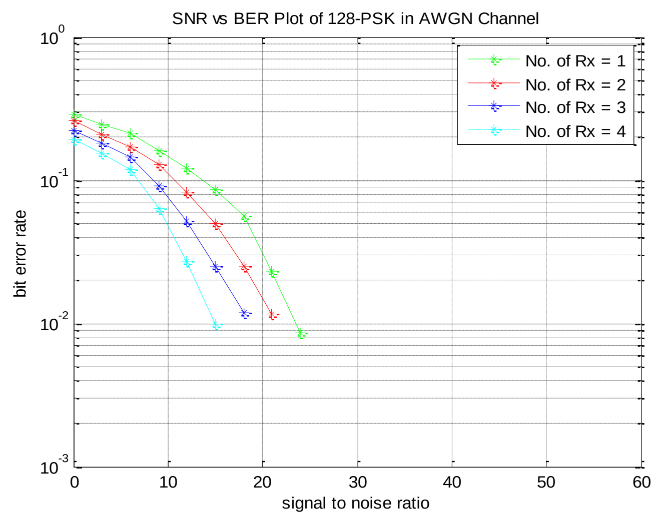
(A) M-PSK over AWGN Channel



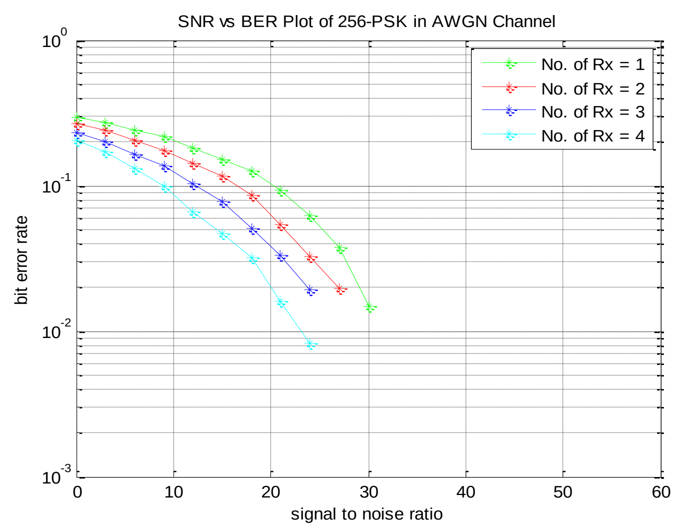
(a) 32-PSK



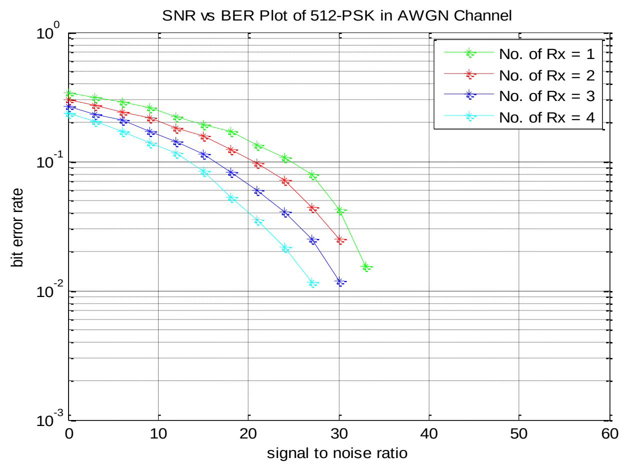
(b) 64-PSK



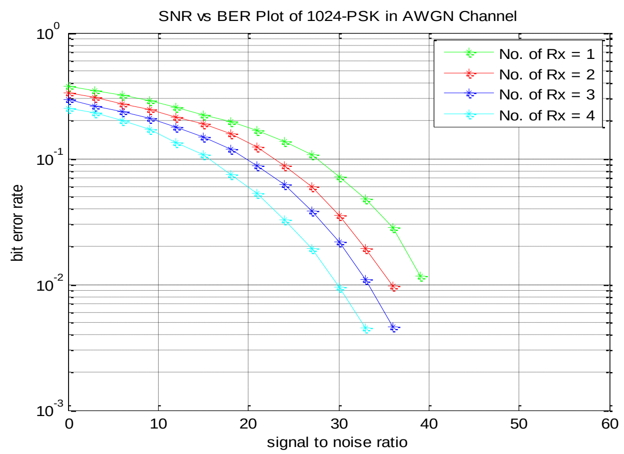
(c) 128-PSK



(d) 256-PSK



(e) 512-PSK



(f) 1024-PSK

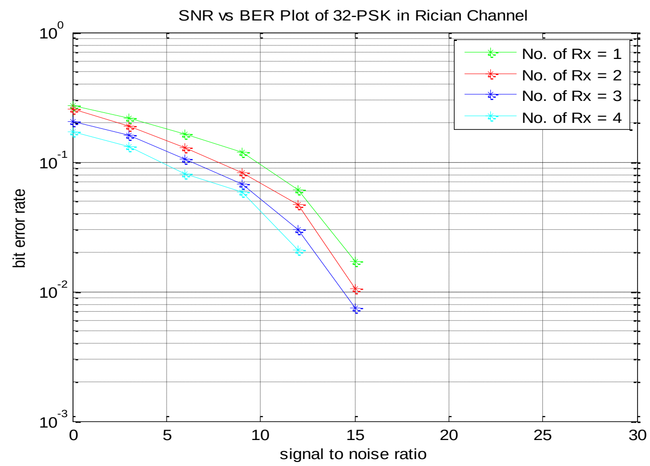
Fig. 1.4. SNR vs BER plots for M-PSK over AWGN channel

In Fig. 1.4 (a) – (f), SNR vs. BER plots for M-PSK over AWGN channel for MIMO system with different antenna configurations using OSTBC4 with zero forcing receivers are presented. It can be concluded from the graphs that 