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Performance Analysis of MIMO Spatial Multiplexing using different Antenna Configurations and Modulation Technique in Rician Channel

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Abstract— MIMO systems which employs multiple antennas at the transmitter as well as at the receiver side is the key technique to be employed in next generation wireless communication systems. MIMO systems provide various benefits such as Spatial Diversity, Spatial Multiplexing to improve the system performance. In this paper the MIMO SM system is analysed for different antenna configurations (2×2, 3×3, 4×4) in Rician channel. The performance of the MIMO SM system is investigated for higher order modulation schemes (M-PSK, M-QAM) and Zero Forcing equalizer is employed at the receiving side. The simulation results points that if antenna configurations are shifted from 2×2 to 3×3 configuration, an improvement of 0 to 2.9 db in SNR is being noted and an improvement of 0 to 2.9 db is visualized if antenna configurations are changed from 3×3 to 4×4 configuration.

Index Terms— Multiple Input Multiple Output (MIMO), Zero Forcing (ZF), Spatial Multiplexing (SM), M-ary Phase Shift Keying (M-PSK) M-ary Quadrature Amplitude Modulation (M-QAM), Bit Error Rate (BER), Signal to Noise Ratio (SNR).

1 Introduction

MIMO (Multiple Input Multiple Output) systems employ multiple antennas at both the ends of a communication link. The MIMO systems provide various applications such as beamforming (increasing the average SNR at receiver side), Spatial Diversity (to achieve good BER at low SNR), Spatial Multiplexing (to transmit independent data streams) in communication systems. In antenna diversity schemes, the independent data streams of the same signal from the transmitter side are combined in such a way that the average SNR must increases at the receiving side. One of such schemes is Maximal Ratio Combining in which different data streams of same transmitted signal are multiplied with weight factors before they are combined at the receiver. If a MIMO system has 'M' transmit antennas and 'N' receive antennas then the diversity order of such a system is given by M×N. The antenna diversity schemes (Maximal Ratio Combining) can also be employed at the transmitter side if the channel state is known at the transmitter side. The capacity of MIMO systems increases logarithmically with SNR, if spatial diversity and beamforming techniques are employed [1], but capacity increases linearly with SNR if Spatial Multiplexing scheme is employed in MIMO systems. In a rich scattering environment, the benefits of MIMO spatial diversity scheme can be obtained to a higher extend, but the benefits of beamforming technique are limited in such environments.

In order to obtain channel state information at receiving side, the pilot bits are sent along with the transmitted sequence to estimate the channel state. The channel has to be estimated from each transmit antenna to the receiving antenna, but at the same time this process requires a large overhead and it is usually avoided because of its high cost. The channel state information at the transmitter side can be obtained via a feedback from the receiving side, but this process requires a special feedback channel, which increases the system complexity.

In this paper, the MIMO Spatial Multiplexing technique is analysed for different antenna configurations (2×2, 3×3, 4×4) and for different modulation schemes (M-PSK, M-QAM) in Rician channel. The ZF equalizer is used at the receiving section. The 2×2 antenna configuration is compared with 3×3 antenna configuration in terms of BER and similarly 3×3 antenna configuration is compared with 4×4 antenna configuration.

2 MIMO Spatial Multiplexing

The data can be transmitted at a higher rate if we employ MIMO SM scheme in a communication system. In MIMO SM scheme the independent data streams are transmitted from independent antennas and the no of receiving antennas must be greater than or equal to the no of transmitting antennas [2].

The Spatial Multiplexing model for MIMO system is represented as:

$$y = Hx + n \qquad (1)$$

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In equation 1 'y' represents the received vector, 'H' is the channel matrix, 'x' is the transmitted vector and 'n' is the noise vector. The capacity of the MIMO system derived from the Shannon's law is given by

$$c = tr(r_{xx}) \leq p^{max} \log_2\left(det(I + H r_{xx} H^H)\right) \qquad (2)$$

In equation 2 'c' denotes the capacity of MIMO system, 'r_{xx}' denotes the covariance matrix of transmitted vector x, 'H' is the channel matrix and 'I' represents the identity matrix.

