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A study to evaluate the efficacy of multilevel coding scheme in wireless communication

Sakshi Aneja[1*], Indu Bala[2], Kamal Kumar Sharma[3], Ashutosh Sharma[4]

Assistant Professor, Lovely Professional University[1]

Associate Professor, Lovely Professional University[2]

Professor, Lovely Professional University[3]

Assistant Professor, Lovely Professional University[4]

sakshi.aneja088@gmail.com*

Abstract:

Numerous research studies claim that multilevel coding scheme reduces the effects of multipath fading by providing effective error-correction. A good design of multilevel code results in high data transmission rate, coding gain and spectral efficiency with a low decoding complexity. This study evaluates the performance of multilevel coding scheme to become a potential technique for future wireless communication systems.

1. Introduction

The multilevel coding scheme is based on performing independent coding at various levels. The main advantage of this scheme is that a high spectral efficiency can be obtained. However, the multilevel signals are prone to channel noise, therefore, these must be accompanied with suitable error-correcting codes to generate efficient communication systems. The multilevel coding scheme can use error-correcting codes as component codes to provide coding gain and flexible data transmission rate. The multistage decoding is usually used for the detection of multilevel coded information which results in low decoding complexity [1-3].

Multilevel coding scheme combines error-correcting codes and modulation. As shown in figure 1, the information stream is partitioned into sub information streams which are encoded at independent levels to generate error-correcting component codes.

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These component codes are mapped to M-ary constellation based on a partitioning strategy that maximize the minimum Euclidean distance. The mapped symbols are modulated and transmitted over wireless channel.

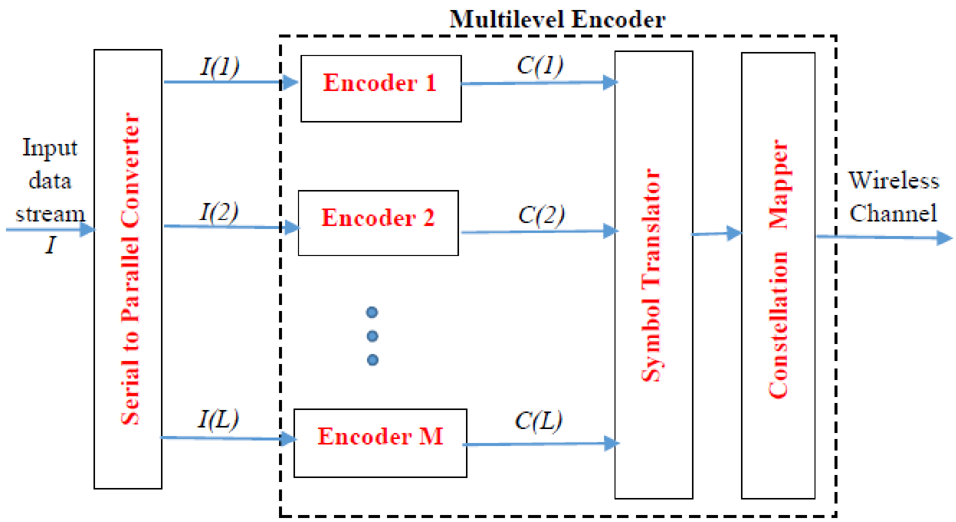

Figure 1: Multilevel coding of information stream

The multilevel codes can be decoded by a multistage decoder at a low complexity. As shown in figure 2, the received signal is decoded in various stages, commencing from stage 1 and ending at stage L to estimate the corresponding data at each level.

