THE UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUE OF SCIENCE AND TECHNOLOGY

SIMULATION AND COMPARATIVE STUDY FOR PEAK TO AVERAGE POWER RATIO (PAPR) REDUCTION TECHNIQUES IN OFDM FOR WIRELESS COMMUNICATIONS

MASTER THESIS

Mohanad Mahdi Abdulkareem ABDULKAREEM

THE DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING
THE PROGRAM OF ELECTRICAL & ELECTRONICS ENGINEERING

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Supervisor: Assist. Prof. Dr. Javad RAHEBI

Mohanad Mahdi Abdulkareem ABDULKAREEM, having student number 1406030005 and enrolled in the Master Program at the Institute of Science and Technology at the University of Turkish Aeronautical Association, after meeting all of the required conditions contained in the related regulations, has successfully accomplished, in front of the jury, the presentation of the thesis prepared with the title of: "SIMULATION AND COMPARATIVE STUDY FOR PEAK TO AVERAGE POWER RATIO (PAPR) REDUCTION TECHNIQUES IN OFDM FOR WIRELESS COMMUNICATIONS".

Supervisor: Assist. Prof. Dr. Javad RAHEBI
Turk hava kurumu Üniversitesi ....

Jury Members : Assist. Prof. Dr. Hüseyin POLAT
Gazi Üniversitesi. ....

: Assist. Prof. Dr. Özgür KELEKÇI
Turk hava kurumu Üniversitesi ....

: Assist. Prof. Dr. Javad RAHEBI
Turk hava kurumu Üniversitesi ....

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THE UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUTE OF SCIENCE AND TECHNOLOGY

I hereby declare that all the information in this study I presented as my Master's Thesis, called: "Simulation and Comparative Study For Peak to Average Power Ratio (PAPR) Reduction Techniques in OFDM For Wireless Communications", has been presented in accordance with the academic rules and ethical conduct. I also declare and certify with my honor that I have fully cited and referenced all the sources I made use of in this present study.

08.09.2017

Mohanad Mahdi Abdulkareem ABDULKAREEM

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With all my love

September 2017 Mohanad Mahdi Abdulkareem ABDULKAREEM

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LIST OF ABBRIVIATION

ADC	**:**	Analog to Digital Converter
AWGN	**:**	Additive White Gaussian Noise
BER	**:**	Bit Error Rate
BPSK	**:**	Binary Phase Shift Keying
BWA	**:**	Broadband wireless access
CCDF	**:**	Complementary Cumulative Distribution Function
CDF	**:**	Cumulative Distribution Function
CLT	**:**	Central Limit Theorem
COFDM	**:**	Coded Orthogonal Frequency Division Multiplexing
CP	**:**	Cyclic Prefix
DAB	**:**	European Digital Audio Broadcasting
DAC	**:**	Digital To Analog Converter
DCA	**:**	Dynamic Channel Allocation
DFT	**:**	Discreet Fourier Transform
DRM	**:**	Digital Radio Mondiale
DSP	**:**	Digital Signal Processing
DSR	**:**	Distortion-to-Signal power Ratio
DVB-T	**:**	Digital Video Broadcasting-Terrestrial
FDM	**:**	Frequency Division Multiplexing
FFT	**:**	Fast Fourier Transform
FIR	**:**	Finite Impulse Response
FT	**:**	Fourier Transform
GPP	**:**	General Purpose Processors
HDTV	**:**	High Definition Television
HPA	**:**	High Power Amplifier
IBO	**:**	Input backoff
IDFT	**:**	Inverse Discrete Fourier Transform
IEEE	**:**	Institute for Electrical and Electronic Engineers
IFFT	**:**	Inverse Fast Fourier Transform
ISI	**:**	Inter Symbol Interference
LDPC	**:**	Low density parity check codes
LPC	**:**	Linear predictive coding
LTE	**:**	Long-Term Evolution
MBWA	**:**	Mobile Broadband Wireless Access
MC	**:**	Multicarrier Communication
MoCA	**:**	Multimedia over Coax Alliance
OBI	**:**	Output backoff
OFDM	**:**	Orthogonal Frequency Division Multiplexing
OFDMA	**:**	Orthogonal Frequency Division Multiple Access
PA	**:**	Power Amplifier
PAPR	**:**	Peak-to-Average Power Ratio

PLC	**:**	Power Line Carrier communication
PSD	**:**	Power Spectral Density
PSK	**:**	Phase Shift Keying
PTS	**:**	Partial Transmit Sequences
QAM	**:**	Quadrature Amplitude Modulation
QPSK	**:**	Quadratic Phase Shift Keying
RF	**:**	Radio Frequency
SFN	**:**	Single frequency network
SLM	**:**	Selective Level Mapping
SLM	**:**	Selective Mapping
SNR	**:**	Signal-to-Noise Ratio
TR	**:**	Tone Reservation
UWB	**:**	Ultra Wideband
VDSL	**:**	Very-high-speed Digital Subscriber Lines
Wi-Fi	**:**	Wireless Fidelity
WiMAX	**:**	Worldwide Interoperability for Microwave Access
WLAN	**:**	Wireless Local Area Network

ABSTRACT

SIMULATION AND COMPARATIVE STUDY FOR PEAK TO AVERAGE POWER RATIO (PAPR) REDUCTION TECHNIQUES IN OFDM FOR WIRELESS COMMUNICATIONS

Mohanad Mahdi Abdulkareem ABDULKAREEM
Master, Department of Electrical & Electronics Engineering
Thesis Supervisor: Assist. Prof. Dr. Javad RAHEBI
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Orthogonal Frequency Division Multiplexing (OFDM) is an effective method for transmission data with high speed rate. OFDM system uses orthogonal subcarrier to transfer data which make this system more efficient than multi carrier system, by exploit all the carrier frequency band. OFDM communication system recently become significantly in wired communications (Optical communication, ADSL, MoCA) and wireless communications (DVB, WiMAX, LTE). OFDM system be faced with many challenges, one of the biggest challenges is large peak to average power ratio (PAPR) these come from many subcarrier components are added in same phase. The effect of large peak-to-average power ratio (PAPR) is distortion the signal, because the transmitter signal include a non-linear components, therefore the Power Amplifier (PA) work in non-linear region, which reduce the efficient of the system, therefore reducing the value of PAPR is practical in interest. There are several PAPR reduction techniques like Amplitude Clipping, Selective Mapping (SLM), and Partial Transmission Sequence (PTS), all of them have some disadvantages. In this thesis a Linear predictive coding (LPC) are implement in OFDM system and calculate the result of PAPR, Bit Error Rate (BER) and Signal to Noise Ratio (SNR) with different modulation techniques like QAM, PSK, and make comparison between them.

Keywords: OFDM, Wireless communication, PAPR reduction.

ÖZET

OFDM'DE KABLOSUZ İLETİŞİM İÇİN ORTAK GÜÇ ORANININ AZALTILMASI TEKNİKLERİ İÇİN ZORUNLU İŞLEM İÇİN SİMÜLASYON VE KARŞILAŞTIRMA ÇALIŞMASI

Mohanad Abdulkareem
Yüksek Lisans, Elektrik ve Elektronik Mühendisliği Anabilim Dalı
Tez Danışmanı: Yrd. Doç. Dr. Javad RAHEBI
Eylül 2017, 50 sayfa

Dik Frekans Bölmeli Çoğullama (OFDM), yüksek hızdaki iletim verileri için etkili bir yöntemdir. OFDM sistemi, bu sistemi çoklu taşıyıcı sisteme göre daha verimli hale getirmek için tüm taşıyıcı frekans bandından yararlanarak dikey alt taşıyıcıyı kullanır. OFDM iletişim sistemi son zamanlarda kablolu iletişimlerde (Optik iletişim, ADSL, MoCA) ve kablosuz iletişimlerde (DVB, WiMAX, LTE) önemli ölçüde kullanılmaktadır. OFDM sistemi birçok zorlukla karşı karşıya kalmaktadır, en büyük zorluklardan biri, aynı fazda eklenen birçok alt taşıyıcı bileşenden gelen yüksek tepe gücü/ortalama güç oranı (PAPR)'dir.Yüksek tepe gücü/ortalama güç oranı (PAPR)'nin etkisi sinyalin bozulmasıdır, çünkü verici sinyali doğrusal olmayan bileşenleri içerir, böylece Güç Amplifikatörü (PA) sistemin etkisini azaltan doğrusal olmayan bölgede çalışır, böylece PAPR'nin değerinin düşürülmesi gereklidir. Genlik Kırpma, Seçici Haritalama (SLM), ve Kısmi İletim Dizisi (PTS) gibi birkaç PAPR azaltma tekniği vardır. Bunların hepsi birkaç dezavantaja sahiptir. Bu tezde Doğrusal önkestirim kodlama (LPC), OFDM sisteminde uygulanmıştır ve farklı modülasyon teknikleriyle PAPR, Yüksek Hata Oranı (BER) ve Sinyal Gürültü Oranı (SNR)'nın sonucunu hesaplanmıştır ve onlar arasında karşılaştırma yapılmıştır.

Anahtar Kelimeler: Dik Frekans Bölmeli Çoğullama (OFDM), Kablosuz İletişim, Yüksek tepe gücü/ortalama güç oranı (PAPR) azaltım

CHAPTER 1

INTRODUCTION

1.1 Background

In 1960s, Military HF radio links were the first systems using MCM. In a typically MCM system, the whole frequency band of the signal is split into N non-overlapping frequency sub-channels [1]. OFDM (Orthogonal Frequency-Division Multiplexing) is a special implementation of multicarrier modulation (MCM). By using the overlapping in MCM, its save near 50% of the total bandwidth. To achieve this technique, however, it should obtain orthogonality between subcarriers. A modulation method using multiple orthogonal carriers for digital data transmission. Thus, the method is a special form of FDM in which, by virtue of orthogonally, the carrier (i.e. the maximum of a carrier lies with its neighboring carriers on a zero-crossing) is reduced between signals which are modulated on adjacent carriers [2].

The useful data to be transmitted with a high data rate is first divided into several partial data streams with a low data rate. These partial data streams are each individually modulated with a conventional modulation method such as the quadrature amplitude modulation (QAM) with low bandwidth and then the modulated HF signals are added. In order to be able to distinguish the individual signals during the demodulation in the receiver, it is necessary for the carriers to be orthogonal to one another in the function space. This has the effect that the partial stream of material is as little as possible interfering with each other.

The advantage of OFDM is that the data transmission to the peculiarities of a transmission channel, such as, for example, a radio channel, can be easily adapted by fine granulation. If a narrowband interference occurs within the OFDM signal spectrum, carriers affected by the interference can be excluded from the data transmission. The entire data transfer rate is therefore only a small fraction. In the case of broadband quadrature amplitude modulation with only one carrier, however, a narrow-band interference in the transmission channel can make the complete data transmission impossible. Also destructive interferences due to multipath reception concern only individual carriers.

Since data is placed on many carriers (subcarriers), it belongs to multicarrier modulation. Since these subcarriers are orthogonal to each other, it is not advantageous that they interfere with each other unlike the conventional frequency division multiplexing system (FDM) despite being ordinarily arranged so as to cause overlapping on the frequency axis is there. Subcarriers can be efficiently distinguished using Fast Fourier Transform (FFT) algorithm [3].

Each subcarrier is modulated at a low symbol rate in a conventional manner such as quadrature amplitude modulation (QAM). The data rate at this stage is comparable to that of single carrier modulation with the same bandwidth. What is the main advantage is that it can cope with a bad transmission path (channel) situation even without a complex filter circuit. Specifically by long copper wire high frequency attenuation, multipath by narrowband interference and frequency selective (fading strong), and the like. OFDM can be regarded as using a large number of narrowband signals subjected to slow modulation, not a single wideband signal subjected to high-speed modulation. Therefore, it is easy to equalize the channel.

Thanks to the low symbol rate, guard intervals between symbols can be used, so that it is possible to cope with spreading on the time axis and to remove Inter Symbol Interference (ISI). Further, there is also an advantage that the configuration of the single carrier network is facilitated. This is because signals from a plurality of transmitters at a long distance can be overlapped so as to intensify each other (in the conventional system, it was normal for the signals to interfere with each other by interference).

For a long time, there is a limitation of uses OFDM in practical systems, the complication of the real time of the Fourier Transform (FT) and the linearity demand in radio frequency power amplifiers are the main reason for this limitation. However since 1990s, OFDM is widely used in broadband digital communication regardless of wireless / wired distinction. Specific applications include mobile Network [4].

1.2 Key Features

1.2.1 Benefits

It can easily adapt to bad transmission line (channel) situation without using complicated equalizer.

It is strong against narrowband transmission line interference.

1. Multipath by transmitting the inter symbol interference and fading robust against.
2. High frequency utilization efficiency.
3. Efficient implementation by using FFT.
4. It is strong against timing synchronization error.
5. Unlike conventional FDM, no tuned sub channel receiver filter is needed.
6. Single frequency network (SFN), that is, macro diversity of transmitter can be easily realized.

1.2.2 Disadvantages

Whilst OFDM has been widely used, still there are a few disadvantages which need to be handled.

1. PAPR is high in OFDM signal. Such impacts of power amplifier efficiency, the amplifier cannot operate with a higher efficiency level. For this reason, the output efficiency is poor for requiring an expensive transmitter circuit.
2. Sentient to carrier offset and drift: Orthogonal frequency division multiplexing system is critical when compared to single carrier system in carrier frequency offset and drift.
3. Receiver complexity: for higher number of sub channel the complexity of the OFDM receiver increases.
4. It is susceptible to frequency synchronization problems.

1.3 Problem Definition

Although the OFDM system has many advantages, there is one of the biggest problems that determine the work and efficiency of the system. The OFDM signal is aggregate of several sinusoids due to implement IFFT in time domain, which it produce a high PAPR. It causes the power amplifiers move in saturation region, whom is set at the front end of the transmitter. It caused to nonlinear distortions.

1.4 Organization of The Thesis

In this thesis report will contain of four chapters with introduction of topic, overview of the system and objectives of dissertation, and the proposed work which are covered at Chapter 1. In Chapter 2, the main concept of the OFDM and literature review will be discussed. In Chapter 3, will describe the methodology. Chapter 4 a very important chapter which defines our result and discussion in which involve the system module design and technical consideration of practical environments. Results are taken and graphs are plotted accordingly. In Chapter 5, will involve the conclusion of the work we done and future work. And finally the references will demonstrate at the end of this thesis.

