COMPARATIVE ANALYSIS OF DIFFERENT RECEIVE ALGORITHMS FOR BLAST ARCHITECTURE IN MOBILE COMMUNICATION SYSTEMS

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DOI: 10.36724/2664-066X-2021-7-4-12-15

ABSTRACT

The Layered Space-Time Processing approach to STC was first introduced by Lucent's Bell Labs, with their BLAST family of STC structures. The information bits are demultiplexed into individual streams, which are then fed into individual encoders. These coders may be binary convolutional coders, or even no coding at all. The outputs of the coders are modulated and fed to the separate antennas, from which they are transmitted, using the same carrier-frequency/symbol waveform (TDMA) or Walsh code (CDMA). At the receiver, a spatial beamforming/nulling (zero-forcing) process is used at the front end in order to separate the individual coded streams, and feed them to their individual decoders. The outputs of the decoders are multiplexed back to reconstruct the estimate of the original information bitstream. Various receivers for communication system with Space-Time Coding in MIMO Channel are considered. Performance analysis was provided by statistical simulation for various parameters of communication system.

KEYWORDS: *Multiple-Input Multiple Output, BLAST, Space-Time Coding, Zero-Forcing, MMSE, V-BLAST detector*

The article is reworked from unpublished 2nd IEEE International Conference on Circuits and Systems for Communications (ICCSC) materials.

INTRODUCTION

The Layered Space-Time Processing approach to STC was first introduced by Lucent's Bell Labs, with their BLAST family of STC structures [1]. The basic concept behind layered STC is illustrated in Figure 1. The information bits are demultiplexed into individual streams, which are then fed into individual encoders. These coders may be binary convolutional coders, or even no coding at all. The outputs of the coders are modulated and fed to the separate antennas, from which they are transmitted, using the same carrier-frequency/symbol waveform (TDMA) or Walsh code (CDMA). At the receiver, a spatial beamforming/nulling (zero-forcing) process is used at the front end in order to separate the individual coded streams, and feed them to their individual decoders. The outputs of the decoders are multiplexed back to reconstruct the estimate of the original information bitstream.

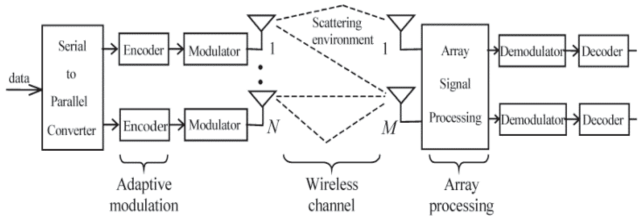

Fig. 1. Model of digital communication system with multiple transmitting and receiving antennas

Several types of BLAST structures were proposed [1]-[6]: Horizontal BLAST (H- BLAST), Diagonal BLAST (D-BLAST) and Vertical BLAST (V-BLAST). The system model with V-BLAST architecture is shown by the Fig.1. This model may be considered as a system with spatial multiplexing.

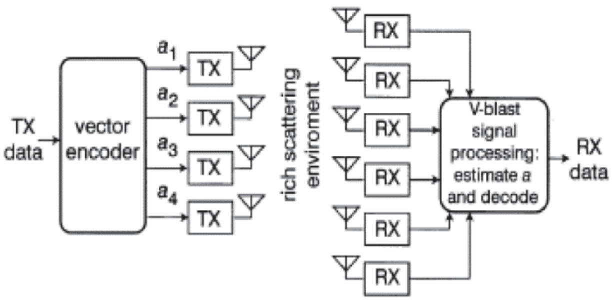

Fig. 2. V-BLAST high-level system diagram

The system model with V-BLAST can be described by the following observation equation:

$$Y = \sqrt{\frac{E_s}{N}}\mathbf{H}A + \eta\,,$$

where A – is the complex QAM symbol vector with dimension N; Y – is the complex observations vector with dimension M; H – is an ($M \times N$) dimensioned channel matrix, whose each element is complex Gaussian random value with zero mean and unit variance; η – is the complex Gaussian random vector with zero means and σ_n^2 variances; E_s – is energy of radiated signal.

MIMO RECEIVER ARCHITECTURES

In this section, we shall discuss receiver architectures for spatial multiplexing (N= M). Hence, receiver techniques (that have been studied in detail) such as zero-forcing (ZF), minimum-mean square error estimation (MMSE) and (optimal) maximum-likelihood sequence estimation (MLSE) can be applied directly.

The problem faced by a receiver for spatial multiplexing is the presence of multi-stream interference (MSI), since the signals launched from the different transmit antennas interfere with each other (recall that in spatial multiplexing the different data streams are transmitted co-channel and hence occupy the same resources in time and frequency). For the sake of simplicity we restrict our attention to the case (N= M).

