

# Performance Evaluation of MIMO-OFDM Communication Systems

M. I. Youssef, A. E. Emam, M. Abd Elghany

**Abstract**— This paper evaluates the bit error rate (BER) performance of MIMO-OFDM communication system. MIMO system uses multiple transmitting and receiving antennas with different coding techniques to either enhance the transmission diversity or spatial multiplexing gain. Utilizing Alamouti algorithm where the same information is transmitted over multiple antennas in different time intervals and then collected again at the receivers to minimize the probability of error, combat fading and thus improve the received signal to noise ratio. While utilizing V-BLAST algorithm the transmitted signals are divided into different transmitting channels and transferred over the channel to be received by different receiving antennas to increase the transmitted data rate and achieve higher throughput.

The paper provides a study for different diversity gain coding schemes and spatial multiplexing coding for MIMO systems. A comparison of various channels estimation and equalization techniques are given. The simulation is implemented using MATLAB and the results had shown the performance of transmission models under different channel environments.

**Keywords**— Alamouti, BER, Channels, MIMO communication, Space Codes, V-BLAST.

## I. INTRODUCTION

Due to the enormous growth in the wireless communication industry in the last decade, there is need for techniques to reliably communicate at higher data rates and efficiently use the available bandwidth. One such technology is the use of multiple antennas at both transmitter and receiver sites of wireless communication systems known as multiple –input – multiple-output (MIMO) communication system. In MIMO systems, the information signal at both sides of the communication link is combined in such a way that the quality (bit-error-rate) or data rates (bit-per-sec) is improved.

A base idea of MIMO systems is Space–Time Processing (STP) [2, 11]. In order to protect transmission against errors caused by channel fading and additive white Gaussian noise (AWGN), joint coding across transmit antennas and time, known as space-time (ST) coding was introduced, which include different class, as Space–Time Block Codes (STBC) that provide diversity and coding gain at the same time, and spatial multiplexing methods using Space–Time (V-BLAST)

algorithm that provide multiplexing gain and increased channel capacity.

The paper start in section 2 to introduce model for MIMO system, section 3 provide different coding methods: Space-time block codes and spatial multiplexing codes, section 4 & 5 define the Alamouti and V-Blast system models, section 6 provide methods for evaluating the diversity and MIMO performance, section 7 simulation results are provided to measure the system performance and finally in section 8 a conclusion is being provided.

## II. FADING AND MIMO CHANNELS

The Multiple-In Multiple-Out (MIMO) system shown in figure 1 is based on both transmit and receive diversity, with  $N_t$  transmission antennas and  $N_r$  receiver antennas there are  $N_t N_r$  branches [9, 12].

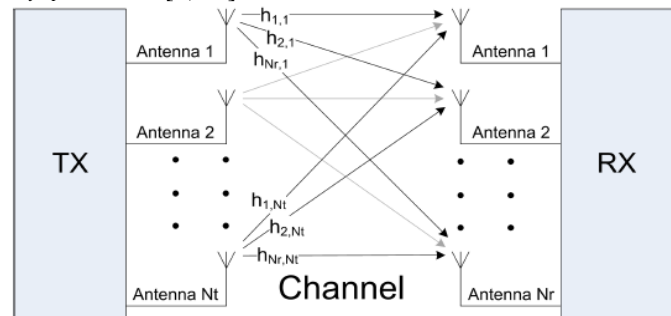


Fig (1): MIMO communication Channel

The standard received signal vector can be calculated as:

$$R = S h + n \quad (1)$$

Where;

S the transmitted symbol,

n the noise

h MIMO channel matrix can be represented by a  $N_t \times N_r$  matrix

There are a wide variety of fading models which are well-known in wireless communication system. In this paper we will discuss mainly four models: AWGN, RAYLEIGH, RACIAN and NAKAGAMI fade channel models.

### A. AWGN Channel

Additive white Gaussian noise (AWGN) channel [1] is a universal channel model for analyzing any new scheme. In this model, the channel does nothing but add a white Gaussian noise to the signal passing through it. Fading does not exist or if exists than it is of very less amount. The only distortion is introduced by the AWGN. AWGN channel is a theoretical channel used for analysis purpose only.

So, if  $s(t)$  is transmitted symbol, then the received symbol is given as:-

$$R(t)=s(t)+\eta(t) \tag{2}$$

Where;

$\eta(t)$  is the Additive White Gaussian Noise (AWGN).

*B. Rayleigh Channel*

The Rayleigh fading channel [1, 5] is statistical channel representation to simulate multi-path propagation environment over transmission symbols or radio signals. Rayleigh fading is mostly applicable when there is no Line-Of-Sight between transmitter and receiver. So, if  $s(t)$  is transmitted symbol then the received symbol is given as:-

$$R(t) = s(t)*h(t)+\eta(t) \tag{3}$$

Where;

$\eta(t)$  is the Additive White Gaussian Noise (AWGN).

