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TURBO CODES - INTRODUCTION AND APPLICATIONS

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Abstract: *The paper deals with the turbo codes and their development. The paper covers the description of the fundamentals of turbo codes and their design taking into account turbo codes with non-uniform constellations, multiple turbo codes. In addition, some chosen improvements and techniques of turbo codes are shortly described, such as improvement of turbo decoding using cross-entropy, decoding using linear programming, frame synchronization, weight distribution analysis for improved performance, design of two step deterministic interleaver etc. Moreover the application of turbo codes are mentioned, their application covers the deep-space communication, tactical communication, on optical links, turbo codes for 3G systems, for satellite communication.*

Key words: *3G systems; interleaver; linear programming; satellite communication; turbo codes*

1. INTRODUCTION

According to Sklar (Sklar, 2002), turbo codes were first introduced in 1993 by Berrou, Glavieux, and Thitimjshima achieving a bit-error probability of 10^{-5} using a rate ½ code over an additive white Gaussian noise channel and BPSK modulation at an E_b/N_0 of 0.7 dB. The codes are constructed by using two or mote component codes on different interleaved versions of the same information sequence. For a system with two component codes, the concept behind turbo decoding is to pass soft decisions from the output of one decoder to the input of the other decoder, and to iterate this process several times so as to produce more reliable decisions (Sklar, 2002). The generalization of the original turbo coding scheme to a multiple parallel concatenation of convolutional encoders is called a multiple turbo code (MTC) (Divsalar & Pollara, 1995). It is possible to design turbo codes that can achieve near-Shannon-limit performance where rate constituent codes are used in the encoder and they are designed by using primitive polynomials (Divsalar & Pollara, 1995).

There is always a space to improve the existing scheme of turbo codes or its parts, for instance the improvement of turbo decoding using cross-entropy. The turbo codes that achieve near-Shannon limit performance have been chosen for the third mobile communication standard (IMT-2000/3GPP). The usage of cross-entropy is based firstly to check the sign consistency between a-priori information and the extrinsic information, and then compute the associated number of sign differences between the extrinsic information, and then compute the associated number of sign differences between the extrinstic information sequence and the a-priori information sequence so as to normalize the output information of soft-in soft-out (SISO) turbo decoder (Lu et al., 2009).

The main idea of the paper is based on the fact that somebody might find it useful to have short introductory paper about turbo codes with respect to their applications mainly for educational purposes. Nice paper about the role of knowledge was written by Tekic et al. (Tekic et al., 2009).

2. APPLICATIONS OF TURBO CODES

There are many applications of turbo codes in practice, for instance in satellite communication, therefore let us mentioned some of them here.

Consider two different turbo-like codes, allowing analytical or semi-analytical tools for the prediction of the performance at very low BER values. These turbo codes are useful for satellite digital broadcasting services requiring quasi error free transmission. In satellite digital broadcasting services the Forward Error Correction code currently in use is a concatenated code with an inner convolutional-Viterbi coder/decoder and an outer Reed-Solomon (RS) code. This code is included, for instance, in the DVB-RCS standard, with interleaver depth 12. The main role of the convolutional code is to achieve barely acceptable performance with low SNR. Then the action of the Reed-Solomon code is to revert from this high BER to the almost "error free" performance required by the service, at the cost of a little extra SNR due to the increased redundancy. Since the appearance of turbo codes and their excellent behavior (at least at high-medium BER values), it has been thought of involving these codes in digital satellite communications (Ferrari & Bellini, 2001).

In symmetric turbo code system, both systematic and parity bits are allocated with equal power levels. This way of typical power allocation does not guarantee an optimal power allocation, which produces less optimum performance. Therefore, in order to overcome this problem, an unequal power allocation (UPA) scheme is used. Asymmetric turbo encoder for 3G systems performs well in both "water fall" and "error floor" regions (Ramasamy et al., 2009).

