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A REVIEW OF CONSTELLATION SHAPING AND BICM-ID OF LDPC CODES FOR DVB-S2 SYSTEMS

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Abstract— ***Here an energy-efficient approach is presented for constellation shaping of a bit-interleaved low-density parity-check (LDPC) coded amplitude phase-shift keying (APSK) system. APSK is a modulation consisting of several concentric rings of signals, with each ring containing signals that are separated by a constant phase offset. APSK offers an attractive combination of spectral and energy efficiency, and is well suited for the nonlinear channels. A subset of the interleaved bits output by a binary LDPC encoder is passed through a nonlinear shaping encoder. An iterative decoder shares information among the LDPC decoder, APSK de-mapper, and shaping decoder. Information rates are computed for a discrete set of APSK ring radii and shaping bit probabilities, and here the additive white Gaussian noise (AWGN) channel is considered. In this paper, an adaptive equalizer is added in the iterative decoding path and its purpose is to reduce inter symbol interference to allow recovery of the transmit symbol. An adaptive equalizer one that automatically adapts to time-varying properties of the communication channel. The combination of shaping, use of LDPC codes, iterative decoding and with adaptive equalizer we can achieve a gain in excess of 1.18 dB in AWGN compared with a system that does not use shaping, uses an un optimized code from the DVB-S2 standard, and does not iterate between decoder and demodulator.***

Keywords— APSK, LDPC, BICM-ID, DVB-S2, AWGN, Adaptive equalizer.

I. INTRODUCTION

The vision of being able to communicate and access data anywhere and anytime has driven the research and development of powerful communication systems forward at a remarkable speed. Today, digital communication systems have become an integral part of our everyday life. The technical challenge faced today is to enable high data transmission rates with a high power and bandwidth efficiency.

Power efficiency describes the minimum ratio of signal to noise power required to achieve a desired quality of service. Bandwidth efficiency describes the minimum bandwidth required to transmit at the desired data rate. The DVB-S2 standard has been specified around three key concepts: best transmission performance, total flexibility and reasonable receiver complexity. To achieve the best performance-complexity trade-off, DVB-S2 benefits from more recent developments in channel coding (adoption of LDPC codes) and modulation (use of 16APSK and 32APSK). The result is typically a 30 % capacity increase over DVB-S under the same transmission conditions. To achieve the best performance, DVB-S2 is based on LDPC (Low Density Parity Check) codes, simple block codes with very limited algebraic structure. LDPC codes have an easily parallelizable decoding algorithm which consists of simple operations.

Amplitude Phase Shift Keying (APSK) represents an attractive modulation scheme for digital transmission over nonlinear satellite channels due to its power and spectral efficiency combined with its inherent robustness against nonlinear distortion. APSK has recently become widely adopted, due primarily to its inclusion in the second generation of the Digital Video Broadcasting Satellite standard, DVB-S2, as well as some other standards such as DVB-SH.

In this paper, information-theory to jointly optimize parameters used by both the APSK constellation and the shaping codes were used. A model for bit-interleaved coded APSK [1] with constellation shaping is considered in this paper. This also describes the operation of the nonlinear shaping encoder, constellation shaping strategies for constellations with mappings that are equivalent to those in the DVB-S2 standard.

At the receiver side, the application of constellation shaping to bit-interleaved coded modulation with iterative decoding (BICM-ID) is done. An iterative decoding algorithm is used to exchange extrinsic information between the channel decoder, shaping decoder, and demapper blocks.

II. BACKGROUND

Xingyu Xiang et al. [2] proposed a technique in which shaping is used for a turbo coded amplitude-phase shift keying (APSK) constellation. In that, turbo codes are generated by a turbo encoder and the then the turbo codes are bit interleaved. After interleaving, bits are separated and a subset of these bits is passed through a nonlinear shaping encoder. The bits at the output of the shaping encoder are more likely to be a zero than a one. These shaping bits are again interleaved and used to select from among a plurality of sub constellations. At the same, the unshaped bits are used to select the symbol within the sub constellation.

Symbols from lower-energy sub constellations are selected more frequently chosen than those from higher-energy sub constellations. Constellation shaping strategies are proposed for constellations with mappings that are equivalent to those in the DVB-S2 standard. The shaping and modulation parameters are optimized using an information-theoretic approach. In theory, shaping gains of slightly over 0.3 dB may be achieved with 16-APSK and 32-APSK in AWGN. BER results suggest that gains beyond 0.3 dB may be possible in AWGN when an iterative decoder is used.

