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BER Performance Enhancement of MIMO Systems Using Hybrid Detection Techniques Based on Sphere Decoding

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Abstract

MIMO system is used in new communication systems to improve the bit error rate (BER), capacity, and the co-channel interference. In this paper, new hybrid detection techniques based on a combination between the sphere decoder (SD) and linear/non-linear detection techniques such as zero forcing (ZF), minimum mean square error (MMSE), Vertical Bell Lab Layered Space Time (V-BLAST), and lattice reduction are introduced. These hybrid techniques are intended to improve the BER performance of MIMO system. The proposed techniques are mainly based on dividing the received signal matrix into two equal size halves. The first half of the received symbols is detected using the selected linear or non-linear detector and the second half is detected using SD as the first scenario. For the second scenario, the first half of the received symbols is detected using SD and the second half is detected using the selected linear or non-linear detector. Several simulations are carried out to verify the efficiency of the proposed techniques. The simulations results show that the proposed techniques provide better performance than the traditional ones.

Index Terms: Multiple-input multiple-output (MIMO); Sphere decoder (SD); Zero forcing (ZF); Minimum mean square error (MMSE); Vertical Bell Lab Layered Space Time (V-BLAST); Lattice reduction (LR).

1. Introduction

Multiple-input multiple-output (MIMO) systems are used as possible solutions to fulfill the increasing demand for high data rate, low BER, and efficient power utilization in wireless communication systems.

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MIMO communication systems achieve higher data rates than single antenna elements based systems by using multiple antennas to transmit and to receive multiple independent data streams simultaneously over a communication channel [1]. Each receiving antenna gets a superposition of these transmitted data streams. The process of separating out each independent data stream is called MIMO detection. The job of any detection algorithm is to obtain an estimate of the transmitted symbols. MIMO detection has two main directions [2], one direction including sub-optimal detectors such as linear detectors based on zero forcing (ZF) and minimum mean square error (MMSE) detectors [3], and non-linear Vertical Bell Lab Layered Space Time (V-BLAST) detector which based on the ZF or MMSE principles with the optimal successive interference cancellation (OSIC) [4-5]. Although these simple detection algorithms reduce the computational complexity, their bit error rate (BER) performances are far worse than those of the sphere decoder (SD) especially at high signal-to-noise–ratios (SNRs). For a fast detection, the lattice reduction aided (LRA) algorithms have been introduced in [6-9]. In these algorithms, efficient lattice reduction sub-routines such as Lenstra-Lenstra-Lovász (LLL) algorithm [10] in conjunction with linear detectors such as ZF and MMSE provide better performances than linear detectors alone. On the other hand, LRA conditional detection was proposed in [11-12] where the orthogonality defect factor has been used to select the best LLL reduced sub-matrix for the conditional detection. The other main direction is the Sphere decoding detection [13-15]. Sphere decoding achieves the optimal maximum-likelihood (ML) performance but does not scale well in complexity. In this paper, new hybrid detection techniques based on a combination between SD and different detection algorithms such as ZF, MMSE, V-BLAST, and LR are proposed. To reduce the computational complexity of the SD, two scenarios of the proposed hybrid technique are introduced. The first technique is based on using the ZF, MMSE, V-BLAST, and LR detectors for detecting the first symbols sub-matrix, then using the SD for detecting the remaining symbols sub-matrix. In the second technique, the SD is used for detecting the first symbols sub-matrix and the linear or non-linear detectors are used for detecting the remaining symbols sub-matrix. Several simulations are performed to compare the performance of the two scenarios and to recommend the best scenario.

2. MIMO Signal Model

Consider a flat-fading MIMO system with M transmit antennas and N receive antennas as shown in Figure (1). The received signal model can be expressed as:

$$r = W S + n \tag{1}$$

where $S = [s_1, s_2, \dots \dots, s_M]^T \in S^M$ represent the $M \times 1$ trasmitted data vector at one time slot. W is the $N \times M$ channel matrix and $r = [r_1, r_2, \dots \dots, r_N]^T$ is the received signal at one time slot from the N receive antennas. $n = [n_1, n_2, \dots \dots, n_N]^T$ is the additive white Gaussian noise (AWGN) vector that has zero mean and covariance matrix $E[\, n\, n^H] = \sigma_n^2 \, I_N$ where σ_n^2 is the noise variance, and I_N signifies a $N \times N$ identity matrix. We assume that the noise variance σ_n^2 and the channel matrix W are known at the receiver. At the receiver, the detector forms an estimate of the transmitted symbol $\tilde{S}$.

