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Performance analysis of different types of multiple antenna systems using BPSK and QPSK modulation

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Abstract: Multiple antenna systems can be considered as one of the most important technologies in modern high speed wireless communication. They provide many types of advantages, diversity gain, multiplexing gain, etc. This paper present implementation and comparison among different types of multiple antennas systems: SIMO (Single input Multiple Output), MISO (Multiple input Single Output) and MIMO (Multiple input Multiple Output), in these schemes, multiple antennas at the transmitter and/or receiver are used to enhance the performance. The Bit Error Rate of Rayleigh fading channels in these schemes are analyzed using BPSK and QPSK Modulation. The MATLAB environment is used to simulate the optimal trade off curve to evaluate the performance of these multiple antenna schemes. The experiment results showed that, the BER decrease as the number of antennas increase and the BPSK modulation gives better performance than QPSK.

Keywords: SIMO, MISO, MIMO, BER, Rayleigh.

Introduction

The next-generation wireless systems are required to have high voice quality as compared to current cellular mobile radio standards and provide high bit rate data services [1], at the same time, the remote units are supposed to be small lightweight pocket communicators. Furthermore, they are to operate reliably in different types of environments: macro, micro, and picocellular; urban, suburban, and rural; indoor and outdoor. In other words, the next generation systems are supposed to have better quality and coverage, be more power and bandwidth efficient, and be deployed in diverse environments [2].

Increased spectral efficiency and improved link reliability are the major challenges in future wireless communication systems. The use of multiple antennas at both ends of a wireless link promises significant improvements in terms of spectral efficiency and/or link reliability [3].

Recently, multiple antenna systems have received a great deal of attention, mainly due to their potential to meet the growing demand of data rates for current and future wireless systems. Current cellular standards have already made provisions for two antennas on the handsets while allowing for more at the basestations. The efficient deployment of multiple antenna elements in practical systems requires algorithms which achieve the desired spectral efficiency at a low computational cost [4].

Wireless Communication has made a tremendous impact on the lifestyle of a human being. Wireless Network provides high speed mobility for voice as well as data traffic from variety sources. The fundamental phenomenon which makes transmission unreliable is time varying fading [5].

A phenomenon is assigned for a constructive and/or destructive interference between signals arriving at the same antenna via different paths, and hence with different delays and phases, resulting in random fluctuations of the signal strength at the receiver. When destructive interference occurs, the signal power can be significantly reduced and the phenomenon is called as fading. Deep fades that may occur at particular time or frequency or in space result in severe degradation of the quality of the signal at the receiver making it sometimes impossible to decode or detect. Multipath fading arises due to the noncoherent combination of signals arriving at the receiver antenna [6].

The classical approach is to use multiple antennas at the receiver and perform combining or selection and switching in order to improve the quality of the received signal by reducing the effect of multipath fading. The major problem with using the receive diversity approach is the cost, size, and power of the remote units. The use of multiple antennas and radio frequency (RF) chains makes the remote units larger and more expensive. As a result, diversity techniques have almost exclusively been applied to base stations to improve their reception quality. A base station often serves hundreds to thousands of remote units. It is therefore more economical to add equipment to base stations rather than the remote units. For this reason, transmit diversity schemes are very attractive [7]. For instance, one antenna and one transmit chain may be added to a base station to improve the reception quality of all the remote units in that base station's coverage area. The alternative is to add more antennas and receivers to all the remote units. The first solution is definitely more economical [8].

Rayleigh fading is a statistical model for the strong influence of a propagation environment on a radio signal, used by wireless communication devices. Rayleigh fading models consider that the magnitude of a signal that has passed through a transmission channel or medium will vary often and in a random manner, or fade, according to a Rayleigh distribution [9].