A practical multifunctional system comprising a turbo decoder, low complexity turbo equalizer and turbo synchronizer is developed to compensate for frequency-selective channels with fading. The combined synchronizer, equalizer and decoder are based on a turbo scheme where soft extrinsic information is exchanged between these processes and between iterations. The turbo codes are based on Partial Unit Memory Codes, which may be constructed with higher free distance than equivalent recursive systematic convolutional codes and can achieve better performance than the latter. The purely digital multifunctional receiver is targeted for end-applications such as combat-radio and radio-relay, providing robust communication at lowsignal-to-noise ratio with performance approaching the Shannon limit (Fagoonee & Honary, 2004).

A novel superforward error correction (SFEC) coding scheme, based on the block turbo code (BTC) of Bose–Chaudhuri–Hocguenghem (BCH) in high-speed long-haul dense wavelength division multiplexing (DWDM) optical communication systems is used This SFEC coding scheme is applicable in high-speed long-haul DWDM optical communication systems (Yuan & Ye, 2009).

Turbo Code is also used in optical OFDM multimode fiber communication system in order to decrease the bit error rate (BER) of the system. The performance of the optical OFDM system is significantly degraded if there are some carriers located at the deep nulls of the fiber. Although the number of such carriers is small, the bit error rate (BER) of the received signal for the whole optical OFDM multimode fiber system is high. In order to avoid the effect of deep nulls, the coding technique becomes especially important. Turbo Code is a promising technique which assisted in attaining a performance approaching the Shannon theoretical limits of channel coding for transmissions over Gaussian channels (Wei et al., 2008).

Turbo and LDPC codes offer near-capacity performance with iterative decoding at IEEE 802.16e Mobile WiMAX. IEEE 802.16 is a family of standards for Wireless MAN's. There are four codes specified in IEEE 802.16e, tailbiting convolutional code, block turbo code (BTC), convolutional turbo code (CTC) and low-density Parity-check (LDPC) code. A low-density parity check code is a code that may be represented by a sparse H matrix and it may be regular or irregular and i tis iteratively decoded using a message-passing decoder. Encoding of LDPC codes is not necessarily straightforward. For any LDPC code, it is possible to encode with an H matrix that permits back-substitution (Valenti, 2009).

Convolutional turbo codes are very flexible codes, easily adaptable to a large range of data block sizes and coding rates. This is the main reason for their being adopted in the DVB standard for Return Channel via Satellite (DVB-RCS). The DVB Committee approved a standard - known as DVB-RCS, for Return Channel via Satellite, or EN 301 790 in ETSI - to provide two-way, full-IP, asymmetric communications via satellite. One advantage that satellite offers is that the service can be deployed quickly, all over a large area, once a single “hub” infrastructure is in place. Another advantage is that service quality and the cost per subscriber is independent of the distance between the terminal and the access point. This standard specifies an air interface allowing a large number of small terminals to send “return” signals to a central gateway, also called a “hub” and at the same time receive IP data from that hub on the “forward” link in the usual DVB/MPEG2 broadcast format, thus leveraging the ubiquity of both DVB and IP technologies, while avoiding a return connection via terrestrial means (such as a dial-up telephone line). Since DVB-RCS applications involve the transmission of data using various block sizes and coding rates, the coding scheme has to be very flexible, with better performance than the classical concatenation of a convolutional code and a Reed-Solomon code (Douillard et al., 2000).

3. CONCLUSION

The main idea of the paper was based on the fact that somebody might find it useful to have short introductory paper about turbo codes with respect to their applications, mainly in education. The part of paper describing the applications of turbo code mentioned for instance the IEEE 802.16e Mobile WiMAX. Other known examples are for example the project Mars Reconnaissance Orbiter by NASA or MeidaFLO by Qualcomm, but turbo codes are mostly known from 3G mobile telephony standards.

Although turbo codes are quite young, their area of usage is wide nowadays. The author would appreciate to find more people who are interested in turbo codes in purpose to create the team which will design the extension of existing software tools in MATLAB.

Due to the fact the paper is de facto only a very brief introduction to the area of turbo codes, the future plans are following this research. Firstly, there should be created a software tool in MATLAB for verifying the behavior of selected multiple turbo codes. The role of interleaver will be studied. The author has experience with decentralization and supervisors in control and would like to implement them in the area of turbo codes and design of interleaver. First results seem to be interesting but several more experiments have to be done.

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