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A Review: Multi-Dimensional Space-Time Multilevel Codes using Rician Fading

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Abstract

This paper reviews multi-dimensional space-time multilevel codes (ST-MLCs). Basic construction methods, including conventional STCs. The space-time multilevel encoders partition a $2N_t$ dimensional signaling space, which spans all N_t transmit antennas. Complexity of detection/ decoding can be reduced by multi-dimensional partitioning. Space time multistage decoder for the proposed ST-MLCs is reviewed. The complexity of soft decision decoding to be significantly reduced by comparing a single level approach. In addition, significant performance gains are obtained over a single level approach.

Keywords

Space-time coding, Multilevel, Channel Coding, Rician Fading, MIMO.

1. Introduction

Space-time coding (STC) [1, 2, 3] is a set of practical signal design techniques that offers an efficient means for providing diversity over fading channels with multiple transmit antennas. STC is performed in both the temporal and spatial domains to introduce correlation between signals transmitted in different time periods from various antennas. The spatial-temporal correlation is then used to exploit the scattering environment and at the receiver minimize transmission errors. STC can achieve transmit diversity and coding gain compared to spatially uncoded systems without sacrificing bandwidth [2]. Since their introduction in 1998 [1], STC and the corresponding MIMO signal processing have engendered one of the most research areas in wireless communications. Many variants of these coding structures are developed [2, 3, 4]. STBCs and STTCs can be considered to be the two main classes of space-time codes.

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This paper focuses on STCs, which have been developed to simultaneously provide coding gain and diversity in MIMO systems [1]. Similar to convolutional codes, STCs use encoder to introduce redundancy, and to achieve gain. The coding gain is dependent on the construction criteria of the code, and on the length of the memory in the encoder. A number of different structures have been proposed for STCs [2, 5, 6, 7]. This paper focus is on the STCs proposed by Tarokh et.al. [1] and improved by others, most notably Baro et.al. [7] and Vucetic et.al. [10, 11, 2], conventional STCs (CSTCs), though the names are sometimes used interchangeably throughout.

2. MIMO

MIMO wireless communication systems are important due to their potential to achieve very high spectral efficiency. To exploit the de-correlation of multiple received signals in the presence of multi-path propagation. The same bandwidth is allowed to data streams occupying. Unlike traditional radio systems that try to directly combat the effects of multi-path propagation, MIMO systems exploit it thus providing an increase in throughput and reliability with reduced error rates. Since training sequences are typically available in a practical system, MIMO schemes that assume the channel knowledge is only available at the receiver have in particular attracted a lot of research attention [8].

Practical MIMO modulation schemes with receive-only channel knowledge are principally of two types, diversity systems and spatial multiplexing systems [9]. Diversity modulation, or space-time coding [1, 9, 2], to maximize the diversity advantage of the transmitted information codewords are designed. Such codes tend to maximize diversity gain at the expense of some loss in available capacity. Spatial multiplexing [8] or Bell Labs Layered Space Time (BLAST) type systems, on the other hand, transmit independent data streams from each transmitting antenna, allowing spectral efficiency to be achieved at the expense of a loss in diversity advantage for a fixed number of receive antennas. The space-time coding work can be dated back to a 1994 paper by

Wittenben [8], which proposes a system using coding techniques and transmit diversity. This paper sparked a lot of research in this area, most significantly that of Tarokh, Seshadri and Calderbank in 1998 [1]. In their landmark paper, they state the fundamental theory of space-time coding and introduce the first true space-time codes, namely space-time codes (STCs). This paper was followed by Alamouti's paper [9], which led to the development of space-time block codes (STBCs) [7, 1, 11, 3]. STBCs are the two main classes of space-time codes (STCs). STCs are the main focus of this review paper. The original BLAST structure was developed by Foschini, at Bell labs, in the mid 1990's [8]. It uses a multi-element antenna array at both the transmitter and receiver, where every antenna transmits an independent sub stream of data. Advanced signal processing at the receiver is used to estimate and decode the received signal blocks. A BLAST system requires more receive than transmit antennas and a rich scattering environment, which often occurs indoors. Vertical-BLAST (V-BLAST) and Diagonal-BLAST (D-BLAST) [11, 10, 3, 9] are the two classes of BLAST transmission formats.

