Performance Evaluation of Vertical Bell Labs Layered Space Time (Vblast) Algorithms For Mimo System

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Abstract

In this paper a possible way of MIMO technique is used to exploit the multipath scattering properly, it is the Spatial Multiplexing, where the parallel streams of data are mixed up in the air but can be recovered at the receiver by using different Vertical Bell Labs Layered Space- Time (VBLAST algorithms like, Zero Forcing (ZF), Minimum Mean Square Error (MMSE), and QR-decomposition decoding methods.

This paper focused in performance evaluation between these different algorithms in terms of Bit Error Rate (BER) performance using different modulation schemes (4PSK, 8PSK, 16PSK, and 16QAM), and different numbers of antennas. The results derived have shown that 4PSK has the best performance and 16PSK has the worst for all different types of receiver algorithms, with 16QAM constellation performance better than 16PSK, although they use the same bit rate. The BER performance degrades when the constellation size increases. Also the VBLAST receivers with VBLAST-MMSE perform better than VBLAST-ZF and VBLAST-QR receiver in terms of BER when 2X2 antennas are used. Also, it is noted that with increasing modulation constellation the curves of BER are shifted to right due to the higher data rate that is transmitted. MMSE loses the advantage over ZF that is observed for lower constellations, and VBLAST-QR performs better than lower constellations. Finally it is noticed that the BER performance degrades with increasing the number of antennas.

Keywords: MIMO system, BLAST,VBLAST -ZF, VBLAST -MMSE , VBLAST -QR-decomposition, Spatial Multiplexing

1. Introduction

The use of multiple antennas at both ends of a wireless link sending information over the same bandwidth promises significant improvements in terms of spectral efficiency and link reliability without the need for increasing the power or bandwidth. This technology is known as Multiple-Input Multiple-Output (MIMO) system, as one of implementations for High Speed Downlink Packet Access (HSDPA) protocol through third generation (3G) of mobile system. Physical limitations of the wireless medium provide a technical challenge for reliable wireless communication. Techniques that improve spectral efficiency and overcome various channel impairments such as signal fading and interference have made an enormous contribution to the growth of the wireless communication. Moreover, the need for high speed wireless Internet access has led to demand for technologies delivering higher capacities and link reliability than that achieved by current systems. For 3rd generation (3G) Universal Mobile Telecommunications System (UMTS) networks based on Wideband Code Division Multiple Access (WCDMA), the High Speed Downlink Packet Access (HSDPA) is being introduced to meet this demand and improve spectral efficiency. Multiple Input Multiple Output (MIMO) based communication systems combined with HSDPA are capable of achieving either of higher capacities and link reliability. The capacity gain and link reliability of MIMO systems can be maximized under the assumption that channels between pairs of transmit and receive antennas are independent of each other. This independency between channels arises due to multipath between source and destination [1,2]. Independence of channels also means that the receiver will have more than one independent copy of the transmitted signal. This phenomenon known as "diversity" is exploited by Space Time Coding (STC) to provide reliable communication.

The aim of this work is to study different types of MIMO algorithms and architectures focusing on spatial multiplexing systems with VBLAST architectures, its comparison with respect to their BER performance, and their detection algorithms, this comparison shows how important VBLAST is for the future high speed wireless communication networks.

2. Multiple-Input-Multiple-Output Antenna System (MIMO)

MIMO systems uses an array of transmit and receive antennas for enormous gains in spectral efficiency by exploiting a rich multipath fading environment. The systems split a single user's data stream into multiple sub streams and use an array of transmit antennas for simultaneously transmit the streams into the same frequency band using different codes. At the receiver, an array of antennas picks up the multiple transmitted sub streams. Using the MIMO technique, the rate of transmission is increased in proportion to the number of antennas used to transmit the signal. Furthermore, previous techniques to orthogonally channels, like Code Division Multiple Access (CDMA), can be laid on top of MIMO systems to ensure that the bandwidth can still be a shared resource. A MIMO system can be added to a 3G system in a seamless manner, boosting the data-carrying capacity of the network without impacting the other 3G services [3].

Fig (1) demonstrates how data is transmitted in a MIMO system. Consider the 6-bits data stream shown, this data stream is broken down (demultiplexed) into M equal rate data streams, where M is the number of transmitting antennas, which is three in this case. Each of the lower bit rate sub streams are transmitted from one of the antennas. All these sub streams are transmitted at the same time and at the same frequency, therefore they mix together in the channel. Since all sub streams are being transmitted at the same frequency, it is very spectrally efficient.

