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Optimized Behaviour of MIMO System under Different Equalization Techniques and Modulation Schemes over Rayleigh and Rician Fading Channels

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Abstract-Wireless communications using Multiple-Input Multiple-Output (MIMO) links has emerged as one of the most significant breakthroughs in modern communications because of the huge capacity and reliability gains promised even in worst fading environment. This paper presents the optimized behaviour of MIMO systems over Rayleigh and Rician Fading channel environments. MIMO transmission systems are investigated in terms of Bit Error Rate (BER) performance. BER performance of MIMO systems is simulated for different transmit-receiver combinations such as 2×2, 2×3 and 2×4 using BPSK and QPSK modulation schemes and various equalization techniques such as Zero Forcing (ZF), Minimum Mean Square Error (MMSE) and Maximum Likelihood (ML). Results show that the BER performance of a MIMO system using BPSK modulation and ML equalizer over Rician fading channel is optimum compared to the choice of other modulation schemes, equalizers and fading channels.

***Keywords*— MIMO, ZF, MMSE and ML equalizers, Multiple antennas, fading channels, BPSK, QPSK, BER.**

I. INTRODUCTION

A mobile radio channel is characterized by a multipath fading environment. The signal is offered to the receiver contains not only Line Of Sight of radio wave, but also a large number of reflected waves that arrive at different times. Delayed signals are the result of reflections from terrain features such as trees, hills, mountains, vehicles or buildings. These reflected delayed waves interfere with direct waves and cause Inter Symbol Interference (ISI) which causes significant degradation of network performance. Multiple-Input Multiple-Output (MIMO) wireless antenna systems have been recognized as a key technology for future wireless communications because it offers significant increases in data throughput and link range without additional bandwidth or transmit power. One common approach to exploit the capacity of MIMO system is to employ spatial multiplexing where independent information streams are then separated at the receiver by means of appropriate signal processing techniques such as Maximum Likelihood (ML), Minimum-Mean-Square-Error (MMSE) and Zero-Forcing (ZF) detectors. The better detector that minimizes the bit error

probability is the ML detector. But, the ML detector is practically difficult as it has computational complexity is exponential. The ZF detector and MMSE detector have lesser computational calculations as they require only a matrix operation to be carried out, e.g. pseudo-inverse. However error performance in case of both ZF and MMSE detector are greatly lower than the optimal ML detector.

In previous work [4], [5], for a 2×2 and 4x4 MIMO system for different equalization techniques such as ZF, MMSE and ML has been analyzed and it showed that the MIMO receiver with ML detection has the least BER for a given SNR for 4x4 MIMO. In [6], the performance of MIMO system with ZF detectors over Rayleigh & Rice fading channels are studied and the degradation in the performance of MIMO systems under exponential correlation matrix is investigated and analyzed and it is found that the SNR degradation is related to the Rician factor K.

In this paper we have simulated BER performance for different SNR by different equalizers like ZF, MMSE and ML. And also for 2×2, 2×3, 2×4 MIMO system and comparison of BER by different modulation techniques over Rayleigh and Rician fading channels. The aim of the study is to identify the MIMO technology that gives best bit error rate (BER) performance of different equalizers and transmit-receiver combinations of MIMO by BPSK and QPSK modulation techniques over Rayleigh and Rician fading channels using MAT LAB simulation.

II. MIMO SYSTEM MODEL

A. MIMO system model

We consider a MIMO system as shown in Fig.1 with array of Nt transmit antennas and Nr receiving antennas.

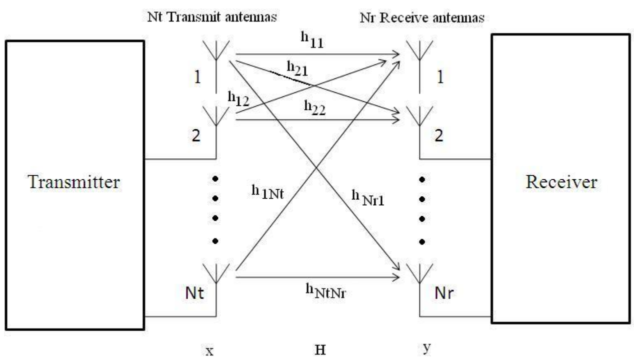

Figure 1. MIMO System

The received signal denoted by y are represented by Nrx1 column matrix (2). The received signal yj in the jth antenna is