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 and thus the proposed system provide better BER performance as compared to the other antenna configurations. With the variation in number of receiving antennas from NR = 1 to NR = 4, the SNR varies from 4 dB to 8 dB as presented in table I.

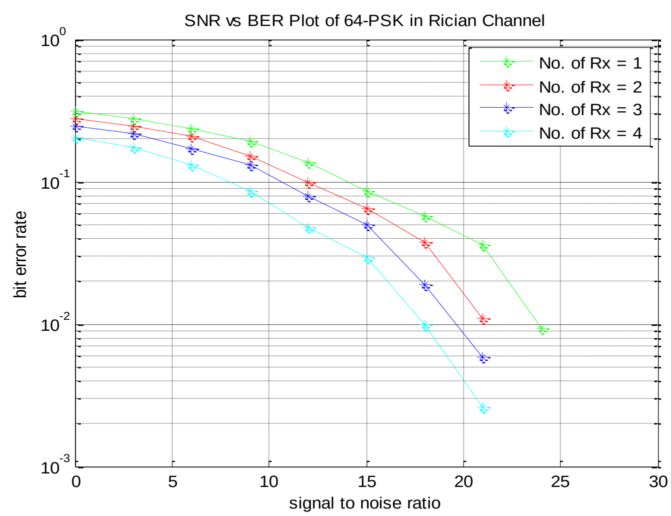
TABLE I
SNR VALUES FOR HIGHER ORDER M-PSK OVER AN AWGN CHANNEL

Number of Receiving Antennas	SNR for different M values of M-PSK Modulation Scheme (in dB)					
	32	64	128	256	512	1024
1	12	18	23	30	32	39
2	9	15	21	27	30	36
3	9	13	19	23	30	35
4	6	12	15	22	28	32

