BER PERFORMANCE EVALUATION OF OFDM SYSTEM USING LDPC-RS AND LDPC-CC PRODUCT CODES

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BER PERFORMANCE EVALUATION OF OFDM SYSTEM USING LDPC-RS AND LDPC-CC PRODUCT CODES

By

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LIST OF ABRREVIATIONS

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase-Shift Keying
CC	Convolutional Code
CC-LDPC	Convolutional Code concatenation with Low-Density Parity-Check code
DFT	Discrete Fourier Transform
DIF	Decimation-In-Time
EEC	Error Correcting Codes
FDM	Frequency Division Multiplexing
FEC	Forward Error Correction
FFT	Fast Fourier Transform
ICI	Inter-Carrier Interference
ISI	Inter-Symbol Interference
IFFT	Inverse Fast Fourier Transform
LDPC	Low-Density Parity-Check
LDPC-CC	Low-Density Parity-Check code concatenation with Convolutional Code
LDPC-RS	Low-Density Parity-Check code concatenation with Reed-Solomon
MSE	Mean Squared Error
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak-to-Average Power Ratio
QPSK	Quadrature Phase-Shift Keying
RS	Reed-Solomon

RS-CC	Reed-Solomon concatenation with Convolutional Code
RS-LDPC	Reed-Solomon concatenation with Low-Density Parity-Check code
SNR	Signal-to-Noise Ratio
XOR	Exclusive-OR

PENILAIAN PRESTASI BER SISTEM OFDM DENGAN MENGGUNAKAN KOD LDPC-RS AND LDPC-CC

ABSTRAK

Teknik kawalan ralat pengekodan ialah bahagian yang penting di dalam sistem perhubungan digital. Teknik ini digunakan untuk menyelesaikan kesilapan yang dikeluarkan oleh saluran hingar semasa penghantaran data dalam sistem perhubungan digital. Kod LDPC telah terbukti dapat menawarkan prestasi yang bagus dan berhampiran dengan limitasi saluran hingar yang mempunyai bunyi rawak tambahan. Tesis ini terutamanya menyiasat prestasi Kod LDPC dengan gabungan kod Reed-Solomon (LDPC-RS) dan kod konvolusi (LDPC-CC) dengan menilai prestasi BER berbanding dengan Pemultipleksan Pembahagian Frekuensi Orthogon (OFDM) yang mengalami pelbagai pudaran. Model anggaran saluran untuk sistem OFDM telah direka. Saiz IFFT di dalam sistem OFDM yang direka ialah 64. Selepas itu, isyarat BER di dalam sistem OFDM ditentukan menggunakan kod FEC iaitu kod konvolusi, kod Reed-Solomon, LDPC, LDPC-RS dan LDPC-CC. Kod konvolusi dan kod Reed-Solomon dilaksanakan menggunakan tiga kadar kod yang berbeza iaitu 1/2, 1/3 dan 2/3. Kod FEC yang mempunyai prestasi BER terbaik ditentukan dengan menganalisa graf SNR terhadap BER. Prestasi BER LDPC-CC dan LDPC-RS telah berbanding dengan LDPC pada BER bernilai 10^{-1}. Prestasi BER LDPC-CC dan LDPC-RS telah meningkat sebanyak 6 dB dan 5 dB masing-masing. Oleh itu, dapat disimpulkan bahawa kod LDPC-CC dan LDPC-RS mempunyai prestasi BER yang terbaik.

BER PERFORMANCE EVALUATION OF OFDM SYSTEM USING LDPC-RS AND LDPC-CC PRODUCT CODES

ABSTRACT

Error control coding techniques is a crucial part of digital communication systems. It is used to solve the errors created by the noise channel during data transmission of digital communication systems. LDPC codes have been shown to offer significant performance gain close to the fundamental limits of channels corrupted by an additive random noise. This thesis particularly investigates the performance of LDPC codes with concatenated Reed-Solomon code (LDPC-RS) and convolutional codes (LDPC-CC) for possible bit-error-rate (BER) performance gain over the Orthogonal Frequency Division Multiplexing (OFDM) system that experiences multipath fading. A channel estimation model for the OFDM system is developed. The OFDM system has an IFFT size of 64. Subsequently, the BER of the signal in OFDM system is examined using Forward Error Correcting (FEC) code namely Convolutional code, Reed-Solomon code, LDPC, LDPC-RS and LDPC-CC. Convolutional code and Reed-Solomon code are implemented using three different code rates which are 1/2, 1/3 and 2/3. The best FEC code with the best BER performance is determined by analysing the SNR versus BER graph. LDPC-CC and LDPC-RS has a performance gain of 6 dB and 5 dB respectively, compared to LDPC at BER of 10^{-1}. It is concluded that concatenated codes (LDPC-CC and LDPC-RS) have better BER performance.

CHAPTER 1

INTRODUCTION

1.1 Background

Communication is crucial to enable human kinds to stay connected with each other. It delivers information from the source to the user. Communication technology is now the forefront of the modern world and has increased at a startling rate over the past few decades [1], [2]. The technology improved through time has made human life easier and more convenient. In the past decades, human used birds as a tool to convey messages to other people which in itself are not sufficient in meeting their multidimensional needs [3]. Due to civilization, communication now plays an important role in the daily life of a human being. As the demand of communication increases, most of the researchers have focused on improving the accuracy of this field. However, this has enhanced the information transmission performance of signals over fading channels [3], [4].

