A New Transmission Scheme for MIMO – OFDM

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Abstract— This contribution introduces a new transmission scheme for multiple-input multiple-output (MIMO) Orthogonal Frequency Division Multiplexing (OFDM) systems. The new scheme is efficient and suitable especially for symmetric channels such as the link between two base stations or between two antennas on radio beam transmission. This survey Paper presents the performance analysis of V-BLAST based multiple inputs multiple output orthogonal frequency division multiplexing (MIMO-OFDM) system with respect to bit error rate per signal to noise ratio (BER/SNR) for various detection techniques. A 2X2 MIMO-OFDM system is used for the performance evaluation. The simulation results shows that the performance of V-BLAST based detection techniques is much better than the conventional methods.

Alamouti Space Time Block Code (STBC) scheme is used with orthogonal designs over multiple antennas which showed simulated results are identical to expected theoretical results. With this technique both Bit Error Rate (BER) and maximum diversity gain are achieved by increasing number of antennas on either side. This scheme is efficient in all the applications where system capacity is limited by multipath fading.

Keywords: Multiple Input Multiple Output (MIMO), OFDM, STBC, Bit Error Rate (BER), Maximum Receiving Ratio Combining (MRRC), Alamouti Scheme, V-BLAST.

I. INTRODUCTION

During the past decades, wireless communication has benefitted from substantial advances and it is considered as the key enabling technique of innovative future consumer products. High transmission data rate, spectral efficiency and reliability are necessary for future wireless communication system. Unlike Gaussian channels, wireless channels suffer from attenuation due to multipath in the channel. Multiple copies of a single transmission arrive at the receiver at slightly different times. Without diversity techniques, severe attenuation makes it difficult for the receiver to determine the transmitted signal [1].

Specifically, the employment of multiple antennas at both the transmitter and the receiver, which is widely referred to as the MIMO techniques, constitutes a cost-effective approach to high throughput wireless communication and remote sensing. The concept MIMO for both wired and wireless systems was first introduced by Jack Winter in 1987 for two basic communication systems. The first was for communication between multiple mobiles and a base station with multiple antennas and the second for communication between two mobiles each with multiple antennas. Where, he introduced a technique of transmitting data from multiple users over the same frequency/time channel using multiple antennas at both the transmitter and receiver ends. In 1996, Raleigh proposed new approaches for improving the efficiency of MIMO systems which inspired numerous further contributions for two suitable architectures for its realization known as Vertical Bell-Labs Layered Space-Time (V-BLAST) algorithm has been proposed by Foschini, which is capable of achieving a substantial part of the MIMO capacity. It is capable of achieving high spectral efficiency which being relatively simple to implement. The basic motive was to increase the data rate in a constrained spectrum. The promises of information theoretic MIMO analysis for the channel capacity were the main trigger for this enthusiasm and also ignited the study of related area such as MIMO channel modeling Space time signal processing, Space – Time coding etc. The objective of such multi-channel diagonalization is to partition or distribute multi user signals into disjoint space and resultant channel gains are maximized to optimize the overall system capacity under the constraint of a fixed transmit power. Also improve the quality (BER).

II. MIMO CHANNEL MODELS

MIMO System is an extension of smart antennas systems. Traditional smart antenna system employs multiple antennas at the receiver. Whereas in a general MIMO system multiple antennas are employed both at the transmitter and the receiver. The addition of multiple antennas at the transmitter combined with advanced signal processing algorithms at the transmitter and the receiver yields significant advantage over traditional smart antenna systems – both in terms of capacity and diversity advantage.

A MIMO channel is a wireless link between M transmits and N receive antennas. It consists of MN elements that represent the MIMO channel coefficients. The multiple transmit and receive antennas could belong to a single user modem or it could be distributed among different users. The later configuration is called distributed MIMO and cooperative communications. Statistical MIMO channel models offer flexibility in selecting the channel parameters. Temporal and spatial correlations. Fig.1(a), (b), (c) and (d) shows conceptual diagram of existing technology, smart antenna system and MIMO channels respectively.

