Performance Evaluation of ML-VBLAST MIMO System using various antenna configurations with Ricean and Rayleigh Channel

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Abstract

Wireless communication technology has shown that the application of multiple antennas at both transmitter and receiver sides improve the possibility of high data rates through multiplexing or to improve performance through diversity compared to single antenna systems. In this article, we studied the BER performance of Maximum Likelihood (ML)- Vertical Bells Lab Layered Space Time Architecture (V-BLAST) Spatial Multiplexing Technique with using different modulation techniques such as BPSK and QPSK, in independent, identically distributed (i.i.d) flat fading channel like Rayleigh and Ricean Channel. In this article we will compared a different multiple antenna configuration with BPSK and QPSK modulation techniques in different channel and finally we will concluded that ML-VBLAST decoding technique using BPSK modulation scheme gives better result than QPSK modulation technique in both the channels. In this we got more optimal result for 1×4 antennas for V-BLAST system in rician fading channel and for Rayleigh channel 4 X 4 antennas for ML-V-BLAST system. Finally we compare the Rayleigh and Ricean Channel for 2 X 2 antenna configurations and in this we found Ricean Channel have better results than Rayleigh Channel in ML-VBLAST MIMO System.

Keywords: Binary Phase Shift Key (BPSK), Bit Error Rate (BER), Multiple input multiple output (MIMO), Maximum Likelihood (ML), Vertical Bell Laboratories Layered Space-Time (V-BLAST)

1. Introduction

Wireless communication system with multi-antenna arrays has been a field of intensive research on the last years [14]. The use of multiple antennas at both the transmitter and the receiver sides can drastically improve the channel capacity and data rate [12]. The study of the performance limits of MIMO system [1] becomes very important since it will give lot ideas in understanding and designing the practical MIMO systems [4]. Vertical-Bell Laboratories Layered Space-Time (V-BLAST) Architecture and first practical implementation of this architecture on MIMO wireless communications to demonstrate a spectral efficiency as high as 40bits/s/Hz in real time in the laboratory [3]. Many schemes have been proposed to explode the high spectral efficiency of MIMO channels, among which V-BLAST [3] is relatively simple and easy to implement and can achieve a large spectral efficiency. In V-BLAST [2] at the transmitter de-multiplexes the input data streams into 'n' independent sub-streams, which are transmitted in parallel over the 'n' transmitting antennas. At the receiver end, antennas receive the sub-streams, which are mixed and superimposed by noise. Detection process [2] mainly involves three operations: Interference Suppression (nulling), interference cancellation (Subtraction) and Optimal Ordering. The interference nulling process is carried out by projecting the received signal into the null subspace spanned by the interfering signals. This process is done by Gramm-Schmidt Orthogonalization procedure that converts the set of linearly independent vectors into orthogonal set of vectors. Then the symbol is detected. The interference cancellation process is done by subtracting the detected symbols from the received vectors. The optimal Ordering is the last process that ensures the detected symbol has highest Signal to noise ratio (SNR). So, V-BLAST algorithm [3] integrates both linear and non-linear algorithms presented in the interference nulling and interference cancellation respectively. In an independent, identically distributed (i.i.d) Flat fading Ricean channel [5] with 'N' transmitting antennas and 'M' receiving antennas In this we will considered receiving antennas are greater than or equal to transmitting antennas (M≥N), the first detected sub-stream has a diversity gain of only M-N+1 [9].

2. MIMO Channel Model

Let us consider a communication system with 'N' number of transmitting antennas and 'M' number of receiving antennas in an i.i.d Ricean Flat Fading channel [5] shown in Fig. 1.

