Communication Simulation with Error Correcting Code using Matlab

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Abstract– The objective of this study is to evaluate the performance of different type of error correcting code in an Additive White Gaussian Noise (AWGN) channel. Error control coding incorporates information into the signal that allows a receiver to find and correct bit error occurring in transmission and storage. Since such coding detects or correct errors incurred in the communication or storage channel, it is often referred to as channel coding. This project involves the design of a complete communication system. The error correcting codes that were used are Bose-Chaudhuri-Hocquenghem code (BCH) and Hamming code. The BCH code and Hamming code are hard decision codes. The capability of these error correcting codes to detect and rectify error were assessed and evaluated. The bit error rate (BER) of a communication system is defined as the ratio of number of error bits to the total number of bits transmitted during a specific period. It is the likelihood that a single error bit will occur within the received bits, independent of the rate of transmission. The maximum codeword length (n) used in the hamming code is 63 and the message length (k) is 57. For BCH code, the maximum N is 63, K is 36 and error-correction capability, t is 5.The results show that the best performance occurs when the communication system uses a BCH code with N=31, K=11 and t=5 with BPSK modulator/demodulator. The higher the values of N, K and t, the better the performance and in general BCH codes are better than Hamming code. Programming used is Matlab Software.

Keywords: Additive White Gaussian Noise (AWGN) channel, Bose-Chaudhuri-Hocquenghem code (BCH), energy per bit to noise power spectral density ratio (Eb/No), Bit Error Rate (BER), codeword length (N), message length (K), error-correction capability (t).

1. Introduction

1.1 Block diagram

The basic block diagram for a communication system must include the data source, error encoder, modulator, channel, demodulator error decoder and received signal. Figure 1 shows the block diagram of a basic communication system.

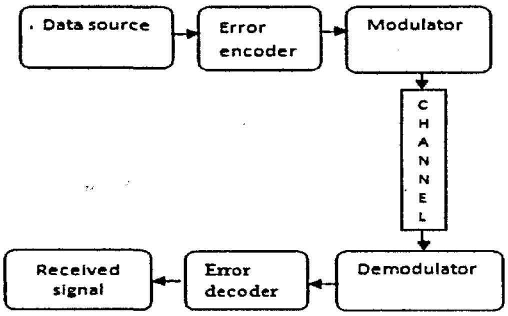


Figure 1: Block Diagram of Communication System.

Data source generates the information signal that is intended to be sent to a particular receiver. An encoder can be used to add redundancy to a digital data stream, in the form of additional data bits, in a way that provides an error correction capability at the receiver. Modulation refers to the specific technique used to represent the information signal as it is physically transmitted to the receiver. Once the signal is modulated, it is sent through a transmission. In this channel, noise with uniform power spectral density (hence the term white) is assumed to be added to the information signal [1]. When the transmitted signal reaches the intended receiver, it undergoes a demodulation process. This step is the opposite of modulation and refers to the process required to extract the original information signal from the modulated signal. When data encoding is included at the transmitter, a data decoding step must be performed prior to recovering the original data signal. The signal decoding process is usually more complicated than the encoding process and can be very computationally intensive. An estimate of the original signal is produced at the output of the receiver [2].

The objective of this research is to design a complete communication system which is able to simulate the performance of different type of block code and also to evaluate the performance of the communication system when different parameters are used. In this project, the modulator and the demodulator used were BPSK and QPSK. The block codes used for the simulation are Hamming code and BCH code. The channel used was the Additive White Gaussian Noise (AWGN) channel.

A similar research has been carried out but by using Rayleigh fading channel as the medium of transmission. Figure 2 shows the block diagram for BER calculation with channel coding when using Rayleigh fading channel.

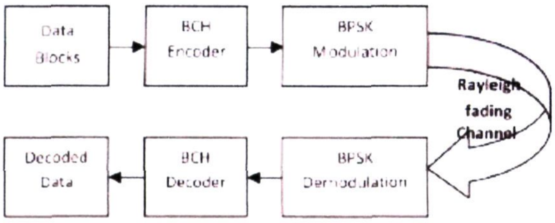


Figure 2: General Block diagram for BER calculation with channel coding (In Matlab).