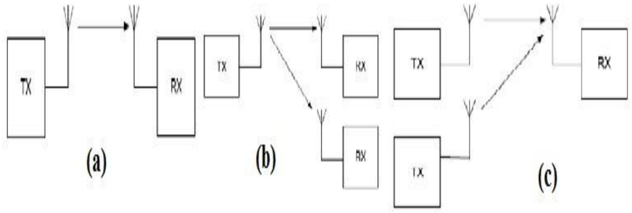

Figure 1 (a) SISO (b) SIMO (c) MISO [1]

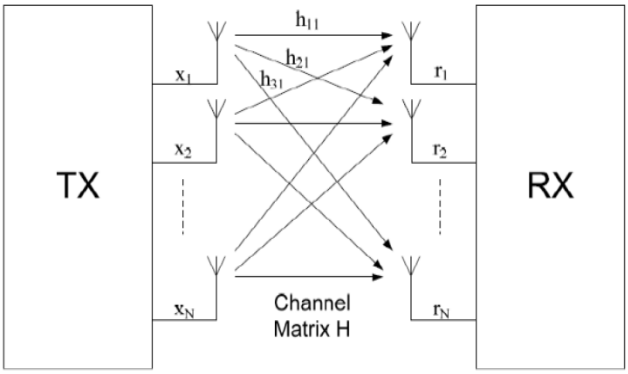

Figure.2 : (d) MIMO system model [1]

III. MIMO SYSTEM CHANNEL CAPACITY

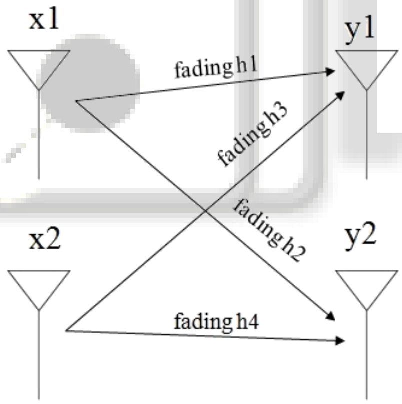

Figure.3 : MIMO Channel

Multipath propagation has long been regarded as “impairment” because it causes signal fading. To mitigate this problem diversity technique were developed. Antenna diversity is a widespread form of diversity.

Channel capacity is the maximum information rate that can be transmitted and received with arbitrarily low probability of error at the receiver. A common representation of the channel capacity is within a unit bandwidth of the channel and can be expressed in bps/Hz. MIMO channel capacity depends heavily on the statistical properties and antenna element correlations of the channel.

$$C = B\log_2(1+SNR) \tag{1}$$

When multiple antennas are used, channel faces multiple input and output, and its capacity in determined by extended Shannon’s capacity. Antenna with N_t input from transmitter and N_r output in a receiver channel is expressed as $N_t * N_r$ matrix of channel H.

The capacity of a MIMO channel can be estimated by the following equation:

$$C = \log_2\left(1+\frac{1}{\sigma_n^2}HR_xH^H\right) \tag{2}$$

Where H is $N_t * N_r$ channel matrix, R_x is covariance of input signal x, H^H is transpose conjugate of H matrix and σ_n^2 is the variance of the uncorrelated and Gaussian noise.

To achieve more precise results linear transformation at both transmitter and receiver can be performed by converting MIMO channel (N_r,N_t) to a SISO sub channel min (N_r,N_t). According to singular value decomposition (SVD) every matrix can be decomposed. Suppose the channel matrix H transformation is given by

$$H = UDV^H$$

Where the matrix U is N_r x N_r matrix, V is N_c x N_c matrix and D is non-negative diagonal matrix of N_r x N_t. Therefore capacity of N SISO sub channels is sum of individual capacity and results the total MIMO capacity.

IV. DIVERSITY IMPROVEMENT TECHNIQUES

One of the methods to increase the capacity in MIMO system is through diversity technique. Diversity is defined as a method in which transmitter sends multiple copies of same information signal over two or more channels and proper combining of signal is done by a receiver. When the replicas of signal are transmitted the probability that the signal will fade decreases exponentially. So diversity techniques enhance the performance of the system over fading channels.