Although wired communication system is more dedicated as compared to the wireless communication system, the potential advantages associated with the wireless communication systems in terms of flexibility and ease of use has made the wireless system more preferred [1]. Hence, telecommunications in the 21st century are increasingly relying on wireless communications services for personal, commercial, or emergency purposes since; wireless communication network provides large service for transmitting voice, video, and data signals in local or wide areas [1], [5], [6]. However, the maximum distance range between transmitter and receiver to perform data transmission and reception and data transferring rate are the main concerns for users. Nonetheless, the demand for higher efficiency and high-speed data transfer rate in wireless communication increases to meet the requirements of future communication systems which can provide high data rate, robust performance and low complexity within a limited resource, such as spectrum limitation, size, cost, and power consumption of the receiver terminal [7], [8].

In 1948, Claude Elwood Shannon promulgated "A Mathematical Theory of Communication" by introducing channel capacity and demonstrated the occurrence of Error Correcting Codes (EEC) which allows communication systems to transfer information at rates below channel capacity with an arbitrarily low probability of error [9]. Moreover, it was reported that the random sequence generation of codebooks is capable of approaching channel capacity with high probability if the codeword length N tends towards infinity. However, random code generation over an Additive White Gaussian Noise (AWGN) channel requires an exhaustive search over all the possible codeword combinations. Hence, its computational complexity grows exponentially with regards to the optimality of the decoding scheme [9], [10]. This, therefore, leads to the investigation of codebooks which imposes certain structure on the codebook in order to make the generation of codes more efficient. In the following decades, several families of codes have been proposed which includes the convolutional codes, Reed-Solomon codes, etc. The major objective is to construct codes with good properties, i.e. which allows carrying the biggest amount of information, and to correct the maximum number of errors, and also to determine an efficient and low-complexity decoding algorithms, that are able to achieve optimal decoding for these families of codes [9]. The notion of turbo codes could surpass all previously known coding methods by employing codeword lengths that are very long. This was made possible by the corresponding iterative decoding algorithm whose computational complexity is linear in the length of the code.

Recently, developments in the coding community are now focused on the use of iterative decoding algorithms. After the invention of turbo codes in 1993 [11], the Low-Density

Parity-Check (LDPC) codes which was first invented by Gallager in early 1960s [12] and later re-discovered by Mackay and Neal [13] after being neglected for nearly 35 years. This code forms a class of codes that approaches Shannon limit [13]. Consequently, to this new discovery, much research investigations have been dedicated to find the capacity of LDPC Codes, the design of encoder and decoder, as well as the practical implementation of LDPC codes for different channels. More recently, the LDPC code (a class of linear block codes) characterized by sparse parity-check matrices, has received a huge interest from the researcher. Generally, LDPC codes can be subdivided into two distinct classes, namely, unstructured LDPC codes and structured LDPC codes, in relation to their construction technique [14]. LDPC codes with extremely long block lengths experience implementation challenges as a result of a lot of nodes and edges requirement [15]. For long block lengths, it has been shown that the performance of structured LDPC codes is close to or even more satisfactory than its random counterparts constructed via an exhaustive search [14], [15]. Consequently, several works on LDPC codes in the recent years now focused on the construction and analysis of structured LDPC codes [5], [16], [17].

1.2 Problem Statements

Fuelled by the ever-increasing demand for high data rate transmission over wireless communication services, necessitate technologies that make use of the available electromagnetic resource in the most intelligent way. It is known that communication system plays an important role in the lives of today's modern society [1]. Hence, for successful transmission of signals, a key objective of spectrum efficiency (bits per second per Hertz) and robustness against the multipath fading channel must be satisfied [18]. These objectives are usually contrary, so methods and implementations are investigated towards offering the best possible trade-off between them. One of these methods widely used in wireless communications in achieving these objectives is Forward Error Correction (FEC) or channel coding. In this research, different FEC codes such as Reed-Solomon (RS) code and the Convolutional Code (CC) will be investigated to determine their Bit Error Rate (BER) performances over the various code rates. Additionally, the Low-Density Parity-Check (LDPC) codes will be investigated. To construct a code with good minimum distance and girth properties that will perform efficiently well with iterative decoding, the concatenation of LDPC-RS codes and LDPC-CC codes will further be investigated for a probable increase in BER performance.

1.3 Research Objectives

The main objectives of this research are stated as below:

1. To design and implement an OFDM system that incorporating two hybrid code methods, such as Low-Density Parity-Check concatenated with Convolutional Code (LDPC-CC) and Low-Density Parity-Check concatenated with Reed Solomon code (LDPC-RS) structures.

2. To analyse the performance of OFDM system by using Bit Error Rate (BER) Performance Evaluation.

1.4 Scope of Research

For wireless OFDM system, Signal-to-Noise Ratio (SNR) estimation is vital due to the operations of many key techniques to improve the OFDM system performance, such as adaptive coding and modulation, soft decoding procedures, mobile assisted handoff and channel assignment which closely depending on the correct SNR value [11]. In this research, a few SNR values will be tested out to obtain the best performance of OFDM system.

