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Comparative study of Error Control Codes in Communication Systems

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Abstract: In present era of information theory and coding theory where applications of computer science and telecommunications are used, error control techniques are used for reliable delivery of digital data over unreliable communication channels.Error-detection and correction schemes are of two types: systematic or non-systematic: Systematic scheme, consist of transmitting data with attachment of fixed parity data bits. The parity bits are determined from the data bits by using predefined algorithm. In error detection the receiver apply only the same algorithm and by comparing with the check bits it can detect whether an error has occurred at any stage of transmission. In Non- systematic code encoding is done on the original data that has the same no of bits as the original data. In this paper, we have made a comparison between various error control techniques like soft viterbi decoding algorithm, hard decision algorithm, BCGR algorithm and also the results are compared in the matlab environment.

With the help of simulations in MATLAB Communication Toolbox we have find the ber performance of various codes and also their performance in various environment. In the end a conclusion will be drawn that compares the performance of all the schemes

Keywords: BCGR, LOGMAP, MAP, SOVA.

I. INTRODUCTION

Communication systems are designed to transmit messages or information from a source that generates the messages to one or more destinations. The transmission of information takes place over a physical medium called the channel. In general, a digital communication system can be modeled by Fig. 1[1,2,4]

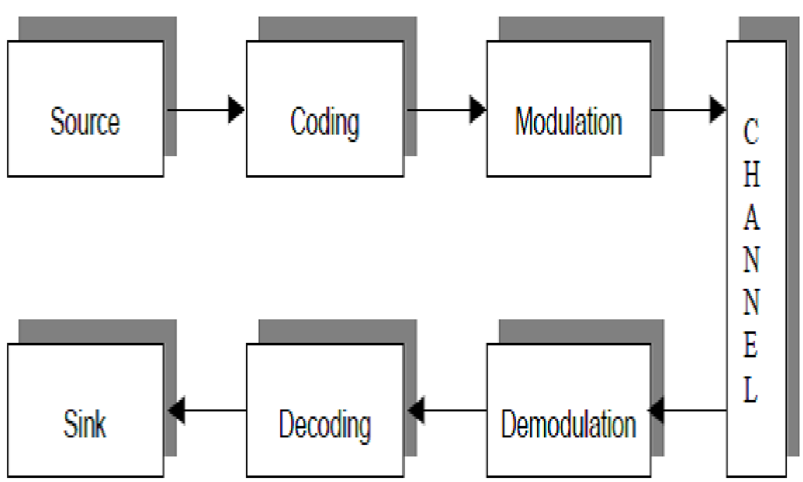

Fig. 1: Block diagram of a digital communication system.

Additive White Gaussian Noise Channel: The Additive White Gaussian Noise (AWGN) channel is one of the most commonly used channel model and is generally used to model an environment with a very large number of additive noise sources. Most additive noise sources in modern electronics are a direct consequence of zero-mean thermal noise, which is caused by random electron motion within the resistors, wires, and other components. By the Central Limit Theorem, we can model these additive sources as a Gaussian random process[5,6]. This assumption becomes more accurate as the number, and variety of noise sources is increased. The statistical model for the AWGN channel with zero mean is given by its probability density function alongwith its variance (σ^2)(for BPSK modulation) .

$$p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp(-\frac{1}{2\sigma^2} x^2)$$

$$\sigma^2 = \frac{N_0}{2RE_b}$$

Where, R is the coding rate (R = number of transmitted bits/ number of information bits) and E_b / N_0 is the ratio of the bit energy to noise power spectral density. The modulated and the received signal r at any time instant t is given as follows

$$r_t = x_t + \eta_t$$

Where, $x_t$represents the information sequence and η_t is the white noise added by thechannel at time t.