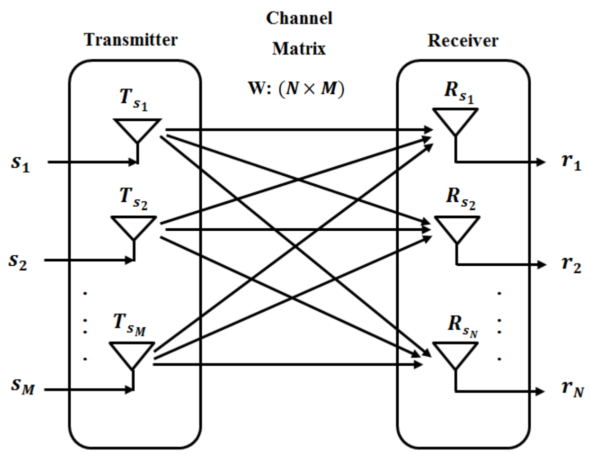

Figure 1: The model of Flat-fading MIMO system with M transmit and N receive antennas.

3. MIMO Detection Techniques

In this section, brief descriptions for the most commonly used MIMO detection techniques including linear and non-linear detectors are introduced.

3.1 Zero Forcing Detector (ZF)

The ZF detector calculates the inverse of the channel matrix to compute the transmitted symbol vector which can be expressed as:

$$\tilde{S} = (W^H W)^{-1} W^H \ r \ = W^{\dagger} r \tag{2}$$

where W^H is the hermitian transpose of the channel matrix and $(.)^{\dagger}$ denotes the pseudo inverse. It is worth noting that the ZF has lowest complexity and completely eliminates the inter-symbol interference (ISI). But its performance is highly degraded at low signal to noise (SNR).

3.2 Minimum Mean Square Error Detector (MMSE)

The MMSE detector is another type of linear detectors which minimizes the mean squared error between the transmitted symbols and the estimated symbols. That is, the transformation matrix G is given by the solution of the following minimization problem:

$$min_G \ \ E\,[||S \ - \ G\,r\,||^2] \tag{3}$$

Then the MMSE transformation matrix can be given by:

$$G_{MMSE} = (W^H W \ + \sigma_n^2\, I_M)^{-1} W^H \tag{4}$$

and the estimated symbols can be expressed as

$$\tilde{S}_{MMSE} = G_{MMSE}\, r \qquad (5)$$

And the quantized estimated symbols $\tilde{S}$ are given by:

$$\tilde{S} = Q_s\,[\,\tilde{S}_{MMSE}] \qquad (6)$$

where Q_s is the quantization function which quantizes each vector element to the closest symbol in S. The MMSE detector performs better than the ZF detector in terms of noise and ISI cancellation. But it requires the knowledge of the noise variance.

3.3 V-BLAST Detector

V-BLAST is such a system that has multiple antennas at both the transmitter and the receiver. It is used to maximize the data rate by transmitting independent data streams simultaneously from multiple antennas. The detector used in the V-BLAST system was the optimal successive interference cancelation system such as (ZF-OSIC or MMSE-OSIC), which uses ZF or MMSE for symbol detection in each stage. The V-BLAST detection schemes are summarized as follows:

Initialization

a) Compute a linear transformation matrix for ZF or MMSE detectors.

$$G_{ZF} = W^{\dagger} = (W^H W)^{-1} W^H \qquad (7)$$

$$G_{MMSE} = (W^H W + \sigma_n^2\, I_M)^{-1} W^H \qquad (8)$$

where $(.)^{\dagger}$ denotes pseudo-inverse and $(.)^{H}$ denotes the Hermitian matrix.

b) i=1

Recursion

c) Determine the optimal ordering for detection of the transmitted symbol by

$$\mathrm{K}_i = \arg\, min_{j \notin \{k_1 \ldots . k_{i-1}\}} \left\|(G_i)_j\right\|^2 \qquad (9)$$

where $(G_i)_j$ is the j 'th row of G_i.

d) Obtain the $\mathrm{K}_i{}^{th}$ nulling vector v_{K_i} by

$$v_{\mathrm{K}_i} = (G_i)_{\mathrm{K}_i} \qquad (10)$$

e) Using nulling vector v_{K_i} form decision statistic y_{K_i}:

$$y_{K_i} = v_{K_i}^T r_i \quad (11)$$

where r is the received symbol which is a column vector.