A. *Maximum Ratio Receive Combining:*

To eliminate the effect of multipath fading antenna diversity is practical, effective and commonly used technique. MRRC is classical **receive diversity technique**, which uses the multiple antenna at the receiver and performs combining or selection and switching to improve the quality of received signal. Since the cost, size and power are the important factors to be considered, MRRC uses selection and switching circuit in the receiver which makes it larger in size and costly. Due to this reason transmit diversity schemes are found more attractive than the receive diversity.

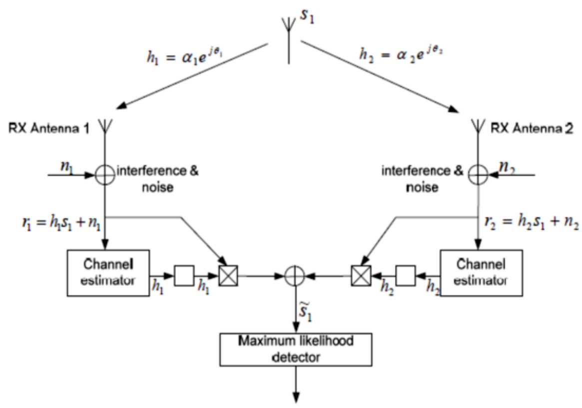

Figure .4: Two branches MRRC [2]

At a time t signal s1 is transmitted and the channel is presented with complex multiplicative distortion. Let h1 be the channel between transmit antenna and receiving antenna 1 and h2 be channel between transmit antenna and receive antenna 2 and are given by

$$\mathbf{h_1 = \alpha_1 e^{j\theta_1}, h_2 = \alpha_2 e^{j\theta_2}} \quad (3)$$

The received signal with added noise and interference are below as shown in figure.

$$r_1 = h_1 S_1 + n_1,\ r_2 = h_2 S_1 + n_2 \quad (4)$$

Where n_0 and n_1 are noise and interference which is assumed to be Gaussian distributed. The two branch MRRC combiner combines the received signal as follow:

$$\tilde{s} = h_1^* r_1 + h_2^* r_2$$
$$= h_1^*(h_1 S_1 + n_1) + h_2^*(h_2 S_1 + n_2)$$
$$= (\alpha_1^2 + \alpha_2^2) S_1 + h_1^* n_1 + h_2^* n_2 \quad (5)$$

After combining the signal, maximum likelihood decision rule is used at receiver to choose the signal which symbol was actually transmitted.

Choose $s_1 = s_i$ if and only if

$$(\alpha_1^2 + \alpha_2^2 - 1)\,|S_i|^2 + d^2(\tilde{s_1}, S_i) \le (\alpha_1^2 + \alpha_2^2 - 1)\,|S_k|^2 + + d^2(\tilde{s_1}, S_k)\ \ \forall i \ne k \quad (6)$$

Where, $d^2(\tilde{s_1}, S_i)$ is the square Euclidean distance between signals s_1 and s_i Calculated by the following:

$$d^2(\tilde{s_1}, S_i) = (\tilde{s_1} - S_i)(\tilde{s_i}^* - S_i^*) \quad (7)$$

Finally the maximum likelihood detector will produce the signal s_1 which is maximum likelihood estimate of s_1.

B. *ALAMOUTI SCHEME*

The new **transmit diversity** scheme was introduced by Alamouti known as Alamouti scheme. Alamouti scheme uses two transmit antenna and N_r receive antenna and can have a maximum diversity order of $2N_r$. Alamouti scheme has the rate of unity i.e. full rate since it transmits two symbols after every two time periods. This scheme is efficient in all the applications where system capacity is limited by multipath fading. Here we will explain only two transmit and three receive antenna Alamouti scheme [2].

Two Transmit and three receive antennas: Alamouti scheme works for two transmit and N number of receive antennas. Let us consider case with two transmits and three receive antennas. The transmission sequence of information symbol for this configuration is identical with 2x1 and 2x2 antenna scheme. Moreover it can be seen in Table 1.