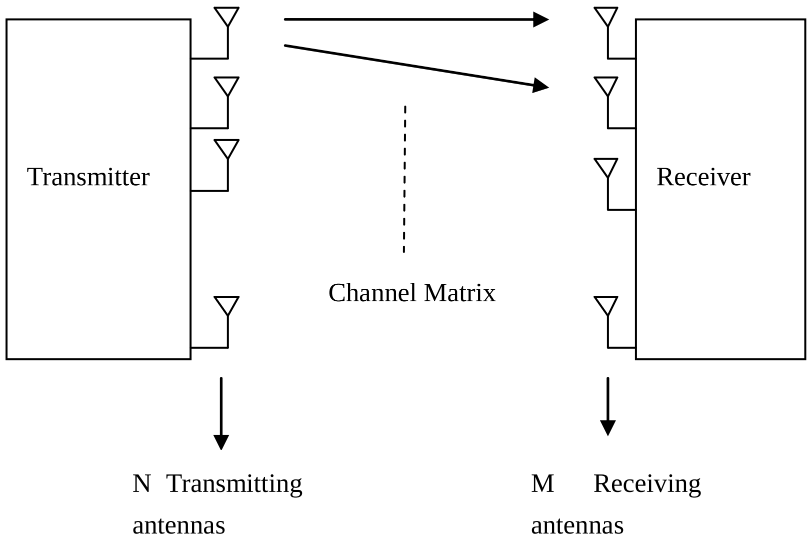

Figure.1 MIMO Channel Model

The sampled baseband representation of signal is given by

$$y = Hx + n \tag{1}$$

And the complex baseband representation of signal [15] is given by

$$y = \sqrt{\frac{P}{M}} Hx + n \tag{2}$$

where $y \in C^{N \times 1}$ is the received signal vector, $x \in C^{M \times 1}$ is the transmitted signal vector with zero mean and unit variance,

P is the total transmit power, $H \in C^{N \times M}$ is the channel response matrix with possibly correlated fading coefficients. In order to access the performance of V-BLAST in correlated channel, we adopted a correlation-based channel model which is expressed as

$$H \sim R_{Rx}^{\frac{1}{2}} H_w \left(R_{Tx}^{1\backslash 2}\right)^T \tag{3}$$

where x ~ y denotes that x and y are identical in distribution, R_{Rx} and T_{Tx} are the normal correlation distribution matrices at the R_x and transmitter (T_x) respectively, and $H_W \epsilon\, C^{NXM}$ contains i.i.d complex Gaussian entries with zero mean and unit variance.

3. Fading Channel

Fading is used to describe the rapid fluctuations of the amplitudes, phases or multipath delays of a radio signal over a short period of time or travel distance, so that large scale path loss effect may be ignored

3.1 Rayleigh Fading Channel

The fading effect is usually described statistically using the Rayleigh distribution. The amplitude of two quadrature Gaussian signals follows the Rayleigh distribution whereas the phase follows a uniform distribution. The probability distribution function (PDF) of a Rayleigh distribution is given by

$$p(r) = \begin{Bmatrix} \frac{r}{\sigma^2} exp\left(\frac{-r^2}{2\sigma^2}\right) & (0 \le r \le \infty \\ 0 & (r < 0) \end{Bmatrix} \quad (4)$$

where σ is the RMS (amplitude) value of the received signal and σ^2 is the average power.

3.2 Ricean Fading Channel

In practice, the behavior of H can significantly deviate from H_w due to a combination of inadequate antenna spacing and/or inadequate scattering leading to spatial fading correlation. Furthermore, the presence of a fixed (possibly line-of-sight or LOS) component in the channel will result in Ricean fading [5].

In the presence of an LOS component between the transmitter and the receiver, the MIMO channel may be modeled as the sum of a fixed component and a fading component and given by following equation

$$H = \sqrt{\frac{k}{1+k}}\,\bar{H} + \sqrt{\frac{k}{1+k}}\,H_w$$

$\sqrt{\frac{k}{1+k}}\,\bar{H} = E[H]$ is the LOS component of the channel.

$\sqrt{\frac{k}{1+k}}\,H_w$ is the fading component.

$k \ge 0$ in equation is the Ricean k-factor of the channel and is defined as ratio of the power in the LOS component of the channel to the power in the fading component. When k = 0, we have pure Rayleigh fading channel. At the other extreme k = ∞ corresponds to a non-fading channel. In general, real-world MIMO channels will exhibit some combination of Ricean fading [5] and spatial fading correlation. With appropriate knowledge of the MIMO channel [1] at the transmitter, the signalling strategy can be appropriately adapted to meet performance requirements. The channel state information could be complete (i.e., the precise channel realization) or partial (i.e., knowledge of the spatial correlation, K-factor, etc.).

