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IMPROVING THE TRANSMISSION OF UWB MB-OFDM SYSTEM USING ADAPTIVE MODULATON

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The thesis study titled " IMPROVING THE TRANSMISSION OF UWB MB-OFDM SYSTEM USING ADAPTIVE MODULATION " is submitted by Murat ALBOĞA in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in the Department of Electrical Electronic Engineering Gazi University by the following committee.

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Murat ALBOĞA

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(M. Sc. Thesis)

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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

December 2019

ABSTRACT

The adaptive modulation scheme is proposed to minimize bit-error-rate (BER) performance in the Orthogonal Frequency Division Multiplexing (OFDM) system. In OFDM communication systems adaptive modulation algorithms based on Signal To Noise Ratio (SNR) and based on BER changed with over MB-OFDM (Multiband OFDM) UWB (Ultra Wideband) is a communication method produced over OFDM over the bandwidth and defined parameters based on the IEEE 802.15.3a standard. Adaptive Modulation helps solve the BER problem in varying noises in the MB-OFDM method. Appropriate modulation methods is selected by means of Adaptive Modulation, it helps to obtain the smallest BER value in the smallest transmission. Quadrature Phase Shift Keying (QPSK) and (Quadrature Phase Shift Keying (QAM) are one of the modulation methods used with OFDM.

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UWB MB-OFDM SİSTEMLERİNDE ADAPTİF MODÜLASYON KULLANARAK İLETİMİ GELİŞTİRME

(Yüksek Lisans Tezi)

Murat ALBOĞA

GAZİ ÜNİVERSİTESİ

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Aralık 2019

ÖZET

Adaptif Modülasyon ve Kodlama, OFDM (Orthogonal Frequency Division Method)'de BER (Bit Error Rate)'i minimize etmeye yarayan bir yöntemdir. OFDM'in kullanıldığı haberleşme sistemlerinde Adaptif Modülasyon algoritması adaptif kodlama SNR(Signal to Noise Ration) ve BER'in zamana bağlı olarak değişimlerine dayanır. MB-OFDM (Multiband OFDM) UWB (Ultra Wideband) bant aralığında OFDM üzerinden üretilen bir haberleşme yöntemidir ve IEEE 802.15.3a standartı baz alınarak parametreleri tanımlanır. Adaptif Modülasyon MB-OFDM yönteminde değişen gürültülerde BER probleminin çözmeye yardımcı olur. Adaptif Modulasyon aracılığı ile farklı modulasyon yöntemlerinden uygun olanı seçilerek en küçük iletimde en küçük BER değeri elde etmeye yardımcı olur. Quadrature Phase Shift Keying (QPSK) and (Quadrature Phase Shift Keying (QAM) OFDM ile kullanılan modulasyon yöntemlerinden biridir.

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TABLE OF CONTENTS

Page

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

Figure **Page**

ABBREVIATIONS AND ACRONYMS

Symbols and abbreviations used in this study are presented below with their explanations.

Symbols	Explanations
MHz.	Megahertz
dBm	Desibel milliwatt.

Abbreviation	Explanations
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CP	Cyclic Prefix
ECMA	European Computer Manufacturers Association
FFT	Fast Fourier Transform
ICI	Inter Channel Interference
IFFT	Inverse Fast Fourier Transform
ISI	Inter Symbol Interference
MAC	Media Access Control
MB	Multiband
MCM	Multi Carrier Modulation
OFDM	Orthogonal Frequency Division Multiplexing
PHY	Physical Layer
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RX	Receiver
SNR	Signal to Noise Ratio
TFC	Time Frequency Coding
TX	Transmitter
UWB	Ultra Wideband

1. INTRODUCTION

Ultra Wideband (UWB) system is provided to decrease the interference and multipath fading effect. This system also provide spectral efficiency in low cost application and low power consumption limits. UWB has attracted attention recently due to these important features. According to Federal Communications Commission (FCC) is specified the UWB parameter for implement communication technologies. The bandwidth of UWB is 3.1-10.6 GHz the transmit power is -41dBm/MHz. The minimum bandwidth for communication systems is 500 MHz. The UWB bandwidth effects multipath condition. The UWB studies focusing generally short range signal transmission. Commercial UWB applied fields: High speed LAN / WAN (>20 Mbps), Avoidance radar, Altimeter (aviation), Tags for intelligent transport systems, Intrusion detection, Geolocation. Military UWB fields are Radar, Covert communications, Intrusion detection, Precision geo-location, Data links. New UWB technologies are emerged recently and new implementing fields are emerging [1-5].

Orthogonal Frequency Division Multiplexing (OFDM) is used multicarrier system. A data stream is transmitted a number of subcarriers in transmission with OFDM Modulation. This method gives robustness against the selective fading in communication systems. If data signal faded or interfered with any reason and the channel completely faded in single carrier systems. But only small percentage channel is faded in multicarrier systems. Because of these properties multicarrier systems are more efficient than single carrier system. Some conditions effect negatively in communication systems. Inter-Symbol Interference (ISI) is one of them probably come to first. OFDM increase the robustness across to ISI for communication systems. Inter-Carrier Interference (ICI) other important parameter effect negatively in transmission. Orthogonal properties between OFDM components are significant properties and it provide some advantages to OFDM transmission. OFDM has two part. One of them is guard interval and other one is Inverse Fast Fourier Transform (IFFT) process. Some subcarriers are added to main subcarriers for prevent ISI and ICI. The names of these subcarriers are cyclic prefix, pilot interval, guard interval, null values. These subcarriers are added the main data signal in transmitter and removed in receiver. The IFFT process is implemented in transmitter in transmitter and converted to data signal from frequency domain to time domain. Generally IFFT step is last process before to digital analog converter. FFT process likes the IFFT process. It converts to data signal time domain

to frequency domain. FFT step is implemented in receiver in transmission. FFT and IFFT order can obtain OFDM modulation [6-10].

UWB Multi Band (MB) OFDM is a type of a OFDM transmission. This method uses some OFDM properties and bring to some extra properties for improve the transmission effectively in UWB system. MB OFDM divide to UWB channel 14 bands. Every band has 528 MHz width on UWB. The UWB MB OFDM parameters proper FCC rules. OFDM parameters are adjusted UWB MB OFDM parameters [6].

The data signal is binary data signal. The data signal is converted to complex valued the data signal with PSK or QAM modulation. After converting process the signal is carried with complex valued signal. In the receiver the complex valued signal is converted to binary valued signal with demodulation of PSK or QAM. PSK and QAM modulation methods give better result for OFDM modulation methods. Modulation process is necessary for data signal carries in transmission. The data signal is converted with this kind of modulation method. The parameters which has been in modulation effect the transmission results. Bits rate, the number of symbol etc. properties should have consider in transmission [7].

Additive White Gaussian Noise (AWGN) channel is noise environment for implement to noise to data signal between transmitter and receiver. The signal is converted to time signal with IFFT in transmitter. After the signal converted to analog signal and it is ready to send information. Effective noises can calculate in receiver in transmission. The noise is important for calculate the signal transmission quality. Signal to Noise Ratio (SNR) important parameter and it comes from AWGN condition. The transmission results graphics are obtained with related SNR values. Also SNR values effects the transmission quality. The modulation methods effect the SNR because of it effects the data signal [11].

Bit Error Rate (BER) firstly parameter for detect the quality of transmission quality. The recovered data signal that calculated in output of receiver and Input data is significant parameters for calculate the BER. The BER value should be minimum in transmission calculation. The small BER value means that the signal less damaged in nose in transmission. So more accurate signal can recover in receiver [12].

The adaptive modulation and coding method can implement in OFDM system. Focus point in adaptive modulation and coding method is (BER). BER should be minimize to efficient transmission in wireless communication systems. SNR is another important parameter for Adaptive modulation and coding in transmission systems. Calculations of SNR and BER can implement in receiver. After calculation BER and SNR value should feedback the transmitter [13-17].

2. ULTRA WIDEBAND(UWB)

Ultra Wideband (UWB) is a new emerging technology in last 20 years about Wireless Communication and continuing to improve in projects. UWB decreases the interference and multipath fading with some multicarrier transmission in high bandwidth. Because of these properties UWB is chosen in wireless applications.

There is no notable interference against to licensed other bandwidth. It also gives efficient spectral distribution with low cost. UWB transmission enables better multiple user communication because of wide bandwidth, faster communication links and detecting right location products.

It supports bit rates greater than 100 Mbps in 10m radius in Wireless Personal Area Communication. Generally, UWB is used in indoor application due to low transmission power and low power limits. These low lower properties are support the collaborate with such as 802.11 LAN, 802.16 MAN and KAN standards [5]. The capacity of communication systems can be explained for non-fading condition in below.

$$C = B * \log_2(1 + S/N) \quad (2.1)$$

where,
C: Channel Capacity
B: Channel bandwidth
S: Signal Power (Wattt)
N: Noise Power (Wattt)
S/N can increase the channel capacity also B can increase the capacity. According to above equation bandwidth provides the more capacity in communication channels.

Signal properties of UWB systems are explained in some properties like below;

- Time hopping or direct sequence
- Low- duty cycle
- Short duration.

The first experimental work was started in 1990s. The 1993 Multiple Access scheme for UWB is proposed. After these many investigations are emerged in 1990-2000. All these works provide improve the UWB parameters learn and tested with other parameters.

The UWB usage field can categorized as commercial and military applications.

- Commercial fields: High speed LAN / WAN (>20 Mbps), Avoidance radar, Altimeter(aviation), Tags for intelligent transport systems, Intrusion detection, Geolocation.
- Military fields: Radar, Covert communications, Intrusion detection, Precision geolocation, Data links.

2.1. Federal Communications Commission (FCC)

The Federal Communications Commission (FCC) regulate communication law in U.S. about radio, TV, wire, satellite and cable. The commission primarily responsible for communication laws. FCC defined the UWB characteristic for efficiently using especially power and bandwidth. According to FCC minimum transmission bandwidth and maximum transmitted power are 500 MHz and -41dBm/MHz respectively [6].

Today, Generally the rules set by FCC are applied in almost all of the study in the UWB field. This usage has also become widespread commercially.