Channel Capacity

Channel capacity is the maximum rate at which reliable transmission of information over the communication channel is possible. Shannon's fundamental result of information theory states that for discrete memoryless channels, the capacity is given by the following expression:

$$C = \max_{p(x)} I(X;Y)$$

whereI(X;Y)denotes the mutual information between X (channel input) and Y(channel output) and the maximization is carried out over all input probabilitydistributions of the channel.The mutual information between two random variables X and Y is defined as:

$$I(X;Y) = \sum_{x \in X} \sum_{y \in Y} p(x) p(y \mid x) \log_2 \frac{p(x,y)}{p(x)p(y)}$$

Where the mutual information is in bits[9,10]. For the case of binary symmetric channel, the capacity is given by the following expression:

$$C = 1 - H_b(\in)$$

where ϵ is the crossover probability of the channel and $H_b(.)$ denotes the binary entropy function given as follows

$$H_b(x) = -x \log_2(x) - (1-x)\log_2(1-x)$$

Table 1: Channel limits for coherent BPSK capacity

Code Rate	Rayleigh	AWGN Channel
R=1/2	$\frac{E_b}{N_o} = 2.6$ dB	$\frac{E_b}{N_o} = 0.2$ dB
R=1/3	$\frac{E_b}{N_o} = 1.4$ dB	$\frac{E_b}{N_o} = -0.5$ dB

II. THEORETICAL DEVELOPMENT

Turbo coding

A turbo code (TC) is a parallel concatenation of two or more recursive systematic convolution codes. A generalized turbo encoder is shown in Fig 2

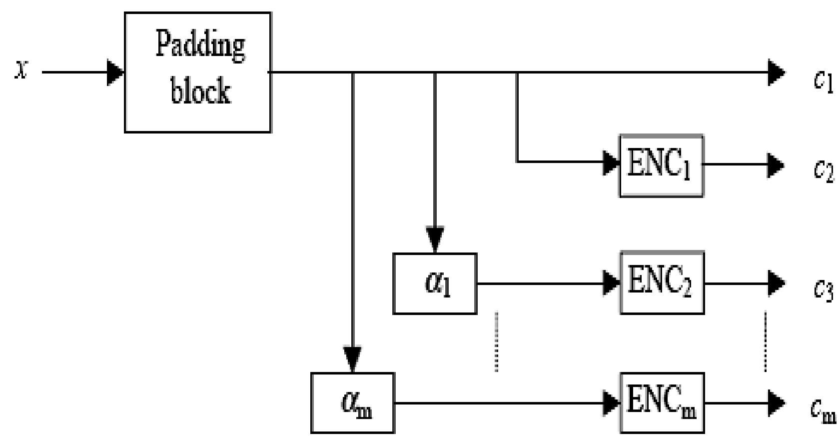

Fig. 2: Generalized turbo encoder

The input of the TC encoder is a data block x, with k information bits. To this information sequence the padding block appends v (memory size) tail bits, which then yield the sequence c1. This sequence of bits is then fed in parallel into m parallel sets of interleavers (αi) and encoders. The aim of the interleaver is to scramble the sequence c1 before feeding the output of the padding block into other constituent encoders.For most applications, and also for this thesis, only two rate 1/2 constituent encoders are used and the input to the first encoder is not interleaved[7,6,11,12]. The encoders are identical and are recursive systematic convolutional encoders. The purpose of adding the tail bits is to make sure that the first encoder returns to the all zero state at the end of each data block. Fig 3shows a rate 1/3 turbo encoder. The first RSC encoder outputs the systematic (c1) and recursive convolutional sequence (c2) while the second RSC encoder discards its systematic sequence and only outputs the recursive convolutional sequence (c3).