CHAPTER 2

THE MAIN CONCEPT OF OFDM AND LITERATURE REVIEW

2.1 OFDM

The general concept of OFDM theory is dividing the frequency spectrum that is allotted to the channel into several subcarriers. Therefore the frequency-selective channel is being transform to collections of frequency which are parallel organized at sub-channels. Another step must be taken so as to achieve high spectral efficiency that signal spectra relating to un-similar sub-carriers must be overlapping in frequency and as result, the separation in frequency will be minimized to maintain the level of orthogonality of waveforms components in the related time domain. The OFDM Signal is shown in Figure 2.1 [4].

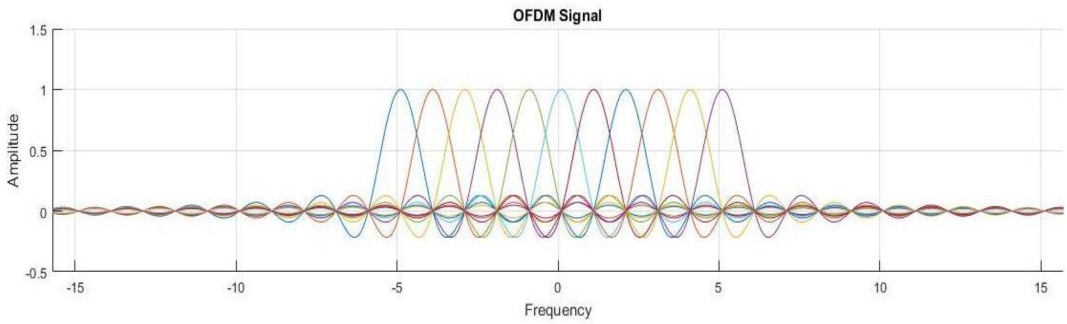

Figure 2.1: OFDM signal.

For OFDM if the system bandwidth is B, Number of sub-carriers is given by:

$$N_C = \frac{B}{1/2T_s} = 2BTS \tag{2.1}$$

Where, T_s is time symbol OFDM has the potential to at least double the number of sub-carriers (i.e., double the total transmission rate over the system bandwidth).

The goal of using a cyclic prefix is preserving the orthognality of signals and reducing the inter symbols interfaces which exist between the symbols of OFDM. OFDM baseband system is demonstrated at Figure 2.2 block diagram [3].

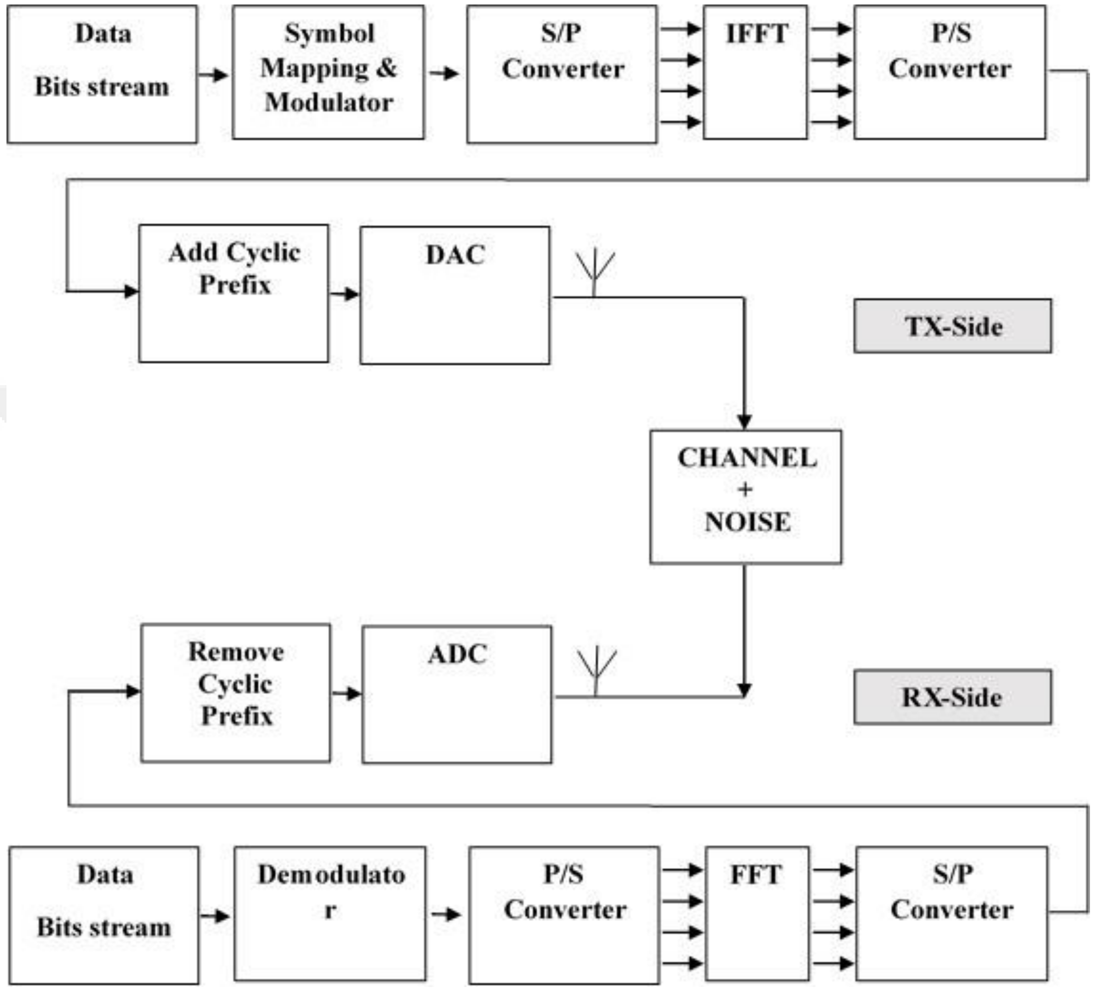

Figure 2.2: OFDM system block diagram.

Post to the grouping, coding and modulating of the information bits, they will be an input to Inverse Fast Fourier Transform (IFFT) block to get the signal back into the time domain i.e.,

$$Zn \ = \ IFFT_N \ \{ \ Y_K \} \tag{2.2}$$

$$\sum_{K=0}^{N-1} Y_K e^{j*2*pi*n*\frac{K}{N}} , 0 \leq n, k \leq N-1 \tag{2.3}$$

Where n stands for sampling index in time domain, Y_k represents the input data stream at subcarrier which entitled with K, the total subcarriers are equal to N. Following blocks IFFT, a cyclic extension whose length in time domain and TG block are selected to be larger enough the longer delay preparation the channel had inserted so that the inter-carrier interferences and Inter-Sample Interface can be avoided [5].

The block entitled with (D/A) the analog to digital conversion is involving low pass filter whose bandwidth equal to 1/Ts. The filter bandwidth is the inverse of OFDM samples interval. The channel is being modulated to be the impulse response, D(t), affected by complex n(t) as (AWGN) additive white Gaussian noise.

$$g(\tau) = \sum_{m=0}^{M-1}(\alpha_m \delta(\tau - \tau_m T_s) \quad (2.4)$$

Where multipath/s number is equal to M and α is the complex form of each path gain, and finally each path delay is T. On receiver end, after the received signal being passed through A/D block for initialing the analog to digital process, According to Figure 2.2 the signal then processed to remove the cyclic prefix components; the Fast Fourier Transform is conducting to get back frequency domain of the transmitted signal. Ultimately, decoding process and demodulation are taking place to extract the information bits. We can right the received signal as:

$$Y = FFT_N\{FFT_N\{X\} \times g + n\} \quad (2.5)$$

Considering that the cyclic prefix is assuring the orthogonal tones to exist as well as the impulse response will be lie entire the guard period. i.e., 0 ≤ T Ts ≤ TG. Wherein; Y = [Y0, Y1, …. , YN-1]T symbols are being the received vector of the signal, X = [X0, X1 ….., XN-1]T is being the transmitted symbols vectors of signal end system, finally the, G = [G0, G1 ….., GN-1]T and N =[N0, N1 …., NN-1]T representing the symbols of frequency response g(t) with AWGN noise respectively. Focusing of the fact shows that X vector and Y vector are represented on frequency domain. Actually, the expression in formula (2.5) is equivalent to the data transmission through a group of Gaussian channels in form of parallel set, as explained on Figure 2.3 [6].

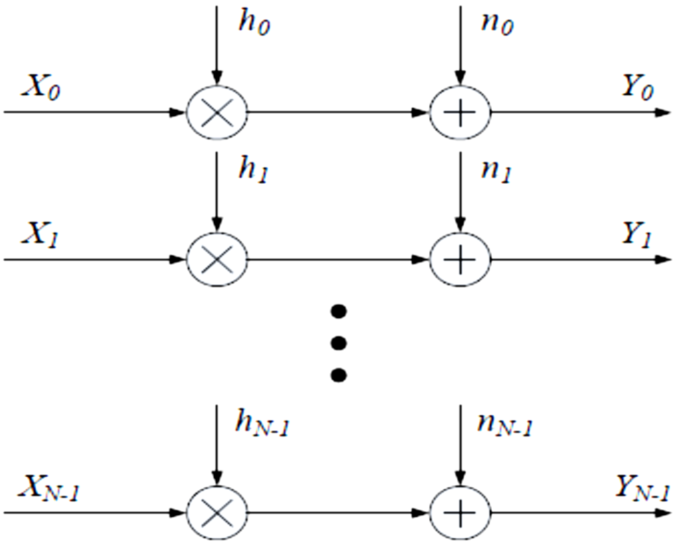

Figure 2.3: OFDM parallel gaussian channel.

As a result, the final system illustrated by the formula (2.5) can be re-explained as:

$$Y = XFg + Fn \tag{2.6}$$

Diagonal matrix is presented by X which is involving the elements stated by equation (2.6) as below:

$$\boldsymbol{F} = \begin{bmatrix} W_N^{00} & \cdots & W_N^{0(N-1)} \\ \vdots & \ddots & \vdots \\ W_N^{(N-1)0} & \cdots & W_N^{(N-1)(N-1)} \end{bmatrix}$$

And has a Fast Fourier Transform matrix of:

$$W_N^{nk} = \frac{1}{\sqrt{N}} e^{-j2*pi*\frac{nk}{N}} \tag{2.7}$$

2.2 Modulation Method

Each carrier is first modulated separately. Depending on which of the three free parameters frequency, amplitude and phase are used, it carries one information of one or more bits per symbol step. Pro symbol and carrier are transmitted with DAB 1 bit, with DVB-T 2, 4 or 6 bits and with DVB-T2 up to 8 bits [7].

The signal sequence $S_{OFDM}(t)$ of a symbol is composed of the sum of all modulated carriers in OFDM. Thus, with OFDM, a very large number of bits are transmitted in parallel. For example, if, as in practical applications, approximately 7,000 carriers are used and four bits are transmitted per carrier, a symbol has a maximum of 28,000 bits of information which is transmitted in parallel in one symbol step. Practically, the number of bits is slightly lower, since some carrier frequencies are used for synchronization, as pilot tone, and for operation. Channel coding for forward error correction also reduces the useful data volume [8].

Corresponding to the low spectral distance between the carrier frequencies, one modulates with only a small bandwidth. Therefore, the symbol duration of OFDM is much longer compared to single-carrier methods. Thus, with a total bandwidth of 8 MHz and 7000 carrier frequencies, a symbolic duration of 875 μs is obtained as a rough guide value, which corresponds to a symbol rate of 1143 baud. The maximum bit rate achievable is around 32 MBit / s. For precise design, various additional parameters such as the maximum delay spread for multipath reception must be considered.

OFDM signals are generated with the complex- computed inverse discrete Fourier transforms (IDFT). The IDFT assumes that all subcarrier frequencies are orthogonal to each other. The block length of the IDFT corresponds to the number of subcarriers. IDFT can be implemented entirely in digital technology with digital signal processors so that the high frequency part of the circuit remains relatively simple [9].

Orthogonality exists if and only if:

$$f_v = \frac{v}{T},\ f_w = \frac{w}{T},\ w, v, \in N \tag{2.8}$$

$$\frac{1}{T}\int_0^T e^{j2\pi f_v t}\, e^{j2\pi f_w t}\, dt = \begin{cases} 1, & when\ v = w \\ 0, & OW \end{cases} \tag{2.9}$$

On the receiver side, the individual carriers must be separated from the signal mixture. This could be done with individual filters, which however becomes more complex at more than a handful of frequencies. Therefore, today, a fast Fourier transform (FFT) is used for all OFDM decoders, which undoes the IFFT at the sender. The input data of the FFT are the digitized values of the signal from an analog-to-digital converter (ADC).

The synchronization to the received signal is problematic and complicated with an OFDM receiver since the receiver does not have a direct feed of the transmit clock. For this purpose, a plurality of synchronization stages run successively. First of all, the sampling rate of the ADC and the frequency of the RF carrier must be adjusted in such a way that all carriers fall exactly to the FFT frequencies (corresponds to stretching / compression and displacement of the spectrum). Due to the presence of many echoes, there is a time at which the impulse response has the greatest energy. From this point in time, it is possible to conclude the period of time in which echoes are received and superimposed symbols appear. It is found via certain reference symbols or pilots with an autocorrelation. Finally, the phase reference necessary for quadrature amplitude modulation (QAM) must be extracted (so-called channel estimation) [10].

Depending on the OFDM method, various additional signals support this synchronization. In the condition of digital audio broadcasting (DAB), a symbol is used to transmit no energy (zero symbol) and then a so-called phase reference symbol for exact frequency and time synchronization. DVB-T uses a systematic pattern of pilot tones. By means of these pilot tones, the phase change can be determined over the frequency and time.

2.3 COFDM

Coded OFDM stands a transmission technique for digital information that supplements the modulation method OFDM by a forward error correction within the symbol [11].

The strengths of COFDM lie in resistance to the general interfering multipath reception and its echoes and the resulting possibility to be able to operate several spatially neighboring transmitters on the same transmission frequency as a so-called equal- wave network. It is also suitable for the mobile reception of transmitted signals.

Due to the simultaneous operation or in the case of multipath reception, constructive and destructive interference occurs within the time of a symbol, which leads to the cancellation or amplification of individual carrier frequencies. Since, however, a big number of carrier frequencies are available in parallel within the channel and interference is frequency-selective, only individual carriers at specific spatial reception points are actually canceled out or amplified [12].

In the case of OFDM, the same physical problems as in the case of single-carrier methods are in principle, however, these interfering influences of the interference can be greatly reduced by two methods since the symbol duration of OFDM is much longer compared to single-carrier methods.