This research will be focusing on BER performance of OFDM system using different Channel Coding Techniques with different code rates. The FEC codes that will be tested are Convolution code, Reed-Solomon code and Low-Density Parity-Check code. After obtaining the BER performance for each coding, 2 different FEC codes will be combined to overcome each other's disadvantages and get an improved BER performance of OFDM system.

1.5 Thesis Organization

This project report incorporates of five main chapters that show the BER performance evaluation of OFDM system using LDPC-RS and LDPC-CC Product Codes.

In Chapter 2, theoretical background and literature review will be done. The basic concept of OFDM system and OFDM structure will be presented. The theory for each FEC codes will be discussed and compared to find out the advantages and disadvantages.

In Chapter 3, the methodology of the research will be done. The steps required throughout the whole research will be presented to make sure the research is done step by step.

In Chapter 4, the result and discussion of the research are explained in detail. The result of the research is recorded and shown in several graphs. Some explanations and discussions on the results are done.

In Chapter 5, the conclusion and future works of the research are included. It sums up the overall research works and achievements. The potential improvements are also recorded for future works.

CHAPTER 2

LITERITURE REVIEW

2.1 Introduction

In this chapter, the basic concept of OFDM system and FEC codes are discussed. From these, the advantages and disadvantages of FEC codes such as Convolution Code, Reed-Solomon code and Low-Density Parity-Check code are the core study of this research to find out the FEC codes with the best BER performance. The research on the application of concatenated FEC codes is carried out to improve the current FEC method.

2.2 OFDM System History

Wireless communication system always faces problem in distortion of the received signal caused by multipath fading channel when there is an increase in the data rate. OFDM system is one of the techniques to solve this problem. OFDM is a digital modulation scheme. The wideband signal is split into numerous narrowband signal during transmitting of the signal. OFDM is also a multicarrier modulation scheme in which the user symbols are transmitted in parallel using different orthogonal subcarriers [19].

In a classical parallel data system, the total signal bandwidth can be divided into N non-overlapping frequency sub-channels. Each of the sub-channels is modulated by using a separate symbol and all sub-channels are frequency multiplexed. This practice is to avoid spectral overlapping of sub-channels which can prevent inter-carrier interference (ICI) in the system. Figure 2.1 shows the frequency spectrum of eight channel Frequency Division Multiplexing (FDM) and OFDM system separately [20]. This indicates that user can save half of the bandwidth using OFDM system as compared to FDM system.

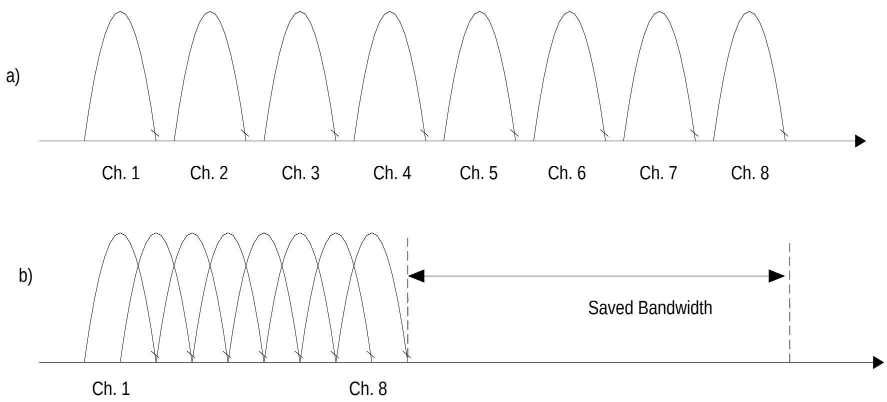

Figure 2.1: Frequency spectrum of a) FDM and b) OFDM [21]

OFDM system started in the late 1950's with the introduction of FDM for data communication [22]. In 1966, Chang [23] proposed the first OFDM scheme, which is a principle of orthogonal multiplexing for transmitting data messages simultaneously. This principle work using a linear band-limited transmission medium at a maximum data rate without inter-channel and inter-symbol interferences. In 1971, Weinstein and Ebert [24] introduced the use of the Discrete Fourier Transform (DFT) for FDM system to reduce the computational complexity in the part of carrier modulation and demodulation in the Fourier transform domain. By using Fast Fourier Transform (FFT), the banks of subcarrier oscillators and coherent demodulators can be eliminated. This then presents an efficient implementation of the OFDM system for practical applications [24].

In 1980, Peled and Ruiz [25] introduced cyclic extension for OFDM system. This can allow better channel bandwidth utilization and maximize the usage of channel. In 1985, Cimini [26] proposed a pilot-based correction to improve the protection against co-channel interference and provide a large improvement on BER performance at the expense of decrease of the overall bandwidth efficiency. In 1990s, OFDM was used for wideband data communication and high speed communication systems.

2.3 OFDM Structure

OFDM system can be described as a combination of modulation and multiple-access scheme that several users can use at a time [27]. OFDM allows spectrum to overlap but they will not interfere with each other [27]–[30]. A block diagram of OFDM system is shown in Figure 2.2 to show a clearer picture of overall process of OFDM system [22].