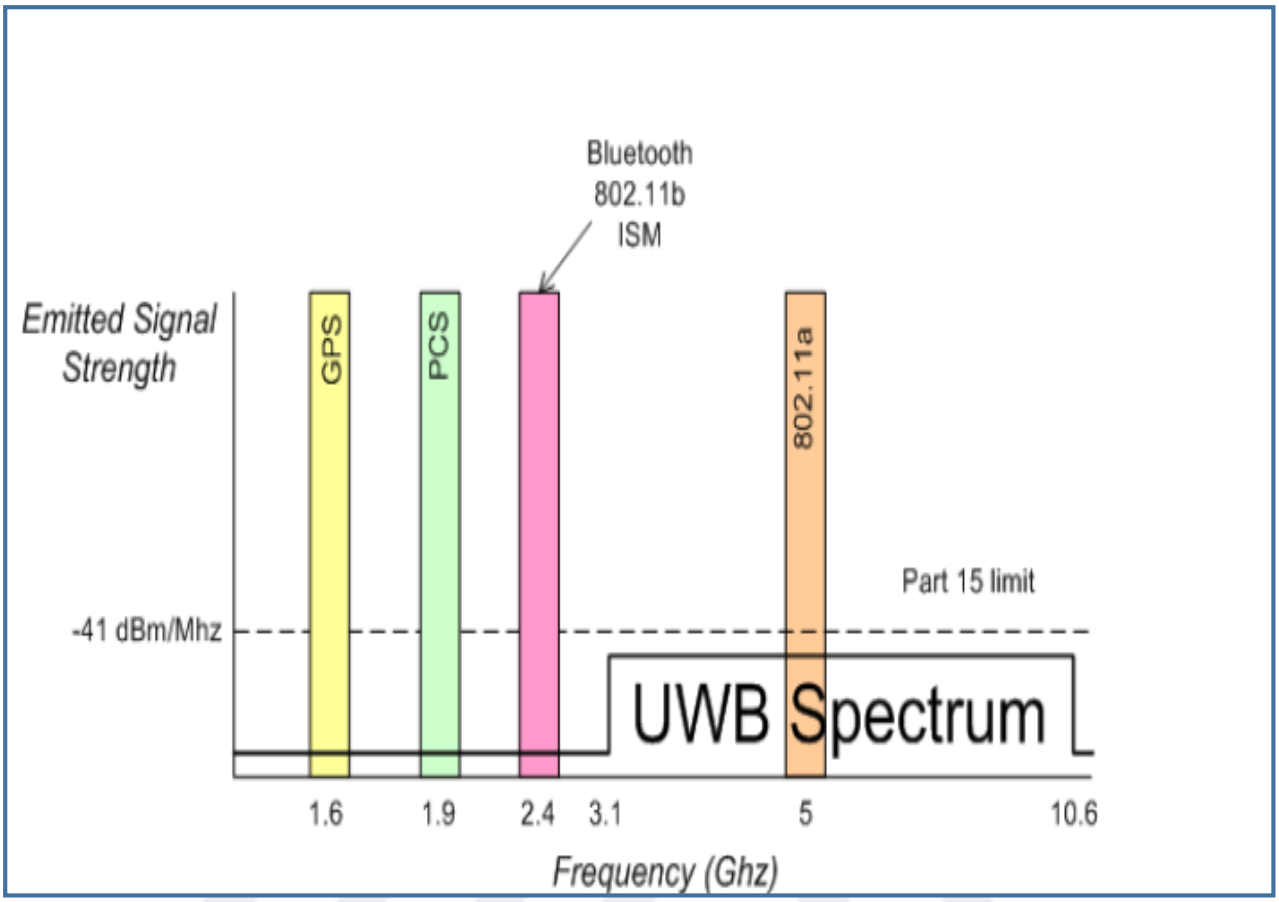

Figure 2.1. UWB Spectrum

3. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier system in communication systems. The signal is transmitted simultaneously over much subcarriers. PSK or QAM methods can be implemented with OFDM Modulation. Properties of OFDM signals are generally different sources. In OFDM progress some steps are performed. Firstly, the OFDM signal transmitted with different independent channels. Secondly, data is modulated, then finally the signal is again multiplexed to create OFDM carrier. The signal is parallelly transmitted end of transmitter. N parameter is number of parallel channel that used end of the transmitter. The signal carry with N parallel channel [4, 6].

OFDM is normally Frequency Division Multiplexing (FDM) method. OFDM is multicarrier system and subchannels are used in transmission. The data signal is carried with subcarriers and the subcarrier frequencies are defined as with orthogonality principle for prevent interference in symbol and subcarrier. Without orthogonality data signal that used FDM method exposed to some interference. Effective of orthogonality in OFDM can be seen in Figure 3.1.

The Inter Symbol Interference (ISI) and (Inter Carrier Interference) ICI effect the transmission negatively in communication systems. Some steps are inserted to OFDM for decrease the ISI and ICI effects in transmission. Otherwise the data signal exposed the distortion with ICI and ISI. The Guard Interval is a type of precaution for remove the ISI in transmission. Cyclic Prefix is added to signal prevent to ICI. In multipath channel, because of multipath channel properties the ICI can occur in transmission. Cyclic Prefix method is used prevent to ICI [4].

3.1. Inverse Fast Fourier Transform (IFFT)

Multi Carrier Modulation (MCM) signal consists of transmitted N subcarrier signals.

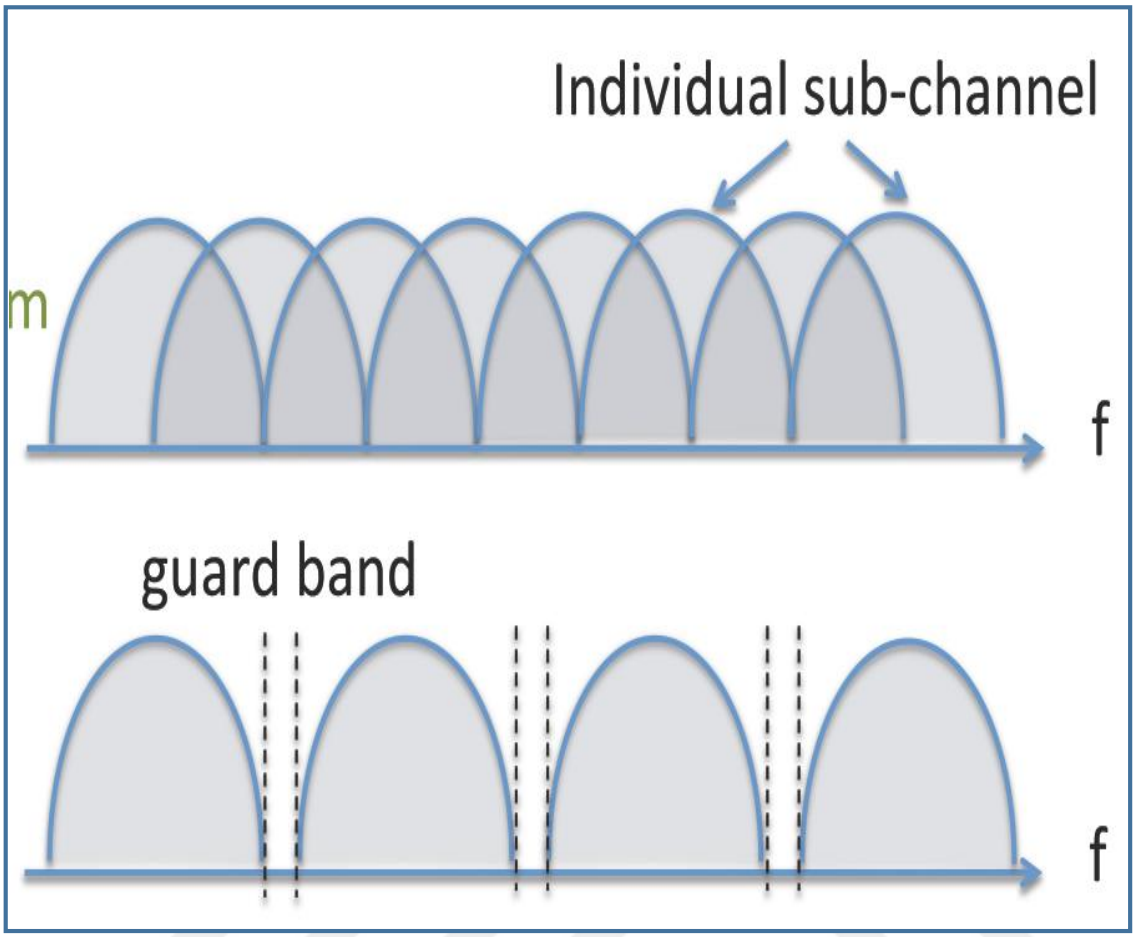

Figure 3.1. Effect of orthogonality in OFDM

$$(t) = \sum_k \left(X_k e^{j2\pi k F_0 t}\right) \tag{3.1}$$

X_k: The symbol is transmitted kth subcarrier.

$e^{j2\pi k F_0 t}$: kth subcarrier, kF_0: kth subcarrier frequency.

N: The number of total subcarriers.

Equation (3.1) is IFFT expression. In this study 100 subcarrier is used so it needs 100 oscillator according to equation 3.1. The orthogonality is implemented in this case. The orthogonality principle is below, k and l subcarriers are orthogonal according to (3.2) equation.

$$e^{j2\pi(k-l)} \begin{cases} 1, k = l \\ 0, k \neq l \end{cases} \tag{3.2}$$

To overcome large subcarriers following equations can explain:

Let a signal of a maximum frequency of B hence $F_{MAX} = \frac{1}{B}$. This is bandlimited signal and Nyquist rate is used to take sample.

$2F_{MAX} = B$, for Nyquist rate.

Sampling duration or sampling interval = $\frac{1}{(Sampling\ Frequency)} = \frac{1}{B} = T$

l^{th} sampling instant: $lT = \frac{1}{B}$.

The sample will be,

$$x(t) = x(lT) = \sum_k \left(X_k e^{j2\pi k F_0 lT}\right) \quad (3.3)$$

$$x(t) = x(lT) = \sum_k \left(X_k e^{j2\pi \frac{kl}{N}}\right) \quad (3.4)$$

Equation (3.4) is IFFT which is l^{th} IDFT point of $X(0)$, $X(1)$, …… $X(N-1)$ symbols are transmitted on N^{th} subcarrier which are different symbols. This can be easily generated with the help of N bank modulators. $x(0)$, $x(1)$, …….., $x(N-1)$ are the samples of the transmitted signals. X(0), $X(1)$, …… $X(N-1)$ are the transmitted symbols on transmitted samples of $x(0)$ signals.

N point IFFT will be $x(0)$, $x(1)$, …….., $x(N-1)$ transmitted samples.
Similarly, $y(0)$, $y(1)$, …….., $y(N-1)$
N point FFT will be $Y(0)$, $Y(1)$, ……..,$Y(N-1)$.

We should send symbols with N subcarriers. N is IFFT and FFT parameter in transmitter and receiver. In above process we implemented IFFT operation and generation steps on transmitted signals. We will implement reverse process at the receivers for recover signal. The reverse of IFFT is FFT process and FFT will be implemented at the receiver.

As seen equation 3.4 IFFT converts to data signal from frequency domain to time domain in transmitter in OFDM. Also, FFT converts to received data signal from time domain signal

to frequency domain. These FFT and IFFT process briefly explained with some figures in Figure 3.2.

3.2. The Guard Interval and Its Implementation

Linear distortion can happen because of multipath channel in OFDM signal. Subchannel spread to energy to adjacent channels and cause the ISI. ISI causes the distortion on signal. Simple solution for this problem increasing the symbol duration or adding to subcarriers to OFDM symbol. In this case signal has not any distortion related to ISI due to added subcarriers. However, implement of this method can be difficult in terms of carrier stability. Implementing of this method is explained in below.

- C_D : 100 data subcarriers,
- C_G : 10 guard subcarriers,
- C_P : 12 pilot sub-carriers.

OFDM symbol parameters are located according to number series.

- C_G, 10 guard subcarriers are located -61, -60,…,-57 and 57, 58, …, 61 logical frequencies.
- C_P, 12 pilot subcarrier are located -55, -45,-35, -25, -15, -5, 5, 15, 25, 35, 45 and 55 logical frequencies.