BPSK is the simplest form of phase shift keying (PSK). Two phases are used here which are separated by 180 degrees and so can also be termed as 2-PSK. It does not particularly matter exactly where the constellation points are positioned in a figure, since it is always shown on the real axis, at 0 degrees and 180 degrees. This modulation technique is the most robust and efficient of all the PSKs since it takes the highest peak of noise or distortion to make the demodulator reach an incorrect decision. In the presence of an arbitrary phase-shift introduced by the communications channel, the demodulator reaches an incorrect decision. For high data rate applications it is mostly unsuitable since it can modulate at 1 bit/symbol [10].

QPSK is also known as quaternary PSK, quadriphase PSK, 4-PSK, or 4-QAM. QPSK uses four points on the constellation diagram, equispaced around a circle. With four phases, QPSK helps to encode two bits per symbol [11].

Common notations have been used in this paper such as H^{-1} denotes inverse matrix operation, H^H and $*$ denote conjugate transposition and complex conjugate operations respectively, H^+ denoting the Moore-Penrose pseudo inverse.

This paper analyzes the performance of SIMO (Single Input Multiple Output) receive diversity combining scheme namely Maximum Ratio Combining (MRC) , MISO (Multiple Input Single Output) transmit diversity scheme namely Alamouti space time block code (STBC) and MIMO (Multiple Input Multiple Output) scheme namely Zero Forcing (ZF).

System Model

This model focused on single-user to single-user communication, it is assumed that the communication is carried out in baseband representation, baseband simulation are faster and yields performance results same as that of passband simulation.

2.1 SIMO (MRC)

A SIMO system with a single transmit antenna and M receive antennas is considered as shown in Figure 1. Maximum ratio combining achieves the maximum signal to noise ratio at the receiver's output by weighting each received replica y_i by the corresponding complex conjugate channel coefficient h_i and then summed.

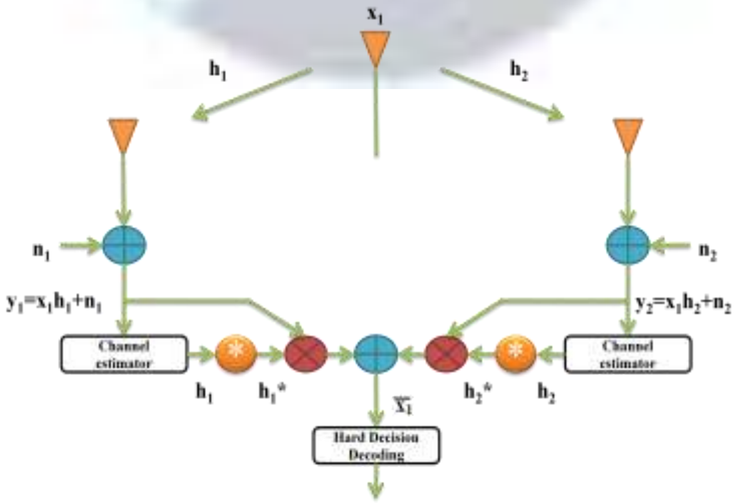

Figure 1: Structure of SIMO system

Firstly, a binary input bit sequence is mapped into a complex valued symbol sequence, where each element is selected from a finite set or constellation alphabet and then transmitted; the signal is then transmitted via the Raleigh fading channel, the received signal is given as:

$$\mathrm{y_i = h_i x + n_i} \quad \dots (1)$$

Where y_i is the $N_r \times 1$ received symbol on the i^{th} receive antenna, h_i is the $N_r \times 1$ channel matrix of the fading, x is the transmitted symbol and n_i is the $N_r \times 1$ additive white Gaussian noise.

It is assumed that the transmitted signal x is normalized to have average transmit power of unity in one symbol; the channel is assumed to be flat fading and known at the receiver (e.g., using training sequences).The estimated symbol after equalization is,

$$\hat{\mathrm{x}} = \frac{\mathrm{h^H y}}{\mathrm{h^H h}} = \frac{\mathrm{h^H hx}}{\mathrm{h^H h}} + \frac{\mathrm{h^H n}}{\mathrm{h^H h}} = \mathrm{x} + \frac{\mathrm{h^H n}}{\mathrm{h^H h}} \quad \dots (2)$$

Then a hard decision decoding is used to find the transmitted symbol.