The Spatial Multiplexing scheme increases the data rate without requiring any additional power and bandwidth [3]. The different data streams from different transmitting antennas follow different paths through the channel and these data streams show different spatial signatures at different receiving antennas. The equalizer can be employed at the receiving side to combat inter symbol interference. The ZF, Minimum Mean Square Error or Maximum Likelihood equalizer can be employed to perform this operation. But Maximum Likelihood offers high computational complexity [4]. The multiplexing gain equals min (N_t, N_r) where N_t represents the no of transmitting antennas, N_r represents the no of receiving antennas. Spatial Multiplexing can be implemented with or without channel knowledge. The MIMO SM system is represented by Fig .1

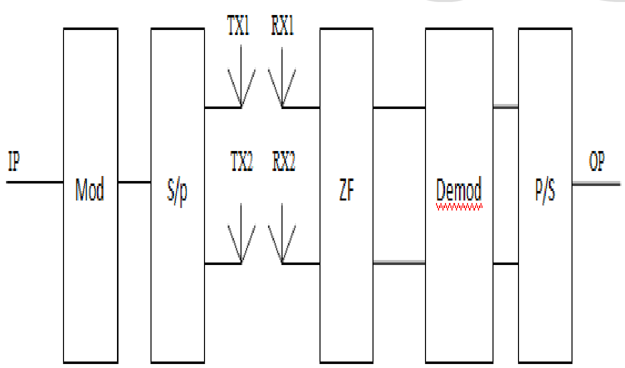

Fig 1 MIMO SM system representation

In figure 1 a group of data streams is passed as input to the modulator which performs the modulation operation on input data streams and the modulated data stream is passed to serial to parallel converter, which converts the serial data streams into independent parallel data streams. These parallel data streams are transmitted from independent antennas. At the receiving side ZF equalizer is used to mitigate the effects of inter symbol interference, the output of ZF equalizer is passed to the demodulator which performs the inverse operation of modulator. After that the demodulated data stream is passed to parallel to serial converter, which converts the parallel data streams into serial data stream.

3 MODULATION TECHNIQUES

In modulation schemes the parameters of a sinusoidal waveform are changed to convey the information. In these schemes a stream of digital bits are mapped into the signal waveforms. Modulation schemes are responsible for maintaining the quality of a wireless network. In digital modulation schemes, either the phase, amplitude or frequency of the carrier wave is varied to convey the information. The high frequency sinusoidal waveform is used as a carrier signal. The modulation schemes must be bandwidth and power efficient.

3.1 M-PSK (M-ary Phase Shift Keying)

When the phase of the carrier is varied in accordance with the modulating signal then the modulation scheme is termed as Phase Shift Keying [5]. In Binary Phase Shift Keying normally two phases of the carrier are possible and this modulation scheme is used for high speed data transfer applications. These modulation schemes are power as well as bandwidth efficient. The M-PSK modulated signal $X_i(t)$ is represented as:

$$X_i(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left(2\pi f_c t + 2\pi\left(\frac{i-1}{M}\right)\right) \qquad (3)$$

$i = 0,1,2 \ldots\ldots M$

$0 < t < T_s$

In equation 3 'E_s' represents the signal energy, 'T_s' represents the symbol duration, f_c is the carrier frequency and 'M' represents the possible signal waveforms. The carrier phase θ_i will have M possible values which is given by:

$$\theta_i = 2(i-1)^{\frac{\pi}{M}} \qquad (4)$$

3.2 Quadrature Amplitude Modulation (M-QAM)

In QAM both amplitude and phase of a carrier wave are varied in accordance with the modulating signal to represent information [6]. The spectral efficiency of the QAM modulation schemes is better as compared to PSK modulation schemes. The two carrier waves used in QAM are 90° out of phase with respect to each other. The data can be sent in a smaller spectrum if higher order M-QAM modulation schemes are employed. But the transmission will be more prone to errors due to smaller distance between two constellation points in the signal space diagram. So this modulation scheme will require more power as compared to other modulation schemes [7]. The QAM modulated signal $Z_i(t)$ is represented as:

$$Z_i(t) = \sqrt{\frac{2}{T_s}} g_n \cos(2\pi f_c t) - \sqrt{\frac{2}{T_s}} h_n \sin(2\pi f_c t) \quad (5)$$

