

A Modified Grouped Linear ZF Algorithm Using Different Modulation Schemes for MIMO Systems

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Received on: 5/6/2011 & Accepted on: 3/11/2011

ABSTRACT

A new algorithm for a group iterative linear Zero-Forcing (ZF) receiver for multiple-input multiple-output (MIMO) systems is proposed in this paper. The proposed algorithm merges between the group linear ZF receiver and V-Blast algorithms, where the signals in every group are detected by linear ZF method and then successive interference cancellation detection is applied between the different groups. Three types of modulation schemes are adopted for testing this algorithm namely; BPSK, QPSK, and 16 QAM. Simulation results show that the proposed algorithm achieves a performance improvement over the ZF algorithm and the grouped linear ZF algorithm at modulations (BPSK, QPSK). The proposed scheme offers better performance gain for BPSK modulation of about 7dB and 2dB compared with ZF and MMSE schemes respectively at BER of 10^{-3} . On the other hand, the proposed scheme offer better performance gain of about 3dB and 1dB compared with ZF and minimum mean square error schemes for QPSK modulation at BER 10^{-3} . However, at using modulation of (16QAM), the performance of the proposed algorithm is almost the same as that of the aforementioned algorithms. A little increase of computational complexity is noticed with this proposed algorithm compared with both the ZF, MMSE and the grouped linear ZF algorithms.

Keywords: V-Blast, Zero Forcing, Minimum mean square receiver and MIMO.

تحويل خوارزمية الاجبار الصفري (ZF) الخطية المُجمَّعة باستخدام انواع تضمين مختلفة في الأنظمة متعددة الادخال متعددة الاخراج (MIMO)

الخلاصة

في هذا البحث، تم اقتراح خوارزمية محورة لغرض الاستخدام في مستقبل مجموعة الاجبار الصفري الخطية (ZF) في الأنظمة متعددة الادخال متعددة الاخراج. الخوارزمية المقترحة تجمع بين مستقبل الاجبار الصفري وبين خوارزمية (V-Blast)، حيث ان كل مجموعة يتم كشفها في مستقبل الاجبار الصفري وبعد ذلك تكشف بإلغاء تداخل متعاقب تطبيقي بين المجموعات المختلفة. تم اعتماد ثلاث انواع من التضمين لاختبار هذه الخوارزمية وهي مفتاح الازاحة الطوري الثنائي (BPSK)، ومفتاح الازاحة الطوري الرباعي (QPSK)، وتضمين السعة التربيعي ذي الستة عشر مستوى (16 QAM). نتائج المحاكاة اظهرت ان الخوارزمية المقترحة تنتج تحسين أداء على خوارزمية الاجبار الصفري وخوارزمية (ZF) الخطية المُجمَّعة في التضمين (BPSK) و

(QPSK). وقد لوحظ بأن الطريقة المقترحة تعطي كسب أداء أفضل لأنظمة التضمين (BPSK) بحوالي (7) ديسيبل و(2) ديسيبل إذا ما قورنت مع طرق (ZF) و (MMSE) على التوالي في معدل الخطأ التثائي 10^{-3} . من الناحية الأخرى، كان كسب الطريقة المقترحة في الأداء للتضمين (QPSK) بحوالي (3) ديسيبل و(1) ديسيبل إذا ما قورنت مع طرق (ZF) و (MMSE) على التوالي في معدل الخطأ التثائي 10^{-3} . لقد لوحظ بأن أداء الخوارزمية المقترحة يشبه الخوارزميات الأخرى تقريباً وذلك عند استعمال التضمين (16 QAM). كما لوحظ أيضاً وجود زيادة طفيفة بالتعقيد الحسابي في الخوارزمية المقترحة إذا ما قورنت بكل من الطرق (ZF) و (MMSE) و خوارزمية (ZF) الخطية المجمعة.

