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Advantages of Error Control Coding for Long Distance Communication–A Study

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Abstract—*Modern digital communication system requirements are becoming more and more stringent with respect to error-free transmission. Next generation systems would like to offer Quality of Service (QoS) guarantees to users, this cannot be done unless more efficient error correction schemes can be implemented.This paper initially illustrates the need of error correcting codes with the help of "waterfall" model in long distance communication. The most efficient and adopted version(type) of channel coding is convolution coding technique is also mentioned in this paper. The performance of structured sequence is implemented and analyzed with the help of MATLAB. As the current technologies, requires an efficient coding method which performs in the region where there is infeasibility of retransmission and high bit error rate as well. The elementary performance of convolution code with lower and higher modulation rate in AWGN channel is shown with the help of simulated results of MATLAB.*

1. INTRODUCTION

Now-a-days reliability in communication becomes a concerning issue. So any communication network should be designed to prevent, detect and correct the errors introduced during transmission. In digital, satellite, wireless and deep space communication error reduction is critical. There are various causes of noise such as poor connection (echo), closeness in the guard band (cross talk), sudden raise in electricity(impulsive noise), gradual decrease in signal (attenuation), movement in electron(thermal noise), interference, fading etc.Depending upon the network design, error comes into the picture.

Normally error are bursts in nature which means more than one bit changed in transmission. This leads to reduction in reliability and performance of the system. To maintain errors channel codes arises with the feature of detection and correction as well.In the late 1940's the approach to error correction coding taken by modern digital communications system started with the ground breaking work of Shannon, Hamming and Golay[1,2,3].The theoretical limits of reliable communication were defined by the Shannon while Hamming and Golay were developing the first practical error control schemes. All communication channels are subject to the additive white Gaussian noise (AWGN) around the environment. Forward error correction (FEC) techniques are used in the transmitter to encode the data stream and receiver to detect and correct bits in errors, hence minimize the bit error rate (BER) to improve the performance. Performance of using coding techniques is shown in Fig. 3 in this paper.

2. NEED OF ERROR CORRECTING CODE

Error correction coding can be regarded as a vehicle for effecting various system trade-offs. The deep-space channel turned out to be the perfect link on which to first demonstrate the power of coding. There were several reasons for this, most notably those listed below[6,10].

1) The deep-space channel is almost exactly modeled as the memoryless AWGN channel that formed the basis for Shannon's noisy channel coding theorem. Thus, all the theoretical and simulation studies conducted for this channel carried over almost exactly into practice.

2) Plenty of bandwidth is available on the deep-space channel, thus allowing the use of the low-spectral efficiency codes and binary-modulation schemes that were most studied and best understood at the time.

3) Because of the large transmission distances involved, which caused severe signal attenuation, powerful, low rate codes, with complex decoding methods, were required,resulting in very low data rates. However, since a deep-space mission is, by nature, a very time-consuming process, the low data rates realized in practice did not present a problem.[6].

E_b/N_o is the Fig. of merit in long distance communication.Fig. 1 compare the two curves depicting bit error performance versus E_b/N_o.The Solid line curve shows a typical modulation scheme without coding and a solid line (with arrow)represents the same modulation (here it is BPSK) with coding(Convolution coding with hard decision).As stated below are few advantages or trade-offs that can be achieved with the use of channel coding.

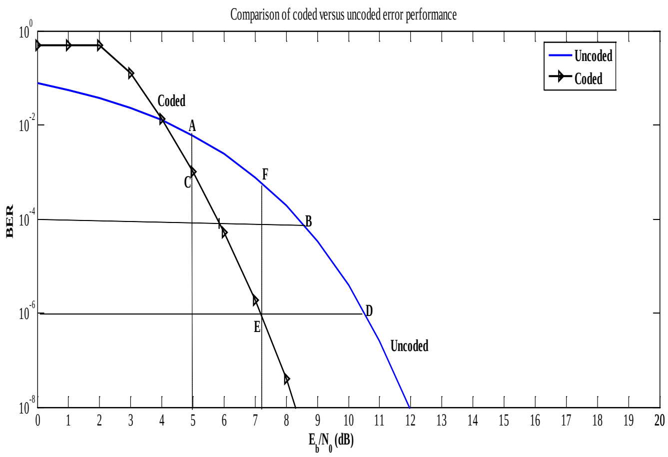

Fig. 1: Comparison of typical coded versus uncoded error performance

2.1. Error performance versus bandwidth

Let us consider a communication system without error correction codes. Consider the operating point of the system can be limned by point A in Fig. 3 (E_b/N_o=5dB and BER = 0.005954).After few trials the quality of data subsidence and it is suggested to lowered the bit error probability to 10^{-4}.One way to obtain better error performance in such a system would be by effecting operating point movement from A to Another way is to move operating point A to point C i.e “walking down ”the vertical line to point C(E_b/N_o=5dB and BER = 0.000981). on the coded curve can also provide improved error performance for the same value of E_b/N_o.For coded transmission ,it need encoder as well as decoder. For real time communication system the addition of redundant bits impose a fast rate of transmission which lead to more bandwidth.