*C. Rician Channel*

The Rician fading channel [1, 6] is statistical channel representation to simulate multi-path propagation caused by partial affection of transmitted symbols itself. It means that Rician fading occurs when one of the paths, typically a line of sight signal is much stronger than others. So, if  $s(t)$  is transmitted symbol then the received symbol is given as:-

$$R(t)=s(t)*h(t)+\eta(t) \tag{4}$$

*D. Nakagami Channel*

It is possible to describe both Rayleigh and Rician fading channel with change in only one parameter which is generally denoted mainly as 'm'. Here, as we increase or decrease the value of the nakagami factor 'm', it changes the value of the probability distribution function towards the Rician or Rayleigh fading distribution, respectively.

III. CODING TECHNIQUES

Space-time block coding (STBC) and Spatial Multiplexing (SM) are MIMO based techniques that provide link quality and high capacity in the system.

*A. Space-Time Block Coding*

Space-Time Block Coding (STBC) is a scheme in which the information is transmitted simultaneously on different antennas. An algorithm of this scheme is the Alamouti algorithm [2, 12] which proposed an orthogonal block code using (N) transmitters and (M) receivers. The encoding and decoding operation is carried out in sets of two modulated symbols. Hence, the information data bits are first modulated and mapped into their corresponding constellation points.

Therefore, let  $x_1$  and  $x_2$  are the two modulated symbols that enter the space-time encoder. Usually, in systems with only one transmit antenna, these two symbols are transmitted at two consecutive time instances  $t_1$  and  $t_2$ . The times  $t_1$  and  $t_2$  are separated by a constant time duration  $T$ .

In the Alamouti scheme, during the first time instance, the symbol  $x_1$  and  $x_2$  are transmitted by the first and the second antenna element, respectively. During the second time instance  $t_2$ , the negative of the conjugate of the second symbol is sent to the first antenna while the conjugate of the first constellation point, i.e.,  $x_1^*$ , is transmitted from the second antenna. The encoding operation is described in the Table 1.

**Table 1: Encoding of the Alamouti's Transmit Diversity Scheme**

	Antenna 1	Antenna 2
Time $t_1$	$x_1$	$x_2$
Time $t_2$	$-x_2^*$	$x_1^*$

The space-time encoding mapping of Alamouti's two-branches transmit diversity technique can be represented by the coding matrix:

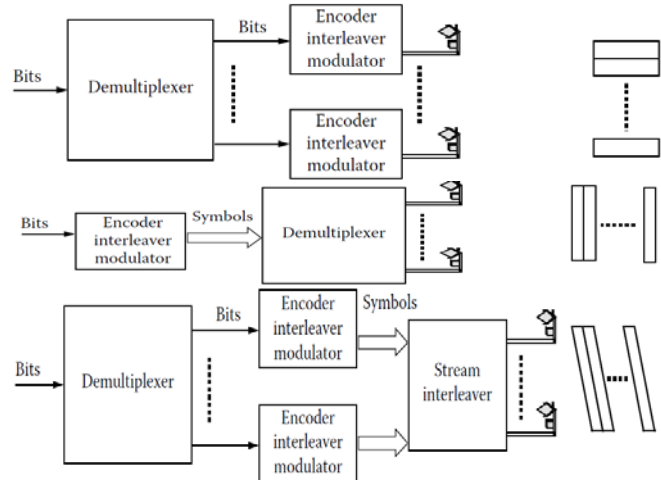
$$\mathbf{X} = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \tag{5}$$

*B. Spatial multiplexing*

A fundamental difference between the MIMO and SIMO/MISO antenna the concept of spatial multiplexing (SM) is different from that of space-time block coding method. [8]

The general operation behind SM processing is to break the sequence of information bits into a certain set of sub-streams that will be treated differently. In SM,  $M_T$  independent symbols are transmitted from  $M_T$  transmitting antennas.

The main idea behind SM encoding techniques relies on the use of powerful decoding techniques on the receiver side. At the transmitter side, the information sequence is subdivided into several sub-streams through a demultiplexer. The sub-stream where the signal processing is conducted is identified as "Layer." Hence, SM is also called the Layer Space-Time (LST). The demultiplexing operation can be applied to bits or symbols. Consequently, the demultiplexing of the data information stream can be realized in three different ways according to the demultiplexer position in the transmitter chain and the directions of the layers. The encoding processes are known as horizontal, vertical and diagonal SM and are schematically drawn from top to bottom in Fig. (2).



**Fig. (2): Spatial Multiplexing Encoding Schemes [Horizontal, Vertical, Diagonal]**

An algorithm of this scheme is the V-Blast code, which is a vertical SM encoding scheme. The information data are at first coded, interleaved and mapped into their corresponding symbols. Then, the symbols are demultiplexed to the  $M_T$  transmit antennas. Hence, the symbols transmitted are independent of each other. Each set of  $M_T$  symbols composes a transmission vector as shown in the second scheme of Fig.(2).