Where 'g_n' and 'h_n' are amplitudes values and 'f_c' is the carrier frequency.

$$g_n, h_n = \pm a, \pm 3a, \ldots \ldots \ldots . \pm(\log_2(M-1))a \qquad (6)$$

Where 'M' is mostly taken as power of 4 and it represents the possible waveforms. The signal energy E_s can be related to parameter a as:

$$a = \sqrt{\frac{3E_s}{2}}(M-1) \qquad (7)$$

4 CHANNELS

The signals from transmitter follow different paths through the channel to reach the receiving antenna. The signal get scattered when it encounter objects in the environment, thus leads to multipath structure. The phase and amplitude of the resultant signal gets randomly distributed which accounts for fading of the signal [8].

4.1 Rician Channel

When there is line of sight component present between the transmitter and the receiver, the distribution of the received signal follows Rician distribution. The pdf of such function is given by:

$$f_{rician}(r) = \frac{r}{\sigma^2} exp\left(\frac{-(r^2+A^2)}{2\sigma^2}\right) I_0\left(\frac{Ar}{\sigma^2}\right) \qquad (8)$$

$$r \geq 0, A \geq 0$$

In equation 8 σ^2 represents the variance of in-phase and quadrature components,' A' represents the amplitude of the signal following line of sight, I_0 is the Bessel function of zeroth order first kind. The level of fading is reduced due to line of sight component present in case of Rician fading and this channel provides superior performance in terms of BER as compared to Rayleigh channel [9].

5 ZERO FORCING EQUALIZER

Zero Forcing equalizer is a linear equalization technique which removes the inter symbol interference. It offers unity impulse response function to the symbol which is being detected and zero impulse response function to other symbols. The noise gets enhanced in the process of ZF equalization technique [10]. If no of transmitting antenna is equal to the no of receiving antennas and channel matrix 'H' is a full rank matrix, then we can multiply the inverse of channel matrix H with equation 1 to estimate the transmitted vector.

$$yH^{-1} = x + nH^{-1} \qquad (9)$$

From equation 9 we can conclude symbols are separated from each other. To estimate 'x' we need to determine a weight matrix W_{zf} which agrees W_{zf}H=I. The weight matrix W_{zf} for zero forcing equalizer is given by:

$$W_{zf} = (H^H H)^{-1} H^H \qquad (10)$$

Before quantization the result of ZF equalizer is given by:

$$\hat{x} = (H^H H)^{-1} H^H y \qquad (11)$$

Where $\hat{x}$ is the estimate of transmitted vector.

6 RESULTS AND DISCUSSIONS

In this paper, the performance of MIMO SM scheme is analysed in terms of SNR vs. BER. The MIMO SM system is analysed for different antenna configurations (2×2, 3×3, 4×4) in Rician channel. The system is implemented with higher order modulation schemes (M-PSK, M-QAM) and ZF equalizer is employed at the receiving side. The improvement in SNR is being noted when antenna configurations are shifted from 2×2 to 3×3 and from 3×3 to 4×4. The result corresponding to these improvements have been presented in table 1(when M-PSK modulation schemes are employed) and in table 2 (when M-QAM modulation schemes are employed). It is clearly visible from the figures 2(a)-(j) that larger SNR is required for higher antenna configurations (4×4) as compared to lower antenna configurations (3×3) in order to achieve the same amount of BER (10^{-3}). It is clearly visible from the results mentioned in table 1 &2 that M-QAM modulation schemes are providing superior performance as compared to M-PSK modulation schemes.

