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Research Article

Parameters Optimization of the Multithreshold Decoders for Non binary Error Correcting Codes[#]

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Abstract: Efficiency of symbolic multithreshold decoders (*q*MTD) for non-binary self-orthogonal codes in *q*-ary symmetric channel with alphabet size q are analyzed. It has been shown the bit error rate performance of *q*MTD depends on many discrete variables. A new optimization algorithm for minimization of the decoding function on the alternating variable descent method base is proposed. Simulation results shown new optimized scheme can offers better performance.

1. Introduction

Now some specialists take an active interest in non binary codes operating with information at symbolic level, for example data with byte structure. Non binary (symbolic) codes are applied in channels with grouped errors and as constituent elements of various cascade codes [1]. Not binary codes are used to information protection on different storage devices (CD, the DVD, Blu-ray, etc.) and in data storage systems [2], including perspective holographic storages of data [3].
Computing complexity of decoding of the majority of non binary codes depends on the size q of the alphabet of used symbols [1]. In real transfer and storage systems the codes working with symbols no more than one byte in size ($q \leq 256$) meet only. Special attention among non binary algorithms to correct errors should be given to non binary self-orthogonal codes and special high-speed non-binary multithreshold decoders (qMTD) corresponding to them [4, 5], being the development of binary multithreshold decoders (MTD). Research results given in [4, 5] show that qMTD greatly exceed in other decoder efficiency for non binary codes being used in practice remaining as simple to be implemented. It is also very important not to use multiplication in non-binary fields during encoding and decoding as well as total independence of symbolic codes lengths from the size of applied symbols. That's the reason why such codes will find broad application in the sphere of processing, storage and transmission of large volumes of audio, video and other types of data.
This paper presents the results of improving the work efficiency of symbolic multithreshold decoder based on the problem of decoding function optimization. The possibility of simultaneous parameters variation of the encodes and the decoders creates additional conditions for further improving of the decoders' performance. It is shown that an automated computer search of parameters, which was optimized according to the criteria of decoder's error probability, at the stage of its design noticeably improves the characteristics of qMTD without significant increasing of the amount of calculation.

2 Proposed method

2.1 Operating principles of the multithreshold decoding procedure

The description of the qMTD operating principles is given for q-ary symmetric channel (qSC) having alphabet size q, q > 2, and symbol error probability p0.
Let it be further a linear non-binary code, which check matrix H consists of zeroes and ones. This matrix corresponds to self-orthogonal code (qSOC).
The example of a scheme realizing the operation of encoding by block qSOC, given by generator polynomial poly(x)=1+x+x4+x6, is given on Figure 1.

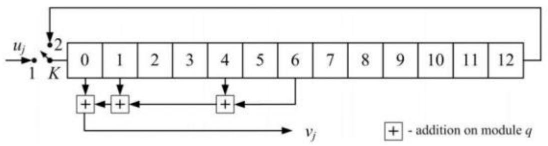

Figure 1. *Encoder block qSOC with R = 1/2 and k = 13.*

Let's assume that encoder has performed encoding of information vector U and received code vector A = [U, V], where the check vector V= U·G. When code vector A having the length n with k information symbols on qSC is transmitted decoder is entered with vector Q, having differences from original code vector due to errors in the channel: Q=A + E, where E – error vector of qSC channel type.
Operating algorithm of qMTD during vector Q decoding is the following [5]
1. Syndrome vector is calculated S = H·Qt . Difference register D is reset. This register will contain data symbols changed by decoder. Note that the number of nonzero elements of D and S vectors will always determine the distance between message Q received froam the channel and code word being the current solution of qMTD. The task of decoder is to find such code word which demands minimal number of nonzero elements of D and S vectors.
2. For arbitrarily chosen decoded q-ary data symbol ij of the received message let's count the number of two most frequent values of checks sj of syndrome vector S from total number of all checks relating to symbol ij, and symbol dj of D vector, corresponding to ij symbol. Let the values of these two checks be equal to h0 and h1, and their number be equal to m0 and m1 correspondingly when m0 ≥ m1.
3. If m0–m1>t, where t – a value of a threshold (some integer number), then from ij, dj and all checks regarding ij error estimation equal to h0 is subtracted. This step change of decoded symbol and correction via feedback of all syndrome symbols being the checks for decoded symbol.
4. The choice of new im, m ≠ j is made, next step is clause 2.

The example of qMTD implementation for encoder from Figure 1 is given on Figure 2.

2.2 Algorithm of decoding function minimization
Analysis of *q*MTD operating principles shows that its effectiveness (as a symbol decoding error probability) depends on many parameters:

$$P_s = f\,(T, w, poly, p_0) \qquad (1)$$

where T – a vector of thresholds at the different iterations I, $T = \{t^1, t^2, ..., t^I\}$; w – a vector of weighting coefficients for d_j, elements of difference register D at the different iterations I, $w = \{w^1, w^2, ..., w^I\}$; *poly* – a generator polynomial; p_0 – the noise in the communication channels.
Let's try to estimate the number of different combinations of the decoder's parameters. Experimentally it has been found that the elements of the t vector can accept $t_n = 5$of different values, and the elements of the w vector can accept $w_n = 4$ values.