A. Maximum-likelihood (ML) receiver. The ML receiver performs vector decoding and is optimal in the sense of minimizing the error probability. Assuming equally likely, temporally uncoded vector symbols, the ML receiver forms its estimate of the transmitted signal vector according to

$$A = \arg\min_{A}\left(\left\| Y - \sqrt{\frac{E_s}{N}}\mathbf{H}A \right\|^2\right)$$

where the minimization is performed over all possible transmit vector symbols A. Denoting the alphabet size of the scalar constellation transmitted from each antenna by Q, a brute force implementation requires an exhaustive search over a total of vector Q^N symbols rendering the decoding complexity of this receiver exponential in the number of transmit antennas. However, the recent development of fast algorithms [7], [8], [9] for sphere decoding techniques [10] offers promise to reduce computational complexity signi_cantly (at least for lattice codes). As already pointed out above, the ML receiver realizes N-th order diversity for Horizontal Encoding (HE) and (full) NM-th order diversity for Vertical Encoding (VE) and Diagonal Encoding (DE).

B. Linear receivers. We can reduce the decoding complexity of the ML receiver significantly by employing linear receiver front-ends to separate the transmitted data streams, and then independently decode each of the streams. We discuss the zero-forcing (ZF) and minimum mean squared error (MMSE) linear front-ends below.

ZF receiver: The ZF front-end is given by

$$G_{ZF} = \sqrt{\frac{M}{E_s}}\left(H^H H\right)^{-1} H^H$$

The output of the ZF receiver is obtained as

$$Z = A + G_{ZF}\eta ,$$

which shows that the ZF front-end decouples the matrix channel into MT parallel scalar channels with additive spatially-colored noise. Each scalar channel is then decoded independently ignoring noise correlation across the processed streams. The ZF receiver converts the joint decoding problem into N single stream decoding problems (i.e., it eliminates MSI) thereby signi_cantly reducing receiver complexity. This complexity reduction comes, however, at the expense of noise enhancement which in general results in a signi_cant performance degradation (compared to the ML decoder). The diversity order achieved by each of the individual data streams equals (M-N+1) [11], [12].

MMSE Receiver: The MMSE receiver front-end balances MSI mitigation with noise enhancement and is given by

$$G_{MMSE} = \sqrt{\frac{N}{E_s}}\left(H^H H + \frac{\sigma_\eta^2 N}{E_s} I_N\right)^{-1} H^H .$$

In the low-SNR regime $E_s / \sigma_\eta^2 >> 1,$ the MMSE receiver approaches the matched-filter receiver given by

$$G_{MMSE} = \frac{1}{\sigma_\eta^2}\sqrt{\frac{E_s}{N}} H^H ,$$

and outperforms the ZF front-end (that continues to enhance noise). At high SNR $E_s / \sigma_\eta^2 >> 1,$

$$G_{MMSE} = G_{ZF}$$

i.e., the MMSE receiver approaches the ZFreceiver and therefore realizes (M-N+1)-th order diversity for each data stream.

Successive cancellation receivers. The key idea in a successive cancellation (SUC) receiver is layer peeling where the individual data streams are successively decoded and stripped away layer-by-layer. The algorithm starts by detecting an arbitrarily chosen data symbol (using ZF or MMSE) assuming that the other symbols are interference. Upon detection of the chosen symbol, its contribution from the received signal vector is subtracted and the procedure is repeated until all symbols are detected. In the absence of error propagation SUC converts the MIMO channel into a set of parallel SISO channels with increasing diversity order at each successive stage [2], [13]. In practice, error propagation will be encountered, especially so if there is inadequate temporal coding for each layer.

The error rate performance will therefore be dominated by the first stream decoded by the receiver (which is also the stream experiencing the smallest diversity order).

Ordered successive cancellation receivers. An improved SUC receiver is obtained by selecting the stream with the highest SINR at each decoding stage. Such receivers are known as ordered successive cancellation (OSUC) receivers or in the MIMO literature as V-BLAST [3], [4].

OSUC receivers reduce the probability of error propagation by realizing a selection diversity gain at each decoding step. The OSUC algorithm requires slightly higher complexity than the SUC algorithm resulting from the need to compute and compare the SINRs of the remaining streams at each stage.

SIMULATION

BER versus SNR curves are shown by the Figures 3-6 for ZF receiver, MMSE receiver V-BLAST receiver with ZF algorithm, V-BLAST receiver with MMSE algorithm and optimal ML receiver.

QPSK case and N=M=4 is shown by the Fig.3. Spectral efficiency of such system is 8 bps/Hz. 16QAM case and N=M=4 is shown by the Figure 4. Spectral efficiency of such system is 16 bps/Hz. QPSK case and N=M=8 is shown by the Figure5.

Spectral efficiency of such system is 16 bps/Hz. 16QAM case and N=M=8 is shown by the Figure 6. Spectral efficiency of such system is 32 bps/Hz. Channel with independent Rayleigh fadings is considered in all mentioned cases.