Each of the receive antennas picks up all of the transmitted signals superimposed upon one another. If the channel impulse response **H** is a sufficiently rich scattering environment, each of the superimposed signals will have propagated over slightly different paths and hence will have different spatial signatures. The spatial signatures exist due to the spatial diversity at both ends of the link, and therefore create independent propagation channels. Each transmit receive antenna pair can be treated as parallel sub channels (i.e. a Single-Input Single-Output (SISO) channel), Since the data is being transmitted over parallel channels, one channel for each antenna pair, the channel capacity increases in proportion to the number of transmit-receive pairs [4].

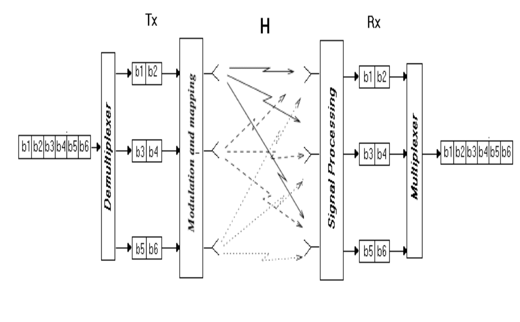

Fig (1) Data transmission in MIMO systems

One of the major factors holding back the standardization of MIMO systems is the complexity and performance of the receiver design. The computational complexity of a MIMO receiver increases dramatically with the number of antennas in the system and the type of constellation used. In an asymmetric standard like HSDPA the cost and power consumption of the receiver is therefore critical to enable widespread commercial deployment. It all comes down to the type of detection algorithm used [3].

If today's 3G wireless communications system is considered, it is more reasonable to expect MIMO systems with small numbers of antennas. For example, the MIMO-HSDPA working group in the 3GPP standard is considering up to four antennas. A mobile Personal Digital Assistant (PDA) can easily fit two antennas in its form factor, and a notebook screen can support four antennas integrated into the case. Instead of pursuing suboptimal linear receivers or complex iterative schemes, it is better to leverage technology advances in silicon to use the optimal detection strategy for MIMO. The optimal detection strategy for a MIMO receiver is to perform a maximum-likelihood search over all possible transmitted symbol sets. To date, such an approach has been considered too complex to implement for high data rates.

3. Vertical Bell Labs Layered Space Time (VBLAST)

The Bell-laboratories Layered Space-Time (BLAST) architecture was proposed by Foschini [5], and consists of a multi-layer transmitter scheme that enables to achieve spatial and temporal diversity. Coding of information data at each layer is optional. The received signal of interest is corrupted by data from other layers, causing interference and hence requiring an interference canceller at the receiver. Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) detectors are used for this purpose [6].

A communication system comprising M transmit (TX) and N receive (RX) antennas is

considered. This system, assumed to operate in a Rayleigh flat-fading environment, exploits the spatial dimension by using Spatial Multiplexing as shown in Fig(2)
Where MAPU stands for Multi Antenna Processing Unit .

Assume that at discrete times, the transmitter sends an M-dimensional (complex) signal vector **a** (i.e., it transmits M parallel streams of data), and the receiver records an N-dimensional complex vector **x**. Then the following signal model describes the relation between **a** and **x**:

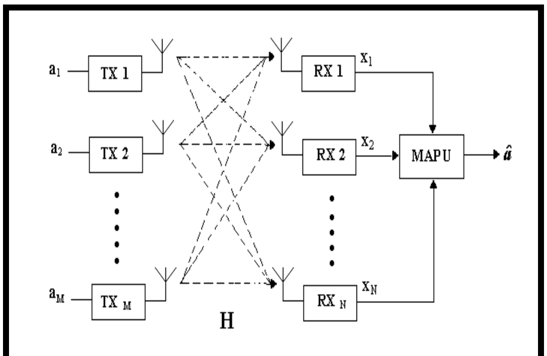

Fig (2) the physical model of system with Spatial Multiplexing

$$\mathbf{x} = \mathbf{Ha} + \mathbf{n} \quad (1)$$

where **H** is an $N \times M$ complex propagation matrix of the channel, and **n** (N-dimensional) represents Additive White Gaussian Noise(AWGN)
To explain the different Spatial Multiplexing techniques, the following notations will be used:

$$\mathbf{a} = \begin{bmatrix} a_1 \\ . \\ . \\ a_M \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} x_1 \\ . \\ . \\ x_N \end{bmatrix} \quad \mathbf{H} = \begin{bmatrix} H_1 \\ . \\ . \\ H_N \end{bmatrix} = [h_1 \; . \; . \; h_M] \quad (2)$$

where a_i and x_i represent the i-th element of **a** and **x** respectively. The H_i and h_i vectors denote the i-th row and the i-th column of **H**, respectively [7].