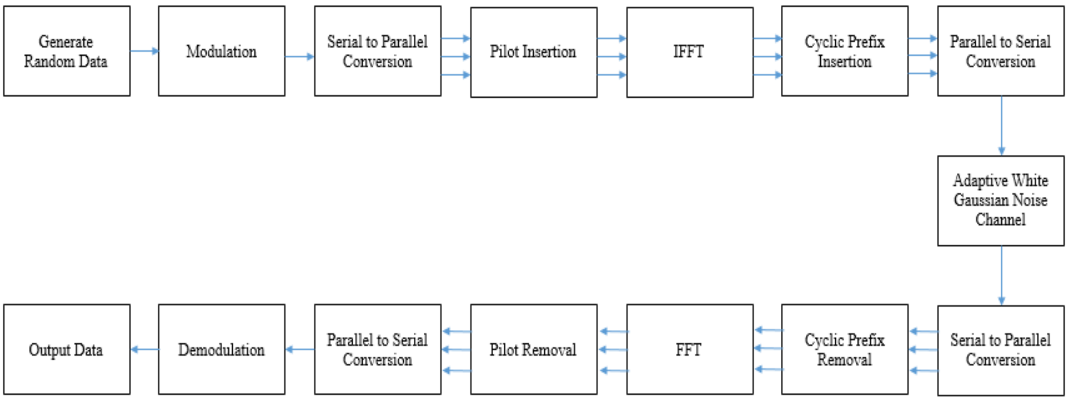

Figure 2.2: Block Diagram of OFDM System [30]

2.3.1 Modulation

Modulation is a process of modifying the properties of high frequency carrier signal with the reference of the baseband signal. In 2012, Dawood et al. [31] stated that implementation of modulation scheme can improve the bandwidth and energy efficiency. For example, BPSK modulation is the simplest modulation scheme which is simple to generate, demodulate and has a constant envelope. In BPSK, the binary information is in two phase shifts of the carrier where the carrier signal will take two amplitudes level [32].

However, for QPSK, the modulation scheme is characterized by the information carried by the transmitted wave in the phase. The phase of the carrier has equally spaced values such as $\pi/4$, $3\pi/4$, $5\pi/4$, and $7\pi/4$ [21].

2.3.2 Series to Parallel Conversion

After modulation, the data will then convert from series to parallel for the further process [21]. OFDM system breaks each channel to different sub-carriers which can optimal the use of bandwidth. Therefore, data in parallel or data in matrix form are needed so that the data can be divided into each sub-carrier during transmission of data. The processes after series to parallel conversion such as pilot insertion, Inverse Fast Fourier Transform (IFFT), Fast Fourier Transform (FFT) and cyclic prefix insertion required the data in matrix form to ease the process.

2.3.3 Inverse Fast Fourier Transform and Fast Fourier Transform

In OFDM system, carrier bank generates a set of sub-carriers in conventional or analogue approach which is bulky and costly. IFFT makes the system digital, simpler, cheaper and more efficient [21]. FFT and IFFT are derived from DFT where FFT and IFFT will do computation simultaneously. IFFT transform the spectrum from frequency domain to time domain signal where FFT reverse the process of FFT [33]. Figure 2.3 shows a radix-2 Decimation-In-Time (DIF) IFFT.

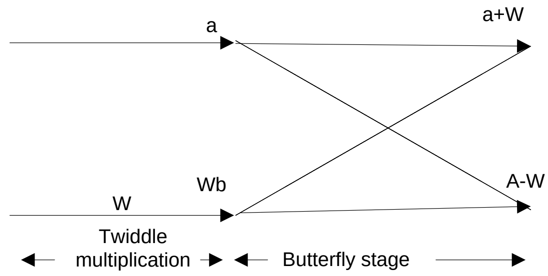

Figure 2.3: Basic Butterfly Unit for radix-2 Decimation-In-Time IFFT [33]

2.3.4 Cyclic Prefix Insertion

During transmission data in OFDM system, Inter-Symbol Interference (ISI) may occur as two adjacent blocks may overlap and cause distortion of symbol. By using cyclic prefix, this problem can be minimized [32]. Cyclic prefix is a process of adding guard period to the start of each symbol. The cyclic prefix consists of the last part of the data block that is copied and pasted at the front part of the data block. By using cyclic prefix, the carriers' periodicity remains the same and eliminate ISI between sub-carriers [34]. Figure 2.4 shows the basic concept of cyclic prefix. T_1 represented the guard period. When the guard period is not added, the symbol period of IFFT output is T_2 only. However, when guard period is added at the output of IFFT, then the symbol period is $T_1 + T_2$. Therefore, the symbol period of transmitted data is increased and ISI is reduced [19].

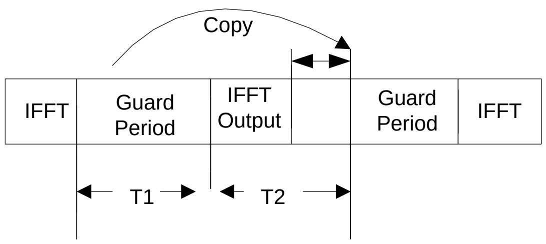

Figure 2.4: Concept of Cyclic Prefix [19]

2.3.5 Parallel to Series Conversion

After the process of cyclic prefix insertion and IFFT, the signal data must be transmitted as one signal. This stage is the process of summing all sub-carriers and combining them into one signal for transmitting [35]. Before passing through the Adaptive White Gaussian Noise (AWGN) channel, the data will be converted to series form. This is to make sure the data in digital form can be changed to analogue form during transmission.