In addition to forward error correction by channel coding, the information to be transmitted is distributed redundantly to several carrier frequencies in COFDM. As a result, the COFDM receiver can reconstruct the correct useful data information even when individual carrier frequencies are canceled by interference, and a simultaneous wave transmitter operation with overlapping zones of the individual transmitters is possible [13].

A guard interval (guard interval) ensures that a "rest" time is maintained between two sent symbols, so that symbols do not appear in successive symbols. Typical protection times are between 1/32 symbol duration and 1/4 symbol duration. The length of the guard interval determines the possible intersymbol-interference-free distance difference to the transmitters. At a resting time of 33 μs, distance differences of ten kilometers or more are interfering, which permits transmitter distances of approximately 20 km, since extinction requires similar field strengths [14].

2.4 OFDMA

In the case of Orthogonal Frequency Division Multiple Access (OFDMA), the OFDM subcarriers are distributed over more than one user channel. A prerequisite for the method is bidirectional radio communication, in which, unlike the unidirectional, the channel can be measured. By continuous measurement, the receiving quality of the subcarriers is known to the transmitter by the individual users. Based on this knowledge, he can optimize the use of the subcarriers and thus the spectral efficiency [15].

The table 2.1 summarizes the typical basic data of some OFDM or COFDM-based systems:

Table 2.1: Typical basic data of some OFDM or COFDM-based systems.

transmission standard	**DAB, Eureka 147**	**DVB-T**	**DVB-H**	**T-DMB**	**IEEE 802.11a**	**LTE**
development year	1995	1997	2004	2006	1999	2006
frequency range (MHz)	174-240 1452-1492	470 - 862 174-230	470 - 862	470 - 862	4915 - 5825	800, 1800, 2600
Bandwidth *B* (MHz)	1712	8, 7, 6,	8, 7, 6 & 5	8th	20	1.4, 3, 5, 10, 15, 20
Number of carriers *N*	192, 384, 768 or 1536	2K mode: 1705 8K mode: 6817	1705, 3409, 6817	1 (single carrier) 3780 (multiple support)	48 (+4 pilots)	72, 180, 300, 600, 900, 1200
carrier modulation	DQPSK	QPSK (= 4-QAM), 16-QAM or 64-QAM	QPSK, 16-QAM, or 64-QAM	QPSK, 16-QAM, 32-QAM or 64-QAM.	BPSK, QPSK, 16-QAM, or 64-QAM	QPSK, 16-QAM, or 64-QAM
Typical symbol length T_S (Microseconds)		2K mode: 224 8K Mode: 896	224, 448, 896	500 (multiple carrier)	3.2	66.67
Protection interval T_G (Part of T_S)		1/4, 1/8, 1/16, 1/32	1/4, 1/8, 1/16, 1/32	1/4, 1/6, 1/9	1.4	

Table 2.1: (Devam) Typical basic data of some OFDM or COFDM-based systems.

transmission standard	DAB, Eureka 147	DVB-T	DVB-H	T-DMB	IEEE 802.11a	LTE
carrier spacing Δf = 1 / (T_s) ≈ B / N (Hz)		2K mode: 4464 8K mode: 1116	4464, 2232, 1116	8 M (Single Carrier) 2000 (multiple carrier)	312,5k	15000
User data rates *R* (Mbps)	0.576 - 1.152	4.98 - 31.67 (Typically 24)	3.7 - 23.8	4.81 - 32.49	6-54	3 - 300
Spectral efficiency*R* / *B* (Bit / s / Hz)	0.34 - 0.67	0.62-4.0	0.62-4.0	0.60-4.1	0.30 - 2.7	
Internal FEC	Folding code with code 1/4, 3/8 or 1/2	Folding code with code 1/2, 2/3, 3/4, 5/6, or 7/8	Folding code with code 1/2, 2/3, 3/4, 5/6, or 7/8	LDPC with code 0.4, 0.6 or 0.8	Folding code with code 1/2, 2/3 or 3/4	
External FEC	none	RS (204.188, t = 8)	RS (204.188, t = 8) + MPE-FEC	BCH code (762,752)		
Maximum relative speeds (Km / h)	200-600	53-185 frequency Dependent				350
Interleaving depth (Ms)	385	0.6 - 3.5	0.6 - 3.5	200-500		

OFDM also stands for Optical Frequency Division Multiplexing, which is a synonymous term for wavelength division multiplexing. However, the term "optical frequency division multiplexing" emphasizes more strongly that this optical technology is a frequency multiplexing technique known from electrical communications technology [16].

CHAPTER 3

CHARACTERISTICS AND PRINCIPLE OF OPERATION

3.1 Orthogonality

In a communication system, bandwidth must be occupied on the channel to be as small as possible. For that reason, in a multicarrier communication system. Minimum frequency space must be set between frequency carriers, and insuring no Inter carrier interference (ICI) occurred. A lowest space happened when the carriers are orthogonal to each other. There is a small overlap in the signal with other but without causing interference that what is meant by the «O» (Orthogonal) of OFDM. The OFDM Orthogonal Subcarrier is illustrated in figure 3.1 [17].

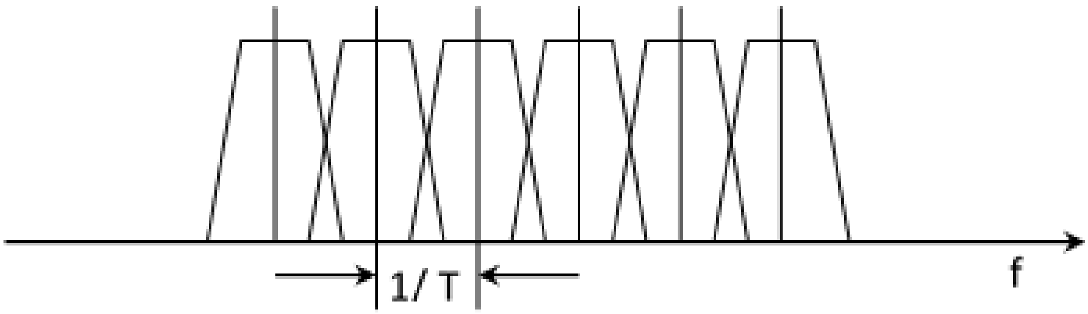

Figure 3.1: OFDM orthogonal subcarrier.

In OFDM, the frequencies of subcarriers are chosen so that their subcarriers are orthogonal. Therefore, interference between the sub channels disappears, so that the carrier interference guard band is not required and the design of the transceiver can be greatly simplified. Specifically, unlike the conventional FDM, it is unnecessary to prepare separate filters for each sub channel [18].

System orthogonally has high spectral efficiency is obtained, comparable to the theoretical limit of Nyquist rate. Almost all allocated frequency bands can be used without waste.

In OFDM, the FFT algorithm can be used by its orthogonality, and it could be implemented effectively by using IFFT in the modulator and FFT in the demodulator. Although its principle and advantages were known since the 1960's, it was necessary to wait for popularization of low price value of digital signal processing IC which can effectively calculate FFT in order to be widely used [19, 20].

Figure 3.2 shows the frequency response of five carriers signal where the orthogonal of the signals clearly seen because of the maximum of a specific signal match to a null in all different carriers, therefore remove the effects of interference.

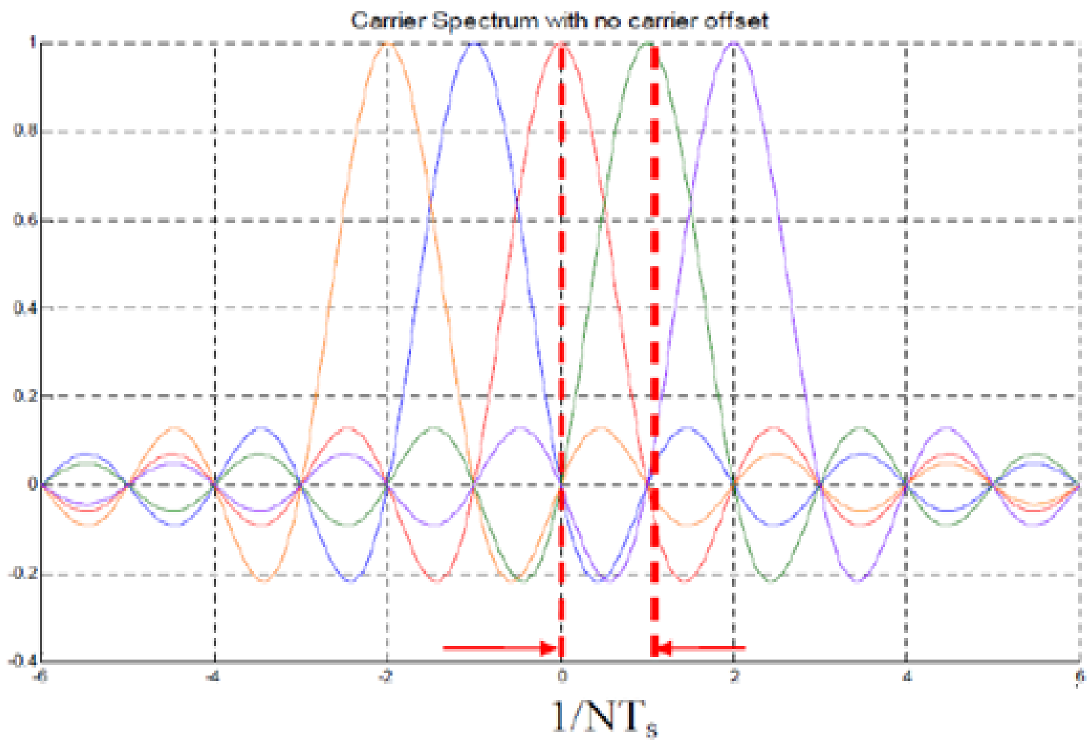

Figure 3.2: The frequency spectrum for 5 orthogonal subcarriers for orthogonal frequency-division multiplexing.

The orthogonality between subcarriers could be shown in time domain in Figure 3.3. Any curve symbolize the time domain view of the wave for a subcarrier.

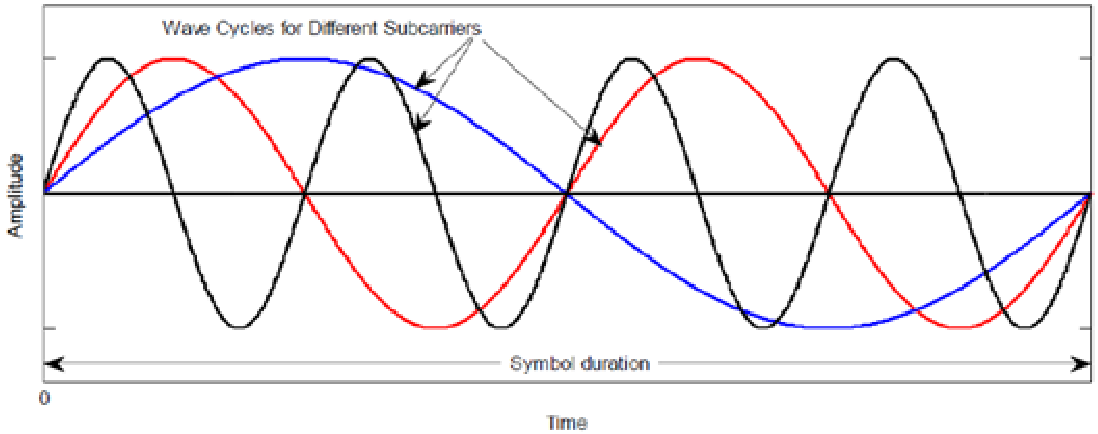

Figure 3.3: Signal waveform for time domain representation.

OFDM requires very accurate frequency synchronization for receivers and transmitters. This is because if the frequency deviates, the orthogonally between the subcarriers collapses, causing carrier-to-carrier interference, that is, interference (ICI) between subcarriers. Frequency offset is generally caused by a shift in oscillation frequency of a local oscillator of a transmitter or a receiver, or a Doppler shift due to a movement. Although it is possible to correct the Doppler shift independently by the receiver, in the presence of multipath reflection appears in various frequency offsets, so it is more difficult to correct and the situation gets worse. This effect generally deteriorates as the traveling speed raises, and it is an important factor restrict the use of OFDM in fast moving vehicles. Many methods for suppressing ICI have been proposed, but there is a problem that the receiver becomes complicated [15].

3.2 Inter Symbol Interference

In planning stage of the transmitting/receiving filters in communications system the aim is to reduce effects of ISI and therefore transmit the digital signal to its target with the little possible value of error rate. Figure 3.4 shows the two symbol of OFDM signal with Inter-Symbol Interference in Time [21].

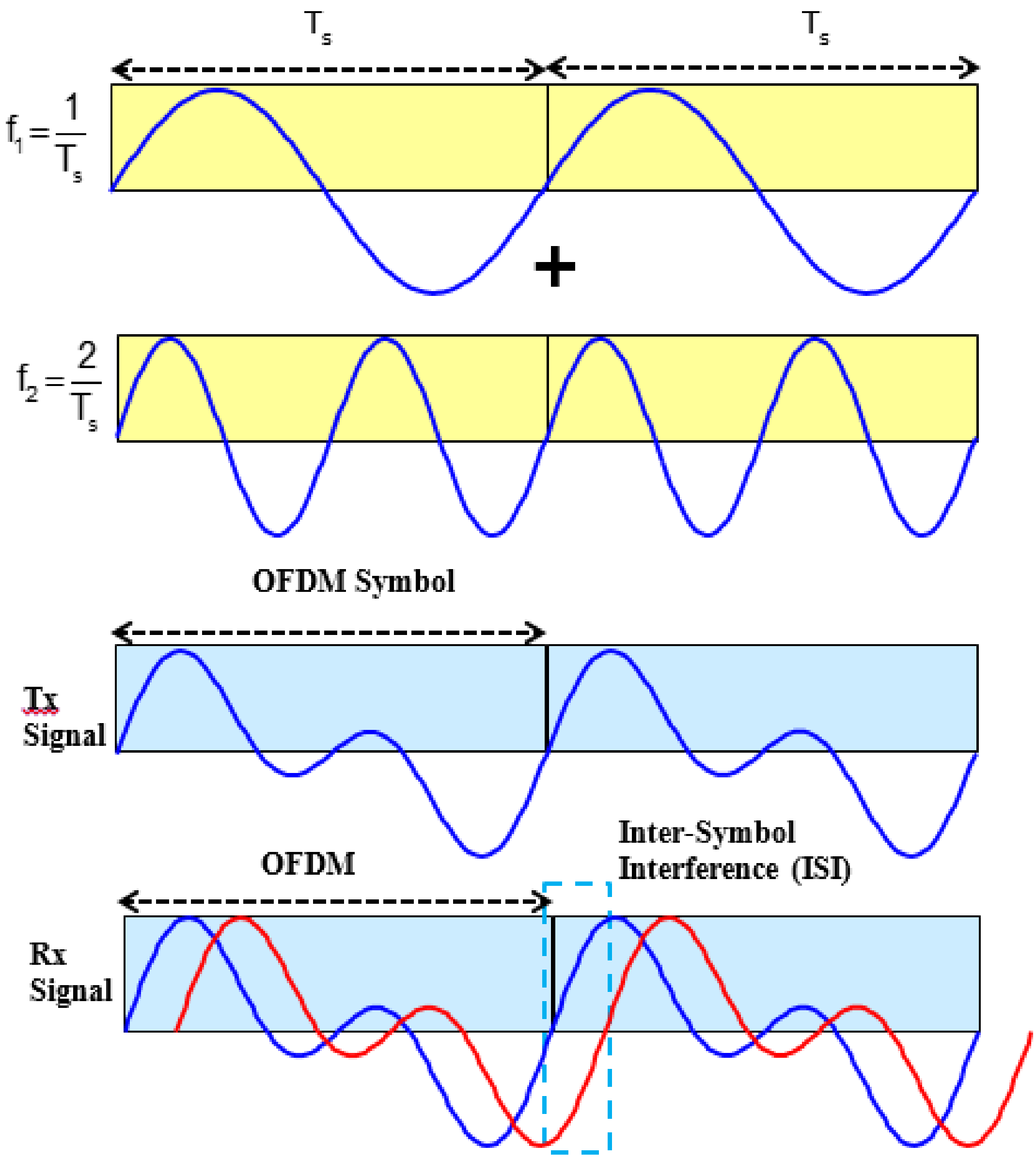

Figure 3.4: Two symbol of OFDM signal with inter-symbol interference in time domain.