IV. ALAMOUTI SYSTEM MODEL

The Alamouti scheme [4, 7] is considered the only space-time block coding that can achieve its full diversity gain without the need to sacrifice its data rate, which gives it the advantage over other high order STBCs although other codes would provide better error-rate performance.

The block diagram in figure (3) provide a 2x2 Alamouti STBC architecture;

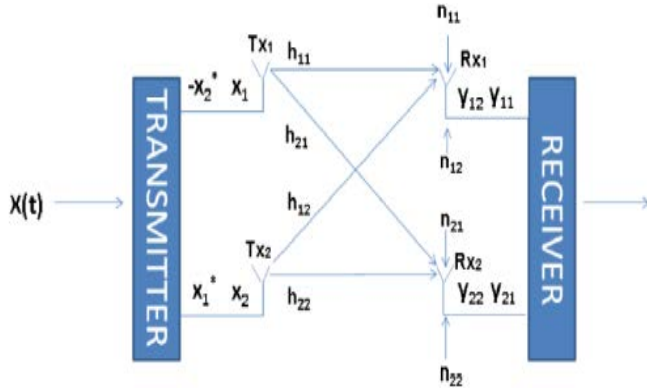


Fig. (3): Alamouti MIMO System

$$Y = X H + N \tag{6}$$

Where;

$X_1, X_2$  are transmitted data

$Y_{11}, Y_{21}$  are received data (from the first time slot)

$Y_{12}, Y_{22}$  are received data (from the second time slot)

$n$  is the AWGN components

$h$  is the Rayleigh channel

And, the bit-error analysis is performed through following the flow chart presented in Fig (4);

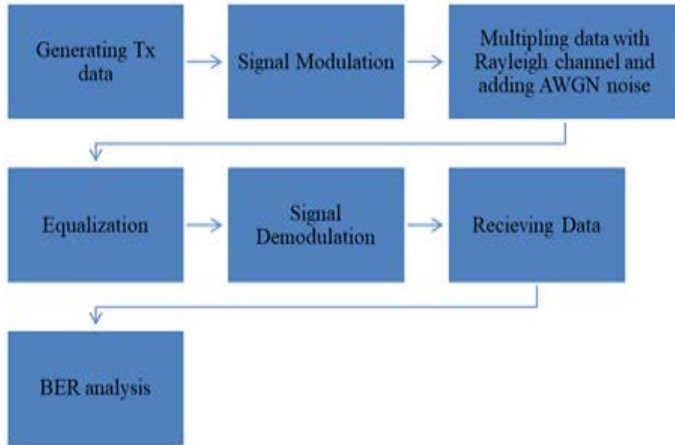


Fig. (4): BER analysis Flow Chart

V. V-BLAST SYSTEM MODEL

It is a detection algorithm [10, 13] to the receipt of multi-antenna MIMO systems that is based to firstly detect the most powerful signal. It regenerates the received signal from this user from this decision. The signal is regenerated subtracted from the received signal, and cleared, then goes to the detection of the second user's most powerful, and so forth. The block diagram shown in figure (5) provide a high level architecture for the algorithm;

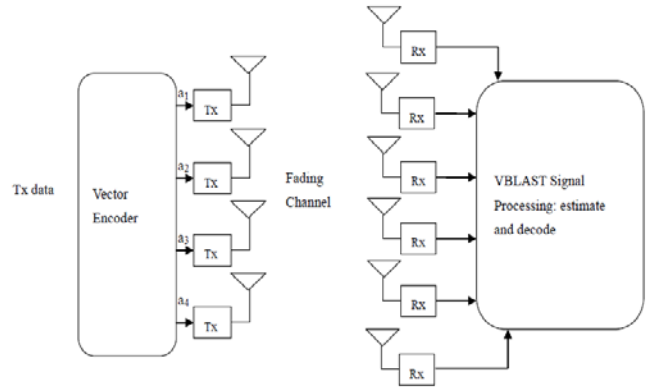


Fig. (5): V-BLAST MIMO System

A. Vector Encoder

Supposing the system consists of  $M_T$  transmitting antennas, and  $M_R$  receiving antennas, we use a QAM modulation technique. The matrix channel transfer function is  $H_{R \times T}^{M \times M}$ .

We assume that the transmission is organized in bursts of  $L$  symbols and the channel time variation is negligible over the  $L$  symbol periods.