2.4 Forward Error Correction

Forward Error Correction (FEC) is a technique used to control errors in data transmission under a noise channel. It is done by adding redundant bits to the original data using a predetermined algorithm such as Convolutional Code (CC), Reed-Solomon (RS) Code and Low-Density Parity Code (LDPC). FEC enables the receiver to correct the errors once detected without the need for retransmission. Although it reduces the amount of available bandwidth but it can speed up the process of transmission [36]. FEC codes normally are added into the data before the data undergo further processes such as modulation, IFFT and others.

2.4.1 Convolutional Codes

Convolutional Codes (CC) are used for real-time error correction where it is done by combining the fixed number of input bits. The input bits are stored in a fixed length shift register and perform mod-two addition to produce an output sequence. CC produced n-bit of symbol of the output sequence from the linear operation of the input k-bit symbol and the content of shift register. Therefore, a convolutional encoder with k/n rate processes k-bit input and produce n-bit output with every shift register update. CC are normally specified by three parameters (*n*,*k*,*K*), where *n* represents number of output bits, *k* represents number of input bits and *K* represents constraints length, which is the past number of input bits in the memory register that affect the output code word [37]. Figure 2.5 shows a simple diagram of convolution encoder with parameter (2,1,3).

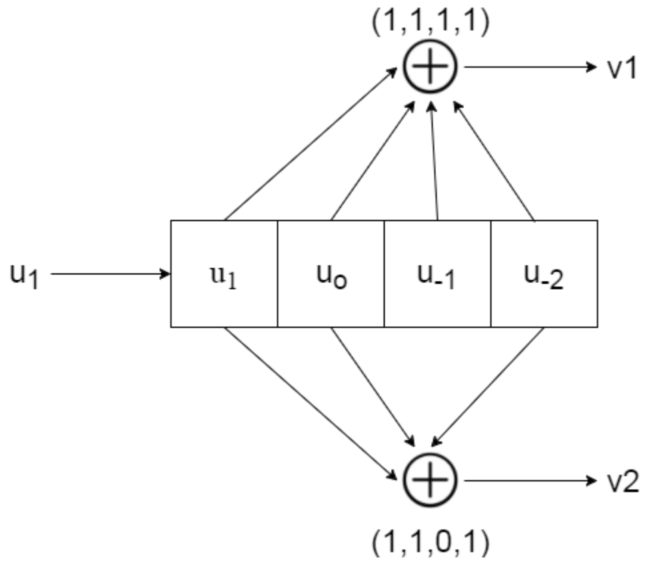

Figure 2.5: Convolutional Encoder (2,1,3) [38]

The selection of bits is to be added using XOR operation to produce the output bits called generator polynomials. In Figure 2.5, the generator polynomials for v_1 and v_2 are $g_1 =$ (1,1,1,1) and $g_{2=}$(1,1,0,1) respectively. Therefore, $g_1 = 1 + x + x^3$ and $g_2 = 1 + x + x^2 + x^3$. The generator polynomials are used to generate the output sequence by multiplexing the bits of input sequence. The basic design of CC encoder depends on code rate and constraints length. The design of CC encoder will be less complex if the constraints length decreases as it has lesser number of shift register. With a smaller code rate, the code will have better performance but it will take up larger spectral efficiency compared to bigger code rate. The design of CC is very useful in low error probability but high data rates of data transmission because it is less complex [38]. However, CC will become more complex for long codes with large error correction capability. It is also not suitable for non-binary input data.

2.4.2 Reed-Solomon Code

Reed-Solomon (RS) Codes are block-based error correcting code that can deal with multiple errors especially burst errors. A burst error is contiguous errors occurred in the bit stream especially in mass storage devices, wireless and mobile communication units, digital television and broadband modem. RS codes are maximum distance separable codes which give them the most powerful linear codes among their class as they have the ability to correct both errors and erasures [39].

RS codes are block codes and they are represented as $RS(n, k)$, where n represent the size of output code and k is the number of data symbols. The numbers of parity symbols are represented by $2t = n - k$. Figure 2.6 show the structures of basic RS codeword where the whole data block length is represented by n. The data of k-bits long are added with $2t$-bits of parity symbols to give n-bits RS code [40].

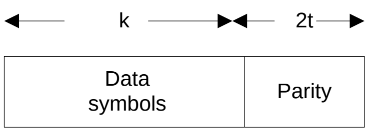

Figure 2.6: Structure of RS codeword [40]

RS encoder performs division and shifting operation. Figure 2.7 shows the block diagram of RS encoder which consists of shift register labelled from b_0 until g_{2t-1} which represent the coefficient of generator polynomial. During the initial state, each parity register is set with value zero. After that, the k-bits long message is divided into m-bit words. Each word will be associated with increasing power of x forming message polynomial m(x). During the first *k*-clock pulse switches 1 and 2 are in position B where the output will be the message symbols. When message symbols are finished, switches are positioned to A [40].

