Increasing Channel Capacity Using MIMO Spatial Modulation Technique

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Abstract-Multiple Input Multiple Output (MIMO) multiplexing is a promising technology that could greatly increase the channel capacity without additional spectral resources. The challenge is to design low complexity and high performance algorithms that capable of accurately detecting the transmitted signals. In this study, the general model of MIMO communication system was introduced in addition to several MIMO Spatial Multiplexing (SM) detection techniques. The BER performance and computational complexity of the optimal and sub-optimal MIMO detection schemes have been analyzed and compared to each other. For ease of understanding and fair comparison, the MIMO detection techniques are categorized into three main categories; viz., linear schemes, successive interference cancellation, and tree-search techniques. Different aspects have been considered and discussed in this evaluation such as; signal to noise ratio, channel matrix conditionality, number of transmit and receive antennas, and other performance limiting factors. The complexity evaluations and performance comparisons and graphs have been generated using an optimized simulator. This simulator has been developed using MATLAB platform, hence, it can be considered as a reference implementation for any further research on the field of MIMO SM detection.

Index Terms - Channel, Coding, communication, Diversity, Multi Antenna, Receiver, transmitter, Wireless.

1 INTRODUCTION

MIMO communications systems can exploit spatial multiplexing (SM) approach to increase the channel capacity and improve spectral efficiency as well. Therefore, the MIMO SM-based system is one of currently promising techniques that can achieve high-speed wireless communications networks. In MIMO SM-based systems, independent data streams are transmitted from sufficiently-separated antennas. These results in a linear increase in the channel capacity proportional to the minimum number of receive and transmit antennas. However, MIMO SM-based system requires powerful signal processing procedures at the receiver to efficiently recover the signal transmitted from the multiple antennas, and hence to explore the advantages of MIMO systems. Therefore, the potential advantages of MIMO system can be guaranteed and the wireless system will work in the best possible way. Some special detection techniques have been proposed in the literature in order to exploit the high spectral capacity offered by MIMO systems.

2 MIMO SYSTEM MODEL

In this Paper, we consider a conventional MIMO SM system with N_t transmit antennas and N_r receive antennas where $N_t \leq N_r$ as shown in Figure 1. Independent data streams a, b, and c, are encoded and modulated before being transmitted. Herein, consider a transmitted vector $x = [x_1, x_2 \ldots x_{Nt}]^T$ whose elements are drawn independently from a complex constellation set Ω , e.g. Quadrature Amplitude Modulation (QAM) constellation. The vector is then transmitted via a MIMO channel characterized by the channel matrix H whose element $h_{i,j}$ $CN(0, 1)$[1] is the complex channel coefficient between the jth transmit and ith receive antennas. The received vector $r = [r_1, r_2 \ldots r_{Nr}]^T$ can then be given as following,

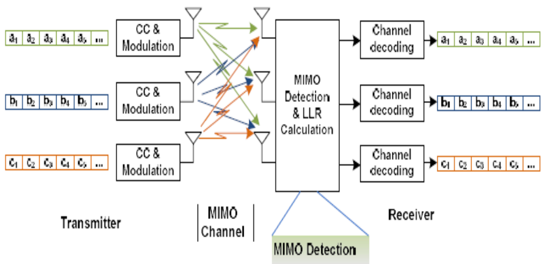

Figure 1 SM System Model Including Transmitter and Receiver

Where the elements of the vector $n = [n_1, n_2 \ldots ns_{Nr}]^T$ are drawn from independent and identically distributed (i.i.d.) circular symmetric Gaussian random variables. The system model of (1) is then given in the matrix form as following.

$$\begin{bmatrix} r_1(k) \\ \vdots \\ r_{Nr}(k) \end{bmatrix} = \begin{bmatrix} h_{11} & \cdots & h_{1Nt} \\ \vdots & \ddots & \vdots \\ h_{Nr1} & \cdots & h_{NrNt} \end{bmatrix} \begin{bmatrix} x_1(k) \\ \vdots \\ x_{Nr}(k) \end{bmatrix} + \begin{bmatrix} n_1(k) \\ \vdots \\ n_{Nr}(k) \end{bmatrix}$$
(1)

3 DETECTION TECHNIQUES FOR MIMO SPATIAL MULTIPLEXING SYSTEMS

3.1 V-BLAST Detection

Although linear detection techniques are easy to implement, they lead to high degradation in the achieved diversity order due to the linear filtering. Another approach that takes advantage of the diversity potential of the additional receive antennas, uses nonlinear techniques such as Successive Interference Cancellation (SIC) (for instance, V-BLAST decoder).

