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Reducing the Bit Error Rate of a Digital Communication System using an Error-control Coding Technique

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Abstract - Digital communication systems have played a vital role in the growing demand for data communications. In communication systems when data is transmitted or received, error is produced due to unwanted noise and interference from the communication channel. For efficient data communications it is necessary to receive the data without error. Error-control coding technique is to detect and possibly correct errors by introducing redundancy to the stream of bits to be sent to a channel. In this paper error rate reduction is simulated and analyzed using hamming code in MATLAB/Simulink environment. It was found that the injected bit errors reduced considerably using a hamming code.

Keywords— Bit Error Rate, Data, Error-control code, MATLAB/Simulink, Noise.

1 INTRODUCTION

Recent technological advancement in communication systems has seen an evolution from analog communication systems to digital communication systems[1]. This is as a result of increasing demand in data communication and digital communication gives the perfect solution to this demand. Such solutions include data processing options and flexibilities which are not available with analogue communication.

The primary advantage of digital signals for digital communication has over the analog signals for analog communication is that it can be regenerated[2]. Fig1 below shows the degradation and regeneration of a digital system.

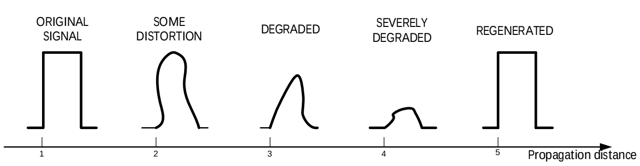

Fig1.Signal degradation and regeneration

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The distortion in the waveform is as a result of unwanted noise and interference. This can be regenerated using a digital repeater to recover it to its original state. However, this is not achievable for analog signals. In this paper, a digital communication system with injected bit error was simulated. Analysis of the error reduction rate using a block coding technique was carried out in the MATLAB/Simulink environment.

2 ERROR-CODING TECHNIQUES

The digital communication system deals with information in the form of data, video or voice for transmission form one point to another. A typical digital communication system is shown in fig2. During transmission digital signal is greatly distorted as a result of errors caused by sorts of noise. To increase the possibility of detecting and possibly correcting such errors, a certain degree of redundancy is needed to be added to the information carrying signal as a form of control digits[3]. Such technique known as error-control coding technique provides a secure and reliable transmission of data over the imperfect noisy channel by detecting and possibly correct errors by introducing redundancy to the stream of bits to be sent through the channel. The channel encoder will add bits to the message bits to be transmitted. The channel decoder interprets what it receives, using the redundant symbols to detect and possibly correct whatever errors might have occurred during transmission.

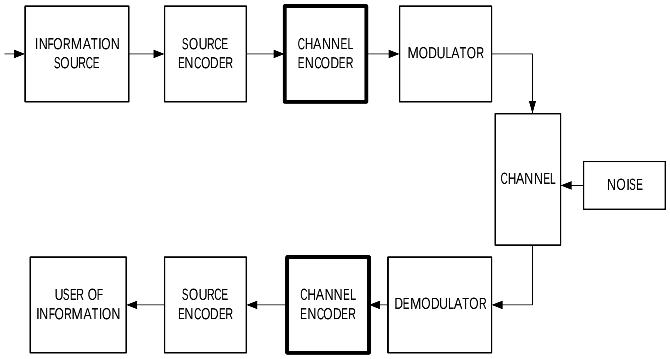

Fig2. Typical block diagram of a digital communication system

Error-control coding is typically used if the transmission channel is very noisy or if the data is very sensitive to noise. Depending on the nature of the noise or data a specific type of error-control coding is applied. Linear block codes and convolution codes are mainly used for error-control coding. In this paper, the linear block code or block coding is used for the error-control coding because it is easier to work with and form a large class of useful codes[4]. Moreover, most of the codes that exist today belong to the class of linear block codes[5]. Another significant advantage of the linear block code is that it is very easy to implement in hardware[6]The block coding technique maps a fixed number of message symbols to a fixed number of code symbols. A block coder treats each block of data independently and is a memoryless device. The class of block coding techniques includes categories shown in fig.3 and the hamming code specifically would be used for simulation.

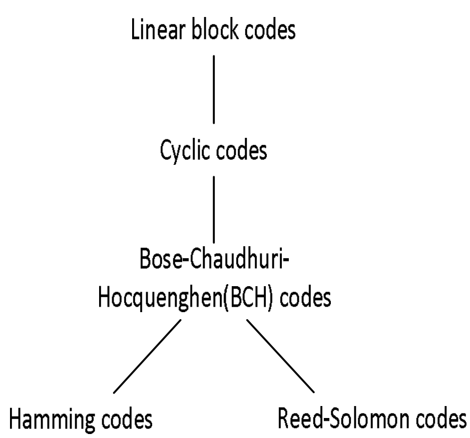

Fig3. Block coding techniques

Error control codes have found many applications among which are CD applications, data storage and retrieval in computers, digital audio and videos systems, control and communication systems for aerospace applications, cellular telephony and security enhancements in banking and barcodes[7].