Guard interval parameters and its location on logical frequencies is obtained from the formula.

$$C_{G,n}[l] = \begin{cases} C_{D,n}[l] & l \in \left[0, \frac{N_G}{2} - 1\right] \\ C_{D,n}[l+90] & l \in \left[0, \frac{N_G}{2} - 1\right] \end{cases} \tag{3.5}$$

The place of these subcarriers can see in Figure 3.3. Also, the aim of subcarriers is explained in below:

- Data subcarriers: These subcarriers carry the data information signal.
- Pilot subcarrier: These subcarrier carries the parameters of channel properties and carries out time and frequency synchronization to prevent ISI and ICI respectively.

- Guard subcarriers: These subcarriers consist of end of OFDM symbol and it provide demodulation the OFDM symbol in receiver.

3.3. OFDM Transmission

OFDM is a kind of multicarrier system. N orthogonal subcarriers is modulated in that system. OFDM employs to eliminate of ISI. Also, these data parallelly transmitted. In this case N is IFFT parameter it means that symbol period is multiplexed with N. To remove ISI the guard interval is added to OFDM symbol. Moreover, CP as guard interval and it is used to avoid the ICI. ICI is caused by multipath channel. These process improved spectrum efficiency.

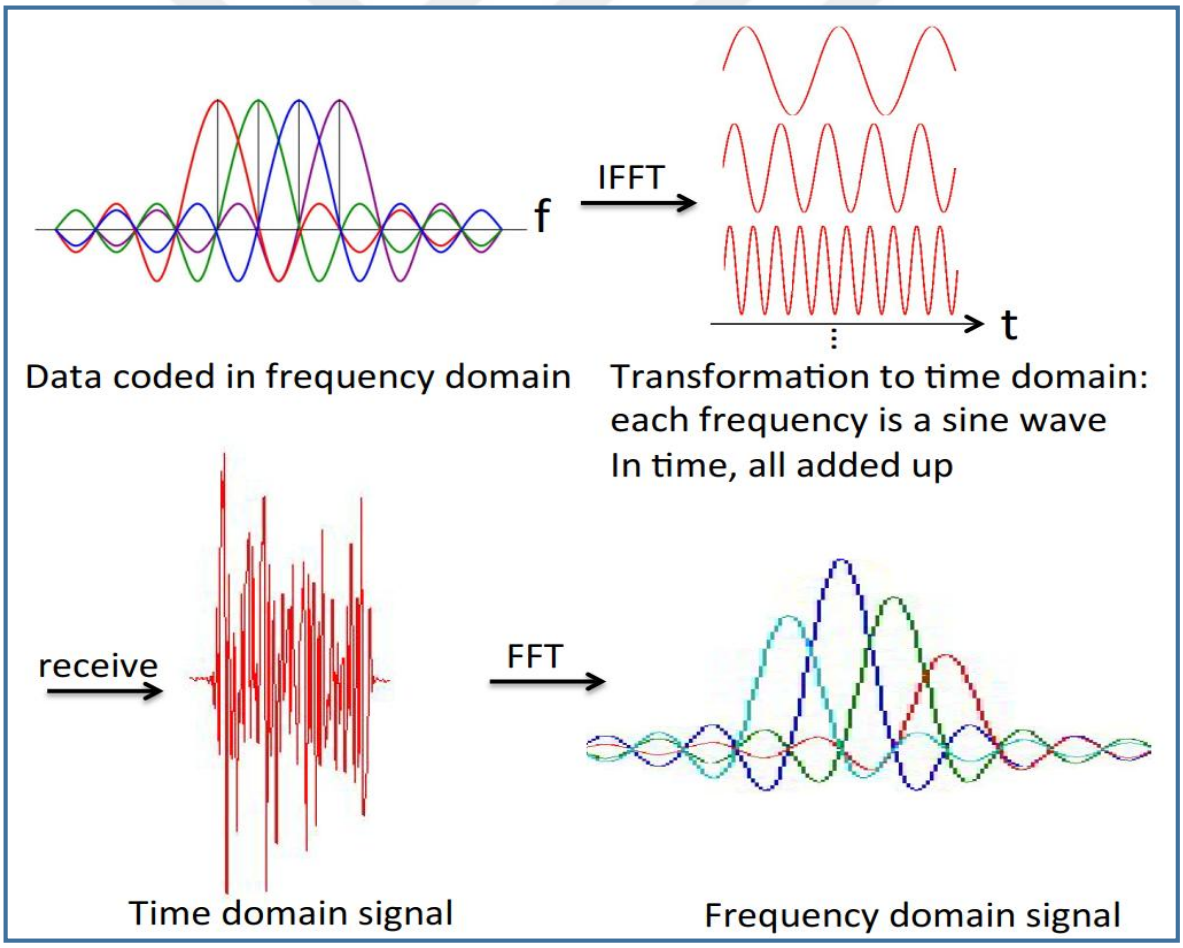

Figure 3.2. IFFT and FFT process in OFDM

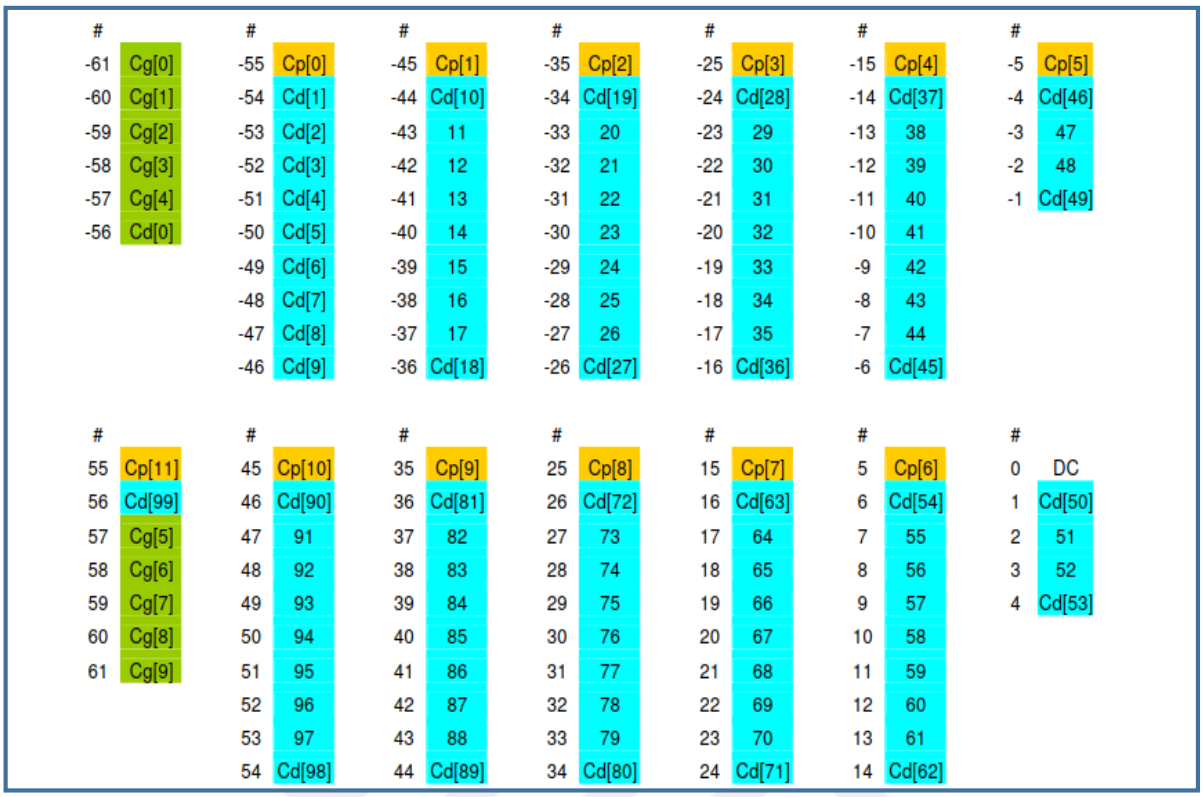

Figure 3.3. OFDM Symbol Scheme

4. OFDM ON UWB TECHNIQUES

Generally, two techniques are used in OFDM. Modulation. One of them is Direct Sequence and the other one is Multiband OFDM.

4.1. Direct Sequence (DS) OFDM Technique

The short impulses are used to send information in DS technique. When the pulse is shorter in time domain, these signals occupy wider bandwidth in frequency domain because of time and frequency domain FFT relationship.

4.2. MB OFDM Method

ECMA-368 [6] announced UWB MB OFDM standard in 2005. According to this standard UWB bandwidth is separated into 14 bands. Each bandwidth is 528 MHz in UWB. These 14 bands are grouped as can be seen Figure 4.2. Every Band Group (BG) has 3 bands exception BG5. The BG5 has 2 bands. According to FCC for each bandwidth minimum should have 500 MHz BG1 used generally in market recently. BG1 has 3 bands and each band is 528 MHz. This condition can be seen in Figure 4.3.

Each single OFDM symbol is transmitted in one different band. Frequency hopping method is used for each OFDM symbol. This frequency selection is detected with Time Frequency Cosine (TFC). TFC has to be known in receiver and transmitter. Figure 4.4 shows frequency hopping method.

The function block diagram can be used to better understand the MB OFDM steps. This functional diagram can be seen in Figure 4.1. The functional diagram consists of three part Transmitter, Receiver and Channel. The channel is selected as AWGN channel in this thesis and some properties of AWGN channel can be observed briefly as in this figure. At the end of the process our system tries to recover original input data with minimum loss.