f) Slice y_{K_i} to obtain $\hat{S}_{K_i}$

$$\hat{S}_{K_i} = Q\,(y_{K_i}) \quad (12)$$

where Q(.) denotes the quantization (slicing) operation.

g) Interference cancelation subtract $\hat{S}_{K_i}$ from r_i to get the canceled output r_{i+1} as

$$r_{i+1} = r_i - \hat{S}_{K_i}\,(W)_{K_i} \quad (13)$$

where $(W)_{K_i}$ denotes the $k_i{}^{th}$ column of W.

h) Obtain $W_{\overline{k_i}}$ by setting the $k_i{}^{th}$ column of W to zero

$$W = W_{\overline{k_i}} \quad (14)$$

i) Form the linear transform matrix (G) using $W_{\overline{k_i}}$ for ZF or MMSE detectors.

$$G_{i+1_{ZF}} = W^{\dagger}{}_{\overline{k_i}} \quad (15)$$

$$G_{i+1_{MMSE}} = \left(W^{H}{}_{\overline{k_i}}\, W_{\overline{k_i}} + \sigma_n^2\, I_M\right)^{-1} W^{H}{}_{\overline{k_i}} \quad (16)$$

j) Determine the optimal ordering for detection of the transmitted symbol by

$$K_{i+1} = \arg\min\ \left\|(G_{i+1})_j\right\|^2 \quad (17)$$

k) i = i+1.

3.4 Lattice Reduction-Aided Detection

The aim of the lattice reduction is to transform a given basis W into a new basis $\widetilde{W}$ with vectors of shortest length, or, equivalently, into a basis consisting of roughly orthogonal basis vectors. The lattice–reduced channel matrix after the LR can be expressed as, $\widetilde{W} = WT$, and the transmitted signal is also multiplied by T^{-1} such that $z = T^{-1}S$ for the reduced basis. The lattice-reduced channel matrix $\widetilde{W}$ can be obtained from the LLL algorithm [10] with the orthogonality defect factor parameter δ $(1/4 < \delta \leq 1)$, which is summarized as follows:

Input: Q, R, P ($default\ P = I_m$)
Output: $\tilde{Q}, \tilde{R}, T$
Initialize: $\tilde{Q} := Q,\ \tilde{R} := R, T := P$

1. $k = 2$
2. while $k \leq m$
3. $for\ \ l = k-1, \dots\dots\dots, 1$
4. $\mu = [\tilde{R}(l,k)/\tilde{R}(l,l)]$
5. $if\ \mu \neq 0$
6. $\tilde{R}(1{:}l,k) := \tilde{R}(1{:}l,k) - \mu\, \tilde{R}(1{:}l,l)$
7. $T(:,k) := T(:,k) - \mu\, T(:,l)$
8. end
9. end
10. $if\ \ \delta\, \tilde{R}(k-1,k-1)^2 > \tilde{R}(k,k)^2 + \tilde{R}(k-1,k)^2$
11. $Swap\ columns\ k-1\ and\ k\ in\ \tilde{R}\ and\ T$
12. Calculate the Givens rotation matrix θ such that element $\tilde{R}(k,k-1)$ becomes zero:

$$\theta = \begin{bmatrix} \alpha & \beta \\ -\beta & \alpha \end{bmatrix} \quad with \quad \begin{array}{l} \alpha = \frac{\tilde{R}(k-1,k-1)}{\|\tilde{R}(k-1:k,k-1)\|} \\ \beta = \frac{\tilde{R}(k,k-1)}{\|\tilde{R}(k-1:k,k-1)\|} \end{array}$$

13. $\tilde{R}(k-1{:}k, k-1{:}m) := \theta\, \tilde{R}(k-1{:}k, k-1{:}m)$
14. $\tilde{Q}(:, k-1{:}k) := \tilde{Q}(:, k-1{:}k)\, \theta^T$
15. $k := max\{k-1, 2\}$
16. else
17. $k := k+1$
18. end
19. end