INTRODUCTION

Increased spectral efficiency and improved link reliability are the major challenges in future wireless communication systems. The use of multiple antennas at both ends of a wireless link promises significant improvements in terms of spectral efficiency and/or link reliability. MIMO technology has recently become very popular since it can improve link reliability without sacrificing bandwidth efficiency [1]. MIMO systems can achieve very high spectral efficiency in rich multipath environment through exploiting the extra space dimension [2]. In 1996, Raleigh and Cioffi [3] and Foschini [4] 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 (VBLAST), and Diagonal Bell-Labs Layered Space-Time BLAST (D-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 while being relatively simple to implement. This structure offers highly better error performance than other existence detection method and still has low complexity [5]. In V-BLAST, the receiver performs iterative nulling and cancellation with ordering, where the optimal order of detection is determined and nulling vectors are computed at each iteration. Many detection algorithms are proposed based on the characteristics of V-BLAST system, such as; ZF algorithm, least mean square algorithm, QR decomposition detection algorithm, maximum likelihood algorithm, etc. The

Maximum likelihood algorithm is the optimal of all, but it is not practical due to its high computational complexity [6-7]. In [7] group iterative linear zero-forcing receiver for MIMO system is presented. The signals of all layers are firstly grouped and the signals in every group are detection by linear ZF method.

In this paper, a modified grouped linear ZF receiver detecting algorithm is proposed. Its performance is estimated and compared with the other conventional algorithms.

The rest of this paper is organized as follows. In section 2, system model of V-BLAST is analyzed. Section 3 presents the detection schemes for V-BLAST architecture. The proposed algorithm is discussed in Section 4. Simulation results and performance comparisons are presented in Section 5 and finally conclusion is presented in Section 6.

Common notations have been used in this paper such as $(\cdot)^{-1}$ denotes inverse matrix operation. $(\cdot)^T$ and $(\cdot)^H$ denote transposition and conjugate transposition operations, respectively, of a matrix or a vector. $\|\cdot\|^2$ stands for the Frobenius norm. I_m denotes the $m \times m$ identity matrix. H^+ denoting the Moore-Penrose pseudo inverse. $Q(x)$

denotes the hard decision on \mathbf{x} . $(\mathbf{w})_i$ is the i -th row of (\mathbf{w}) . the value of \mathbf{x} that minimizes the function $f(\mathbf{x})$. $E[x]$ the expected value of random variable x .

V-BLAST SYSTEM

Consider a MIMO system with n_T transmitting antennas and n_R receiving antennas as shown in Fig. (1). Firstly, a binary input bit sequence is mapped into a complex valued symbol sequence $\mathbf{x}(n)=[x_1(n),x_2(n),\dots,x_{n_T}(n)]^T$, where each element is selected from a finite set or constellation alphabet and transmitted by different antennas [6-8]. The signal is then transmitted via the Raleigh fading channel and detected by the V-BLAST detector. The received signal vector in the k -th symbol duration can be expressed as:

$$\mathbf{y}(n) = \mathbf{H}\mathbf{x}(n) + \mathbf{n}(n) \quad \dots(1)$$

where $\mathbf{y}(n)=[y_1(n),y_2(n),\dots,y_{n_R}(n)]^T$ is the received signal vector, $\mathbf{H} = [h_{ij}]_{n_T \times n_R}$ represents the channel matrix, and $h_{ij}, (i = 1, 2, \dots, n_R, j = 1, 2, \dots, n_T)$ is the complex matrix element expressing the channel frequency response coefficient between the j -th transmitting antenna and the i -th receiving antenna. The AWGN vector is given by $\mathbf{n}(n)$, where $E\{\mathbf{n}\mathbf{n}^H\} = N_o \mathbf{I}_{n_R}$ and $E\{\mathbf{x}\mathbf{x}^H\} = \mathbf{I}_{n_T}$