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given by

$$y_j = \sum_{k=1}^{Nt} h_{jk} x_k + n_j \qquad (1)$$

Where, j = 1, 2, 3...Nr, the wireless channel between transmitter and receiver is described by Nr × Nt complex matrix(3), denoted by H. h_{jk}(H) is the fading corresponding to the path from transmit antenna k to receive antenna j. The transmitted signals denoted by x_k (x) in each symbol period are represented by an $Nt \times 1$ column matrix (4). Similarly, the noise at the receiver is represented by $Nr \times 1$ column matrix (5), denoted by n. n_j(n) is the noise corresponding to receive antenna j. The received vector can be represented as

$$Y = Hx + n$$

$$y = \begin{bmatrix} y_1 \\ y_2 \\ . \\ . \\ . \\ y_{Nt} \end{bmatrix} \ldots (2), \quad H = \begin{bmatrix} h_{11} & h_{12} & . & . & h_{1Nt} \\ h_{21} & h_{22} & . & . & h_{2Nt} \\ . & . & . & & . \\ . & . & & . & . \\ . & . & & & . \\ h_{Nr1} & h_{Nr2} & . & . & h_{NrNt} \end{bmatrix} \ldots (3)$$

$$x = \begin{bmatrix} x_1 \\ x_2 \\ . \\ . \\ . \\ x_{Nr} \end{bmatrix} \ldots.. (4), \qquad n = \begin{bmatrix} n_1 \\ n_2 \\ . \\ . \\ . \\ n_{Nr} \end{bmatrix} \ldots.. (5)$$

Transmitter part

At the transmitter firs, the data is generated from a random source, consists of a series of ones and zeros. Data input bits are converted into symbol vector using modulation. Modulation scheme used to map the bits to symbols are BPSK and QPSK.

For the BPSK modulation, a series of binary input message bits are generated of which 1´s are represented by 1 and 0´s are translated as -1.

For the QPSK modulation, a series of binary input message bits are generated. In QPSK, a symbol contains 2 bits. The generated binary bits are combined in terms of two bits and QPSK symbols are generated. From the constellation of QPSK modulation the symbol ’00′ is represented phase rotation) and ’11′ by -j (270 degrees phase rotation by 1, ’01′ by j (90 degrees phase rotation), ’10′ by -1 (180 degrees).

MIMO Channel part

i. Rayleigh Fading Channel

In wireless telecommunications, multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. Causes of multipath include atmospheric ducting, ionosphere reflection and refraction, and reflection from water bodies and terrestrial objects such as mountains and buildings. The effects of multipath include constructive and destructive interference, and phase shifting of the signal. This causes Rayleigh fading. The standard statistical model of this gives a distribution known as the Rayleigh distribution. Rayleigh fading is a term used when there is no direct component, and all signals reaching the receiver are reflected. The Rayleigh probability density function of the received signal envelope, *p(r)*, is given by

$$p(r) = \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right) \text{ When r} \geq 0 \qquad (6)$$

Where r is the envelope amplitude of the received signal σ^2 is the variance of the random variable and $2\sigma^2$ is the average power of the multipath signal.

ii. Rician Fading Channel

A Rician fading channel occurs when the receiver signal is a combination of a significant line of sight path and multiple fading paths between a transmitter and receiver. The line of sight path is the strongest signal path that travels directly from the transmitter to receiver. Because of the line of sight path, the effect of Rician fading on the transmitted signal will be less than in the case of Rayleigh fading. The Rician probability density function of the received signal envelope is given by

$$p(r) = \frac{r}{\sigma^2}\left[-\frac{(r^2 + A^2)}{2\sigma^2}\right] I_0\left(\frac{rA}{\sigma^2}\right) \text{ For } r \geq 0, A \geq 0 \qquad (7)$$

Where $I_0(.)$ is the modified Bessel function of zero order and A is the peak magnitude of the line of sight component and the multipath components.