2.2 MISO (Alamouti STBC)

Consider a MISO system with 2 antennas at the transmitter and one antenna at the receiver as shown in Figure 2. Two symbols x_1 and x_2 are transmitted simultaneously from antennas 1 and 2 during the first symbol period, followed by symbols $-x_2^*$ and x_1^* transmitted from antennas 1 and 2 during the next symbol period. Assuming that the flat fading channel remains constant over the two successive symbol periods,

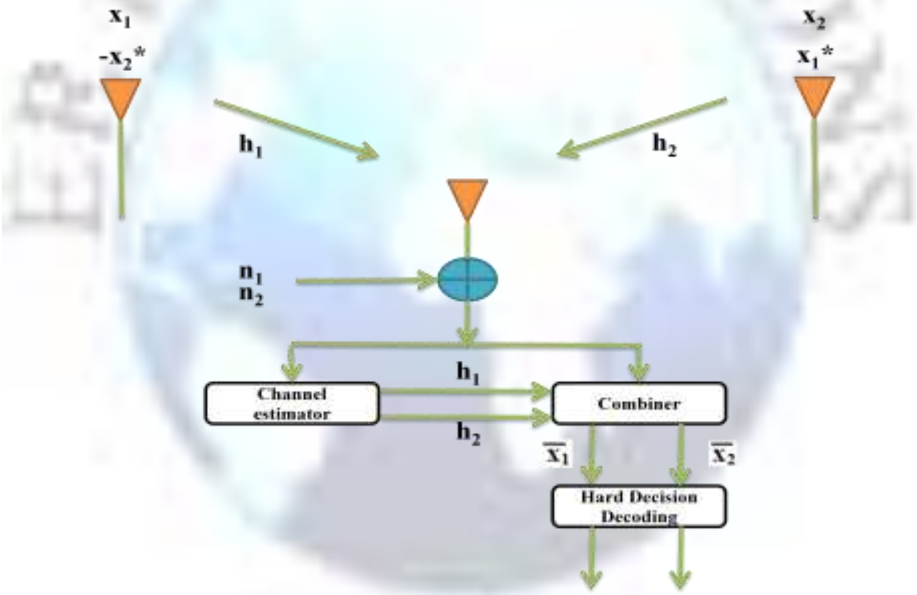

Figure 2: Structure of MISO system

So that in first time slot, the received signal is,

$$\mathrm{y_1 = h_1 x_1 + h_2 x_2 + n_1} \quad \dots (3)$$

In second time slot, the received signal is,

$$\mathrm{y_2 = -h_1 x_2^* + h_2 x_1^* + n_2} \quad \dots (4)$$

Where y_1, y_2 is the received symbols on the first and second time respectively, h_1 is the channel from the first transmit antenna to the receive antenna, h_2 is the channel from the second transmit antenna to the receive antenna and n_1, n_2 is the noise on first and second time slots.

The above equations can be represented in matrix form as follows:

$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \quad \dots (5)$$

Let the channel defined as

$$H = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}$$

To find x_1, x_2 , the inverse of H is needed. As assumed before the receiver knows h_1 and h_2 , the estimated symbols transmitted are,

$$\begin{aligned} \begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} &= H^{-1} \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} \\ &= H^{-1} \left(H \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \right) \\ &= \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + H^{-1} \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \end{aligned} \quad \dots (6)$$

2.3 MIMO (ZF)

Figure 3 illustrates the system architecture used for MIMO wireless communications with 2 transmit antennas and M receive antennas. MIMO systems use multiple sources and multiple receivers to improve communication performance, Allowing for higher spectral efficiency.

