Implementation and Analysis of Convolutional Codes Using MATLAB

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***Abstract*– Maintenance of the quality of data is the most important thing in communication. There are various factors that affect the quality of data when it is transferred over a communication channel like noise, fading etc. To overcome these effects channel coding schemes are introduced. In this paper one type of channel coding is described namely Convolutional Codes. Algorithms used for encoding of data are NSC (Non-systematic Convolutional Codes) and for decoding part Viterbi algorithm is used. Their performance is analyzed in terms of BER for different parameters such as code rate, coded and un-coded data. Furthermore, performance of convolutional codes is analyzed when a binary image is transmitted over the channel. All the simulations are conducted in MATLAB over AWGN channel using BPSK modulation scheme.**

***Keywords*–** Channel Coding, Convolutional Codes, Non-Systematic Convolutional Codes, Viterbi Algorithm, MATLAB, AWGN and BPSK

I. INTRODUCTION

In digital communication systems to improve the quality of data at output, channel coding is employed. It deals with various numbers of techniques that are being used for the improvement of performance of our communication system. It increases the information transfer rate at a fixed error rate or error rate can be reduced with a fixed information transfer rate. The maximum performance of the system is restricted by Shannon limit. Forward Error Correction (FEC) and Automatic Repeat Request (ARQ) are two basic errors correcting schemes, [1] being used in communications systems. Choice of these schemes is application dependent.

Amongst various types of channel coding convolutional codes are the one of those, which provides better performance. Convolutional codes are represented by three parameters n, k, K. where K represents the number of shift registers used in the encoding part [2]. In convolutional codes the input message is not divided into streams of k bits like block codes instead a continuous stream of data is used at the encoder's input. The coded sequence of n bits obtained after encoding not only depends on the k bit information message but also on the previous information bits that is transmitted [3]. Convolutional codes are same as block codes but encoder has an additional structure. Convolutional code is a linear code and its mapping is bijective.

In convolutional codes decoding is done by using both hard decision method and soft decision method. For constraint length K<5, Viterbi algorithm is used and for K>5 MAP algorithm is used [4]. These codes are finite state machines. The convolutional codes are useful in dealing with random errors instead of bursty errors. Convolutional codes can be used with block codes in order to provide good performance in case of burst errors, as block codes are good against burst errors. Inner codes are convolutional codes and outer codes are block codes to form concatenated codes. Communication in which low-latency is required such as speech transmission convolutional codes is being employed and they are very effective [5].

In this paper, convolutional encoder and decoder are implemented. Convolutional encoder having shift registers (constraint length) K=3 and code rate ½ is implemented. Furthermore a binary image has been used to analyze the performance of the convolutional codes.

II. SYSTEM MODEL

Fig. 1 shows the whole system model. Image file is used as data source. After binary conversion of image, convolutional coding is applied on the binary data [6]. After encoding of image, modulation is performed. Additive White Gaussian Noise (AWGN) is added when this coded data is passed through the channel. This noise distorts the image. Noise is added to include the channel response, as mostly noise is added to the data when it is passed through the channel. Demodulation of the image is performed at the receiver end. After demodulation convolutional decoding is performed and original transmitted image is retrieved.

A. *Convolutional Encoder*

In Fig. 2, a simple convolutional encoder is shown. It has

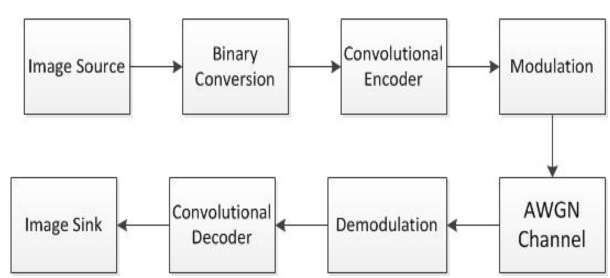

Fig 1: System Model Block Diagram

constraint length 3 and because two adders are used in it its rate is ½. A bit is shifted into the leftmost stage at each input and the bits previously existing in the shift registers are shifted one position to right. After applying the modulo-2 operation corresponding outputs are obtained. This process of continues until the arrival of data at the input of encoder. The choice of connection between the shift registers and adders describes the characteristics of code. By varying the connections, characteristics of the code can be varied.

Convolutional codes do not have a predefined word length like block codes [7]. These codes are being pushed into a frame structure by periodic truncation. Zero bits are appended in the message, for the sake of flushing the shift registers. Code rate may fall below k/n because of these added bits do not carry any information along with them. In order to stabilize the code rate, large truncation period is required.