Line 2-9 : Size reduction
Line 10 : Lovász condition
Line 11-14 : Column swapping

where $Q = (q_1 \dots q_m)$ is an $n \times m$ column-orthogonal matrix and R is an $m \times m$ upper triangular matrix with positive diagonal elements. The received signal $r = W$ S + n can be rewritten as

$$r = W\ T\ T^{-1} S + n = \widetilde{W}\ z + n \tag{18}$$

Note that WS and $\widetilde{W}z$ denote the same point in the lattice, but the reduced matrix $\widetilde{W}$ is much better conditioned than W. The LR aided detection operates on $\widetilde{W}$ and z instead of W and S. After lattice-reduction of the channel matrix, we can perform the linear detection, as described in sections 3.1& 3.2, based on $\widetilde{W}$. Consider using ZF with LR. The LR aided ZF (LR-ZF) detector can be expressed as

$$\tilde{z}_{LR-ZF} = \widetilde{W}^{\dagger}\, r = z + \widetilde{W}^{\dagger}\, n \tag{19}$$

The estimated signal $\tilde{S}$ can be expressed as

$$\tilde{S}_{LR-ZF} = Q_s\, [T\, \tilde{z}_{LR-ZF}] \tag{20}$$

Matrix T is an unimodular matrix of integers .The LR algorithm is applied on the QR decomposed channel matrix W to obtain the modified $\tilde{Q}$ and $\tilde{R}$. Afterwards, the lattice reduced channel matrix can be obtained as $\widetilde{W}=\tilde{Q}\tilde{R}$. The same structure can also be used for MMSE detection which takes the noise term into account and thereby leads to an improved performance. The LR aided MMSE (LR-MMSE) can be written by

$$\tilde{z}_{LR-MMSE} = \left(\widetilde{W}^H\widetilde{W} + \sigma_n^2\ T\,T^{-1}\right)^{-1}\widetilde{W}^H\, r \qquad (21)$$

Similar to LR-ZF, the transmitted signal is estimated as

$$\tilde{S}_{LR-MMSE} = Q_s\,[T\ \tilde{z}_{LR-MMSE}] \qquad (22)$$

Finally, the LR- aided detection process involves first finding an estimate $\tilde{z}$ of the transmitted symbol vector in the z-domain using linear detection or SIC. Then we determine $\tilde{S}$ by transforming each element of $\tilde{z}$ back to the original signal constellation using $\tilde{S} = Q_s[\,T\,\tilde{z}]$. The following Figure (2) shows the block diagram of LR aided detection schemes [6].

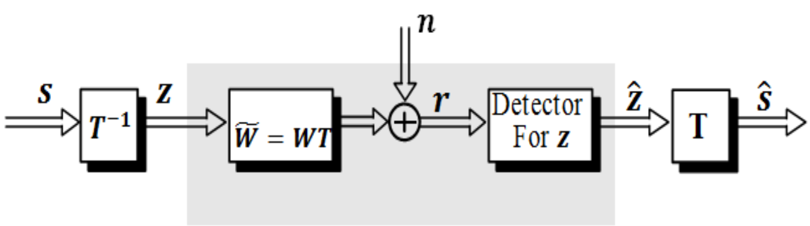

Figure 2: Block diagram of the Lattice-Reduction based detector.

3.5 Sphere Decoder

Sphere decoder is a detection method that finds the exact ML solution vector. SD adjusts the sphere radius until there exists a single vector (ML solution vector) within the sphere. This goal is achieved by constraining the search to only those points of WS that lies inside a hyper sphere with radius R around the received point. SD reduces the complexity by limiting the search space in a hyper sphere. SD can be expressed as

$$\|r - WS\|^2 < R^2 \qquad (23)$$

It increases the radius when there exists no vector within the sphere, and decreases the radius when there exist multiple vectors within the sphere [16]. The sphere decoder is developed on two stages [17]. Firstly, a preprocessing stage computes the QR factorization of the channel matrix $W = Q\begin{bmatrix} R \\ 0 \end{bmatrix}$ and after this stage finds the estimation of transmitted symbol $\tilde{S}$.

$$\tilde{S} = \arg min_{S\in C^M}\ \|r - WS\|^2 \qquad (24)$$

$$= \arg min_{S\in C^M}\ \left\|r - Q\begin{bmatrix} R \\ 0 \end{bmatrix}S\right\|^2 \qquad (25)$$

$$=\arg min_{S\in C^M} \quad \left\|Q^T r - \begin{bmatrix} R \\ 0 \end{bmatrix} S\right\|^2 \qquad (26)$$

$$=\arg min_{S\in C^M} \quad \|\tilde{r} - RS\|^2 \qquad (27)$$

The estimated value is must inside the sphere radius

$$\tilde{S} = \arg min_{S\in C^M} \quad \|\tilde{r} - RS\|^2 \leq R^2 \qquad (28)$$

The sphere radius R_{SD} will impact on the performance of SD detector. If the radius R_{SD} is chosen too small, there would be no points inside the sphere and the algorithm would fail. If the radius R_{SD} is chosen too large, there would be too many points to test and hence more complexity while the efficiency would decrease.