3.3 Guard Interval for Inter Symbol Interference Elimination

One of the important principles of OFDM is that the modulation planner at a low symbol rate (that is, the symbol is relatively long compared with the channel time characteristic), and Inter Symbol interference caused by multipath is suppressed, that is, It is beneficial to transmit several lower symbol rates in parallel than one high symbol rate transmission. Therefore the duration of every symbol is long, it is possible to insert guard intervals between each OFDM symbol, and Inter Symbol interference can be eliminated [22].

In the time domain, for OFDM signal if the first symbol get delayed a slightly bit. In this situation, the ending part of the first symbol will overflow into the following symbol. This type of interference between sequential symbols are called 'Inter Symbol Interference (ISI). However, prevent the signal from getting delayed it is not possible because, we have no control through the media channel itself. Therefore the only method is to design system to handle this type of status. The simple solution is to set some time gap between symbols so that one symbol would not fall into next symbol even if there is some delayed. According to Figure 2.2 the addition of Cyclic Prefix (CP) takes position after the parallel to serial conversion (P/S) in the transmitter side of OFDM system and being removed Cyclic Prefix (CP) at the receiver side system before the DFT operation. The OFDM symbol with considering the Cyclic Prefix is shown in Figure 3.5.

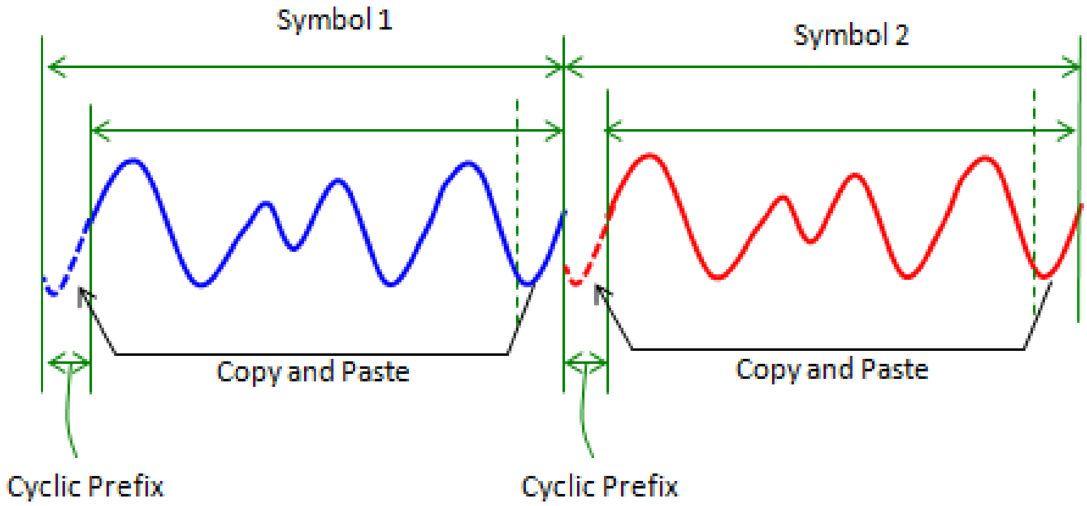

Figure 3.5: Cyclic Prefix in the OFDM symbol.

The guard interval also remove the requirement for pulse shaping filters moreover at the same time reduces the effect of the problems time synchronization [23].

A normal example, if a 1,000,000S/sec (symbols per second) by the wireless transmission path when transmitting using a conventional single-carrier modulation, the interval of each symbol is below one microsecond. This requires strict constraints on timing synchronization and requires elimination of multipath interference. If 1,000,000 symbols per second are divided into 1000 sub channels, the duration of each symbol can be increased to 1000 times, or 1 millisecond, with approximately the same bandwidth due to orthogonality. This is the length of the path, corresponding to a difference of up to 37.5 kilometers [24].

Cyclic Prefix has an extra advantages by copying the ending part of the original symbol. When performing demodulation of OFDM using FFT, it is to integrate the respective multipath an integral multiple of the sine wave period of the sub-carrier. This makes it possible to simplify the channel estimator (equalizer), and it helps find the symbol boundary (the start and end of a symbol).

3.4 Simplified Equalizer

For example, if the sub channel is sufficiently narrow band, that is, the number of subcarriers is sufficiently large, the influence of the frequency selective channel due to fading occurring in the multipath environment is that the channel characteristics are constant (flat) when viewed in subcarrier units, Can be regarded as. This makes the OFDM receiver much simpler than classical single carrier modulation. Specifically, the equalizer (equalizer) only multiplies each subcarrier by a fixed value or a value that hardly changes. Simple example: Equalization of OFDM in the above example is performed for each OFDM symbol in the receiver N = 1,000 complex multiplications, that is, 1 million multiplications per second are required. For each OFDM symbol, the FFT algorithm complex operations, that is, 10 million operations per second are required for both transmitter and receiver. Here, in the case of the corresponding single carrier modulation, that is, compared with one million symbols per second, in the case of single carrier, it is 125 times for each symbol to equalize the delay of 125 microseconds using the FIR filter, for 1 second It will require multiplication of 125 million times [25].

Some of the subcarriers in some OFDM symbols can also add the pilot signal to measure the condition of the channel, that is, the equalizer gain of each subcarrier. This pilot signal can also be used for synchronization.

In the case where differential modulation such as DPSK is used for each subcarrier, there is almost no influence on slow amplitude and phase distortion, so equalization can be completely omitted.

3.5 Channel Coding and Interleaving

For OFDM, channel coding such as forward error correction (F-EC) is always used, and frequency / time interleaving is usually used.

When the channel band of a certain part attenuates, bit errors due to subcarriers within the channel band attenuated by frequency interleaving are reliably diffused into the bit string as it is. Likewise, time interleaving can reduce the effects of severe fading that occurs during high-speed movement by temporally separating bits that were originally immediately in the bit string [26].

However, there is little effect of time interleaving in slow fading channels such as, for example, stationary receiving environments. Also, the frequency interleave has little meaning under the flat fading (the whole channel attenuates at the same time) environment. This is because it is impossible to correct all bit errors even if the decoder inputs data including a large amount of errors, and explosively uncorrectable errors occur.

Error correction, which is commonly used for OFDM-based systems, is a convolutional code and is usually used in conjunction with Reed-Solomon codes. Normally the above frequency / time interleave is added between these two encodings. Viterbi decoder used for decoding a convolutional code inputs data including a large number of errors, a short burst error occurs, while a Reed-Solomon code generates a burst error since it is inherently suited for correcting [27].

Recently, an error correction code based on a more optimal turbo principle is adopted in an environment where it is used repeatedly for a solution to find a decoder. Turbo codes and low density parity check codes (LDPC) are used as examples of types of such error correction codes.

3.5.1 Extension to Multiple Access

Since the basic form of the OFDM system is a mode of transmitting data using OFDM symbols in one transmission line, it is considered that it is a digital modulation technology but not a multiuser channel access technology. However OFDM is by utilizing the time / frequency / code division access can be incorporated (multi-access).

By allocating different number of subcarriers to each user, OFDMA can differentiate service quality like CDMA, and it is possible to avoid problems such as complex packet scheduling like CDMA and medium access control scheme. In general, the IEEE 802.16 standard known for WiMAX adopts OFDMA [28]. Frequency setting can be simplified or complex dynamic channel allocation, (DCA) co-channel interference in spite of avoiding the setting there is a merit that it can be reduced [29].

3.5.2 High Power Amplifier HPA

Since the OFDM signal is a combination of subcarriers having independent phases, depending on the combination of the phases of each subcarrier, it may have high peak power. Therefore, there is a problem that the peak-to-average power ratio (PAPR) increases.

When nonlinearity exists in signal transmission, the following intermodulation distortion occurs.

1. Rising noise floor
2. Inter Symbol interference (ISI) occurrence
3. Spurious radiation out of band

In particular, the High Power Amplifier HPA used in the RF output circuit of the transmitter is often designed nonlinearly to suppress the increase in power consumption, to get extreme output power efficiency HPA have to be run at or close the saturation region. In practical OFDM systems, signal should carefully trade off the suppression of PAPR and the above problem by allowing some peak clipping. However, for the input signal, the higher peak of average power create out-of-band energy and in-band distortion. These effects on the OFDM signal and can hardly degrade the communication system performance. The Characteristic of HPA is illustrated in figure 3.6 [30].

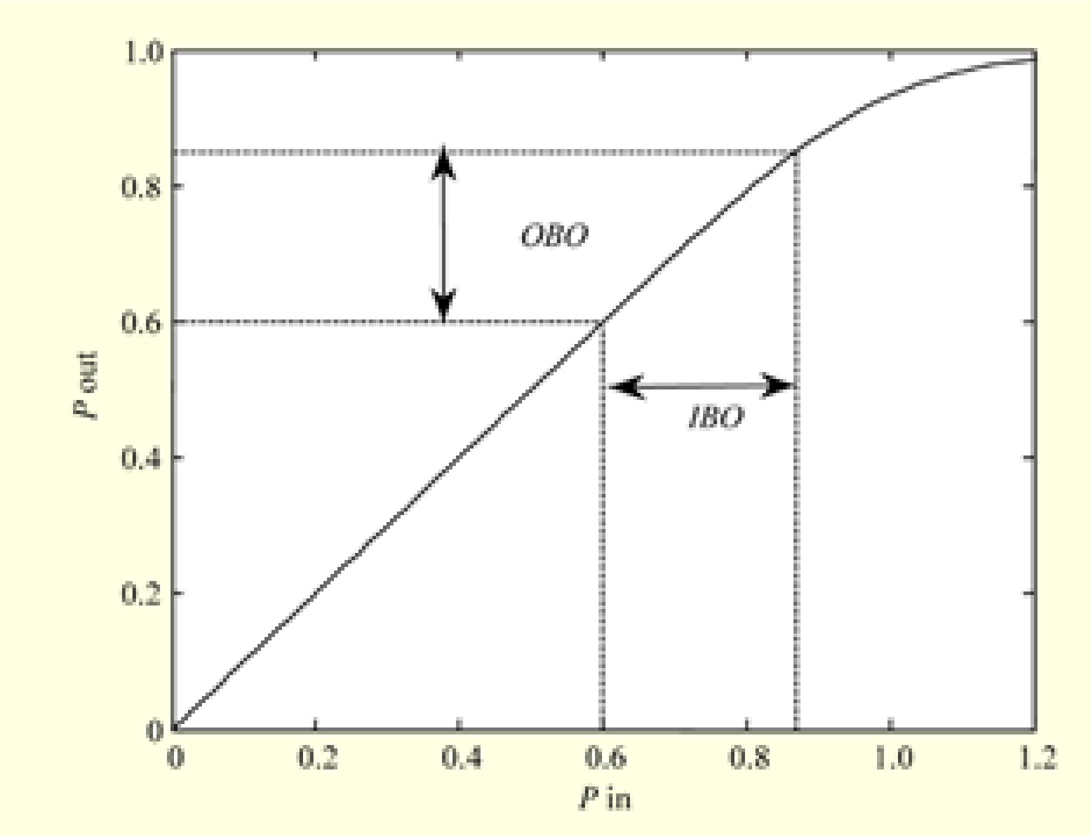

Figure 3.6: Characteristic of HPA.

$$V_{out} = \frac{V_{in}}{(1+(\frac{V_{in}}{V_{sat}})^{2S})^{1/2S}} \tag{3.1}$$

The IBO parameter can be mathematically defined as:

$$IBO = 10\log({}^{P_{max}}/_{P_{in}}) \tag{3.2}$$

In this equation the Pmax is peak power of the input signal and the Pin is the average power of the input signal [31].

3.6 Ideal System Model

Here we describe an ordinary ideal (OFDM) system Transmitter and Receiver compatible for time-invariant AWGN channels.

3.6.1 Transmitter

An OFDM signal is a combination of some orthogonal subcarriers, and baseband data is generally modulated independently using quadrature amplitude modulation or phase shift keying modulation and placed on a subcarrier. The synthesized baseband signal is generally modulated with a high frequency carrier wave.

s[n] Is a binary number data string. By de-multiplexing, this data is first separated into N pieces of parallel data, each of these pieces is modulated by QAM, PSK or like (probably complex) symbol data string.

When these symbol sequences are calculated by IFFT, N time domain complex data are obtained. The standard method then orthogonally modulates these data into pass band signals. First, the real components and imaginary components (of the complex data output from IFFT) are converted into analog signals using a digital-analog conversion circuit. This analog signal is converted into carrier frequency fc (Up-conversion) by using a cosine wave and a sine wave of cosine wave. After that, when these signals are synthesized, the transmission signal s(t) Is obtained.