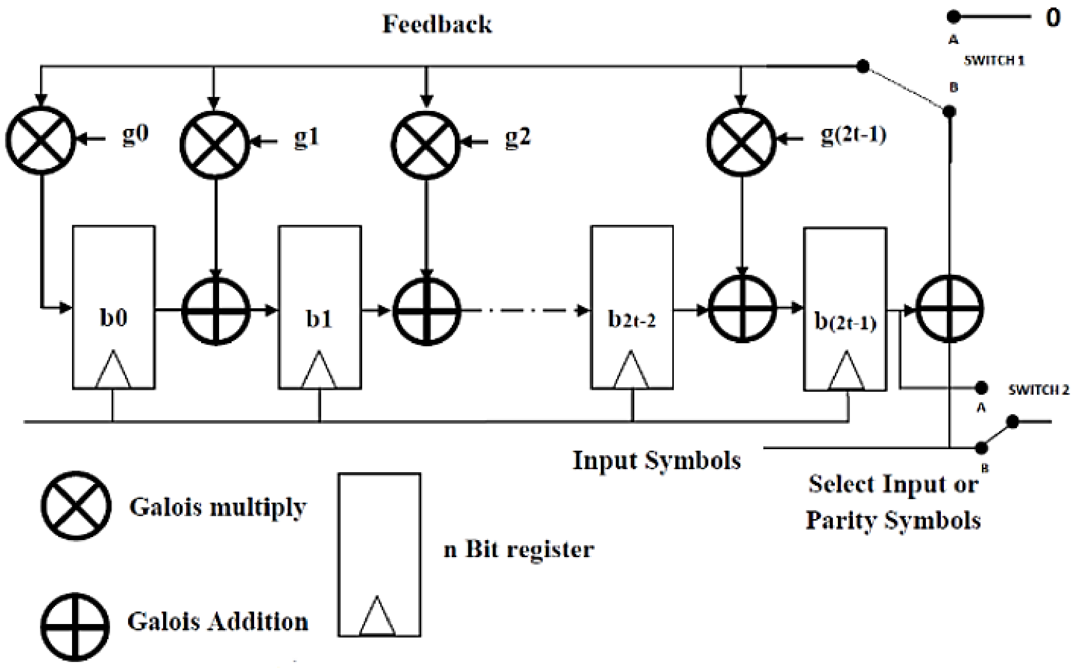

Figure 2.7: Block Diagram of RS encoder [40]

RS decoder functions as correcting error and erasures by calculating the syndromes for each codeword. If there are errors in the received block, RS decoder will try to find out the error location. Using Forney’s algorithm, RS decoder can correct up to *t* symbol errors in the codeword which is the half of the number of parity symbols [41]. Therefore, RS are best in solving burst errors. However, RS decoding is complex because it is a bulky and complicated code which require high knowledge in higher mathematics.

2.4.3 Low-Density Parity-Check Code

In the 1960s', Robert Gallger invented Low-Density Parity-Check (LPDC) codes. LDPC codes have attracted researchers' interest because of its excellent error-correcting performance and highly parallel decoding scheme. It is used in digital video broadcasting, magnetic storage, 10GB Ethernet and high-throughput wireless local area network [42]. LDPC codes are one of a few FEC codes that can allow transmission of data at a rate close to Shannon's limit for a wide range of channels. It can correct the channel errors at relatively low signal-to-noise (SNR) ratio with feasible complexity [43].

LDPC is a linear block code where the parity check matrix has sparse property, which means it consists of very few number of non-zero element. The decoder complexity and minimum distance of the LDPC are determined by sparseness of parity check matrix. The number of non-zero elements in each row and column is called the degree of distribution. If the degree of distribution in each row and column is the same the matrix is said to be a regular matrix, otherwise it is an irregular matrix [44]. Figure 2.8 shows a regular matrix with the length of 9 and bit rate of 2/3. LDPC matrix can be represented by using Tanner graph as shown in Figure 2.9.

$$H = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 \end{bmatrix}$$

Figure 2.8: Regular LDPC Matric with length of 9 and bit rate of 2/3 [44]

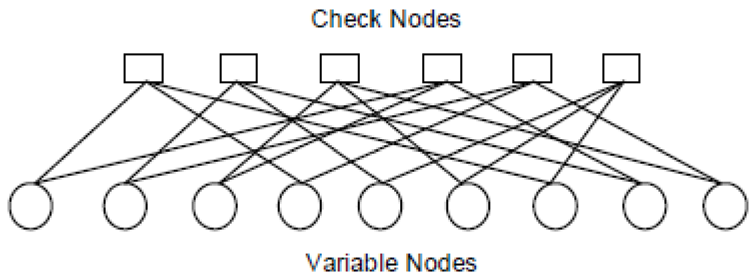

Figure 2.9: Tanner Graph Representing LPDC matrix [44]

In LPDC encoding, there are generator matrix, G and parity check matrix, H. H can be obtained by performing Gauss-Jordan elimination, H can be obtained in the form of

H = $[A, I_{n-k}]$, where A is a $(n-k) \times k$ binary matrix and I_{n-k} is the identity matrix with size $(n-k)$, n represent the number of output bits and k represent the number of data bits. The generator matrix is in the form of

$G = [I\ , A^k\ ]$, where I_k is the identity matrix with size k and A^k is the binary matrix with size k.