Let h_1, h_3, h_5 and h_2, h_4, h_6 be the channel between two transmit and three receive antenna which is also shown in table 1 below:

Tx antenna	rx antenna 1	rx antenna 2	rx antenna 3
1	h_1	h_3	h_5
2	h_2	h_4	h_6

Table 1: Channel parameter for 2 x 3 antennas.

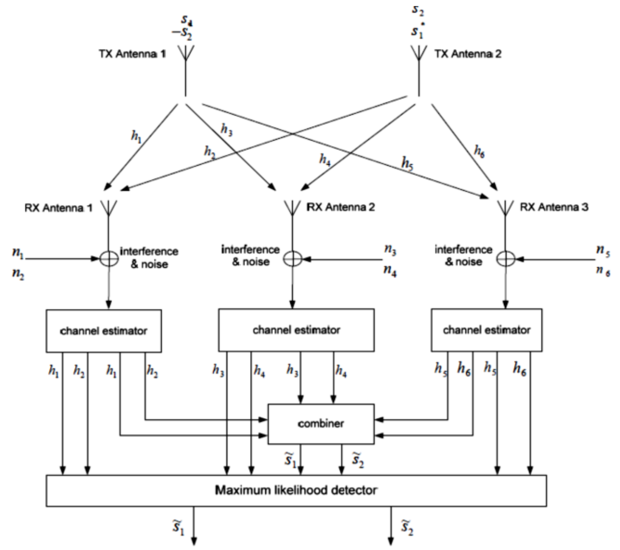

Figure 5: Two Transmit and three receive Alamouti scheme [2]

The received signals at time t and t+T are r_1, r_3, r_5 and r_2, r_4, r_6 respectively, which can be seen in table 2.

Time	rx antenna 1	rx antenna 2	rx antenna 3
t	r_1	r_3	r_5
t+T	r_2	r_4	r_6

Table 2: Received signals at three receive antennas.

Here,

$$r_1 = h_1 S_1 + h_2 S_2 + n_1$$
$$r_2 = -h_1 S_2^* + h_2 S_1^* + n_2$$
$$r_3 = h_3 S_1 + h_4 S_2 + n_3$$
$$r_4 = -h_3 S_2^* + h_4 S_1^* + n_4$$
$$r_5 = h_5 S_1 + h_6 S_2 + n_5$$
$$r_6 = -h_5 S_2 + h_6 S_1^* + n_6 \quad (8)$$

Where n_1, n_2, n_3, n_4, n_5 and n_6 are complex random variables representing noise and interference. As it can be seen in Figure 4-4, the received signals are combined and following two signals are generated.

$$\tilde{s_1} = h_1^* r_1 + h_2 r_2^* + h_3^* r_3 + h_4 r_4^* + h_5^* r_5 + h_6 r_6^*$$
$$\tilde{s_2} = h_2^* r_1 - h_1 r_2^* + h_4^* r_3 - h_3 r_4^* + h_6^* r_5 - h_5 r_6^* \quad (9)$$

Substituting eq (8) and eq (9) which gives eq (10):

$$\tilde{s_1} = (\alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2 + \alpha_5^2 + \alpha_6^2) S_1 + h_1^* n_1 + h_2^* n_2 + h_3^* n_3 + h_4 n_4^* + h_5^* n_5 + h_6 n_6^*$$

$$\tilde{s_2} = (\alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2 + \alpha_5^2 + \alpha_6^2) S_2 - h_1 n_2^* + h_2^* n_1 - h_3 n_4^* + h_4^* n_3 - h_5 n_6^* + h_6^* n_5 \quad (10)$$

Performance of Alamouti scheme: The BER performance comparison of Alamouti transmit diversity scheme with coherent BPSK on slow Rayleigh fading channel with two and four branch MRRC receive diversity scheme as shown in figure. 5. It is assumed that the total transmit power in two transmit antenna in Alamouti scheme is same as the transmit power from single transmit antenna for MRRC.

And also assumed that receiver has perfect knowledge of the channel.