DETECTION SCHEMES FOR V-BLAST

A. ZF Receiver

The ZF receiver is a linear receiver, which behaves like a linear filter and separates the data streams and thereafter independently decodes each stream. The channel matrix (\mathbf{H}) is assumed to be invertible and the transmitted data symbol vector is estimated as:

$$\mathbf{G} = \mathbf{H}^+ = (\mathbf{H}^H \mathbf{H})^{-1} \mathbf{H}^H \quad \dots(2)$$

$$\hat{\mathbf{s}} = \mathbf{Q}(\mathbf{G}.\mathbf{y}) \quad \dots(3)$$

Where $\hat{\mathbf{s}}$ is the output of ZF receiver. The inverse of \mathbf{H} can only exist if the columns of \mathbf{H} are independent [9].

The ZF receiver eliminates multi-stream interference at the expense of noise enhancement.

B. MMSE Receiver

The Minimum Mean Square error (MMSE) detection scheme balances noise amplification and interference suppression and minimizes the total error.

$$\mathbf{G} = \mathbf{H}^+ = (\mathbf{H}^H \mathbf{H} + N_o \mathbf{I}_{n_T})^{-1} \mathbf{H}^H \quad \dots(4)$$

In a linear detector, the received signal vector (\mathbf{y}) is multiplied with a filter matrix \mathbf{G} , followed by a parallel decision on all layers [7].

C. MMSE V-BLAST Receiver

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. Hence, MMSE is superior to ZF in the presence of noise. This algorithm can be summarized as follows [7, 10]:

INITIALIZATION

$$i = 1 \quad y = y_1 \quad \dots(5a)$$

$$G_1 = H^+ \quad \dots(5b)$$

$$k_1 = \arg \min_j \| (G_1)_j \|^2 \quad \dots(5c)$$

Recursion

$$w_{k_i} = (G_i)_{k_i} \quad \dots(5d)$$

$$d_{k_i} = w_{k_i}^T \cdot y_{k_i} \quad \dots(5e)$$

$$\hat{s}_{k_i} = Q(d_{k_i}) \quad \dots(5f)$$

$$y_{i+1} = y_i - \hat{s}_{k_i} (H)_{k_i} \quad \dots(5g)$$

$$G_{i+1} = H_{k_i}^+ \quad \dots(5h)$$

$$k_{i+1} = \arg \min_{j \in (k_1, k_2, \dots, k_i)} \| (G_{i+1})_j \|^2 \quad \dots(5i)$$

$$i = i + 1$$

D. Group linear ZF receiver

Fig. (2) represents the group linear ZF receiver structure, which is considered as a multiple input multiple output system with 4 transmitting antennas and 4 receiving antennas. The transmitting data streams are grouped into 2 groups, and every group has two data streams. The receiver scheme can be described by the following steps [7]:

Step.1: Do linear ZF detection to obtain the first estimation \hat{s} using equations (2) and (3). The first group signals are made up of \hat{s}_1 and \hat{s}_2 while the second group signals are made up of \hat{s}_3 and \hat{s}_4

Step.2: Detect the first group signals again. In the processing, the group detected signals being interference are cancelled. The new MIMO is made up of two transmitting antennas and four receiving antennas. The new relation between the input signal and the output signal is

$$y_1 = [h_1 \quad h_2] \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + w \quad \dots\dots(6)$$

where y_1 is equal to $(y_0 - h_3s_3 - h_4s_4)$ and

$$y_0 = [h_1 \quad h_2 \quad h_3 \quad h_4] \cdot \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix} + w \quad \dots(7)$$

It has been used h_i to state the i -th column of matrix H. In equation (6), the linear ZF algorithm is applied again, and the new detected group signals may be obtained with more order diversity than the former detected signals. The original estimated signals are thus updated.

Step.3: Detect the group signals again, and the receiver signal is modified by ($y_2 = y_0 - h_1s_1 - h_2s_2$). The new signal model is thus modified by

$$y_2 = [h_3 \quad h_4] \begin{bmatrix} s_3 \\ s_4 \end{bmatrix} + w \quad \dots(8)$$

Therefore, the second group signals are again detected by linear ZF detections method.

