

# Performance of Hierarchical Quadrature Amplitude Modulation in Layered Space-Time Coding

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**Abstract**—In this paper, the error performance of hierarchical Quadrature Amplitude Modulation in layered space-time block code (LSTBC) system is investigated. Different hierarchical constellations are considered to obtain bit error performance over quasi-static Rayleigh flat fading channel. Comparison between BER in LSTBC system and BER in single antenna system is evaluated. BER performance with different priority vectors is also investigated.

## I. Introduction

The demand for broadcast and multimedia services over wireless and mobile communication networks is growing at a rapid pace. The next generation mobile networks need to support mixed traffic such as voice, text messages, fax messages, email messages, file transfer, Internet access, multimedia, video on demand, etc. where different kind of traffic needs different priority and protection. Cover [1] showed that broadcast messages can be divided into two or more classes to provide every class a different degree of protection according to its significance. The most important information must be recovered by all receivers while less important information can only be recovered by some receivers due to propagation conditions, to achieve this objective, hierarchical modulation is employed, which is constituted of non-uniform signal constellations to provide unequal bit error protection [2], [3]. Non-uniform constellations have already been incorporated in the digital video broadcasting-terrestrial (DVB-T) standard [4]. Several applications have been proposed in the literature, such as broadcasting digital HDTV [5], image transmission [6], multimedia services [7], etc.

New broadcast and multimedia services in mobile networks need high data rate and capacity, where multiple-input multiple-output (MIMO) has recently emerged as a key technology to achieve capacity

increments [8]. One of the MIMO techniques that received considerable attention in recent times is Vertical Bell-Labs Layered Space-Time Architecture (V-BLAST), which is used to achieve spatial diversity [9]. For transmit diversity, Space-Time Block Codes (STBC) has been proposed [10]. V-BLAST with space-time coding has been proposed to achieve both transmit and spatial diversity [11]. The combination of V-BLAST and STBC is usually referred to as layer space-time block codes (LSTBC). In layer space-time coding, the transmit antennas are partitioned into different groups and each group has been assigned a layer of V-BLAST. Within each group, the signals are space-time block coded, so the transmit diversity of the layered architecture increases as well as exploits the orthogonal nature of STBC.

Motivated by the above information, the use of hierarchical QAM in layer space-time coding is proposed to achieve different priority and protection for mixed traffic in future generation mobile networks. In past, hierarchical modulation has been used with STBC in [12], [13], with V-BLAST in [14], with space-time OFDM in [15]–[17]. In this paper we consider the use of hierarchical QAM with layer space-time block codes (LSTBC) to achieve higher performance. The error performance of the proposed system is evaluated with different hierarchical constellations.

The remainder of the paper is organized as follows. The next section briefly reviews the hierarchical modulation and non-uniform signal constellations of QAM. Section III explains the layered space-time block coding system. The numerical results are explained in section IV and conclusion is presented in section V.

## II. Hierarchical $M$ -QAM Modulation

Hierarchical modulation has been proved to be a practical method to implement multi-class informa-

tion broadcasting [1] [18], where transmission data is divided into two or more classes. The most important information is known as basic data, which is more protected and can be recovered by all receivers, while less important information is known as refinement or enhancement data, which is only recovered by the fortunate receivers depending on propagation conditions. In hierarchical constellations, symbols are non-uniformly spaced to provide unequal bit error protection.

Let us consider figure 1, where 4/16/64-QAM hierarchical constellation is shown with Karnaugh map style Gray coding. 64-QAM constellation can be constructed from 16-QAM constellation, and 16-QAM constellation can be from 4-QAM. The basic idea is that the constellation can be viewed as a 64-QAM constellation if the channel conditions are good enough, otherwise as a 4-QAM constellation. The triangular and squared symbols in the figure 1 represent only fictitious symbols and will not be transmitted, while circular symbols that are labeled with respect to their nearest fictitious symbols, are transmitted. These constellations can be characterized by the distances between symbols as shown in the figure 1. The distance vector is defined as  $d = [d_1, d_2, \dots, d_n]$  and the ratio between the distances specifies the priority ( $p = d_1/d_2$ ), which controls the relative message priorities. The priority vector  $p$  can be written as [18]

$$\mathbf{p} = [p_1 \ p_2 \ \dots \ p_n] = \left[ \frac{d_1}{d_n} \ \frac{d_2}{d_n} \ \dots \ 1 \right] \quad (1)$$