Boon Kien Khoo et al. [3] proposed the association between constellation shaping and bit-interleaved coded modulation with iterative decoding (BICM-ID). In his work, he considered a shaping technique which consists of partitioning the basic constellation into several sub-constellations so that the lower energy signals are transmitted more frequently than their higher energy counterparts. In practice, such a technique can be implemented by inserting shaping block codes between mapping and channel coding functions. At the receiver side, an iterative decoding algorithm is used to exchange extrinsic information between the channel decoder, shaping decoder, and demapper blocks. Throughout this work, he focuses on the design of a 2-bit/s/Hz BICM-ID system employing a 16-ary quadrature amplitude modulation (QAM) constellation. This technique can improve the performance of BICM-ID schemes by a few tenths of decibels.

Kewu Peng et al. [4] presented the AMI of constellation-constrained AWGN channel in his paper, especially for APSK constellations that have been employed by DVB-S2 but without Gray mapping exist. Analysis show that the gaps between BICM capacities and CM capacities cannot be neglected for 16 or 32 APSK constellations with pseudo-Gray mapping. Iterative demapping is presented to regain such loss. Numerical results show that at 4/5 coding rate, such gap is about 0.18 dB for 16APSK and about 0.41 dB for 32APSK. For 32APSK, such gap is up to 0.6 dB at 2/3 coding rate. To regain the capacity loss due to independent demapping, BILCM-ID system is proposed in this paper. Comparing with Bit Interleaved Low-density parity-check (LDPC) Coded Modulation (BILCM) system, BILCM with Iterative Decoding (BILCM-ID) system can obtain considerable iterative gain in the case of large constellation and long interleaving size. For instance, for 32APSK and 8-codeword interleaving, BILCM-ID system can obtain about 0.5 and 0.3 dB over AWGN channel compared with BILCM system at coding rates 2/3 and 4/5, respectively. Another advantage of BILCM-ID is that the transmitter in it is exactly the same with that in BILCM because they both employ Gray or pseudo-Gray mapping, and therefore BILCMID is compatible with the existed BILCM system.

III. PROPOSED METHOD

This system comprises transmitter and receiver sections.

3.1 Transmitter section

Figure 1 shows the transmitter section. The information bits from DVB-S2 [5] had been encoded using a LDPC encoder. The encoded codewords are passed through a bit interleaver and the interleaved codeword is separated into two groups using a bit separator.

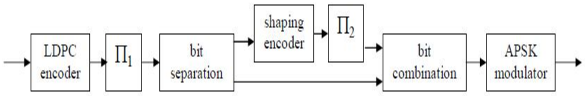

Fig 1: Transmitter section

One group is passed through a shaping encoder and the shaping used is 16 symbols and 32 symbols APSK. The shaped output is then interleaved by a second bit interleave and passed to the bit combiner. The other group directly goes to the bit combiner and there the shaped bits and the unshaped bits are combined and it then goes to the APSK modulator. The modulated signal is transmitted through the AWGN channel. Noise is added when signal is transmitted through the channel.

The system input is a length-Lc vector a of equally-likely information bits, which is encoded by a rate $Rc = Lc/Mc$ binary LDPC encoder. The length-Mc codeword b at the output of the LDPC encoder is permuted by a interleaver Π_1 to generate the interleaved codeword **v**. A bit separator arbitrarily separates **v** into two disjoint groups, **d** of length Ls and $\mathbf{s}_2$ of length $Mc - Ls$. The vector **d** is segmented into J short blocks of length ls, where $Ls = Jls$ and passed through a rate $Rs = ls/ns$ shaping encoder. The shaping encoder produces zeros more frequently than ones. The J short length-ns blocks at the output of the shaping encoder are concatenated to produce the length-Ms vector **c**, where $Ms = Jns$. The vector **c** is then permuted by a second interleaver Π_2 to produce $\mathbf{s}_1$.