Codeword can be generated by using modulo 2 additions of message bits with G as shown below,

$C = mG$, where m is message bits [45].

Decoding of LPDC includes the transferring of data between check nodes and variable nodes along the connected edges in the tanner graph. Each edge in the tanner graph works alone with the information available on the connected edges only. The decoding algorithm involves the passing of messages between nodes for a fixed number of iterations or until the parity is satisfied. We called it iterative algorithms [44]. Parity check condition is known as CH^T. If parity check condition is = 0, then the received code is correct without errors. Iterative decoding includes two different algorithms which are hard decision and soft decision decoding algorithms. Hard decision is the decision made by the decoder based on the received information if the value of a single bit can either be 0 or 1. Soft decision decoder is a decoder that is able to distinguish between a set of quantized values between 0 and 1, for example the sum product algorithm [45].

2.4.4 Concatenated Code

Concatenated codes are the combination of two different FEC codes together. For example, RS-CC, LPDC-CC and LDPC-RS. Different FEC codes have different characteristics in terms of handling errors. They have their own advantages and disadvantages. When two different FEC codes are combined, they can overcome each other problem and disadvantages. This can improve the performance of OFDM system in handling errors.

LDPC-CC is more suitable for some application such as streaming video and variable-length, packet switching networks. Besides, the packet encoding and decoding can be done starting from a known state. It reduces the probability of bit error over first few hundred bits of the packet [46]. LDPC codes also can achieve the capacity-approaching performance with iterative message-passing decoding [47].

For LDPC-RS, it can counter different types of errors, have robustness against co-channel interference and relatively low decoding complexity and system latency [48].

2.5 Related Works

In [49], convolutional code (CC) is used widely in many applications to achieve reliable data transfer such as mobile communication, digital video and satellite communication.

In [50], it is stated that Reed-Solomon (RS) code is weak to the random errors but strong to burst errors. Therefore, RS has good performance in fading channel which has more burst errors. RS is used in many applications such as storage devices, wireless or mobile communications, satellite communication and space communication.

In [51], it showed that the system reliability can be improved by the modern coding techniques even there is an increase in complexity and power consumption are caused by LDPC. Therefore, high-speed data transmission with a moderate cost in decoding implementations is supported. Signal distortion can be efficiently compensated by the powerful error correction capability of LDPC.

In [52], structure of the convolutional code is inherited by LDPC-CC and continuous encoding and decoding of variable-length codes are allowed. Therefore, the transmission of codewords with different code length is possible. Besides, a pipelined decoding architecture in the iterative decoding procedure is used by LDPC-CC, therefore, the procedure can be performed in parallel as each iteration is processed by a separate processor.

In [53], LDPC-RS is combined together because LDPC code can perform well in combating short random errors and RS code is efficient against burst errors. however, LDPC-RS has high decoding complexity due to its iterative decoding feature.

From the related works done, the performance evaluation is done on one particular FEC code only. Therefore, in this study, the BER performance evaluation of all FEC codes will be performed together to obtain the best FEC code.

2.6 Summary

In this chapter, the history of OFDM system, OFDM structure and FEC codes are discussed. Different FEC codes have their own advantages and disadvantages. Some reviews are given for each FEC in this chapter so that we can compare and get a FEC with better BER performance. Besides, concatenated code such as LDPC-RS and LDPC-CC may possibly provide better performance. In the next chapter, the method of implementation of FEC codes and concatenated FEC codes will be presented.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the overall research method to achieve the objectives of the study. In this research work, the focus is to improve the BER performance in OFDM system with the aid of FEC codes. The whole research includes four main stages. Figure 3.1 shows the overview of the four stages.

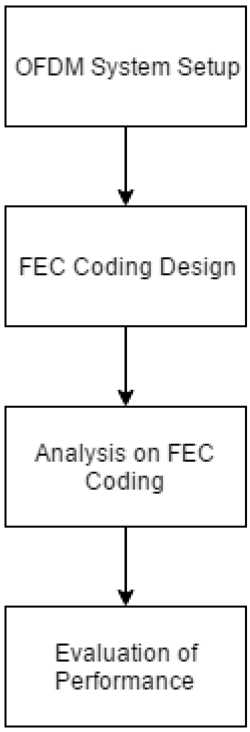

Figure 3.1: General Flowchart of This Research Work

Besides this overview, a detailed flow chart is shown in Figure 3.2. This can show the overall methodology process of the research.