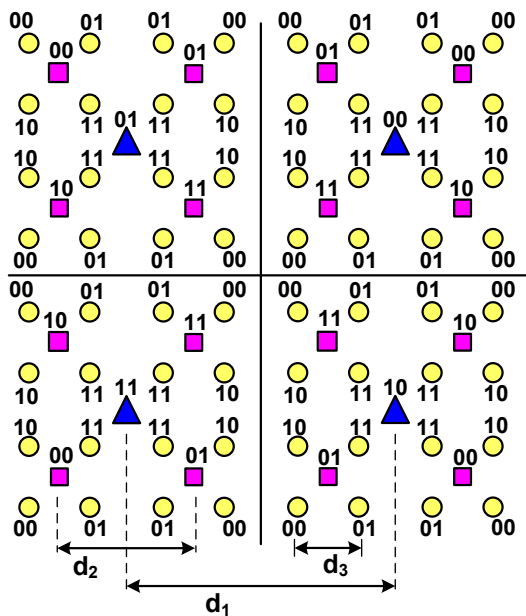


Fig. 1. Hierarchical 4/16/64-QAM Constellations

If the distance in immediate higher level of hierarchical constellation is half than the distance in lower level constellation, such as  $d_2 = d_1/2$  then it results the uniform QAM constellation.

### III. System Model

We consider a MIMO system that has  $n_T$  transmitting and  $n_R$  receiving antennas and is denoted by a  $(n_T, n_R)$  system. Throughout this paper, we assume that all the transmitters are synchronized. Figure 2 shows the system architecture of LSTBC. A block of  $B$  input bits is sent to the vector encoder of V-BLAST that produces  $q$  bit streams (layers) of length  $B_1, B_2, \dots, B_q$  with  $B = B_1 + B_2 + \dots + B_q$ . The transmit antennas  $n_T$  are partitioned into  $q$  groups of  $n_1, n_2, \dots, n_q$ , with  $n_T = n_1 + n_2 + \dots + n_q$ , where  $n_1$  is the number of antennas in the first group and so on. Each bit stream,  $B_i, 1 \leq i \leq q$ , is then sent through the corresponding space-time block codes (STBC) encoder. The output of the STBC encoder is a  $n_i \times l$  codeword,  $\mathbf{c}_i$ , over  $l$  time intervals. The coded outputs from all the layers are transmitted simultaneously over the wireless channel. The transmit antennas of all the groups are allocated equal power and the total transmission power is fixed. At any time instant, the transmitted symbols can be written as

$$\mathbf{C} = [\mathbf{c}_1, \mathbf{c}_2, \dots, \mathbf{c}_q]^T \quad (2)$$

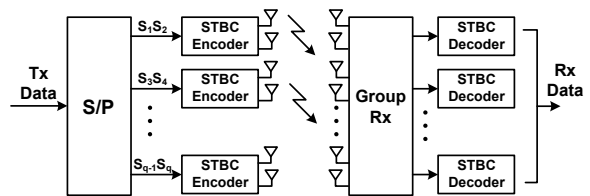


Fig. 2. System Model of Layered Space-Time Block Coding Architecture

The channel is assumed to be quasi-static Rayleigh flat fading, i.e. the channel variation is assumed to be negligible over two consecutive symbols. Each fade coefficient is a complex Gaussian random variable with zero mean and 0.5 variance per dimension. The channel state information (CSI) is assumed perfectly known at the receiver, however, the transmitter has no knowledge of the channel. Let  $h_{mn}$  be the path gain from the transmitting antenna  $n$  to the receiving antenna  $m$ , with  $n = 1, 2, \dots, n_T$  and  $m = 1, 2, \dots, n_R$ . The channel matrix is defined as

$$\mathbf{H}_{n_R \times n_T} = \begin{bmatrix} h_{1,1} & \cdots & h_{1,n_1} & h_{1,n_1+1} & \cdots & h_{1,n_T} \\ h_{2,1} & \cdots & h_{2,n_1} & h_{2,n_1+1} & \cdots & h_{2,n_T} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ h_{n_R,1} & \cdots & h_{n_R,n_1} & h_{n_R,n_1+1} & \cdots & h_{n_R,n_T} \end{bmatrix} \quad (3)$$