Let  $a = (a^1 a^2 \dots a^M)^T$  denote the vector of transmitting symbols. Then the corresponding received signal  $M_R$  vector  $i$ .

$$r_i = H a + n \tag{7}$$

B. Decoder

The decoder will demodulate the symbols on the received vector. This is done by using a “divide-and-conquer” strategy, by decoding the strongest symbol first, then cancelling its effect from all received signals, then detecting the next strongest symbol, and so on till all symbols are detected. This algorithm has a limitation that it works only if the number of received antennas is more than the transmitted ones.

The decoding algorithm V-BLAST as shown in Figure (6); consists to three main steps: Symbol ordering, Interference cancellation, and Interference nulling.

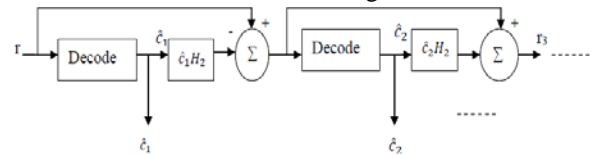


Fig. (6): V-BLAST Decoder Block

The re-ordering of the symbols is done by a process of decoding the first symbol, and considering the interference from all other symbols as noise, and when selected its effects in the entire receiver equations are canceled, then derive a new set of equations, and so on. Interference cancellation is done through the next algorithm.

At stage  $n$  of the algorithm, when  $c_n$  is being detected, symbols  $c_1, c_2, \dots, c_{n-1}$  have been already detected. For a perfect decoder, that is the decoded symbols  $\hat{c}_1, \hat{c}_2, \dots, \hat{c}_{n-1}$  are the same as the transmitted symbols. Then, by subtracting the remaining symbols from the received vector we could derive an equation that relates the remaining undetected symbols to the receiver vector.

$$r_n = r - \sum_{i=1}^{n-1} c_i H_i + N, \quad i = 1 \text{ to } n-1 \tag{8}$$

$$r_n = \sum_{i=n}^N c_i H_i + N, \quad i = n \text{ to } N \tag{9}$$

Interference nulling is then done by detecting  $c_n$  from  $r_n$  by first removing the effect of undetected symbols.

### C. Maximum-Likelihood V-BLAST Decoder

The Maximum-Likelihood (ML) V-BLAST decoder performs optimum vector decoding as it minimizes the probability of error. It compares the received signals with all possible transmitted signals vectors and estimates the transmit symbol vector  $\hat{C}$  based on maximum likelihood principle.

$$\hat{C} = \underset{C}{\operatorname{argmin}} \left[ \|r - C'H\|_F^2 \right] \quad (10)$$

Where;

$F$  is the Frobenius norm.

## VI. EVALUATION PERFORMANCE METHODS

The system performance is measured through measuring the signal-to-noise ratio (SNR or  $E_b/N_0$ ) enhancement at a specific outage probability and the SNR reduction for achieving a desired average BER, or by means of its Capacity enhancement.

### A. Diversity Performance Evaluation

When there is no line-of sight path and fading characteristics are predominantly Rayleigh, which is typical of urban environments, the beam forming needed for array gain deteriorates to the point where most if not all of the array gain is lost. In addition to this there is also a significant increase in the amount of fade margin needed to ensure that the outage probability is acceptably small. Under these operating conditions, the performance enhancement provided by the various antenna configurations is that they reduce the amount of fade margin needed rather than increasing the effective received signal power as in the case of array gain.

This fade margin reduction is achieved using diversity, which typically requires an antenna separation of at least the coherence wavelength of the channels to ensure that the received signals have independent fading.

Diversity gain can be achieved using selection, switched equal-gain, or maximal ratio combining techniques, and, although the last gives the best performance, the spread of their respective received signal-to-noise ratios needed for a given outage probability is around 2 dB.

### B. Spatial Multiplexing Performance Evaluation

The capacity of a MIMO system, comprising the same number  $M$  of transmitting (Tx) and receiving (Rx) antennas, with no CSI at the transmitter and assuming that the transmitted signals are Gaussian distributed with identity covariance matrix and the received ones add coherently at the receiver, is given by;

$$C = n \cdot \log_2(1 + p) \quad (11)$$

Where;  $p$  is the maximum normalized transmit power.

The benefit of spatial multiplexing is its ability to increase the effective channel transmission rate by exploiting random fading. Consequently, it requires a very rich multipath environment, so it works best when there are no direct line-of-sight paths between transmit and receive antennas.

Unfortunately, spatial multiplexing gain has to be traded against diversity gain. Therefore, the gain of one is increased at the expense of the other, which means that a trade-off has to

be made between system capacity and the amount of fade margin.

## VII. SIMULATIONS RESULTS

In this section, the results obtained from the MATLAB simulations are discussed. It is necessary to explore what happens to the signal as it travels from the transmitter to the receiver through a MIMO communication system that uses algorithms to optimize communication channel.

### A. Antenna Type Effect:

Using a BPSK modulation scheme the effect of different antenna diversity schemes is tested as seen in Fig. (7.a), and Fig (7.b).