The vectors $\mathbf{s}_1$ and $\mathbf{s}_2$ are together used by the APSK modulator to select symbols from the constellation $X = \{x_1, \ldots, x_P\}$, where each constellation symbol is a complex scalar. The elements of $\mathbf{s}_1$ are said to be *shaping* bits, because they are used to select from among several sub constellations with a no uniform probability. This is in contrast with the *unshaped* bits $\mathbf{s}_2$, which select symbols from the selected sub constellation with uniform likelihood. Let $g < q$ be the number of shaping bits per symbol, where $q = \log_2(P)$. It follows that X is partitioned into $2g$ sub constellations, each of size $2q-g$. The variables g and q are related to the lengths of $\mathbf{s}_1$ and $\mathbf{s}_2$ by

$$\mathrm{Ms}/(\mathrm{Mc} - \mathrm{Ls}) = \mathrm{g}/(\mathrm{q} - \mathrm{g}) \rule{4cm}{0.4pt}(1)$$

Each symbol is selected from X according to the prescribed symbol mapping by using g bits from $\mathbf{s}1$ to select the sub constellation and $q - g$ bits from $\mathbf{s}2$ to select the symbol within the sub constellation. The symbols in X are normalized to have average energy

$$Es = \sum_{i=1}^{P} p(xi)\,|xi|^2 \rule{4cm}{0.4pt}(2)$$

Where $p(xi)$ is the probability that xi is selected. In Fig 1, the two bit streams are combined to form the vector $\mathbf{z}$, where each group of q consecutive bits consists of g bits from $\mathbf{s}_1$ and $q - g$ bits from $\mathbf{s}_2$. The APSK modulator uses this input and the symbol labeling map to produce a vector $\mathbf{x}$ of coded symbols of length

$$M = (Mc - Ls + Ms)/q \rule{4.5cm}{0.4pt}(3)$$

Let p_0 denote the probability that a particular bit in $\mathbf{s}1$ is equal to zero, and p_1 be the probability that it is equal to one. The purpose of the shaping encoder is to produce an output with a particular $p_0 > 1/2$. The codebook is constructed such that it contains the 2^{ls} distinct *ns*-tuples of lowest possible Hamming weight. Construction is a recursive process, with C initialized to contain the all-zeros codeword of length *ns*. Code words of higher weight are recursively added to C until $|C| = 2^{ls}$. Suppose that C contains all code words of weight $w - 1$ or lower. During the next recursion, weight-w code words are repetitively drawn and added to C until either the number of distinct codeword in C is 2^{ls} or all weight-w codeword have been used. In the former case, the code construction is complete, while in the latter case it moves on to begin adding code words of weight $w + 1$.

The overall rate of the system, $R = Lc/M$, is the number of information bits per modulated symbol, and is related to the rates of the LDPC and shaping codes by:

$$\mathrm{R} = \mathrm{Rc}\,[\mathrm{q} + \mathrm{g}(\mathrm{Rs} - 1)]\rule{4.5cm}{0.4pt}(4)$$

When shaping is used, $g > 0$ and $Rs < 1$, which implies that for a fixed R, the rate of the LDPC code Rc with shaping must be higher than the rate of the LDPC code when shaping is not used.

3.2 LDPC Encoder

The LDPC encoder takes information from the DVB-S2 system. In this paper, syntax of Mat lab is used. The syntax is H=dvbs2ldpc(r) returns the parity-check matrix of the LDPC code with code rate r from the DVB-S.2 standard. Possible values for r are 1/4, 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9, and 9/10. The block length of the code is 64800. LDPC encoder constructs a binary symmetric LDPC code with a parity check matrix H.H must be a sparse zero-one matrix. N and N-K are the number of columns and rows in H. The last N-K columns in H must be an invertible matrix in GF(2).

An LDPC encoder function in Mat lab has the following properties. Only Parity Check Matrix is writable. All other properties are derived from it.

- ParityCheckMatrix – H, stored as a sparse logical matrix.
- Block length – N, total number of bits in a codeword.
- NumInfoBits – K, number of information bits in codeword.
- NumParityBits – N-K, number of parity bits in a codeword

3.3 Bit Interleave

An interleaver permutes symbols according to a mapping. A corresponding deinterleaver uses the inverse mapping to restore the original sequence of symbols. Interleaving and deinterleaving can be useful for reducing errors caused by burst errors in a communication system.

3.4 Bit Separator

This block just separates the interleaved output into two sets. One set goes to shaping encoder and other set goes directly to bit combiner.