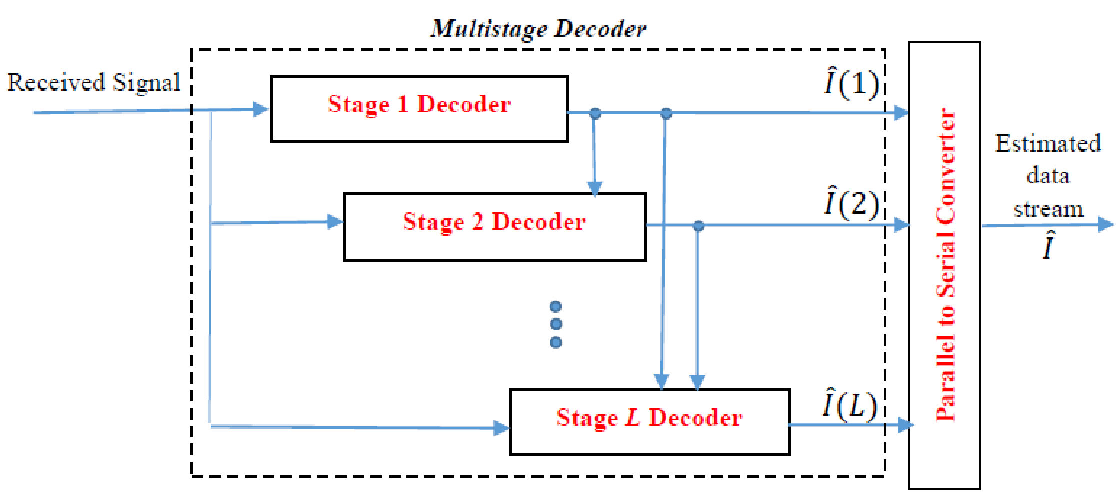

Figure 2: Multistage decoding of multilevel codes

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The design of good multilevel codes depends on various factors such as signal constellation size, partitioning strategy, Euclidean distance between signal points, type of error-correcting codes used as component codes and code rates of component codes.

2. Performance Analysis of Multilevel Coding Scheme in Wireless Networks

Massey [4] proposed an efficient digital communication system based on the concept that coding techniques are more effective when combined with suitably designed modulation scheme. The design of coded modulation system is such that the modulator can generate any of the q-ary codewords for transmission. This system provides improved error performance and coding gain.

Ungerboeck and Csajka [5] extended Massey's work by designing a trellis coded modulation (TCM) system that intends to provide coding gain and spectral efficiency without compromising data rate. It is based on optimising the Euclidean distance while mapping codewords to signal constellation. Ungerboeck [6]–[8] described a new procedure for mapping trellis codes, known as 'set partitioning'. This involves designing the trellis codes for multilevel/phase signals such that minimum Euclidean distance is maximised. By transmitting same amount of information within same bandwidth, it was observed that TCM can provide significant coding gain in comparison to uncoded multilevel modulation. Calderbank and Mazo [9] proposed an analytical description of trellis codes which describes many practical codes simply. It combines the two steps used for designing trellis codes viz. specification of convolutional code and mapping of codewords to signal constellation. Calderbank and Sloane [10] proposed a new technique to construct trellis codes that maps the codes to a set of points in n-dimensional lattice. This technique enabled the coding theorists to use larger signal constellation and complicated lattices. Later than, researchers contributed in improving the performance of TCM by combining error-correcting codes with multidimensional signal constellations [11], [12].

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Imai and Hirakawa [13] introduced another coded modulation technique known as multilevel coding that improves coding gain and spectral efficiency. It involves partitioning the information sequence into M component information sequences. Each of these component information sequences is passed through an independent error-correction encoder to generate M component codes. The symbols of component codes are combined to produce 2^M-ary symbols. These symbols are mapped to M-ary signal constellation such that minimum Euclidean distance is maximised. Finally, mapped symbols are transmitted over wireless channel. The multilevel coded symbols are decoded by a multistage decoder. The multistage decoder detects corresponding component codes by processing the received signal in multiple stages where the output of one stage is passed to subsequent stages. Imai and Hirakawa used block codes in multilevel coding scheme.

The main advantage of multilevel coding scheme over TCM is that it provides flexibility in code design as well as data transmission rate. Any error-correcting code can be used for multilevel coding of information, and coded symbols can be mapped to M-ary signal constellation using any partitioning strategy. Moreover, constellation dimensionality can be decoupled from code rate.

Ginzburg [14] extended the work of Imai and Hirakawa by using multidimensional signal constellation for mapping coded symbols in order to improve the performance of multilevel coding. Biglieri and Elia [15] introduced a class of multidimensional signals based on generalized group alphabets and examined their performance by combining with convolutional codes using Ungerboeck's scheme and block codes using Ginzburg's scheme. It was observed that transmission systems based on this technique show a good performance at the cost of modest complexity. Calderbank [16] extended multilevel coding technique to coset codes in order to design a coding scheme that is immune to Gaussian noise and resistant to impulse noise. These codes are accompanied with a multistage decoder due to its low decoding complexity. Pottie and Taylor [17] showed that any code which is designed in accordance with the partitioning of signal constellation can be combined into a multilevel code in order to reduce decoding

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complexity. Fazel and Ruf [18] combined multilevel coding and multiresolution modulation (MRM) [19] for digital broadcast applications and analysed its performance by optimising different parameters. This technique shows a significant coding gain and can be used to reduce emitter power or to enlarge the broadcasting area. Calderbank and Seshadri [20] proposed two different combinations of multilevel coding and modulation for unequal error protection in a bandlimited environment.