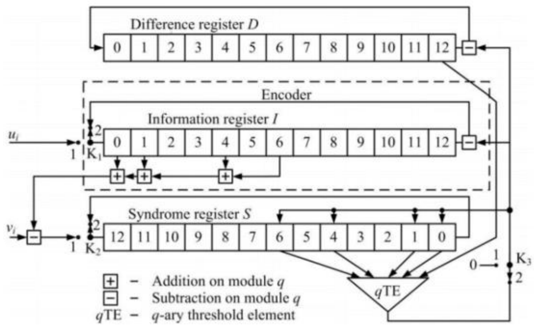

***Figure 2**. qMTD for block qSOC.*

Accordingly, the number of combinations of different values of the decoder's parameters approximately equal $t^I_n w^I_n$, where I is the number of decoding iterations (parameter I usually takes values from 10 to 30 depending on the noise level). Total number of choices of parameters' values can be up to 20^{30}, and even more in some cases. Consequently, it is required to work out algorithms of minimization of decoding functions, which allows significant reducing in the number of searched options.
Another feature of the problem of the optimization is that the objective function $f\,(T, w, poly, p_0)$ is not given analytically. Its value in large noise can be assessed only by means of computer simulation, which takes a lot of time. It additionally complicates the process of optimization.
Proposed algorithm of decoding function minimization.
Step 1.Initial set of decoder parameters. The initial values of weight vector's elements is a unit vector, and threshold vector - zero vector

Step 2. Optimization by iterations. The process of finding the optimal parameters of *q*MTD can be performed independently for each iteration. The total number of searched for variants of the parameters of this approach is reduced to $I*t_n*w_n$.
Step 3. Optimization of the decoder as a whole. Decision from the previous step can be further improved by modifying weights and thresholds values on ± 1 at each decoding iteration and by controlling of the decoding error probability at the last iteration output. This process can be repeated as long as the decision decoder ceases to improve. The total number of searched is no more $9*I*K$ (where K - the number of optimization loops, usually does not exceed several tens).

3 Results and discussion

Let's estimate the effect of applying of the optimization of the decoder parameters. Dependencies of symbol error rate P_s after decoding from symbol error P_0 probability in qSC for codes with code rate R=1/2 code distance d=11 and code length n=20,000 symbols are given in Fig. 3. In Fig. 3 the curve 1 shows the characteristics for MTD with the initial parameters (step 1), curve 2 - characteristics for MTD with parameters after optimization of parameters separately for each of the iterations (step 2), and curve 3 characteristics for MTD with parameters after optimization as a whole (step 3). The dashed line in the figure is an assessment of the probability of an error of the optimum decoder for the used code.
Note that the optimization for iteration and optimization in general allow obtaining slightly better characteristics. And this gain is obtained not as a result of complication of the algorithm (the decoder stays as simple), but only because of the better choice of parameters of the decoder at the stage of its development.

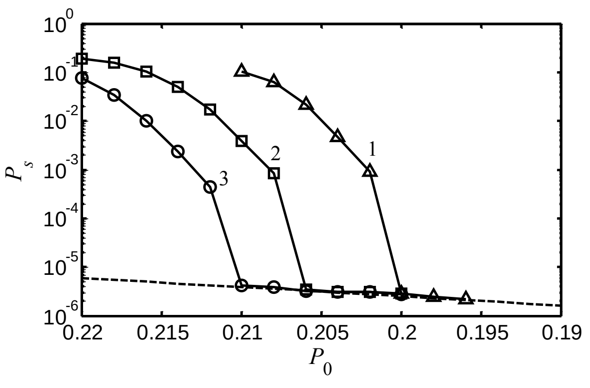

Figure 3. *Effect of the optimization decoder's parameters*

4 Conclusions

In the paper the abilities of symbolic multithreshold decoders (*q*MTD) for block self-orthogonal codes in *q*-ary symmetric channel (*q*SC) with alphabet size q are considered. It has been shown that *q*MTD efficiency depends on a variety of parameters. It has been proposed to use the optimization procedures used to minimize the decoding function of based on the alternating-variable descent method. The simulation results has shown that optimization (by iterations and by integrally optimization) can increase the overall coding gain compared with non-optimized version of the non-binary multithreshold decoder.
Note that *q*MTD implementation complexity does not depend on alphabet size which enables to produce decoders of multithreshold type efficiently correcting errors even in multibyte symbols for which development of other decoders is very difficult. Thus *q*MTD can replace Reed-Solomon codes in different data transmission and data storage systems.

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