The Vertical Bell Laboratories Layered Space Time (V-BLAST) scheme was originally proposed by Foschini [1] and has been discussed in details in literature. The main idea behind the V-BLAST architecture (i.e., transmitter) is to demultiplex the data stream into several sub-streams and transmit them simultaneously. At the receiver side, each antenna observes all the transmitted signals, which are mixed due to the environment surrounding the wireless propagation channel. V-BLAST detection algorithm detects the signals one after another in an iterative way. The construction of the filtering matrix can still be based on any of the aforementioned linear criteria, i.e. ZF or MMSE.

The V-BLAST algorithm utilizes the already detected symbol x_i, obtained by the ZF or MMSE filtering matrix, to generate a modified received vector with x_i cancelled out. Thus the modified received vector becomes with fewer interferers and better performance due to a higher level of diversity. The algorithm continues until all Nt symbols being detected.

If we rewrite the system in (1) into a matrix form with $Nt = Nr = 4$,

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \\ h_{41} & h_{42} & h_{43} & h_{44} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix} \quad (2)$$

Then, using ZF or MMSE criterion, the estimate of x_i can be calculated. Assuming that this symbol is correct, it is weighted with its corresponding channel coefficient and then subtracted from the received vector *r*. The new modified vector *y* becomes:

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} h_{12} & h_{13} & h_{14} \\ h_{22} & h_{23} & h_{24} \\ h_{32} & h_{33} & h_{34} \\ h_{42} & h_{43} & h_{44} \end{bmatrix} \begin{bmatrix} x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix} \quad (3)$$

Iteratively, the nulling matrix is computed. The newly detected symbol x_i is subtracted of the already modified received vector *y* to produce the following equations:

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix}_{\text{mod}} = \begin{bmatrix} h_{13} & h_{14} \\ h_{23} & h_{24} \\ h_{33} & h_{34} \\ h_{43} & h_{44} \end{bmatrix} \begin{bmatrix} x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix} \quad (4)$$

Definitely the diversity level is getting better at each stage of detection and the performance is improved because the equations become more than unknowns. This method of successive interference cancellation is continued until all Nt symbols are detected.

3.1.1 Zero-Forcing VBLAST (ZF-VBLAST)

The Zero-Forcing V-BLAST algorithm (ZF-VBLAST) is based on detecting the components of *x* one by one. For the first decision, the pseudo-inverse, i.e., *G* equals $H^{\dagger}$, of the matrix *H* is obtained. Assume that the noise components are i.i.d. and that the noise is independent of *x*. Then, the row of *G*, with the least Euclidean norm, corresponds to the required component of *x*. That is,

$$k_1 = \arg_j \min\left(\left\| \underline{g}_j \right\|^2 \right),$$

$$\tilde{x}_{k_1} = \underline{g}_{k_1} r^{(1)},$$

and,

$$\hat{x}_{k_1} = Q(\tilde{x}_{k_1}),$$

where $\underline{g}_j$ is the j^{th} row of the filtering matrix *G*, *Q* (.) is the demodulation function, and the superscript is the iteration index. At the first iteration, $r^{(1)} = r$ and $G^{(1)} = H^{\dagger}$. At the end of the first iteration, the interference due to the k_1^{th} component of *x* is cancelled out as follows:

$$r^{(2)} = r^{(1)} - \hat{x}_{k_1} h_{k_1},$$

$$H^{(2)} = H^{(1)-k_1} = \left[\ldots, h_{k_1-1}, h_{k_1+1}, \ldots \right]$$

Doing so until detecting the last element of *x*. When the sorting step is discarded, the code is called Unsorted ZF-VBLAST or ZF-VBLAST.