MIMO channel with 2×2 configuration

Let us, consider a 2×2 MIMO channel with two transmit two receive antennas. Consider a transmission sequence $x_1 x_2 \ldots.. x_{Nt}$. In normal transmission, we will send *x*, in the first time slot, x_2 in the second time slot, and so on. In the present case, we have two transmit antennas, so we may group the symbols into groups of two. In the first time slot, x_1x_2 send from the first and second antenna. In second time slot x_3x_4 send from the first and second antenna and so on. As we are grouping two symbols and sending them in one time slot, we need only r/2 time slots to complete the transmission. It is the formations of a probable MIMO transmission scheme containing 2 transmit antennas and 2 receive antennas.

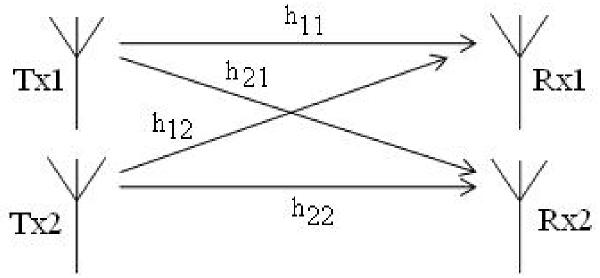

Figure 2. 2×2 MIMO configuration

From the figure let us now try to solve the math for extracting the two symbols which is interfered with each other. In the first time slot, the received signal on the first receiver antenna is,

$$y_1 = h_{11}x_1 + h_{12}x_2 + n_1 = [h_{11}h_{12}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \qquad \ldots (8)$$

The received signal on the second receiver antenna is

$$y_2 = h_{21}x_1 + h_{22}x_2 + n_1 = [h_{21}h_{22}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \quad \dots (9)$$

Where y_1, y_2 are the received symbol on the first and second antenna respectively, h_{11} is the channel from 1st transmit antenna to 1st receive antenna, h_{12} is the channel from 2nd transmit antenna to 1st receive antenna, h_{21} is the channel from 1st transmit antenna to 2nd receive antenna, h_{22} is the channel from 2nd transmit antenna to 2nd receive antenna, x_1,x_2 are the transmitted symbols and n_1, n_2 is the noise on 1st, 2nd receive antenna. We assume that the receiver knows h_{11}, h_{12}, h_{21} and h_{22}. The receiver also knows y_1 and y_2. The unknowns are x_1 and x_2.

For convenience, the above equation can be represented in matrix formation as follows:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

B. Detectors

1) Zero Forcing (ZF)

An ISI channel may be modeled by an equivalent finite-impulse response (FIR) filter plus noise. A zero-forcing equalizer uses an inverse filter to compensate for the channel response function. In other words, at the output of the equalizer, it has an overall response function equal to one for symbol that is being detected and an overall zero response for other symbols. If possible, this results in the removal of the interference from all other symbols in the absence of the noise. Zero Forcing is linear equalization method that does not consider the effect of noise.

Let us assume the case that $Nt = Nr$ and H is a full rank square matrix. In this case, the inverse of the channel matrix H exists and if we multiply both sides of equation (3) by H^{-1} , we have

$$yH^{-1} = x + nH^{-1} \quad \dots (10)$$

From the above equation we can see that symbols are separated from each other. To solve for x, we know that we need to find a matrix W which satisfies $WH=1$. The Zero Forcing linear detector for meeting this constraint is given by

$$W = \left(H^H H\right)^{-1} H^H \quad \dots (11)$$

2) Minimum Mean Square Error (MMSE)

The MMSE receiver suppresses both the interference and noise components, whereas the ZF receiver removes only the interference components. This implies that the mean square error between the transmitted symbols and the estimate of the receiver is minimized.

The Minimum Mean Square Error (MMSE) approaches tries to find a coefficient W which minimizes the criterion,

$$E\left\{\left[W_y - x\right]\left[W_y - x\right]^H\right\} \text{ Solving,}$$

$$W = \left[H^H H + N_0 I\right]^{-1} H^H \quad \dots (12)$$

When comparing to the equation in Zero Forcing equalizer, apart from the $N_0 I$ term both the equations are comparable. In fact when the noise term is zero, the MMSE equalizer reduces to Zero Forcing equalizer.