2.8 million random data bits were generated and sent through Multipath Rayleigh Fading channel which Eb/No was varied from -3 dB to 12 dB for each iteration. Upon reception, each received bit was compared with its corresponding sent bit and number of errors was counted. This error number value, found above, was divided by the total number of bits (2.8 million) to get probability of error for a specific value of Eb/No (e.g. -3 dB). This process was repeated for all values of Eb/No (up to 12 dB), for both uncoded and coded data blocks. Figure 3 shows the performance of (63, 56) BCH codec for uncoded vs. coded data blocks [3].

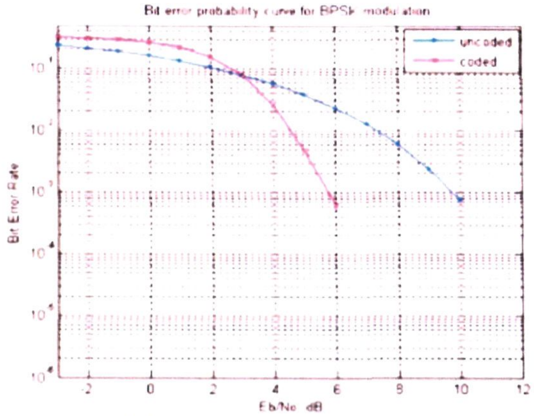


Figure 3: BER curve for uncoded and coded data sent Through BPSK modulation over Multipath Rayleigh fading channel.

2. Methodology

The simulation was divided into three parts: simulation without block codes, simulation with hamming code and simulation with BCH code when using the BPSK/QPSK modulator/demodulator.

2.1 Block Diagram for Simulation of a Communication System without Error Correcting Code.

Figure 4 shows the design of a communication system without incorporating error correcting codes in Matlab software.

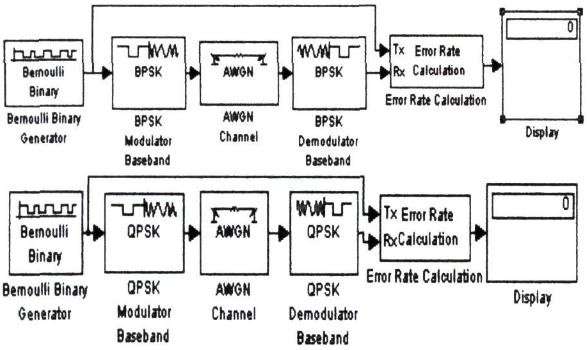


Figure 4: Simulation without error correcting codes.

In this simulation, it uses Bernoulli binary generator. The Bernoulli generator is used for sending the data to the BPSK/QPSK modulator. The Bernoulli Binary Generator block generates random binary numbers using a Bernoulli distribution. Then for modulator, it uses the BPSK/QPSK modulator baseband and BPSK/QPSK demodulator baseband. The channel used in this simulation is AWGN channel. When the simulation is started, the value of (Eb/No) in AWGN channel varies from 0(dB) to 10(dB).This is to see the performance of BER when (Eb/No) varies. The Error Rate Calculation block compares the input data from a transmitter with the input data from the receiver. It calculates the error rate as a running statistic, by dividing the total number of unequal pairs of data elements by the total number of input data elements from one source. The display is to show the Bit Error Rate at the end of the simulation. Equation (1) is the BER theory calculation for BPSK and Equation (2) is the theory calculation for QPSK [4].

BER=0.5ERFC [sqrt (Eb/No)] .... (1)
BER=0.5ERFC [sqrt (Eb/2No)] .... (2)

2.2 Block Diagram for Simulation of a Communication System with Hamming Code.

Figure 5 shows the design of a communication system with hamming code in Matlab software.