The original BLAST system uses diagonally-layered space-time architecture, now known as D-BLAST, and uses multi-element antenna arrays at both transmitter and receiver and an elegant diagonally-layered coding structure in which code blocks are dispersed across diagonals space-time. In an independent Rayleigh scattering environment, this processing structure leads to theoretical rates which grow linearly with the number of transmit antennas, with these rates approaching 90% of Shannon capacity. However, the diagonal approach suffers from certain implementation complexities which make it inappropriate for initial implementation. Instead, a modified version known as Vertical Bell Labs Layered Space Time, or VBLAST for short was proposed. VBLAST improves the performance at the cost of increased computational complexity. In VBLAST, instead of jointly detecting all the transmit signals, the detection is done iteratively. At each symbol time, for each subcarrier, it first detects the "**strongest**" layer (depending on the channel matrix) and then cancels the effect of this strongest layer from each of the received signals, considered as interference. The detection continues with the strongest remaining layer, and so on [8]. The optimal detection order in such a nulling and cancellation strategy is from the strongest to the weakest signal. Assuming that the channel **H** is known for the receiver, let the ordered set

$$S \equiv \{k_1 , k_2 , . . . , k_M\} \quad (3)$$

be a permutation of the integers 1 , 2 , . . . , M specifying the order in which components of the transmitted symbol vector **a** are extracted. The main steps of the VBLAST algorithm can be summarized as follows:

step 1 : **Nulling** : An estimation of the strongest transmit signal is obtained by nulling out all the weaker transmit signals. Using nulling vector $\mathbf{w}_{k1}$, form decision statistic y_{k1} :

$$y_{k1} = \mathbf{w}_{k1}^{T} \mathbf{x}_1 \quad (4)$$

step 2 : **Slicing** : Slice y_{k1} to obtain $\hat{\mathbf{a}}_{k1}$:

$$\hat{\mathbf{a}}_{k1} = \Phi(y_{k1}) \quad (5)$$

Where $\Phi(.)$ denotes the quantization (slicing) operation appropriate to the constellation in use, and , $\hat{\mathbf{a}}_i$ can be sliced to the nearest constellation point.

step 3 : **Cancellation** : Assuming that $\hat{\mathbf{a}}_{k1} = \mathbf{a}_{k1}$, cancel $\mathbf{a}_{k1}$ from the received vector $\mathbf{x}_1$, resulting in modified received vector $\mathbf{x}_2$:

$$\mathbf{x}_2 = \mathbf{x}_1 - \hat{\mathbf{a}}_{k1} (\mathbf{H})_{k1} \quad (6)$$

4. VBLAST-ZF Receiver

The vertical Bell Labs layered space time (VBLAST)-ZF receiver uses the same linear-ZF criterion but the detection is done iteratively. At each symbol time, for each subcarrier, it first detects the strongest layer then cancels the effect of this strongest layer from each of the received signals, considered as interference. The detection continues with the strongest remaining layer, and so on .The optimal detection order is determined by choosing the row of **G** with minimum Euclidean norm (to maximize the SNR). Where **G** is a matrix that represents the linear processing in the receiver. The *i*-th row of **G** is equal to the transpose of the *i*-th weight vector $\mathbf{w}_i$ and **I** is the identity matrix. If **H** is not square, **G** equals the *pseudo-inverse* of **H [7]**:

$$\mathbf{G} = \mathbf{H}^{+} = (\mathbf{H}'\mathbf{H})^{-1}\mathbf{H}' \quad (7)$$

The row index is obtained as :

$$k = \arg\{\min_i \|(\mathbf{G})i\|^2\} \quad (8)$$

5. VBLAST-MMSE Receiver

The VBLAST minimum mean-square error (MMSE) receiver uses the Wiener equalization of the channel matrix **H** instead of the ZF equalization [9]. This receiver balances the mitigation of the interference with noise enhancement, minimizing the total error at the expense of a higher complexity. To obtain the linear Minimum Mean Square Error (MMSE), **G** must be chosen such that the Mean Square Error ε^2 is minimized:

$$\varepsilon^2 = E[(a-y)'(a-y)] \\ = E[(a-\mathbf{G}\mathbf{x})'(a-\mathbf{G}\mathbf{x})] \quad (9)$$