4. V-BLAST System Model

A high-level block diagram of a V-BLAST system [2] is shown in

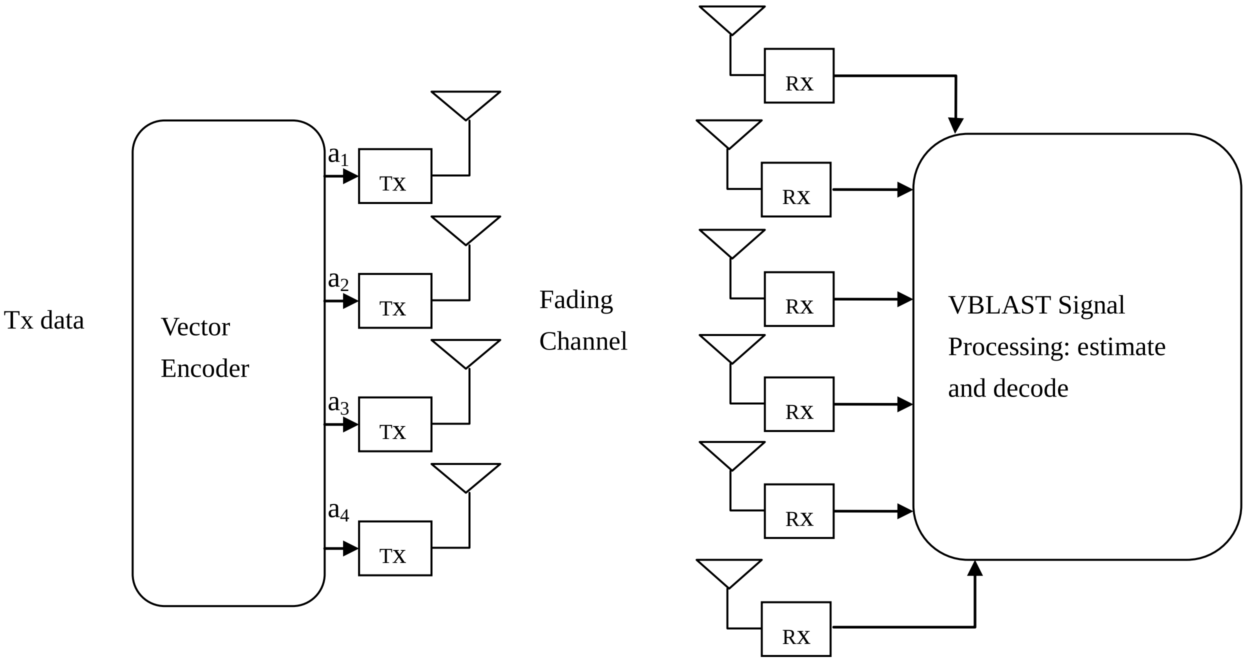

Figure.2 V-BLAST MIMO System

4.1 Encoder

For simplicity, we base our explanation on Figure 2. Suppose the number of transmitting antennas is M_T and the number of receiving antennas is M_R . For example we take QAM modulation, transmitters 1 to M_T operate co-channel at symbol rate 1/T symbols, with synchronized symbol timing. This collection of transmitters constitutes a vector drawn from a QAM constellation. Receivers 1 to M_R are individually conventional QAM receivers. The receivers also operate co-channel, each receiving the signals radiated from all M_T transmit antennas.

Flat fading is assumed and the matrix channel transfer function is $H^{M_R \times M_T}$, where $h_{i,j}$ is the complex transfer function from transmitter j to receiver i and $M_T \times M_R$. We assume that the transmission is organized in bursts of L symbols and that the channel time variation is negligible over the L symbol periods, comprising a burst, and that the channel is estimated accurately using training symbols embedded in each burst.

Let $a = (a_1 \ a_2 \ \dots a_M)^T$ denote the vector of transmit symbols. Then the corresponding received M_R vector i

$$r_1 = Ha + n$$

where n is a wide sense stationary (WSS) noise vector [6] with i.i.d. components.