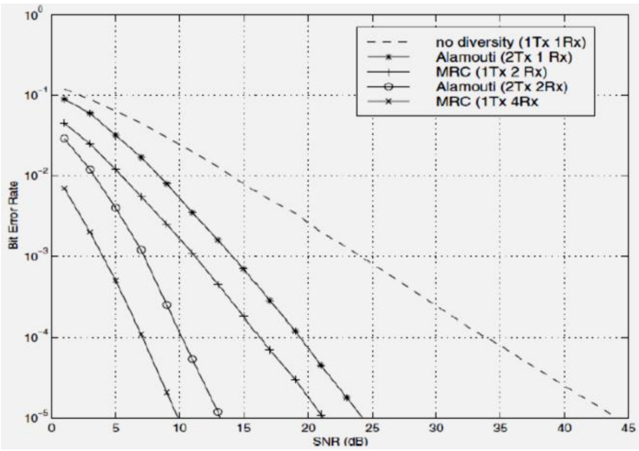

Figure .6 : BER performance comparison of BPSK Alamouti scheme Rayleigh fading to MRRC.

The simulation output shows that the Alamouti scheme with two transmit and a single receive antenna achieves the same diversity order as MRRC scheme with one transmit and two receive antenna as the slope of two curves are almost same. However, it can be seen that Alamouti scheme is 3dB behind than MRRC. The fact is that due to energy radiated from two transmit antenna in Alamouti is half of the energy radiated from a single antenna in MRRC. If the energy radiated is same for each transmit antenna in Alamouti and MRRC than resulting curve would be same.

V. V-BLAST ARCHITECTURE

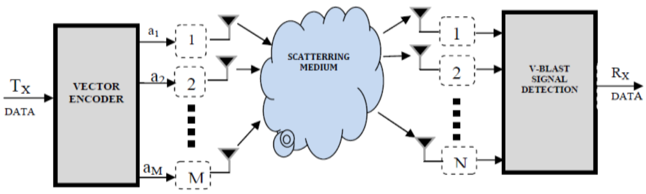

Figure .7 : Block diagram of V-Blast architecture [4]

One of the earliest communication systems that were proposed to take advantage of the promising capacity of MIMO channels is the BLAST architecture. It achieves high spectral efficiencies by spatially multiplexing coded or uncoded symbols over the MIMO fading channel. Symbols are transmitted through M antennas. Each receiver antenna receives a superposition of faded symbols. The ML decoder would select the set of symbols that are closest in Euclidean distance to the received N signals. However, it is hard to implement due to its exponential complexity. More practical decoding architectures were proposed in the literature.

A. *V-BLAST Technique*

The transmission is described as follows. A data stream is demultiplexed into M sub-streams termed layers. For D-BLAST at each transmission time, the layers circularly shift across the M transmit antennas resulting in a diagonal structure across space and time. On the other hand, the layers are arranged horizontally across space and time for V-BLAST and the cycling operation is removed before transmission is shown in Fig.6. At the receiver, as mentioned previously, the received signals at each receive antenna is a superposition of M faded symbols plus additive white Gaussian noise (AWGN). Although the layers are arranged Differently for the two BLAST systems across space and time, the detection process for both systems is performed vertically for each received vector. Without loss of generality, assume that the first symbol is to be detected. The detection process consists of two main operations:

1) Interference suppression (nulling):

The suppression operation nulls out interference by projecting the received vector onto the null subspace (perpendicular subspace) of the subspace spanned by the interfering signals. After that, normal detection of the first symbol is performed [1].

2) Interference cancellation (subtraction):

The contribution of the detected symbol is subtracted from the received vector [1].

BLAST detection algorithm combines linear (interference suppression) and nonlinear (serial cancellation) algorithms. This is similar to the decorrelating decision feedback multiuser detection algorithm. A drawback of BLAST algorithms is the propagation of decision errors. Also, the Interference nulling operation requires that the number of receive antennas be greater than or equal to the number of transmit antennas. Furthermore, due to the interference suppression, early detected symbols benefit from lower receives diversity than later ones. Thus, the algorithm results in unequal diversity advantage for each symbol.