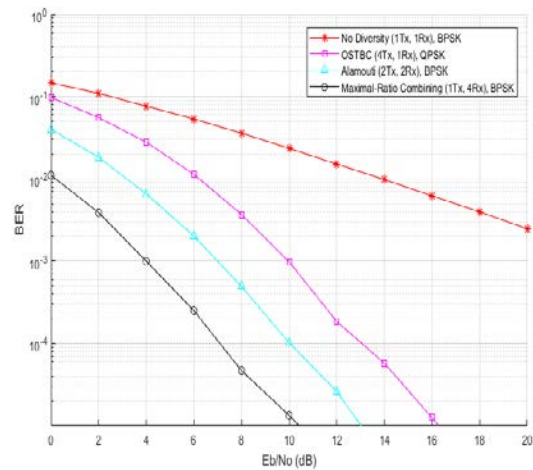


Fig. (7.a): BER Vs.  $E_b/N_0$  for Tx/Rx systems

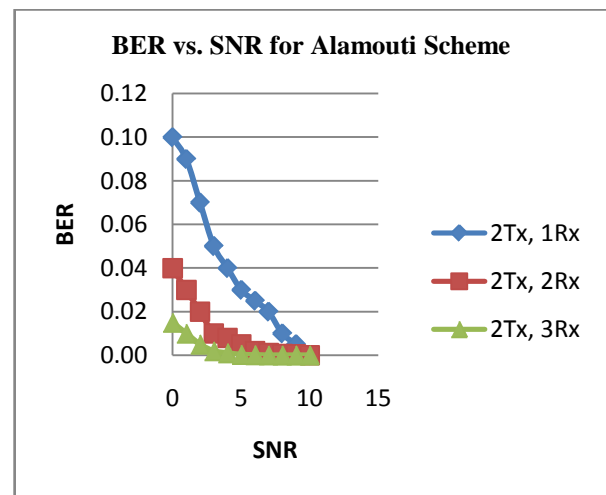


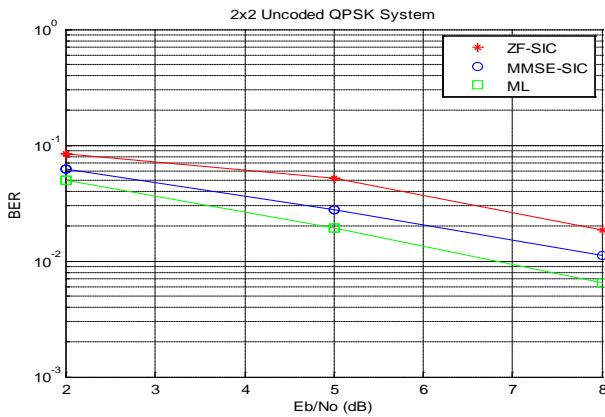
Fig. (7.b): BER Vs. SNR, MIMO Tx/Rx systems

Where it is shown in Fig (7.a and 7.b) the different diversity schemes either in the transmitter or at the receiver side were tested, and the results showed that receive diversity provide better BER performance in comparison to transmit diversity.

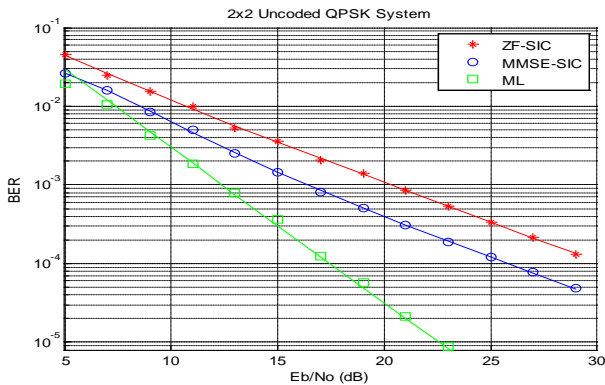
### B. Spatial multiplexing Decoding Schemes:

Spatial multiplexing requires strong decoding techniques at the receiver though. So, in this simulation we will highlight two ordered Successive Interference Cancellation (SIC) detection schemes; the first is Zero-Forcing (ZF) and the

second is “Minimum-Mean-Square-Error (MMSE)” and comparing their performance with the Maximum-Likelihood (ML) optimum receiver.