4.2 Decoder

The decoder needs to demodulate the symbols on the received vector. If channel encoding is used, then the demodulated symbols need to be buffered until the whole block can be decoded. Otherwise, the demodulation can be done immediately.

4.2.1 Decoding Algorithm for VBLAST System

One approach to a lower complexity design of the receiver is to use a “divide-and-conquer” strategy instead of decoding all symbols jointly. First, the algorithm decodes the strongest symbol. Then, canceling the effects of this strongest symbol from all received signals, the algorithm detects the next strongest symbol. The algorithm continues by canceling the effects of the detected symbol and the decoding of the next strongest symbol until all symbols are detected. The optimal detection order is from the strongest symbol to the weakest one. This is the original decoding algorithm [9] of V-BLAST preset. It only works if the number of receive antennas is more than the number of transmit antennas, that is M x N. Decoding Algorithm of V-BLAST is shown in Figure.3

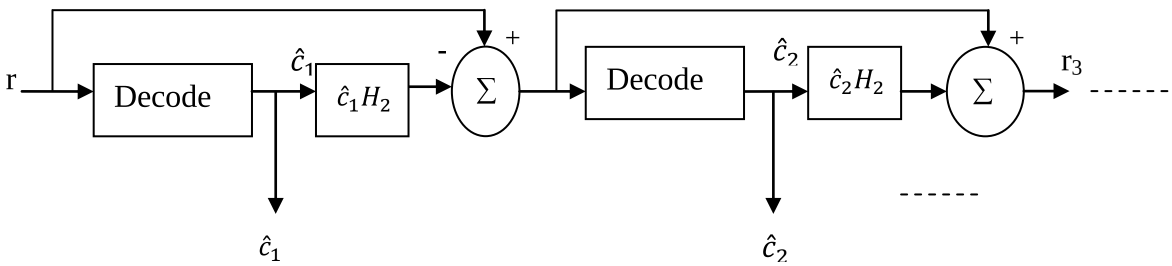

Figure.3 VBLAST Decoder block

The algorithm includes three steps:

- ordering;
- interference cancellation;
- Interference nulling.

4.2.1.1 Ordering

In decoding the first symbol, the interference from all other symbols is considered as noise. After finding the best candidate for the first symbol, the effects of this symbol in all of the receiver equations are canceled. Then, the second symbol is detected from the new sets of equations. The effects of the second detected symbol are canceled next to derive a new set of equations. The process continues until all symbols are detected. Of course, the order in which the symbols are detected will impact the final solution.

4.2.1.2 Interference Cancellation

At stage n of the algorithm, when c_n is being detected, symbols $c_1, c_2, \ldots, c_{n-1}$ have been already detected. Let us assume a perfect decoder, that is the decoded symbols $\widehat{c_1}, \widehat{c_2}, \ldots \ldots \ldots, \hat{c}_{n-1}$ are the same as the transmitted symbols $c_1, c_2, \ldots, c_{n-1}$.

One can subtract $\sum_{i=1}^{n-1} c_i H_i$ from the received vector r to derive an equation that relates remaining undetected symbols to the received vector:

$$r_n = r - \sum_{i=1}^{n-1} c_i H_i + N, \tag{5}$$

$$r_n = \sum_{i=n}^{N} c_i H_i + N, \qquad n = 1,2 \ldots . N-1 \tag{6}$$

In fact, by using induction in addition to the convention $r_1 = r$,one can show that

$$r_{n+1} = r_n - c_n H_n, \qquad n = 1,2,3 \ldots . . N-1 \tag{7}$$

Therefore, at the n^{th} stage of the algorithm after detecting the nth symbol as $\hat{c}_n$, its effect is canceled from the equations by

$$r_{n+1} = r_n + \hat{c}_n H_n \tag{8}$$

This interference cancelation is conceptually similar to DFE [8].

4.2.1.3 Interference nulling

Interference nulling is the process of detecting c_n from r_n by first removing the effects of undetected symbols. Basically, in this step the nth symbol is detected by nulling the interference caused by symbols $c_{n+1}, c_{n+2}, \dots, c_N$. Like any other interference suppression problem, there are many different methods to detect a symbol in the presence of interference.