3.5 Shaping Encoder

The idea behind constellation shaping [6] is that signals with large norm are used less frequently than signals with small norm, thus improving the overall gain by adding shaping gain to their original coding gain. The non-uniform signaling reduces the entropy of the transmitter output, and hence, the average bit rate. However, if points with small energy are chosen more often than points with large one, energy savings may compensate for this loss in bit rate. Theoretically, constellation points would be selected according to a continuous Gaussian distribution at every dimension, and thus achieve the maximum shaping gain. Here in my paper two shaping strategies are considered. They are 16 APSK shaping and 32 APSK shaping.

3.6 16 symbol APSK shaping

Consider the 16-APSK constellation, which uses two rings. The inner ring contains 4 symbols, while the outer ring contains 12 symbols, thus making a total of 16 symbols. The bit mapping is as indicated on the figure. This constellation is identical to the 16-APSK constellation in the DVB-S2 standard. The ratio of the radius of the outer ring to the radius of the inner ring is denoted γ which according to the DVB-S2 standard may assume a value from the set [2.57, 2.60, 2.70, 2.75, 2.85, 3.15].

3.7 32 symbol APSK shaping

Consider the 32-APSK constellation, which consists of three concentric rings, with 4 symbols in the inner ring, 12 symbols in the middle ring, and 16 symbols in the outer ring. This constellation is identical to the 32-APSK constellation in the DVB-S2 standard. The ratio of the radius of the middle ring to the radius of the inner ring is denoted γ_1, while the ratio of the radius of the outer ring to the radius of the inner ring is denoted γ_2. According to the standard, the value of γ = { γ_1, γ_2} must be one of the following: {2.53, 4.30}, {2.54, 4.33}, {2.64, 4.64}, {2.72, 4.87}, or {2.84, 5.27}.

3.8 APSK modulator

Amplitude and phase-shift keying or asymmetric phase-shift keying (APSK), is a digital modulation scheme that conveys data by changing, or modulating, both the amplitude and the phase of a reference signal (the carrier wave). In other words, it combines both Amplitude-shift keying (ASK) and Phase-shift keying (PSK) to increase the symbol-set. It can be considered as a superclass of Quadrature amplitude modulation (QAM). The advantage over conventional QAM, for example 16-QAM, is lower number of possible amplitude levels, resulting in fewer problems with non-linear amplifiers.

The DVB-S2 specification permits the use of 16APSK and 32APSK modes, allowing 16 and 32 different symbols respectively and are intended for mainly professional, semi-linear applications.

The APSK modulator accepts the bit combiner output which consists of shaped and unshaped symbols and modulates it.

3.9 Receiver section

The receiver section is shown in fig 2. The received signal goes to an adaptive equalizer. The adaptive equalizers purpose is to reduce inter symbol interference to allow recovery of the transmit symbols. It is typically a linear equalizer or a DFE. It updates the equalizer parameters as it processes the data. Typically, it uses the MSE function, it assumes that it makes the correct symbol decisions, and uses its estimate of the symbol to compute the error signal e.

The signal from the adaptive equalizer goes to an APSK demodulator and the output signal is passed through a serial to parallel converter and the output will be split into two sets. One set passes through a de-interleave and then to a shaping decoder and its output to a parallel to serial converter. At the same time, other set of signal directly goes to the parallel to serial converter. The output from this converter is again de-interleaved and then it goes to LDPC decoder.

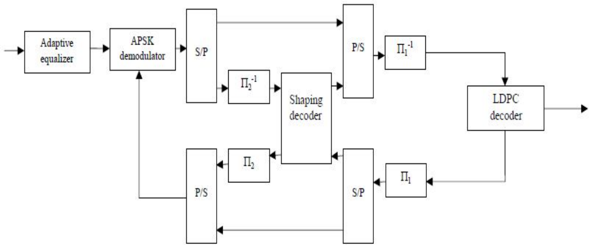

Fig 2: Receiver section

The LDPC decoder consists of a variable-node decoder (VND), an edge interleave, and a check-node decoder (CND). The LDPC decoded output is then bit interleaved and passed through serial to parallel converter. The converted output is split into two sets. One set goes to shaping decoder then to a bit interleave and then to parallel to serial converter, while the other set directly goes to this converter. Then its output goes to an APSK demodulator. Its output is feedback to the APSK demodulator. This is the iterative process between decoding and demodulator and this repeats for 50 times.

