TURBO CODES FOR WIRELESS COMMUNICATIONS APPLICATIONS: SIMULATION AND ANALYSIS

Ing. Vishwas LAKKUNDI, Doctoral Degree Programme (2)
Dept. of Radio Electronics, FEEC, BUT
E-mail: vishwas@feec.vutbr.cz

Supervised by Dr. Miroslav Kasal

ABSTRACT

Error correction techniques play an important role in making wireless communications ever the more efficient and reliable. This paper discusses the scenario of turbo codes as applied to third generation wireless systems, and their propriety for AMSAT Phase 3-E satellite applications.

1 INTRODUCTION

Error control schemes are an integral part of every wireless communications system. Their efficiency is measured in terms of the degree of error correction they provide. Choosing an optimum scheme is a challenging task. The choice depends, among other factors, on the type of application and its design considerations.

Typical error control schemes used for continuous transmission include convolution codes, interleaving, concatenated convolution and block codes, and soft-decision decoding, whereas a combination of block coding and automatic repeat request (ARQ) is used for bursty data, and packet transmissions. Concatenated encoder/decoder schemes involving Reed-Solomon and convolutional codes are used in most of the satellite systems. Turbo codes are one of the most powerful and recent forward error correction (FEC) coding schemes. They are being considered extensively for deep space and next-generation mobile radio communications.

A brief general description of turbo codes is given in the following section. UMTS turbo codes are presented next. The subsequent section explores the possibility of applying turbo codes for a low data rate application in AMSAT Phase 3-E satellite system. Simulation results and their analysis are given thereafter. Finally, conclusions have been drawn.

2 TURBO CODES

The bit error probability (BEP) of turbo codes, which has been shown to be very close to the Shannon limit, is the main reason for their popularity. For a BEP of 10^{-5} and code rate of ½, the required E_b/N_o is 0.7 dB [2]. A general schematic of turbo encoder/decoder is illustrated in figure 1, shown below. Concatenated coding and iterative decoding concepts form the basis of operation of turbo codes. They make use of recursive systematic convolutional (RSC) codes with parallel concatenation, wherein the information is encoded simultaneously in two encoders with one of them being fed through a pseudo-random block interleaver. To make better decisions, MAP iterative soft-decision decoder is used. However, the MAP algorithm involves intense computations. The log-MAP algorithm converts all the likelihoods into logarithmic form, thus reducing computational complexity significantly.

Recently, a license agreement for the use of turbo codes has been signed between the intermediary license holder-France Telecom and AMSAT-DL. Hence the non-commercial use of the codes will be permitted for P3-E and P5-A missions [5].

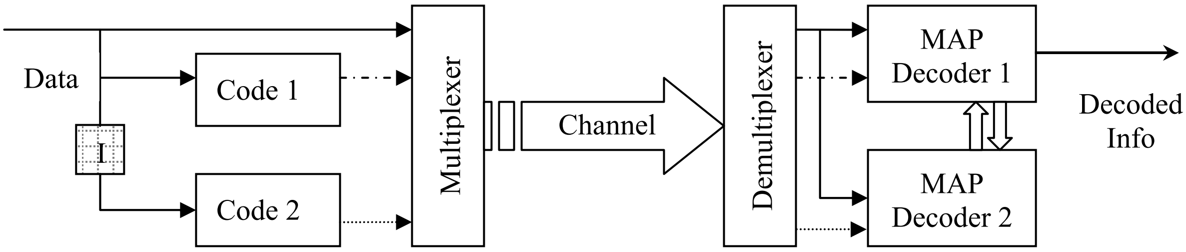

Fig. 1: *Parallel Concatenated Encoder and Turbo*

2.1 UMTS TURBO CODES

Universal Mobile Telecommunications System (UMTS) is a third generation cellular standard, which represents an evolution in terms of capacity, data rates and advanced services from second generation systems. It is standardized by the Third Generation Partnership Project (3GPP).