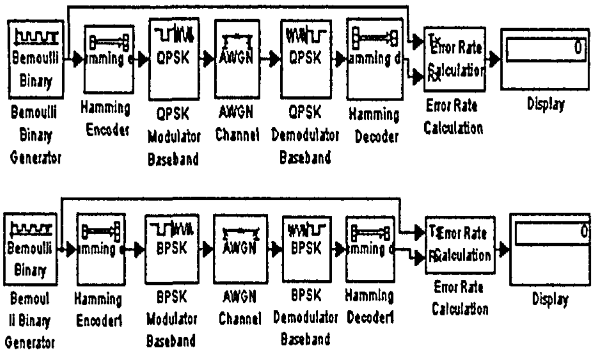


Figure 5: Simulation for BPSK and QPSK modulator/demodulator with hamming code.

For this simulation, hamming encoder and hamming decoder were used. The output from the Bernoulli Binary Generator is frame based. The Hamming Encoder block creates a Hamming code with message length K and codeword length N. The number N must have the form 2^M-1, where M is an integer greater than or equal to 3. Then K equals N-M. The value for the sample per frame in Bernoulli Binary Generator must be the same as the value of the massage length (K) in Hamming encoder. The outputs of the hamming encoder are sent to QPSK/BPSK modulator baseband. In QPSK modulator, the phase offset (rad) is set to $\pi/4$ and for BPSK set to 0. For mode in AWGN channel, it changes to ratio of signal energy to noise power spectral density (Es/No).The Equation for (Es/No) is:

$$Es/No = (Eb/No)\ dB + 10\log(K/N) \quad \ldots\ldots (3)$$

The (Eb/No) varies from 0dB to 10dB. The value of the codeword length (N) increases from 7,15,31 to 64. The Hamming Decoder block recovers a binary message vector from a binary Hamming codeword vector. For proper decoding, the parameter values in this block should match those in the corresponding Hamming Encoder block. Equation (4) is the BER theory calculation for block codes [5].

$$BER = \frac{dmin * Pe}{n} \qquad \ldots\ldots\ldots (4)$$

$$Pe = 1 - \sum P(i,n)$$

$$P(i,n) = \frac{n!}{i!\,(n-i)!}\, p^i (1-p)^{n-i}$$

Where dmin = 2t+1, error-correction capability, t.
n = codeword length
Pe = probability of error in block code
P(i,n) = probability of i erroneous symbols in a block of n symbol.

2.3 Block Diagram for Simulation of a Communication System with BCH code.

Figure 6 shows the design of a communication system with BCH code in Matlab software.

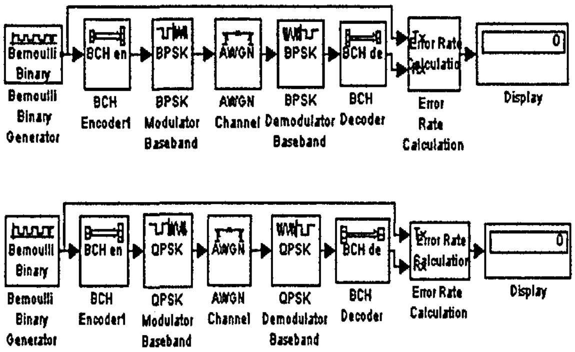


Figure 6: Simulation for BPSK and QPSK modulator/demodulator with BCH code.

For this simulation, BCH encoder code and BCH decoder code were used. The BCH Encoder block creates a BCH code with message length K and codeword length N. The input must contain exactly K elements. The output is a vector of length N For a given codeword length N, only specific message lengths K are valid for a BCH code. No known analytic formula describes the relationship among the codeword length, message length, and error-correction capability. The tables below list valid [N, K] pairs for small values of N, as well as the corresponding values of the error-correction capability, t [6].

Table 1: The value of codeword length (N), message length (K) and error-correction capability (t).