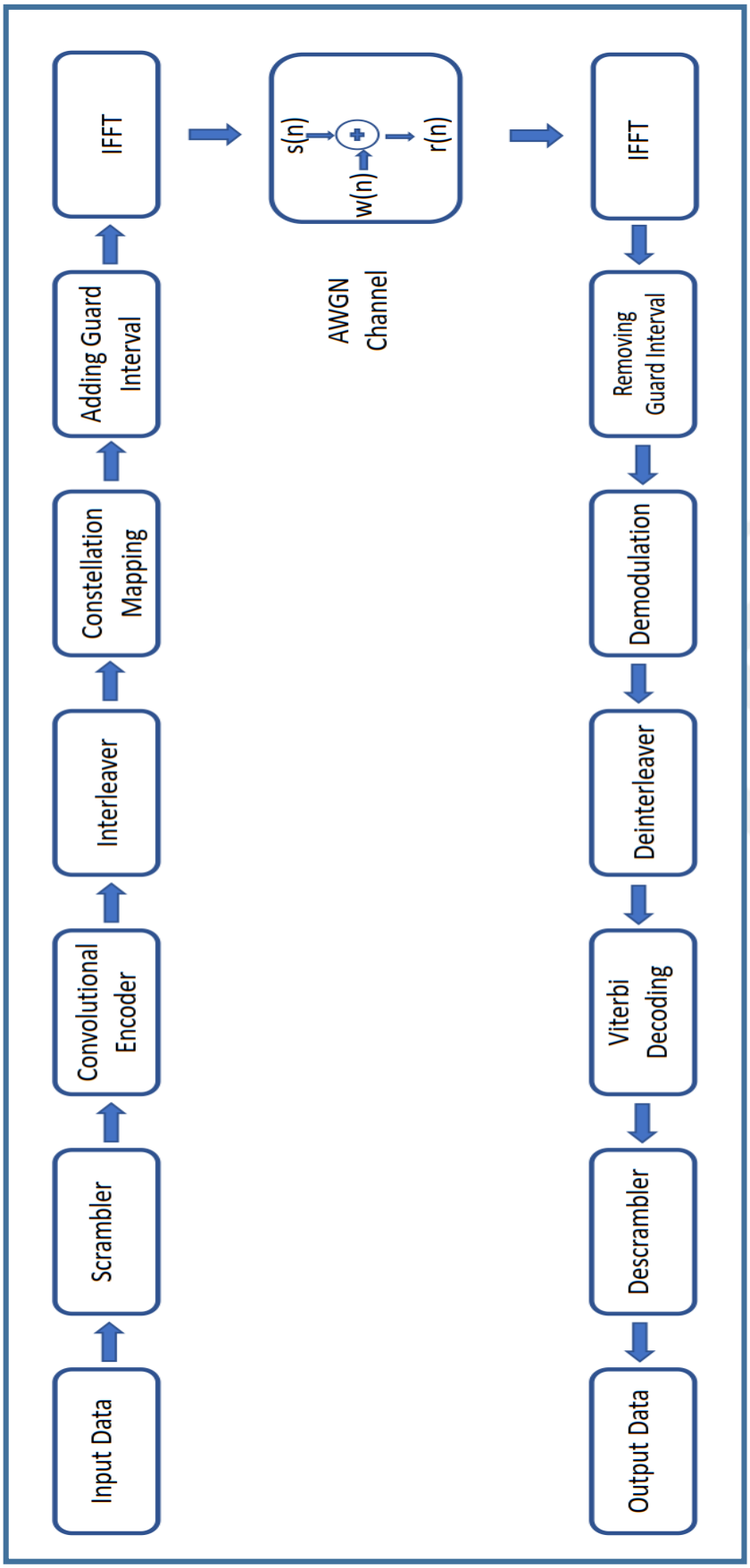

Figure 4.1. MB OFDM system model

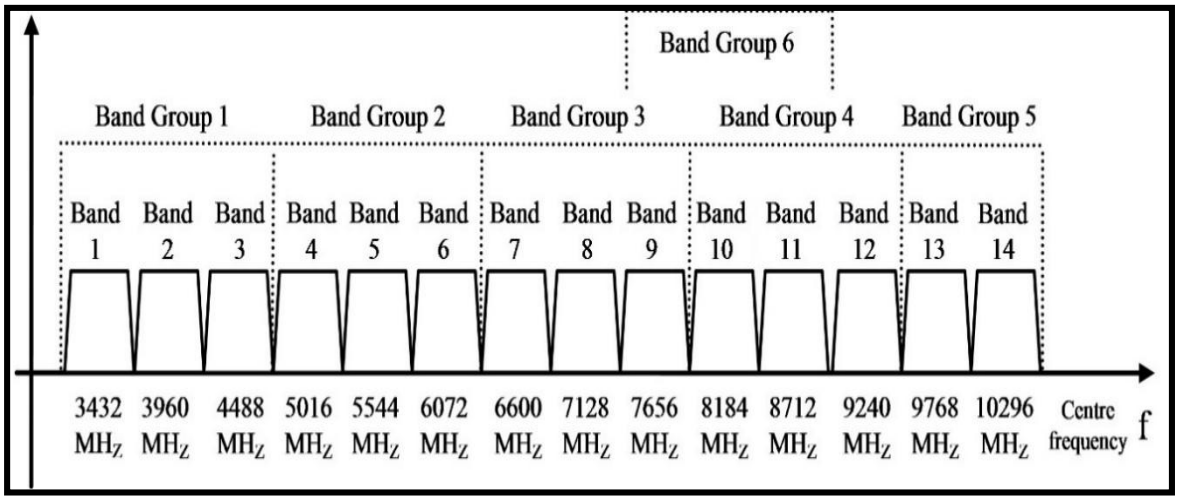

Figure 4.2. UWB bandwidth grouping (ECMA-International, 2008)

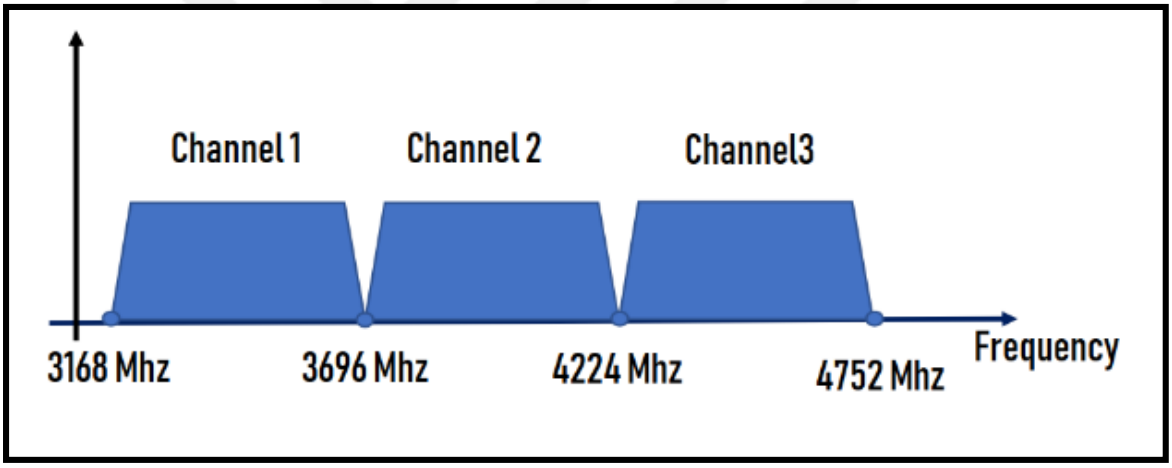

Figure 4.3. BG 1 frequency allocation

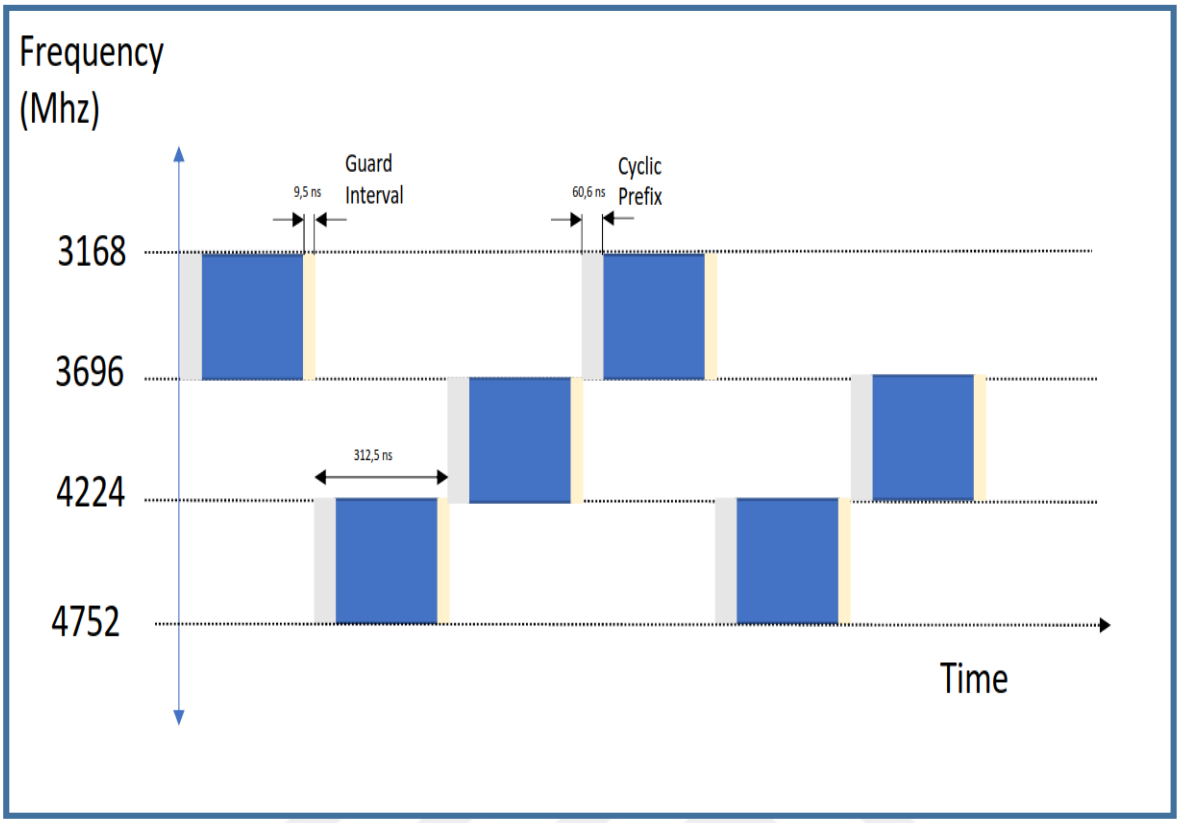

Figure 4.4. Frequency hopping method with TFC.

Table 4.1. MB OFDM Parameters with different modulation

Data Rate (Mbps)	Modulation	Code Rate	TDS	FDS
53.3	QPSK	1/3	Yes	Yes
80	QPSK	1/2	Yes	Yes
106.7	QPSK	1/3	No	Yes
110	QPSK	11/32	No	Yes
160	QPSK	1/2	No	Yes
200	QPSK	5/8	No	Yes
320	DCM	1/2	No	No
400	DCM	5/8	No	No
480	DCM	3/4	No	No

4.2.1. Input data

Input data sequence is binary data. Normally, according to OFDM modulation in one transmitting process 6 OFDM symbol can be transmitted. This length can change with Convolutional Encoder process and other block properties. Our input data is 1200 binary input data. For each one OFDM symbol has 100 binary data. The symbol length 12 OFDM symbol in our OFDM modulation.

4.2.2. Scrambler and descrambler

Scrambler is a manipulation process used in telecommunication and recording field. In MB OFDM progress scrambler is done before transmitting. The signal should be descrambled to obtain to true data signal. Descrambling operation is used in receiver side. The scrambler provides an XOR operation to input data. The scrambler steps can be seen in Figure 4.5. $g(D)$ is a polynomial generator and D shows a single bit delay element. The generator is pseudo random binary sequence generator. The $g(D) = 1 + D^{14} + D^{14}$ is generated by $g(D)$. $x[n]$ is generated by using this generator polynomial $g(D)$.

$$x[n] = x[n-14] \oplus x[n-15], \; n = 1,2, \ldots \tag{4.1}$$

where "$\oplus$" denotes modulo-2 addition.

Initialization vector x_{init} is specified by "seed value". Also, these seed value and related output can be seen in Table 4.1:

$$x_{init} = [x_i[-1]\, x_i[-2] \ldots x_i[-14]\, x_i[-15]\,] \tag{4.2}$$

Table 4.2. Scrambler Operation

Seed Identifier(S1,S2)	Seed Value $x_{init} = [x_i[-1]\, x_i[-2] \ldots x_i[-14]\, x_i[-15]\,]$	Output $x_i[1]\, x_i[2] \ldots x_i[14]\, x_i[15]$
00	0011 1111 1111 111	0000 0000 0000 1000
01	0111 1111 1111 111	0000 0000 0000 0100
10	1011 1111 1111 111	0000 0000 0000 1110
11	1111 1111 1111 111	0000 0000 0000 0010

$x_i[-k]$ shows the binary initial value at the output of the kth delay element.
$v[m]$ is scrambled data bit as defined in Figure 4.5.

$$v[m] = s[m] \oplus x[m], m = 1,2, \ldots \quad (4.3)$$

where $s[m]$ represents the non-scrambled data bit.