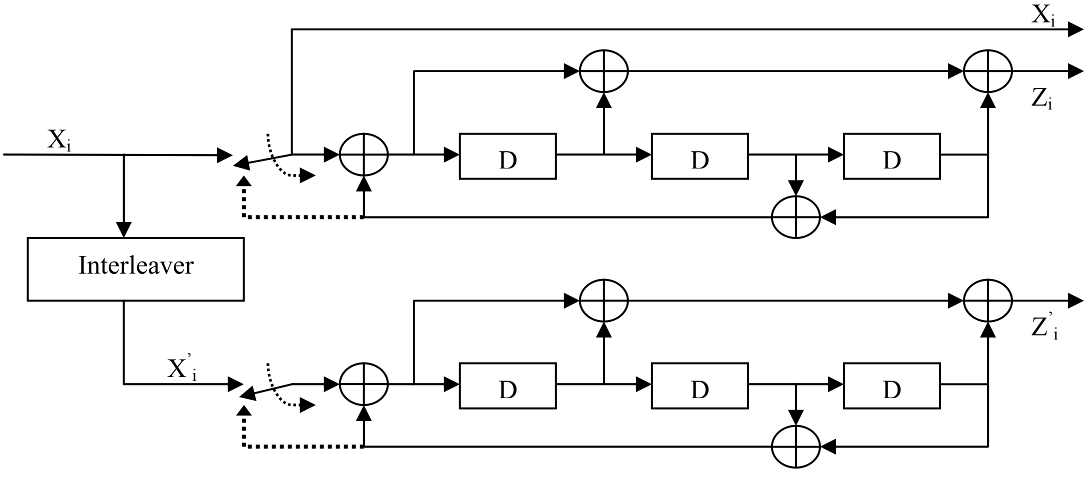

Fig. 2: *Turbo Encoder for UMTS*

The encoder used by UMTS turbo codes is comprised of a pair of constraint length K=4 RSC encoders. The output of the UMTS turbo encoder is a serialized combination of the systematic bits $\{X_i\}$, the parity output of the first encoder $\{Z_i\}$, and the parity output of the second encoder $\{Z'_i\}$, as shown in figure 2. Thus, the overall code rate is approximately 1/3.

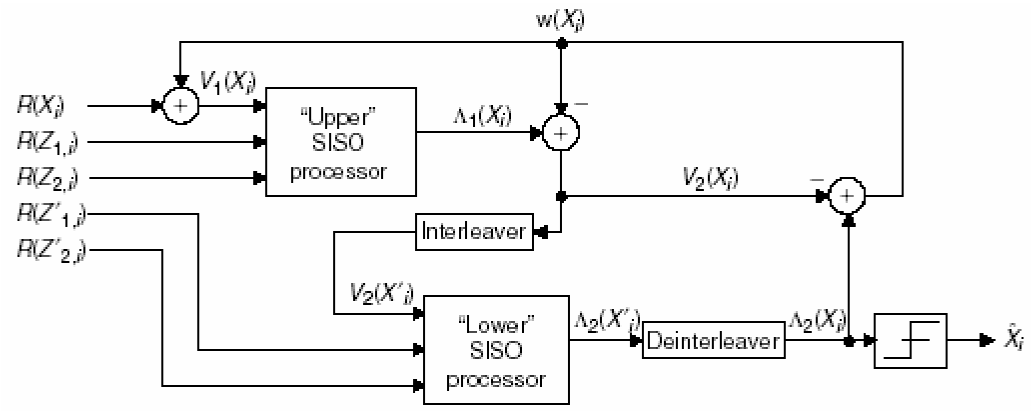

Fig. 3: *Decoder Scheme for UMTS and cdma2000 Turbo Codes*

The received values for the systematic and parity bits are put into the log-likelihood ratio (LLR) form and fed into the input of the turbo decoder shown in figure 3. The $R(Z_1,i)$ and $R(Z'_1,i)$ inputs are the LLR values corresponding to the upper (Z_i) and lower (Z'_i) parity outputs, respectively, of the encoder shown in figure 2. The turbo decoder uses the received code word along with knowledge of the code structure to compute $\Lambda(X_i)$. The LLR estimate computed using the structure of the upper encoder is denoted $\Lambda_1(X_i)$ and that computed using the structure of the lower encoder is denoted $\Lambda_2(X_i)$ [3]. Each of these two LLR estimates is computed using a soft-input soft-output (SISO) processor and the exchange of information back and forth between processors makes the decoding algorithm iterative.