**Fig (8.a): Performance of varies spatial multiplexing techniques for low  $E_b/N_0$**

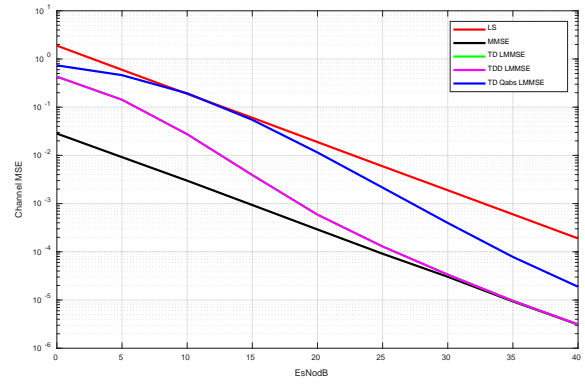


**Fig (8.b): Performance of varies spatial multiplexing techniques for larger  $E_b/N_0$**

From Fig (8.a) and (8.b) we could observe that the ML receiver is the best in performance followed by the MMSE-SIC and ZF-SIC receivers. In terms of receiver complexity, ML grows exponentially with the number of transmit antennas while the ZF-SIC and MMSE-SIC are linear receivers combined with successive interference cancellation.

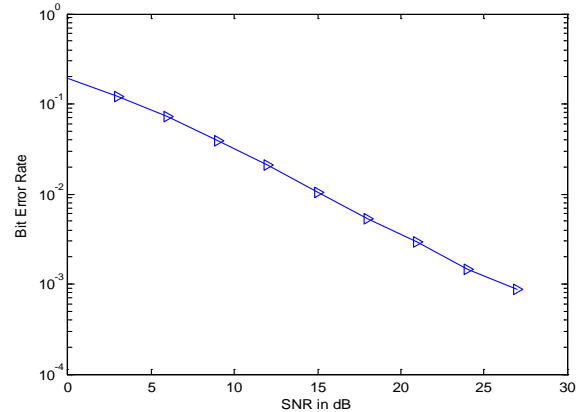
*C. Channel Estimation techniques:*

Now study the effect of different channel estimation techniques, as least square, minimum mean square error, linear minimum mean square error, and others. We could see from Fig (9) that LMMSE (Linear minimum mean square error) scheme provide better performance in comparison to LMS. But this comes on the expense of the complexity of the system.

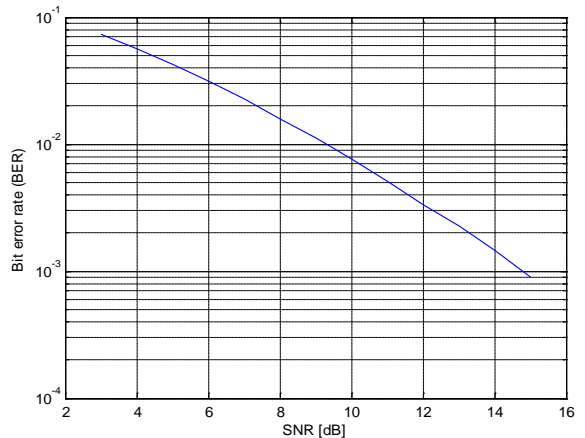


**Fig. (9): Channel MSE vs.  $E_s/N_0$  for Varies Channel Estimation**

Then, to see the effect of MIMO on channel estimation performance, we could see from Fig (10.a) and (10.b), that for a SNR equal 10 db, the BER in OFDM system is 0.015, while for MIMO-OFDM it is only 0.008. Thus, MIMO configuration improves the performance of the communication system in-comparison to OFDM system alone.



**Fig (10.a): BER of the OFDM with LSE channel estimation**



**Fig (10.b): BER of MIMO-OFDM with LSE channel estimation**

*D. Modulation techniques:*

From Table 2, the effect of different modulation schemes for varies antenna transmit/receive configuration is seen.

**Table 2: BER vs. SNR in 2\*2 MIMO with different modulation**

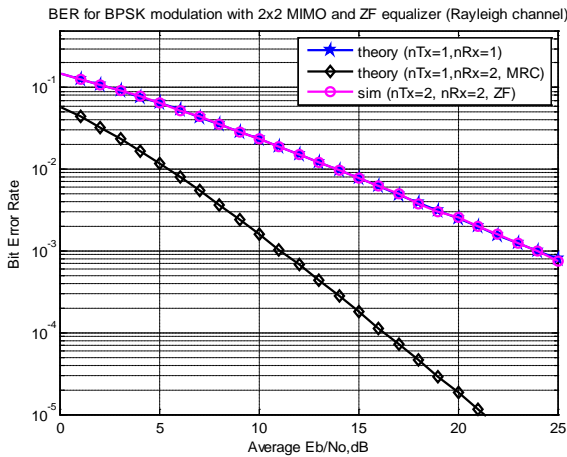
$E_b/N_0$ (db)	BER in BPSK	BER in QPSK	BER in 16-PSK

0	0.035	0.07	0.18
2	0.018	0.04	0.16
4	0.006	0.01	0.15
6	0.0015	0.003	0.12
8		0.0025	0.09
10		0.00015	0.05

