A Review on the Performance of Multilevel Linear Block Codes

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Abstract- **In this, we propose to evaluate the performance of multilevel linear block codes on different fading channels, for which the fading coefficients are constant within one frame but vary independently from one frame to another. Linear Block Codes perform up to mark in case error detection and correction problems. If we can use this capability of error detection and correction of the linear block codes in a multilevel environment then we can achieve higher throughput along with a reliable and less error prone wireless communication. Also we can compare the performance of the linear block codes with and without error detection and error correction capability and accordingly deduce the results.**

Keywords--- MSD, STTC, GMLSTTC, MIMO, CSI

I. INTRODUCTION

Linear block codes are a class of parity check codes that can be characterized by the (n, k) notation. Then coder transforms a block of k message digits (a message vector) into a longer block of n codeword digits (a code vector) constructed from a given alphabet of elements. When the alphabet consists of two elements (0 and 1), the code is a binary code comprising binary digits (bits).The k-bit messages form 2^k distinct message sequences, referred to as k-tuples (sequences of k digits). The n-bit blocks can form as many as 2^n distinct sequences, referred to as n-tuples. The encoding procedure assigns to each of the 2^k message k-tuples *one* of the $2^n n$-tuples. A block code represents a one-to-one assignment, where by the 2^k message k-tuples are uniquely mapped into a new set of 2^k codeword n-tuples; the mapping can be accomplished via a look-up table. For linear codes, the mapping transformation is, of course linear.The code rate is the ratio $\mathbf{R} = k/n$. For a binary code, $\mathbf{R} \leq 1$, so after encoding a k-digit message or information block, there are $n - k$ remaining redundant digits in the code word. The redundant digits give the code words the ability to reduce the effect of channel noise, which could introduce errors during the transmission of the message.

Multilevel coding is a *coded modulation* technique using which we can construct higher complexity code using simple component codes. It employs hierarchical partitioning of the signal constellation into various levels and defines a code over each level. These codes are generally decoded in a sequential manner using a multistage decoder (MSD). Multilevel codes were originally designed for the AWGN channel. Multilevel codes developed for multiple antenna systems primarily use block component codes. The error-correction codes like block codes and convolutional codes when used in real time communication systems provide improvements in error performance at the cost of bandwidth expansion. For both block codes and convolutional codes, transforming each input data k-tuple into a larger output codeword n-tuple, requires additional transmission bandwidth. Therefore, in the past, coding generally was not popular for band limited channels such as telephone channels, where signal bandwidth expansion is not practical.

Coded modulation refers to a class of techniques in which coding and modulation is combined and jointly optimized in order to improve the performance of a given digital transmission scheme, usually without incurring bandwidth expansion. It is a bandwidth efficient signaling technique.

Space time trellis codes (STTCs) [12], [7] can simultaneously provide coding and diversity gain, but typically transmit only one data symbol per time slot. In [14], higher rate full-diversity STTCs are derived, but no examples beyond BPSK and 2-3 transmit antennas are given1. In [13], [8] throughput is increased by splitting the transmit antennas into groups and transmitting a different STTC from each group. Each STTC spans only a subset of the antennas thus limiting diversity gain. They use successive interference cancellation and require as many receive as transmit antennas. Multilevel coding [15] allows the construction of a high complexity coded signal constellation using simple component codes. Here we utilize multilevel coding, antenna grouping [13], [8] and STTCs to develop grouped multilevel spacetime trellis codes (GMLSTTCs), capable of simultaneously providing coding gain, diversity improvement and increased spectral efficiency. More than one data symbol per time slot is achieved by grouping antennas on some levels and using a separate STTC for each group as in [13], [8]. By retaining at least one level encoded with a STTC that spans all antennas, diversity gains can be realized compared to [13], [8] while still improving throughput. A key advantage of the GMLSTTC structure is that, by using multistage decoding, any number of receive antennas can be used. Decoding complexity remains manageable even for high order modulations [1].