6.1 Simulations using M-PSK scheme

In this section the results of the performance analysis of MIMO SM scheme using different antenna configuration is presented for M-PSK modulation schemes. It is clearly visible from the figures 2(a)-(j), as antenna configuration goes on increasing the value of SNR required to achieve same amount of BER is also goes on increasing.

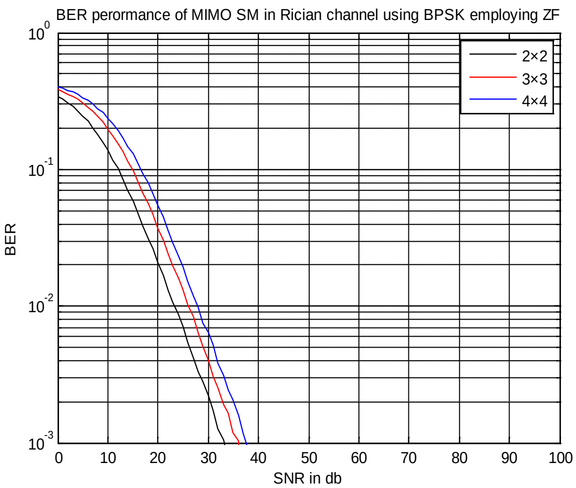

Figure 2 (a) BER performance of MIMO SM using BPSK in Rician channel

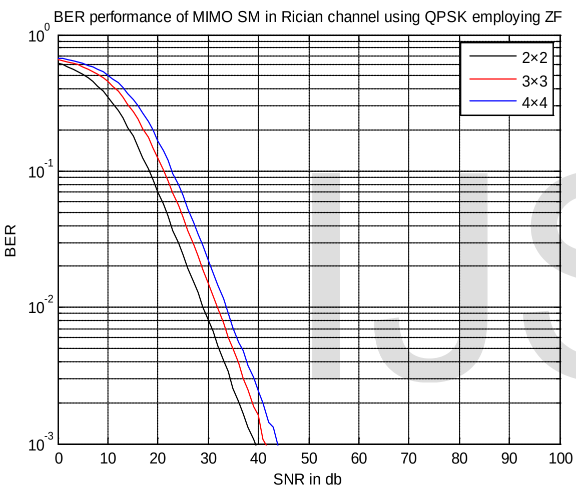

Figure 2 (b) BER performance of MIMO SM using QPSK in Rician channel

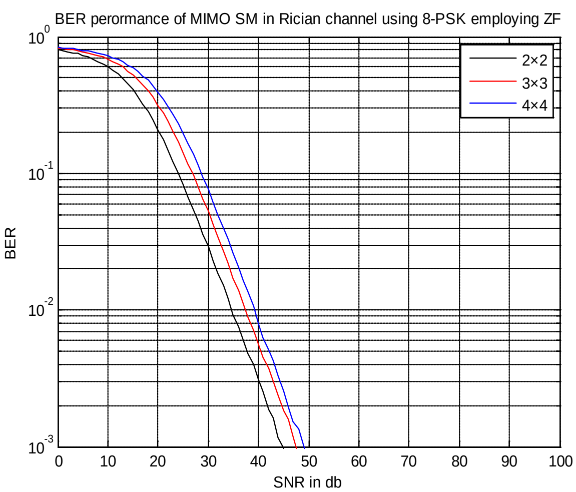

Figure 2 (c) BER performance of MIMO SM using 8-PSK in Rician channel