To minimize the Mean Square Error (over **G**), the processing at the receiver must be equal to:

$$\mathbf{G} = \frac{1}{M}\left(\frac{1}{M}\mathbf{H}'\mathbf{H} + \sigma^2\mathbf{I}_M\right)^{-1}\mathbf{H}' \quad (10)$$

The MMSE receiver is less sensitive to noise at the cost of reduced signal separation quality .In other words , the co-channel signals are in general not perfectly separated . In the high SNR case ($\sigma^2 \approx 0$) the MMSE receiver converges to the ZF receiver [10].

The optimal detection order is obtained selecting the maximum signal to interference plus noise ratio (SINR) of the transmitted streams still to be decoded on each iteration as expressed below :

$$k = \arg\{\max_i (\text{SINR}_i)\} \quad (11)$$

The SINR is calculated on each iteration for each *i*, where *i* value (1, ... , *M*) transmitted stream, that has not been decoded in previous iterations, using equation blow :

$$\text{SINR}_i = \frac{(g_i\ h_i)^2\ E_S}{g_i\ g'_i\ \sigma^2 + \sum (g_i\ h_i)^2\ E_S} \quad (12)$$

In this equation g_i is the *i*-th row of **G**, h_i is the *i*-th column of **H**, σ^2 is the variance of the noise, E_S is the symbol energy (assumed to be equal for each transmitted antenna) . The MMSE criterion always results in better SNR and thus a better performance. But the disadvantages are that the SNR has to be known at the receiver and matrix inverse needs to be computed.

6. VBLAST Detection Algorithm

The full ZF VBLAST detection algorithm can now be described efficiently as a recursive procedure, including determination of the optimal ordering, as shown in Table(1) [6] below: where the notation $\mathbf{H}^{+}_{\overline{k_i}}$ denotes the matrix obtained by zeroing columns k_1 , k_2 , . . . , k_i of $\mathbf{H}^{+}$. Note that in step 3 (and 6) $\min_j \|(\mathbf{G}_1)_j\|^2$ is used to pick the strongest symbol in ZF receiver . This is due to the reason that the row *j* of **G**, Which has the minimum 2-norm, corresponds to the j-th column of **H** which will have the maximum 2-norm.

In the MMSE V-BLAST algorithm the same steps are used except in step2 where G is calculated using eq.(10), and in step3 (and 6) $\max_j(\text{SINR}_j)$ is used to pick the strongest symbol after calculating SINR_j from eq.(12) .

Table (1) VBLAST algorithm [6]
• *initialization:*
1. $i \leftarrow 1$
2. $\mathbf{G}_1 = \mathbf{H}^{+}$
3. $k_1 = \arg\min_j \|(\mathbf{G}_1)_j\|^2$
• *iteration:*
1. $\mathbf{w}_{k_i} = (\mathbf{G}_i)_{k_i}$
2. $y_{k_i} = \mathbf{w}_{k_i}\mathbf{x}$
3. $\hat{\boldsymbol{a}}_{k_i} = \Phi(y_{k_i})$
4. $\mathbf{x}_{i+1} = \mathbf{x}_i - \hat{\boldsymbol{a}}_{k_i}(\mathbf{H})_{k_i}$
5. $\mathbf{G}_{i+1} = \mathbf{H}^{+}_{\overline{k_i}}$
6. $k_{i+1} = \arg\min_{j \notin \{k1,k2,....,ki\}} \|(\mathbf{G}_{i+1})_j\|^2$
7. $i \leftarrow i+1$

7. VBLAST Algorithm Using QR-decomposition

The QR decomposition of the channel matrix H is used to derive bounds for the error probability of layered space time codes . Therefore, the $N \times M$ channel matrix H is factorized into $N \times M$ unitary matrix Q, and $M \times M$ upper triangular matrix R (for simplicity consider $M = N$).

$$H = Q \cdot R \qquad (13)$$

By multiplying equation (1) from the left with the conjugated transpose of matrix Q, a $M \times 1$ modified received signal vector d is created from the $N \times 1$ received signal vector x [1].

$$\begin{aligned} d &= Q' \cdot x \\ &= Q'.(Ha + n) \\ &= Q' Ha + Q'n \\ &= Q' (QR)a + Q' n \\ &= Ra + \eta \end{aligned} \qquad (14)$$

