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MULTITHRESHOLD DECODERS FOR COMMUNICATION CHANNELS WITH VERY HIGH NOISE LEVEL

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Abstract. It's considered a multithreshold decoders provided almost optimal decoding of self-orthogonal error-correcting codes with linear complexity in wide range of code rates and signal-to-noise ratios. It's discussed a using of this decoder in concatenated coding schemes. It's described a hardware implementation of a multithreshold decoder on PLIS Xilinx.

Introduction. One of the major problems at development of high-speed communication systems is the correct choice of methods of error-correcting coding. Use of error-correcting codes allows to get a coding gain each decibel of witch more than 20 years ago was estimated in millions dollars in mesoscale systems. Now cost of a coding gain has repeatedly increased, as it allows to reduce the sizes of very expensive antennas, to raise range of communication, to increase speed of a data transfer.

In the coding theory some methods for coding and decoding which allow to work near of channel capacity are known. The review of the most perspective methods of coding by criterion "efficiency - productivity" has been made in [1] where it was specified, that the greatest preference in high-speed communication channels multithreshold decoders (MTD) [2, 3, 4] deserve. The given decoders, being further developing of a threshold decoder (TD), allow to decode even very long codes with linear from length of a code complexity of realization.

The multithreshold decoder. The diagram for MTD with two decoding iterations of convolutional self-orthogonal code (SOC) with code rate R=1/2, code distance d=5, length of code restriction n_A=14 is shown in fig 1. If necessary uses of the greater number of iterations all subsequent iterations are completely similar to the second.

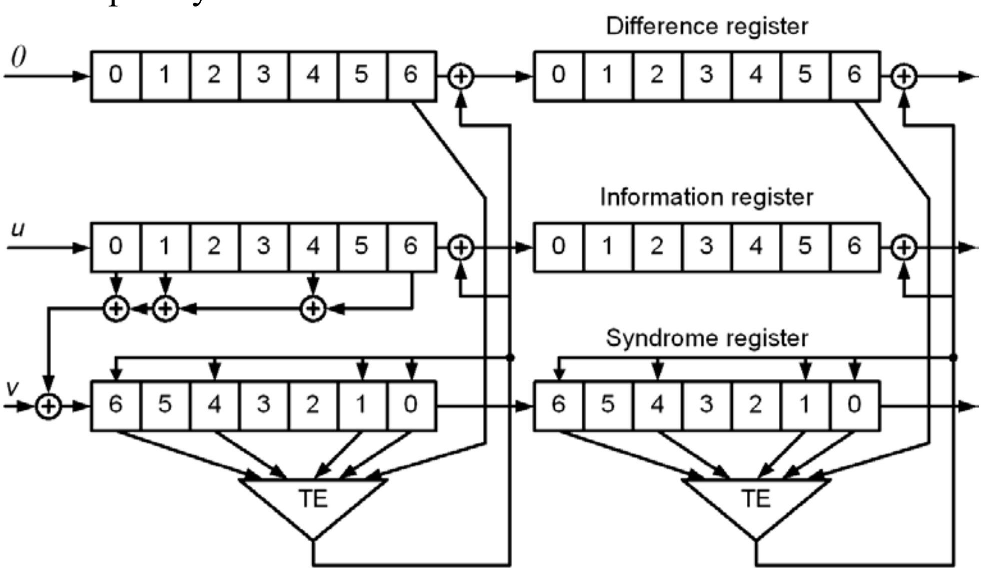

Figure 1

Apparently from the submitted diagram, each iteration of the MTD differs from a usual TD only presence of the difference register in which changed by a threshold element (TE) information symbols are marked. It is essential, that decisions of the TE from the difference register then are used by other TE on the following decoding iteration.

Bit error performance of the MTD over a channel with additive white Gaussian noise (AWGN) and binary phase-shift keying (BPSK) is shown in fig. 2. Here SOCs with code rate *R*=1/2 and code distance *d*=9 were used. These codes were selected according to criterion of minimization of error propagation (EP) effect [9]. We shall note, that in this case with the help of the MTD the decision of the optimum decoder is practically achieved. We shall notice, that such results are unattainable at use of practically sold optimum Viterbi decoder (its characteristics also are submitted on fig. 2 by curves "VA R=1/2" and "VA R=1/3") because of its complexity is growth exponentially with constructive length of a used code. In the given figure characteristics PLIS of the MTD for a convolutional code, developed by leading experts in the field of error correcting coding [4] also are submitted (curve "MTD PLIS").