In V-BLAST [9], data stream is multiplexed into N_t independent sub streams. Each is passed through an optional temporal encoder, interleaved, mapped to a signal constellation point and transmitted over its corresponding transmit antenna. This process encoding of the serial data into a vertical vector can be considered and is thus referred to as vertical coding. D-BLAST [8] is somewhat more complex and uses a diagonal coding structure. The data stream are firstly parallel encoded but then, rather than transmitting each codeword from one antenna, the codeword symbols are staggered across antennas. As such, a codeword is transmitted by all N_t transmit antennas. If the frame sizes are not chosen properly, a D-BLAST based system may suffer a significant efficiency loss due to the wasted space-time dimension introduced by the staggering effect [2]. At rates of tens of bits/sec/Hz, V-BLAST has been shown [9] to have better performance and relatively simple decoding and encoding. Due to the (successive) interference cancelation techniques are employed in the decoding process of V-BLASTs, their decoding with the number of transmits antennas complexity increases linearly. However, with fewer receive antennas than transmit antennas BLAST schemes are unable to work. This deficiency is especially important for modern cellular systems where a base-station typically has more antennas than the mobile handsets. Furthermore, because BLAST transmits independent data streams from each antenna there is no built-in spatial coding to guard against deep fades suffered by a given transmitted signal. The initial application of MIMO was proposed for indoor WLANs and fixed wireless access networks. However, it has since found wider applications and some practical MIMO systems have been built and experimentally tested in industry [8, 9]. There is an ongoing effort to standardize a MIMO approach under the name IEEE 802.11n [1]. It will offer up to eight times coverage and about six times the data rates, of current 802.11g [1] networks.

3. System Model

Consider a MIMO wireless link, with N_t transmit antennas and N_r receive antennas. The symbol transmitted at time t by the *j*th transmit antenna is denoted by Q_t^j , for $1 \leq j \leq N_t$. Following [1, 10, 11, 3], assume that the channel exhibits quasi-static frequency flat Rayleigh fading over a frame duration. Thus, it is constant over one frame and between frames varies independently. Assume that at the receiver perfect CSI is available, but there is no knowledge of the channel is available at the transmitter. The received signal at time *t*, at the *i*th receive antenna is a noisy superposition of independently Rayleigh faded versions of the N_t transmitted signals and is denoted r_i^t for $1 \leq i \leq N_r$. The discrete complex baseband output of the i^{th} receive antenna at time *t* is given by

$$r_i^t = \sum_{j=1}^{N_t} h_{ij} Q_t^j + n_t^i \qquad (1)$$

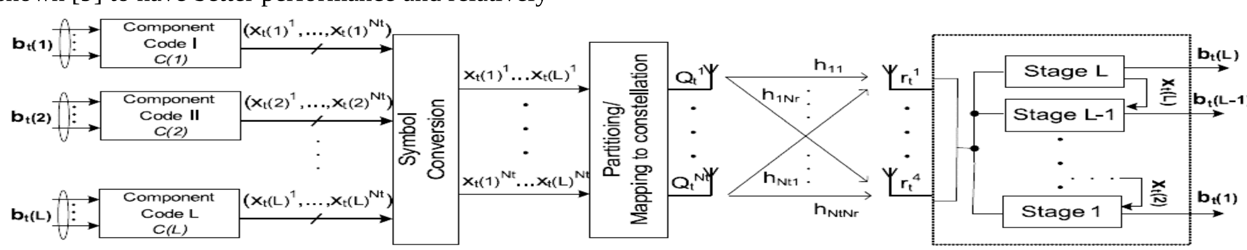

Figure 1: General structure of an MLSTTC system

where, h_{ij} is the path gain between the *j*th transmit and *i*th receive antennas and n_t^i is the noise associated with the *i*th receive antenna at time *t*. The path gains, h_{ij}, are modeled as samples of independent complex Gaussian random variables with zero mean and variance of 1/2 per dimension, implicitly assuming that the signals transmitted from different antennas undergo independent fading. The noise quantities are samples of independent complex Gaussian random variables with zero mean and variance of $N_0/2$ per dimension. Where,