Descrambler is the process of recovering scrambled data. The descrambler process is used in receiver and same $s[m]$ and same parameters are used in receiver.

4.2.3. Convolutional encoder and viterbi decoder

The Convolutional Encoder block provides the insertion of redundancy bits to signal to increase to performance of SNR. The insertion of redundancy bits also increases accurate signal decoding. Convolutional Encoder supports the five different coding rates: 1/3, 11/32, 1/2, 5/8, and 3/4. In this application the rate R is 1/3 is used. In convolutional encoder process generator polynomials are used. For $R = \frac{1}{3}$ generator polynomials are $g_0 = 133_8$, $g_1 = 165_8$, and $g_2 = 171_8$. Constraint length is K = 7 in Figure 4.6 [6].

The employing puncturing is derived from $= \frac{1}{3}$. This encoder should start from all zero state. The Viterbi Algorithm is recommended for decoding Convolutional Encoder at the receiver.

4.2.4. Bit interleaving and deinterleaving

The scrambled data shall be interleaved to be resistant to burst error. The data will modulate after interleaving data in transmitter. Interleaving process is necessary before modulation[10]. The bit interleaving consists of three distinct steps and it is shown in Figure 4.7 and depends on parameters presented on Table 4.3. Each one step is briefly explained below.

Symbol interleaving

The 6 OFDM consecutive symbol is processed in Symbol Interleaving. This 6 OFDM consecutive symbols also called block of N_{CBP6S}. Block interleaver size is N_{CBPS} by $6/N_{TDS}$. $a[i]$ is input of symbol interleaving and $a_S[i]$ is output of symbol interleaving $i = 0, \ldots.,$ $N_{CBP6S} - 1$. Symbol interleaving relationship:

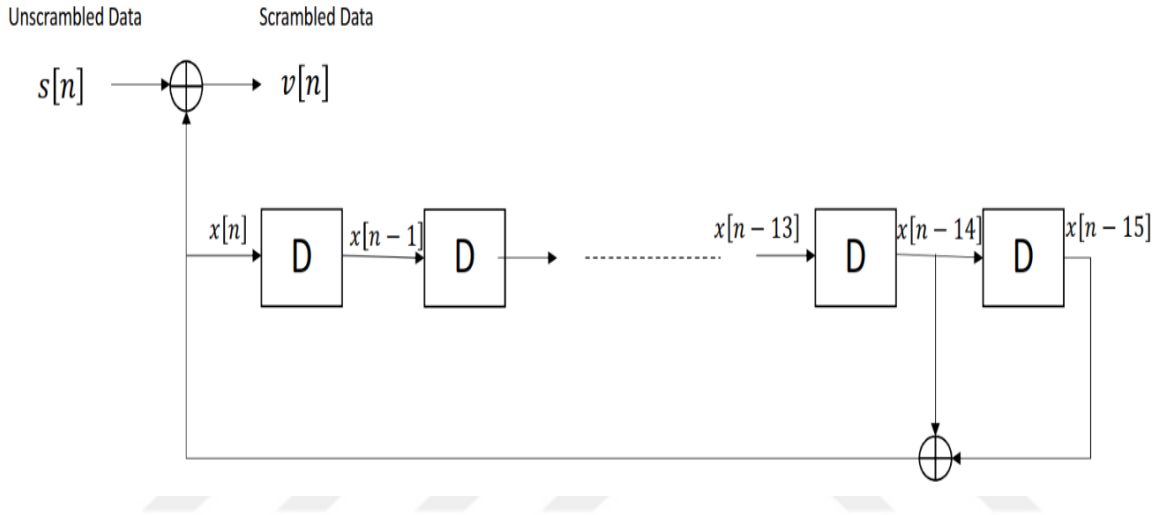

Figure 4.5. Scrambler diagram

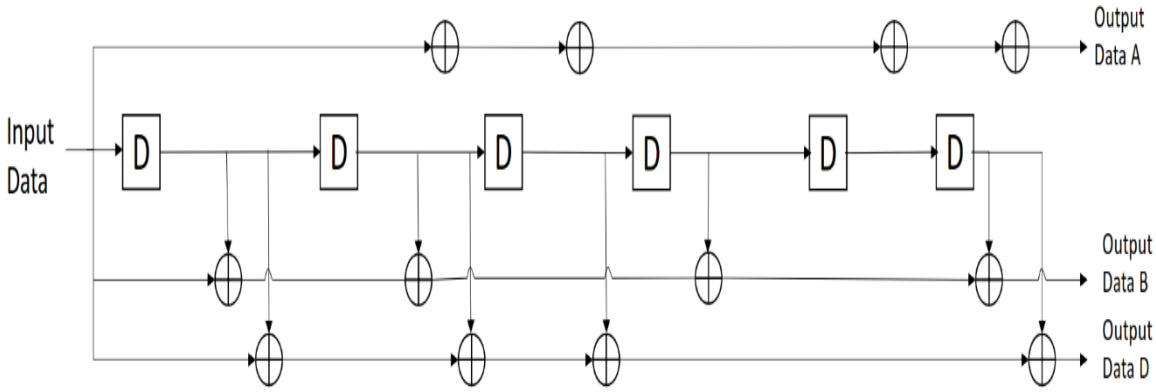

Figure 4.6. Convolutional encoder: rate R = 1/3, constraint length K = 7

$$a_S[i] = a\left[\left\lfloor \frac{i}{N_{CBPS}} \right\rfloor + \left(\frac{6}{N_{TDS}}\right) \times mod(i, N_{CBPS})\right] \quad (4.4)$$

Intra-symbol tone interleaving

Intra-symbol one interleaving size detected by Per OFDM symbol and time domain spreading factor. Its size depends on the number of coded bits of per OFDM symbol and the value of the time domain spreading factor. The output of symbol interleaver is permuted in intra-symbol tone interleaving. The size of this process is $N_{Tint} \times 10$. $a_S[j]$ is input of Intra-symbol tone interleaving and $a_T[j]$ is output of Intra-symbol tone interleaving $i = 0, \ldots.,$ $N_{CBP6S} - 1$. Intra-symbol tone interleaving relationship:

$$a_T[j] = a\left[\left\lfloor \frac{j}{N_{Tint}} \right\rfloor + 10 \times mod(j, N_{Tint})\right] \quad (4.5)$$

Intra-symbol cyclic shifts

It provides the shift bits in OFDM symbols with deterministic amounts. Interleaving process needs some parameters which are listed in Table 4.3. The signal is passed through to Intro-symbol cyclic shift after Intra-symbol tone interleaving. The block consists of different cyclic shift for per N_{CBPS}.

$a_T[j]$ is input of Intra-symbol cyclic shifts and $b[i]$ is output of Intra-symbol cyclic shifts $i = 0, \ldots.,\ N_{CBP6S} - 1$. Intra-symbol tone interleaving relationship:

$$b[i] = a_T\left[m(i) \times N_{CBPS} + mod(i + m(i) \times N_{cyc}, N_{CBPS})\right] \quad (4.6)$$

where $m(i) = \left\lfloor \frac{i}{N_{CBPS}} \right\rfloor$ where $i = 0, \ldots.,\ N_{CBP6S} - 1$.

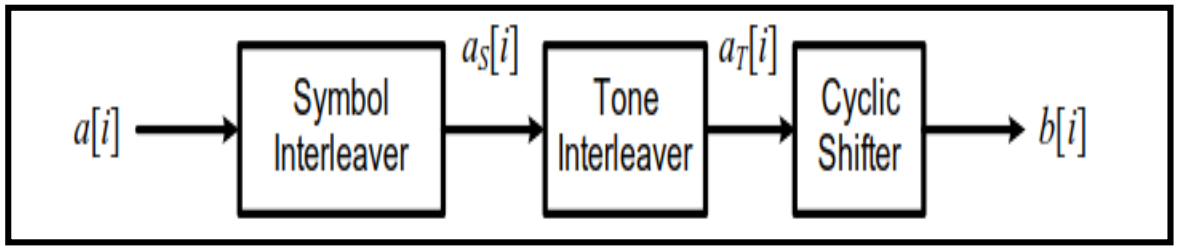

Figure 4.7. A block diagram of interleaver

Table 4.3. Interleaver Parameters

Data Rate (Mb/s)	TDS Factor(N_{TDS})	Coded Bits / OFDM Symbol(N_{CBPS})	Tone Interleaver Block Size(N_{Tint})	Cyclic Interleaver Shift(N_{cyc})
53,3	2	100	10	33
80	2	100	10	33
106,7	2	200	20	66
160	2	200	20	66
200	2	200	20	66
320	1	200	20	33
400	1	200	20	33
480	1	200	20	33

4.2.5. Constellation mapping and demodulator

This block provides to converting the data sequence from binary data onto complex data sequence. QPSK modulation is focused algorithm in this progress. Other modulation types are implemented in this project. Some properties of these applied modulation types are explained briefly in below.

Quadrature phase shift keying (QPSK) modulation

The binary data sequence is encoded and interleaved before progress, but it is still binary value. Input data sequence of QPSK is $b[i] = 1, 2, \ldots..,$ is divided two bits groups. After that these grouped values are converted into complex number. According to Gray-Coded constellation mapping the complex number is shown mapped to proper places as can see in Figure 4.8

In QPSK Modulation, $b[2k]$ where $k = 0, 1, 2 \ldots..$, and output of QPSK is $d[k]$.

$$d[k] = [K_{MOD} \times (2 \times b[2k] - 1) + j(2 \times b[2k+1] - 1)] \quad (4.7)$$

where $k = 0, 1, 2 \ldots..,$

$K_{MOD} = \frac{1}{\sqrt{2}}$ is Normalization Factor in Constellation Mapping for QPSK Modulation. For Gray Coded QPSK Modulation can be seen I and Q values in Figure 4.8 and $b[2k]$ shows I value and $b[2k+1]$shows Q value as define Table 4.4. After QPSK modulation the data signal format is complex number and length of data is doubled.

Quadrature amplitude modulation (QAM) modulation

QAM signal consists of two amplitude-modulated (AM) signal for one signal channel. The used bandwidth becomes twice because of two signals combining for one signal channel. The QAM signal is carried over two carrier, both carriers are same frequency but whose phases are 90 degrees different between these carriers (The quarter name for AM comes from 90 degrees phase different means that one quarter of a cycle.) One of these signals is called I signal and the other is called Q signal. If one these signals is sine wave in time domain and the other signal is cosine wave in time domain. AM modulation which has undergone these carriers should be incorporated in the transmission source. These coupled carriers are separated at the transmission target. Data is obtained from each of these separated signals. The resulting signals are combined in the modulation information plane.
The QAM signal;

$$s(t) = m_1(t)\cos w_c t + m_2(t)\sin w_c t \quad (4.8)$$

$m_1(t)$ and $m_2(t)$: two data information signals.
$\cos w_c t$ and $\sin w_c t$: The phases of sent data signals.
If the phase of one of sent data signal accepted by multiplying it with $\cos w_c t$. The other phase of sent data signal in quadrature becomes the by multiplying it with $\sin w_c t$. The data signals sent in with different phase are added to recover one QAM signal. [21].

QAM modulation is more susceptible to noise because of QAM statuses are closer to each other. The low level noise is necessary for QAM modulation because of this susceptible properties of QAM Modulation.