Huber and Wachsmann [21] reported that multistage decoding of multilevel codes results in predominance of errors at lowest level in the case of Ungerboeck set partitioning. In an endeavour to reduce the errors at lowest level, it was proposed that rates can be selected in accordance with the capacities of equivalent channels for different coding levels. Fischer et al. [22] emphasized the importance of information theory in designing optimal multilevel coded modulation. The code rates for different component codes are assigned by calculating capacity or random coding exponent of equivalent channels. Duan et al. [23] designed a multilevel coding scheme that approaches AWGN channel capacity by mapping the output of each encoder to an independent signal constellation. Morelos-Zaragoza [24] analysed the performance of multilevel coded modulation and multistage decoding for unequal error protection using non-standard and hybrid set partitioning of 2^M-ary modulation. Besides, theoretical upper bounds were derived for designing good multilevel coding schemes. Isaka et al. [25] investigated asymmetric signal constellations to increase the flexibility of multilevel coding scheme and multistage decoding for unequal error protection. Wachsmann et al. [26] reported that multilevel coding in combination with full maximum-likelihood decoding can be designed using a large space of rate combinations to approach capacity. But, maximum likelihood decoding is much more complex than multistage decoding. Isaka and Imai [27] proposed iterative decoding of multilevel codes due to sub-optimality of multistage decoding in some cases. The sub-optimality is caused by an increase in error multiplicity at lower stages which is further propagated to higher stages. Iterative decoding improves error performance at the cost of complexity.

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Yuan et al. [28] combined multilevel coding and multistage decoding with orthogonal space-time block codes (OSTBC) using punctured convolutional codes based on capacity rule. Yuan et al. [29] designed another structure based on the combination of multilevel coding and OSTBC for Rayleigh fading channels. It considers Bose, Chaudhuri, and Hocquenghem (BCH) codes as component codes, block partitioning technique and 8-ASK modulation. It was observed that such a structure shows same spectral efficiency but better power efficiency in comparison to multilevel coding structure without space diversity. Lampe et al. [30] designed multilevel coding with orthogonal space-time block codes as component codes based on binary partitioning of two dimensional signal constellation for the case of single transmit antenna. Martin et al. [31], [32] developed space-time multilevel codes based on multi-dimensional partitioning of $2N_t$ dimensional signal constellation in such a way that each component code spans N_t transmit antennas. In addition, space-time multistage decoder was designed that reduces the decoding complexity in comparison to space-time low density parity check code or turbo space-time code. Diggavi et al. [33] designed multilevel diversity-embedded space-time codes to support applications with different quality of service requirements. Diversity-embedded space-time codes are high-rate space-time codes having multiple levels of reliability. Chui and Calderbank [34] designed multilevel diversity-embedded space-time codes for parallel multiple-input multiple-output (MIMO) channels to implement video-broadcasting in WiMAX. Ma [35] proposed a space-time block code-spatial modulation (STBC-SM) scheme in conjunction with multilevel coding. This scheme shows an improved error performance in comparison to traditional STBC-SM for the same spectral efficiency and space diversity order.

Baghaie Abchuyeh [36] designed multilevel space-time trellis coding scheme by combining multilevel codes and space-time trellis codes. Such a combination can provide high coding gain, spectral efficiency and throughput at a low decoding complexity, even for big constellations and larger number of states. Baghaie Abchuyeh et al. [37] further developed a multilevel space-time trellis coding scheme which

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involves grouping of transmit antennas. This scheme uses independent space-time trellis code (STTC) for each group. It transmits multiple data symbols in a time slot and provides an enhanced spectral efficiency with manageable decoding complexity.

Sharma [38] extended the work of Baghaie Abchuyeh by designing weighted multilevel space-time trellis coding scheme using channel state information (CSI) at transmitter in order to improve error performance. The transmission signals were weighted by exploiting feedback information from receiver. Jain and Sharma [39] presented another technique of improving the performance of multilevel space-time trellis codes. The generator sequences for component STTC were selected in a dynamic manner based on the current channel profile at receiver. Further, grouped multilevel dynamic space-time trellis coding scheme [40] was designed by grouping the transmit antennas to enhance spectral efficiency and error performance. Furthermore, CSI at transmitter was used to design adaptively grouped multilevel space-time trellis coding scheme [41], [42], weighted adaptively grouped multilevel space-time trellis coding scheme [43], and weighted adaptively grouped multilevel dynamic space-time trellis coding scheme [44].

3. Future Scope

The multilevel coding scheme can be incorporated with various diversity methods, partitioning strategies and modulation schemes to enhance the system performance. Other possible area of future research can be to find alternative decoding techniques for multilevel coding system without compromising performance and complexity.

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