

Performance Analysis of MIMO Systems over Rayleigh Channel with antenna selection using Zero Forcing Receivers

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Abstract – Multiple-input multiple-output (MIMO) have been employed in present wireless systems to achieve high data rates within the limited radio frequency (RF) spectrum. MIMO systems make use of multiple transmitting antennas and multiple receiving antennas. The performance analysis of MIMO system over Rayleigh fading channel with ZF receiver is presented. It can be improved by making use of spatial diversity which can be employed using multiple transmitters and receivers. The BER is analyzed for M-PSK modulation over Rayleigh Channel and effects of the antenna selection is also presented in the paper using simulated results.

Keywords – Multiple-Input, Multiple-Output, RF, spatial diversity, Rayleigh, Bit Error Rate, Zero Forcing, M-ary Phase shift Keying, fading

I. INTRODUCTION

High data rates can be achieved using multiple antennas employed at transmitter and receiver in wireless communication through spatial multiplexing [1]. Some future trends of wireless communication are mentioned below which leads to the use of MIMO:

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

Wireless communication using multiple-input multiple-output (MIMO) systems enables increased spectral efficiency for a given total transmit power. Increased capacity is achieved by introducing additional spatial channels that are exploited by using space-time coding [2]. The MIMO is to improve BER or data rate (bits/sec) by using multiple TX/RX antennas. For

achieving high data rate or improved BER, the core scheme used in MIMO system is space-time coding (STC). An efficient implementation of space-time block coding (STBC) for broadband wireless communications 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[3][4].

MIMO systems provide a number of advantages over single-antenna-to-single-antenna communication. Sensitivity to fading is reduced by the spatial diversity provided by multiple spatial paths [5]. Under certain environmental conditions, the power requirements associated with high spectral-efficiency communication can significantly reduced by avoiding the compressive region of the information-theoretic capacity bound. Spectral efficiency is defined as the total number of information bits per second per Hertz transmitted from one array to the other.

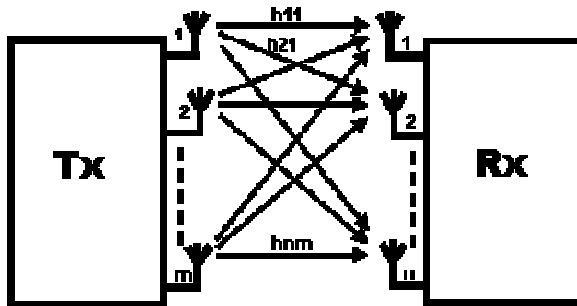


Fig. 1.1: Block Diagram of MxN MIMO System

The block diagram of MIMO system is shown in the Fig. 1.1. In this paper, we are considering the effects of Rayleigh channel on the performance of MIMO systems with different antenna selection using Zero Forcing receivers. Data experiences much impairment during transmission, especially noise in the channel.

A simple two-branch transmit diversity scheme was presented by S. Alamouti [6]. The scheme uses two transmit antennas and one receive antenna. It provides the same diversity order as maximal-ratio receiver combining (MRR) with one transmit antenna, and two receive antennas.

The comparison of MIMO with SISO technology was discussed by S. G. Kim et. al [7]. MIMO can 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.

A. I. Sulyman [8] describes the impact of antenna selection on the performance of multiple input-multiple output (MIMO) systems over nonlinear communication channels. The author has derived exact analytical expressions for evaluating the

PWEP performance of space-time trellis codes over nonlinear MIMO channel.

V. Tarokh et.al [9] 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.

C. Wang [10] explains the approach to increase the capacity of MIMO systems by employing the spatial multiplexing where independent information streams are transmitted from the antennas. These information streams are then separated at the receiver by means of appropriate signal processing techniques such as maximum 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.

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 was discussed by C. Chen [11].

II. MODULATION TECHNIQUE

Modulation is the process of conveying a message signal, for example a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted. A modulator performs modulation and a demodulator performs the

inverse operation of modulation. 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:

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

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.

$$\theta = 2(i-1)\pi/M \quad i = 1, 2, \dots, M \quad (1.2)$$

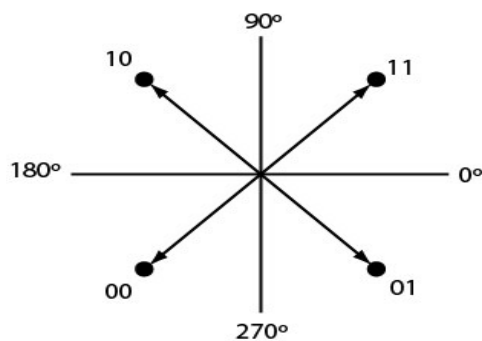


Fig. 1.2: Signal Constellation Diagram for 4-PSK

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.