Obviously, incorrect symbol detection in the early stages will create errors in the following stages; i.e. error propagation. This is a severe problem with cancellation based detection techniques particularly when the number of transmit and receive antennas are the same. The first detected symbol's performance is quite poor as it has no diversity. To reduce the effect of error propagation and to optimize the performance of VBLAST technique, it has been shown in that the order of detection can increase the performance considerably. By detecting the symbols with largest channel coefficient magnitude first, the effect of the noise vector producing an incorrect symbol can be reduced, and reducing error propagation as result.

In order to achieve best performance, it is optimal to start detecting the components of *x* that suffer the least noise amplification i.e the layer with the largest SNR. Then sorting step in the code will be activated. This algorithm is called sorted Zero-Forcing VBLAST (SZF-VB).

ZF is the simple linear receiver with low computational complexity and suffers from noise enhancement. But it can works well at high SNR. However, in Zero-Forcing we can choose any row of G_i to null the signal from the i^{th} transmit antenna, while in ZF-VBLAST it was shown that it is best to start with the signal that has the greatest signal to noise ratio (SNR) in which is known by ordering, which results in a better performance as seen above. The ZF solution in general is an easier solution but not optimum as it enhances the noise. Instead we have used the MMSE method, which gives us better performance.

3.1.2 Minimum Mean Square Error VBLAST (MMSE-VBLAST)

In section 3.1, it was shown that MMSE algorithm suppresses both the interference and noise components, whereas the ZF algorithm removes only the interference components. This implies that the mean square error between the transmitted symbols and the estimate of the receiver is minimized. Therefore, MMSE is superior to ZF in the presence of noise. The MMSE filtering strategy can be used with VBLAST, where the resulting detector is referred to as the MMSE-VBLAST detector.

Also, we refer to the MMSE-VBLAST as the "Unsorted MMSE-VB" when the sorting stage is skipped. In this case, the components of *x* are detected in an ascending order.

The MMSE-VB detection algorithm can be obtained by the MMSE criterion in constructing the filtering matrix.

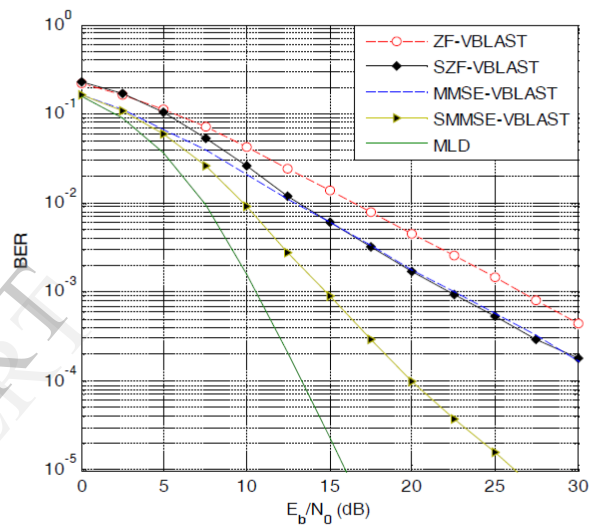

Figure 2 BER of VBLAST Detection Schemes

The main drawback of the VBLAST detection algorithms lies in the computational complexity, because multiple calculations of the pseudo-inverse of the channel matrix are required .

Figure 2 shows the performance of various VBLAST detection schemes that utilizing both ZF and MMSE criteria with and without using optimal ordering. Comparing the simulation results of ZF-VBLAST and MMSE-VBLAST separately, the sorted detection schemes achieve an improved performance in comparison to the unsorted ones. At a target BER of 10^{-3} the difference between ZF-VBLAST curves is about 4 dB and the difference between MMSE-VBLAST curves is about 7 dB. This demonstrates the impact of employing signal ordering. Note that the performance advantage of the MMSE is quite considerable in all cases. The sorted MMSEVBLAST lags the MLD curve by about 6.7 dB at a target BER of 10^{-4}.