) Maximum Likelihood (ML)

The Linear detection methods require much lower complexity than the optimal ML detection, but their performance is significantly inferior to the ML detection. Maximum Likelihood detection calculates the Euclidean distance between received signal vector and the product of all possible transmitted signal vectors with the given channel H, and finds the one with minimum distance. Let C and Nt denotes a set of signal constellation symbol points and a number of transmit antennas, respectively. Then, ML detection determine the estimated transmitted signal vector x as

$$\hat{x}_{ML} = \arg_{x \in C^{Nt}} \min \|y - Hx\|^2 \quad \dots (13)$$

Where $\|y - Hx\|^2$ corresponding to the ML metric. The ML method achieves the optimal performance as the maximum a posterior detection when all the transmitted vectors are likely. However, its complexity increases exponentially as modulation order and/or the number of transmit antennas increases.

III. SIMULATION RESULTS

The BER values have been computed as a function of SNR in MIMO Rayleigh fading channel for BPSK modulation scheme with different equalization techniques such as ZF, MMSE and ML. The simulation is done for different transmitter-receiver combinations such as 2×2, 2×3, 2×4 with optimum equalization technique ML over Rayleigh fading channel for BPSK and QPSK modulation techniques and compared those two modulation techniques. For the purpose of comparing the relative performance of fading channels the simulation is done for 2×2 MIMO with ML equalization technique over Rayleigh and Rician fading channels using QPSK.

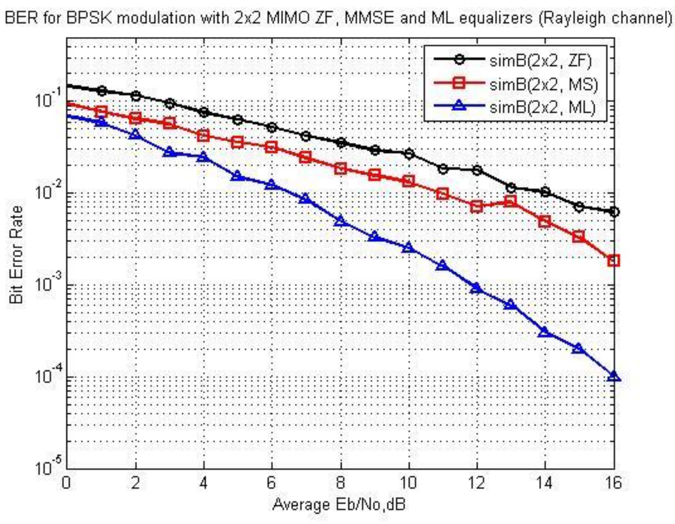

Figure 3. BER performance of BPSK 2×2 MIMO with ZF, MMSE and ML equalizers over Rayleigh fading channel.

We consider MIMO system with 2 transmitting antennas and 2 receiving antennas to distinguish among the performance of equalizers. The ZF equalizer is considered as the basic equalizer and ZF appears to be the low performer among considered equalizers. While ML equalizer shows the high gain also in comparison with MMSE equalizer with the modulation technique BPSK is shown in figure no. 3.

In case of 2×4 combinations the 2 transmitter 4 receiver ML simulation results increase signal to noise ratio than for 2×3 ML simulation. It performs better than other two lower order combinations.

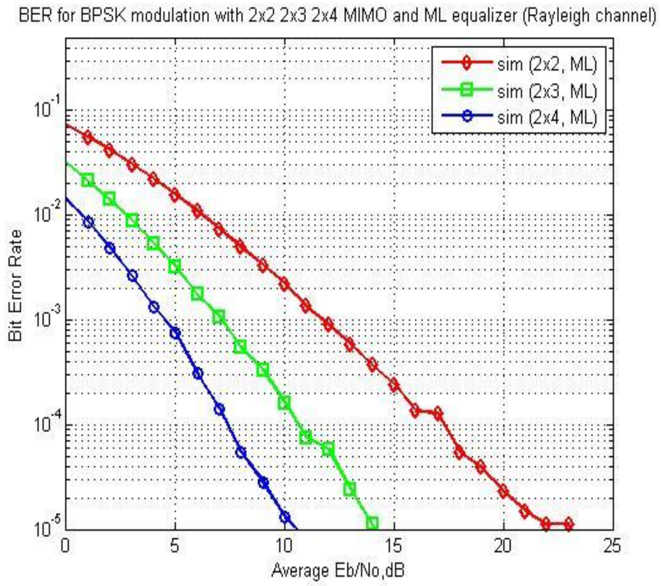

Figure 4. BER performance of BPSK 2×2, 2×3, 2×4 with optimum equalizer ML over Rayleigh fading channel.