2.1 LINEAR BLOCK CODES

Linear block codes are applicable in methods for transmitting symbols(e.g. bits) so that errors can be corrected or detected by a receiver after transmitted on a communication channel. The codewords in a linear block code are block of bits which are encoded using more bits than the original value to be sent.

Assuming the output of an information source is a sequence of binary digits "0" or "1". In block coding, this binary information sequence is segmented into message blocks of fixed length and each message block consists of k information digits. There are a total of 2^k distinct messages. The block coder converts a block of k bits to a block of n bits, where $k < n$. A binary block code is a set of different codewords of n bits as shown in fig4 below.

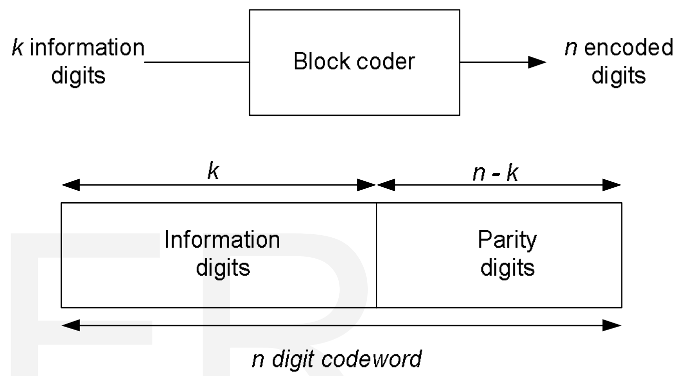

Fig4. Linear Block Coder[8]

Therefore, corresponding to the 2^k possible messages, there are 2^k code words. This set of 2^k code words is called a block code. For a block code to be useful, the 2^k code words must be distinct. Therefore, there should be a one-to-one correspondence between a message and its codewords. For example, the [7,4,3] hamming code is a linear binary code which represents 4-bit messages using 7-bit codewords. Two distinct codewords differ in at least three bits. As a consequence, up to two errors per codeword can be detected while a single error can be corrected[9]. This code contains $2^4 = 16$ codewords.

3 SIMULINK SIMULATION

3.1 CHANNEL NOISE MODEL

The channel noise model generates a random binary signal, which switches the symbols *0* and *1* in the signal, according to a specific error probability, to simulate a channel with noise. This model is depicted in fig5. The model then calculates the error rate and displays the result.

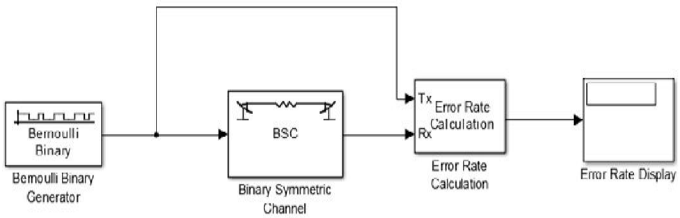

Fig5: Channel Noise Model

The source for the signal is the Bernoulli Binary Generator block, which generates a random binary sequence. The Binary Symmetric Channel block simulates a channel with noise. It introduces random errors to the signal by changing a *0* to a *1* or the reverse, with a set probability of *0.01*. The Error Rate Calculation block calculates the error rate of the channel.

The block compares the transmitted and received signal via the input ports *Tx* and *Rx* and subsequently check for errors. The output of the block is a vector with three entries:

- Bit error rate of 0.01147
- Number of errors equal 100
- Total number of bits that are transmitted to be 8717

The Error Rate Display block displays the output of the Error Rate Calculation as above. It is worthy of note here that the initial seeds in the Bernoulli Binary Generator block and the Binary Symmetric Channel block have different values so that the source signal and the channel noise are statistically independent.

3.2 HAMMING CODE MODEL

In the hamming code model, the hamming encoder and hamming decoder blocks are added onto the channel noise model as shown in fig6.

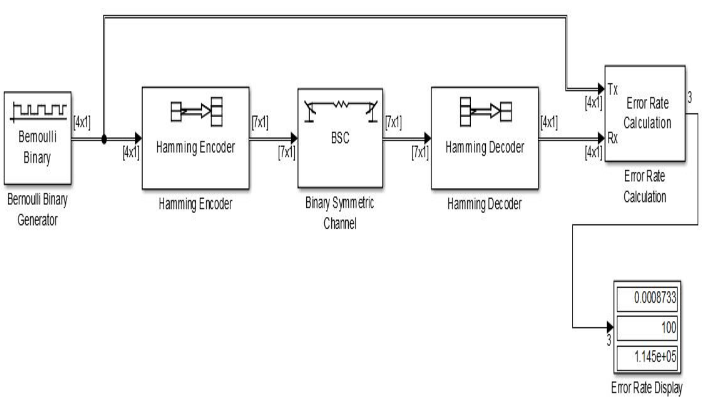

Fig6. Hamming code model

The Hamming Encoder block encodes the data before it is sent to the channel. A [7,4] hamming code encodes message words of length 4 into codewords of length 7. The input of block has a vector of size 4 and converts to a vector of size 7. So its output is labeled [7x1]. Note that the line leading out of the Bernoulli Binary Generator block is labeled [4x1], indicating that its output consists of column vectors of size 4. The code can correct one error in each transmitted codeword. The Hamming Decoder block decodes the data after it is sent through the channel. If at most one error is created in a codeword by the channel, the block decodes the word correctly.