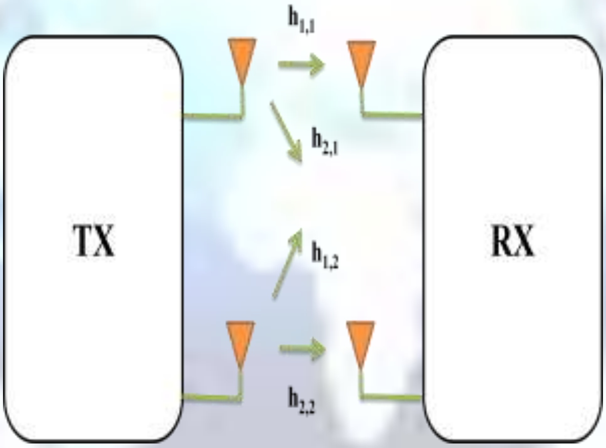

Figure 3: Structure of MIMO system

In first time slot, the signal on the first receive antenna is,

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 \quad \dots (7)$$

The signal on the second receive antenna is,

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 \quad \dots (8)$$

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

As assumed before the receiver knows $h_{1,1}, h_{1,2}, h_{2,1}, h_{2,2}$. Also the receiver knows y_1, y_2. The unknowns are x_1, x_2.

The above equations can be represented in matrix form as follows:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad \ldots (9)$$

To find x_1, x_2, the inverse of H is needed.

$$H^{+} = (H^{H}H)^{-1}H^{H} \quad \ldots (10)$$

This matrix is known as (pseudo inverse) for a general $M \times N$ matrix. The estimates of the transmitted symbols are,

$$\begin{aligned} \begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} &= (H^{H}H)^{-1}H^{H} \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \\ &= (H^{H}H)^{-1}H^{H} \left(H \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \right) \\ &= \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + (H^{H}H)^{-1}H^{H} \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \end{aligned} \quad \ldots (11)$$

Model Assumptions

1- The channel is known at the receiver.
2- Systems operate in slow Rayleigh flat fading.
3- There is synchronization between the transmitter and receiver.

Results and Discussions

In this section, The BER performance of the three systems in Rayleigh fading channels has been analyzed with two basic different modulation schemes (BPSK and QPSK); a BER of 10^{-3} is used as an operating point. Also It is assumed that the total transmit power from the two antennas for the MISO and MIMO is the same as the transmit power from the single transmit antenna for SIMO. These systems are software implemented with the m-file of MATLAB R2012b technical programming language.

Figure 4 shows the simulation results for SIMO, the diversity gain is about 12.77, 17.303, 19.895 and 21.537 dB at $nRx = 2, 3, 4$ *and* 5 respectively for both BPSK and QPSK, the BPSK scheme performed better giving lower value of BER than the corresponding QPSK scheme.