PROPOSED SCHEME

A modified group linear ZF receiver structure is proposed in this section. Fig. (3) shows the proposed receiver structure with 4 transmitting antennas and 4 receiving antennas. The proposed receiver scheme is described by the following steps:

Step.1: Do linear ZF detection to obtain the first estimation \hat{s} using equations (2) and (3). The output of first stage will be $\hat{s} = [\hat{s}_1 \quad \hat{s}_2 \quad \hat{s}_3 \quad \hat{s}_4]$

Step.2: Detect the fourth signal again \hat{s}_4 . In the processing, the group detected signals being interference are cancelled. The new MIMO is made up of three transmitting antennas and four receiving antennas. The new relation between the input signal and the output signal is

$$y_1 = [h_1 \quad h_2 \quad h_3] \cdot \begin{bmatrix} \bar{s}_1 \\ \bar{s}_2 \\ \bar{s}_3 \end{bmatrix} + w \quad \dots,(9)$$

where y_1 is equal to ($y_0 - h_4s_4$) when $[\hat{s}_1 \quad \hat{s}_2 \quad \hat{s}_3]$ are detecting correctly .

Step.3: Detect the third signal again. In the same processing mentioned in step 2 and using the new fourth detected signal .

$$y_2 = [h_1 \quad h_2 \quad h_4] \cdot \begin{bmatrix} \bar{s}_1 \\ \bar{s}_2 \\ \hat{s}_4 \end{bmatrix} + w \quad \dots(10)$$

where y_2 is equal to $(y_0 - h_3 s_3)$. In same way, the first and the second signals are detected by substituting the new detected signals. The above algorithm can be summarized as follows:

$$i = 4$$

Recursion

while $i \geq 1$

$$y_{i-1} = y_i - \tilde{s}_{ki}^i \cdot h_i \quad \dots(11a)$$

Where \tilde{s}_{ki}^i and h_i deleted i -th element from \mathbf{s} and

h vectors

$$w_i = (h_i^H \cdot h_i) h_i \quad \dots(11b)$$

$$d_i = w_{ki}^T \cdot y_{i-1} \quad \dots(11c)$$

$$\hat{s}_i = Q(d_i) \quad \dots(11d)$$

$$\mathbf{s}_i = \hat{\mathbf{s}}_i \quad \dots(11e)$$

$$i = i - 1 \quad \dots(11f)$$

end of the while loop

It is found that our method has less complex than V-Blast algorithm and little complex than group zero forcing method. However, the proposed algorithm has less number of multiplication than V-Blast algorithm.

SIMULATION RESULTS

In this paper, it is assumed the channel to be completely known and its characteristics are given by Rayleigh flat fading. The number of transmitting antenna is 4, and the number of receiving antenna is also 4. BPSK, QPSK and 16 QAM modulation techniques are adopted here in the simulations to test the validity of the proposed algorithm.

Fig. (4) shows the simulation results for the proposed group linear ZF receiver when BPSK modulation is used as the transmission modulation. As a matter of comparison, the performances of ZF, V-BLAST and linear group ZF are also given. It is observed that the proposed scheme and group ZF have better performance than zero forcing and minimum mean square error schemes. At a target BER of 10^{-3} , the proposed scheme offers better performance gain of about 7dB and 2dB compared with ZF scheme and minimum mean square error scheme respectively.

Fig. (5) shows behavior of the proposed system with QPSK modulation technique. It is noticed that the proposed technique has better performance than group ZF, minimum mean square and ZF schemes. At a target BER of 10^{-3} , the proposed

scheme offer better performance gain of about 3dB and 1dB compared with ZF scheme and minimum mean square error scheme.

Fig. (6) shows performance of the proposed system with 16QAM modulation technique. It is obvious that V-BLAST has better performance than all other schemes. Actually, all other schemes approximately have the same performances.