To describe an encoder, set of 'm' connection vectors are required. These vectors have the same dimension as that of K (shift registers). These connections describe which shift register is connected with m adders. A value of '1' in the j^{th} position demonstrates that, that shift register is connected to the adder and a '0' in given position will indicate that not a single connection exits between the stage and adder.

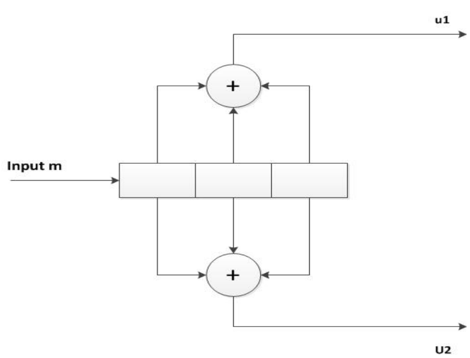

Fig. 2: Convolutional Encoder (Code Rate ½, Constraint length 3)

For encoder shown in Fig. 2, we can write the connection vector h_1 for upper connection and h_2 for lower connection as follows [8]:

$$h_1 = [1, 1, 1] \qquad (1)$$

$$h_2 = [1, 0, 1] \qquad (2)$$

B. Impulse Response of the Encoder

An encoder can be assessed on the basis of its impulse response. Impulse response is that response of the encoder when a single '1' bit is passed through it [9]. Consider the contents of the register shown in Fig. 2 as a '1' moves through it:

Memory Contents	Output (U_1)	Output (U_2)
0 0 0	0	0
1 0 0	1	1
0 1 0	1	0

Table 1: Impulse Response of Encoder

Input sequence: 0 1 0

Output sequence: 0 0 1 1 1 0

The symbol '11' is known as the impulse response of the encoder.

C. Viterbi Convolutional Decoding Algorithm

This algorithm was devised and analyzed by Viterbi in 1967 [10].basically, in this algorithm maximum likelihood decoding is performed. Maximum likelihood decoding is defined as process which decreases the computational load. It does so by taking the average of a particular structure in the code trellis. This algorithm has advantage over brute-force decoding in a way that the complexity is not defined in terms of the number of symbols in the encoded sequence [11].

In this algorithm resemblance between the received symbol and transmitted symbol is measured by hamming distance. Paths which are not suitable for maximum likelihood are rejected by this algorithm. Suppose there is more than one path that emerges from the one particular state, then the state having the lowest path metric is selected and this path is called the surviving path [12]. This process of selecting the surviving path is done for every state.

The decoder proceeds in this way deeper into the trellis, assembling results by rejecting the paths having high metric. This early elimination of the paths with high metrics minimizes the decoding complexity. The authenticity of this algorithm is proved in 1969, when Omura showed that this algorithm is maximum likelihood [13].

D. AWGN Channel

Since it is known that AWGN channel embeds white noise to the signal that has been passed through it. The amount of noise in this channel is described by following quantities:

- Value of SNR for each sample. Value of SNR is the actual parameter of AWGN channel.
- Ratio of Eb/No and ratio of Es/No.

We can define the relation between Eb/No and Es/No by following equation:

$$\frac{E_s}{N_o}(dB) = \frac{E_b}{N_o}(dB) + 10log_{10}(n)$$

Where bits per symbol are denoted by 'n' [14]. This parameter may be influenced by the size of the modulation alphabet and code rate of the error control code [15].

III. SIMULATIONS

This section covers results/simulations done on MATLAB. Analysis of performance of the codes is done in terms of BER and modulation scheme used in these simulations is BPSK. This section covers the BER plots for coded and un-coded data of 600 bits. Then a comparison is made between when different code rates are used.