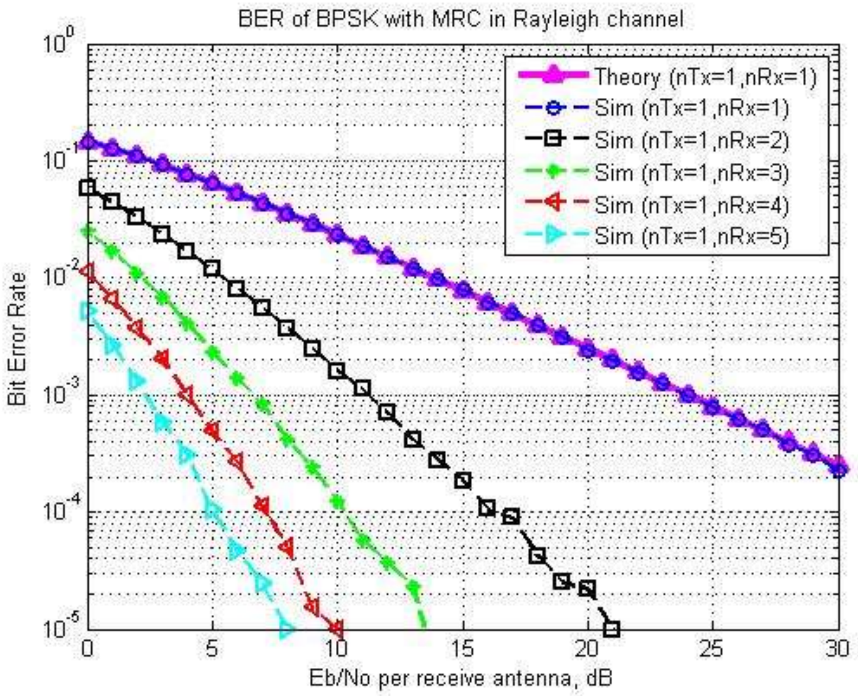

Figure 4-a: Performance of SIMO MRC for BPSK modulation

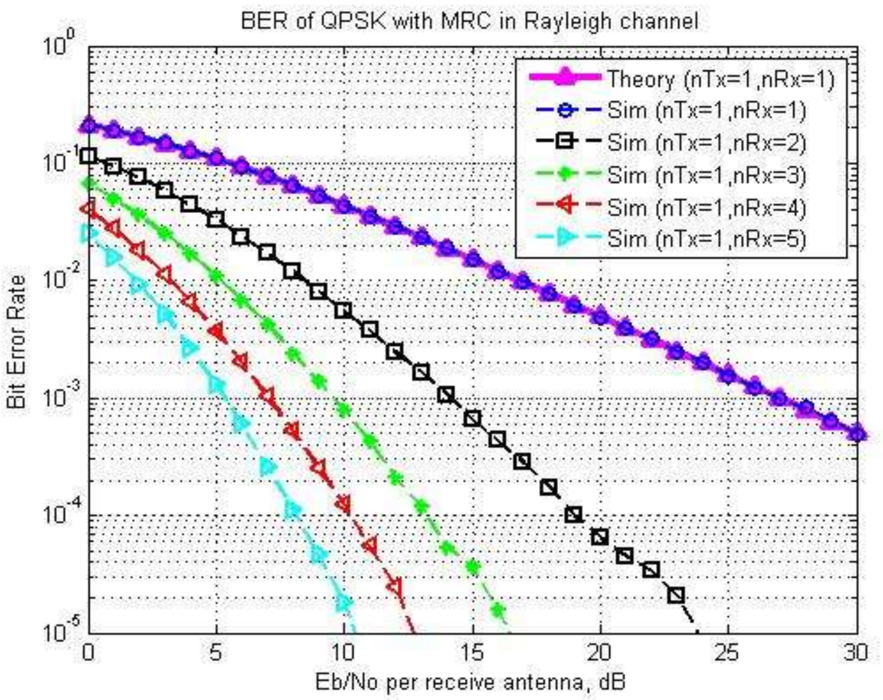

Figure 4-b: Performance of SIMO MRC for QPSK modulation

In Figure 5 the simulation results for MISO are shown, the diversity gain is about 9.81 dB at number of transmitting antennas $nTx = 2$; the diversity gain in this scheme is less than the corresponding $nTx = 1, nRx = 2$ SIMO scheme of about 3 dB.