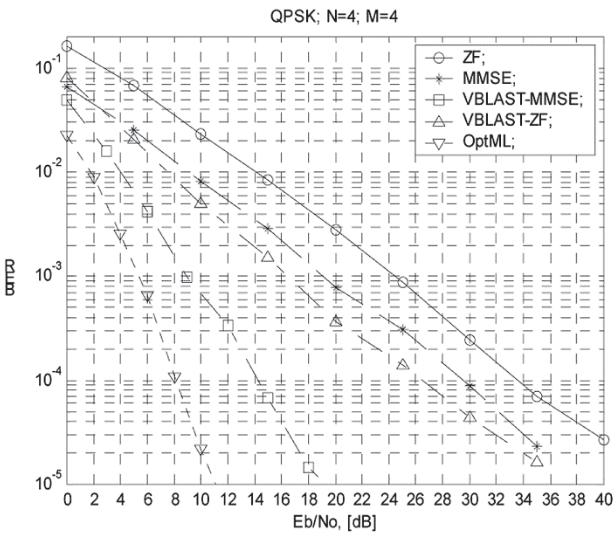

Fig. 3. BER versus SNR for N=M=4 and QPSK modulation

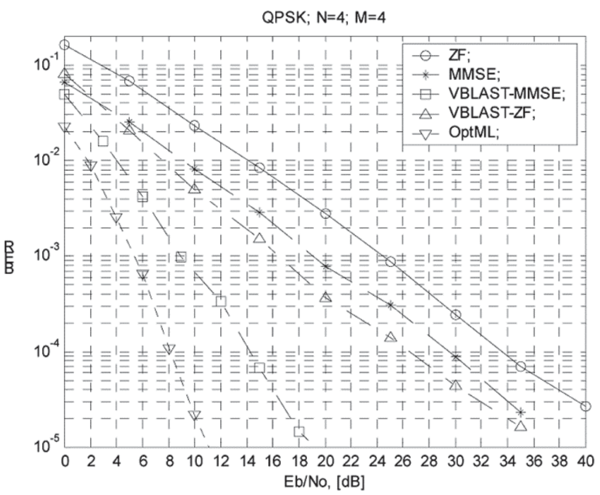

Fig. 4. BER versus SNR for N=M=4 and 16QAM modulation

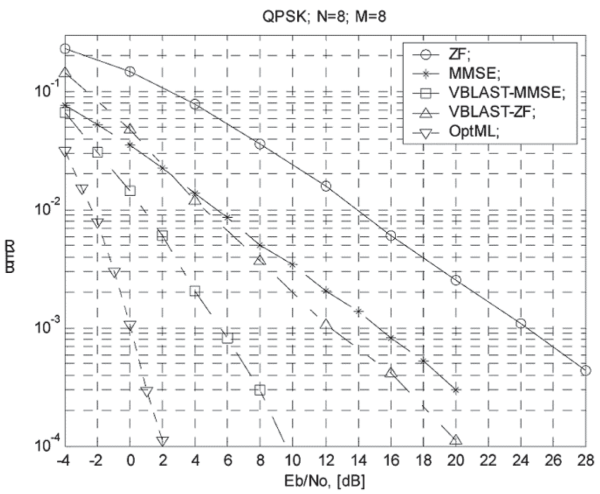

Fig. 5. BER versus SNR for N=M=8 and QPSK modulation

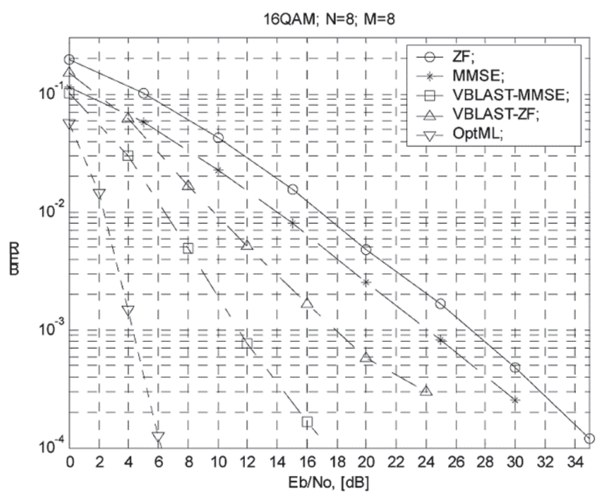

Fig. 6. BER versus SNR N=M=8 and 16QAM modulation

Looking at these plots, it is possible to se, that V-BLAST receiver with MMSE algorithm in each iteration has best performance among suboptimal reception algorithms. This receiver has about 4…9 dB losses at BER=0.001, versus optimal receiver. Note, that efficiency of such algorithm drops for high order modulation.

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