III. CHANNELS

(A) MIMO CHANNEL

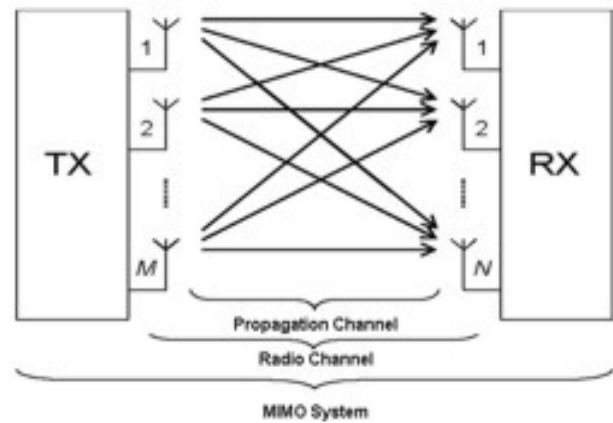


Fig. 1.3: The MIMO Channel

Fig. 1.3 represents the $M \times N$ MIMO channel with an antenna array with M elements at the transmitter and an antenna array with N elements at the receiver is considered.

The input-output notation of the MIMO system can now be expressed by the equation:

$$y(t) = H(\tau, t) \otimes s(t) + u(t) \quad (1.3)$$

where \otimes denotes convolution, $s(t)$ is a $n_t \times 1$ vector corresponding to the n_t transmitted signals, $y(t)$ is a $n_r \times 1$ 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 $n_r \times n_t$ $H(\tau, t)$ matrix:

$$H(\tau, t) = \begin{bmatrix} h_{1,1}(\tau, t) & h_{1,2}(\tau, t) & \dots & h_{1,n_t}(\tau, t) \\ h_{2,1}(\tau, t) & h_{2,2}(\tau, t) & \dots & h_{2,n_t}(\tau, t) \\ \vdots & \vdots & \ddots & \vdots \\ h_{n_r,1}(\tau, t) & h_{n_r,2}(\tau, t) & \dots & h_{n_r,n_t}(\tau, t) \end{bmatrix} \quad (1.4)$$

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 .

(B) RAYLEIGH CHANNEL

Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called a communications channel) will vary randomly, or fade, according to a Rayleigh distribution. The Rayleigh distribution is basically the magnitude of the sum of two equal independent orthogonal Gaussian random variables and the probability density function (pdf) is given by:

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}} \quad 0 \leq r \leq \infty \quad (1.5)$$

IV. ZERO FORCING EQUALIZER

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

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. The name Zero Forcing corresponds to bringing down the inter symbol interference (ISI) to zero in a noise free case. This will be useful when ISI is significant compared to noise.

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 intersymbol interference (ISI).

The zero-forcing equalizer removes all ISI, and is ideal when the channel is noiseless. However, when the channel is noisy, the zero-forcing equalizer will amplify the noise greatly at frequencies f where the channel response $H(j2\pi f)$ has a small magnitude (i.e. near zeroes of the channel) in the attempt to invert the channel completely.

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

$$y = Hx + n \quad (1.6)$$

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

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix} \quad (1.7)$$

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,

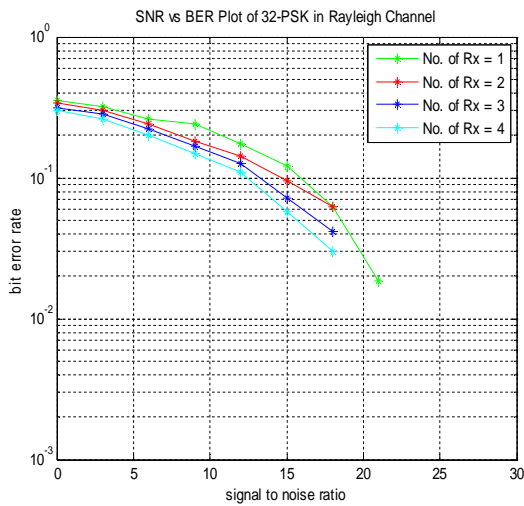
$h_{2,2}$ is the channel from 2nd transmit antenna to the 2nd receive antenna,

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

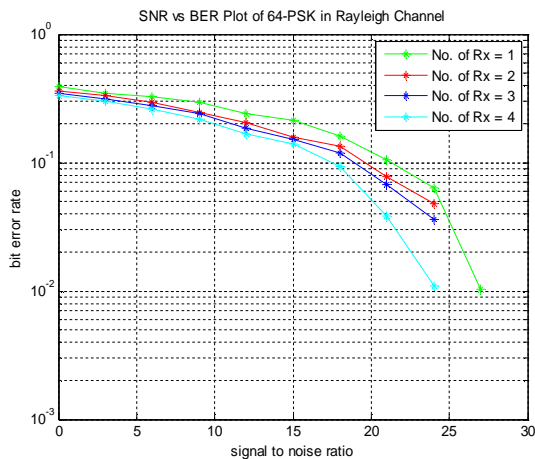
V. SIMULATED RESULTS

In this section, the Bit Error Rate analysis of MIMO system over Rayleigh channel using STBC code structure is done for M-PSK Modulation.. The BER analysis of MIMO system is done for M-PSK over Rayleigh fading channel 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.

