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A REVIEW ON NON-COHERENT DETECTION AND MULTILEVEL BLOCK CODING TECHNIQUE

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ABSTRACT

This paper reviews the multilevel block coding techniques for M-ary phase-shift keying (MPSK) schemes with non-coherent detection. A class of block codes called multilevel block codes is described. The analysis is performed for describing these codes along with a method for constructing such codes for non-coherent detection. It shows that such encoding scheme may be viewed as a specificcode from a particular class of codes in which coding gain is achieved at the expense of signal constellation expansion without expanding bandwidth. Finally, different encoding / decoding techniques based on a modification of information set decoding are presented.

Keywords: *Channel coding, modulation, non-coherent detection.*

1. INTRODUCTION

In the recent past an increased interest towards non-coherent detection schemes with improved performance over systems employing differentially coherent detection has been observed. The main advantages of these detection techniques is that theydo not require carrier phase tracking, while costs only fractional SNR degradation with respect to coherent detection. It seems that these robust detection schemes could be very useful for wireless communications especially over channels where carrier phase tracking is difficult to achieve. In this paper, the problems of channel coding for MPSK modulation with such non- coherent detection techniques are reviewed. The problem of error control with modulation and coherent detection has been already studied extensively in the last decades. The same problem with non- coherent detection has although received a little attention comparatively. This paper also addresses the problem of block-coded modulation for the receivers employing non- coherent detection technique.

2. NON-COHERENT BLOCK DETECTION TECHNIQUE

The paper presents the non- coherent block detection technique for MPSK from the coding view point and the types of the maximum- likelihood (ML) decoder with their performance are presented. In addition, the distance measure technique suitable for non- coherent block detection is also presented, as it will be the main criterion used in the design and comparison of codes.

Next sections presents a mathematical framework for multilevel block codes, which are well suited for MPSK modulation and outlines a systematic technique for building these codes for non- coherent block detection. It is also shown that encoding may be cast into a simple code which can significantly improve performance over a differentially coherent system when the detection is performed on a block basis. Results from computer searches for more powerful codes which achieve significant coding gain over un- coded coherent MPSK systems are presented.

2.1 Non-coherent Detection

Let us consider the transmission of codewords of length N from a code C that are vectors in the ring of integers modulo M, namely Z_M. A codeword will be expressed in the following form:

$$c_i = \left(c_{i0}, c_{i1} \ldots \ldots \ldots .. c_{i(N-1)}\right), c_{ij} \in Z_m$$

We will assume that these vectors are transmitted over an AWGN (additive white Gaussian noise) channel using MPSK modulation via the following mapping between Z_M and the signal points in the complex plane:

$$F_{MPSK}(\alpha) = \exp\left[j\left(\frac{2\pi}{M}\right)\alpha\right], \alpha \in Z_M \ldots \ldots \ldots ..(1)$$

If, in the receiver, we use the duration of an entire codeword as the observation interval, the baseband equivalent received signal $\hat{r}(t)$ whenc_i was transmitted is given by

$$\hat{r}(t) = \sum_{l=0}^{N-1} e^{j} \ \exp\left[j\left(\frac{2\pi}{M}\right)\right] q(t - lT] + \hat{n}(t), 0 < t \leq nT \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .(2)$$

where is the uniformly distributed random phase induced by the channel, $\hat{n}(t)$ is a complex white Gaussian process with zero mean and power spectral density N_0, and $q(t)$ is given by

$$q(t) = \begin{cases} 1, 0 \leq t \leq T \\ 0, otherwise \end{cases} \ldots \ldots \ldots \ldots (3)$$

The optimum decoder must choose the set of phases that correspond to the most likely transmitted code word. By considering the correlations between the shaping wave-form $q(t)$ and the baseband equivalent received signal$\hat{r}(t)$, we have for l$t \leq t \leq (l+1)t$

$$y_l = \int_{lT}^{(l+1)T} \hat{r}(t)dt = Te^{j} \ f_{il} + n_l \ldots\ldots(4)$$

Where is the baseband equivalent of the l^{th} MPSK symbol given by $f_{il} = exp\left[j\left(\frac{2\pi}{M}\right)c_{il}\right]$and n_l, is a complex Gaussian random variable with mean zero and variance N_0. Let us form the vector $y = (y_1, y_2, \ldots. y_N)$ associated with the received signal, and express it as

$$y = Te^{j} \ f_i + n$$

Where $f_i = (f_{i0}, \ldots f_{i(N-l)} \ and \ n = (n_0 \ldots n_{i(N+1)})$. It can be shown that the ML decoder for this scheme chooses the modulated codeword vectorf_m, which satisfies

$$\max_{m=0,1\ldots,|C|-1} |f_m y^*|$$

Where$|C|$the cardinality of the set of code iswords C, and $|f_m y^*|$is the complex inner product between$f_m, and \ y$. We have, therefore, that the decision variables in (6) are given by