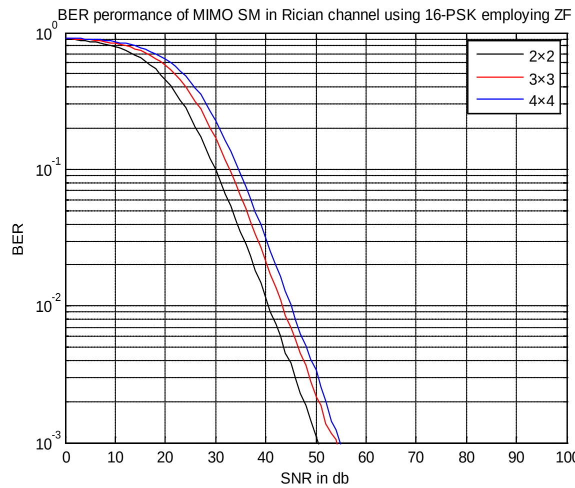

Figure 2 (d) BER performance of MIMO SM using 16-PSK in Rician channel

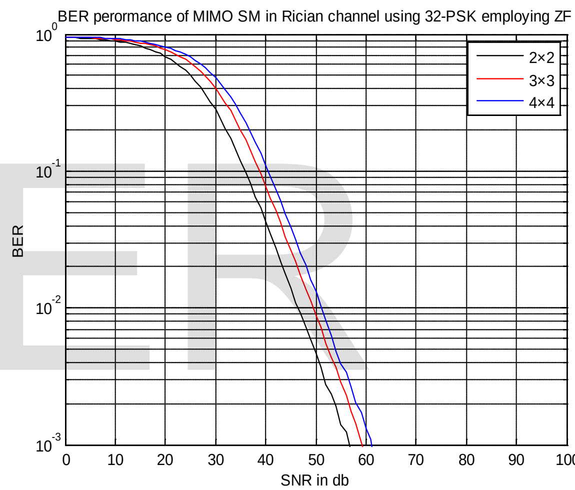

Figure 2(e) BER performance of MIMO SM using 32-PSK in Rician channel

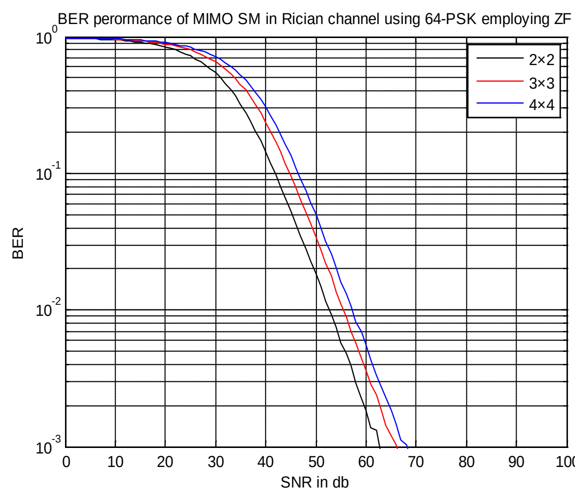

Figure 2(f) BER performance of MIMO SM using 64-PSK in Rician channel

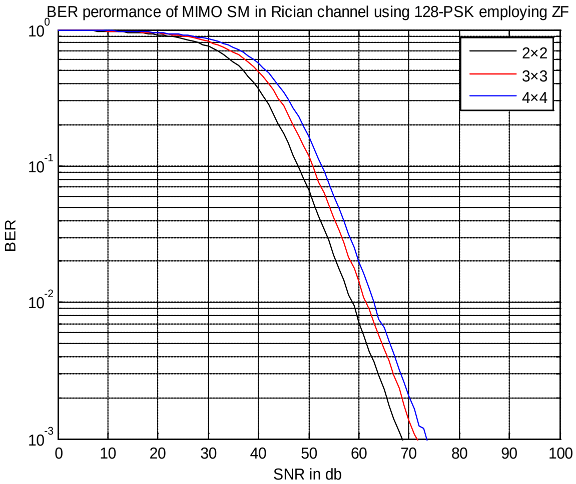

Figure 2(g) BER performance of MIMO SM using 128-PSK in Rician channel

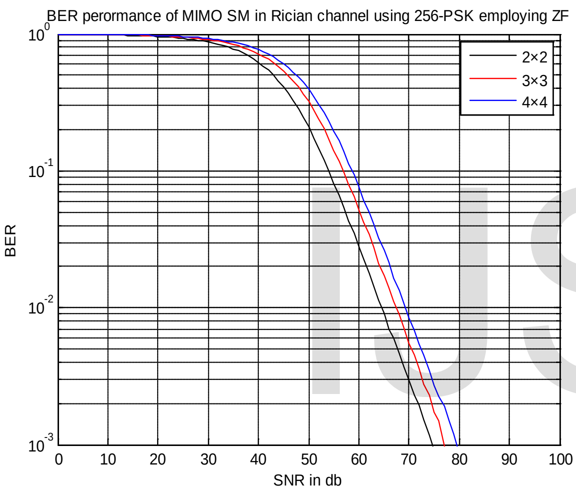

Figure 2(h) BER performance of MIMO SM using 256-PSK in Rician channel

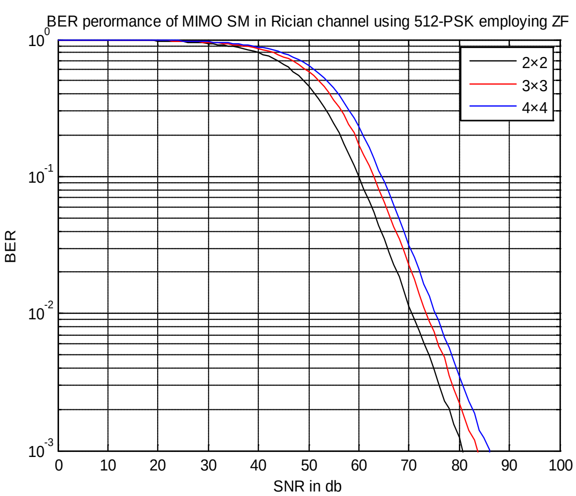

Figure 2(i) BER performance of MIMO SM using 512-PSK in Rician channel

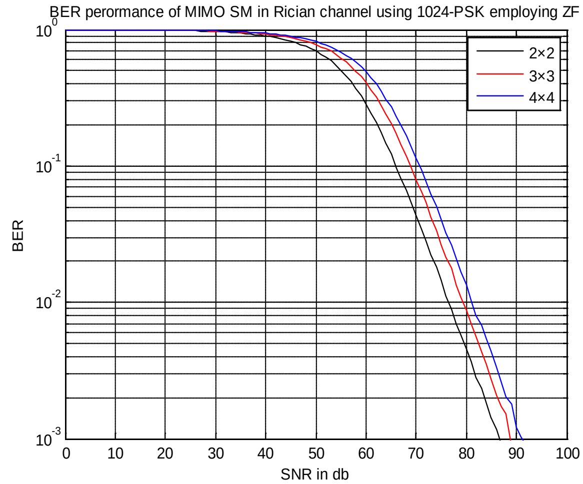

Figure 2(j) BER performance of MIMO SM using 1024-PSK in Rician channel

Figure 2(a)-(j) *BER* vs. SNR plots over Rician channel for MIMO SM technique using different M-PSK modulation schemes

Table 1*:* Comparison of different antenna configurations for MIMO SM technique employing ZF equalizer in Rician channel using M-PSK(M-ary Phase Shift Keying) modulation schemes

Modulation	2×2	3×3	Improvement In SNR	4×4	Improvement In SNR
BPSK	33.2	36.1	2.9	37.6	1.5
QPSK	39.6	42.0	2.4	44.6	2.6
8-PSK	44.8	47.6	2.8	49.1	1.5
16-PSK	50.4	54.1	3.7	54.7	0.6
32-PSK	56.6	59.2	2.6	61.2	2.0
64-PSK	62.7	66.1	3.4	68.1	2.0
128-PSK	68.6	71.6	3.0	73.4	1.8
256-PSK	74.7	76.9	2.2	79.5	2.6
512-PSK	80.7	83.7	3.0	86.0	2.3
1024-PSK	86.6	88.8	2.2	91.2	2.4