4. Proposed Hybrid Detection Techniques

To reduce the complexity of the detection process, efficient hybrid detection techniques based on a combination between SD and linear/non-linear detection techniques are proposed. These hybrid techniques are intended to improve the BER performance of MIMO systems. In [11-12], splitting the optimization set was proposed in such a way that the transmitted signal vector $\boldsymbol{S}$ is divided into two sub-vectors $\boldsymbol{S_1}$ and $\boldsymbol{S_2}$ of lengths $\boldsymbol{P}$ and $(\boldsymbol{M-P})$, respectively. While, the channel matrix $\boldsymbol{W}$ is divided into two sub-matrices $\boldsymbol{W_1}$ and $\boldsymbol{W_2}$ of sizes $(\boldsymbol{N}\times\boldsymbol{P})$ and $(\boldsymbol{N}\times(\boldsymbol{M-P}))$, respectively. Hence, one can write the received signal model as:

$$r = W_1 S_1 + W_2\, S_2 + n \qquad (29)$$

In this paper, two hybrid detection scenarios are proposed and explained as follows:

4.1 First Hybrid Detection Scenario

To implement the first scenario, a low-complexity decoding method such as ZF/ MMSE/ V-BLAST/ LR is performed to detect the first half of signal sub-vector S_1. For example the ZF solution of S_1 is computed by:

$$\tilde{S}_1 = (W_1^H W_1)^{-1} W_1^H (r - W_2 S_2) \qquad (30)$$

$$\hat{S}_1 = Q(\tilde{S}_1) \qquad (31)$$

where Q denotes the QAM symbol quantizer. Using this result, the solution for S_2 is obtained by using the SD that searches over only those points that lie inside a hyper sphere of radius R around the received point.

$$\hat{S}_2 = \arg min_{S_2\in C^{M-P}} \quad \left\|r - W_1\hat{S}_1\right\|^2 \qquad (32)$$

Note that the SD performs N^{M-P} evaluations of the metric in (32) for all possible symbols in S_2. This technique enables the SD to perform a reduced search on a low complexity solution for the remaining parameters.

4.2 Second Hybrid Detection Scenario

In the second scenario, the first half of sub-vector S_1 is detected by using the SD, where the first sub-vector S_1 is computed by:

$$\tilde{S}_1 = \arg min_{S_1 \in C^P} \quad \|r - W_2 S_2\|^2 \tag{33}$$

$$\hat{S}_1 = Q\left(\tilde{S}_1\right) \tag{34}$$

Then, the second half of the sub-vector S_2 is detected using a linear or non-linear detection such as ZF, MMSE, V-BLAST and lattice reduction detection. The solution for S_2 of zero forcing detection is computed by:

$$\hat{S}_2 = (W_2^H W_2)^{-1} W_2^H \left(r - W_1\, \hat{S}_1\right), \tag{35}$$

5. Simulation Results

In this section, a 8×16 MIMO system with 4-QAM constellation is considered. The two scenarios of the proposed hybrid detection techniques are utilized to detect the received symbols. In the first scenario, the first symbols sub-vector is detected by using the linear or non-linear detection, then using the SD for detecting the remaining symbols sub-vector. In the second scenario, the first symbols sub-vector is detected by using the SD detection and the linear or non-linear detectors are used for detecting the remaining symbols sub-matrix.

5.1 Test case 1: ZF/SD and SD/ZF

In this case, the hybrid combination between SD and ZF is introduced. Figure (3) shows the simulated BER various SNR for the two scenarios of the proposed hybrid techniques. The proposed ZF/SD and SD/ZF techniques are simulated and compared to the traditional ZF and SD. It is clear that the proposed ZF/SD and SD/ZF provide lower BERs than the traditional ZF, while their BERs are close to the BER of the SD. Also, it is clear that the second scenario SD/ZF provides better BER performance than the first scenario ZF/SD, which is summarized in Table 1. For SNR $= -4$dB, the BERs of the SD/ZF and ZF/SD are 0.011 and 0.016, respectively.

Table 1: The estimated BER for the proposed ZF/SD and SD/ZF techniques compared to the traditional ZF and SD techniques at SNR $= -4$dB.