Incidentally, quadrature amplitude modulation or phase shift keying "primary modulation" modulation due them further IFFT that may be referred to as "secondary modulation".

3.6.2 Receiver

In the receiver, the received signal r(t) (Down-conversion) using a cosine wave and a sinusoidal wave of the carrier frequency to obtain a baseband signal. At this time, the center frequency 2fc Signal is generated, it is removed by using a filter (low pass filter). This origin signal (baseband signal) is sampled and digitized using an analog-to-digital conversion circuit and returned to frequency domain data by FFT.

These N pieces of parallel data are respectively converted into binary data by using an appropriate symbol detector (demodulator). These data are again stored in the serial data string $S[n\}$ and is an estimate of the transmitted original binary data. The block diagram of OFDM Receiver system is shown in figure 3.7 and 3.8.

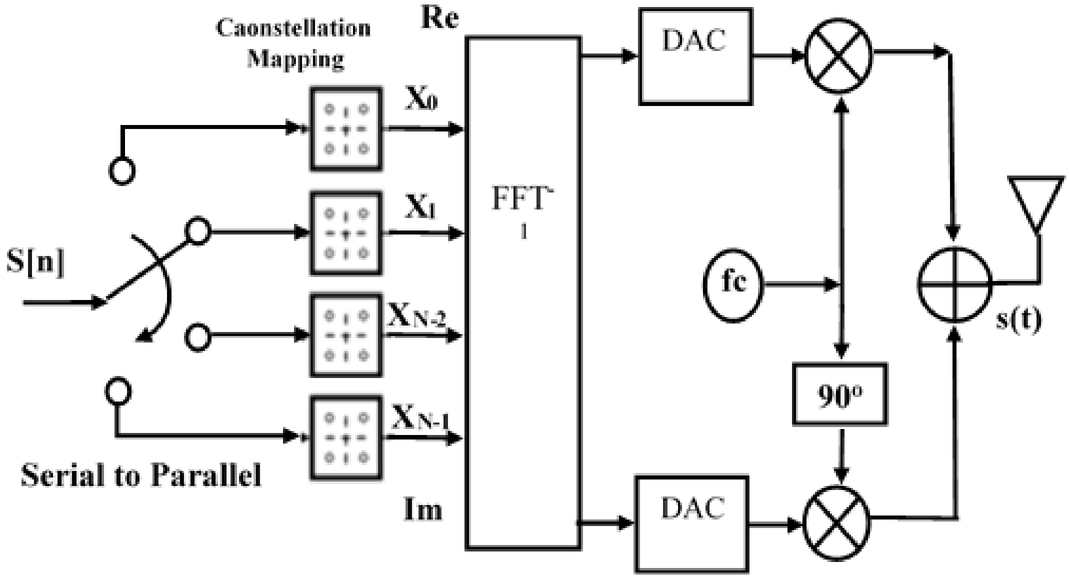

Figure 3.7: Block diagram of OFDM transmitter system.

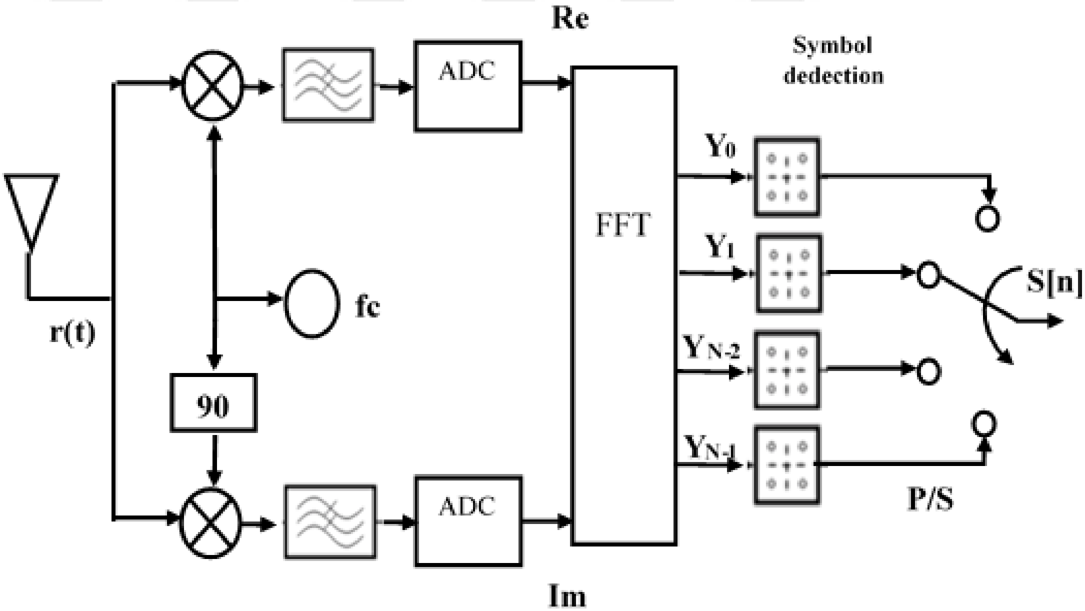

Figure 3.8: Block diagram of OFDM receiver system.

3.7 Mathematical Explanation

The equivalent baseband OFDM signal is written as follows.

$$v_{(t)} = \sum_{k=0}^{N-1} X_k e^{j2\pi kt/T} \quad 0 < t < T \tag{3.3}$$

$\{X_k\}$: Data symbol, *N*: Number of subcarriers, *T*: OFDM symbol length Frequency 1/T all subcarriers arranged at intervals are orthogonal within the same OFDM symbol. This uniqueness is expressed as follows.

$$\frac{1}{T}\int_0^T \left(e^{j2\pi k_1 t/T}\right) * \left(e^{j2\pi k_2 t/T}\right) dt \tag{3.4}$$

$$\frac{1}{T}\int_0^T \left(e^{j2\pi (k_1 - k_2)\, t/T}\right) \, dt = \delta_{k_1 k_2} \tag{3.5}$$

Where δ is Kronecker's Delta.

In order to bypass inter symbol interference by multipath fading transmission path, length. Tg Of the guard interval is inserted before the OFDM symbol. A cyclic prefix is commonly used for this guard interval. Which, $T_g \le t < 0$ the signal in$(T - T_g) \le t < T$. An OFDM signal using cyclic prefix can be expressed as follows.

$$v_{(t)} = \sum_{k=0}^{N-1} X_k e^{j2\pi kt/T} \quad -T_g < t < T \tag{3.6}$$

The above baseband signal is either real or complex. Equivalent baseband signals with only real numbers are generally used for baseband transmission. Wired applications like Digital Subscriber Line use this approach. In wireless implementation, the equivalent baseband signal generally takes the value of a complex number. In this case, the transmission signal has a carrier frequency fc Up-converted. In general, the transmitted signal can be expressed as follows.

$$s(t) = R\{v(t)e^{j2\pi f_c t}\} = \sum_{k=0}^{N-1} |X_k| \cos(2\pi[f_c + \frac{k}{T}]t + \arg[X_k]) \tag{3.7}$$

3.8 Peak to Average Power Ratio

As stated in Chapter 1 in this thesis, In OFDM signal a large Peak to Average Power Ratio (PAPR) would cause the power amplifier to be driven in the saturation region, which lead to signal distortion. Also Power Ratio (PAPR) can control the number of subcarriers N, rise or drop it. The basic and classical solution of this PAPR problem is using a linear power amplifier with a large dynamic domain. This remedy, however, force a stringent requirements on the analog devices in both OFDM transmitter and receiver, and therefore increase the cost of the OFDM system overall. In the last decade, many of PAPR reduction techniques have been proposed from the signal processing sight. Most of these techniques have worked on the discrete-time domain of the OFDM baseband signal that outcome from the IFFT module and tried to decrease the immediately power of the OFDM signal before transmission. In the time interval [0, T], the complex baseband OFDM signal can written as

$$S_{(t)} = \sum_{n=0}^{N-1} a_n e^{j2\pi\frac{n}{T}t} \tag{3.8}$$

Where T is the OFDM symbol duration, a_n the transmitted information symbol in the n the subcarrier/subchannel, which may be a binary number $\{\pm 1\}$ for BPSK modulation or a complex number $\{\pm 1, \pm j\}$ for QPSK modulation, and N the number of subcarrier.

Peak to Average Power Ratio (PAPR) define the ratio between the maximum peak power of the OFDM signal over one OFDM symbol T is define as

$$PAPR = \frac{P_{peak}}{P_{Average}} \tag{3.9}$$

Where P_{peak} represents peak output power, $P_{Average}$ means average output power

$$PAPR\{S_{(t)}\} = \frac{\max\left|S_{(t)}\right|^2 t \in (0,T)}{E\left|S_{(t)}\right|^2} \tag{3.10}$$

Where E(.) denotes the expectation and $E\left|S_{(t)}\right|^2$ represents the average power of the continuous baseband OFDM signal. In dB value the PAPR can be written as:

$\mathrm{PAPR} = 10\log_{10}(\mathrm{PAPR})$.

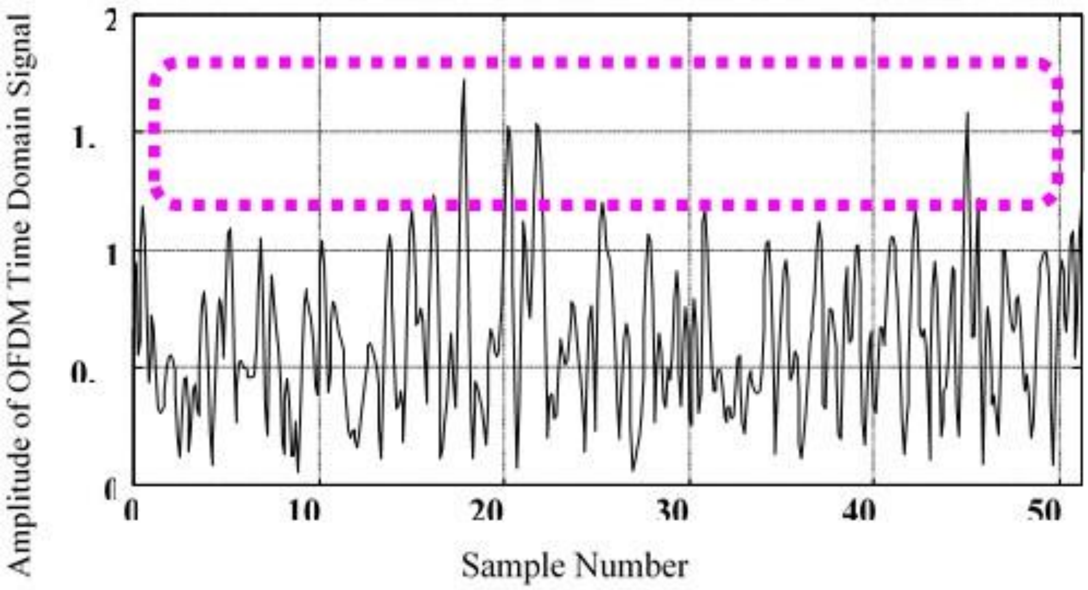

Figure 3.9: OFDM signal with peak to average power ratio.

3.9 PAPR Techniques

A high Peak Average Power Ratio (PAPR) value is one of the major issues of OFDM system. The PAPR parameter could be reduce by several techniques in OFDM system. All reduction techniques have several advantages and abuse. Therefore These PAPR reduction techniques should be picked carefully for getting the desirable minimum PAPR.

During the last few years many new approaches have been developed. These PAPR reduction techniques are divided into two main sets.

Clipping: Clipping naturally occurring in transmitter of the OFDM system whether power back-off is not sufficient. Clipping technique cause to a clipping noise and out of range radiation. Filtering after clipping can reduce out-of-band radiation. Several techniques for easement of the clipping noise at receiver of the OFDM system were determine. One of them reconstructs clipped sample using other samples of oversampled signal.

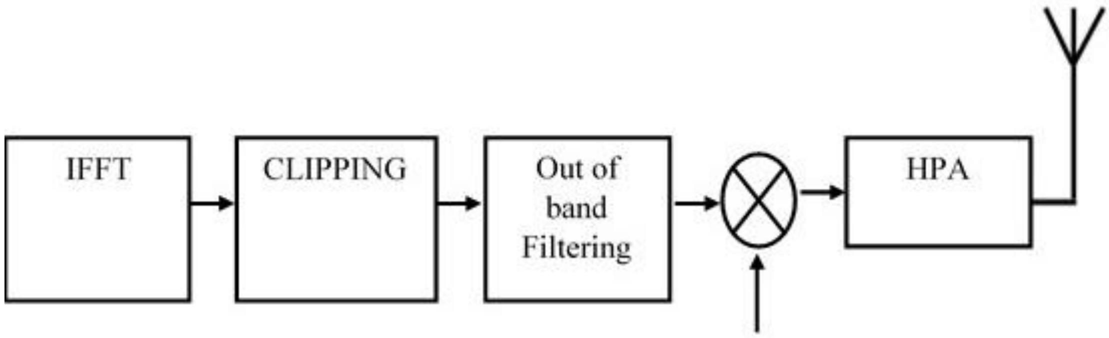

Figure 3.10: Block diagram of clipping reduction technique.

Coding Schemes: while N number of signals which they are in-phase, these signals added jointly results in the high peak power. The major idea of this technique (Coding Schemes) is to pick out codeword that will bring about pretty PAPR in OFDM system.

Partial Transmission Sequence (PTS): it is a significant techniques which is applied to reduce PAPR in the OFDM system. And it can be proceed in two major stages first, by separator the main OFDM signal into a number of sub-blocks. Secondly, for each sub-blocks added phase rotated to improve a number of signals to select the one with lowest PAPR for sending. There is different method that can also be used to represent PTS technique by multiplying the main OFDM signal with a number of phase series.