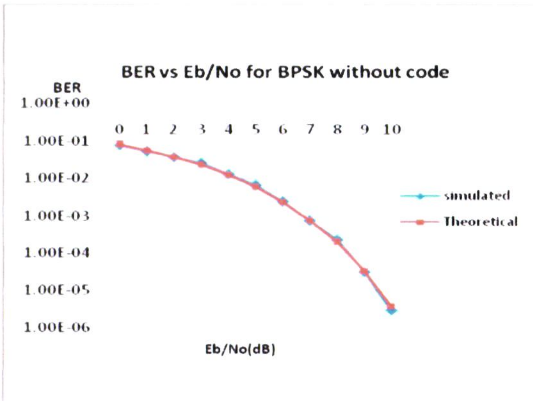
N	K	t
7	4	1
15	7	2
31	11	5
63	36	5

The BCH Decoder block recovers a binary message vector from a binary BCH codeword vector. The value of codeword length (N) and message length (K) in the BCH encoder must be the same with the BCH decoder.

3. Results and Discussion

3.1 Performance of a Communication System (using BPSK) without Error Correcting Codes.

Graph 1 shows the simulated BER and the theoretical BER for BPSK channel without error correcting code .

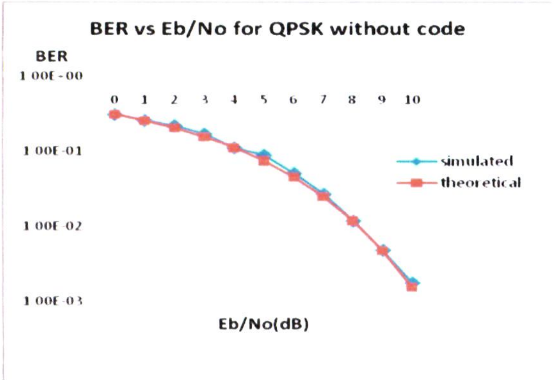


Graph 1:BER vs (Eb/No) of a communication system (using BPSK) without error correcting codes.

The value of Eb/No varies from 0dB to 10dB. At 0dB, the simulated BER is 0.0771 and theoretical BER 0.078649632. The difference between the simulated BER and the theoretical BER is 0.0015496.At 10dB, the simulated BER is 3.00E-06 and the theoretical BER is 3.87211E-06.The difference between the simulated BER and the theoretical BER is very small which is 8.72E-07. As a conclusion, the value of the theoretical BER is similar to the simulated BER.

3.2 Performance of a Communication System (using QPSK) without Error Correcting Codes.

Graph 2 shows the simulated BER and the theoretical BER for QPSK channel without error correcting code .

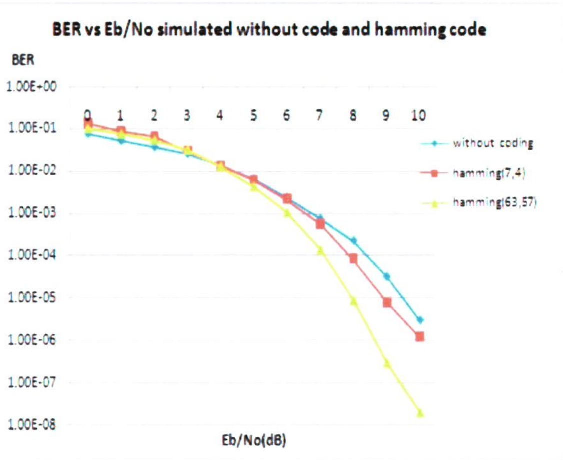


Graph 2: BER vs (Eb/No) of a communication System (using QPSK) without error correcting codes.

At 0dB, the simulated BER is 0.3125 and theoretical BER 0.317310813 . The difference between simulated BER and the theoretical BER is 0.004810813. At 10dB, the simulated BER is 0.001805 and the theoretical BER is 0.001565402. The difference between the simulated BER and the theoretical BER is very small which is 0.000239598. As a conclusion, the simulator developed in this project is reliable and useable.

3.3 Performance Comparison between an Uncoded Communication System, A Communication System with Hamming Code (7,4) and with Hamming Code (63,57) Using BPSK modulator/demodulator.

Graph 3 shows the simulated BER without error correcting codes, hamming code(7,4) and hamming code(63,57) using BPSK modulator/demodulator.