PSK QAM modulation properties

Transmission types with different modulation will give different transmission results since the respective parameter of each modulation is different. If it is aimed to make the transmission efficient, the most appropriate one of these modulations should be selected. PSK and QAM modulation types are used in this study and each modulation

type results are obtained. The varying parameters for each modulation are described with as explanation and visually in Figure 4.9 - Figure 4.15

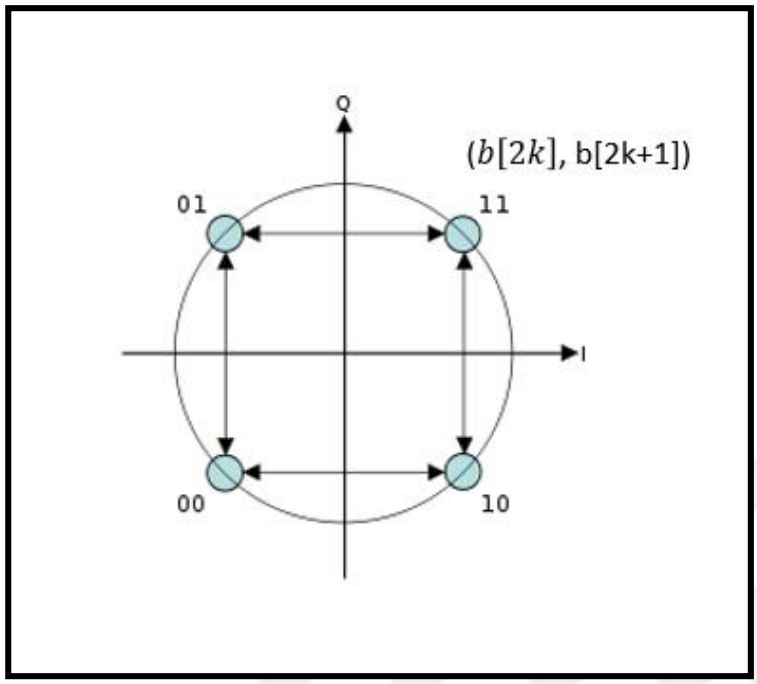

Figure 4.8. Signal Constellation for QPSK Modulation

Table 4.4. QPSK Encoding Table

Input Bits $(b[2k], b[2k+1])$	I-out	Q-out
00	-1	-1
01	-1	1
10	1	-1
11	1	1

Binary phase shift keying (BPSK)

Parameters: 2 separate phase,2 symbol, 1bit/symbol

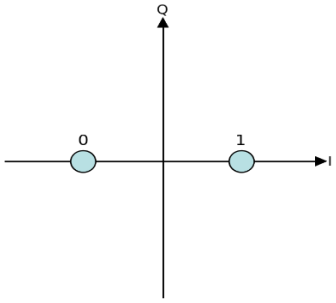

Figure 4.9. BPSK

QPSK

Parameters: 4 separate phase,4 symbol, 2bit/symbol

QPSK and 4 QAM are different modulation methods but the number of parameters is same about phase, symbol and bits/symbol.

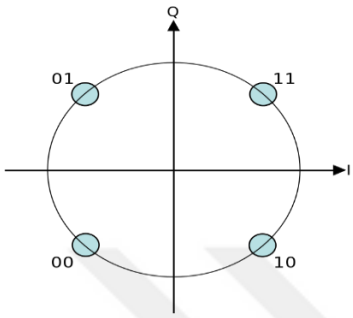

Figure 4.10. QPSK and QAM

8 PSK

Parameters: 8 separate phase,8 symbol, 3bits/symbol

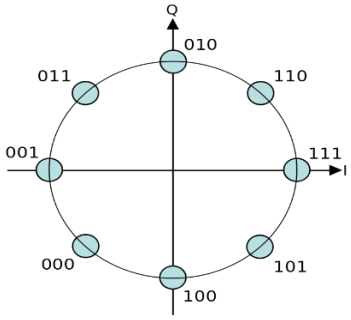

Figure 4.11. 8 PSK

4 QAM

Parameters: 4 separate phase, 1 amplitude, 4 symbol, 2bits/symbol

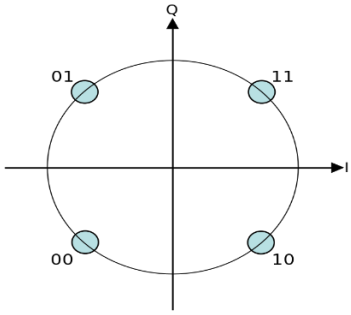

Figure 4.12. 4 QAM and QPSK

16 QAM

Parameters: 8 separate phase, 2 amplitude, 16 symbol, 4 bits/symbol

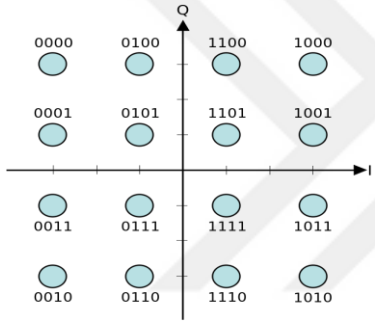

Figure 4.13. 16 QAM

64 QAM

Parameters: 16 separate phase, 4 amplitude, 6 symbol, 6 bits/symbol

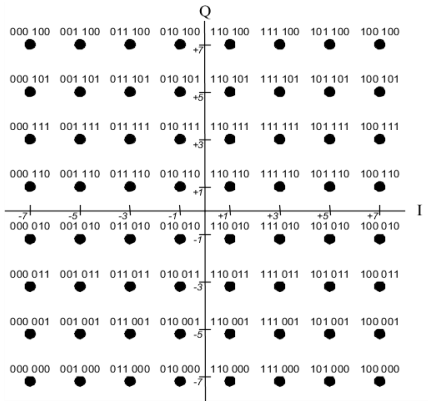

Figure 4.14. 64 QAM

256 QAM

Parameters: 32 separate phase, 8 amplitude, 256 symbol, 8 bits/symbol

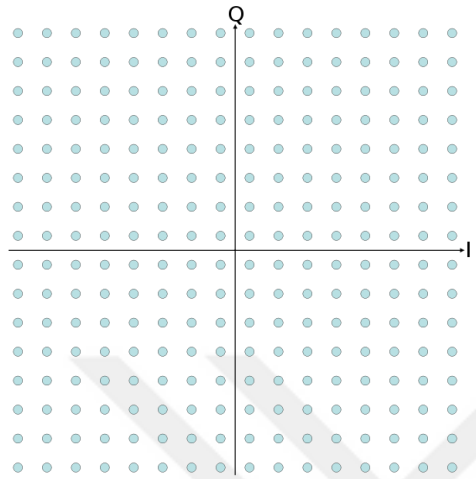

Figure 4.15. 256 QAM

4.2.6. Adding guard interval and removing guard interval

After Constellation Mapping or QPSK Modulation, OFDM Modulation process can be implemented to data signal in MB OFDM Modulation. Output of Constellation Mapping data is complex-valued number data sequence. The data is one vector now and it should be converted to parallel for input of Adding Guard Interval block or OFDM. After from series to parallel conversion one of parallel output is on OFDM symbol. Pilot, Guard and Null carriers will be inserted to one OFDM symbol. Normally the number of data subcarriers are 100 subcarriers. After inserting process the OFDM subcarrier size becomes 128 subcarriers [6].

For 128 OFDM subcarriers, 100 data subcarriers are used to transmit information. The information placed to data tones in OFDM subcarrier, so it is our most imported part. The number of Pilot subcarriers is 12. The number of guard tones is 10 and it is used for including facilitate. There are also 6 null tones. The positions of these tones are shown in Figure 3.3 After Guard, Pilot and Null tones added to OFDM symbol, the cyclic prefix is appended to the OFDM symbol and this OFDM symbol helps to eliminate to ISI.

When data rate is 80 Mbps or lower,

$C_{d,k} = d_{d+50k}$

$$C_{(d+50),k} = d^*_{(49-d)+50k} \quad (4.8)$$

Where $d = 0, 1, 2 \ldots\ldots, 49,$ and $k = 0, 1, 2 \ldots\ldots, N_{SYM} - 1.$ N_{SYM} denote the OFDM symbol.

If data rate is larger from 80 Mbps,

$$C_{d,k} = d_{d+100k} \quad (4.9)$$

Where $d = 0, 1, 2 \ldots\ldots, 49,$ and $k = 0, 1, 2 \ldots\ldots, N_{SYM} - 1.$ There is not frequency – diversity gain in this method.

For removing OFDM symbol from 128 subcarrier OFDM symbols same steps are applied to complex valued data sequence as reversely in receiver. All added sub carriers or data tones positions are known in OFDM subcarriers. At the end of the removing process only data subcarriers are left behind with complex valued data sequences from this process.

4.2.7. IFFT and FFT

IFFT is other part of OFDM modulation. Details are explained before in Figure 3.1. Parameters are mentioned below about FFT in our Thesis.

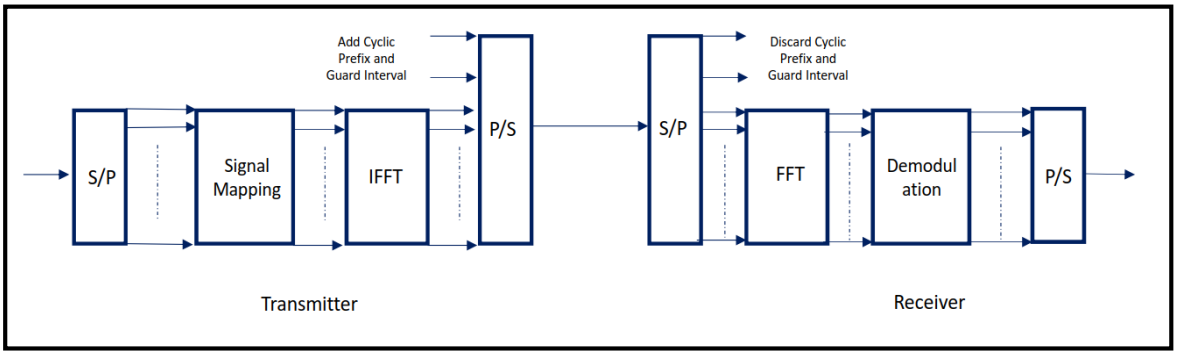

Figure 4.16. Transmitter and receiver of an OFDM system

IFFT size is 128 point,

IFFT period is 242.42 ns,

Each IFFT subcarrier frequency is 528 MHz.

The difference between IFFT and FFT is explained briefly in below.

IFFT equation;

$$X(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) \mathrm{e}^{\mathrm{i}2\pi \mathrm{n} k/N} \quad (4.10)$$

$X(n)$: Samples for time domain.

$X(k)$: Samples for frequency domain.

N = IFFT size

$k = 0, 1, 2 \ldots\ldots, N-1.$

IFFT converts the vector signal from frequency domain to time domain. IFFT block is employing in OFDM in Transmitter.

FFT Equation;

$$X(k) = \sum_{n=0}^{N-1} X(n) \mathrm{e}^{-\mathrm{i}2\pi \mathrm{n} k/N} \quad (4.11)$$

$X(n)$: Samples for time domain

$X(k)$: Samples for frequency domain.