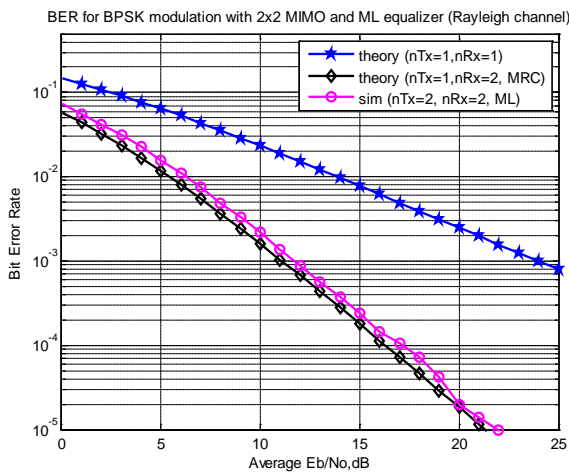
Where; we see from table 2 that the lower modulation order always provides low bit-error-rate than the using higher order modulation scheme.

**E. Different Equalization Techniques:**

Now as seen in Fig (11.a) fig (11.b), we study the performance of different equalization techniques.



**Fig. (11.a): BER vs. Eb/No using ZF equalizer**

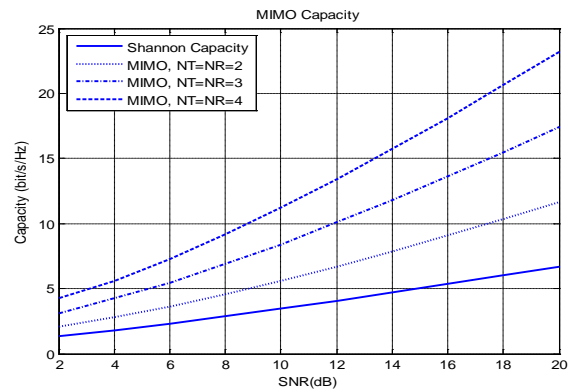


**Fig. (11.b): BER vs. Eb/No using MRC equalizer**

For a  $E_b/N_0 = 10$ , the BER using ZF is around  $10^{-2}$ , while for ML is  $10^{-3}$ . So by observing the simulation results we conclude that by using Maximum likelihood Equalizer interference can be cancelled effectively even in mobile fading channel.

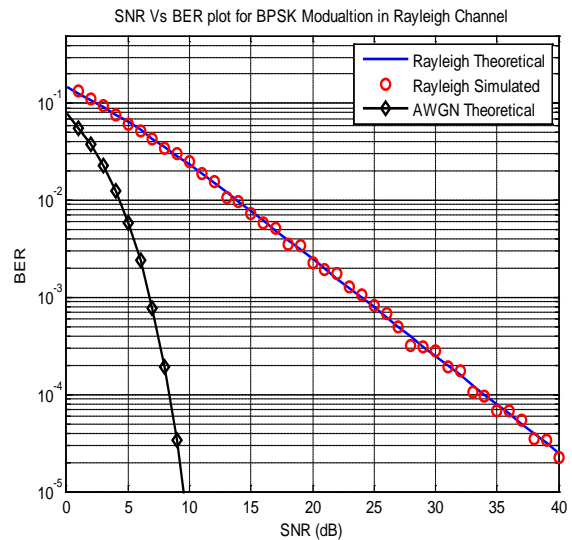
**F. Channel Capacity:**

Also, we could see in Fig. (12) The effect of increasing the number of used antennas on the utilized channel capacity that will increase above the defined Shannon capacity.

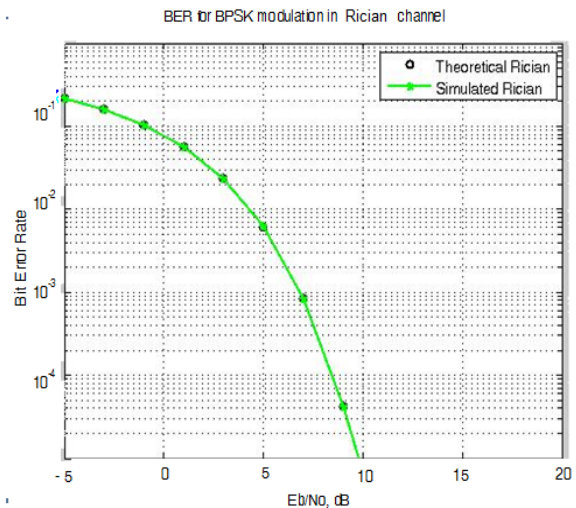


**Fig. (12): Channel Capacity vs. SNR**

**G. Channel fading techniques:**



**Fig. (13.a): BER Vs.  $E_b/N_0$  in Rayleigh channel**



**Fig. (13.b): BER Vs.  $E_b/N_0$  in Rician channel**

**Table 3: BER vs. Eb/No in AWGN, Rayleigh, Rician fading channels in BPSK modulation**

$E_b/N_0$ (db)	BER in AWGN	BER in Rayleigh	BER in Rician
-3	0.1584	0.2107	0.150

<b>0</b>	0.07865	0.1464	0.06
<b>5</b>	0.005954	0.06414	0.005
<b>8</b>	0.0001909	0.03536	0.0008
<b>9</b>	0.00003363	0.02901	0.00004
<b>10</b>	--	0.02323	--

As seen from Fig. (13.a), (13.b) and table 3, the AWGN and Rician channels provide the best BER performance at a given  $E_b/N_o$  value.