CONCLUSIONS

A modified group linear ZF receiver scheme is proposed in this paper. This scheme aiming at minimizing the complexity of ZF-VBLAST and to improve performance of group linear ZF. The performance of the different schemes are tested for BPSK, QPSK and 16QAM modulation techniques by computer simulation. The simulation results show that the performance of the proposed scheme is better when using modulation (BPSK and QPSK). It is also shown that such scheme and the other schemes (except V-BLAST) have almost the same performances. The proposed algorithm has less complexity than ZF-VBLAST algorithms. On other hand, it has a little increase of computational complexity compared with ZF and MMSE algorithms.

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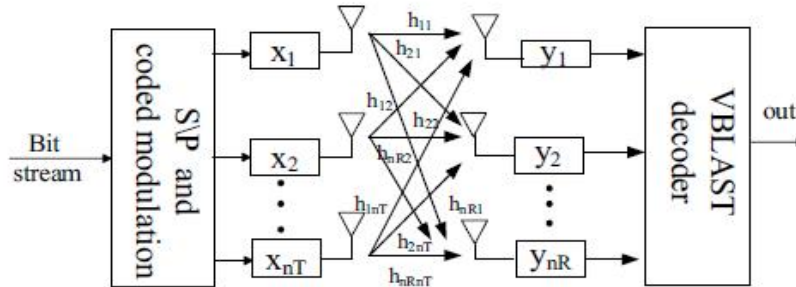