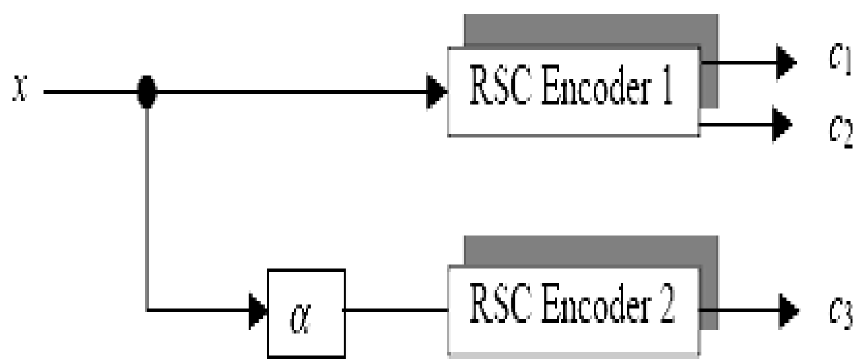

Fig. 3 Rate 1/3 turbo encoder

Turbo code decoder: Turbo codes offer the ability to build powerful codec that utilize a relative simple soft-decision decoding algorithm. This is possible because the turbo decoder is constructed from two identical serial decoding blocks that share information. The turbo code decoders often work iteratively (loop wise) by sharing the a priori information obtained from the log-likelihood ratio (a posteriori information) of the previously cascaded decoder.The constituent decoders are the optimal decoders for the component codes used by the turbo encoder. Fig 4gives a visual representation of the iterative and information sharing nature of the decoding strategy.

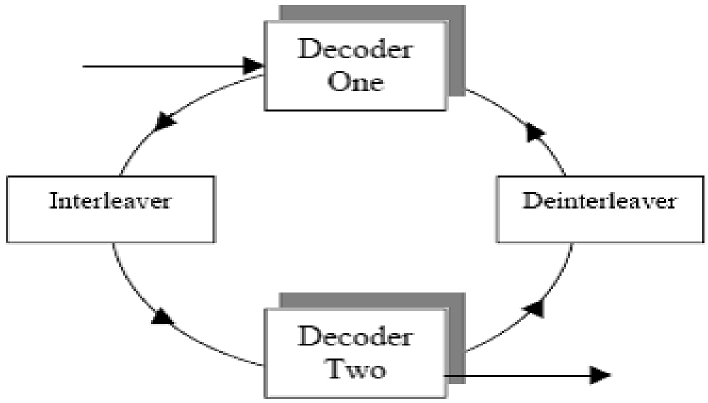

Fig. 4 The iterative structure of a turbo decoding scheme

For turbo codes, the Soft Output Viterbi Algorithm (SOVA), and the Log-MAP decoding algorithm can be used as they produce soft-bit estimates[12,13,15]. The Log-MAP decoding scheme is the modified version of the MAP decoding scheme and is computationally less complex than the original MAP decoding algorithm. The MAP decoding algorithm was first introduced (in 1974) by Bahl, Cocke, Jelinek and Raviv and is also known as the BCJR algorithm. However, due to the push for strikingly low bit error rates, the MAP or the Log-MAP has been most commonly used in turbo codes since they are based on the optimal decoding rule. In contrast, the SOVA is an approximation to the MAP sequence decoder and will have a slightly worse bit error performance[16,17,19]. Though SOVA suffers from performance degradation as opposed to the Log-MAP decoding rules, it has much reduced complexity.

III. SIMULATION RESULTS

The simulation models are implemented using the software package MATLAB. The results of the simulation are displayed using graphs in which the bit error rate is plotted versus bit energy to noise power spectral density (E_b/N_0) in decibels. The performance of turbo codes for the two different decoding algorithms (SOVA and Log-MAP) is studied through intensive simulations for different interleaving schemes, using BPSK signalling. The data frame sizes are chosen to be small with the maximum size of 400 information bits, which is used for independent Rayleigh fading channel, as it is a fairly good model for studying the behaviour of the mobile environment.

Fig 5 Shows BER performance plot for Convolution code Decoding with viterbi decoder. This plot indicates that the viterbi performance is low for low E_bN_o values.

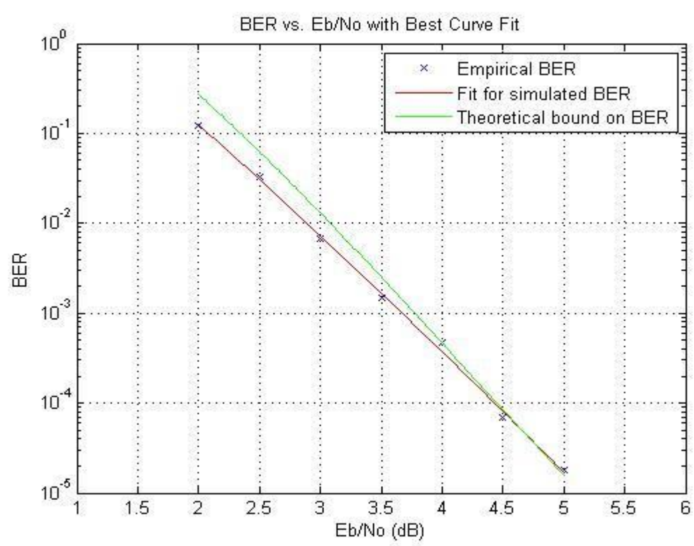

Fig 5: BER plot for Convolutional code and Viterbi decoding with puncturing

Fig 6 shows the viterbi decoder performance over normal decoder. The Encoder used algorithm whose equation is $[1+D^2, 1+D+D^2]$. The fig is plotted for AWGN channel over BPSK modulation.