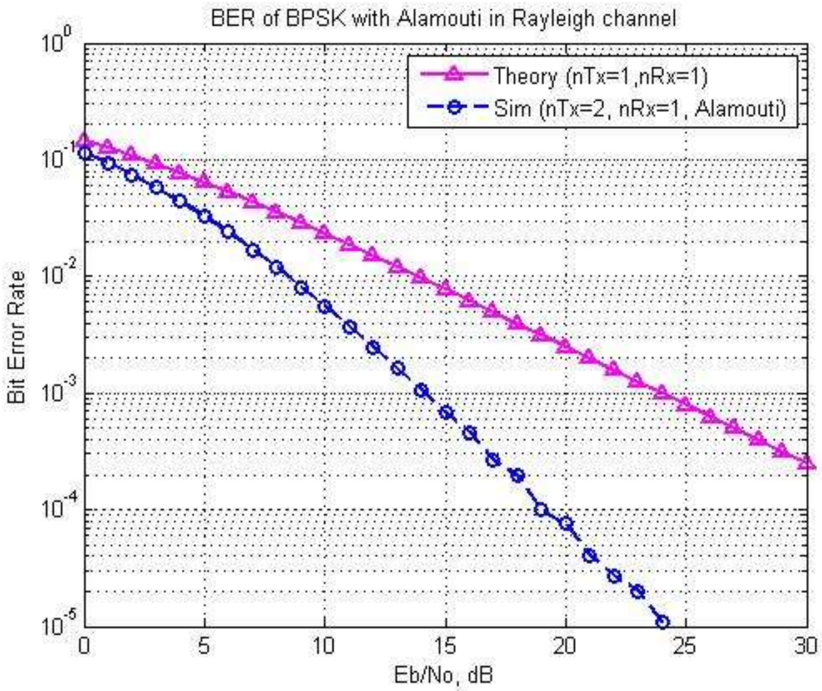

Figure 5-a: Performance of MISO Alamouti for BPSK modulation

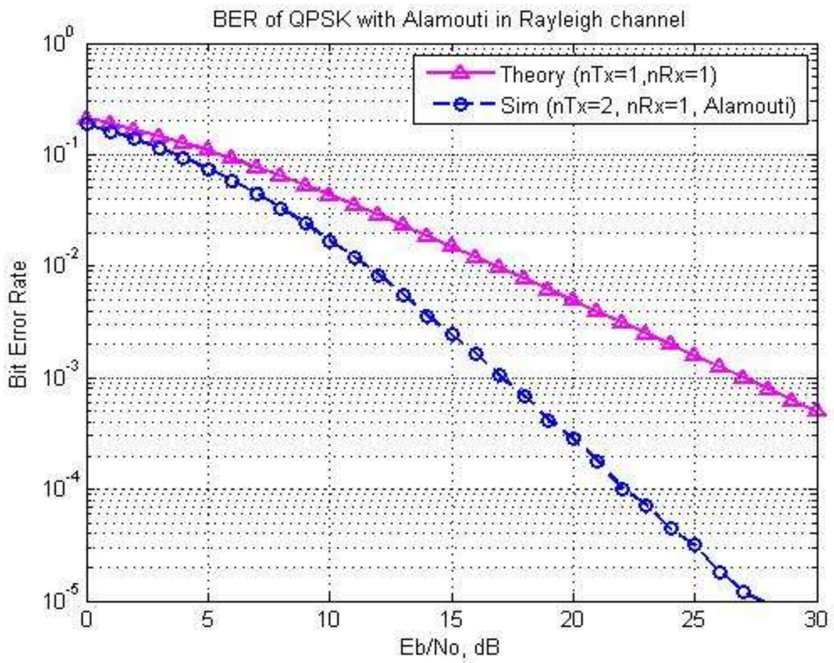

Figure 5-b: Performance of MISO Alamouti for QPSK modulation

Finally, Figure 6 shows the results for MIMO, the diversity gain is about 12.63, 17.245 and 19.736 dB at $nRx = 2, 3$ *and* 4 respectively, the result in this scheme is similar to that of SIMO scheme but the capacity here is twice.