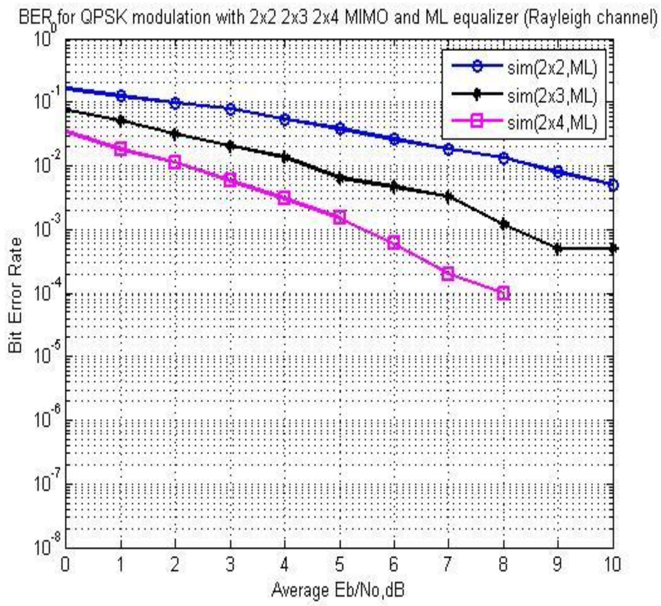

Figure 5. BER performance of QPSK 2×2, 2×3, 2×4 with optimum equalizer ML over Rayleigh fading channel.

The comparison of performance between 2×3 and 2×4 MIMO techniques with Maximum Likelihood equalization indicates that while SNR tend to increasing, bit error rate tends to decreasing. From the figure 4 and 5 it can be concluded that the 2×4 MIMO Rayleigh channel with Maximum Likelihood equalization system offers better BER performance for BPSK modulation technique.

When the BER vs. SNR was evaluated under BPSK and QPSK modulation schemes for MIMO ML over Rayleigh fading channels, the graph obtained as shown in Figure 6. On the careful examination of Figure 6 we can find 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 under BPSK modulation scheme is found to be more efficient is shown in figure no. 6 & 7.

BER performance evaluated under Rayleigh and Rician fading channels for MIMO ML by BPSK modulation technique we can conclude that it gives best BER performance over Rician fading channel than Rayleigh fading channel environment from the figure 8.

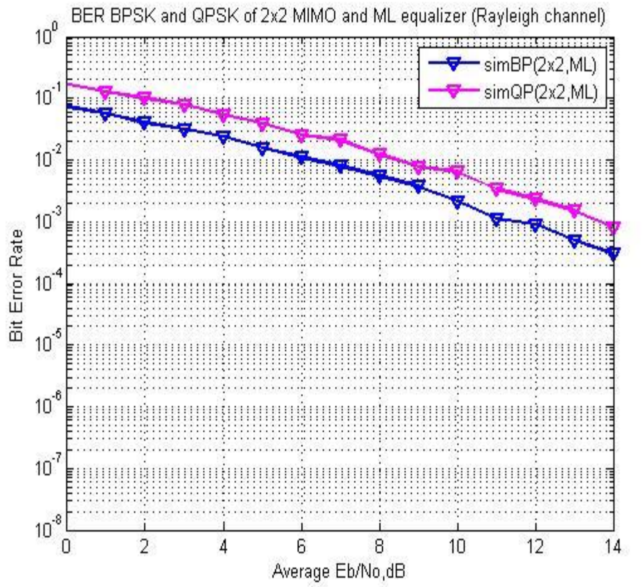

Figure 6. BER performance of BPSK and QPSK 2×2 MIMO with optimum equalizer ML over Rayleigh fading channel.

