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Analysis of Decoding Performance in Turbo Codes

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Abstract— *In general the turbo codes are considered more superior than other conventional channel codes. In this paper, we focused on decoding process in turbo codes. In addition to that, the computational complexities in MAP and MAX-Log MAP decoding algorithm are compared. The code rate required for the process is 1/3, number of iteration was set up to 8 and size of the block is 40 to 6144 using AWGN channel. The turbo decoding performance is analyzed by using MATLAB software and we inferred that this low complexity method along with reduced bit error rate further built the system more efficient.*

Keywords— Turbo codes, AWGN Channel, Matlab. Bit error rate.

I. INTRODUCTION

Today, wireless communication has become an integral part of everyone's life. Wireless communication applications require error correction schemes in order to maintain high quality of service, reliable transmission, improve safety and provide better performance. In digital communication systems, the information is represented as a sequence of binary bits. The binary bits are then mapped (modulated) to analogy signal waveforms and transmitted over a communication channel. The communication channel introduces noise and interference to corrupt the transmitted signal. At the receiver end, the channel corrupted transmitted signal is mapped back to binary bits. The received binary information is an estimate of the transmitted binary information. Normally, during signal transmission through noisy channels, errors can occur on the received data. Bit errors may result due to this transmission and the number of bit errors depends on the amount of noise and interference in the communication channel. These errors can be detected and corrected using coding techniques. Error correction codes decrease SNR by introducing the coding gain for the communication link. In a digital transmission system, error control is achieved by the use of a channel encoder at the transmitter and a corresponding decoder at the receiver, as shown in Fig.1. The main aim of the channel coding is received information is as close as possible to the transmitted information.

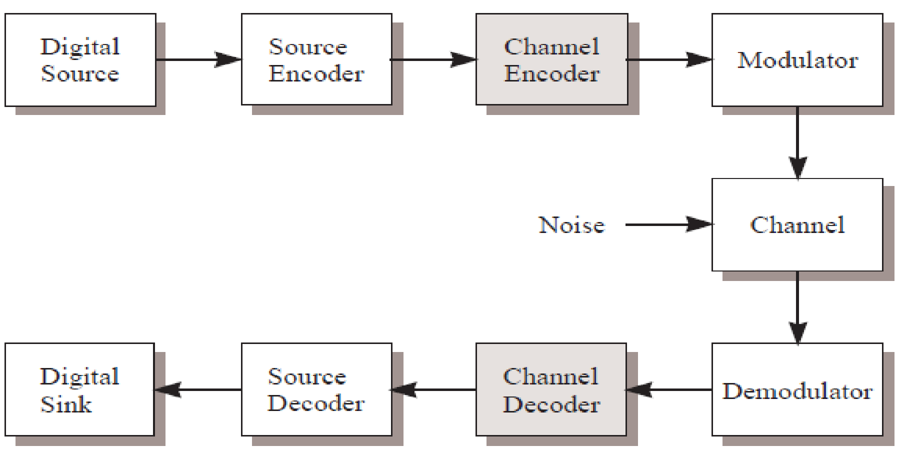

FIGURE 1. BLOCK DIAGRAM OF DIGITAL COMMUNICATION

II. CHANNEL CODING

Channel coding is used to detect the errors in the received information and these errors can be corrected by the use of Error Correction Coding. Error Control Coding has different types of coding schemes such as,

- Linear Block Codes
- Convolution Codes
- Turbo Codes

Turbo codes are most powerful for error detecting and correction codes, which enable reliable communication with bit rates close to Shannon limit for a given bit error probability (BER). Turbo codes are parallel concatenation of two recursive systematic convolutional codes. The fundamental difference between convolution codes and turbo codes is that the performance improve by increasing the constraint length while for turbo codes, the constraint length has a pretty small value. Moreover, it achieves a significant coding gain at lower coding rates. An important factor for achieving this improvement is due to the "soft-input/ soft-output" decoding algorithm to produce soft decisions.

III. STRUCTURE OF TURBO ENCODING

Turbo codes are composed of two or more constituent codes, generally convolutional encoder. Figure 2 shows a typical Turbo encoder. The information sequence contains the original information bits in addition to k termination bits that are appended the encoder. K is the constraint length of the constituent Convolutional encoder. The interleaver (denoted by Π) reorders the information sequence given to the second convolutional encoder. The overall rate of the turbo encoder structure is 1/2. The main purpose of the interleaver is used to scramble the input information. The original information sequence is given to the first encoder and the scrambled information is given to the second encoder after getting the different encoded output.