However, if more than one error occurs, the hamming decoder block might decode incorrectly due to fact that the signal cannot match other codewords. At the end of simulation we can see that the bit error rate is approximately 0.001. Now, theoretically, the probability of error, *P* in a codeword length is given by (1)

$$P = \sum_{j=0}^{n} \binom{n}{j} p^{j} (1-p)^{n-j} \qquad (1)$$

where *p* = error probability(equals 0.01 from section 3.1), *n* = length of codeword(in this case equals 7) and *j* = number of errors[2]. Hence the probability of two or more errors occurring in a codeword of length 7 is

$$P = 21(0.99)^5(0.01)^2 + 35(0.99)^4(0.01)^3 + 35(0.99)^3(0.01)^4 + 21(0.99)^2(0.01)^5 + 7(0.99)^1(0.01)^6 + 0.01^7 = 0.002$$

If the codewords with two or more errors were decoded randomly, the expectation is that half the bits in the decoded message words would to be incorrect. Therefore the displayed 0.001 value is a reasonable value for the bit error rate.

3.3 HAMMING CODE EXPANDED MODEL

In order to see whether the hamming model is functioning correctly, a Scope block is added to display the channel errors produced by the binary symmetric channel block as shown in fig7 below.

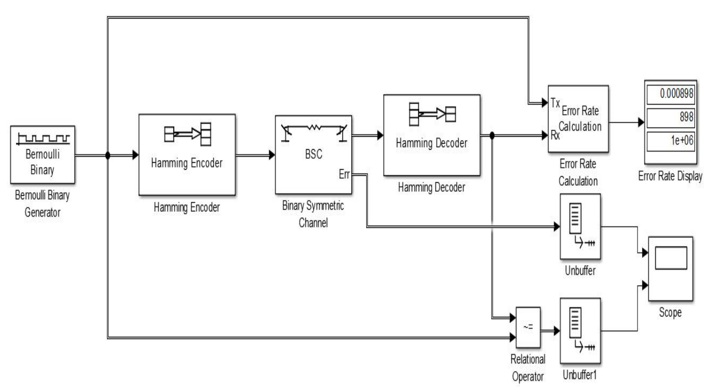

Fig7. Hamming code expanded model

The relational operator block compares the transmitted signal coming from the Bernoulli random generator block with the received signal coming from the hamming decoder block. The block outputs a 0 when the two signals agree and a 1 when they disagree. Now the Scope block displays the injected channel errors and uncorrected errors against time.

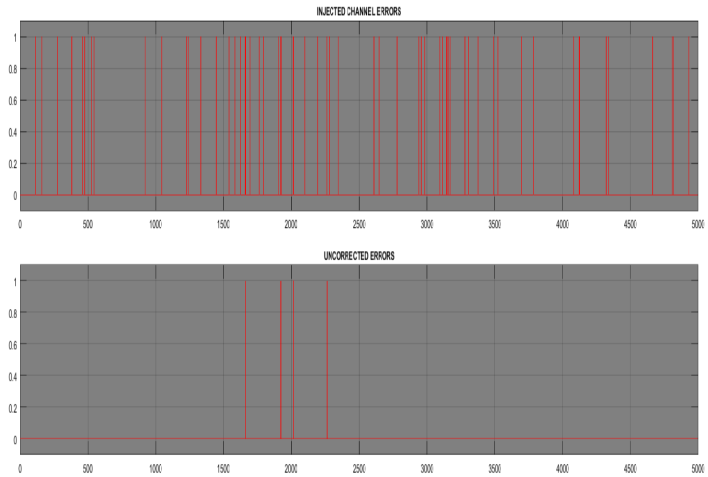

Fig8. Scope Display

At the end of each five thousand time steps, the scope appears as shown above in fig8. The scope then clears the displayed data and displays the next five thousand data points. The upper scope shows the channel errors generated by the binary symmetric channel block. The lower scope shows errors that were not corrected by channel encoding/hamming code.

4 CONCLUSION

The aim of the paper is to simulate a binary communication system in MATLAB/SIMULINK and observe the error rate of the system using a block coding technique in particular the hamming code. From the results shown in section 3.0 it can be observed the error rate reduces to a considerable level and the results verified using theoretical and practical methods.

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