N = FFT size

$k = 0, 1, 2 \ldots\ldots, N-1.$

Most important duty for FFT is converting process. FFT converts the vector signal from time domain to frequency domain. The FFT block is employing in OFDM in Receiver. After IFFT in transmitter parallel complex valued data sequence is converted to serial data sequence and send to receiver. The data is taken as a serial complex data sequence in receiver. For FFT process the data have to be converted to parallel. After this conversion the complex valued data sequence FFT is applied to data. To complete the OFDM Demodulation after FFT some subcarriers will be removed from data sequence [2].

4.2.8. AWGN channel

The noise causes distortion on transmitted symbol and when the receiver recovers the signal which include OFDM symbol as a different signal. In average AWGN circumstances, one or more-bit error can happen in each symbol in receiver. The errors are calculated by bit error rate (BER) [11]. AWGN channel can be showed as a block in

Figure 4.17 for our thesis.

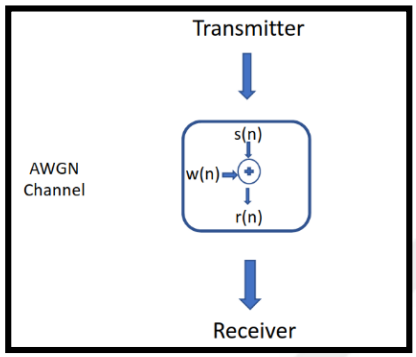

Figure 4.17. AWGN Channel

For a thermal noise in communication systems some basic rules are explained below:

- The noise is added to transmitted signal and the received signal equals the sum of noise and transmitted signal. The channel noise is called the additive because of this rule. This principle is shown in
- Figure 4.18. The noise is statistically independent from data signal.

$$r(n) = s(n) + w(n) \tag{4.12}$$

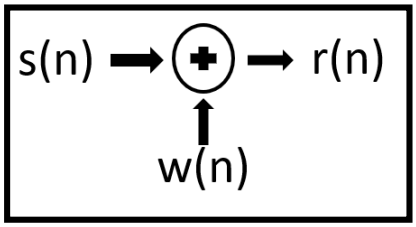

Figure 4.18. AWGN additive channel

- There is White noise in AWGN channel. So PSD is flat as shown in Figure 4.19 below;

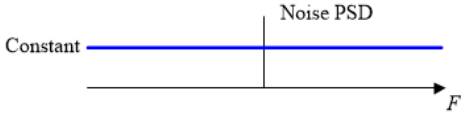

Figure 4.19. AWGN is white noise

- Gaussian with a zero mean is considered the probability distribution of the noise samples.

AWGN channel is represent noise channel between transmitter and receiver. The signal can expose the distortion because of multipath effects. Normally the data signal is converted to analog signal after IFFT for sending on wireless channel. And Receiver take the signal as analog signal before the FFT and converts to digital signal for transform. In this study, our processes are implemented on Matlab program. Also, result of our study is considered with these Matlab program result. The study didn't implement normally under real circumstances but added all some steps to receiver and transmitter for closed to real world application [11].

4.2.9. SNR

SNR is probably most common performance detection method in digital communication system. SNR generally is measured at the output of receiver. Because of this the process directly related to data detection. SNR is explained in terms of power ratio between data signal and noise. As a formulation SNR briefly can be explained below;

$$SNR = \frac{P_s}{P_n} = \left(\frac{A_s}{A_n}\right)^2 \tag{4.13}$$

Where, P_s is signal power (average),
P_n is noise power (average),
A is RMS amplitude for signal and noise.

To obtain true healthy result signal power and noise power should be measured under same condition in same system and with the same system bandwidth. For example; if signal power value is in decibel(dB) scale noise power should be noise scale.
If the signal and the noise is measured across the same impedance, then the SNR can be obtained by calculating 20 times the base-10 logarithm of the amplitude ratio:

$$SNR(dB) = 10\log\left(\frac{P_s}{P_n}\right) = 20\log\left(\frac{A_s}{A_n}\right) \quad (4.14)$$

In BER calculation different SNRs are used to obtain the graphic results. SNR is an important characteristic for this study. At the end of the receiver SNR is calculated. The BER curves are obtained with these calculated SNR values. In real application some methods are implemented to keep up high SNR value. If the noise is more than the limit value the data signal has much distortion and BER value exceeds the fixed value. The receiver can not recover the signal as a requested and emerges the signal loss [14].

4.2.10. Eb/No and SNR relationship

We used the BER-SNR graphical demonstration for showing the results in this project. The result graphics axes are BER – Eb/No in last chapter. Some explanations are necessary for understanding the SNR and Eb/No relationship for understand the graphics.

$$\frac{S}{R_b} = E_b \quad (4.15)$$

R_b: Bit rate (bits/second)
E_b: Energy per bit (Joules/bit)
S: Total Signal Power (Watt)

$$\frac{E_b}{N_0} = \frac{S}{(R_b * N_0)}$$

$$SNR = \frac{R_b * E_b}{N_0} \quad (4.16)$$

SNR and Eb/No are similar according to equation 4.16. But $R_b$factor is added to this equation. If data rate is increase, it will be caused to ascend the SNR. Ascending the bit rate (R_b) will ascend the SNR but ascending the bit rate (R_b) causes noise. It can cause also ISI. We can use both parameters SNR and Eb/No in our graphics because of the bit rate (R_b) is not changing in our project.

4.2.11. BER

BER is an important indicator parameter of the health of the system. Error means that some transmitted bits are not correctly received in transmitted data. It is important to know which part of the bits are in error, so you can calculate the BER. The defined of the quality of the link is error free received data signal. The error bits are detected in receiver. Then this detected error bits divided to total numbers of bits for BER calculation. Communication systems aim to minimize the BER value to improve the quality of communication. All steps are implemented in this project on MATLAB. The BER results of each transmission are also obtained with MATLAB Communication Toolbox [18, 19]. After these step graphics are calculated by these simulation values.

4.2.12. Adaptive modulation and coding

The aim of this process is to enable the adaptive algorithm to select and transmit the most appropriate modulation method at a given SNR value. The selection should be done before from constellation mapping process in Figure 4.1. The transmission BER results of these modulation should be known for each SNR value in defined SNR range in order to select most appropriate modulation method with minimum BER value [20].

The different modulation BER results for each SNR value in defined SNR range are kept to create to database for adaptive algorithm. The algorithm will decide appropriate modulation method among to this algorithm database.

The transmission must be carried out by any selected modulation method at the beginning. The obtained BER and SNR information in result of transmission is sent back via Feedback Mechanism to Adaptive Algorithm. The mechanism can be summarized as shown in

Figure 4.20. The Adaptive Algorithm processes the SNR value that comes with feedback in transmitter. Adaptive algorithm selects the modulation method that has lowest BER value among the modulation methods corresponding to the SNR value that comes with feedback in the database. The transmission is performed again with selected modulation method. The obtained BER and SNR values from last transmission are sent again by the feedback mechanism. This process is repeated for subsequent transmissions.

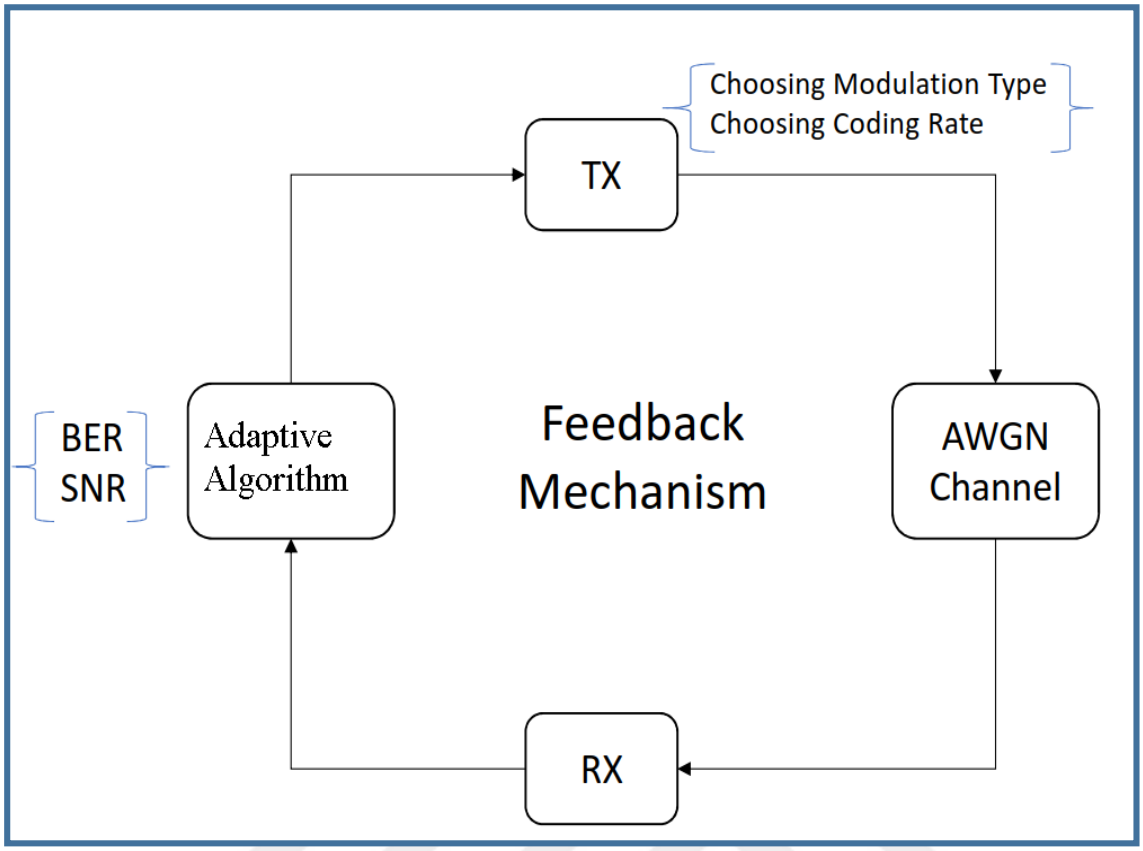

Figure 4.20. Feedback Mechanism

Table 4.5. Adaptive Modulation Selection

Eb/No(dB) VALUE	QPSK MODULATION BER VALUE	8PSK MODULATION BER VALUE	REUSLTS OF COMPARISON (LOWER BER)
1	0,071327684	0,123352166	QPSK
2	0,051318267	0,104519774	QPSK
3	0,037076271	0,084039548	QPSK
4	0,024011299	0,067231638	QPSK
5	0,013225475	0,054143126	QPSK
6	0,006002825	0,033270559	QPSK
7	0,002761072	0,019585687	QPSK
8	0,000886058	0,010130528	QPSK
9	0,000183598	0,005943974	QPSK
10	4,14E-05	0,003067857	QPSK
11	4,10E-06	0,000888818	QPSK

After explaining how this adaptive algorithm works, as an example the adaptive modulation with QPSK and 8PSK modulation results are shown in Figure 4.21for QPSK modulation and for 8PSK modulation and BER values obtained as a result of the transmission of MB OFDM for 1 dB – 11 dB between Eb/No(dB) shown in Table 4.5. The type of the selected modulation method is added to show that the modulation method with lower BER value as a result of comparison of BER values in the last column of the Table 4.5. The transmission is carried out by modulation method which has the smallest the BER values in each transmission.