Equation (14) can be rewritten in explicit matrix form

$$\begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ \vdots \\ \vdots \\ d_M \end{bmatrix} = \begin{bmatrix} r_{1,1} & r_{1,2} & \dots & r_{1,M} \\ 0 & r_{2,2} & \dots & r_{2,M} \\ 0 & 0 & \dots & r_{3,M} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \dots & r_{M,M} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ \vdots \\ a_M \end{bmatrix} + \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \\ \vdots \\ \vdots \\ \eta_M \end{bmatrix} \qquad (15)$$

Since Q is unitary, the statistical properties of the noise term $\eta = Q'.n$ remain unchanged. Element *k* of vector d becomes

$$d_k = r_{k,k} \cdot a_k + \eta_k + I_k \qquad (16)$$

with the interference term

$$I_k = \sum_{i=k+1}^{M} r_{k,i} \cdot a_i \qquad (17)$$

Thus, d_k depends on the weighted transmit signal $r_{k,k} \cdot a_k$, the noise η_k and the interference term I_k. Since R is upper triangular, I_k is independent of the upper layer signals $a_1, \dots, a_{k-1}$, and hence the lowest layer (transmit signal a_M) is described by [11]

$$d_M = r_{M,M} \cdot a_M + \eta_M \qquad (18)$$

Then, the decision statistic d_M is independent of the remaining transmit signals and it can be used to estimate $\hat{a}_M$ by applying the quantization operation Φ [.].

$$\hat{a}_M = \Phi \frac{d_M}{r_{M,M}} \qquad (19)$$

For detecting layer $M-1$, the interference term $r_{M-1,M} \cdot \hat{a}_M$ is eliminated in the modified received signal

$$d_{M-1} = r_{M-1,M-1} \cdot a_{M-1} + r_{M-1,M} \cdot a_M + \eta_{M-1} \qquad (20)$$

Consequently, an interference free decision statistic to estimate a_{M-1} is obtained under the assumption $\hat{a}_M = a_M$. Detecting layer $k = M-1, \dots, 1$ takes place in an equivalent way. With previous decisions $\hat{a}_{k+1}, \dots, \hat{a}_M$, the interference term I_k is calculated and cancelled out in the modified received signal d_k . Assuming that all previous decisions are correct ($I_k = I_k$), the value

$$z_k = d_k - I_k = r_{k,k} \cdot a_k + \eta_k \qquad (21)$$

is free of interference and thus it can be used to detect a_k with

$$\hat{a}_k = \Phi [z_k / r_{k,k}] \qquad (22)$$

Then the detection algorithm for V-BLAST using QR-decomposition is shown in Table (2)[6] , below given channel matrix **H** , and received signal vector **x** :

Table (2) VBLAST algorithm using QR decomposition [6]

1- Decompose **H** into two matrices **Q** and **R**
2- $\mathbf{d} = \mathbf{Q}' \cdot \mathbf{x}$
3- for $k = M, \dots, 1$
4- $\mathbf{I}_k = \sum_{i=k+1}^{M} r_{k,j} \cdot \hat{a}_i$
5- $\mathbf{z}_k = \mathbf{d}_k - \mathbf{I}_k$
6- $\hat{a}_k = \Phi [\mathbf{z}_k / \mathbf{r}_{k,k}]$
7- end

8. Simulation Results

With the system model and detection algorithms described in the previous sections, the simulation have been implemented using the system shown in Fig (3).

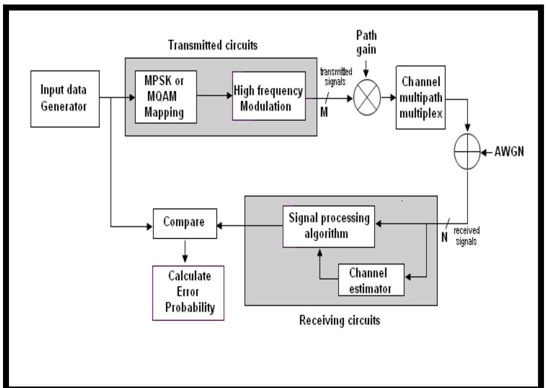

Fig (3) Block diagram for system Simulations

<u>Case 1</u> (One receiver type for all modulation schemes):-

Figure (4) shows the Bit Error Rate (BER) performance of MIMO system using different modulation schemes (4PSK, 8PSK, 16PSK, and 16QAM) each subfigure uses a different type of receiver using 2 transmit and 2 receive antennas with 1000 blocks of data. All these figures show that 4PSK has the best performance and 16PSK has the worst for all different types of receiver algorithms with 16QAM constellation performance better than 16PSK, although they use the same bit rate. In general, the BER performance degrades when the constellation size increases.