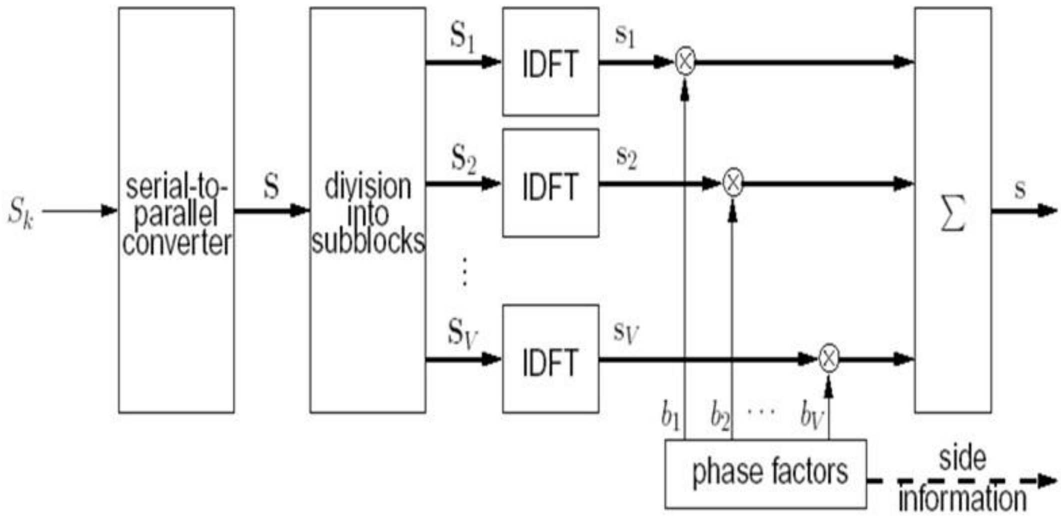

Figure 3.11: Block diagram of partial transmission sequence reduction technique.

Tone Reservation (TR): Tone Reservation technique is built on reserving small groups of tones which are called as peak reduction carriers, which reduce PAPR. These tones are added to data signal the aim of it to reduce the high peak. They are orthogonal to each other. Depended on place and number of reserved tones the quantity of PAPR reduction will change the performance of TR also depends on allowed power on reserved tones and amount of complexity. Tone Reservation method is lower complicated and it is achieve great minimization in PAPR.

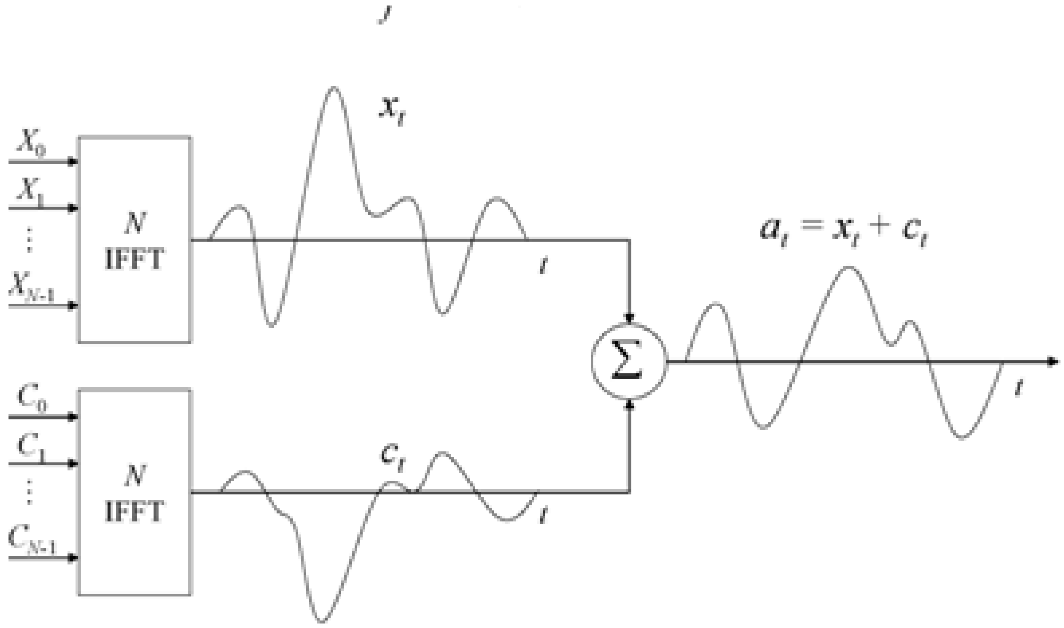

Figure 3.12: Block diagram of tone reservation reduction technique.

Selective Mapping Selective mapping (SLM): in OFDM communication system Selective Mapping is a powerful PAPR reduction technique. The basic principle of this technique is to generate U alternative transmit sequences from the same information source, after that pick out the transmit signal appear the lowest PAPR. Finally, selected data block with lowest PAPR for transmission by comparing the PAPR among the independent data blocks.

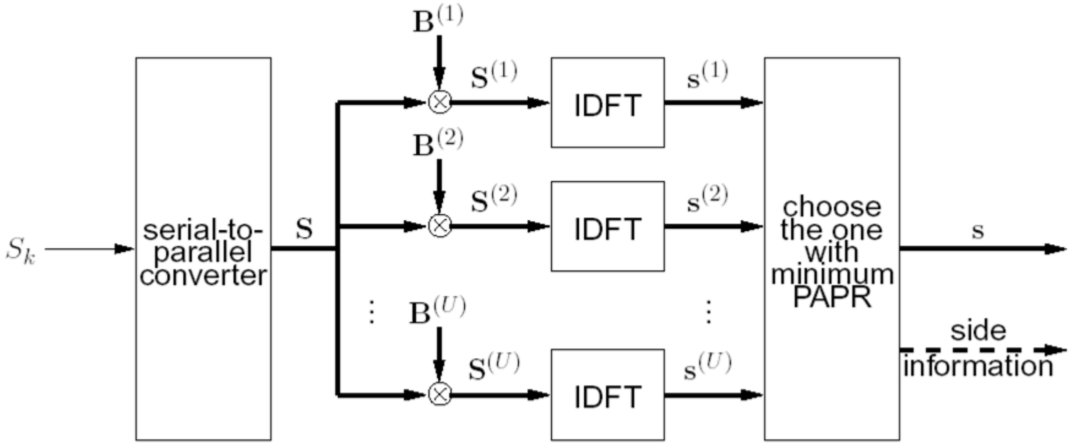

Figure 3.13: Block diagram of selective mapping selective mapping (SLM) reduction technique.

CHAPTER 4

SIMULATION RESULT AND DISCUSSION

4.1 Description of Proposed Algorithm

In this thesis the figure 4.1., descript the proposed algorithm, which is used for reduction PAPR in OFDM system by using Linear Predictive Coding tools.

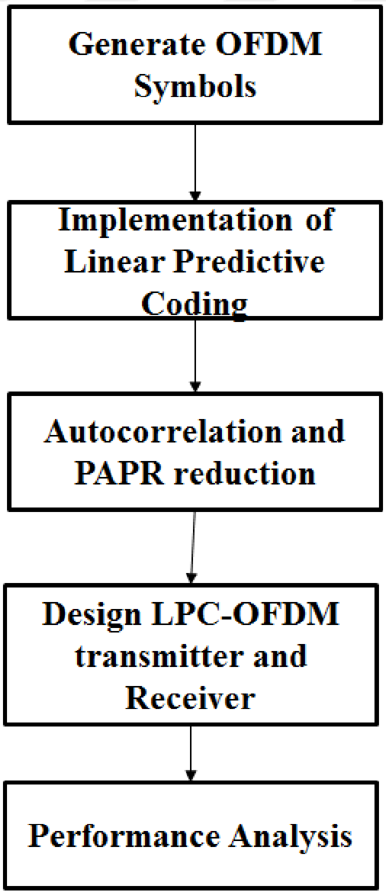

Figure 4.1: Flow chart of proposed method.

In this thesis we have four steps:

1. OFDM Symbol Generation
2. Linear Predictive Coding Implementation
3. PAPR Reduction
4. Performance Analysis

4.2 Autocorrelation and PAPR

Built-up OFDM signals can show clearly a very high PAPR when the symbols sequences are highly correlated. The concept of reduction PAPR using linear prediction coding (LPC) is to decorrelate the input signal sequence before enter Inverse Fast Fourier Transform (IFFT) in the transmitter so that PAPR of OFDM signal is also decrease. For the OFDM signal X, PAPR has relationship with aperiodic auto-correlation function (ACF). Let ρ(i) be the ACF of the signal X, [32], and therefore

$$p(i) = \sum_{k=1}^{N-1-i} X_k \, iX *_k \quad (4.1)$$

Where * denotes the complex conjugate. Then the PAPR of the transformed signal is bounded by

$$\text{PAPR} \leq 1 + 2N\times \lambda \quad (4.2)$$

Where λ is defined as

$$\lambda = \sum_{i=1}^{N-1} |\, p(i)| \quad (4.3)$$

Where | ρ(i)| is the absolute aperiodic ACF. It is explicate from Eqs. (4.2) and (4.3) that the signal (X_k) with a lower λ can produce an OFDM signal have lower PAPR.

4.3 Linear Prediction Coding Transceiver

Linear predictor error filtering suppose that the signal to be whitened is a stationary stochastic process can be modeled by an Autoregressive (AR) model of order M, this mean the nth sample of a sequence in discrete time x(n) can be perform by a linear combination of the previous M samples. By this supposition, the predicted sequence ˜x(n) can define in terms of M

$$\tilde{x}(n) = \sum_{k=1}^{M} c(k)\, x(n-k) \qquad (4.4)$$

Figure (4.2) shows the block diagram of the implementation system, [33].

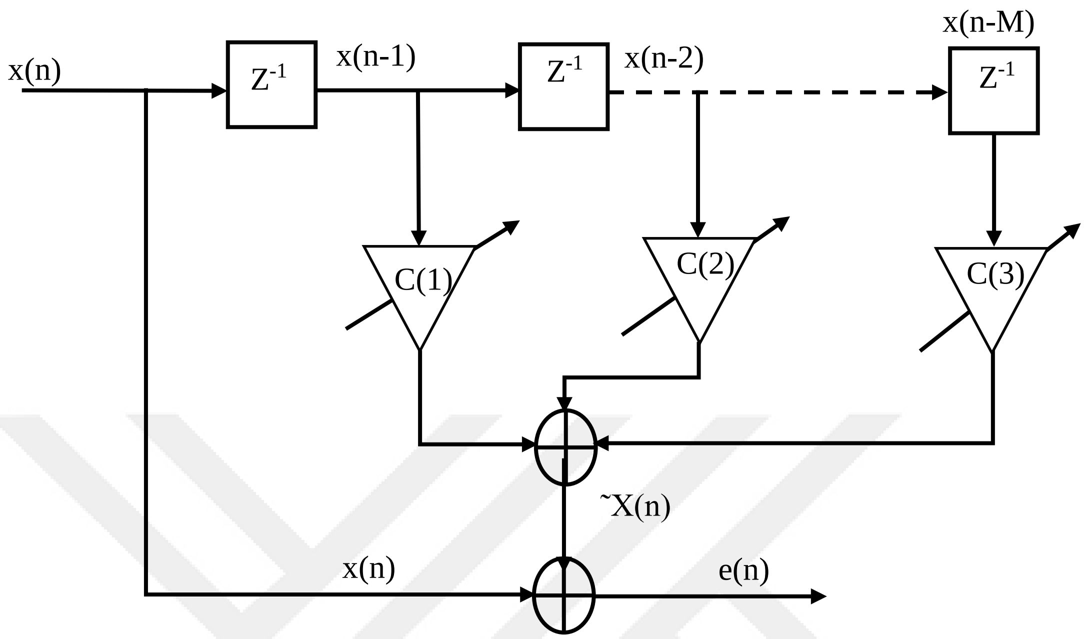

Figure 4.2: Block diagram of linear predictor.

The prediction error sequence e(n) can calculate as the difference between the original sequence and the predicted sequence:

$$e(n) = x(n) - \tilde{x}(n) \qquad (4.5)$$

When the coefficients c(k) in (4-4) are selection correctly, then the resulting prediction error sequence is generally formation of sample to sample uncorrelated white noise. Therefore, the prediction error is the whitened data sequence which will be demonstrate to have a lower value of PAPR. The linear predictor error filter can be specify as Mth order finite impulse response (FIR) filter with coefficients b(k), where the prediction error sequence e(n) can be restore while applied to a data sequence x(n)

$$e(n) = x(n) + \sum_{k=1}^{M} b(k)\, x(n-k) \qquad (4.6)$$

From Eq. (4.6),in frequency domain e(n) can be calculate by depending on b(k),which is the linear prediction coefficients, so the Eq. (4.6) can be represented as,

$$E(z) = X(z) + \sum_{k=1}^{M} b(k)\, X(z)\, z^{-k} \qquad (4.7)$$

$$A(z) = \frac{E(z)}{X(z)} = 1 + \sum_{k=1}^{M} b(k)\ z^{-k} \qquad (4.8)$$

From Eq. (4, 6) x(n) and e(n) represent as input signal and output signal. The residual error signal with the filter coefficients together are sending to the receiver. At the OFDM receiver, signal can be rebuild by the residual error signal out of the synthesis filter. Therefore Eq. (4.6) can be reformulate as in Eq.(4.9), where input is e(n) and output is x(n) it look like as the difference equation of an FIR filter.

$$x(n) = \sum_{k=1}^{M} b(k)\ x(n-k) + e(n) \qquad (4.9)$$

in the receiver, the original signal can be rebuild if the linear prediction coefficients and the residual error sequence are available and using the synthesis filter. Eq.(4.10) represent the the synthesis filter H(z),

$$H(z) = \frac{1}{1+ \sum_{k=1}^{M} b(k)\ z^{-k}} = \frac{1}{A(z)} \qquad (4.10)$$

4.4 Proposed Linear Predictive Coding – OFDM System

Linear Prediction Coding with Orthogonal frequency division multiplexing (OFDM) transceiver could be considered like a linear system with an adaptive filter, Figure. 4.3. Illustrate the Linear Prediction Coding -OFDM transceiver. By using N point of IFFT the OFDM signal x(N) will be generated x = [x[0], x[1],..., x[N − 1]]T. Next step, for each symbol the cyclic prefix (CP) will be add, because CP is so important to avoid the inter carrier interference (ICI) and inter symbol interference (ISI) problems. A parallel to serial (P/S) converter used to convert the OFDM signal and Digital to Analog Convertor (DAC) convert it to the analog signal and lastly high power amplifier used to amplified the signal.

At the receiver side, An Analog to Digital Convertor (ADC) convert the received signal to digital signal then the cyclic prefix will be remove through cyclic prefix Removal block next the signal convert from serial sequence to parallel. FFT used to demodulate the subcarrier in the received signal ˜x. After synthesis filter H(z), the signal has been rebuild, then it demapping through the demodulator block and the received signal ˜X.

At the transmitter side, the Linear Predictive Coding (LPC) analysis is implement, and the LPC coefficients will be sent to the receiver, however in backward adaptive coder the LPC coefficients are calculated from the previous reconstructed samples and the LPC analysis is achieved at the receiver, therefore in the backward no want to send the LPC coefficients to the receiver [34].