5. ML-V-BLAST Decoder

The ML receiver [7] performs optimum vector decoding and is optimal in the sense of minimizing the error probability. ML receiver is a method that compares the received signals with all possible transmitted signal vectors which is modified by channel matrix H and estimates transmit symbol vector $\hat{\mathrm{C}}$ according to the Maximum Likelihood principle [7], which is shown as:

$$\hat{\mathrm{C}} = \underset{\hat{\mathrm{C}}}{\operatorname{argmin}} \llbracket \mathrm{r} - \mathrm{C}'\mathrm{H} \rrbracket_{\mathrm{F}}^{2} \tag{9}$$

where $_{\mathrm{F}}$ is the Frobenius norm. Expanding the cost function using Frobenius norm given by

$$\hat{\mathrm{C}} = \underset{\hat{\mathrm{C}}}{\operatorname{argmin}} \left[\mathrm{Tr}[(\mathrm{r} - \mathrm{C}'\mathrm{H})^{\mathrm{H}}.(\mathrm{r}00 - \mathrm{C}'\mathrm{H})] \right] \tag{10}$$

$$\hat{\mathrm{C}} = \underset{\hat{\mathrm{C}}}{\operatorname{argmin}} \left[\mathrm{Tr}\left[\mathrm{r}^{\mathrm{H}}.\mathrm{r} + \mathrm{H}^{\mathrm{H}}.\mathrm{C}'^{\mathrm{H}}.\mathrm{C}'.\mathrm{H} - \mathrm{H}^{\mathrm{H}}.\mathrm{C}'^{\mathrm{H}}.\mathrm{r} - \mathrm{r}^{\mathrm{H}}.\mathrm{C}'.\mathrm{H}\right] \right] \tag{11}$$

Considering $\mathrm{r}^{\mathrm{H}}.\mathrm{r}$ is independent of the transmitted codeword so can be rewritten as

$$\hat{\mathrm{C}} = \underset{\hat{\mathrm{C}}}{\operatorname{argmin}} \left[\mathrm{Tr}\left[\mathrm{H}^{\mathrm{H}}.\mathrm{C}'^{\mathrm{H}}.\mathrm{C}'.\mathrm{H}\right] - 2.\,\mathrm{Real}(\mathrm{Tr}[\mathrm{H}^{\mathrm{H}}.\mathrm{C}'^{\mathrm{H}}.\mathrm{r}\,]) \right] \tag{12}$$

Equation "(12)" can be rewritten for multiple receivers as shown in

$$\hat{\mathrm{C}} = \underset{\hat{\mathrm{C}}}{\operatorname{argmin}} \left[\sum_{\mathrm{m}=1}^{\mathrm{M_R}} [\mathrm{H}_{\mathrm{m}}^{\mathrm{H}}.\mathrm{C}'^{\mathrm{H}}.\mathrm{C}'.\mathrm{H}_{\mathrm{m}} - 2.\,\mathrm{Real}(\mathrm{H}_{\mathrm{m}}^{\mathrm{H}}.\mathrm{C}'.\mathrm{r}_{\mathrm{m}})] \right] \tag{13}$$

where $.^{\mathrm{H}}$ is a Hermition operator. We can write the cost function for only one receiving antenna and then added up to achieve for $\mathrm{M_R}$ receiving antenna.

$$\left[\mathrm{H}_{\mathrm{m}}^{\mathrm{H}}.\mathrm{C}'^{\mathrm{H}}.\mathrm{C}'.\mathrm{H}_{\mathrm{m}} - 2.\,\mathrm{Real}(\mathrm{H}_{\mathrm{m}}^{\mathrm{H}}.\mathrm{C}'.\mathrm{r}_{\mathrm{m}})] \right] \tag{14}$$

where the minimization is performed over all possible transmit estimated vector symbols. Although ML detection offers optimal error performance, it suffers from complexity issues.