<u>Case 2</u>(One modulation scheme for all receiver types):-

A set of simulations are shown in Figure (5), where each of these subfigures use all types of receivers with each figure uses different modulation schemes. All these simulations are achieved using system with 2 transmit and 2 receive antennas and 1000 blocks of data. As shown in the Figure (5), the VBLAST receivers with VBLAST-MMSE perform better than VBLAST-ZF, and VBLAST-QR receiver. Also, it is noted that with increasing modulation constellation the curves are shifted to right due to the higher data rate that is transmitted. MMSE loses the advantage over ZF that is observed for lower constellations, and VBLAST-QR performs better than lower constellations.

<u>Case 3</u> (One modulation scheme and one receiver type for different numbers of transmit and receive antennas):-

As it is seen from Figure(6) each of these subfigures uses one type of receiver and one type of modulation scheme with each figure uses different numbers of antennas. When (M = N) it is noticed that the BER performance degrades with increasing the number of antennas, as it is shown in Fig(6) where VBLAST-ZF and VBLAST-QR are used respectively, (1 × 1) perform better than (2 × 2) and this is better than (4 × 4), but on the other hand an increasing in bit rate has been achieved, where data transmitted by (4 × 4) MIMO system have 4 times bit rate over data with (1 × 1) system. This degrading feature is reversed to improving in Fig (6. B) where VBLAST-MMSE receiver is used at high SNR values. When (M < N) there will be deep increase in the overall BER performance especially, when the ratio of (M/N) is small (1X4 case).

9. Conclusions

This paper has presented measuring MIMO BER performance of different receiver algorithms for spatial multiplexing over a rich scattering environment modeled by a Raleigh flat fading channel assumed static over each symbol period using different modulation schemes (4PSK, 8PSK, 16PSK, 16QAM).. A close insight analysis of simulation results reported in this work leads to the following conclusions:

1. BER performance degrades with increasing constellation size of modulation scheme for all receiver types.
2. 4PSK has the best performance and 16PSK has the worst for all different types of receiver algorithms with 16QAM constellation performance better than 16PSK, although they use the same bit rate.
3. The VBLAST receivers with VBLAST-MMSE perform better than VBLAST-ZF and VBLAST-QR receiver in terms of BER when 2X2 antennas are used.
4. It is noticed that the BER performance degrades with increasing the number of antennas.

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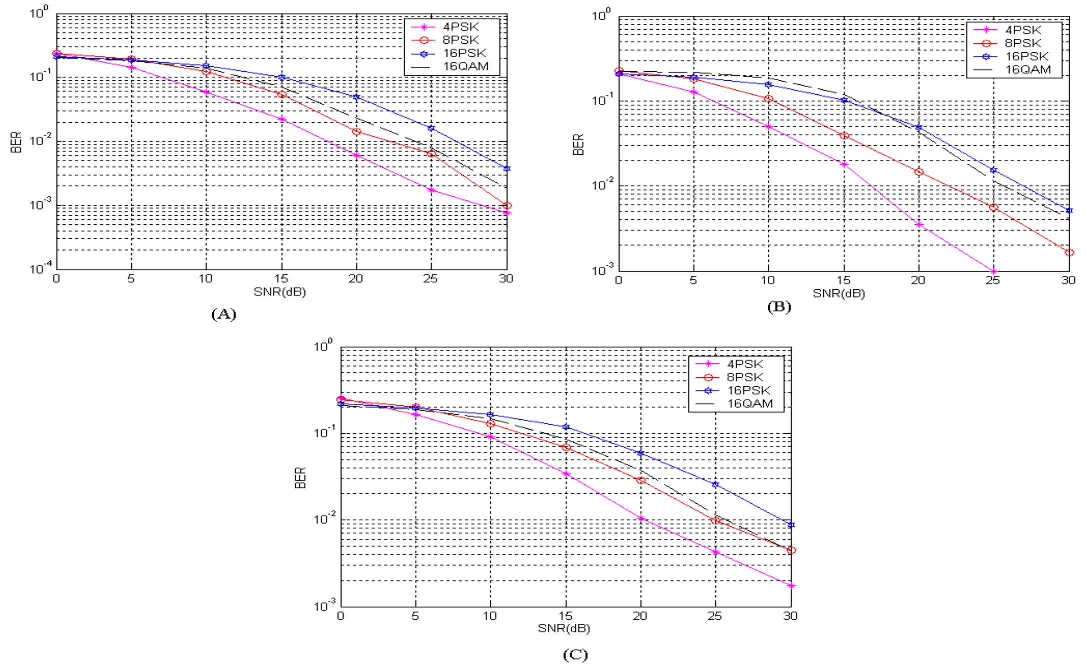

