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Forward Error Correction Schemes for Encoding & Decoding

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Abstract—*This paper deals with implementation of Convolutional encoder and viterbi decoder using matlab where we are showing a simulated model of convolution encoder n viterbi decoder for calculating of error rate of 2/3. As I put the name of topic, shows the working of a forward error correction (FEC) coding schemes which is correcting the errors introduced during transmission. It is used in various fields like computer science, mathematics, information theory, and telecommunication, error detection and correction has great practical importance for maintaining data(information) integrity across noisy channels and less reliable storage media. A channel code is a term, which is broadly used, referring to the forward error correction (FEC) code and bit interleaving in communication and storage where the communication media or storage media is viewed as a channel .*

The FEC code is used to secure data and information sent over the channel for storage as well as recover even in the presence of noise (errors). There are two main categories of channel codes, called convolutional codes and block codes. Convolutional encoders are widely used to improve the performance of mobile phones, Bluetooth implementations, digital radio and satellite links. Unlike block encoders, convolutional encoders are not memoryless devices. Convolutional codes protect information by adding redundant bits to the binary data. Viterbi decoding is the technique for decoding the Convolutional codes. The Viterbi algorithm estimates the maximum likelihood path through a trellis based on received symbols.

1. INTRODUCTION

Reducing error, in satellite, wireless, and space communication systems, is a huge task. Wireless medium is quite different as compared to wired but provides several advantages, like; better productivity, mobility, low cost, scalability and easy installation facility. Along with these there are some restrictions and disadvantages of various transmission channels in wireless medium between transmitter and receiver where transmitted signals reach at receiver with different time delay and power due to the diffraction, reflection, and scattering effects[5]. Besides the BER (Bit Error Rate) value of the wireless medium is relatively high. These disadvantages sometimes introduce destructive effects on the wireless communication[2].

Hence error control is necessary in these applications. During digital data transmission and storage operations, performance criterion is commonly determined by BER which is simply: Number of error bits / Number of total bits. Noise in transmission medium disturbs the signal and causes data corruptions[15]. Relation between signal and noise is known as SNR (signal-to-noise ratio). Generally, SNR is explained with signal power / noise power and is inversely proportional with BER. It means, the less the BER result is the higher the SNR and the better communication quality [1]. There are two different types of FEC techniques, namely block codes and convolutional codes [6].

In telecommunication, information theory, and coding theory, forward error correction (FEC) or channel coding[1] is a technique used for controlling errors in data transmission over unreliable or noisy communication channels. The central idea is the sender encodes their message in a redundant way by using an error-correcting code (ECC). The American mathematician Richard Hamming pioneered this field in the 1940s and invented the first error-correcting code in 1950: the Hamming (7,4) code.

The redundancy allows the receiver to detect a limited number of errors that may occur anywhere in the message, and often to correct these errors without retransmission. FEC gives the receiver the ability to correct errors without needing a reverse channel to request retransmission of data, but at the cost of a fixed, higher forward channel bandwidth.[8] FEC is therefore applied in situations where retransmissions are costly or impossible, such as one-way communication links and when transmitting to multiple receivers in multicast. FEC information is usually added to mass storage devices to enable recovery of corrupted data, and is widely used in modems.[2]

FEC processing in a receiver may be applied to a digital bit stream or in the demodulation of a digitally modulated carrier. For the latter, FEC is an integral part of the initial analog-to-digital conversion in the receiver. The Viterbi decoder implements a soft-decision algorithm to demodulate digital data from an analog signal corrupted by noise.[2] Many FEC coders can also generate a bit-error rate (BER) signal which can be used as feedback to fine-tune the analog receiving electronics. The maximum fractions of errors or of missing bits that can be corrected is determined by the design of the FEC code, so different forward error correcting codes are suitable for different conditions.