6. Simulation and Results

In this paper, we used MATLAB 7.0 software for simulation for the Bit Error Rate (BER) Performance of the ML-VBLAST System [13]. We simulated the BER performance of ML-VBLAST in Ricean and Rayleigh flat fading channel [5] by using the different modulation techniques like BPSK and QPSK

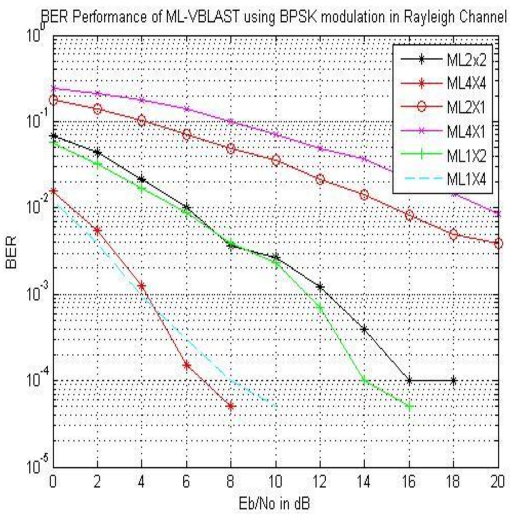

Figure.4: BER for ML-VBLAST using BPSK modulation in Rayleigh Channel

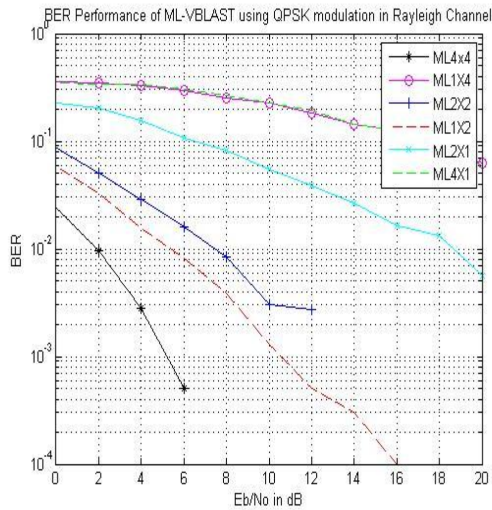

Figure.5 BER for ML-VBLAST using QPSK modulation in Rayleigh Channel

M X N	BER
1X4	.0019
4X4	0.0032
1X2	0.0158
2X2	0.039
2X1	0.001
4X1	0.158

Table1. BER for ML-VBLAST using BPSK Modulation in Rayleigh channel at SNR=2dB

M X N	BER
1X4	0.2511
4X4	0.001
1X2	0.015
2X2	0.0511
2X1	0.125
4X1	0.2511

Table2. BER for ML-VBLAST using QPSK Modulation in Rayleigh channel at SNR=2dB

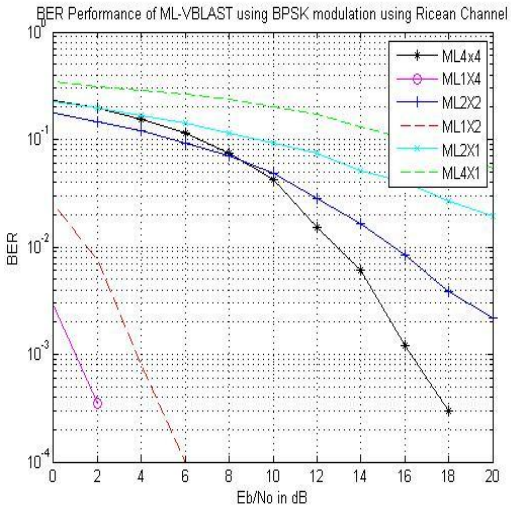

Figure.6: BER for ML-VBLAST using BPSK modulation in Ricean Channel

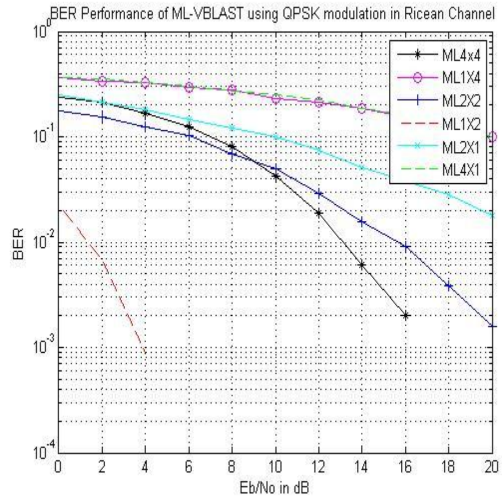

Figure.7: BER for ML-VBLAST using QPSK modulation in Ricean Channel

M X N	BER
1X4	.00019
4X4	0.125
1X2	0.0398
2X2	0.01
2X1	0.134
4X1	0.251

Table.3: BER for ML-VBLAST using BPSK modulation in Ricean Channel at SNR=2dB

M X N	BER
1X4	.00398
4X4	0.125
1X2	0.0031
2X2	0.125
2X1	0.158
4X1	0.2511

Table.4: BER for ML-VBLAST using QPSK modulation in Ricean Channel at SNR=2dB

In Figure.4 we will get a 4x1 antenna configuration gets an optimal result than another antenna configuration and 4x1 gets a worst result using BPSK modulation in Rayleigh channel. From Table. 1, At SNR=2dB, 1X4 antenna configuration has 0.0019 BER have minimum BER than another configuration. So we can say that this configuration gives better BER performance for ML-VBLAST system.

In Figure.5 we will get a 4x4 antenna configuration gets an optimal result than another antenna configuration and 4x1 gets a worst result using QPSK modulation in Rayleigh channel. From table.2, in this we see that 4X4 antenna configuration has minimum BER so we can say that it gives best result. 4X1 have Maximum BER about 0.2511 So we can say that this configuration gives the worst result.