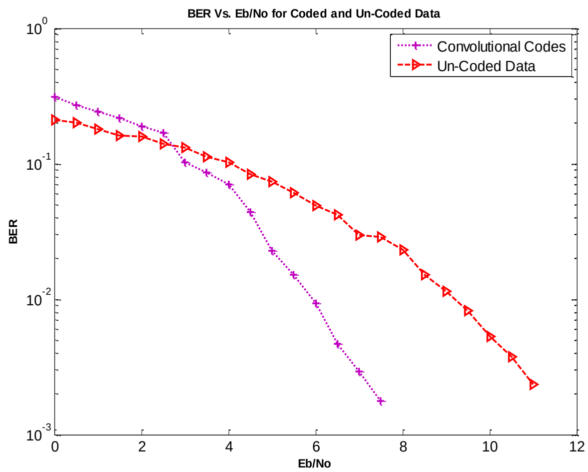

Fig. 3: BER versus Eb/No for coded and Un-coded data

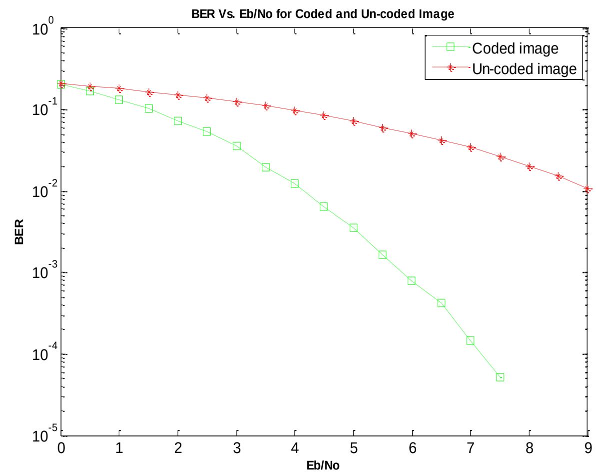

Fig. 5: BER Versus Eb/No for Coded and un-coded image

Second part of this section covers the BER plots for Binary image. Performance is evaluated when image is passed through the channel without using convolutional codes and when image is passed through the channel after being encoded by convolutional encoder and at the receiver convolutional decoder is applied to decode the image.

In Fig. 3, BER plot for coded and un-coded data is shown. It is quite clear from the figure that coded data provides coding gain of about 3 dB for BER 10^{-2}.

In Fig. 4, BER plot for different coding rates that is ½ and $2/3$ are shown. It is clear that by increasing the code rate, BER performance degrades. ½ rate code gives good performance as compared to $2/3$ rate code in the given scenario. Though, it increases the complexity of the system but at the expense of degradation in performance.

In Fig. 5, BER plot is shown for a binary image. It is quite apparent that the convolutional codes provide, much better performance than that of un-coded data. For BER 10^{-2} it is providing coding gain of $5\ dB$. It can be seen through Fig. 5 that with the addition of Convolutional codes BER 10^{-5} can be achieved.

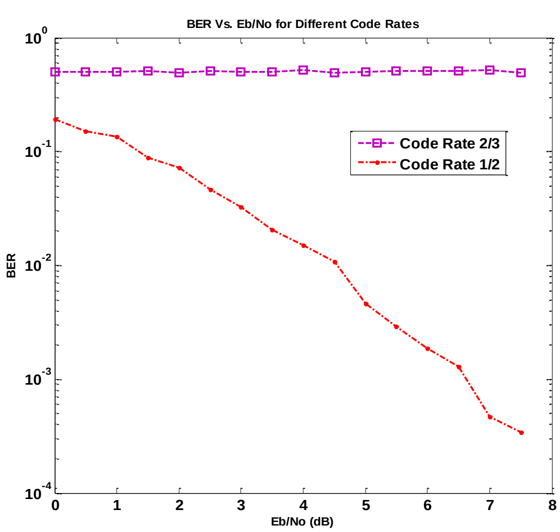

Fig. 4: BER Versus $Eb/N0$ for different Code rates

a) For $Eb/N0$ = 1dB

b) For $Eb/N0$ = 2dB

c) For $Eb/N0$ =6.5 dB

d) For $Eb/N0$ = 7.5dB

Fig. 6: performance of convolutional Codes at different values of Eb/No

In Fig. 6, convolutional codes ability to minimize errors is shown for several values of Eb/No. In Fig. 6(a), image is shown for $Eb/No = 1$ dB; here image is not that clear but by increasing the $\frac{Eb}{No}$ increase the performance improves and image gets clearer as shown in Fig. 6(b), (c) and (d) respectively. At a value of Eb/No say $7.5\,dB$ image is received with BER 10^{-5} whereas un-coded image provides poor performance at this value of Eb/No.

IV. CONCLUSION

This paper covers the performance of convolutional codes by using binary image. It is shown that convolutional codes provide much better error performance as compared with the data in which no coding scheme is used. It is shown that how varying the coding rate will disturb the ability of the system to correct errors. Similarly, it is shown that when a binary image is encoded by convolutional codes before transmission and decoded after reception we get almost the same image which was transmitted. So, we deduce that with convolutional codes BER 10^{-5} can achieved.

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