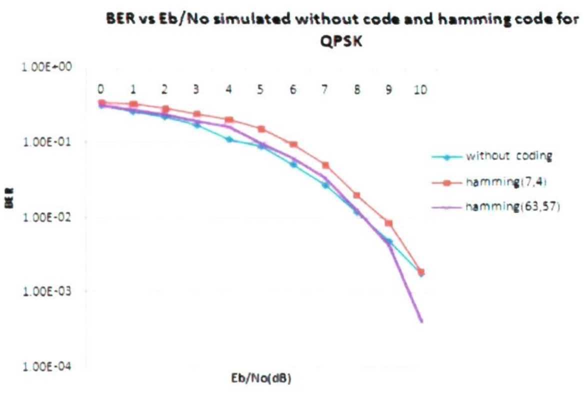


Graph 3: BER vs (Eb/No) of a communication System (using BPSK) without error correcting codes, hamming code(7,4) and hamming code(63,57)

Simulations were performed on both systems with channel coding and without channel coding at Eb/No of 0dB to 10dB.The simulation results were also plotted in Graph 3. From Graph 3, it can be seen that Hamming Code (63,57) has the best error performances due to its small BER.

3.4 Performance Comparison between an Uncoded Communication System, A Communication System with Hamming Code (7,4) and with Hamming Code (63,57) Using QPSK modulator/demodulator.

Graph 4 shows the simulated BER without error correcting codes, hamming code (7,4) and hamming code (63,57) using QPSK modulator/demodulator.

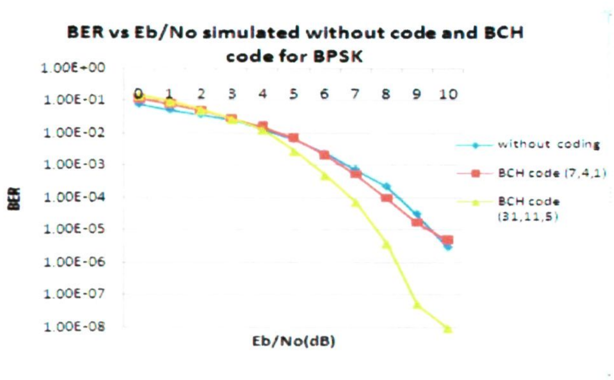


Graph 4: BER vs (Eb/No) of a communication System (using QPSK) without error correcting codes, hamming code(7,4) and hamming code(63,57)

The value of N and K for Hamming are (7,4) and (63,57). At 0dB, the highest BER is hamming (7,4) with 0.3472 and the lowest BER is simulated without code which is 0.3125. At 8dB, the simulated BER without coding and simulated BER hamming (63,57) have similar value. At 10dB, the lowest BER is hamming (63,57) with 0.0004205 and the highest BER is hamming (7,4) with 0.001967 . The difference BER between lowest BER and the highest BER is 0.0015465. From this graph, it can conclude that performance of error at Hamming code (63,57) is better because it has smaller BER compared to the one without code and hamming(7,4).

3.5 Performance Comparison between an Uncoded Communication System, A Communication System with BCH Code (7,4,1) and with BCH Code (31,11,5) Using BPSK modulator/demodulator.

Graph 5 shows the simulated BER without error correcting codes, BCH code (7,4,1) and BCH code (31,11,5) using BPSK modulator/demodulator.

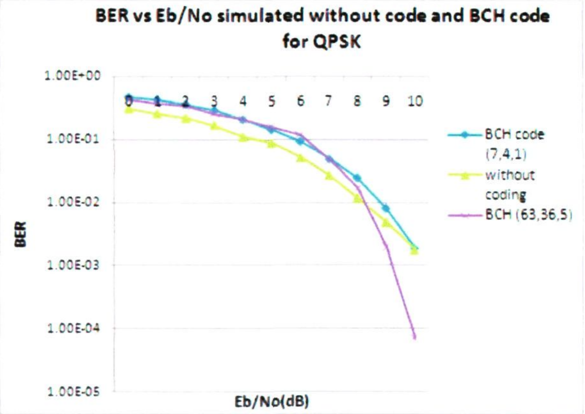


Graph 5: BER vs (Eb/No) of a communication System (using BPSK) without error correcting codes, BCH code(7,4,1) and BCH code(31,11,5).