$$U_m = |f_m y^*| = TNe^{-j}_{\rho_{mi}} + N_m$$

Where p_{mi}, is the normalized inner product or complex correlation between the$m^{th} \ and \ i^{th}$ codewords given by

$$\rho_{mi} = \frac{1}{N} f_m f_i^* = \left(\frac{1}{N}\right) \sum_{k=1}^{N} \exp\left[j\left(\frac{2\pi}{M}(c_{mk} - c_{ik})\right)\right] \ldots(8)$$

and N_m, is a complex Gaussian random variable with mean zero and variance $\sigma^2 = NN_0$given by $N_m = f_m, n^*$. The pair wise error probability $P(c_i \to c_m)$, where $c_i \to c_m$, denotes the event of deciding on c_m when $c_i$was transmitted, is shown in [7] to be

$$P(c_i \to c_m) = Q(a,b) - \frac{1}{2} e^{-\frac{a^2+b^2}{2}} I_0(ab) \ldots\ldots(9)$$

Where

$$a = \sqrt{N\frac{\gamma}{2}\left(1 - \sqrt{1 - |\rho_{mi}|^2}\right)}, \ b = \sqrt{N\frac{\gamma}{2}\left(1 - \sqrt{1 - |\rho_{mi}|^2}\right)},$$

γ is the signal-to-noise ratio (SNR) per coded symbol, $Q(a,b)$ is the Marcum Q-function, and $I_o(.)$ is the modified Bessel function of order zero. A simple asymptotic approximation to (9) is given in [3] (see [l] for a similar expression):

$$P(c_i \to c_m) \approx \left[\frac{1 + |\rho_{mi}|}{2|\rho_{mi}|}\right]^2 Q\left[\sqrt{N\gamma\left(1 - \sqrt{1 - |\rho_{mi}|}\right)}\right] \ldots\ldots(10)$$

This approximation is useful mostly for conceptual purposes since it allows us to define a distance measure that characterizes the asymptotic performance of a given code. The distance measure will be termed the non-coherent distance between two arbitrary code words $c_i, and \ c_j$, is given by

$$d_{NC}^2(i,j) = N(1 - |\rho_{mi}|) \ldots\ldots\ldots\ldots.(11)$$

Using (11) on (10)

$$P(c_i \to c_m) \approx \left[\frac{N - d_{NC}^2(i,m)/2}{N - d_{NC}^2(i,m)}\right]^{1/2} Q\left[\sqrt{\gamma d_{NC}^2(i,m)}\right] \ldots\ldots(12)$$

The performance measure for a coded system is therefore determined by the minimum $d_{NC}^2(i,j)$ over all pairs of codewords $c_i, and \ c_j$, in C. An important feature concerning d_{NC}^2 is that it is not an additive distance measure, unlike Euclidean distance. A decoder, therefore, cannot use a Viterbi- like decoding algorithm with this distance measure.

3. MULTILEVEL BLOCK CODES

This section introduces new block coded M-PSK modulations with unequal error protection (UEP) capabilities.

Let S represent a uniform unit-energy 8-PSK signal set (see Figure 1), natural labeling (i.e., standard mapping by set partitioning) of set S is considered. That is, a label $l_k = b_1 + 2b_2 + 4b_3$ represents the signal point $e(\frac{jk\pi}{4})$, for $0 < k < 8$, where $j = \sqrt{-1}$, and$b_i \in \{0,1\}, 1 \le i \le$ 3.In multilevel

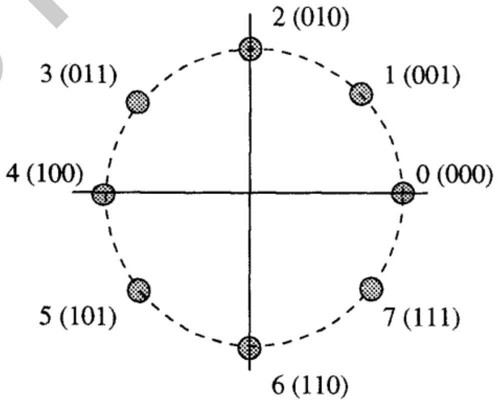

Figure 1: An 8-PSK signal constellation with naturalLabeling

Block coded modulation[l], code words of three linear codes of length n, dimension k_i and minimum distance d_i, denoted C_i, are used to select label bits b_i, for $1 \le i \le$ 3.These to resulting sequences of 8- PSK signals is said to be a block modulation code A of length n and rate (or bandwidth efficiency) $R = (k_1 + k_2 + k_3)/n \ bits/symbol$.

Throughout the paper binary LUEP (linear unequal error protection) codes are used. For simplicity, only LUEP codes with two levels of error protection are considered. A two level (n,k) LUEP code is a linear code that it is not spanned by its set of minimum weight vectors [8]. We use $UEP(n,k)$ to denote such a code and refer to its unequal error protection capabilities as follows: separation vector $\bar{s} = (s_1, s_2)$ for the message space $\{0,1\}^{k(1)} * \{0,1\}^{k(2)}$, where $k = k^{(1)} + k^{(2)}$ This is to say that code words in correspondence to information bits are at a Hamming distance at least $s_i, i = 1,2$. Without loss of generality, we assume that $s_1 \geq s_2$. Then k_2 is equal to the dimension of the span of the minimum weight code words of $UEP(n, k)$. In other words, an information vector of length k bits can be separated into a most significant part of length $k^{(1)}$ bits (the MSB) and a least significant part of length $k^{(2)}$bits (the LSB).

