Vishal Gupta, Anjana Jain, Anjulata Yadav / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 3, May-Jun 2012, pp. 625-629

BER Performance of Different Detection Schemes of V-BLAST

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ABSTRACT

Multiple input multiple output (MIMO) techniques are expected to be widely employed in wireless communications to address the ever-increasing demand for capacity. MIMO systems provide a linear increase in capacity with the number of antenna elements, affording significant increase in capacity over single input single output (SISO) systems. In this paper, we discuss some of the most basic detection schemes of V-BLAST for wireless links with multiple antennas: *M* at the transmit site and *N* at the receive site and also discuss the architecture of V-BLAST techniques. In the simulation result we compare different detection techniques such as zero forcing (ZF), minimum mean square error (MMSE) and maximum-likelihood (ML) of V-BLAST.

Keywords - **Multiple-input multiple output (MIMO), Bell Labs layered space-time (BLAST), V-BLAST, ZF, MMSE, ML.**

I. INTRODUCTION

MIMO systems have emerged as a promising technique for achieving high data rates over wireless channels. In fading channels, utilizing large throughput is a very challenging problem. The reason is that in most applications, the transmitter has no information about the channel state. To overcome this problem, a channel coding is employed by the transmitter to guarantee some level of robustness against channel fading.

In [1] an alternative way of utilizing the large throughput in MIMO systems was introduced under the name of Bell-labs layered space time (BLAST) architectures. In BLAST, the stream of information bits is divided into M sub-streams (layers) that are transmitted in parallel. A standard method for achieving spatial diversity to combat fading without expanding the bandwidth of the transmitted signal is to use multiple antennas at the receiver and/or at the transmitter side. These multiple antennas techniques can also be used to create multiple spatial channels and provide increase in data rate as a result. Generally speaking, with M transmit antennas and N receives antennas, with $N \geq M$, an M fold increase in the data rate could be achieved. Several types of spatial multiplexing systems take advantage of the sufficiently rich multipath scattering wireless channel in order to realize high data rates over the channel by exploiting it using the appropriate processing. Most spatial multiplexing schemes employ a channel coding structure that is composed of one dimensional encoders and decoders operating solely in the time domain. This is in contrast to space-time coding techniques like [2], [3], where two-dimensional coding is performed in time and space, i.e., across the individual transmit antennas. In principle, three different types of (one dimensional) channel coding schemes can be used in conjunction with spatial multiplexing: Horizontal coding (H BLAST), vertical coding (V BLAST), or a combination of both i.e. diagonal coding (D BLAST).

II. SPATIAL MULTIPLEXING TECHNIQUES

The fact that the capacity of a MIMO system with M transmit and N receive antennas grows (approximately) linearly with the minimum of M and N (without requiring extra bandwidth or extra transmission power) [3], [7] is an intriguing result. For single-antenna systems it is well known that given a fixed bandwidth, capacity can only be increased logarithmically with the SNR, by increasing the transmit power. In [1], theoretical capacity results for MIMO systems were complemented by the proposal of the BLAST scheme, which was shown to achieve bit rates approaching 90% of outage capacity, i.e., the maximum bit rate at which error free transmission is theoretically possible. Similar to the theoretical capacity results, the bit rates of the BLAST scheme were characterized by a linear growth when increasing the number of antenna element. the single data stream is encoded, modulated and demultiplexed in to M branches by a space time encoder and transmitted by each of the N transmit antennas. The mapping of symbols to each of the transmit antenna can be done in to these common schemes: Diagonal Blast (D-BLAST), Vertical Blast (V-BLAST), Horizontal Blast (H-BLAST).

For BLAST applications over multipath channels, to overcome the effect of frequency selectivity, orthogonal frequency division multiplexing (OFDM) modulation can be used. In OFDM, the data is transmitted over a number of tones each occupying a small fraction of the entire signal bandwidth so that it encounters flat fading. OFDM then converts multipath channel into a number of parallel flat fading channels eliminating the necessity of equalization in time at the receiver.

Spatial multiplexing techniques simultaneously transmit independent information sequences, often called layers, over multiple antennas. Using *M* transmit antennas, the overall bit rate compared to a single-antenna system is thus enhanced by a factor of *M* without requiring extra bandwidth or extra transmission power. Channel coding is often employed, in order to guarantee a certain error performance. Since the individual layers are superimposed during transmission, they have to be separated at the receiver using an interference cancellation type of algorithm (typically in conjunction with multiple receive antennas). A well-known spatial multiplexing scheme is the Bell-Labs Layered Space-Time Architecture (BLAST) [1]. The achieved gain in terms of bit rate (with respect to a single-antenna system) is called multiplexing gain.
The idea of spatial multiplexing was first published in [5].The basic principle of all spatial multiplexing schemes is as follows. At the transmitter, the information bit sequence is split into M sub-sequences (demultiplexing), that are modulated and transmitted simultaneously over the transmit antennas using the same frequency band. At the receiver, the transmitted sequences are separated by employing an interference cancellation type of algorithm. In the case of frequency-flat fading, there are several options for the detection algorithm at the receiver, which are characterized by different trade-offs between performance and complexity. A low complexity choice is to use a linear receiver, e.g., based on the zero-forcing (ZF) or the minimum mean- squared-error (MMSE) criterion. However, the error performance is typically poor, especially when the ZF approach is used (unless a favorable channel is given or the number of receive antennas significantly exceeds the number of transmit antennas). Moreover, at least as many receive antennas as transmit antennas are required ($N \geq M$), otherwise the system is inherently rank deficient. If the number of receive antennas exceeds the number of transmit antennas, a spatial diversity gain is accomplished.