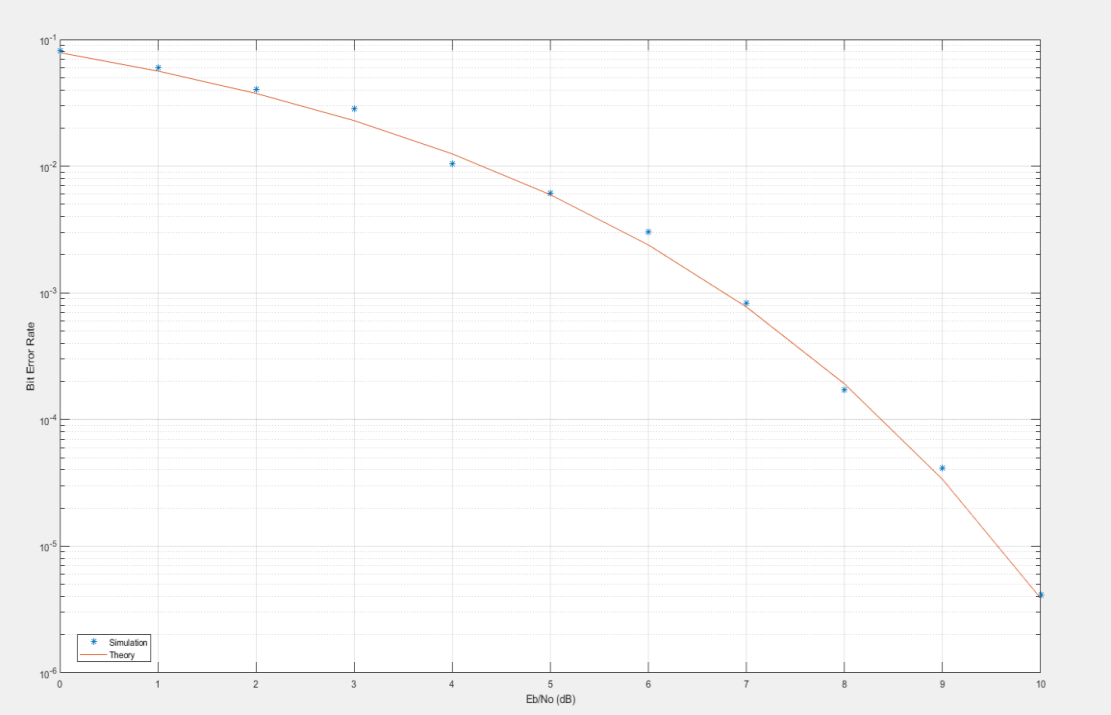

Figure 4.21. QPSK Modulation with MB OFDM method.

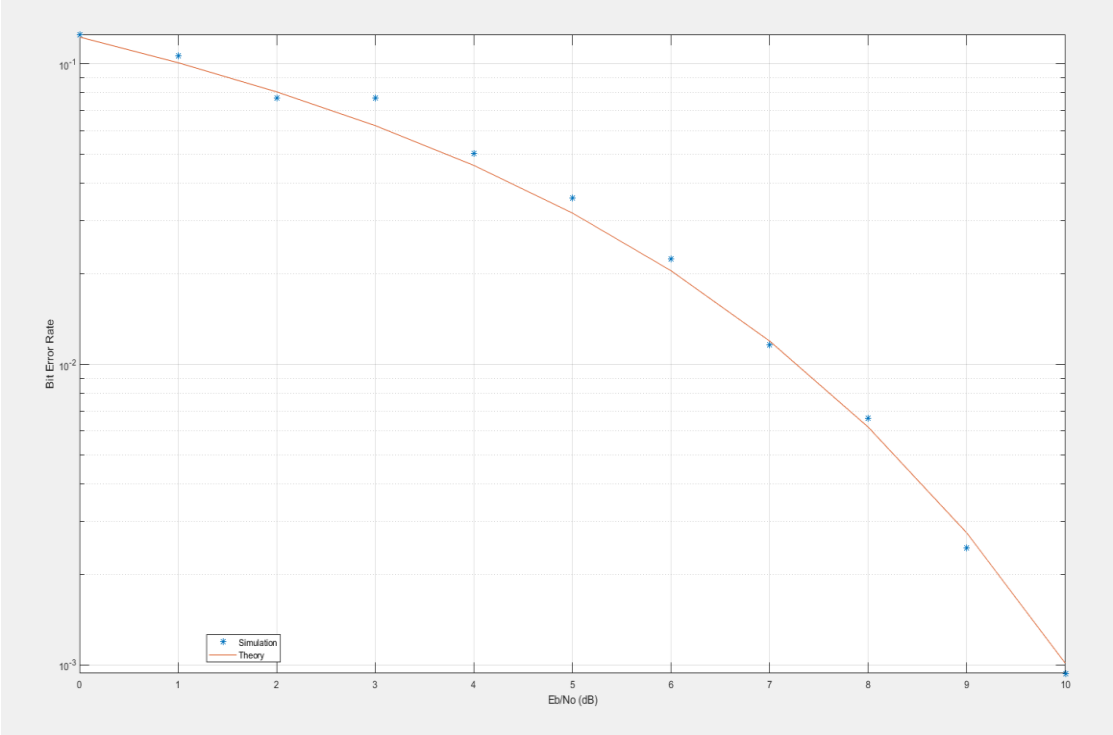

Figure 4.22. 8 PSK Modulation with MB OFDM method.

5. RESULTS

The aim of this study is obtain the minimum BER value in transmission by using Adaptive Modulation and Coding with MB OFDM method in the Ultra Wideband bandwidth.

Different results are obtained in the transmission with different modulations using MB OFDM method in Ultra Wideband bandwidth. PSK and QAM modulation types are considered. QPSK, 8PSK, 16PSK, 4 QAM, 8QAM, 16QAM, 64QAM, 256QAM modulation types are selected among the PSK and QAM modulation types. For each modulation types, the obtained transmission result graphs compared, QPSK modulation is most efficient the modulation type with smallest BER.

The AWGN channel is selected because of when transmitting with OFDM method, AWGN channel which is the most efficient channel. The relevant noise environment is processed with taking into account each type of modulation. A different noise environment with respect to the effect of the selected channel for transmission is not covered by this study.

For the adaptive modulation, a specific SNR interval is selected in the AWGN channel characteristic. The SNR value in selected SNR range is increased by a certain amount for transmission result calculating and all modulation methods are transmitted for each SNR value in this before detected SNR cluster. These result values will be the database of adaptive algorithm. When we compare the results, the adaptive algorithm will select QPSK modulation for each SNR value among the modulation methods. Because the BES value of the QPSK modulation is smaller than the others in the transmission with all SNR values.

QPSK and 8 PSK modulation types are two determined modulation types for the adaptive algorithm. The SNR cluster is specified to applied transmission with the adaptive algorithm. Same steps are applied are applied in same transmission condition. The BER value obtained by QPSK modulation is smaller than the BER value obtained by 8 PSK modulation in specified the SNR cluster. Normally, the number of bits carried in each symbol is higher in the 8PSK modulation but the distance between the bits is shortened compare to QPSK symbol. Because of this condition data signal subject to disturbances in transmission. When

the BER value is calculated in receiver 8 PSK modulation BER value higher than QPSK Modulation.

When the information obtained at the end of the study is compared theoretically, obtained simulation results in Matlab are closed to theoretical results. When using MB OFDM method, the BER can be adjusted by changing the coding ratio while processing on the Convolutional Encoder, but this method is out of the scope of this study.

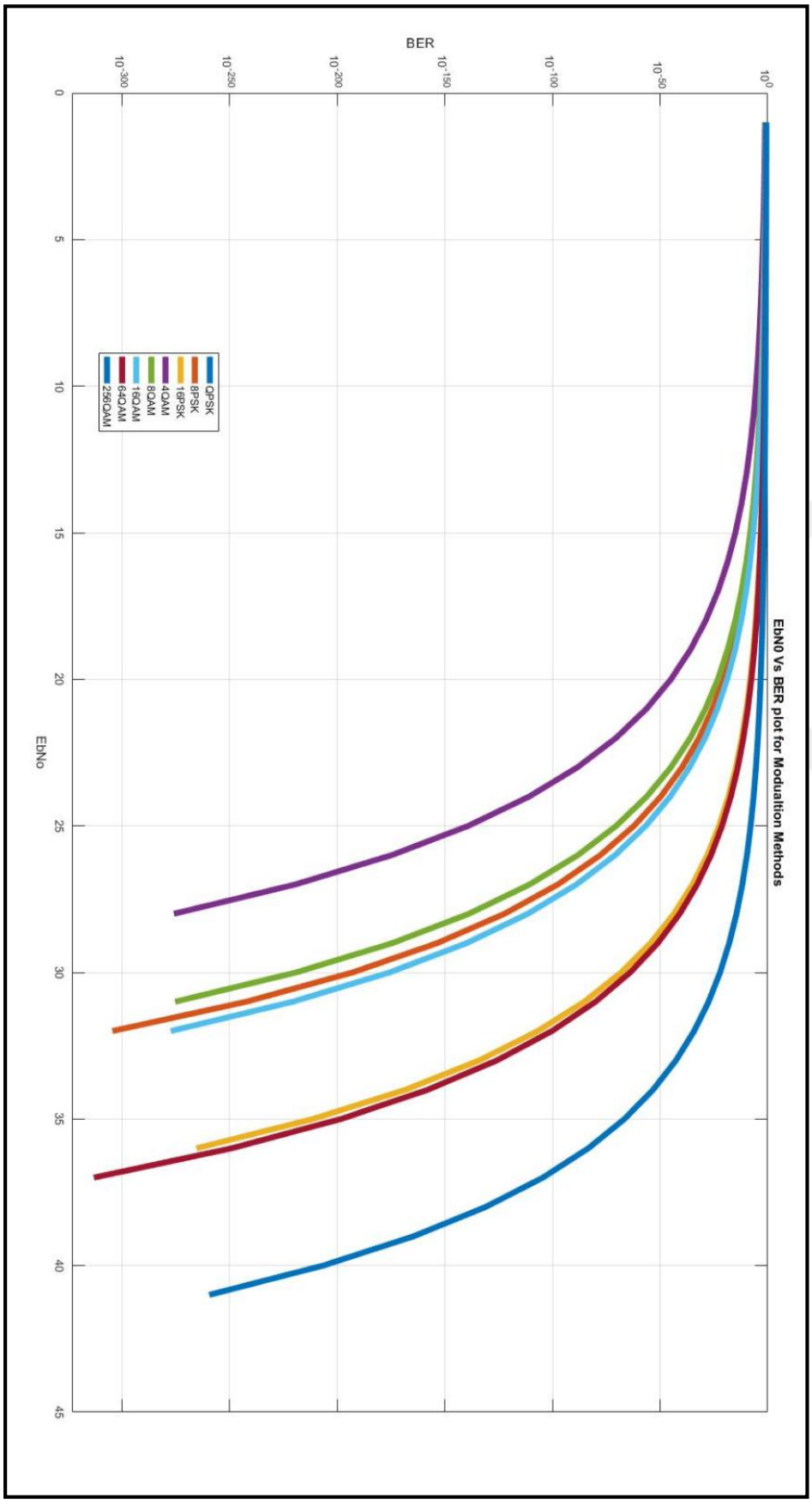

Figure 5.1. MPSK-MQAM modulation methods BER result

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