4 SIMULATION AND RESULT

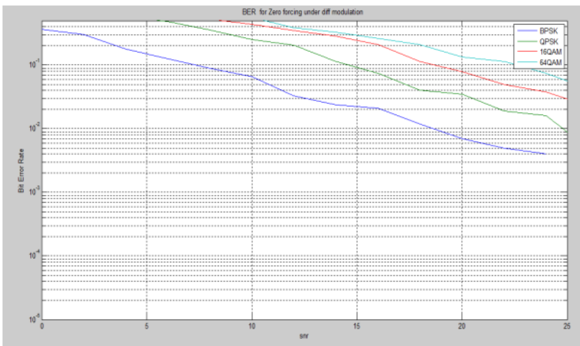

Figure 3 ZF Receiving Technique Under Different Modulation

The above graph represents the behavior of BPSK modulation, QPSK modulation,QAM16 modulation,QAM64 modulation scheme under ZF receiving algorithm, here comparison has been made between BPSK,QPSK,QAM16,QAM64 ,and result shows that BPSK give better ber performance compare to QPSK,QAM16,QAM64 accordingly.BER is worst in QAM64.The simulation model is implemented for MIMO Spatial Multiplexing V BLAST technique.

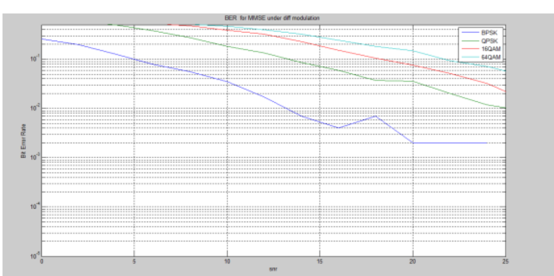

Figure 4: MMSE Receiving Technique Under Different Modulation

The above graph represents the behaviour of BPSK modulation,QPSK modulation,QAM16 modulation,QAM64 modulation scheme under MMSE receving algorithm,here comparision has been made between BPSK,QPSK,QAM16,QAM64 ,and result shows that BPSKgive better ber performance compare to QPSK,QAM16,QAM64 accordingly.BER is worst in QAM64.The simulation model is implemented for MIMO Spatial Multiplexing V BLAST technique.

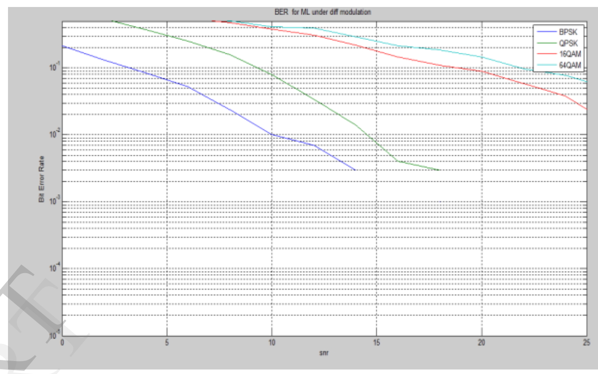

Figure 5 ML Receiving Technique Under Different Modulation

The above graph represents the behavior of BPSK modulation, QPSK modulation,QAM16 modulation,QAM64 modulation scheme under ML receiving algorithm, here comparison has been made between BPSK,QPSK,QAM16,QAM64 ,and result shows that BPSK give better ber performance compare to QPSK,QAM16,QAM64 accordingly.BER is worst in QAM64.The simulation model is implemented for MIMO Spatial Multiplexing V BLAST technique.