1.2. Power versus bandwidth

Consider that a system without coding, operating point D (E_b/N_o=10.3dB and BER = 10^{-6}) is delivered. Now there is no issues about quality of data but the equipment is having some reliability problems. The equipment keeps breaking down. If the requirement on E_b/N_o or power could be reduced. Fig. 1 suggests a trade off by moving the operating point from D to E(E_b/N_o=7.1dB and BER =10^{-6}) .i.e if error correction codes is introduced , a reduction in the required E_b/N_o can be achieved. Hence it is concluded that the same quality of data is achieved but coding allows for reduction in power or E_b/N_o and it costs bandwidth.

For non real time communication system it is possible to obtain improved bit-error probability or reduced power (trade off 1 or 2)by paying the price of delay instead of bandwidth.

1.3. Coding gain

Coding gain is defined as the reduction in E_b/N_o that can be realized through the use of code. Coding gain G is expressed in dB

$$G(\mathrm{dB}) = \left(\frac{Eb}{No}\right)u(\mathrm{dB}) - \left(\frac{\mathrm{Eb}}{\mathrm{No}}\right)c(\mathrm{dB})\ldots\ldots\text{Eqn.} \quad (1)$$

Where $(E_b/N_o)_u$ and $(E_b/N_o)_c$ stands for the required (E_b/N_o)uncoded and coded respectively.

1.4. Data rate versus bandwidth

Consider that a system without coding ,operating at point D in figure1 (E_b/N_o=10.5dB and BER = 10^{-6}) has been developed. Assume that there is no issues with data quality and no particular need to reduce power. If data rate requirement increases at receiver end. Then from equation

$$\frac{\mathrm{Eb}}{\mathrm{No}} = \frac{\mathrm{Pr}}{\mathrm{No}}\left(\frac{1}{\mathrm{R}}\right)\ldots\ldots\ldots\ldots\text{Eqn.(2)}$$

Where P_r = receiver power and R= bit rate. As the above expression shows that the increase in R will reduce E_b/N_o and the operating point would move upward from D to F(say(E_b/N_o=7.2dB and BER = 0.0005653).Now envision “walking” down to point E on the coded modulation curve. Increasing the data rate has degraded the quality of the data. But the use of error correction code maintain same quality at the same power level(E_b/N_o).The E_b/N_o is reduced,but the code facilities getting the same error probability with lower E_b/N_o The increase in data rate will lead to increase in bandwidth.

3. CHANNEL CODING

The main purpose of channel encoding is to improve communications performance by signal transformation. It is categorized into two class, waveform coding and structured sequences. Waveform coding deals with transforming waveform into “better waveform” which make detection process less subject to error .e.g M-ary signaling, Antipodal, Orthogonal etc. Structured sequences deals with transforming data sequence into “better sequence” having redundant bits. These redundant bits used for detection and correction of data.e.g Block code, Convolution code, Turbo code etc[7,8,11]. Basic model of communication system is shown in Fig. 2.

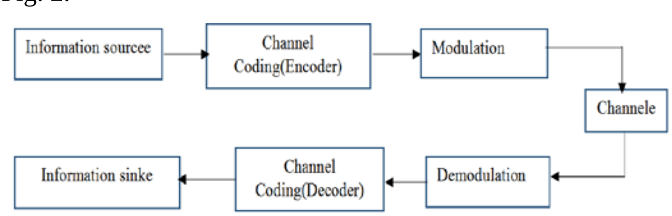

Fig. 2: Communication system with channelcoding.

Here structured sequences is considered as channel encoding and decoding in the model. Those structured sequences are Block and convolution code.

Block code can be characterized by (*n*,*k*) notation. They have very high code rates, usually above 0.95 [4].The encoder transforms a block of *k* message digits into a longer block of *n* codeword word digits. The *k*-bit messages form 2^k distinct message known as *k*-tuples.The *n*-bit block messages can form 2^n distinct sequence known as *n*-tuples.

Convolution code first introduced by Elias [5,12] , have been applied over the past decade to increase the efficiency of numerous communication systems. It is characterized by (*n*,*k*,K) where the integer K describes constraint length. And the ratio *k/n* is the code rate. They have low code rates, usually below 0.90. Convolutional encoding with Viterbi decoding is a powerful FEC technique that is particularly suited to a channel in which the transmitted signal is corrupted mainly by AWGN. It operates on data stream and has memory that uses previous bits to encode. It is simple and has good performance with low implementation cost[13]. The Viterbi algorithm (VA) was proposed in 1967 by Andrew Viterbi [8] and is used for decoding a bit stream that has been encoded using

FEC code. The convolutional encoder adds redundancy to a continuous stream of input data by using a linear shift register. The Convolutional Encoder and Viterbi Decoder used in the long distance communication.