Technique	**First scenario ZF/SD**	**Second scenario SD/ZF**	**ZF**	**SD**
SNR	-4 dB	-4 dB	-4 dB	-4 dB
BER	0.016	0.011	0.101	0.006

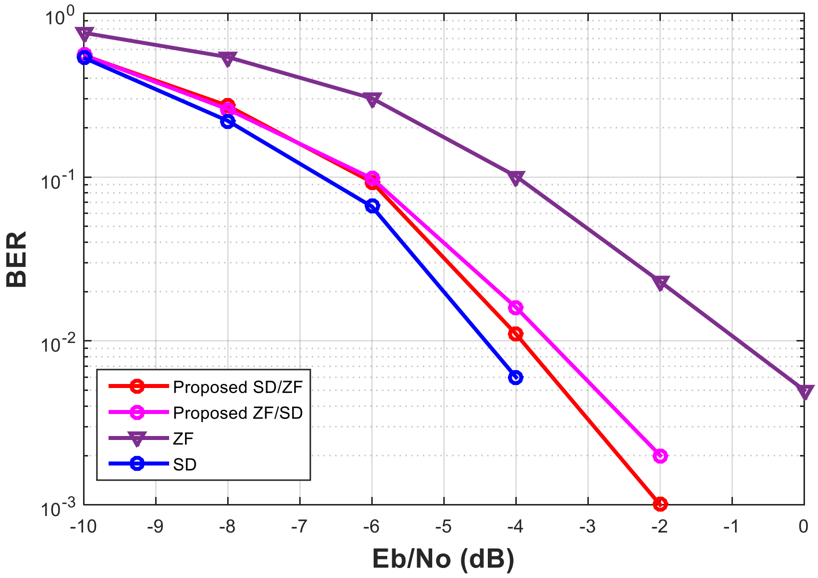

Figure 3: BER performance of the proposed ZF/SD and SD/ZF techniques compared to the traditional ZF and SD techniques for a 8×16 with 4-QAM MIMO system.

5.2 Test case 2: MMSE/SD and SD/MMSE

In this case, the hybrid combination between SD and MMSE is introduced. Figure (4) shows the simulated BER various SNR for the two scenarios of the proposed hybrid techniques. The proposed MMSE/SD and SD/MMSE techniques are simulated and compared to the individual MMSE and SD. Although MMSE detection algorithm reduce the computational complexity, its BER performance is far worse than those of the sphere decoder (SD). The proposed MMSE/SD and SD/MMSE provide lower BERs than the traditional MMSE, while their BERs are close to the BER of the SD. Also, it is clear that the second scenario SD/MMSE provides better BER performance than the first scenario MMSE/SD, which is summarized as following in Table 2.

Table 2: The estimated BER for the proposed MMSE/SD and SD/MMSE techniques compared to the traditional MMSE and SD techniques at SNR $= -4$dB.

Technique	**First scenario MMSE/SD**	**Second scenario SD/MMSE**	**MMSE**	**SD**
SNR	-4 dB	-4 dB	-4 dB	-4 dB
BER	0.018	0.016	0.08	0.01

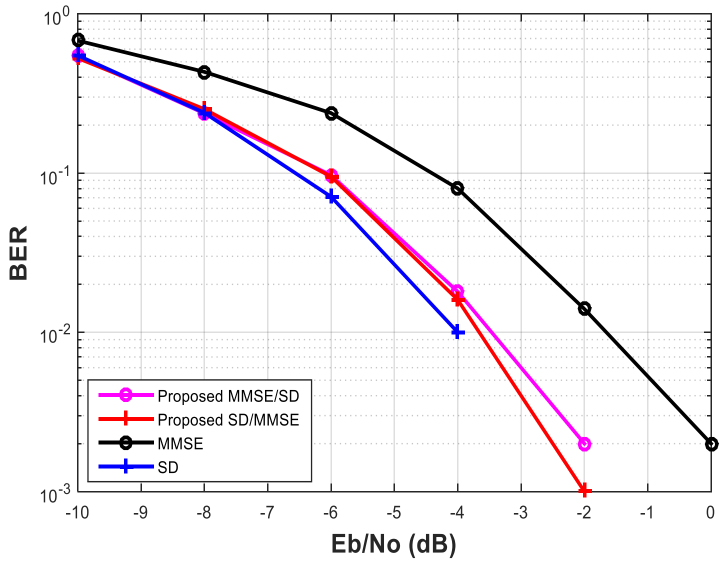

Figure 4: BER performance of the proposed MMSE/SD and SD/MMSE techniques compared to the traditional MMSE and SD techniques for a 8×16 with 4-QAM MIMO system.