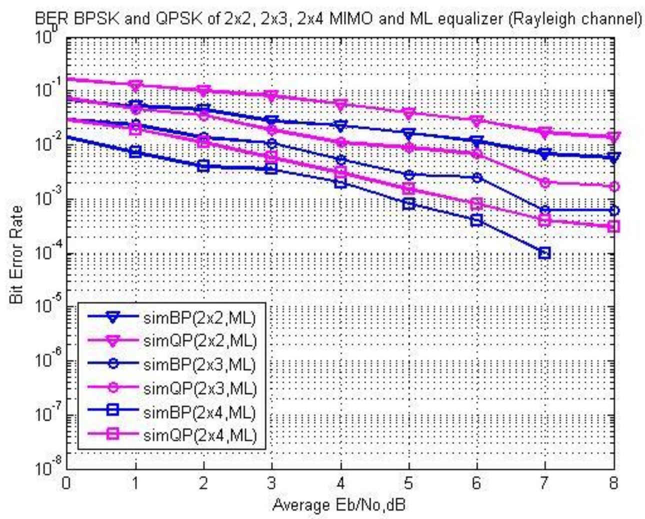

Figure 7. BER performance of BPSK and QPSK 2×2 2×3 2×4 MIMO with optimum equalizer ML over Rayleigh channel.

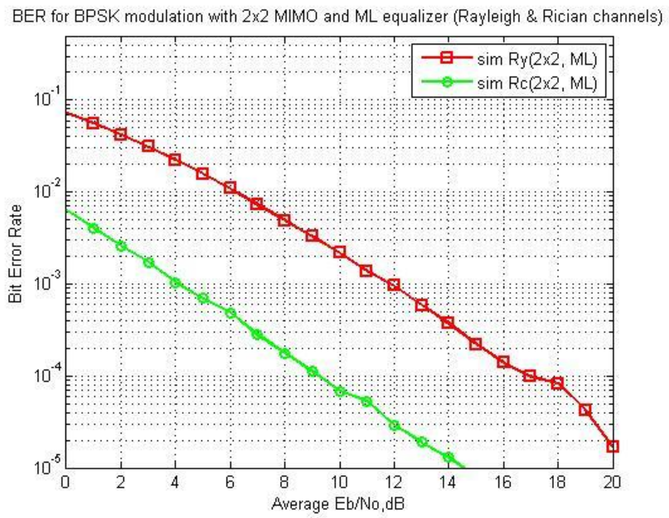

Figure 8. BER performance of BPSK 2×2 MIMO with optimum equalizer ML over Rayleigh & Rician channels.

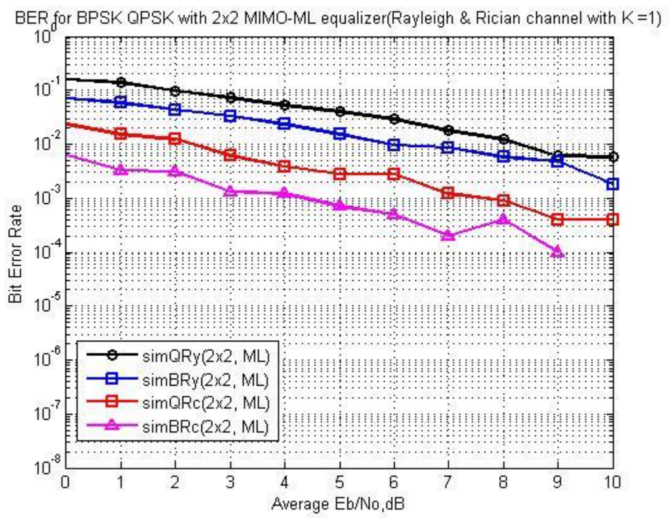

Figure 9. BER performance of BPSK & QPSK 2×2 MIMO with optimum equalizer ML over Rayleigh and Rician channels.

Since Rician channel has the dominant component which is also called as direct path (LOS) component where there is only Non Line Of Sight components (NLOS) present in the Rayleigh fading channel. And It can be seen that the MIMO system is optimized with ML equalizer by BPSK modulation scheme over Rician fading channel as shown in figure 9.

IV. CONCLUSIONS

BER performance of MIMO systems using different modulation schemes and equalization techniques over Rayleigh and Rician fading channels are investigated. The choice of modulation schemes is confined to BPSK and QPSK and that of equalization techniques are limited to ZF, MMSE and ML. Simulation results show that MIMO systems with large constellation (QPSK) are less efficient compared to small constellation (BPSK) and MIMO systems with less number of receive antennas are less efficient compared to large number of receive antennas with similar number of transmit antennas. In conclusion, the BER performance of a MIMO system using BPSK modulation and ML equalizer over Rician fading channel is optimum compared to the choice of other modulation schemes, equalizers and fading channels, it is shown in the Figure 9. Further we conclude that, the performance is further enhanced through increased receive diversity.

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