2.2 TURBO CODES FOR AMSAT PHASE 3-E SATELLITE APPLICATIONS

P3-Express satellite is planned as a successor of P3-D and also as a test platform for the P5-A Mars mission. The main goal of P3-E is to act as communication platform for radio amateurs worldwide. The launch is planned for 2005/2006. The application under our purview is a short message service with minimum signal-to-noise ratio (E_b/N_o), low data rate and low BER requirements intended to be operated in a narrow band satellite mode environment. The salient requirement features are: *narrow band* - to use very less amount of the available spectrum; *minimum E_b/N_o* - to operate it at all reasonable signal strengths available; *low bit error probability* - to keep the loss of information under check; *low data rate* - bursty non-real-time data applications; and *non delay-sensitive data* - typical of satellite systems [4].

The error correcting scheme has to cater to all the above requirements, in addition to keeping the complexity as low as possible. Turbo codes with both log-MAP as well as soft-output Viterbi algorithm (SOVA) decoding techniques have been tried here. The maximum value of the E_b/N_o ratio has been set to 3 dB to conform to the requirements.

3 RESULTS AND PERFORMANCE ANALYSIS

The performance of turbo codes for the applications described in previous sections is illustrated in the figures given below. These simulations have been carried out using MATLAB. Two parameters, namely the signal-to-noise ratio (in terms of E_b/N_o) and the bit error rate form the basis of evaluation. The comparative analysis is based on complexity of the process, in other words on the number of iterations used.

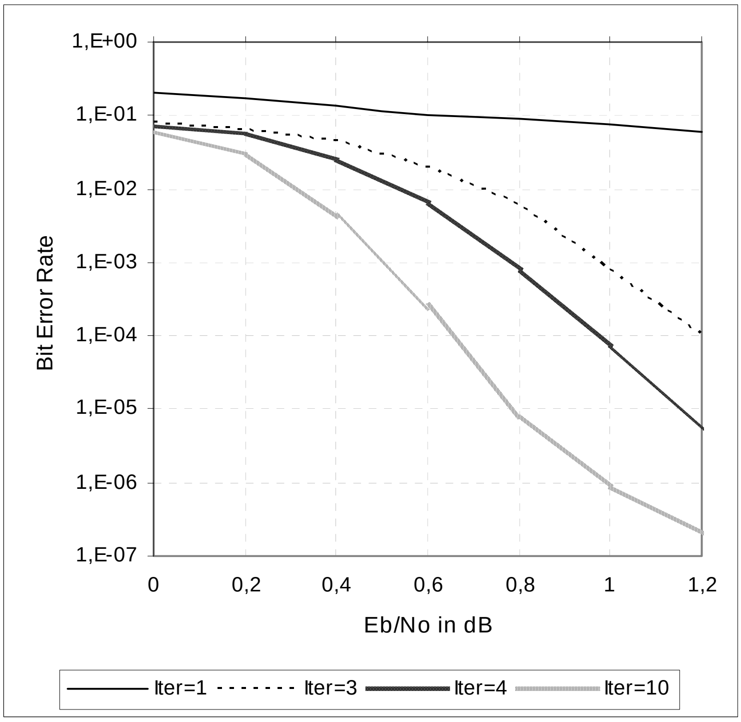

Fig. 4: *Error Performance of UMTS Turbo Codes (Rate 1/3, Log-MAP, N=1530, BPSK in AWGN)*