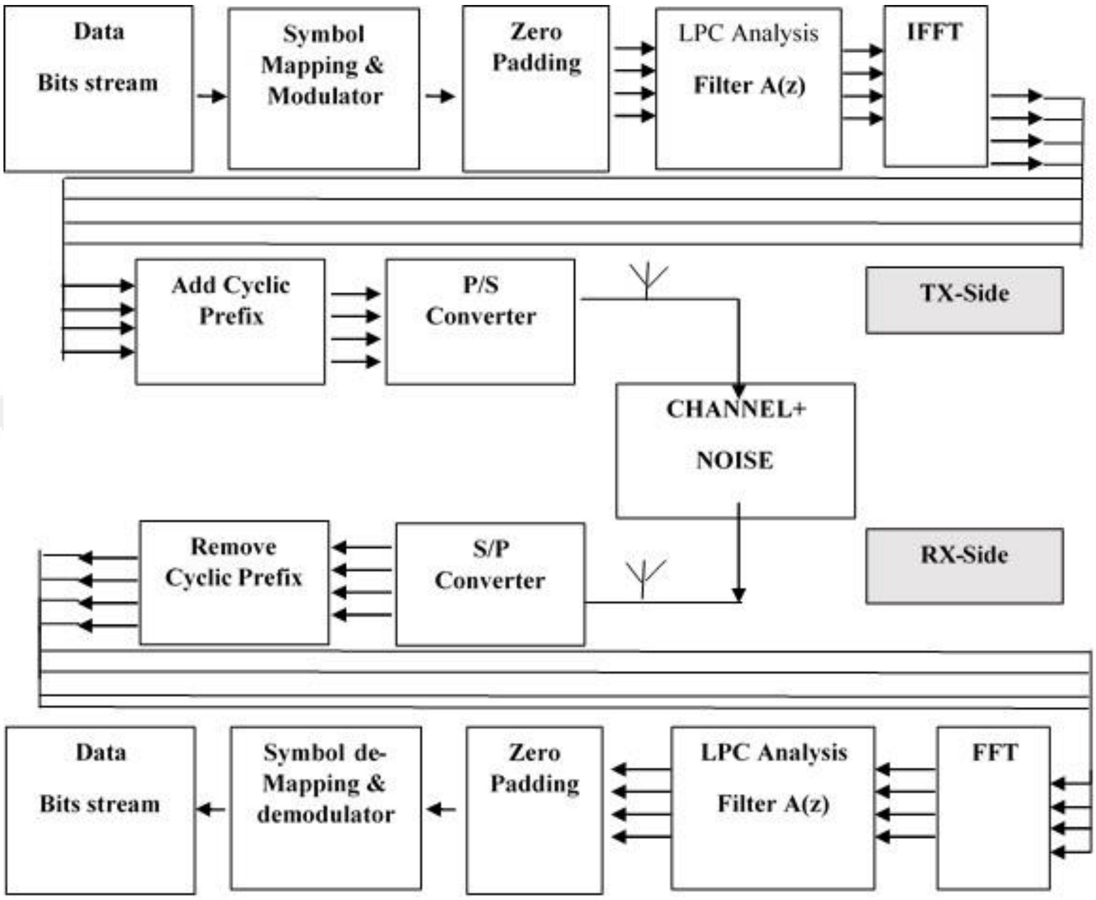

Figure 4.3: Linear predictive coding – OFDM transmitter and receiver.

4.5 Simulation Results

The complementary cumulative distribution function is shown in figure 4.4.

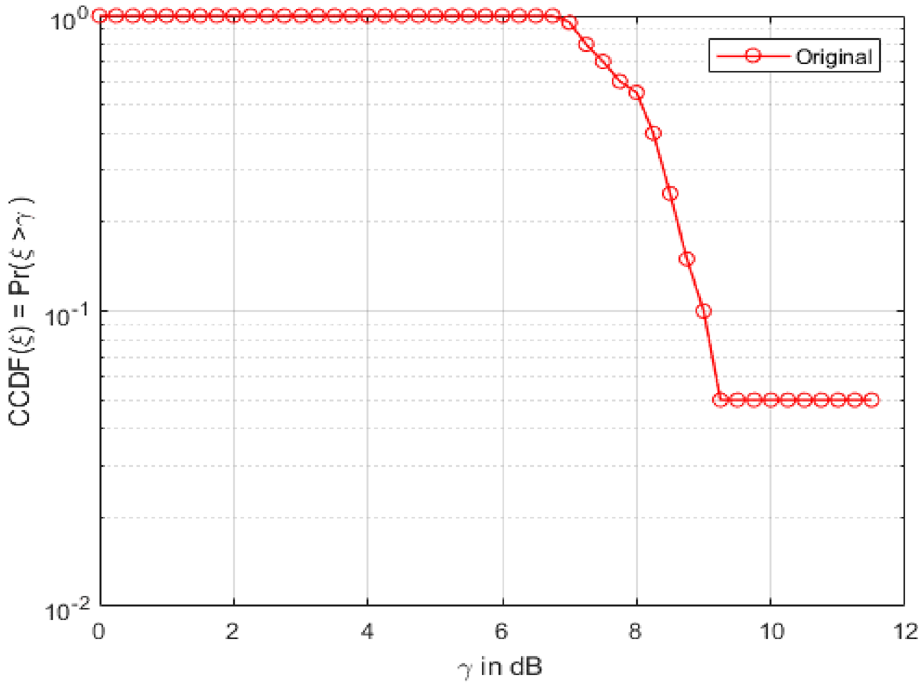

Figure 4.4: Complementary cumulative distribution function.

The Bit Error Rate is shown in figure 4.5.

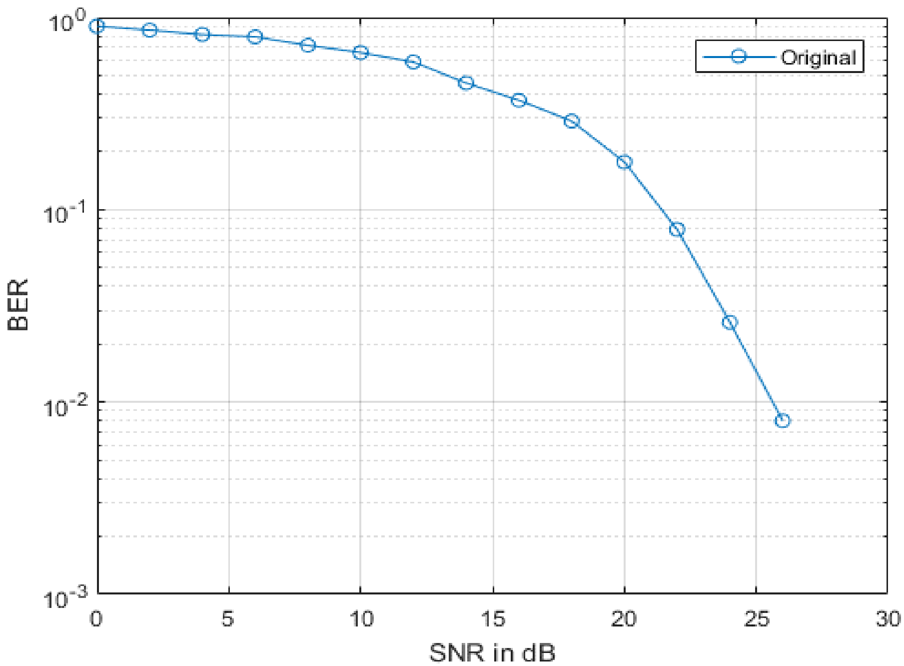

Figure 4.5: Bit error rate (BER).

The power spectral density for original result is illustrated in figure 4.6.

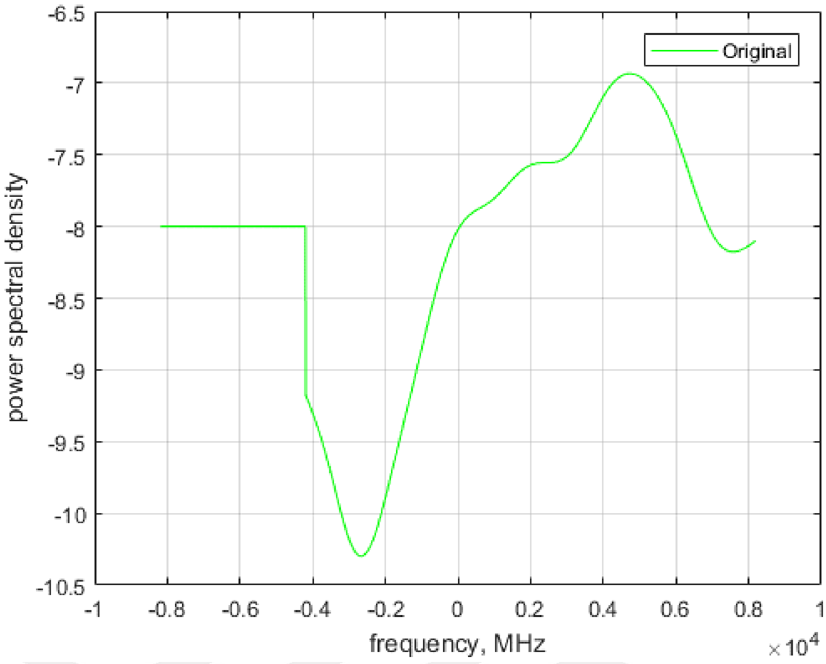

Figure 4.6: (PSD) Power spectral density for original data.

The Power spectral density (PSD) for original data and linear prediction coding is shown in figure 4.7.

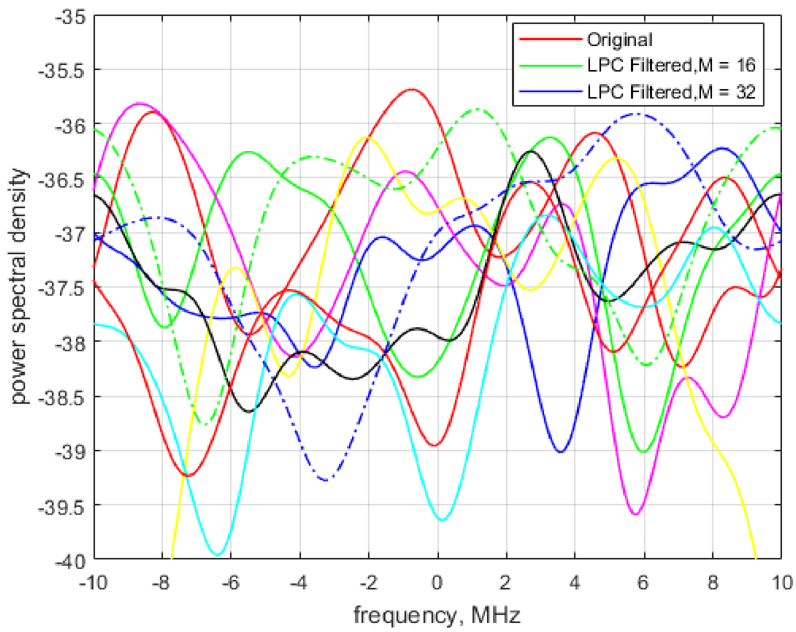

Figure 4.7: Power spectral density (PSD) for original data and linear prediction coding.

The normalized Autocorrelation Function (ACF) is shown in figure 4.8.

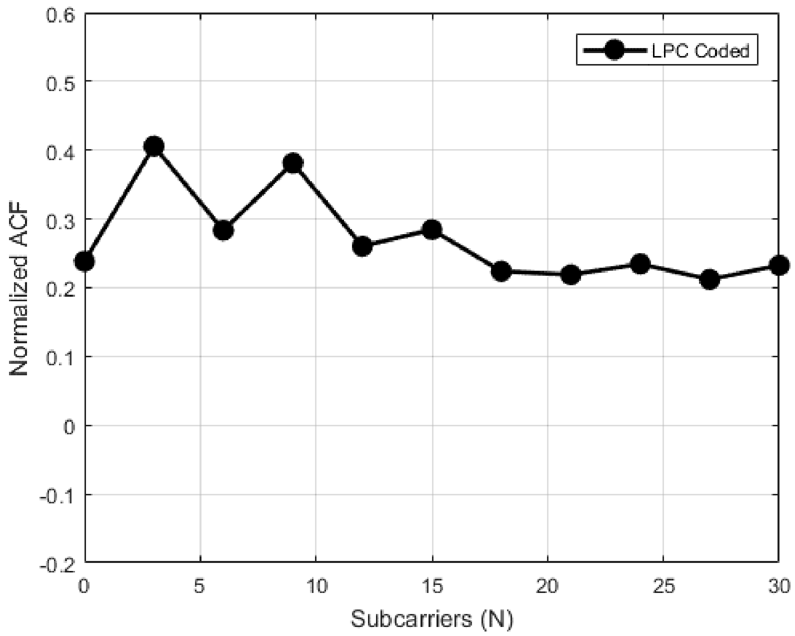

Figure 4.8: Normalized autocorrelation function (ACF).

The PAPR Complementary cumulative distribution function result for proposed LPC-OFDM for M = 8-64 is shown in figure 4.9.

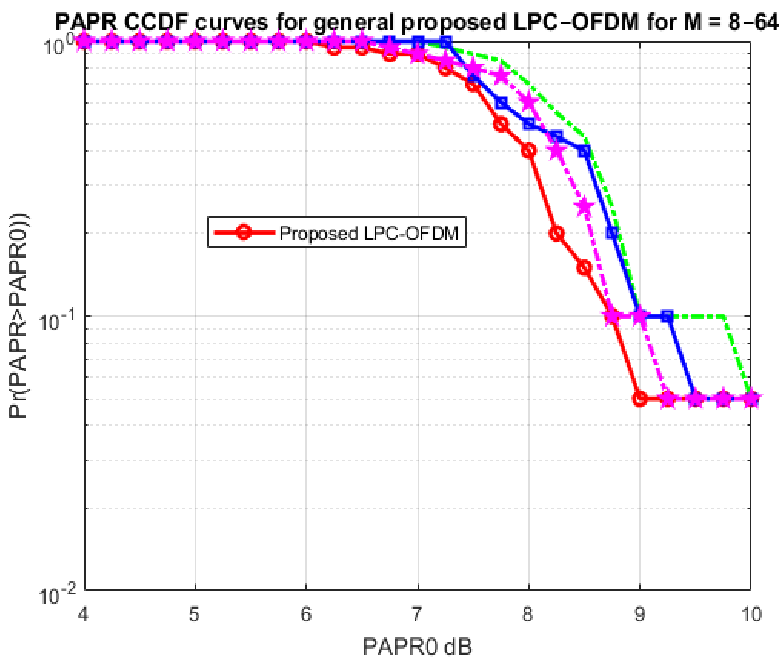

Figure 4.9: PAPR (CCDF) Complementary cumulative distribution function result.