Figure (1) V-BLAST system

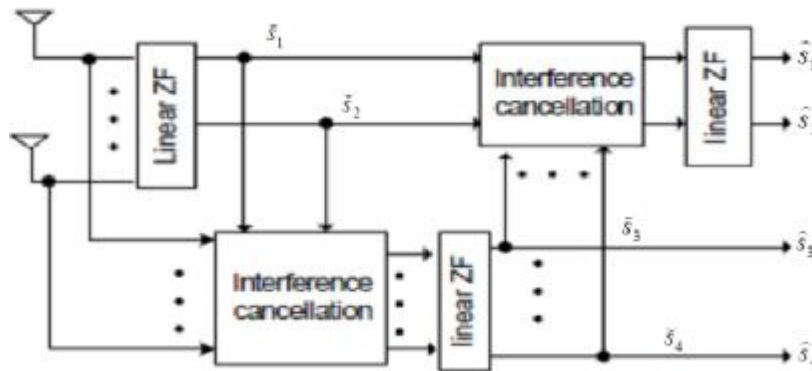


Figure (2) Group linear ZF receiver

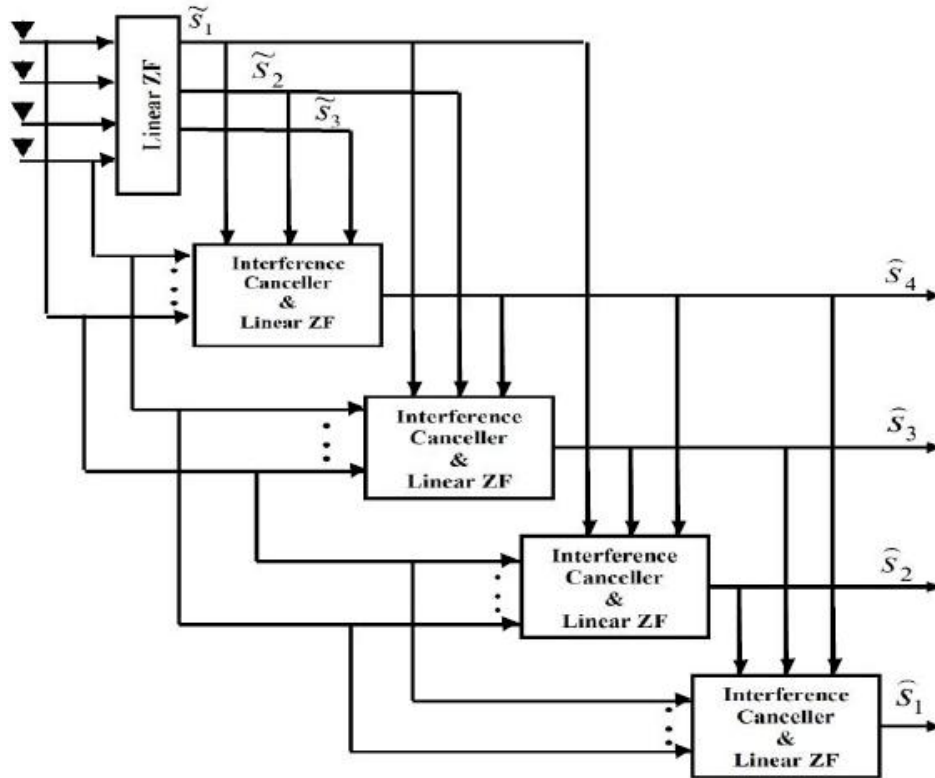


Figure (3) the proposed receiver structure

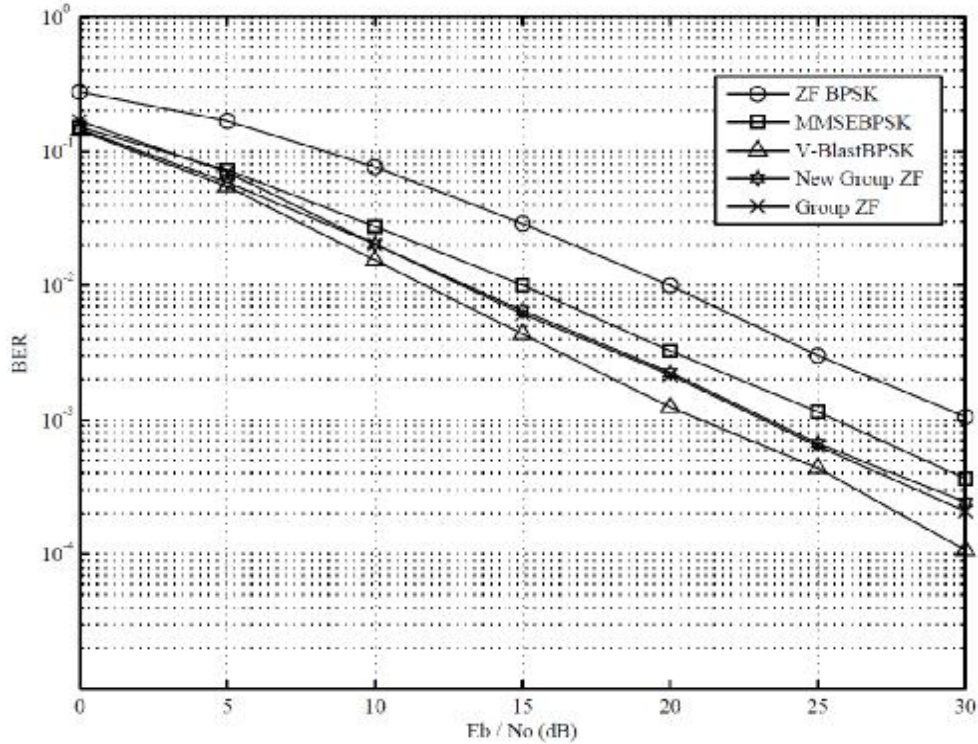


Figure (4) BER performance for BPSK modulation with Different detection schemes using 4Tx antennas