There are few differences between V-BLAST and D-BLAST. While the layers of the V-BLAST can be coded or uncoded, the D-BLAST is intended to be used only with coded layers. This is the reason behind cycling which provides more spatial diversity for each layer particularly over slowly fading channels. Further, due to the diagonal structure of D-BLAST, each layer benefits from the same diversity advantage while V-BLAST layers have unequal diversity advantages. However, DBLAST requires advanced inter-stream coding techniques to optimize the performance of the code across space and time. Finally, some space-time is wasted at the start and the end of the burst for DBLAST.

V-BLAST takes a single data stream and demultiplexed it into M sub-streams with M is the number of transmitter antennas. Each sub-stream is encoded into symbols and fed to a separate transmitter. The modulation method in these systems usually is M Quadrature Amplitude Modulation (MQAM). QAM combines phase modulation with amplitude modulation, making it an efficient method for transmitting data over a limited bandwidth channel. BLAST's receivers operate co-channel, each receiving the signals emanating from all M of the transmitting antennas. For the sake of simplicity, it is also assumed that the channel-time variation is negligible over the L symbol periods in a burst.

B. *Performance analysis of MIMO technology using V-BLAST Techniques*

1) Maximum Likelihood

ML is a non-linear detection technique. The BER/SNR results of ML are better than MMSE detector but at the cost of additional complexity. So ML is used in applications where high efficiency is requires. Now if we apply V-BLAST algorithm on ML, the performance will be better than ML detector [3].

2) Zero Forcing

Zero Forcing is a linear detection technique. The pseudo inverse of the signal is applied to the received signal in order to make a decision about one user. So the equation for filter matrix G for zero forcing will be,

$$G = (H^H\ H)^{-1}\ H^H \quad (11)$$

In this way the received signal is detected by zero forcing detectors. If V-BLAST algorithm is applied on ZF detector, equation 11 will be applied on ZF filter matrix. ZF with V-BLAST shows better performance in comparison to normal ZF in terms of BER/SNR [3].

3) Minimum Mean Square Error

MMSE is also a linear detection technique but more reliable than ZF in case of noisy channel . MMSE does not apply pseudo inverse of signal to make decision about one user, instead it attenuates them to noise level thereby reducing the diversity order. From the filter matrix for MMSE is,

$$G = (H^H\ H + \frac{N_t}{SNR}\ I_{N_r})^{-1}\ H^H \quad (12)$$

Now V-BLAST algorithm can be applied over above filter matrix and results can be generated [3].