5.3 Test case 3: V-BLAST/SD and SD/V-BLAST

In this case, the hybrid combination between SD and V-BLAST is introduced. Figure (5) shows the simulated BER various SNR for the two scenarios of the proposed hybrid techniques. The proposed V-BLAST/SD and SD/V-BLAST techniques are simulated and compared to the individual V-BLAST and SD. The V-BLAST detection performs better than the linear detectors and its performance is far from optimum. The proposed V-BLAST/SD and SD/V-BLAST provide lower BERs than the traditional V-BLAST, while their BERs are close to the BER of the SD. Also, it is clear that the second scenario SD/V-BLAST provides better BER performance than the first scenario V-BLAST/SD, which is summarized as following in Table 3.

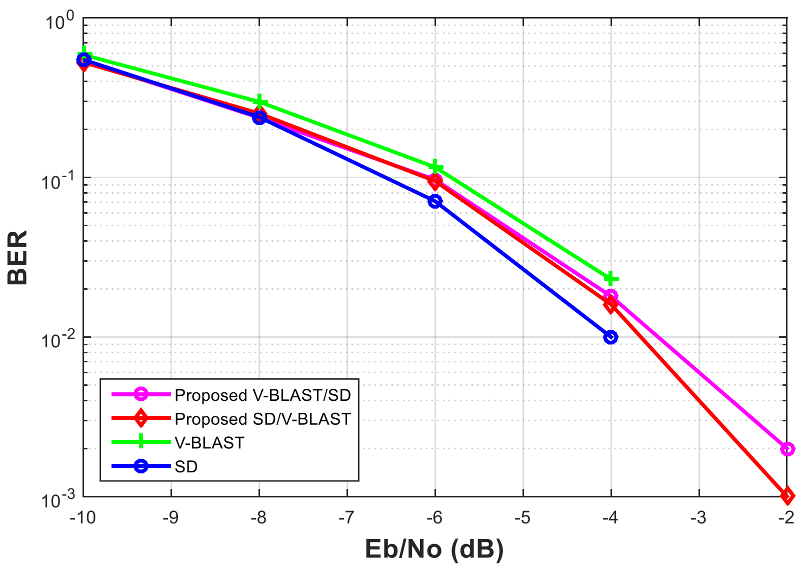

Figure 5: BER performance of the proposed V-BLAST /SD and SD/ V-BLAST techniques compared to the traditional V-BLAST and SD techniques for a 8×16 with 4-QAM MIMO system.

Table 3: The estimated BER for the proposed V-BLAST /SD and SD/ V-BLAST techniques compared to the traditional V-BLAST and SD techniques at SNR $= -4$dB.

Technique	First scenario V-BLAST/SD	Second scenario SD/V-BLAST	V-BLAST	SD
SNR	-4 dB	-4 dB	-4 dB	-4 dB
BER	0.018	0.016	0.023	0.01

5.4 Test case 4: LR/SD and SD/LR

In this case, the hybrid combination between SD and LR is introduced. The BER performances of the proposed LR_ ZF/SD, SD/LR_ZF, LR_MMSE/SD, and SD/LR_MMSE techniques are simulated and compared to the BER performances of the individual LR_ZF, LR_MMSE, and SD techniques as shown in Figure (6) and Figure (7), respectively. The LR-aided linear detection can achieve better performance than the underlying linear detection (without LR aided). It's clear that the proposed LR/SD and SD/LR provide lower BERs than the traditional LR, while their BERs are close to the BER of the SD. Also, it is clear that the second scenario SD/LR provides better BER performance than the first scenario LR/SD as listed in Table 4 and Table 5, respectively.