3.10BICM-ID

BICM is the serial concatenation of a channel coder, interleave and mapped and is used in most recent wireless standards due to its simplicity, flexibility and performance. At the receiver, the signal is consecutively demapped, de - interleaved and decoded. The performance of this standard BICM receiver can be greatly improved through iterative information exchange between the demapper and the decoder. BICM can be obtained by using a bit inter leaver, π, between an encoder for a binary code and a memory less modulator. In an iterating process, the feedback from the section which is less affected by the channel noise removes the ambiguity in the higher-order demodulation and enhances the decoding of the weak data sections. Iterative decoding of BICM not only increases the inter subset Euclidean distance, but also reduces the number of nearest neighbors. This leads to a significant improvement over both AWGN and fading channels.

The interleave is critical to the high performance of BICM-ID systems. The key idea in the design of a good interleave for a BICM-ID [7] system is to make the interleaved coded bits in the same channel symbol as far apart as possible. Two design objectives of a good interleave are as follows:

- To increase the minimum Euclidean distance between any two coded sequences.
- To mitigate the error propagation during the iterative decoding.

A small block size might cause substantial performance degradation to BICM-ID. It should be noted that increasing the block length leads to earlier convergence, in terms of both the SNR and the number of iterations. The reason for this is the reduction in the number of nearest neighbor code words when the interleave size is increased. However, increasing the interleave size does not improve the performance of BICM-ID systems after a certain high SNR level.
Here at the receiver side, the APSK demodulator, shaping decoder, LDPC decoder, bit de-interleaves does the reverse operations of their counterparts at the transmitter section.

IV. SIMULATION RESULTS OF CONSTELLATION SHAPING

Stimulation results of constellation shaped 16 APSK and 32 APSK had been shown here. Depending on the signal to noise ratio (SNR) given the symbols in the constellation plot varies. If small SNR values are given the symbols appears as clusters. When snr value increases, the symbols in the plot becomes distinct. Figure 3 shows the 16 symbol APSK shaping plot for SNR=25.

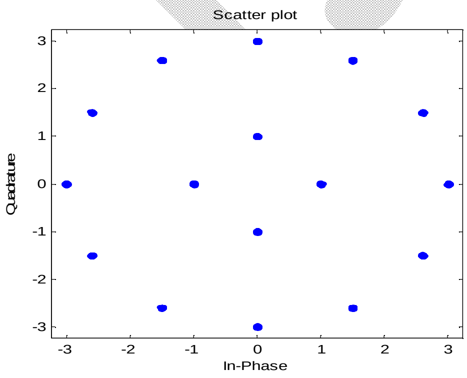

Fig 3: 16 APSK shaping

Fig 4 shows the 32 symbol APSK shaping plot for SNR=25.

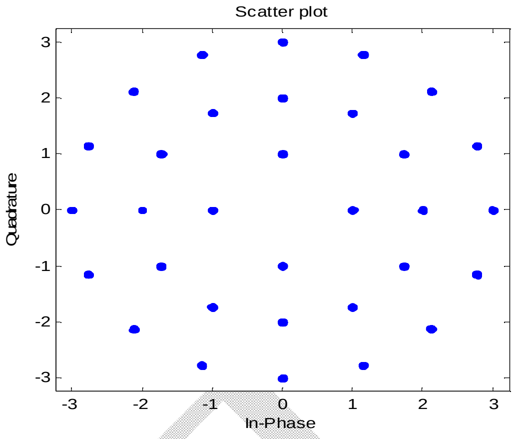

Fig 4: 32 APSK shaping

V. CONCLUSION

The main objective of the paper is to shape the APSK constellation diagram and to remove the inter symbol interference in the signal. This system can be used in DVB-S2 systems. The LDPC codes from DVB-S2 system is used here. Using LDPC encoder, bit interleaves, shaping encoder and APSK modulator the constellation shaping can be attained. At the receiver side, APSK demodulation, shaping decoding, LDPC decoding is done. The principle used here is BICM-ID and because of this iterative decoding the performance of this system can be improved over the BICM where the iterative process is not used. The use of an adaptive equalizer adds additional gain to this system. With the constellation shaping, BICM-ID, and use of adaptive equalizer a gain of 1.18 db can be achieved.

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