Following Ginzburg, a hierarchy of codes was proposed to match the geometric partitioning of a signal set. They showed that coset codes (including Ungerboeck, lattice, and binary codes) and indeed any codes which rely on a partitioning of the signal set are all subclasses of the proposed coding scheme. The combination of such codes in a multilevel scheme often leads to reduced complexity in comparison with previously published schemes. A variety of decoder structures were also discussed[5]. Imai and Hirakawa have proposed a multilevel coding method based on binary block codes that admits a staged decoding procedure. This method has been extended to the design of codes for the Gaussian channel that admit multistage decoding procedures by Ginzburg, by Sayegh, and by Tanner. In [4], they extended the multilevel coding method to coset codes and showed how to calculate minimum squared distance and path multiplicity in terms of the norms and multiplicities of the different cosets. The multilevel structure allows the redundancy in the coset selection procedure to be allocated efficiently among the different levels. It also allows the use of suboptimal multistage decoding procedures that have performance/complexity advantages over maximum likelihood decoding[4]. To date there has been little work done on multilevel codes for the space-time environment. In [3] multi-dimensional space-time multilevel codes (ST-MLCs)was developed. Several construction methods were proposed, including a coset code approach. The space-time multilevel encoders partition a 2Nt -dimensional signalling space, which spans all Nt transmit antennas. The multi-dimensional partitioning can be designed to reduce the complexity of detection/ decoding. It developed a spacetime multistage decoder for the proposed ST-MLCs. It allows the complexity of soft decision decoding to be significantly reduced compared to a single level approach. In addition, significant performance gains over a single level approach were obtained[3].

A. System Overview

Several techniques and systems have been used for achieving higher throughput in wireless communication. All these systems involve certain types of modulation schemes and codes. As we can see in [3] a modulation scheme is considered with $M = 2^l$, $l > 1$, signal points in a *D*-dimensional signal space. The signal points are taken from the signal set $A = \{a_0, a_1, \ldots, a_{M-1}\}$ and is mainly focused on AWGN channel. The mapping is derived by successively partitioning the signal set *A* into subsets. Here basically a binary partioning of 8-ASK (8-ary amplitude shift keying) signal set is illustrated. In [5] a hierarchy of codes is used to match the geometric partitioning of a signal set. A combination of coset codes is used in a multilevel scheme using multilevel code structure. An integral part of the construction method for many channel codes is a geometric partitioning of the signal set. If a signal set S_0 is divided into non overlapping subsets such that the union of all subsets is equal to S_0, then the subsets collectively form a partition of S_0. An equivalence relation may always be associated with the partition, such that the subsets are distinct equivalence classes. Each subset has the same number of elements. Denote one of the equivalence classes (subsets) by S_1. When S_0 is a group, with some appropriately defined group operator, then an equivalence relation exists such that S_1 is a subgroup of S_0, with the other equivalence classes being the cosets of S_1. S_1 may be further partitioned, and in general a partition chain $S_0/S_1/ \ldots S_r$ can be produced. Similarly [4] also uses a multilevel coding method based on binary block codes that uses a multistage decoding procedure. Space-time systems with Nt transmit antennas and Nr receive antennas are considered in [2]. The $(1 \times N_r)$ received vector at time t can be written as $r^t = s^t H^t + n^t$, where s^t is the $(1 \times N_t)$ transmitted vector at time t and n^t is the $(1 \times N_r)$ *additive white Gaussian noise (AWGN)* vector at time *t*. The complex $N_t \times N_r$ channel matrix at time *t* is denoted H^t, where the element representing the subchannel from the i^{th} transmit antenna to the j^{th} receive antenna is denoted $h^t_{i,j}$ .We assume that all transmit to receive antenna sub-channels are independent and that we have ideal *channel state information (CSI)* at the receiver, but none at the transmitter. Also multi-dimensional space-time multilevel codes (ST-MLCs) are used along with two flat Rayleigh fading channel models. [1] also uses Multi-layer schemes but using multiple Space-time trellis codes (STTCs) over subgroups of antennas providing higher throughput. A system with N_t transmit and N_r receive antennas is used. The M-QAM symbol transmitted at time by the j_{th} transmit antenna is denoted Q^j_t, for $1 \le j \le N_t$. We assume a quasi-static Rayleigh fading channel model that is constant over a frame and varies independently between frames. Each subchannel fades independently. In addition, we assume perfect *channel state information (CSI)* at the receiver, but none at the transmitter. Thus taking into consideration all the above techniques we will be using a multilevel MIMO system consisting of n_T transmit and n_R receive antennas, designed for an underlying 16-QAM constellation with up to 4 transmit and 4 receive antennas. Using Linear Block Codes (3,6) and (4,7) as component codes, we will assume a quasi-static Rayleigh fading channel model which is constant over a frame and varies independently between frames.