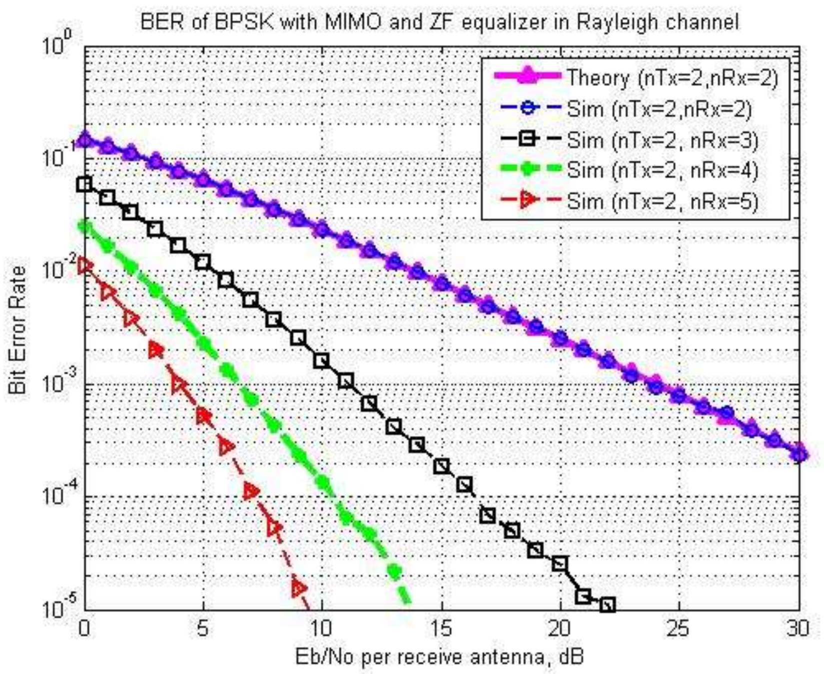

Figure 6-a: Performance of MIMO ZF for BPSK modulation

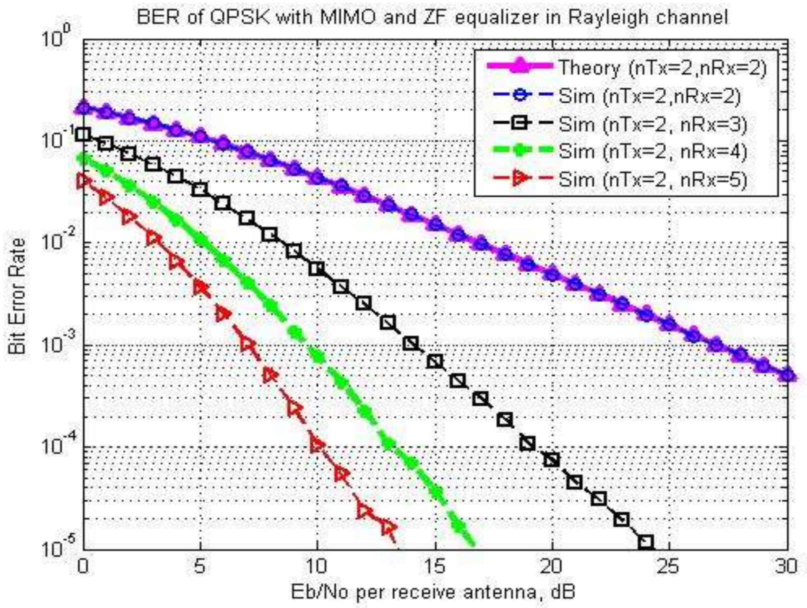

Figure 6-b: Performance of MIMO ZF for QPSK modulation

Conclusions

When the BER was evaluated under BPSK and QPSK modulation schemes for Rayleigh fading channels, the result show that the number of errors in the BPSK modulation scheme is less when compared to the number of errors in the QPSK modulation scheme. Thus the performance analysis of Rayleigh Fading Channels in these systems under BPSK modulation scheme is found to be more efficient. The diversity gain in SIMO-MRC scheme is the same as that of MIMO-ZF but in the MIMO the capacity is twice, the simulated result showed that the BER decrease as the number of antennas increase.

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