Partitioning  $\mathbf{H}$  into groups corresponding to each layer, the channel matrix can be written as

$$\mathbf{H} = [\mathbf{h}_1, \mathbf{h}_2, \dots, \mathbf{h}_q] \quad (4)$$

where

$$\mathbf{h}_1 = \begin{bmatrix} h_{1,1} & \cdots & h_{1,n_1} \\ h_{2,1} & \cdots & h_{2,n_1} \\ \vdots & \ddots & \vdots \\ \vdots & \ddots & \vdots \\ h_{n_R,1} & \cdots & h_{n_R,n_1} \end{bmatrix} \quad (5)$$

is the fade coefficients of the first layer.

In this Layered Space-Time Block Code (LSTBC) system, parallel group interference nulling and cancellation decoding algorithm is used to separate signals from each group of antennas [19]. At each receiving antenna, the received signal is the superposition of  $n_T$  transmitted signals corrupted by Rayleigh fading and noise. The received signal over  $l$  time intervals can be written as

$$\mathbf{r}_1 = \mathbf{H}\mathbf{C} + \mathbf{v} \quad (6)$$

where  $\mathbf{r}_1$  is original received signal matrix of dimension  $n_R \times l$ ,  $\mathbf{v}$  is the  $n_R \times l$  noise matrix with independent complex Gaussian variables of zero mean and  $N_0/2$  variance per dimension.

#### IV. Results

In the simulation, Layer Space-Time Block Codes (LSTBC) with four transmit antennas and four receive antennas is considered. Transmitting antennas are grouped so that each layer has two antennas in STBC resulting in two V-BLAST layers. The simple orthogonal Alamouti code [10] is used as STBC. Several simulation results of average bit error probability (BER) for different hierarchical  $M$ -QAM modulation are obtained by Monte Carlo simulations at the instantaneous  $E_s/N_0$ . Quasi-static Rayleigh flat fading channel is used by assuming perfect channel knowledge at the receiver. The results have been categorized into two-level hierarchical QAM with LSTBC, three-level hierarchical QAM with LSTBC, and basic and refinement bits error performance with

LSTBC, only selected results have been presented in the next subsections.

##### A. Two-Level Hierarchical QAM in LSTBC

In two-level hierarchical QAM modulation, error performance of different  $M$  combinations (such as 4/16-QAM, 16/64-QAM, 4/64-QAM, etc.) is obtained with layer space-time coding and compared with the single antenna. Figure 3 depicts the both basic bits and refinement bits error performances of 16/64-QAM with layer space-time coding, the figure also shows the comparison with single antenna. It is found that layer space-time coding greatly improves the performance of two-level  $H$ -QAM.

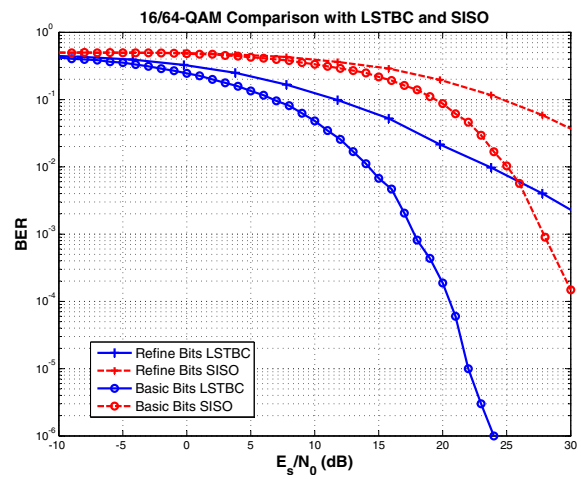


Fig. 3. 16/64-QAM Error Performance Improvement in LSTBC 4(=2+2)Tx 4Rx compared to Single Antenna

##### B. Three-Level Hierarchical QAM in LSTBC

Error performances of basic bits and refinement bits for three-level 4/16/64  $H$ -QAM is obtained with layer space-time coding and compared with the single antenna as shown in the figure 4. This figure clearly shows the performance improvement with layer space-time coding.