The optimum receiver in the sense of the maximum likelihood (ML) detector achieves full spatial diversity with regard to the number of receive antennas, irrespective of the number of transmit antennas used. In principle, the use of multiple receive antennas is optional. Yet, substantial performance improvements compared to a single-antenna system are only achieved when multiple receive antennas are employed. The major drawback of the ML detector is its complexity. It grows exponentially with the number of transmit antennas and the number of bits per symbol of the employed modulation scheme. Due to this, the complexity of the ML detector is often prohibitive in a practical system. However, it can be reduced by means of more advanced detection concepts, such as sphere decoding.

For the BLAST scheme, an alternative detection strategy known as nulling and canceling was proposed. The BLAST detector was originally designed for frequency-flat fading channels and provides a good trade-off between complexity and performance. In contrast to the ML detector, the estimation of the *M* sub-sequences, called layers in the terminology of BLAST, is not performed jointly, but successively layer by layer. Starting from the result of the linear ZF receiver (nulling step) or the linear MMSE receiver, the BLAST detector first selects the layer with the largest SNR and estimates the transmitted bits of that layer, while treating all other layers as interference. Then, the influence of the detected layer is subtracted from the received signals (canceling step). Based on the modified received signals, nulling is performed once again, and the layer with the second largest SNR is selected. This procedure is repeated, until the bits of all *M* layers are detected. Due to the nulling operations, the number of receive antennas must at least be equal to the number of transmit antennas (as in the case of the linear receivers), otherwise the overall error performance degrades significantly. The error performance resulting for the individual layers is typically different. In fact, it depends on the overall received SNR, which layer is best. In the case of a low SNR, error propagation effects from previously detected layers dominate. Correspondingly, the layer detected first has the best performance. At the same time, layers that are detected later have a larger diversity advantage, because less interfering signals have to be nulled. Therefore, in the high SNR regime, where the effect of error propagation is negligible, the layer detected last offers the best performance [8]. A detailed performance analysis of the BLAST detector was, for example, presented in [9].

The BLAST detection algorithm is very similar to successive interference cancellation (SIC), which was originally proposed for multiuser detection in CDMA systems. Several papers have proposed complexity-reduced versions of the BLAST detector, e.g. [10]. Similarly, many papers have suggested variations of the BLAST detector with an improved error performance, e.g. [11]. An interesting approach to improve the performance of the BLAST scheme was presented in [12]. Prior to the BLAST detection algorithm, the given MIMO system is transformed into an equivalent system with a better conditioned channel matrix, based on a so-called lattice reduction. The performance of the BLAST detector is significantly improved by this means and approaches that of the ML detector, while the additional complexity due to the lattice reduction is rather small.

III. V-BLAST

The V-BLAST algorithm, on the contrary, achieves only a part of the full capacity but its implementation capacity is low [15]. The V-BLAST system diagram is shown in Fig. 2. QAM transmitters 1 to *M* operate co-channel at symbol rate $1/T$ symbol/s, with synchronized symbol timing. The collection of transmitters comprises, in effect, a vector-valued transmitter, where components of each transmitted *M*-vector are symbols drawn from a QAM constellation. For simplicity in the sequel, we assume that the same constellation is used for each component, and that transmissions are organized into bursts of

L symbols. The power launched by each transmitter is proportional to $1/M$ so that the total radiated power is constant and independent of M.

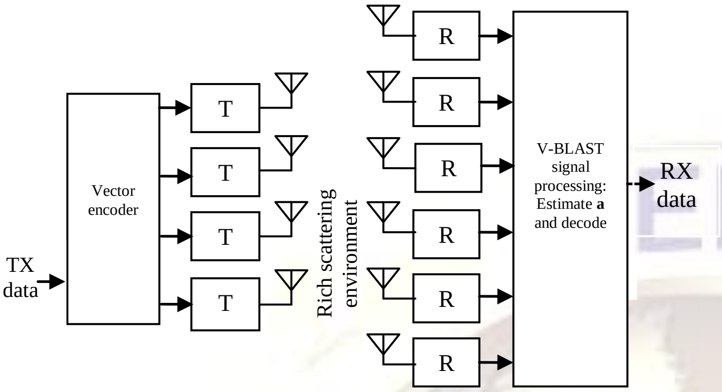

Fig.1. V-BLAST high-level system diagram

Receivers 1 to N are, individually, conventional QAM receivers. The receivers also operate co-channel, each receiving the signals radiated from all M transmit antennas. Flat fading is assumed, and the matrix channel transfer function is $\mathbf{H}^{N\times M}$, where h_{IJ} is the (complex) transfer function from transmitter j to receiver i, and M □ □N.