### VIII. CONCLUSION

Earlier technologies was based on communication forms as SISO (Single Input, Single output), SIMO (Single input, multiple output) or MISO (Multiple input, Single output), but after this fading was reduced and channel capacity were enhanced through the usage of MIMO (Multiple Input, Multiple output) concept.

In this paper, we learned about the MIMO communication system, different system channels, and the theory of both space-time block code and V-BLAST code.

The paper studied the performance of the MIMO communication channel through the usage of different coding techniques as Alamouti and V-BLAST schemes. Various modulation schemes and channel types were studied and evaluated.

### REFERENCES

- [1] Ashraf, K., & Khan, N. M. (2009). Performance comparison of Alamouti ST codes with different STTC over Rayleigh fading channels. *2009 IEEE 13th International Multitopic Conference*. doi:10.1109/inmic.2009.5383136
- [2] Biradar, R. (2015, July). Study and Analysis of 2x2 MIMO Systems for Different Modulation Techniques Using MATLAB. Retrieved September 10, 2017, from <http://www.techrepublic.com/resource-library/whitepapers/study-and-analysis-of-2x2-mimo-systems-for-different-modulation-techniques-using-matlab/>
- [3] Barbarossa, S. (2005). *Multiantenna Wireless Communication Systems*. USA: Artech House. doi:9781580536349
- [4] Devlal, Y. (2015). MIMO Performance analysis with Alamouti STBC Code and V-BLAST Detection Scheme. *International Journal of Science, Engineering and Technology Research (IJSETR)*, 4(1), 199-204. Retrieved from [ijsetr.org/wp-content/uploads/2015/01/IJSETR-VOL-4-ISSUE-1-199-204.pdf](http://ijsetr.org/wp-content/uploads/2015/01/IJSETR-VOL-4-ISSUE-1-199-204.pdf).
- [5] Jakes, W.C. (1974). *Microwave Mobile Communications*, Wiley, 1974.
- [6] Rice, S.O. (1948). "Mathematical analysis of a sine wave plus random noise", *Bell System Technical Journal*, 27 (1), pp.109-157
- [7] Sethi, I. (2016). Comparison of MIMO Modulation Technique under Alamouti Technique. *International Journal of Advanced Research in Computer Science and Software Engineering*, 6(6), 246-248. Retrieved from

- [https://www.ijarcse.com/docs/papers/Volume\\_6/6\\_June2016/V6I6-0175.pdf](https://www.ijarcse.com/docs/papers/Volume_6/6_June2016/V6I6-0175.pdf).
- [8] Singh, H. (2014). Performance Analysis of MIMO Spatial Multiplexing using different Antenna Configurations and Modulation Techniques in AWGN Channel. *Global Journal of Researches in Engineering: F Electrical and Electronics Engineering*, 14(5),
  - [9] Singh, G. (2012). Comparison of Different Modulation Techniques Using V-Blast Mimo System in Rayleigh Channel. *International Journal of Engineering Research and Development*, 4(2), 91-100. Retrieved from <https://pdfs.semanticscholar.org/e5db/6168dfc48030ac84591819e6f9f6f628e6f4.pdf>.
  - [10] Siavash M Alamouti, (October 1998). "A Simple Transmit Diversity Technique for Wireless Communication", *IEEE Journal on selected areas in Communication*, Vol 16, No: 8.
  - [11] Saunders S R, (1999). 'Antennas and Propagation for Wireless Communication Systems', Wiley.
  - [12] Tanmeet, K. (2013). "Performance Evaluation of MIMO Systems with varying number of transmitting antennas", *International Journal of Innovation research in electrical, electronics, instrumentation and control engineering*, 1(2), 6th ser., 38-40.
  - [13] Wolniansky, P. (n.d.). V-BLAST: An Architecture for Realizing Very High Data ... Retrieved September 10, 2017, from <http://www.bing.com/cr?IG=B220BAC254694761B74C4DE7CA3D0797&CID=3ACC8717A1AC6BA30BB68DEEA0AA6A16&rd=1&h=n8Si fGHU87tbFrTol32EmX9SpTpMk8r1rH7-1oUhVAw&v=1&r=http%3a%2f%2fwww.ee.columbia.edu%2f%7ejiantan%2fe6909%2fwolnianskyandfoschini.pdf&p=DevEx,5062.1>