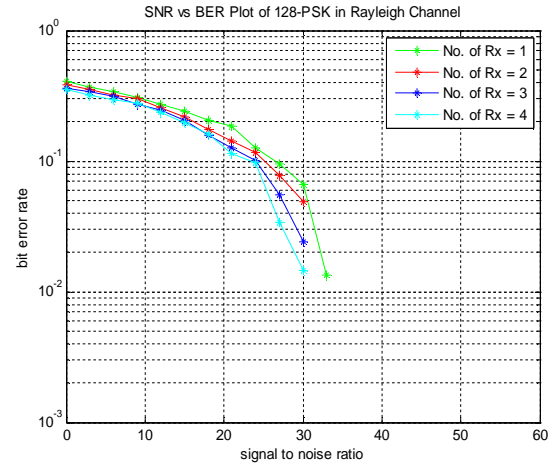
(A) M-PSK over Rayleigh Channel



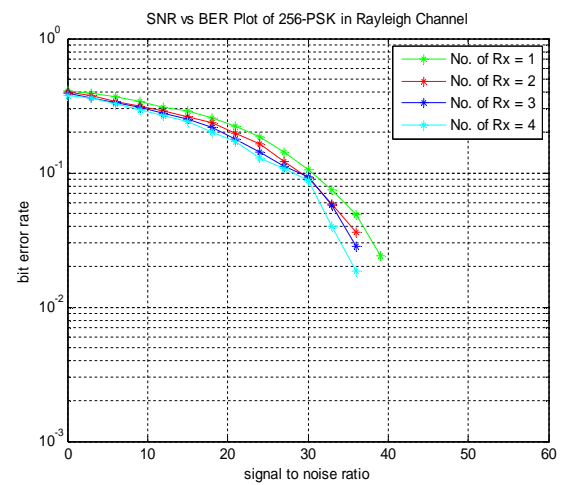
(a) 32-PSK



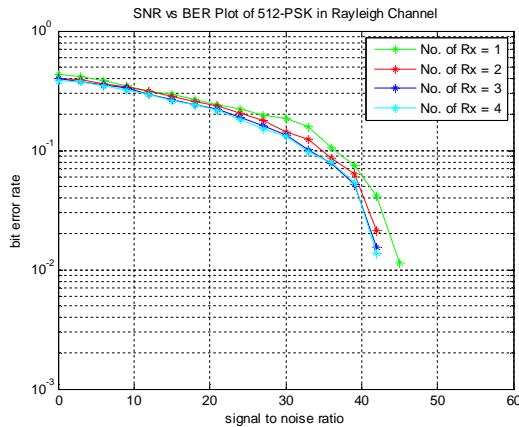
(b) 64-PSK



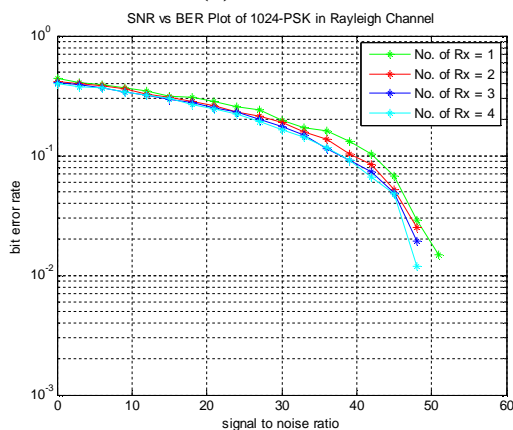
(c) 128-PSK



(d) 256-PSK



(e) 512-PSK



(f) 1024-PSK

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

SNR vs. BER plots for M-PSK over Rayleigh channel for MIMO system with different antenna configurations are as shown in Fig. 1.4 (a) – (f), have been presented. From the graphs, it can be concluded that the BER keeps on decreasing as we goes on increasing the number of receiving antennas in the MIMO system due to the space diversity. Thus the system provides better BER performance.

VI. CONCLUSION

In this paper, the performance analysis of MIMO system over Rayleigh fading channel employing different antenna configurations 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. Here we have used receiving antennas ranging from NR = 1 to NR = 4. Spatial diversity techniques are used so as to have good signal quality and coverage. The multiple transmitting and receiving antennas are used to combat multipath fading and enhance SNR.

VII. REFERENCES

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