We take the quasi-stationary viewpoint that the channel time variation is negligible over the L symbol periods comprising a burst, and that the channel is estimated accurately, e.g. by use of a training sequence embedded in each burst.

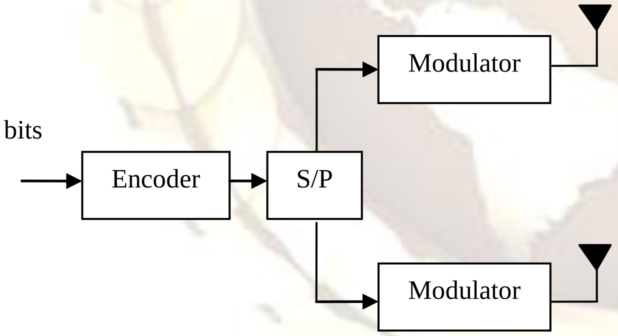

Fig.2. Block diagram of a two layer V-BLAST transmitter

Combination of ordering, nulling and cancelling used in V-BLAST is a widely-used recursive decoding method in spatial multiplexing systems. The order in which the received sub-streams are detected and cancelled affects the overall performance of the system. Detection ordering for V-BLAST based on maximum signal-to-noise ratio (SNR) was introduced in [4], where the sub-stream with the maximum SNR is detected and its contribution from the received signal is cancelled. Following the symbol cancellation the corresponding channel matrix will be zeroed, and the same process is repeated for the remaining undetected symbols.

IV. DIFFERENT DETETION SCHEMES

However, in general ZF leads to noise amplification, which is especially observed in systems with the same number of transmit and receive antennas.

In a linear ZF detection, the received signal vector X is multiplied with a filter matrix G, followed by parallel decision layers. Zero-Forcing means that the means that the mutual interference between the layers shall be perfectly suppressed.

A successive interference cancellation technique i.e. based on the zero forcing. Here the signals are not detected parallel but one after another. The interference caused by this signal is then subtracted from the received signal vector X and the ith column is removed from the channel matrix, leading to a new system with only N_t-1 transmit antennas. This procedure consisting of nulling and cancelling is repeated for the reduced systems until all signals are detected.

The minimum mean square error (MMSE) detector takes the noise term into account and thereby leads to an improved performance. As shown in [16], [17], MMSE detection is equal to ZF with respect to an extended system model.

The problem of noise enhancement through Zero-Forcing has already discussed. An improved performance can be achieved by including the noise term in the design of linear filter matrix G. This is done by MMSE detection scheme where the filter represents a trade-off between noise amplification and interference suppression.

In MMSE the symbols are detected in groups and already detected symbols are fed back for interference subtraction, as known for decision feedback equalization (DFE).

ML detection is optimal in the sense of minimum error probability when all data vectors are equally likely, and it fully exploits the available diversity.

The likelihood and log-likelihood functions are the basis for deriving estimators for parameters, given data. While the shapes of these two functions are different, they have their maximum point at the same value. For multiple-input multiple-output (MIMO) systems, the optimum maximum likelihood (ML) detection requires tremendous complexity as the number of antennas or modulation level increases.

V. SIMULATION RESULT AND PERFORMANCE

The simulation results for two transmitter and two receiver antenna of ZF, MMSE and ML detection for V-BLAST shown in the fig.3. The performance of ML detection is the good response among the all of the detection techniques.

VI. CONCLUSION

In this paper we give the modeling of different detection techniques of V-BLAST scheme is based upon this modeling.

Performance of ML detection is better than the MMSE and ZF scheme.

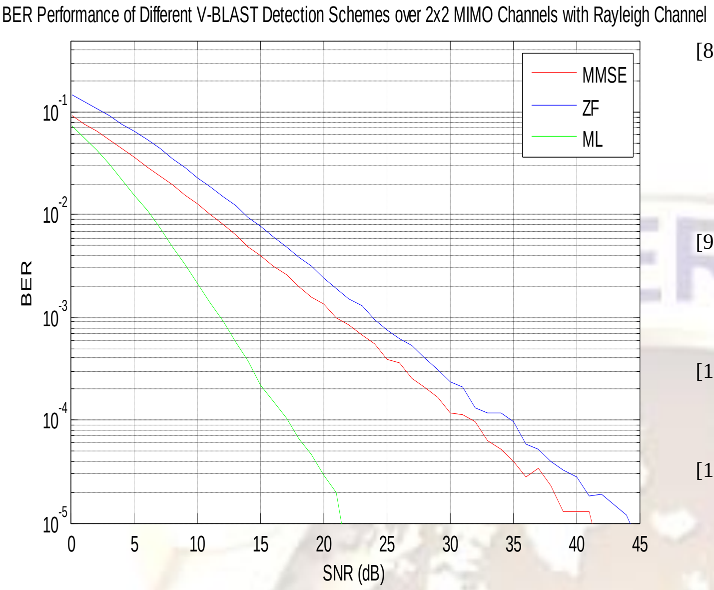

Fig.3. BER performance of Different V-BLAST Detection Schemes over 2×2 MIMO channels with Rayleigh channel

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