2. TYPES OF FEC

The two main categories of FEC codes are block codes and convolutional codes.

i) Block codes work on fixed-size blocks (packets) of bits or symbols of predetermined size. Practical block codes can generally be decoded in polynomial time to their block length. It includes Hamming Codes, BCH Codes, RS Codes and LDPC Codes.

ii) Convolutional codes work on bit or symbol streams of arbitrary length. They are most often decoded with the Viterbi algorithm, though other algorithms are sometimes used. Viterbi decoding allows asymptotically optimal decoding efficiency with increasing constraint length of the convolutional code, but at the expense of exponentially increasing complexity. A convolutional code can be turned into a block code, if desired, by "tail-biting". Convolution codes are defined in terms of Turbo Codes, Trellis Code Modulation.[13]

There are many types of block codes, but among the classical ones the most notable is Reed Solomon coding because of its widespread use on the Compact disc, the DVD, and in hard disk drives. Other examples of classical block codes include Golay, BCH, Multidimensional parity, and Hamming codes.

Hamming ECC is commonly used to correct NAND flash memory errors. This provides single-bit error correction and 2-bit error detection. Hamming codes are only suitable for more reliable single level cell(SLC) NAND. Denser multi level cell (MLC) NAND requires stronger multi-bit correcting ECC such as BCH or Reed–Solomon.[8]

Classical block codes are usually implemented using hard-decision algorithms,[2][8] which means that for every input and output signal a hard decision is made whether it corresponds to a one or a zero bit. Incontrast, soft-decision algorithms like the Viterbi decoder process (discretized) the analog signals.

2.1 Concatenated FEC codes for improved performance

Classical (algebraic) block codes and convolutional codes are frequently combined in concatenated coding schemes in which a short constraint-length Viterbi-decoded convolutional code does most of the work and a block code (usually Reed-Solomon) with larger symbol size and block length "mops up" any errors made by the convolutional decoder. Single pass decoding with this family of error correction codes can yield very low error rates, but for long range transmission conditions (like deep space) iterative decoding is recommended.[4] Concatenated codes have been standard practice in satellite and deep space communications since Voyager 2 first used the technique in its 1986 encounter with Uranus. The Galileo craft used iterative concatenated codes to compensate for the very high error rate conditions caused by having a failed antenna.

2.2. Low-density parity-check (LDPC)

Low-density parity-check (LDPC) codes are a class of recently re-discovered highly efficient linear block codes. They can provide performance very close to the channel capacity (the theoretical maximum) using an iterated soft-decision decoding approach, at linear time complexity in terms of their block length. Practical implementations can draw heavily from the use of parallelism. LDPC codes were first introduced by Robert G. Gallager in his PhD thesis in 1960, but due to the computational effort in implementing encoder and decoder and the introduction of Reed–Solomon codes, they were mostly ignored until recently.[7] LDPC codes are now used in many recent high-speed communication standards, such as DVB-S2 (Digitalvideo broadcasting), WiMAX (IEEE 802.16e standard for microwave communications), High-SpeedWireless LAN (IEEE 802.11n), 10G Base-T Ethernet (802.3an) and G.hn/G.9960 (ITU-TStandard for networking over power lines, phone lines and coaxial cable). Other LDPC codes are standardized for wireless communication standards within 3GPP MBMS .

2.3. Turbo codes

Turbo coding is an iterated soft-decoding scheme that combines two or more relatively simple convolutional codes and an interleaver to produce a block code that can perform to within a fraction of a decibel of the Shannon limit. Predating LDPC codes in terms of practical application, they now provide similar performance. One of the earliest commercial applications of turbo coding was the CDMA2000 1x (TIA IS-2000) digital cellular technology developed by Qualcomm and sold by Verizon Wireless, Sprint, and other carriers. It is also used for the evolution of CDMA2000 1x specifically for Internet access, 1xEV-DO (TIA IS-856). Like1x, EV-DO was developed by Qualcomm, and is sold by Verizon Wireless, Sprint, and other carriers(Verizon's marketing name for 1xEV-DO is Broadband Access, Sprint's consumer and business marketingnames for 1xEV-DO are Power Vision and Mobile Broadband, respectively.).[7, 4]