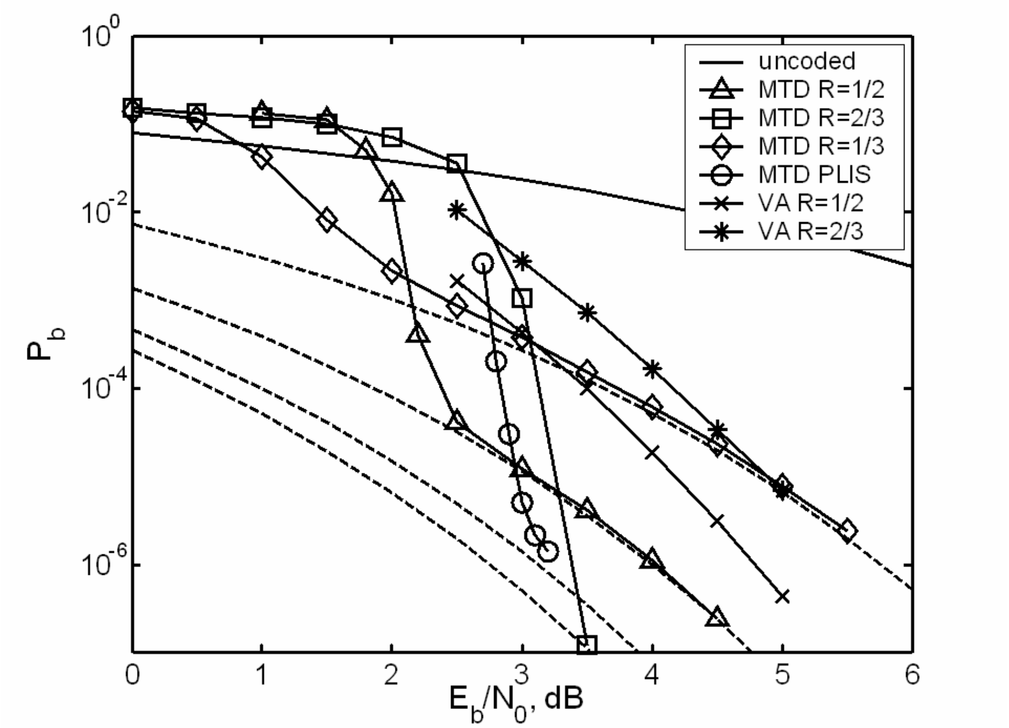

Figure 2

Except for the described opportunities, the MTD is capable to provide high characteristics in channels with erasures and in systems with high-level modulation that makes MTD universal remedy of simple achievement of a high level of noise immunity of messages in systems of a wide spectrum of application.

Complexity of implementation. Further we shall consider questions of complexity of the MTD. Analyzing the schemes of the MTD submitted on fig. 1, it is possible to notice, that in case of software implementation of the MTD for decoding of one information bit it is necessary to execute approximately $N_{MTD}\approx (I+1)\ (d+2)$ additive equivalent operations. In given expression I – number of decoding iterations, d – code distance of a used code. We shall notice, that in most cases at insignificant loss in efficiency (about 0,1 dB) it is possible to lower the number of operations to $N_{MTD}\approx 4d+3I$. It allows the MTD to be more than on the order faster than other decoding methods with comparable efficiency.

In case of hardware implementation of the MTD speed of its work V_{MTD} is determined only by speed of data movement under its registers. As a result the MTD at hardware implementation it appears on two and more orders faster [3, 5] than turbo codes with comparable efficiency.

By present time chipset MTD of a convolutional code on PLIS Spartan-II Xilinx is developed. This MTD is development of a series of decoders for convolutional codes on base MTD and can be considered as the representative of their fifth generation. In given PLIS was used a convolutional code with code distance d=11, code rate R=1/2 and length about 4000. On fig. 2 curve «MTD PLIS» are submitted results of an experimental research of this codec. In given PLIS all opportunities of algorithms of this class on multisequencing decoding operations at a hardware level completely are realized. Therefore productivity of the decoder is limited only to speed of data movement under its registers which concern to the fastest elements of circuitry PLIS. It also determines very much high efficiency MTD on PLIS which makes in the various realized variants of this decoder up to 480 Mbit/s and can be still essentially increased.

Concatenation codes based on the MTD. One more feature of the MTD is that its errors in area of almost optimum decoding appear basically single. It allows to use the MTD in structure of various concatenated codes even without use of additional interleaving. The special place among concatenated codes based on MTD occupies its cascading with parity check codes (PCC) [6] which use allows increasing efficiency of coding application significantly. Feature of this scheme consists that such cascading practically does not demand additional expenses for the equipment (in the circuit of coding it is required to add only one adder on the module 2) whereas use in a cascade code, for example, Reed-Solomon code is much more complex.