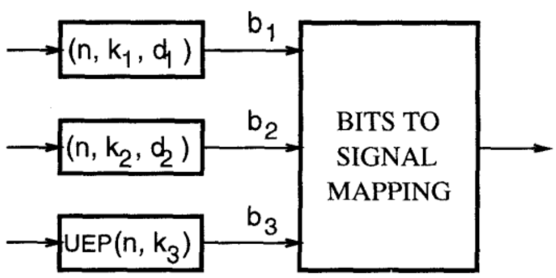

Figure 2: An encoder for the multilevel modulation codes for UEP.

Figure 2 shows the block diagram of an encoder for the multilevel modulation codes. Conventional (n, k_1, d_1) and (n, k_2, d_2) linear block codes C_1 *and* C_2 are selected to ensure that the minimum symbol distance.

$$\delta_H \triangleq \min\{d_1, d_2, d_3\}$$

Will occur at the second or third encoding levels, so that the minimum product distance

$$\Delta_p^2 \triangleq (\delta_k)^{d_k}, k = \min\{i, \delta_H = d_i\},$$

Will be greater than 2, where $\delta_1 = 0.586, \delta_2 = 2$ *and* $\delta_3 = 4$. Details on these and other design considerations can be found in [7] and [9].

3.1 Distance Calculation

This section finds out the minimum non- coherent distance on the basis of appropriate ratio of inner and outer radius, (ignoring the number of nearest-neighbor).

In Fig.3 if the ratio of inner and outer radius b/ais1, the Euclidian distance of C_b denoted by L_2, is larger than that of $C_a$denoted by L_1. If the ratio b/a is increased from 1, the value of L_1 is increased but the value of L_2 is decreased. When the values of L_1 *and* L_2 are equal, the coherent appropriate ratio of b/a is found, which is 1.93.

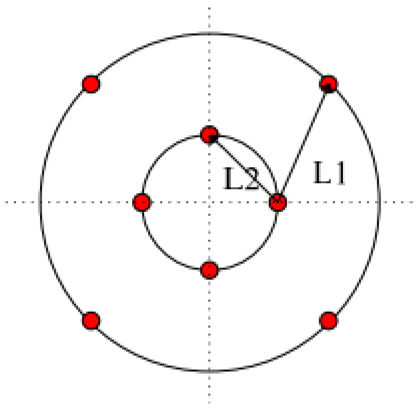

Figure 3: Non-Coherent Distance Calculation for QAM

The minimum squared non-coherent distance of NBC-8QAM is

$$d_{nc,8QAM}^2 = \min\{d_{nc,a}^2, d_{nc,b}^2, d_{nc,c}^2$$

$$d_{nc,a}^2 = \frac{1}{2}\left\{Na^2 - \sqrt{\left(\frac{Na^2}{(N-1)a^2+b^2}\right)\left[\left((N-1)a^2 + \frac{\sqrt{2}ab}{2}\right)^2 + \frac{a^2b^2}{2}\right]}\right\}$$

$$d_{ac,b}^2 = \frac{1}{2}\left[Na^2 - a^2\sqrt{N^2 - 2N + 2}\right], and\ d_{nc,c}^2 = a^2$$

The values of a *and* b are related by $Pa^2 + (1-P)b^2 = 1$ where P denotes the probability of the use of low-energy symbol. The values of a *and* b are decided by. The resulting ratio $\frac{b}{a}$is called theoretical ratio.

4. CONCLUSION

In this work, the problem of channel coding for the non-coherent decoding is addressed. We have attempted to generalize non-coherent block detection of MPSK as a coding problem, and to present codes which not only close the performance gap between coherent and non-coherent detection, but also achieve significant coding gain over un-coded coherent MPSK. Using a coding approach, are view of non-coherent block detection of MPSK was presented. For the design of good codes, a distance measure for non- coherent block detection was presented. We then described a class of block codes called multilevel block codes for UEP. These codes have a rich algebraic structure, as they are based on elements of module theory and in many ways resemble traditional linear block codes.

It has been shown that the use of a binary LUEP code as component code in the multilevel construction produces enhanced UEP Capabilities and increased error performance, at a modest reduction in bandwidth efficiency and a relatively small increase in decoding complexity. The codes constructions offer a good trade-off between bandwidth efficiency, error performance and decoding complexity, which would otherwise be impossible to achieve using conventional linear block codes. Although in this paper the use of a binary LUEP as a component code in the multilevel construction is considered, it is possible to use two binary LUEP codes as component codes in the second and third encoding stages, if bandwidth efficiency and decoding complexity constraints allow it.

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