3. INTERLEAVING

Interleaving is frequently used in digital communication and storage systems to improve the performance of forward error correcting codes. Many communication channels are not memoryless, errors typically occur in bursts rather than independently. If the number of errors within a code word exceeds the error-correcting code's capability, it fails to recover the original code word. Interleaving ameliorates this problem by shuffling source symbols across several code words, thereby creating a more uniform distribution of errors. [12]

Therefore, interleaving is widely used for burst error-correction. The analysis of modern iterated codes, like turbo codes and LDPC codes, typically assumes an independent distribution of errors. [11] Systems using LDPC codes therefore typically employ additional interleaving across the symbols within a code word. [14]For turbo codes, an interleaver is an integral component and its proper design is crucial for good performance. [12][13] The iterative decoding algorithm works best when there are not short cycles in the factor graph that represents the decoder; the interleaver is chosen to avoid short cycles. Interleaver designs include: rectangular (or uniform) interleavers, convolutional interleavers, random interleavers, S-random interleaver (where the interleaver is a known random permutation with the constraint that no input symbols within distance S appear within a distance of S in the output). Another possible construction is a contention-free quadratic permutation polynomial (QPP). [11] It is used for example in the 3GPP Long Term Evolution mobile telecommunication standard. In multi-carrier communication systems, interleaving across carriers may be employed to provide frequency diversity, e.g., to mitigate frequency-selective fading or narrowband interference.

4. TECHNIQUES FOR ERROR CORRECTIONS

Mapping an information into waveforms such that the receiver(with an appropriate demodulator and decoder) can recover the information in a reliable manner is done by Channel coding and modulation. A block diagram which shows this part of the digital communication link, is shown in Fig. 1.

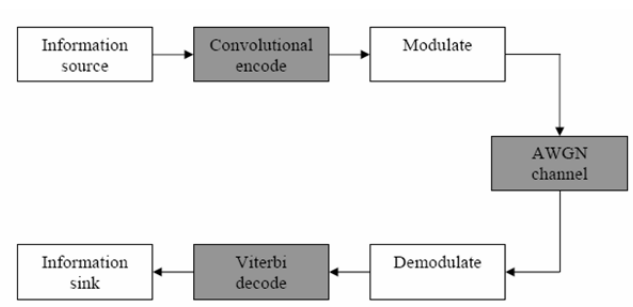

Fig. 1: Encode/decode and modulate/demodulate portions of a digital link

As shown in Fig. 1, convolutional encoding is one way of channel coding. Another method is known as block Codes. For determining the occurrence of an error due to noise present in the channel, the redundant bits are used. Similarly on the receiver side, Viterbi decoding is a way of performing channel decoding. Another encoding method is Turbo codes[7]. In these methods, errors can be "automatically" corrected (within specified limitations) to recover the original information(data). Error correction is a technique defined by the methods of encoding and decoding. One such simple technique, known as the automatic repeat request (ARQ), recognizes the occurrence of an error and requests the sender retransmit the message signal. Another technique, called as the forward error correction (FEC) technique. This technique allows for "automatic" correction of errors[11].

5. CONVOLUTION CODING

A convolutional encoder receives a sequence of message symbols and produces a sequence of code symbols. Its computations depends on the current set of input symbols and some of the previous input symbols as well. Usually, convolutional codes operate on a block at a time and so like block codes, have intra-block memory, and possibly no inter-block memory[12].

5.1 Convolutional Encoder

A convolutional encoder is made of a fixed number of shift registers. Each input bit enters a shift register and the output of the encoder is derived by combining the bits in the shift register. The number of output bits depends on the number of modulo 2-adders used with the shift registers.

1)*Encoder Parameters:* -Convolutional codes are commonly specified by the three parameters (n, k, m)

where, n = number of output bits

k = number of input bits and,

m = number of memory registers.