Fig (4) BER vs. SNR, Rayleigh Fading, for different modulation schemes, using (2X2) antennas.
(A)VBLAST-ZF receiver. (B) VBLAST-MMSE receiver .
(C) VBLAST-QR decomposition receiver

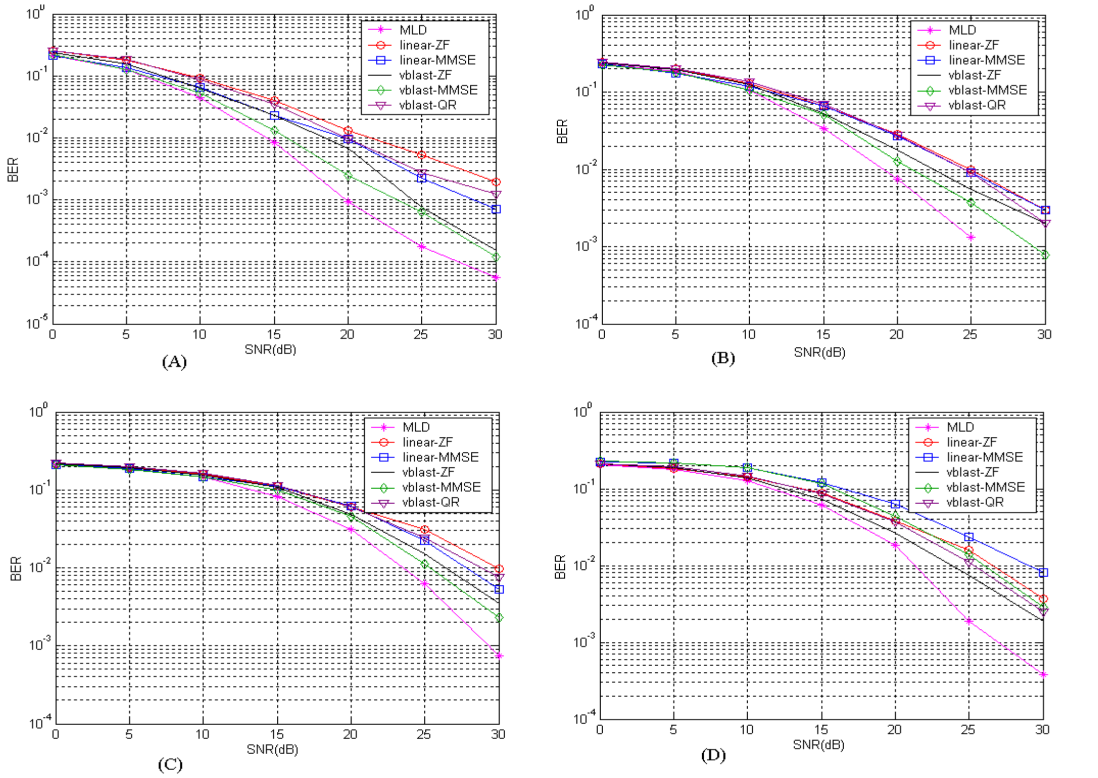

Fig. 5: BER vs. SNR, using Rayleigh fading , for all receiver types, with (2X2) antennas.
(A) 4PSK modulation scheme. (B) 8PSK modulation scheme.
(C) 16PSK modulation scheme. (D) 16QAM modulation scheme