5 CONCLUSION

In recent years, MIMO wireless communication systems have exploited spatial multiplexing (SM) approach to increase the channel capacity and improve spectral efficiency as well. Therefore, the

MIMO SM-based system has been one of currently promising techniques that could realize Gbps high-speed wireless transmission for future communications networks. The main challenge of MIMO SM-based system resides in designing signal processing techniques, i.e., detection techniques. Those are capable of separating the parallel transmitted signals with acceptable computational complexity and achieved performance. An intensive work is being done in this field to investigate several MIMO SM detection techniques such linear, nonlinear and tree based detections. In this study, several MIMO detection techniques have been successfully described, analyzed and compared. In general, linear detection techniques such as ZF and MMSE have an efficient computational complexity; however, the BER performance plots of these techniques demonstrated their relatively poor performance. In an attempt to improve the poor performance of the linear detections, VBLAST have been proposed. It was shown that the ordering strategy over Successive Interference Cancellation (VBLAST) has important benefits. This strategy was applied to the general V-BLAST code and got a higher performance gain. However, performance improvement with SIC techniques is limited due to error propagation, particularly with the same number of transmitter antennas as receiver antennas. Additionally, the main drawback of the VBLAST detection algorithms lies in the computational complexity, because multiple calculations of the pseudo-inverse of the channel matrix are required. This involves expensive computational requirements and makes VBLAST algorithms enduring computational bottleneck.

REFRENCES:

[1] P. W. Wolniansky, G. J. Foschini, G. D. Golden, and R. A. Valenzuela, “VBLAST: An architecture for realizing very high data rates over the rich-scattering wireless channel," URSI Int. Symp. on Signals, Systems and Electronics, (Pisa, Italy), pp. 295-300, Sep. 1998.

[2] G.J.Foschini. and M.J.Gans, “On the Limits of Wireless Communication in a Fading Environment When Using Multiple Antennas,” Wireless Personal Communications, vol. 6, no. 3, pp. 311-355, 1998.

[3] G. J. Foschini, “Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas," Bell Labs Tech. J., vol. 1, no. 2, pp. 41-59, 1996.

[4] Jeffrey G.Andrews, Arunabha Ghosh, and Rais Mohamed,” Fundamentals of WiMAX: Understanding Broadband Wireless Networking”, Prentice Hall, 2007.

[5] S. M. Alamouti, “A simple transmit diversity technique for wireless communications”, IEEE Journal on Select Areas in Communications, vol.16, pp.1451–1458, August 1998.

[6] V. Tarokh, H. Jafarkhani, and A. Calderbank, “Space-time block codes from orthogonal designs,” IEEE Trans. On Information Theory, vol. 45, no. 5, pp. 1456-1467, July 1999.

[7] A. Kaye and D. George, “Transmission of multiplexed PAM signals over multiple channel and diversity systems,” IEEE Trans. On

Communication Technology, vol. 18, no. 5, pp. 520-526, October 1970.

[8] W. Van Etten, “An optimum linear receiver for multiple channel digital transmission systems,” IEEE Trans. On Communications, vol. 23, pp. 828-834, August 1975.

[9] Simon Haykin, and Michael Moher, "Modern Wireless Communications", Prentice-Hall Inc., 2005.

[10] Choo C. Chiau, "Study of the Diversity Antenna Array for the MIMO Wireless Communication Systems ", PHD thesis, University of London, 2006.

[11] E. Telatar, “Capacity of multi-antenna Gaussian channels,” European Trans. on Telecommunications, vol. 10, pp. 585-595, Dec. 1999.

[12] Ezio Biglieri et al.," MIMO Wireless Communications", Cambridge University Press, 2007.

[13] Z. Xu and R. D. Murch, “Performance analysis of maximum likelihood detection in a MIMO antenna system,” IEEE Trans. Commun., vol. 50, no. 2, pp. 187–191, Feb. 2002

[14] G. D. Golden, G.J. Foschini, R. A. Valenzuela, and P. W. Wolniansky, “ Detection algorithm and initial laboratory results using V- BLAST space- time communication architecture,” Electron. Lett., vol. 35, pp. 14– 16, Jan. 1999.

[15] D. Gore, R. W. Heath Jr., and A. Paulraj,“ On performance of the zero forcing receiver in presence of transmit correlation,” in Proc. Int. Symp. Inf. Theory, 2002, p. 159.