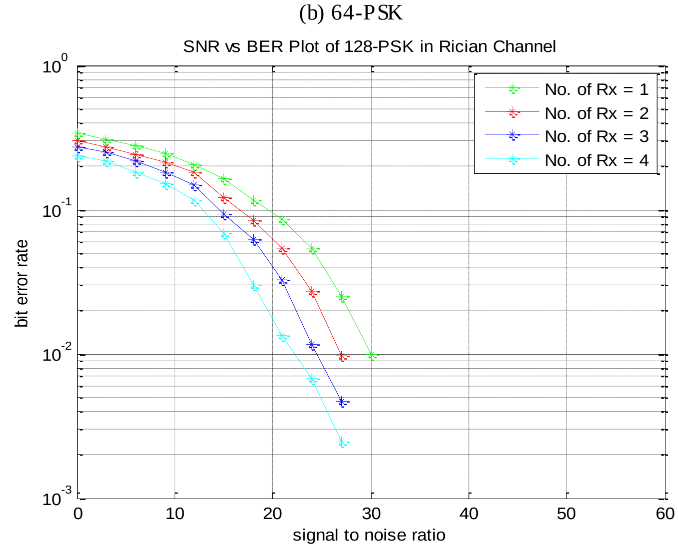
(B) M-PSK over Rician Channel



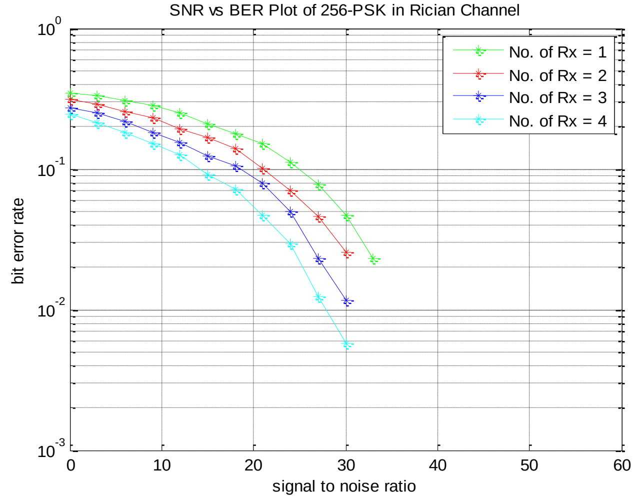
(a) 32-PSK



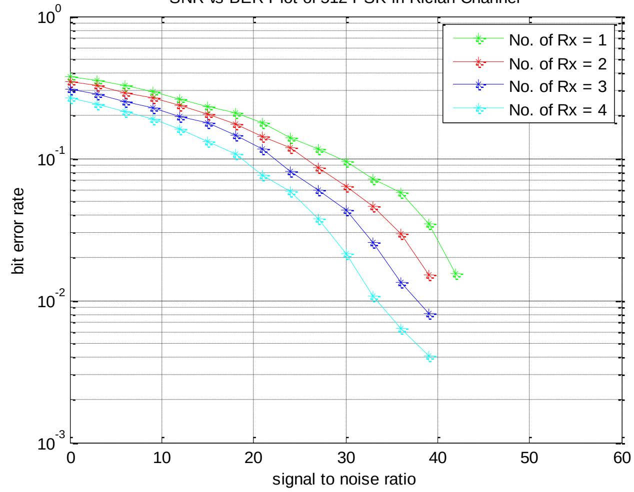
(b) 64-PSK



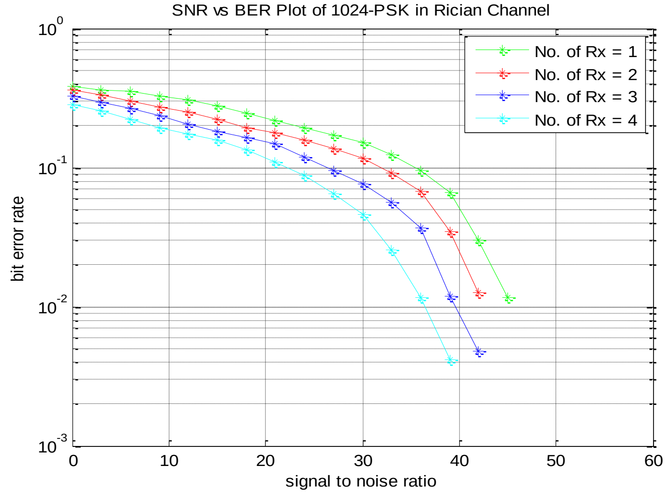
(c) 128-PSK



(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), the SNR vs. BER plots for M-PSK over Rician fading channel for MIMO system with different antenna configurations using OSTBC4 with zero forcing receivers are presented. From the graphs, it can be depicted that in MIMO system, the BER keeps on decreasing as we goes on increasing the number of receiving antennas due to space diversity. Thus the system provides better BER performance. The relation between the different values of M for different number of receiving antennas can be figure out from the BER vs SNR plots. With the variation in number of receiving antennas from NR = 1 to NR = 4, the SNR varies from 2 dB to 6 dB as shown in table II.

TABLE II
SNR VALUES FOR HIGHER ORDER M-PSK OVER A RICIAN CHANNEL

Number of Receiving Antennas	**SNR for different M values of M-PSK Modulation Scheme (in dB)**					
	32	**64**	**128**	**256**	**512**	**1024**
1	15	24	30	32	42	45
2	15	22	28	30	39	42
3	15	22	28	30	39	41
4	13	21	27	29	38	39

VII. CONCLUSION

In this paper, the performance analysis of MIMO system over AWGN and Rician fading channels employing different antenna configurations using OSTBC4 is presented with zero forcing receivers. It can be concluded that due to space diversity, the BER keeps on decreasing in MIMO system as we goes on increasing the number of receiving antennas and also that the BER of Rician channel is higher than that of the AWGN channel. The multiple receiving antennas using OSTBC4 (transmitting antennas = 4) are used to avoid signal fading and thus improving SNR. Thus it leads to improve signal quality and coverage. With the use of higher order modulation schemes over different antenna selection, the performance of MIMO system can further be improved.

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Authors

Navjot Kaur was born in Jalandhar. She received her B.Tech degree in Electronics and Communication Engineering from Lovely Institute of Technology, Phagwara, Punjab Technical University, Jalandhar, in 2008, and presently pursuing M.Tech degree in Electronics and communication engineering from Lovely Professional University, Phagwara, India. Her research interests include MIMO systems and wireless systems.

Lavish Kansal was born in Bathinda. He received his B.Tech degree in Electronics and Communication Engineering from PTU, Jalandhar in 2009 and M.E. degree in Electronics and Communication Engineering from Thapar University, Patiala in 2011.He is working as Assistant Professor in the department of Electronics and communication Engineering, Lovely Professional University, Phagwara, India. He has published 15 papers in International journals. His research area includes Digital Signal Processing, Digital Communication & Wireless Communication.