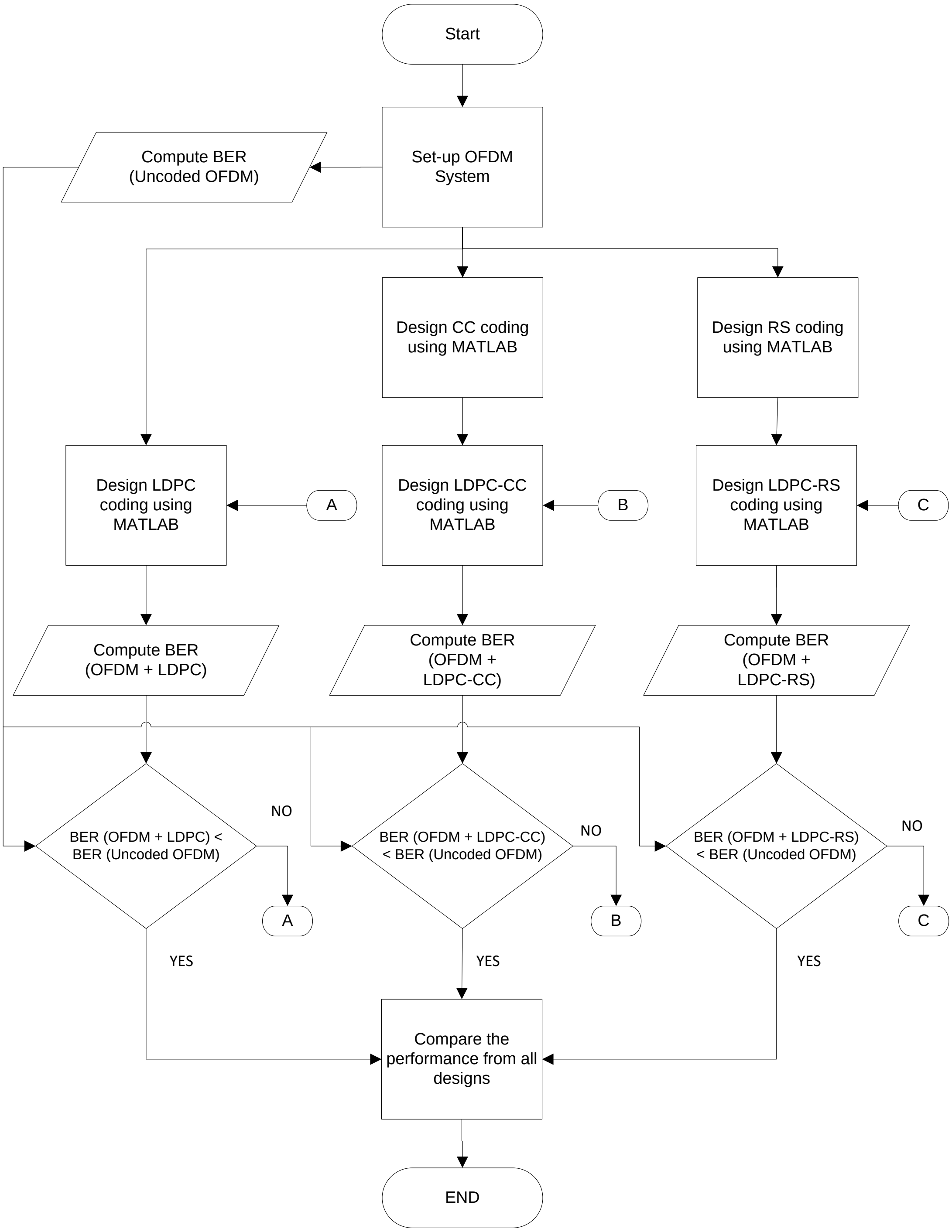

Figure 3.2: Design Flowchart of the Concatenated Error Correction Coding in OFDM System

First of all, an OFDM system is set up using MATLAB coding with a specific specification shown in Table 3.1. The BER performance of the uncoded OFDM system is generated to compare with coded OFDM system. Then, CC and RS codes are designed using MATLAB. The code rate of CC and RS with the best BER performance is determined. After that, LDPC, LDPC-CC and LDPC-RS codes are designed using MATLAB. The BER performance for each coded OFDM system is generated and compared with the BER performance of uncoded OFDM system. If the BER performance of the coded OFDM system is worse than uncoded OFDM system, the specific FEC code is redesigned. Otherwise, the BER performance of three FEC codes are compared and the best code is determined.

3.2 Design and Performance Setting

In this research, the simulation is done using software MATLAB 2014a. MATLAB simulates the condition of OFDM system and AWGN channel by using coding and generates the graph of the performance of OFDM system.

The performance of OFDM system is referred to the comparison of BER versus the Signal-to-Noise Ratio (SNR). The OFDM system is tested with different values of SNR and different FEC coding method. This method eases the final stage of this research which is the evaluation of performance as MATLAB generates the graph of BER versus SNR for different FEC coding method.

3.3 OFDM System Setup

Before adding in FEC codes to improve the BER performance, an OFDM system is needed. The specifications for the OFDM system are shown in Table 3.1.

Table 3.1: OFDM System Simulation Parameter

Inverse Fast Fourier Transform (IFFT) Size	64
Number of Data Subcarrier	52
Number of Pilot Subcarrier	12
Guard Interval	16

In order, to provide a clearer picture of OFDM system, the overall OFDM system block diagram is shown in Figure 2.2. The details of each process are explained in the subtopics below:

3.3.1 Generate Random Data

A stream of data bits of ones and zeros are randomly generated as the mimic information data to pass through the OFDM system and AWGN channel. The data bits after and before are compared to determine the BER. The number of subcarriers must be considered during the generation of random data bits. The generated data bits are arranged in series form.

3.3.2 Modulation

The random data generated are modulated. In MATLAB, a modulation object is created before performing the modulation. For example, the modulation object is set as binary phase-shift keying (BPSK) modulation by inserting `M = modem.pskmod(2)`. After