B. Encoding

The encoders used in all the several multilevel systems are generally the same. It's the different codes used that make the difference. For eg. in [3] each data block is fed into an individual binary encoder, generating words of component code. The codeword symbols are then mapped to a signal point. However in [5] a multilevel partioning is done by using any code which is describable in terms of the multilevel encoder structure. Multilevel coding method is extended to coset codes in [4] for Gaussian channel. The proposed *P*-level ST-MLC encoder structure in [2] includes optional bit or symbol interleaving on each level. Interleaving could also be added before the transmit antennas. The component encoder on each level selects the sequence of cosets to be transmitted. Collectively, they determine the sequence of constellation points to be transmitted. The structure of the GMLSTTC system in [1] uses multilevel coding and set partitioning to partition a *M*-QAM constellation into subsets of constellation points. The level 1 code chooses one of the shaded subsets and then the level 2 code chooses the actual point within the subset transmitted. Set partitioning results in increasing Euclidean distance on each level, meaning the strongest code is required on level 1. . The structure of a multilevel encoder is shown in Fig.1

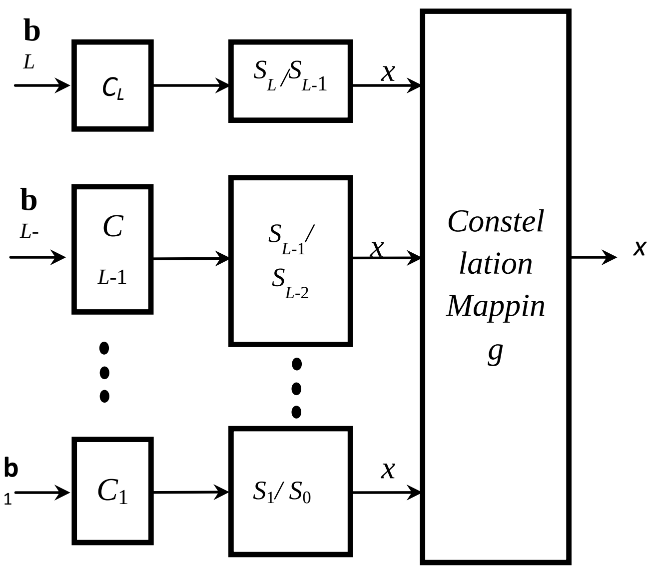

Figure 1**.** General encoder structure for a multilevel code.

Each code, C_i, accepts b_i input bits and outputs $|S_i|/|S_{i-1}|$bits for each time slot. The output of the encoder for C_L selects a co-subset of S_L / S_{L-1}. The next encoder for C_{L-1} selects a co-subset of S_{L-1} / S_{L-2}, and so forth, until finally the code C_1narrows down the selection to a single point on the underlying constellation, *x*, which will be transmitted. An overall code *C*, may be associated with the *L*-level multilevel code. This code is referred to as the multilevel code associated with the partition chain S_L / S_{L-1}/… /S_0 and the *L* independent component codes C_1, C_2, …,C_L.

Several different criteria have been proposed for designing multilevel codes. These include distance based criteria [22],[5], [4], capacity based designs [3], those based on the cutoff rate [3] and the coding exponent [3].