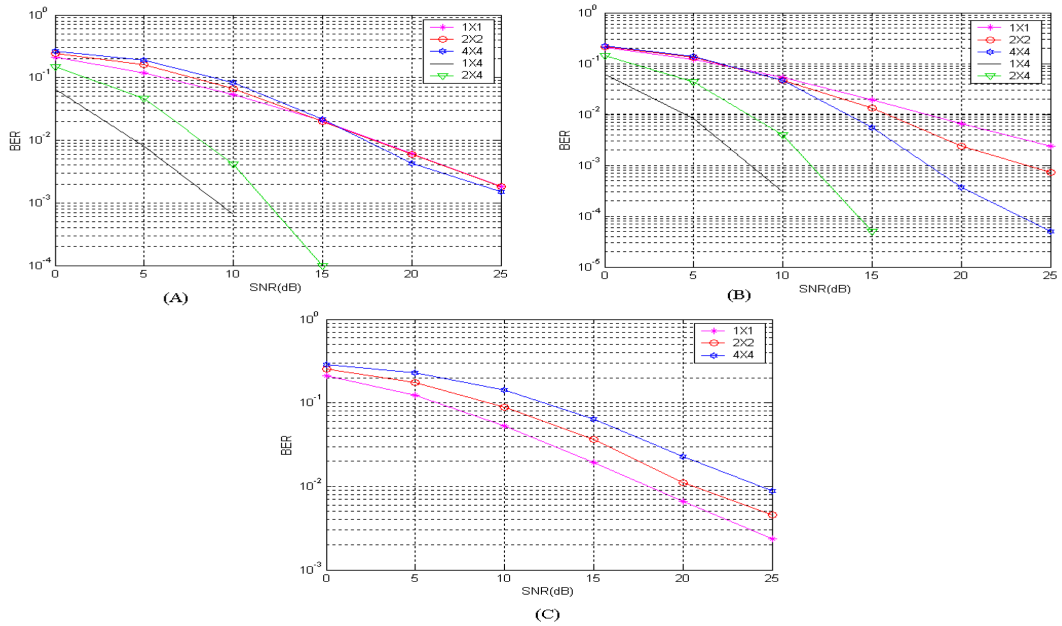

Fig.6 : BER vs. SNR, Rayleigh Fading, 4PSK modulation, with different No.of antennas.
(A)VBLAST-ZF receiver. (B) VBLAST-MMSE receiver .
(C) VBLAST-QR decomposition receiver.

تقييم الكفاءة لخوارزميات (VBLAST) لأنظمة متعدد الدخل متعدد الخرج

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الخُلاصة

في هذه البحث تم إستخدام أحد الطرق الممكنة لتقنية (MIMO) لإستثمار ظاهرة تشتت المسارات المختلفة بشكل صحيح ، وهي طريقة التوزيع المكاني(Spatial Multiplexing)، وفيها يتم مزج المسارات المتوازية للبيانات مع بعضها في الهواء ثم إمكانية إستردادها في المستقبلة بإستخدام خوارزميات(VBLAST) مختلفة مثل الإقحام الصفري (Zero Forcing) ومربع متوسط الخطأ الأدنى (Minimum Mean Square Error)، و طريقة التحليل المعروفة بـ (QR-decomposition).

هذا البحث ركز على تقييم الكفاءة بين هذه الخوارزميات المختلفة بدلالة أداء نسبة خطأ البت (BER) بإستخدام طرق تضمين مختلفة وهي (4PSK, 8PSK, 16PSK, 16QAM) وعدد هوائيات مختلف. النتائج التي تم الحصول عليها تبين أن طريقة التضمين (4PSK) تعطي أفضل أداء ، وأما طريقة التضمين (16PSK) تعطي أسوء أداء لكل أنواع المختلفة من الخوارزميات ، مع أداء لطريقة التضمين (16QAM) بشكل أفضل من (16PSK) بالرغم من إنها تستخدم نفس معدل نسبة البت في الإرسال. نسبة خطأ البت تقل كلما زاد حجم مجموعة التضمين. كذلك مستقبلات VBLAST من نوع VBLAST-MMSE تعطي كفاءة أفضل من مستقبلة VBLAST-ZF ومستقبلة VBLAST-QR بدلالة نسبة خطأ البت عند إستخدام عدد هوائيات يساوي (2X2). كذلك يمكن ملاحظة إن مع زيادة مجموعة التضمين فإن منحنيات نسبة خطأ البت تغير إتجاهها الى اليمين نسبة الى زيادة معدل إرسال البيانات . مستقبلة MMSE تفقد الأفضلية على مستقبلة ZF عند إستخدام مجموعة تضمين قليلة ، ومستقبلة VBLAST-QR تعطي كفاءة أفضل في مجموعة التضمين القليلة. وأخيراً يمكن ملاحظة كفاءة نسبة خطأ البت تقل مع زيادة عدد الهوائيات.