##### C. Basic and Refinement Bits Error Performance in LSTBC

With different priority vectors for 4/16/64-QAM in layer space-time coding, error performances of basic bits and refinement bits is obtained. Figure 5 shows the error performance of basic bits and it is clearly found that the error performance of basic bits improves with increase in the priority vector.

Figure 6 depicts the error performance of refinement bits with different priority vectors. The significant performance degradation for refinement bits is

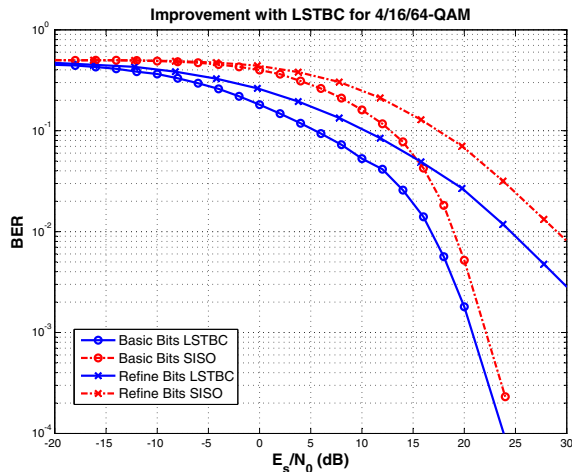


Fig. 4. 4/16/64-QAM Error Performance Improvement in LSTBC 4(=2+2)Tx 4Rx compared to Single Antenna

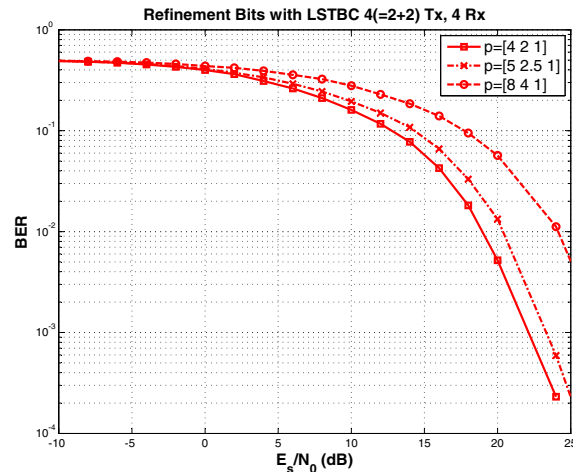


Fig. 6. 4/16/64-QAM Refinement Bits Error Performance in LSTBC with Different Priority Vectors

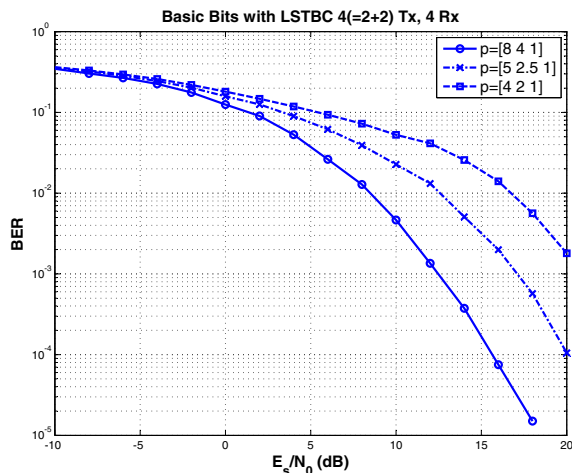


Fig. 5. 4/16/64-QAM Basic Bits Error Performance in LSTBC with Different Priority Vectors

found with the increase in priority vector, showing that priority vector supports basic bits protection.

### V. Conclusions

In this paper, the error performance of hierarchical  $M$ -QAM constellations in layered space-time block coding system is investigated. The bit error performance is obtained by Monte-Carlo simulations over quasi-static Rayleigh flat fading channel. BER in layered space-time coding is compared with BER in single antenna system, and found significant improvement in the error performance of hierarchical modulation.

BER performance with different priority vectors is also investigated and found that higher priority to basic bits improves its error performance while decreases refinement bits error performance.

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