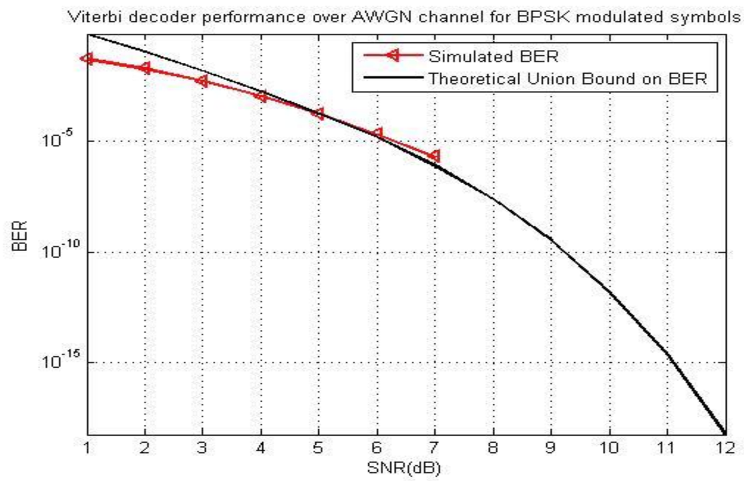

Fig. 6: Simple Viterbi decoder performance over AWGN Channel

As we can see from fig 7, the BER performance of hard decision decoder is appx. 1.5dB better than the normal decoder.However the decoding become complex as we go on increasing the no. of transmitted bits but the BER performance will go increasing

Table 2: PARAMETER FOR HARD DECISION DECODER

No. of Bits Transmitted	10^5
EbNo value	10dB
Hard Decision Table	[00;01;10;11]

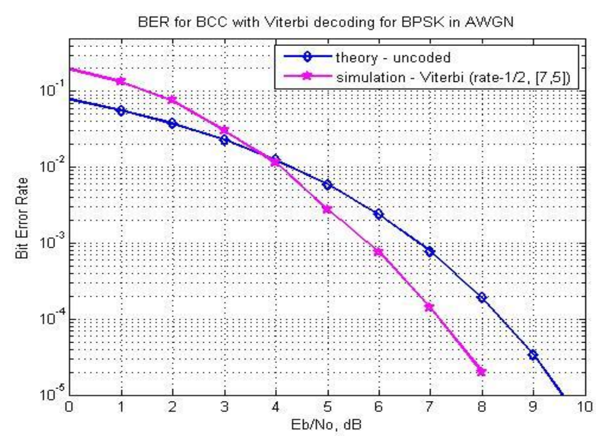

Fig.7: Performance of hard decision decoding algorithm

From fig 8 it is very much clear that the BER performance for soft decision decoder is appx. 2dB better than the hard decision decoding algorithm. But we don't forgot the increase in complexity as the increase in No. of transmitted bits.

Table 3 PARAMETER FOR SOFT DECISION DECODER

No. of Symbols Transmitted	10^5
Reference Hard Decision	[0 0 ; 0 1; 1 0 ; 1 1]
Reference Soft Decision	-1*[-1 -1; -1 1 ;1 -1; 1 1]