In table 1 the value of the SNR required to achieve BER of 10^{-3} in case of MIMO SM is presented when M-PSK modulation schemes are employed in Rician channel. The table 1 provides the improvement in SNR when antenna configurations are shifted from 2×2 to 3×3 and from 3×3 to 4×4 . It is clearly pointing that 0 to 3.8 db improvement in SNR is required to achieve BER of 10^{-3} , when antenna configurations are shifted from 2×2 to 3×3. Similarly an improvement of 0 to 2.7 db is required when antenna configurations are shifted from 3×3 to 4×4 in case of MIMO SM system when M-PSK modulation schemes are employed in Rician channel.

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6.2 Simulations using M-QAM scheme

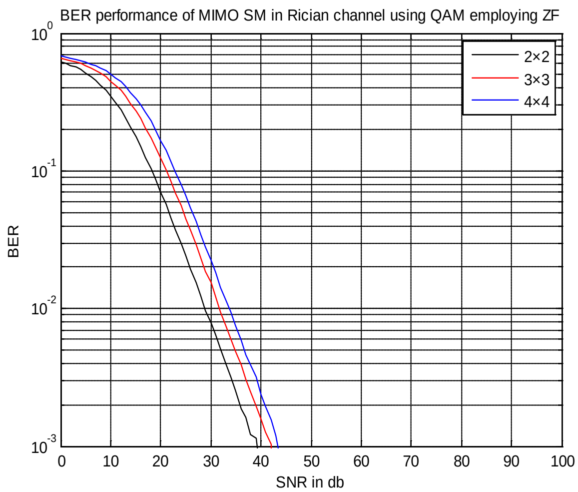

Figure 3(a) BER performance of MIMO SM using QAM in Rician channel

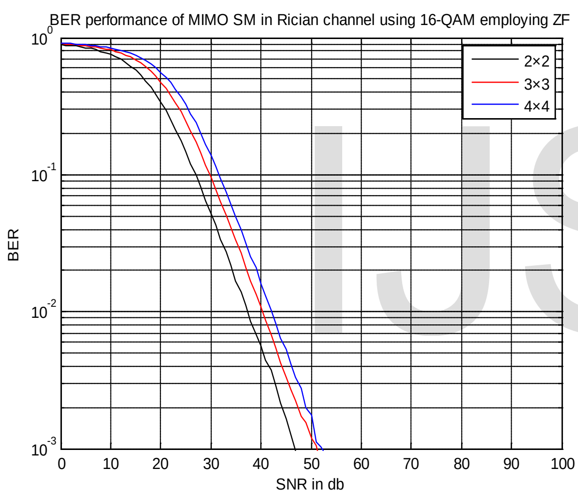

Figure 3(b) BER performance of MIMO SM using 16-QAM in Rician channel

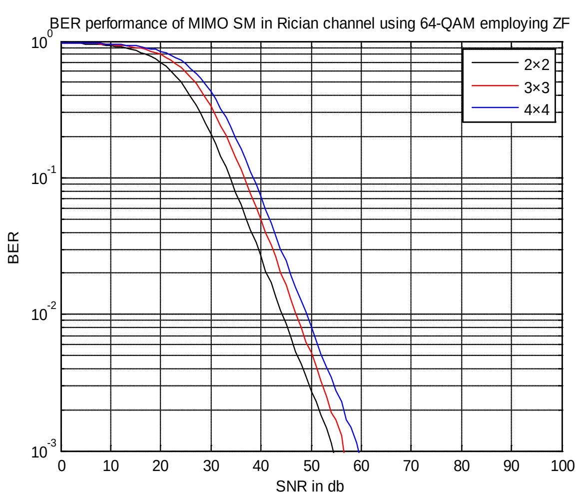

Figure 3(c) BER performance of MIMO SM using 64-QAM in Rician channel

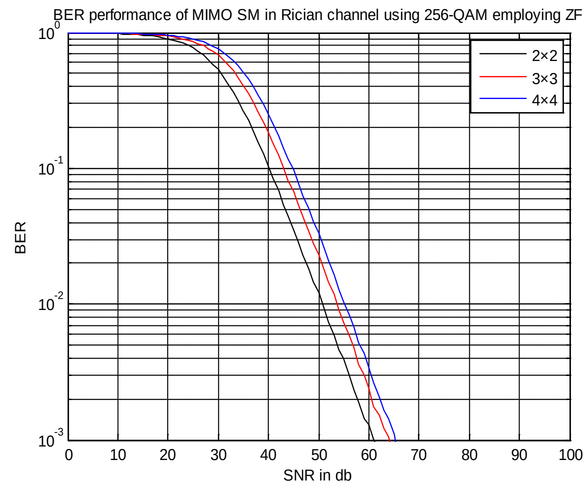

Figure 3(d) BER performance of MIMO SM using 256-QAM in Rician channel

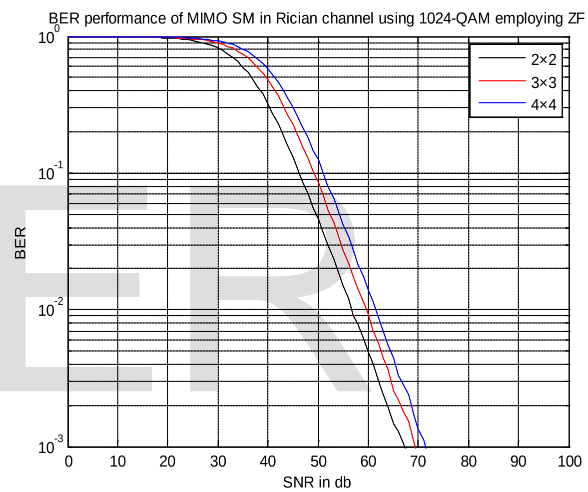

Figure 3(e) BER performance of MIMO SM using 1024-QAM in Rician channel

Figure 3(a)-(e) BER vs. SNR plots over Rician channel for MIMO SM technique using M-QAM modulation schemes.