The quantity k / n called the code rate is a measure of the

bandwidth efficiency of the code. Commonly k and n parameters range from 1 to 8, m from 2 to 10, and the code rate from 1/8 to 7/8 except for deep space applications wherecode rates as low as 1/100 or even longer can be employed.Convolutional codes can also be specified by the parameters. (n,k,L) where, L is known as the constraint length of the code and is defined as the number of bits in the encoder memory that affects the generation of the n output bits. The convolutional codes discussed here will be referred to as (n,k,L) and not as (n,k,m) codes[6].

In order to understand the working of a convolutional encoder and further the forward error correction technique, the following assumptions have been made:

(a) A (2, 1, 3) convolutional encoder is used.

(b) A 3-bit input sequence is used specified by the bits [1 01].

(c) A 2 generator polynomials are used, specified by the bits [1 1 1] and [1 0 1].

It is easy to construct a convolutional encoder. We firstdraw *m* boxes representing the *m* memory registers. Then we draw *n* modulo-2 adders representing the *n* output bits.

Finally, we connect the memory registers to the adders using the bits specifying the generator polynomials[6]. Shown in Fig. 2 is a (2, 1, 3) convolutional encoder. This encoder is going to be used to encode the 3-bit input sequence [1 0 1] with the two generator polynomials specified by the bits [1 1 1] and [1 0 1]. u represents the input bit, and $v1$ and $v2$ represent the output bits 1 and 2 respectively. $u0$ and u_1 represent the initial state of the memory registers which are initially set to zero[14].

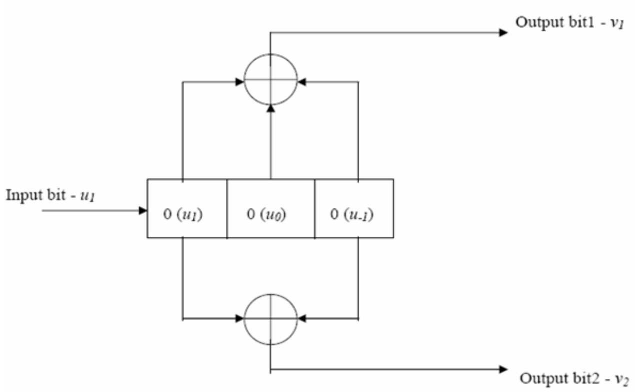

Fig. 2: A (2, 1, 3) convolutional encoder

6. VITERBI DECODER

The Viterbi decoder algorithm proposed in 1967 is a decoding process for convolutional codes. Convolution coding, as we all known, has been widely used in communication systems including deep space communications and wireless communications, such as IEEE802.11a/g, WiMax, DAB/DVB, WCDMA and GSM. Viterbi decoding algorithm is mostly applied to convolutional encoder and it uses maximum likelihood decoding technique [4]. Noisy channels cause bit errors at receiver. Viterbi algorithm estimates actual bit sequence using trellis diagram. Commonly, its decoding algorithm is used in two different forms. This difference results from the receiving form of the bits in the receiver[14]. Decoded information is received with hard decision or soft decision. Decoded information is explained with ±1 on hard decision operation while soft decision decoding uses multibit quantization [4].

Hard decision and soft decision viterbi decoding refer to the type of quantization used on the received bits. Hard decision decoding uses 1 bit quantization on the received channel values while soft decision decoding uses multibit quantization on the received channel values[16]. For hard decision decoding, the symbols are quantized to one bit precision while for soft decision decoding, data bits are quantized to three or four bits of precision. The selection of quantization levels is an important design decision because of its significant effect on the performance of the link [13].