At 0dB, the highest BER value is BCH (31,11,5) with 0.1481 and the lowest BER is without code which is 0.0771. At 7dB, the lowest BER is hamming (31,11,5) and the highest is BER without code. Then at 10dB, the simulated BER for BCH(31,11,5) is 0, BER for BCH(7,4,1) is 5.00E-06 and BER without coding is 0.000003. As a conclusion, BCH(31,11,5) have better performance compared with BCH(7,4,1) and without coding. When error-correction capability (t) increases, the value of the BER will be lower and produce better performance.

3.6 Performance Comparison between an Uncoded Communication System, A Communication System with BCH Code (7,4,1) and with BCH Code (63,36,5) Using QPSK modulator/demodulator.

Graph 6 shows the simulated BER without error correcting codes, BCH code (7,4,1) and BCH code (63,36,5) using QPSK modulator/demodulator.

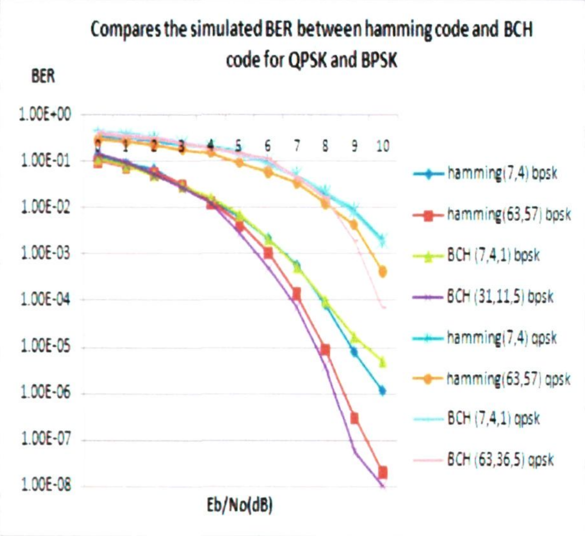


Graph 6: BER vs (Eb/No) of a communication System (using QPSK) without error correcting codes, BCH code(7,4,1) and BCH code(63,36,5).

At 0dB, the highest BER value is BCH (7,4,1) with 0.4246 and the lowest BER is without code which is 0.3125. At 10dB, the simulated BER of BCH (63,36,5) is lowest compared to the BER of BCH(7,4,1) and without code. The value BER of BCH (63,36,5) at 10dB is 7.10E-05 and value of BCH(7,4,1) and without code are similar which is 0.00189 and 0.001805.

3.7 Performance Comparison between a Communication System with BCH Code and with Hamming Code Using BPSK modulator/demodulator and QPSK modulator/demodulator.

Graph 7 shows the simulated BER for Hamming code and BCH code using BPSK modulator/demodulator and QPSK modulator/demodulator.



Graph 7: BER vs (Eb/No) of a communication System (using BPSK and QPSK) for Hamming code and BCH code.

The result show that the best performance occurs when the communication system uses a BCH code with N=31, K=11 and t=5 with BPSK modulator/demodulator. However, this same code has the highest error rate when used with QPSK modulator/demodulator. In general, the BCH codes are better than Hamming code. This is because Hamming codes are capable of detecting and correcting single errors only whereas BCH codes are capable of detecting and correcting multiple errors.

4. Conclusion

The objective of this research is to evaluate the performance of different type of error correcting code in an Add White Gaussian Noise (AWGN) channel. From the simulation, the result show that the best performance occurs when the communication system uses a BCH code with N=31, K=11 and t=5 with BPSK modulator/demodulator. The higher of value of N, K and t is better the performance and in general BCH codes are better than Hamming code.

5. Recommendation

This research can be extended to convolution codes. The modulator/demodulator can be changed to an 8-PSK and 16-PSK. Lastly, Then soft decision coding can be compared with the hard decision coding. One example of soft decision coding that can be used for the comparison is Reed-Solomon (RS).

6. Reference

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