In Figure .6 1X4 antenna configuration gets an optimal result than another antenna configuration and 4x1 gets a worst result using BPSK modulation in Ricean channel. From table.3, At SNR=2dB , 1X4 antenna configuration have Minimum BER approx 0.00019 and for 4x1 antenna configuration BER is 0.251 have more than other antenna configuration so we can say that 4X1 antenna configuration have worst performance.

In Figure.7 we will get a 1x2 antenna configuration gets an optimal result than another antenna configuration and 4x1 gets a worst result using QPSK modulation in Ricean channel. From Table.4 ,At SNR=2dB 1X2, antenna configuration have

0.0031 have minimum values than other antenna configuration and For 4X1 antenna configuration BER have 0.2511 have highest values than another configuration so we can say that 4x1 have worst BER performance.

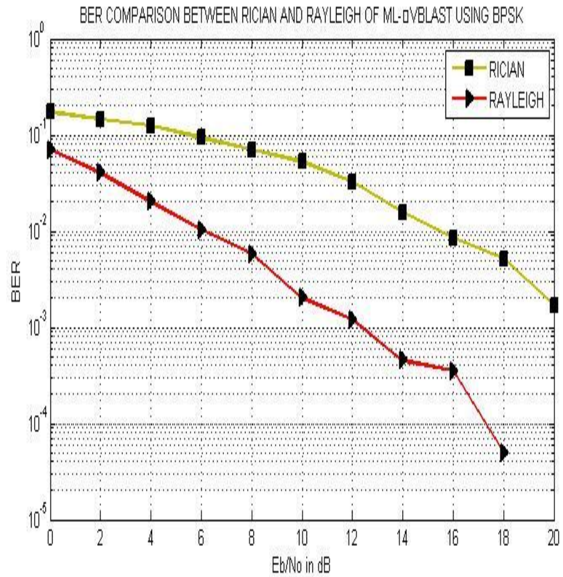

Figure.8: BER Comparison of ML-VBLAST using
BPSK modulation of Ricean and Rayleigh Channel

Finally we will compare a Rayleigh and Ricean Channel in 2X2 antenna configuration using BPSK Figure 8. At SNR=6dB, For Rayleigh BER is 0.001 and for Ricean channel BER value is 0.0001 have the less value of BER than Rayleigh channel. So we can say that Ricean Channel gives the better result than Rayleigh channel.

7. Conclusion

Finally we conclude that as we keeping number of receiving antennas more than transmitting antenna we get better BER performance that means we can remove the more errors. If number of transmitting antennas more than receiving antennas we get worst BER performance that means we can remove fewer errors. If we compare Ricean and Rayleigh channel in BPSK modulation we will get better performance in Ricean channel.

8. References

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