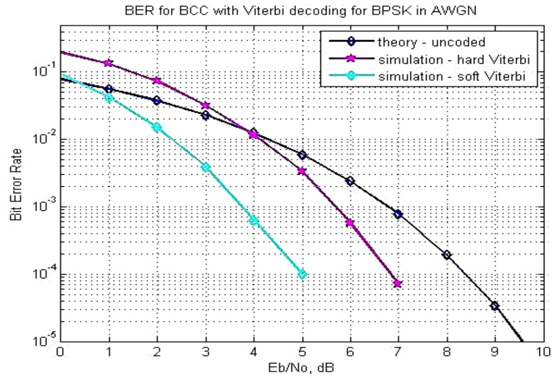

Fig. 8 Comparison between hard and soft viterbi decoding for convolution code

From simulated result Fig 5, 6, 7and fig.8 BER plot for Convolutional code and Viterbi decoding it is concluded that for lower E_b/N_o regions, the error rate with Viterbi decoding is higher uncoded bit error rate. This is because; Viterbi decoder prefers the error to be randomly distributed for it works effectively. At lower E_b/N_o values, there are more chances of multiple received coded bits in errors, and the Viterbi algorithm is unable to recover. Viterbi decoding has 2 dB better performances as compared to without encoding.Fig8 shows the BER performance of the MAP decoding algorithm.

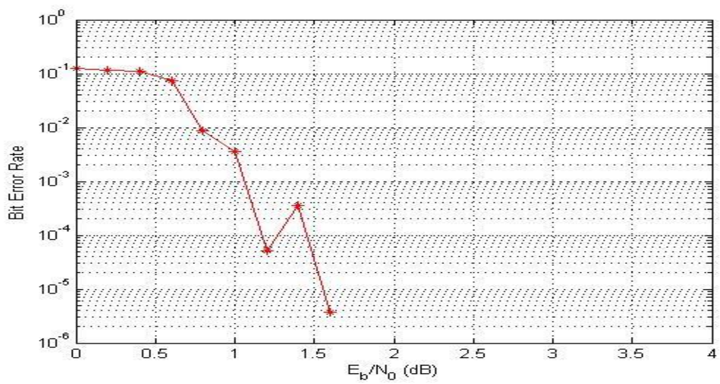

Fig. 9 Ber performance of MAP algorithm for turbo code

BCJR is nothing but the modified form of MAP algorithm. The MAP algorithm requires very less time to compute errors. The plot is drawn using parameters in Table 4.

Table 4 Parameter for map decoder

cutting length	1020bit	**number of iterations**	10
computing frames	298	**Computing bit number**	303960
Operation duration	60 seconds	**computing bit rate**	5.07e+03 bit /s
Input_matrix	2*[0,1;0,1;0,1;0,1]-1		

Fig 9 shows the BCJR algorithm BER performance. This plot shows that as the no of iterations increases the performance also increases. However, there is a limit in reduction of error probability.

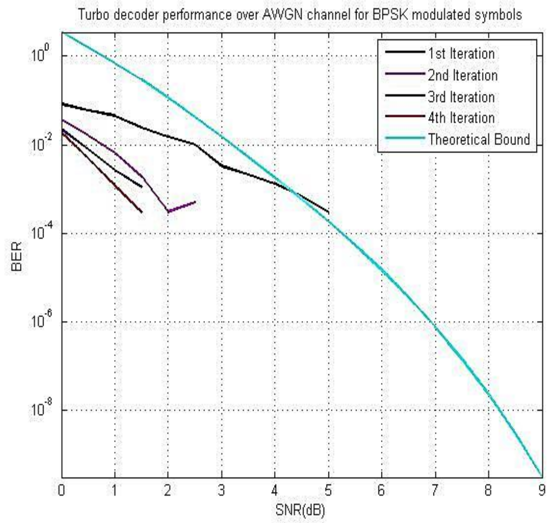

Fig 9 BER performance of turbo decoder using BCJR algorithm

From fig.10 it is clear that the performance of LOG MAP decoder is high with respect to the MAP/BCJR algorithm. The plot shown below is using the parameters listed in table 5. Although the speed of LOG MAP algorithm is slow than MAP algorithm yet the performance is higher with higher no. of frames.