A variety of different partitioning strategies have been suggested [3, 24]. In this work, we consider a partitioning scheme based on multi-resolution modulation (MRM), originally introduced in the context of broadcast channels by Cover [25].

C. Decoding

Multilevel codes are usually decoded by a staged decoder. A low-complexity staged decoding procedure that is well known as multistage decoding (MSD) is used in [3]. The component codes are successively decoded by the corresponding decoders. At decoder processes not only the block of received signal points, but also decisions of previous decoding stages. Similarly a staged decoder structure for a multilevel partition code is used in [5]. The error performance of the staged decoder is easily bounded. The decoders are given the correct sequence of cosubsets by the previous stage regardless of the channel conditions. The multilevel codes in [4] admit a multistage decoding procedure that requires very few trellis states and has performance/complexity advantages over maximum likelihood decoding. Decoding a composite MLC is usually prohibitively complex so in [2] a STMSD was developed for the proposed ST-MLCs. The detection block on each level generates a list of points for that level to enable soft information to be calculated for the component error correction decoder. Similarly in [1] a multi-stage decoder with *L* stages to decode the *L*-level GMLSTTC is used. The decoder starts by decoding the level 1 component code, denoted stage 1. This code offers full-diversity over the constellation subsets it selects, allowing good diversity gains. A staged decoder is shown in Fig.2 The decoder, on level *i* in Fig.2 decodes the component code C_i. The staged decoder operates in a sequential manner. First the decoder at level *L* makes a decision on the code C_L and outputs the corresponding data bits, $\mathbf{b}_L$. This decision information is then passed on from stage *L* to stage $L-1$ and the decoder at level $L-1$ operates in a similar way, outputting $\mathbf{b}_L-1$ and the corresponding co-subset information. The process continues down the partition chain until the received sequence is completely decoded.

The fact that the decision at each level assumes a correct decision from the previouslevel, means there can be error propagation through a MSD. Techniques such as interleavingand iterative multi-stage decoding have been used to combat these effects [5].

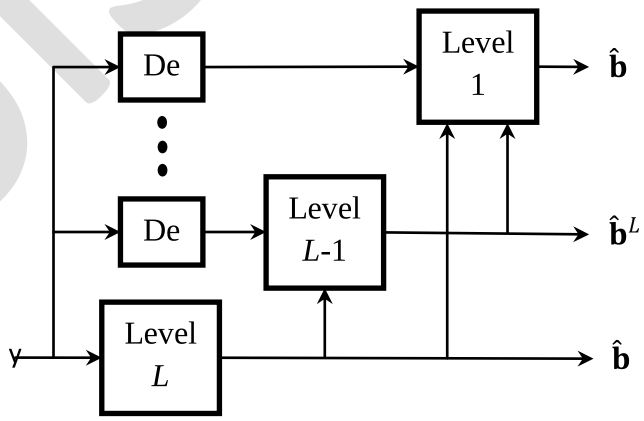

Figure 2**.** General multi-stage decoder for a multilevel code.

In our work we have used linear block codes as the component codes and accordingly we can decode them at each level. Also we have used identical linear block codes at each of the 2 used levels. Either both the levels use (3, 6) block code or both of them use (4, 7) block codes.

II. CONCLUSION

The concept of equivalent channels for the individual coding levels of an MLC scheme establishes a basis to derive tools for the analysis and design of coded modulation schemes [3]. The problem of channel coding can be solved in principle in an optimum way by employing binary codes in an MLC approach. The labeling of signals is also important when a multilevel code is to be used. By partitioning the signal set such that the labels assume a geometric significance in the signal space [5]. The previous research shows several construction methods for ST-MLCs and GMLSTTCs which are capable of simultaneously providing spectral efficiency, diversity improvement and coding gain with manageable decoding complexity. However we presented a multilevel coding scheme that we call Multilevel Linear Block coding, as an extension for the single level Linear Block coding or simply Linear Block coding, without sacrificing the capability of bandwidth efficiency, diversity improvement and coding gain with more or less similar decoding complexity, especially for larger constellations and higher throughputs.

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