$Q_t = (Q_t^1, Q_t^2, \dots, Q_t^{N_t})T$,
$r_t = (r_t^1, r_t^2, \dots, r_t^{N_r})T$,
$n_t = (n_t^1, n_t^2, \dots, n_t^{N_r})T$ and $\mathbf{H}_t$ is
The $N_r \times N_t$ channel matrix whose (*i, j*)th entry is represented by h_{ij} and (.)T denotes the transpose operation. The MLSTC system works by partitioning the underlying signal constellation into a hierarchy of subsets or clusters using the multi- resolution modulation (MRM) approach, originally introduced by Cover in 1972 [12] and later used by others including [13]. Each cluster itself has sub-clusters.

The incoming bits are encoded and mapped to the 2^m point MRM constellation; with the most significant coded bits being mapped to the clusters and the least significant bits to the sub clusters and so forth. Last bits choose a signal point within the underlying constellation. This clusterization provides up to *L* resolutions for an underlying M-QAM constellation, with $M = 4^L$, where each resolution is considered as a 4-QAM constellation. Up to *L* component codes are used to encode the incoming bits. A simplified block diagram of a MLSTC system is presented in Figure 1. Each of these component codes are designed for their cluster size. The output of each encoder is mapped to its corresponding cluster.

CSTC's [10, 11] are used as component codes in the MLSTC's. Potentially, any code (including block codes) is used as a component code. The encoding is over both time and space. Throughout $rN_r \geq 4$, where *r* is the rank of the code difference matrix. These results in the minimum Euclidean distance dominating performance and thus design codes for large Euclidean distances, following the trace criterion [10]. The receiver applies a modified version of a CSTC decoder in each stage. For the detection and decoding process branch metrics to take the effect of the MRM partitioning and multi-stage decoding into account.

4. Conclusion

Demand for capacity in wireless communication systems has been rapidly growing world-wide. This has been driven by the increasing data rate requirements of cellular mobile systems, and increasing demand for wireless Internet and multimedia services. As the available radio spectrum is limited, higher data rates can only be achieved by designing more efficient signaling techniques.

To improve spectral efficiency for future high data rate transmissions, it is desirable to construct STCs with high order signal constellations. However, the design of a STC normally involves the use of computer search, with the search space increasing exponentially with constellation size, the number of transmit antennas and the number of states in the code trellis. A similar increase occurs in the decoding complexity of STCs. Therefore, despite their many benefits, STCs are still faced with reluctance from system designers when it comes to implementation, especially when for systems which require the use of larger signal constellations or a larger number of antennas. This develops a new transmission scheme to benefit from the advantages of STCs but without the complexity disadvantages, especially for large signal constellations. By developing a new class of codes, called Multilevel Space-Time Codes (IMLSTC). The new scheme presents a promising alternative to currently available STCs, by offering the flexibility of having a higher spectral efficiency (if desired) and lower decoding complexity (especially for larger constellations and large number of states).

5. Throughput Improvement

MLSTCs can be designed to achieve higher throughputs for a given constellation, compared to their CSTCs counterparts. MLSTC system that achieved a throughput of 6 bits/sec/Hz using an underlying 16-QAM constellation. CSTC has been developed for a 64 QAM constellation (which is required to give a throughput of 6 bits/Sec/Hz). Therefore, layered space-time codes analyzed [8, 9] as a basis for comparison and found out that MLSTC used fewer antennas (4 transmit and 4 receive antennas as opposed to 6) and achieved the same throughput, while outperforming the layered designs in higher SNR regimes. Another way to achieve a higher throughput would be to use higher rate codes as component codes.

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