Table 5: PARAMETER FOR LOG MAP DECODER

cutting length	1020bit	**number of iterations**	10
computing frames	422	**Computing bit number**	422000
Operationduration	60 seconds	**computing bit rate**	7.03e+03 bit /s

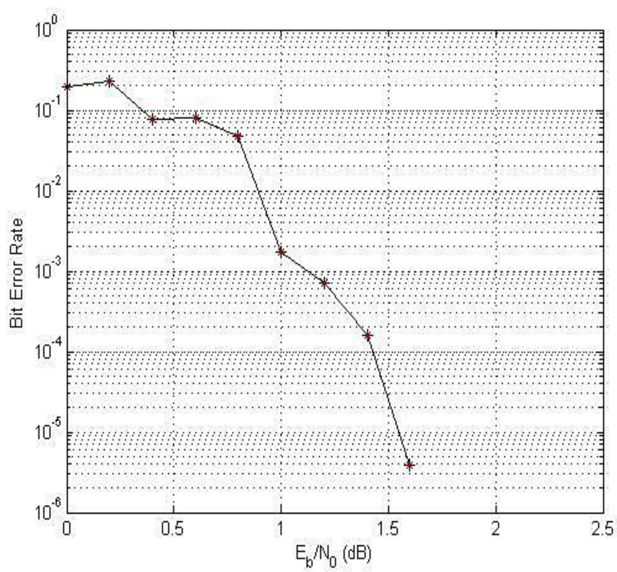

Fig.10 Ber Analysis of LOG-MAP Decoding Algorithm in Turbo Code

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Fig.11 shows the performance of SOVA Decoder. The SOVA decoder is a modified version of MAP decoder. As we can see that the BER performance for this decoder is good but not better than the LOGMAP decoder.

Table 6 PARAMETER FOR SOVA DECODER

Frame size	100
Code generator	1 1 1 1 0 1
code rate	1/3
Iteration number	2
Terminate frame	1
No. of frames	10000

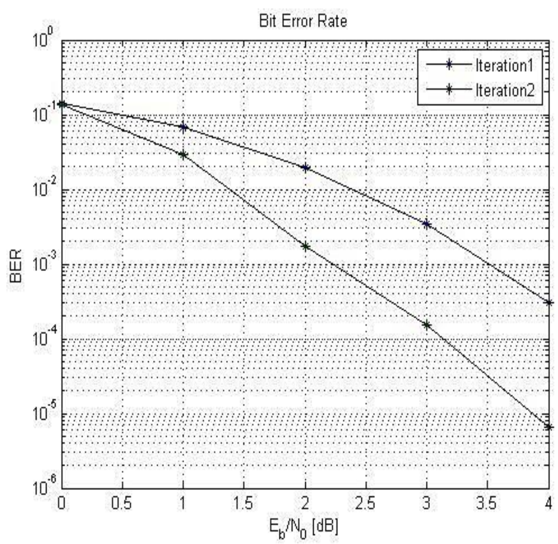

Fig.11 BER plot for SOVA decoder

CONCLUSION

From the simulation results we observed that for a fixed turbo encoder the performance of the decoder improves as the data frame size is increased. This implies that the data frame size is an important factor in the performance of turbo codes and as the frame size is increased the code gives better performance, which on the other hand is not the case with the conventional Viterbi decoder.

The results we get from the Convolution code decoding are as follows:

Algorithm	**Performance**
Hard Decision Viterbi	**2.5 dB better than normal decoder**
Soft Decision Viterbi	**4.5 dB better than normal decoder**

The table shows that the soft decision decoding is better than hard decision decoding. In case of a turbo code, a very powerful error correcting coding scheme, which is formed by the parallel concatenation of two recursive non-systematic convolutional codes, Following are some of the conclusions drawn from the work carried out:

ALGORITHM	BER PERFORMANCE
MAP	BER Performance is average
BCJR	BER performance is good when increasing no. of iterations
LOG-MAP DECODER	1 dB better performance for 1st iteration and 2.5 dB for 2nd iteration
SOVA DECODER	1 dB better performance for 1st iteration and more than 1.5 dB for 2nd iteration

The SOVA decoding scheme has shown less performance than the Log-MAP algorithm and this was expected due to the fact that the SOVA decoder is an approximation to the MAP decoding scheme and hence suffers from performance degradation. Although SOVA has the disadvantage of performance degradation, it has the hardware implementation advantage as it does not require large memory size to store numbers, whereas Log-MAP algorithm despite its superior performance is prone to memory overflows. In order to implement the Log-MAP algorithm in real systems some optimization technique must be used to overcome this problem.

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