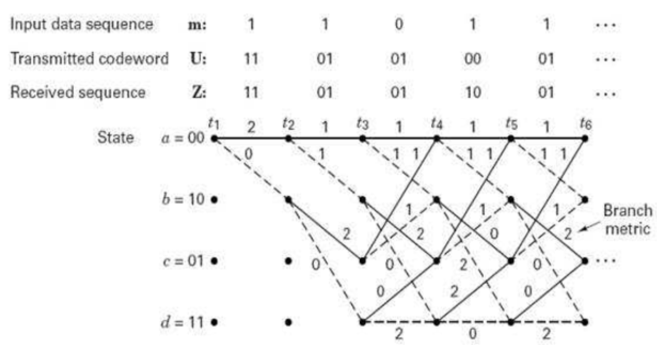

Fig. 3: Trellis diagram of Viterbi decoder

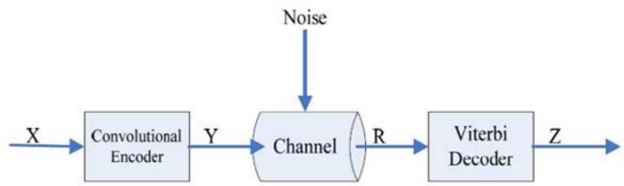

Fig. 4: A simple Viterbi decoding system

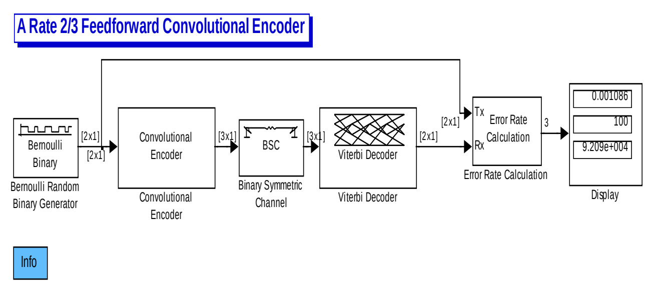

Fig. 5 : Convolutional encoder [17]

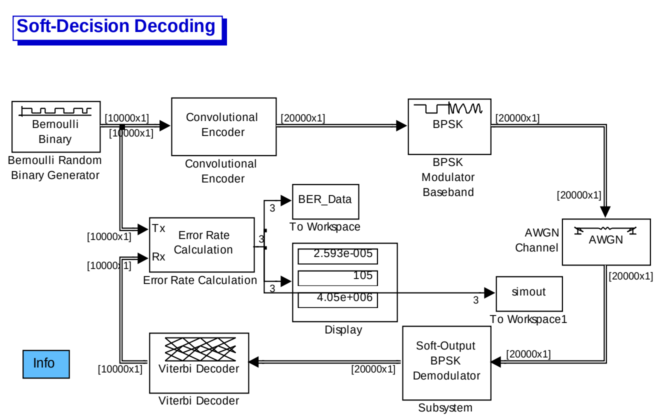

Fig. 6: Viterbi hard decoding decoder [17]

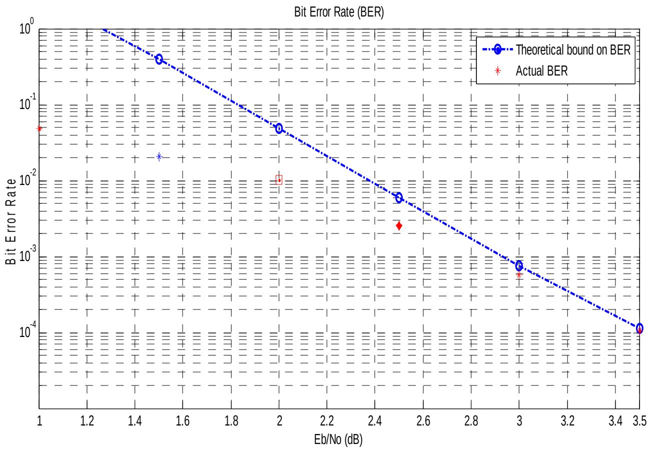

Fig. 7: Simulated bit error rate, theoretical and actual

7. CONCLUSION

The design of a convolutional encoder with a Viterbi decoder that can encode a bit stream of digital information and outputs a code word that has a capability to be transmitted to the destination and then decoded .The encoder was designed with a rate 1/2.The Viterbi decoder design had been driven in such a way that it would calculate the decoding path with the minimum metric to be passed to the decoder output port. Convolutional encoder and Viterbi decoder design has been successfully done using MATLAB and results obtained in terms of BER vs SNR. The motivation of this paper is to help the beginners to understand working of Viterbi algorithm those who wants to works on Viterbi decoder.

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