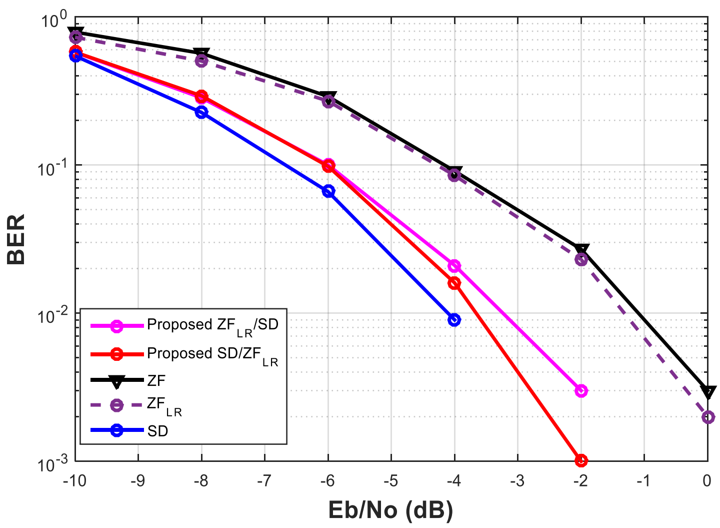

Figure 6: BER performance of the proposed LR_ ZF/SD and SD/ LR_ ZF techniques compared to the traditional ZF, LR_ ZF, and SD techniques for a 8×16 with 4-QAM MIMO system.

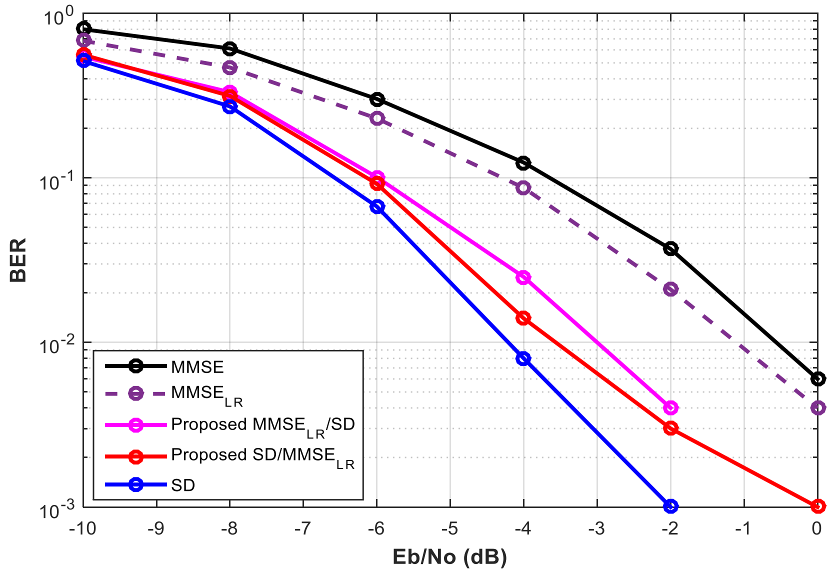

Figure 7: BER performance of the proposed LR_ MMSE/SD and SD/ LR_ MMSE techniques compared to the traditional MMSE, LR_ MMSE, and SD techniques for a 8×16 with 4-QAM MIMO system.

Table 4: The estimated BER for the proposed LR_ZF /SD and SD/ LR_ZF techniques compared to the traditional ZF, ZF_LR, and SD techniques at SNR $= -4$dB.

Technique	**First scenario LR_ZF /SD**	**Second scenario SD/ LR_ZF**	**ZF**	**ZF_LR**	**SD**
SNR	-4 dB	-4 dB	-4 dB	-4 dB	-4 dB
BER	0.021	0.016	0.091	0.085	0.009

Table 5: The estimated BER for the proposed LR_MMSE/SD and SD/LR_MMSE techniques compared to the traditional MMSE, MMSE _LR, and SD techniques at SNR $= -4$dB.

Technique	**First scenario LR_MMSE/SD**	**Second scenario SD/LR_MMSE**	**MMSE**	**MMSE_LR**	**SD**
SNR	-4 dB	-4 dB	-4 dB	-4 dB	-4 dB
BER	0.025	0.014	0.124	0.087	0.008

6. Conclusion

In this paper, efficient hybrid detection techniques for MIMO system are introduced. The proposed techniques are based on the hybrid combination between SD and different detection algorithms such as ZF, MMSE, V-BLAST, and LR. Considering ZF/SD, MMSE/SD, V-BLAST/SD and LR/SD, the ZF, MMSE, V-BLAST or LR are used to detect the first symbol subset while SD detects the remaining symbols subset. Considering SD/ZF, SD/MMSE, SD/V-BLAST, and SD/LR, the SD is used to detect the first symbol subset while the ZF, MMSE, V-BLAST or LR are used to detect the remaining symbols subset. The simulations results are carried out for a 4-QAM (8×16) MIMO system. The simulation results revealed that the second scenario has better performance than the first one with BERs performances close to the BER performance of the SD.

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