The bit error performance of the concatenated codes consisting of SOC with d=7, 9, 11, R=1/2 and PCC with code length 50 over an AWGN channel is shown in fig. 5. Apparently, and in this case the cascade code appears much better not cascade. It is necessary to note, that at reception of submitted curves parity check code it was used on several decoding iterations, thus as though "helping" to MTD at decoding internal SOC. Also we shall note, that considerably more complex concatenated code consisting of a Reed-Solomon code (255, 223, 33) and convolutional code with length of code restriction K=7 and code rate R=1/2 decoding with optimum Viterbi decoder, even at smaller code rate ($R\approx$0,437) concedes to the concatenated code based on MTD at $P_b\sim 10^{-6}$. We shall notice, that the considered way of concatenating allows to improve performance of MTD only in the field of its effective work. A curve «MTD(d=6) + PCC(n=20)» on fig. 3 shows the bit error performance of the concatenated scheme consisting from a convolutional code with R=1/2 and *d*=6 and the PCC with length 20 at use of 45 decoding iterations. We shall emphasize, that the given circuit of coding at very small complexity of realization is capable to work in 1,5 dB from channel capacity.

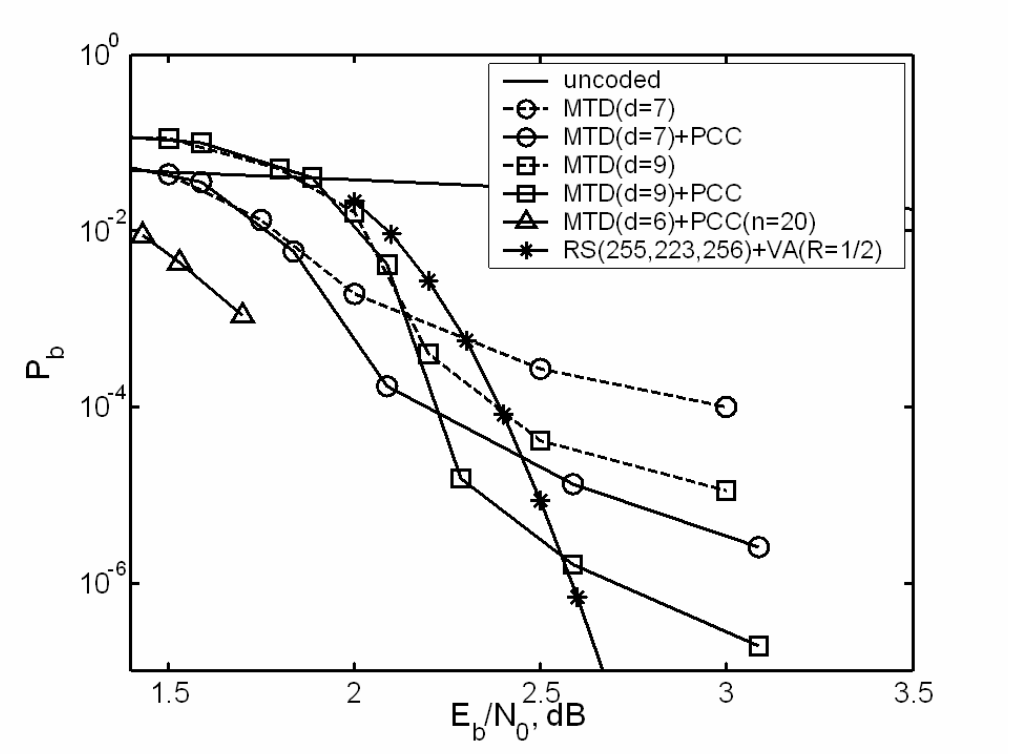

Figure 3

Among possible approaches to improvement of MTD's coding gain performance it is necessary to allocate its use in some concatenated codes, such as parallel codes [7], codes with non-uniform power and codes with the selected branches. Though separate use of each of the given approaches can increase coding gain only on 0,3..0,7 dB, joint application of these schemes allows to get significant better results.

The additional information on a multithreshold decoding can be received on the specialized website [8].

The conclusion. Huge advantage MTD before all other decoding methods on number of operations and an opportunity their full multisequencing at hardware implementation allow to count, that as a result of 30-years researches in Radio research & development institute the wide class of multithreshold algorithms which can be recognized as the basic method of coding for many modern high-speed communication systems with extremely possible levels of a coding gain and very high speed is developed. For today high bit error performance, except for the MTD, can provide only several methods. But the account of a complexity problem at comparable levels of the coding gain shows, that in this case algorithms on the basis of the MTD save affinity on complexity of implementation to the ordinary threshold decoder and consequently in most cases applications of coding are the most preferable methods of decoding in high-speed communication systems comprehensible at cost.

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