VI. MATLAB RESULTS

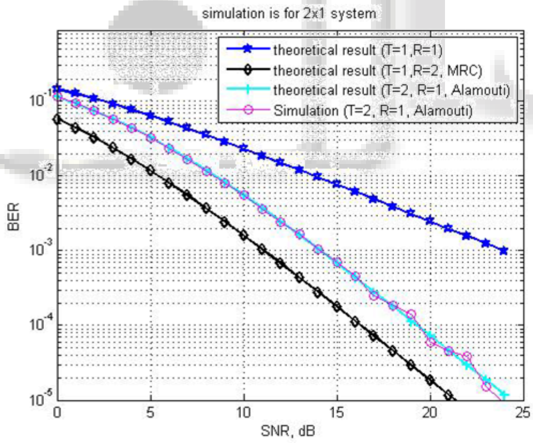

Figure. 7: BER vs. SNR ratio for Alamouti 2*2

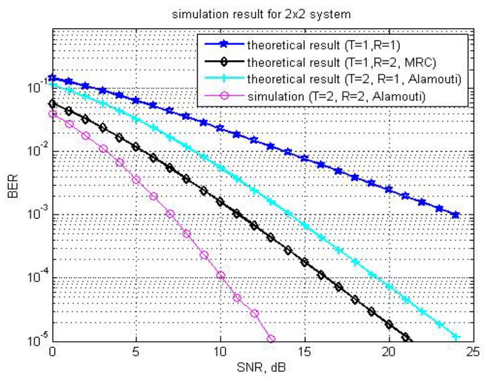

Figure .8: BER vs. SNR ratio for Alamouti 2*2

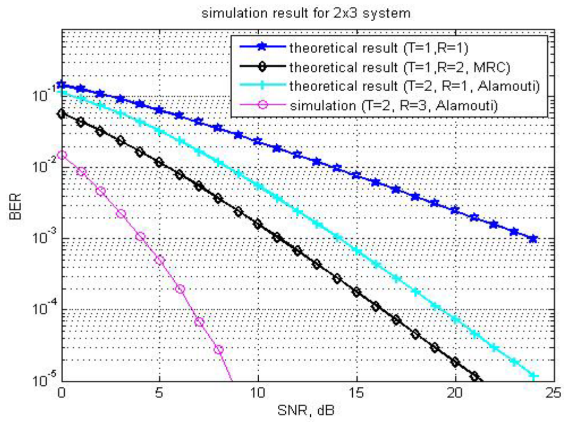

Figure .9: BER vs. SNR ratio for Alamouti 2*3

Comparison of BER performance with different Alamouti scheme

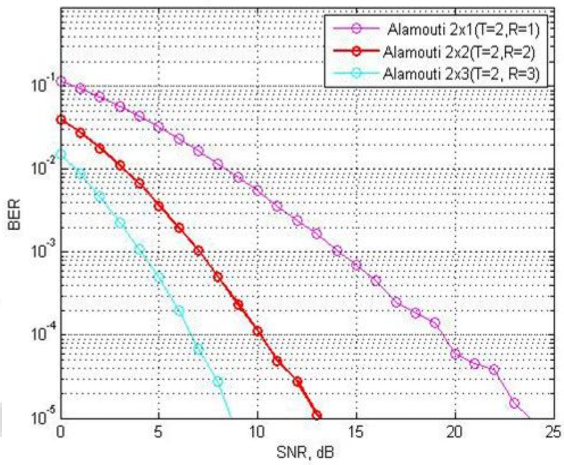

Figure .10: Comparison of BER vs. SNR ratio for Alamouti 2*1, 2*2, 2*3

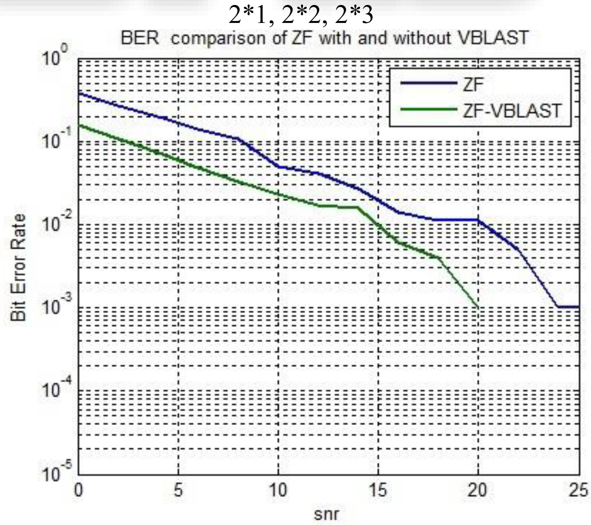

Figure .11: BER vs. SNR ratio for ZF and ZF-VBLAST

VII. CONCLUSION

In this paper, a detailed overview and analysis of OFDM, MIMO and their combination with space time coding were discussed. OFDM modulator and demodulator were designed and simulated for single input and single output. Space time coding (STC) has been implemented on MIMO system and its BER checked. Simulated result for Alamouti

2x1, 2x2 and 2x3 were compared with theoretical results of one transmitter and one receiver (MRRC) and Alamouti 2x1. As diversity increases at the receiver end BER is reduced. MIMO code was designed in such a way that it can be raised up to 2xN receiver. The results of the simulations, in which BER performance of different schemes is, computed shows that MIMO-OFDM with space time coding can provide high data rate transmission and there is no need to increase the transmit power and expansion of bandwidth. The results of the simulations, in which BER performance of ZF-VBLAST and ZF is shown in the figure 1.11.

VIII. FUTURE WORK

The main focus of this paper was BER performance for different Alamouti schemes. In future compare all the three techniques of V-BLAST. In future one can combine MIMO and OFDM and extend it for V-BLAST and Hybrid V-BLAST ARCHITECTURE for higher diversity of antennas. Moreover, further work can also be done to enhance the capacity of the channel.

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