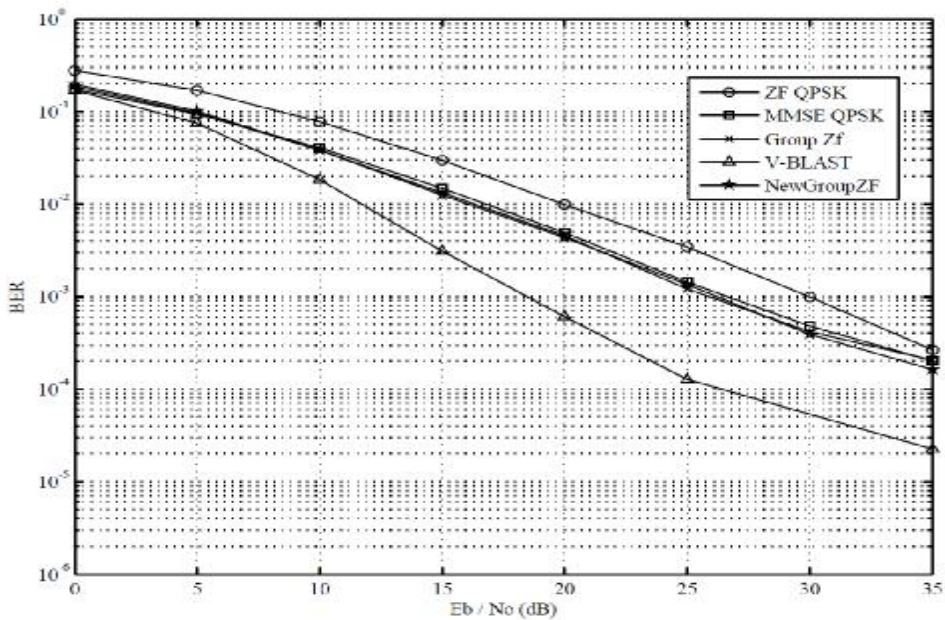


Figure (5) BER performance for BPSK modulation with Different detection schemes using 4Tx antennas

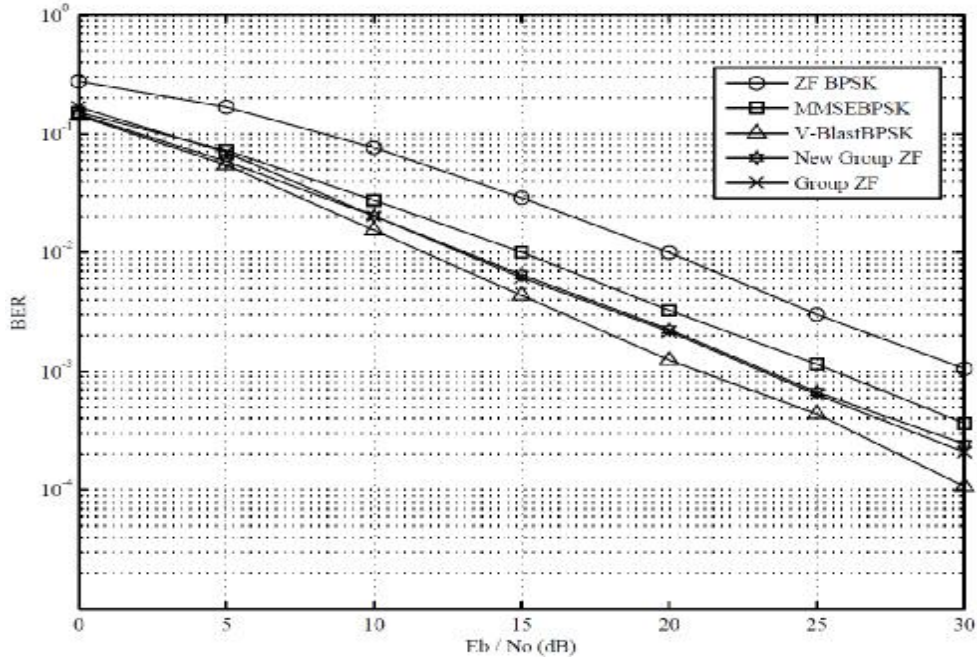


Figure (6) BER performance for 16QAM modulation with Different detection schemes using 4Tx