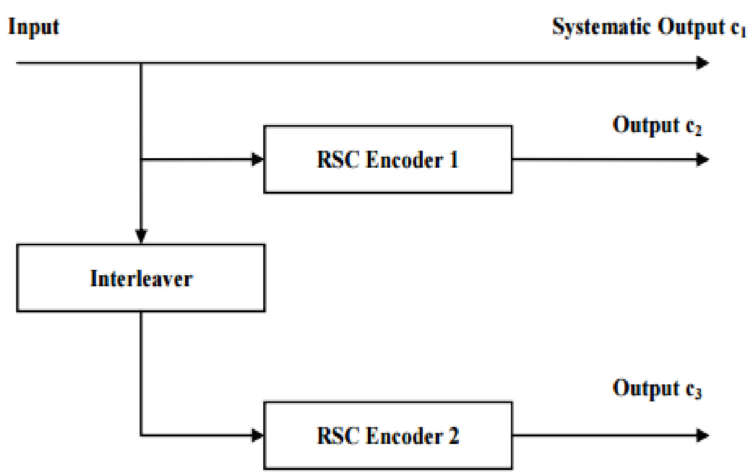

FIGURE 2. TURBO ENCODER

IV. TURBO DECODER

The turbo decoder works in an iterative way. Figure 3 shows a block diagram of a turbo decoder. Only one loop is performed at a time. In practice the number of iterations does not exceed 18, and in many cases 6 iterations can provide satisfactory performance. Actually, the first decoder will decode the sequence and then pass the hard decision together with a reliability estimate of this decision to the next decoder. Now, the second decoder will have extra information for the decoding; a priori value together with the sequence. The interleaver in-between is responsible for making the two decisions uncorrelated and the channel between the two decoders will seem to be memory less due to interleaving. The turbo decoding is mainly based on soft input and soft output (SISO).A SISO decoder can be implemented using the maximum a posteriori(MAP) or the maximum likelihood (ML) decoding algorithm. The basic concept of soft decoding is Log-Likelihood Ratio, several decoding algorithms that use soft decoding and reliability values. These include MAP, Max-Log MAP and Log-MAP.

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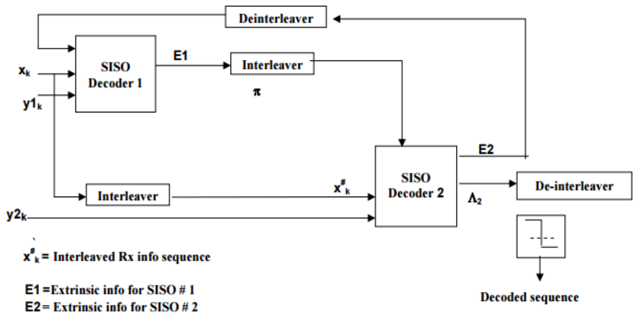

FIGURE 3. TURBO DECODER

V. LOG LIKELIHOOD RATIO

Information is passed from one component decoder to another in the form of Log Likelihood Ratios (LLR). The LLR of a certain bit is the log of the ratio of the probability that a certain bit takes the value 1 to the probability that this same bit takes the value -1. The LLR of a bit u_k is denoted as $L(u_k)$ and is defined as:

$$L(u_k) = \ln\left(\frac{p(uk=+1}{p(uk=-1)}\right) \tag{1}$$

In channel coding, we are interested in $P(u_k=+1)$ given a certain vector y_k of received values y_k's. This is translated into a conditional LLR of a bit u_k conditioned on a received sequence also known as the a-posteriori probability of the decoded bit u_k.

$$L(u_k|y) = \left(\frac{(P(uk=+1|y)}{P(uk=-1|y)}\right) \tag{2}$$

5.1 MAP Algorithm

The Maximum A-Posteriori (MAP) algorithm introduced in 1974 by Bahl, Cocke, Jelinek and Raviv. The MAP algorithm is optimal for Convolution codes and it minimizes the number of bits decoded incorrectly, while the Viterbi algorithm minimizes the probability of an incorrect path in the trellis.

The MAP algorithm provides the decoded bit sequence along with the probability that each bit is decoded correctly.

First we need to define the following:

- α_{k-1}(\`s) is the probability that the trellis is in state (\`s) at time k − 1 given the sequence of bits previous to bit k;
- $\beta_{k(`s, s)}$ is the probability that the trellis moves from \`s to s given the received channel value y_k at time k;
- $\gamma_{k(s)}$ is the probability that the trellis is in state s at time k given the sequence after bit k;

$$\gamma_{k(s',s)} = e^{ukL(uk)/2} e^{\frac{Eb}{2\sigma}} 2a \sum y_k x_k \tag{3}$$

$$\alpha_k(s) = \sum \gamma_k(s',s).\alpha_{k-1}(s') \tag{4}$$

$$\beta_{k-1}(s) = \sum \gamma_k(s',s).\ \beta_k(s) \tag{5}$$

$$L(u_k|y) = \ln\left(\frac{\sum(s',s)\Rightarrow uk=+1.\gamma k(s',s).\beta k(s)}{\sum(s',s)\Rightarrow uk=-1\ \alpha k-1(s').\gamma k(s',s).\beta k(s)}\right) \tag{6}$$

The MAP algorithm is extremely complex.

5.2 Max-Log-MAP ALGORITHM

Max-Log-MAP approximates the extremely complex summation of Equation 2.12 by a maximum operation. Consequently, it is a sub-optimal decoding algorithm.