4. PERFORMANCE ANALYSIS

For the same parameter of transmission the BER vs E_b/N_o curve is simulated and analysed. The performance of the FEC technique improves or the bit error rate (BER) decreases as *Eb/No* increases[7]. To analyse how the noise level affects the performance of the FEC technique, a number of simulation tests were conducted using the MATLAB codes with various coding techniques

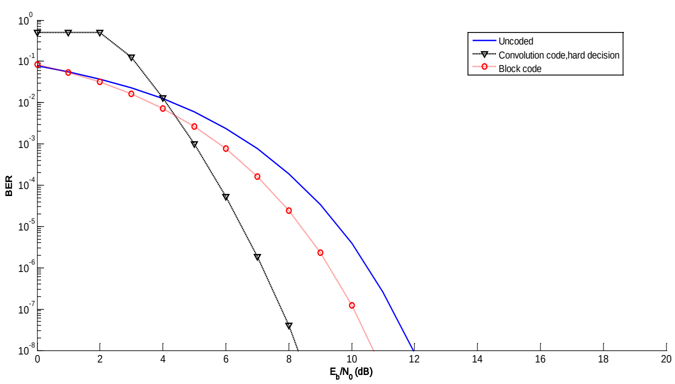

Fig. 3: Performance of different coding techniques.

Table 1 lists the SNR (*Eb/No*) in dB achieved with our MATLAB implementation using both, the block and convolution code. Table 2 lists the coding gain in dB corresponding to Table 1 by using eqn (1).

Table 1: SNR (*Eb/No*) in dB

BER	Eb/No		
	Convolution Coding	Block Coding	Uncoded
10-2	5	5.8	6.8
10-3	5.8	7.2	8.3
10-4	6.3	8.2	9.3

using higher order modulation (e.g. 64QAM, etc)that are able to carry higher data rates as well as lower order modulation offer lower data rates having less power requirement.

Table 3: SNR (*Eb/No*) in dB

BER	Eb/No	
	Lower Order Modulation	Higher Order Modulation
10-2	4	11
10-4	5.8	13
10-6	7.1	14.8

Table 2: Coding Gain in dB

BER	Coding Gain	
	Convolution Coding	Block Coding
10-2	1.8	1
10-3	2.3	1.1
10-4	3	1.1

Table 3 lists the SNR (*Eb/No*) in dB achieved with our MATLAB implementation shown in Fig. 4

4.1. Factor affecting the BER

It can be seen BER can be affected by a number of factors. By manipulating the variables that can be controlled it is possible to optimise a system to provide the performance levels that are required. This is normally undertaken in the design stages of a data transmission system so that the performance parameters can be adjusted at the initial design concept stages.

4.1.1. Interference

The interference levels present in a system are generally set by external factors and cannot be changed by the system design. However it is possible to set the bandwidth of the system. Byreducing the bandwidth the level of interference can be reduced. However reducing the bandwidth limits the data throughput that can be achieved.

4.1.2. Increase transmitter power

It is also possible to increase the power level of the system so that the power per bit is increased. This has to be balanced against factors including the interference levels to other users and the impact of increasing the power output on the size of the power amplifier and overall power consumption and battery life, etc.

4.1.3. Lower order modulation

Lower order modulation schemes can be used, but this is at the expense of data throughput.

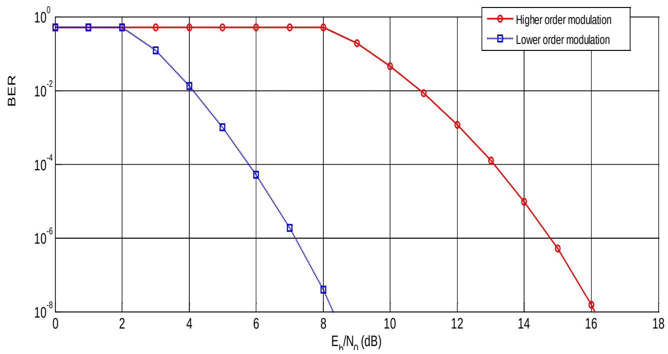

Fig. 4: Performance of convolution code at higer and lower order modulation.

5. CONCLUSION

From the above results it is concluded that the coding gain is more in case of convolution coding as compared to block and uncoded data.Hence convolution coding is better suited for long distance communication. In particular, higher order modulation schemes (e.g. 64QAM, etc) are not as robust in the presence of noise. Lower order modulation formats (e.g. BPSK, QPSK, etc.) are more robust. This fact is varified by the Fig. 4 and.table 3.In addition to this the plenty of banwidth available in deep space communication also helps in better error performace,reduction in power on the cost of bandwidth.BER also affected by transmitted power and the modulation rate. As the value of *Eb/No* is less the coding gain will be high, which improves the performance of the system. Hence keeping all facts together it is concluded that Convolution coding with lower modulation rate have better performance and is well suited for long distance communication where robustness is an important concern.

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