Table 2: Comparison of different antenna configurations for MIMO SM technique employing ZF equalizer in Rician channel using M-QAM (M-ary Quadrature Amplitude Modulation) modulation scheme

Modulation	2×2	3×3	SNR improvement	4×4	SNR improvement
QAM	39.2	42.1	2.9	43.4	1.3
16-QAM	46.7	51.1	4.4	52.2	1.1
64-QAM	54.5	56.6	2.1	59.5	2.9
256-QAM	61.0	64.1	3.1	65.3	1.2
1024-QAM	67.2	69.3	2.1	71.5	2.2

Table 2 presents that MIMO SM technique employing ZF equalizer requires 0 to 3.2 db increment in SNR to achieve BER of 10^{-3}, if antenna configurations are changed from 2×2 to 3×3 when M-QAM modulation schemes are employed. The table also depicts if antenna configurations are shifted from 3×3 to 4×4, an increment of 0 to 3.0 db is required to achieve BER of 10^{-3}.

7 CONCLUSION

In this paper, the performance of MIMO SM system is presented for different antenna configurations (2×2, 3×3, 4×4) in Rician channel. The MIMO SM system is analysed for higher order modulation schemes (M-PSK, M-QAM). The M-QAM modulation schemes are providing superior performance as compared to M-PSK modulation schemes. An improvement of 0 to 2.8 db in SNR is being notedif antenna configurations are shifted from 2×2 to 3×3. The spectral efficiency gets doubled at the expense of 0 to 6.5 db improvement in SNR that has to be provided in case of MIMO SM system when higher order modulation schemes (M-PSK, M-QAM) are employed in Rician channel.

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