$\ln(\sum e^{x_i}) \approx \max_i(x_i)$

$A_k(s) = \ln(\alpha_k(s))$

$B_k(s) = \ln(\beta_k(s))$

$\Gamma_k(s', s) = \ln(\Gamma_k(s', s))$

$L(u_k)\,|y \approx \max_{(s',s)\Rightarrow u_k=+1}(A_{k-1}(s')+\Gamma_k(s',s)+B_k(s))$

$-\max_{(s',s)\Rightarrow u_k=-1}(A_{k-1}(s')+\Gamma_k(s',s)+B_k(s))$

VI. SIMULATION RESULT

The following performance curves were obtained using Matlab software. All the simulation results are using the MAP and Max Log MAP decoding algorithm up to 8 iteration using AWGN channel at the rate 1/3. All figures shows the Bit Error Rate (BER) versus Signal-to-Noise Ratio (SNR) expressed as the ratio between the energy per bit and the noise power spectral density.

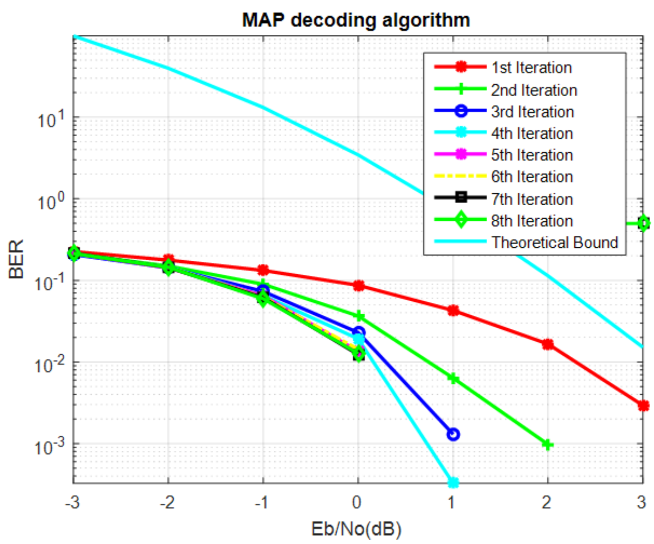

FIGURE 1.4 PERFORMANCE OF MAP DECODING ALGORITHM

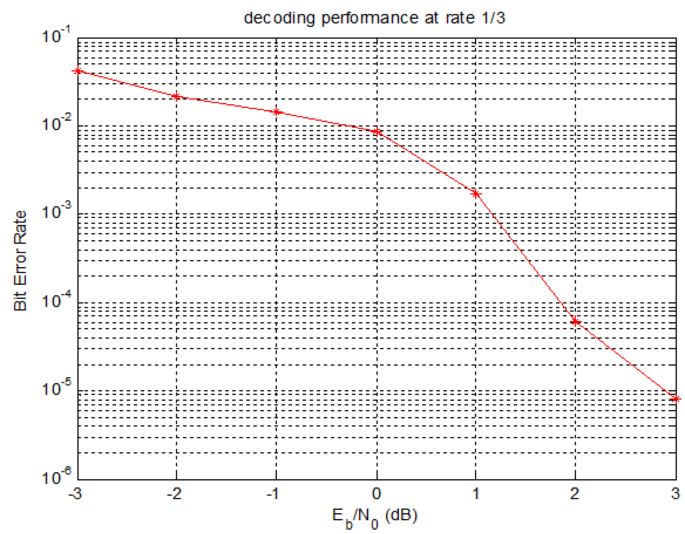

FIGURE 1.5 PERFORMANCE OF MAX-LOG MAP DECODING ALGORITHM

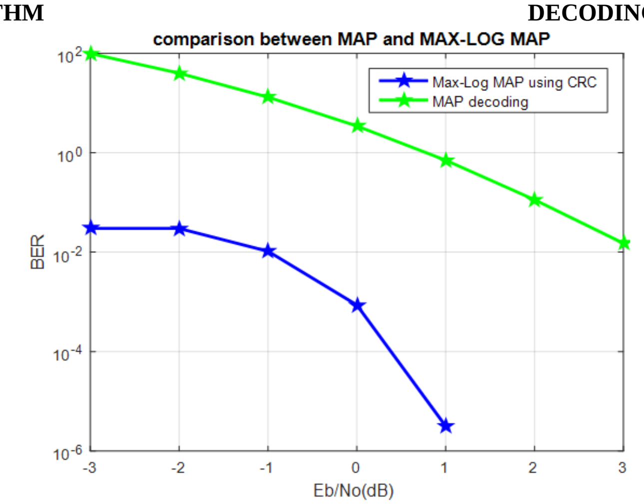

FIGURE 1.6 COMPARISON OF MAP AND MAX-LOG MAP DECODING ALGORITHM

VII. CONCLUSION

Thus the BER performance of turbo codes is evaluated for various decoding algorithm. Compared to MAP decoding algorithm MAX-Log MAP algorithm gives less computational complexity. From the simulated analysis, the better BER performance is obtained from Max-Log MAP algorithm. The size of the interleaver is also one of the important to provide better BER performance, sufficient coding gain and simplicity of decoding process. In order to reduce the computational complexity, choose appropriate decoding algorithm in the decoding process.

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