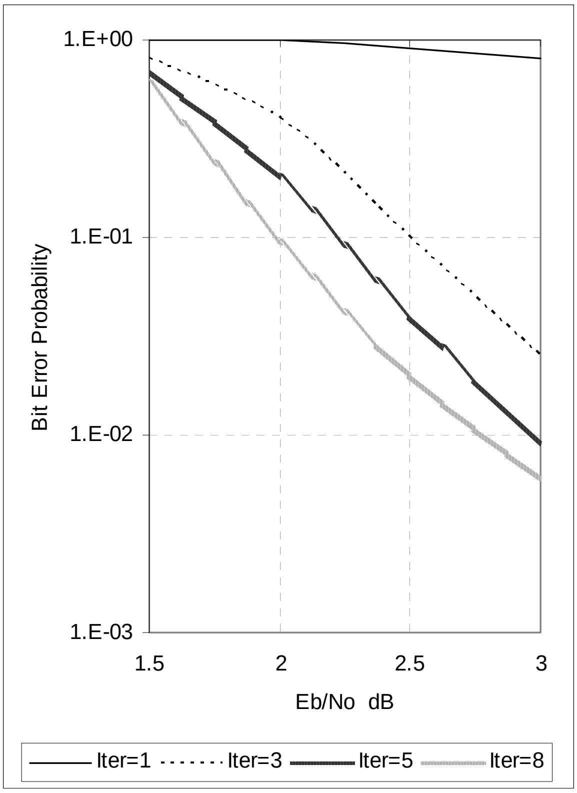

Fig. 5: *BEP v/s E_b/N_o for Turbo Codes (Rate 1/2, SOVA, N=1024)*

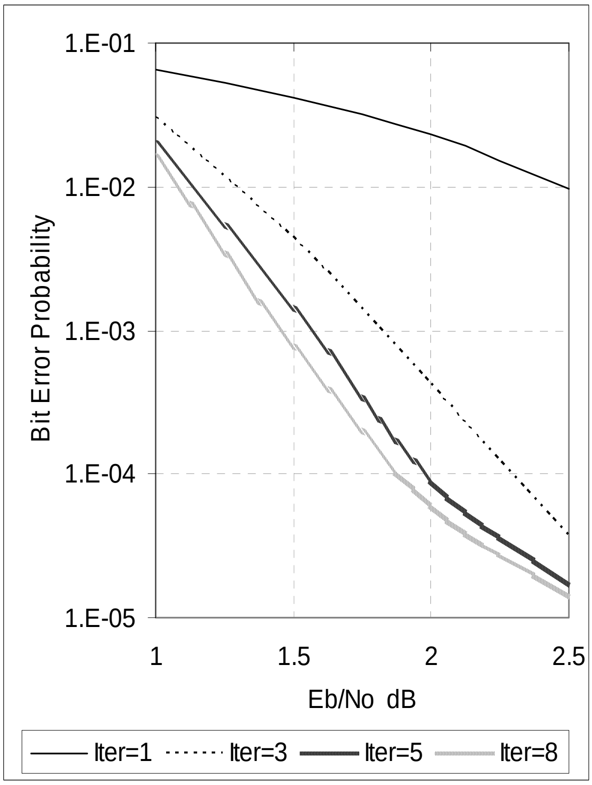

Fig. 6: *BEP v/s E_b/N_o for Turbo Codes (Rate 1/2, Log-MAP, N=1024)*

The performance of UMTS turbo codes in an additive white Gaussian channel (AWGN) with BPSK modulation, applying log-MAP decoding algorithm is shown in figure 4. A code rate of 1/3 and a frame size of 1530 bits are used. As can be seen, the performance improves with the increased number of iterations. However, this leads to additional complexity and delay, which may cause glitches in applications involving real time data transfer.

The error performance graphs of SOVA and log-MAP decoded turbo codes for the satellite mode application are illustrated in figures 5 and 6 respectively. Both the methods employ rate=½, block length=1024 and maximum number of iterations=8. As is evident, the log-MAP decoding yields a better error performance for a given E_b/N_o. However, the additional computational complexity is a major bottleneck.

By comparing the results obtained, we can observe that UMTS turbo codes yield a better performance owing to a larger frame size and a higher code-rate at a given number of iterations. The signal-to-noise ratio required for a particular BER is also nominal. Nevertheless, keeping the complexity factor in mind the results for the satellite mode application are equally encouraging.

4 CONCLUDING REMARKS

From the error performance results, it is evident that turbo codes are quite suitable for the wireless communications applications under consideration with afore mentioned requirements. The major disadvantage pertaining to additional complexity and delay has to be dealt with in order to achieve the desired objectives. An improvement in the present decoding algorithms, utilizing hardware equipment with enhanced capabilities or the use of serial concatenated turbo codes are some of the options worth considering.

ACKNOWLEDGEMENT

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