The PAPR (CCDF) Complementary cumulative distribution function result for proposed LPC-OFDM for M = 4-32 is shown in figure 4.10.

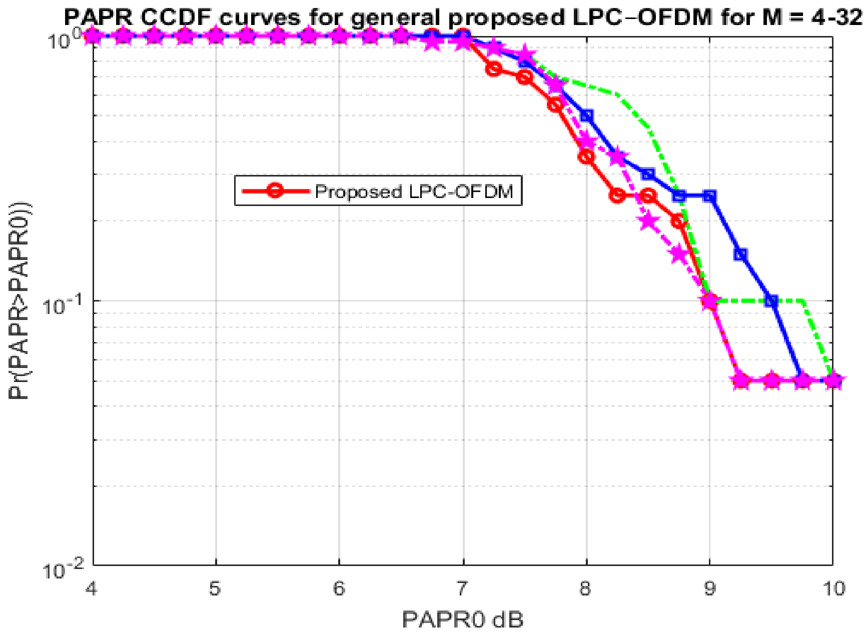

Figure 4.10: PAPR Complementary cumulative distribution function result for M = 4-32.

The PAPR Complementary cumulative distribution function result for proposed LPC-OFDM for M = 64-2048 is shown in figure 4.11.

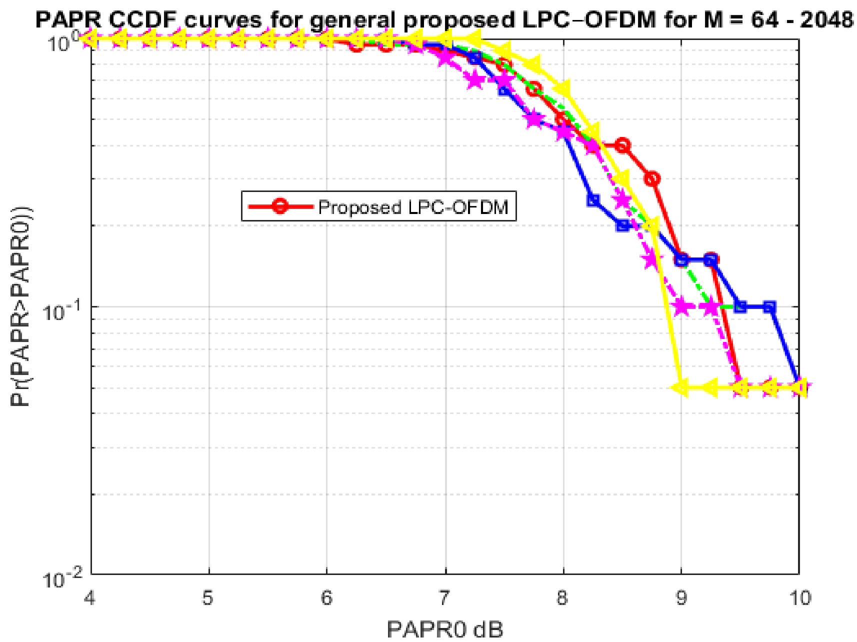

Figure 4.11: PAPR Complementary cumulative distribution function result for M = 64-2048.

The performances of Bit Error Rate (BER) for general LPC-OFDM used for M = 4 - 20 using QAM modulation is shown in figure 4.12.

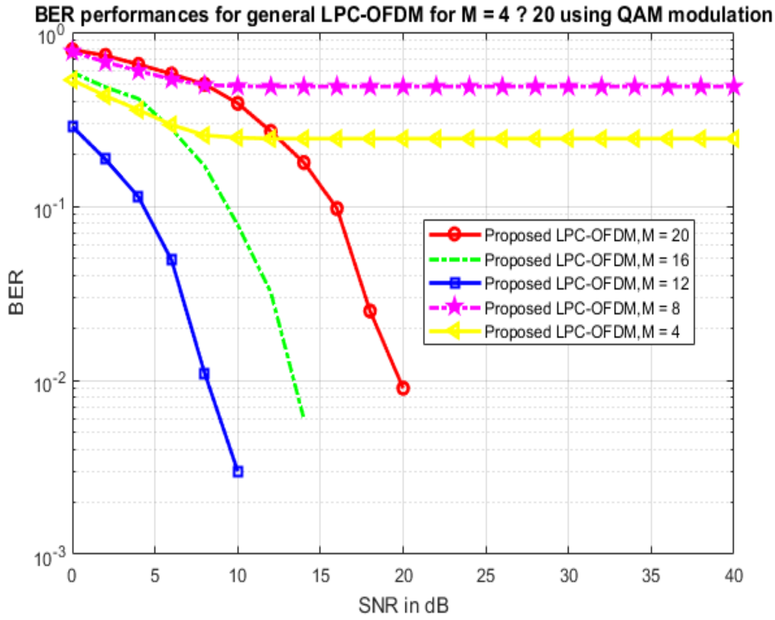

Figure 4.12: Performances of bit error rate (BER) for general LPC-OFDM for M = 4 - 20 using QAM modulation.

The performances of Bit Error Rate (BER) for general LPC-OFDM for M = 4 - 20 using QPSK Modulation is illustrated in figure 4.13.

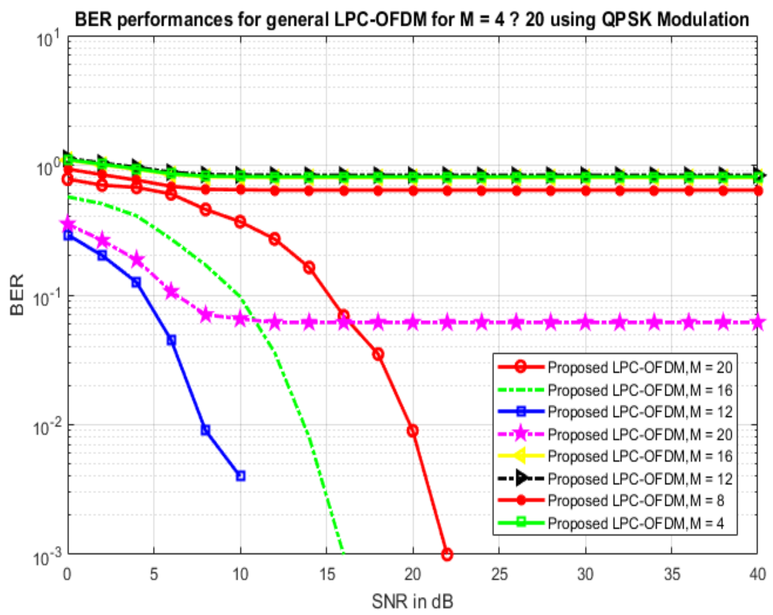

Figure 4.13: performances of bit error rate (BER) for general LPC-OFDM for M = 4 - 20 using QPSK modulation.

The performances of Bit Error Rate (BER) for general LPC-OFDM for M = 64 - 1024 using QAM Modulation is shown in figure 4.14.

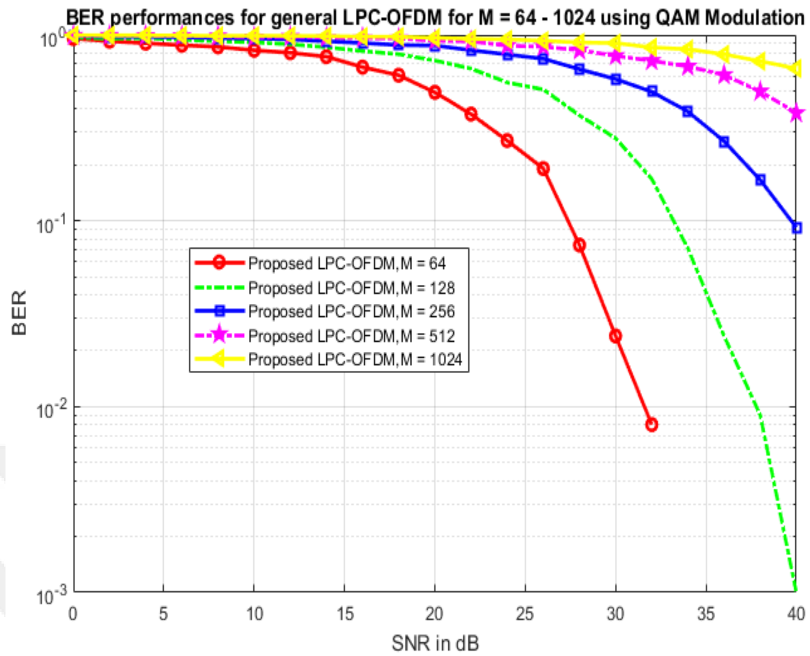

Figure 4.14: Performances of bit error rate (BER) for general LPC-OFDM for M = 64 - 1024 using QAM modulation.

The performances of Bit Error Rate (BER) for general LPC-OFDM for M = 4 - 32 using QAM Modulation is shown in figure 4.15.

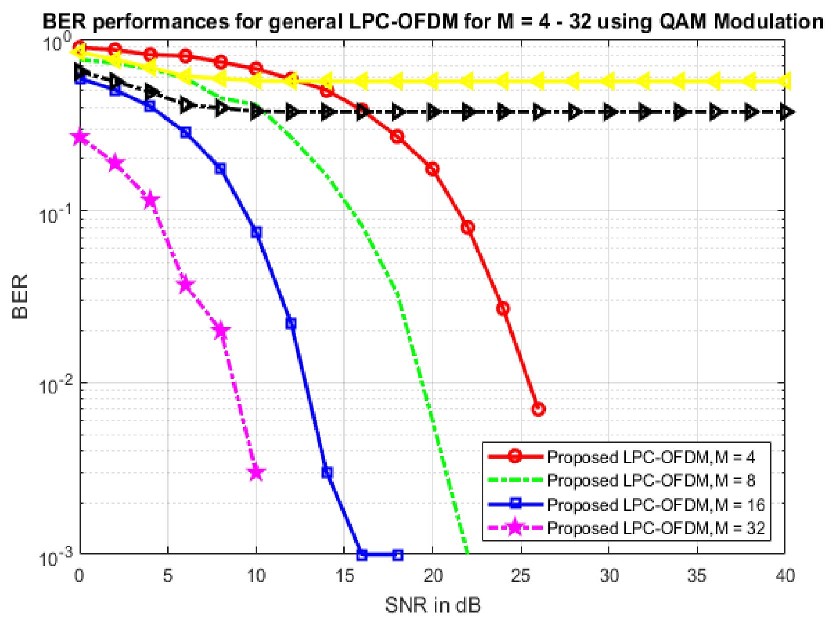

Figure 4.15: Performances of bit error rate (BER) for general LPC-OFDM for M = 4 - 32 using QAM modulation.

CHAPTER 5

CONCLUSION

The OFDM (orthogonal frequency-division multiplexing) is a method of encoding digital signals by orthogonal frequency division in the form of multiple subcarriers. This technique makes it possible to combat frequency-selective channels by allowing low complexity equalization. These channels are manifested in particular in the presence of multiple paths and are all the more disadvantageous as the transmission rate is high. This is why this technique is widely adopted in most high-speed applications.

Several variants of the OFDM exist. DMT (discrete multi-tone) refers to a baseband OFDM transmission system. The Coded orthogonal frequency-division multiplexing (COFDM) introduces an error corrector code. WCP-OFDM (weighted cyclic prefix orthogonal frequency-division multiplexing) provides for adding a cyclic prefix and the weighting of the output signal of the transmitter to adapt to mobile channels multipath.

In the presence of a multi-track channel, the reception of several echoes in phase opposition can give rise to fading (severe attenuation over part of the frequency band). In the context of an OFDM system, it is generally impossible to reconstruct the symbols transported by the subcarriers affected by these phenomena of fading. This is due to the fact that the non-preceded OFDM does not introduce redundancy (or frequency diversity). This disadvantage can be overcome by using the COFDM at the cost of a reduction in spectral efficiency.

Since the OFDM is a block transmission system, a guard interval is generally introduced between the latter. This makes it possible to eliminate the interference between successive blocks in the presence of channels with several paths and to facilitate all the more the equalization, provided that the guard interval is of duration greater than the time of arrival of the last path. Two types of guard intervals are commonly used: the cyclic prefix, which consists in copying the last samples of the block at the beginning of the block and the zeros stuffing which consists of inserting zeros at the beginning of the block. These two techniques naturally lead to a reduction in spectral efficiency.

Therefore the system has N number of modulated subcarriers which they are independently, these can make large value of PAPR when the collect consistent. The PAPR calculate from the R-times oversampled OFDM signal sample in the time domain. The high value of PAPR will caused to the non- linearity for High Power Amplifier (HPA), which leads to degrade the performance of the system overall. There are several reduction techniques which reduce the value of PAPR as shown in Chapter 3.

In this thesis using Linear Predictive Coding (LPC) with orthogonal frequency division multiplexing (OFDM) for reduction PAPR. The system could be considered like a linear system with an adaptive filter, in the transmitter side, after modulated the input data block N,and create mapped symbols, each symbols filtered by LPC analysis filter to calculate the residual error. The analysis filter attempt perform a flat spectrum by reduce the high magnitude of some frequencies which lead to high PAPR.

At the receiver side, after FFT used the synthesis filter is the reverse of the analysis filter, which used to rebuild the received signal synthesis filter is amplifies the frequencies that have been attenuated by the transfer function of the analysis filter.

Therefore Linear Predictive Coding – OFDM overall Computational Complexity increases at the transmitter side. For forward LPC adaptive the receiver complexity could be reduce, but forward LPC adaptive demands the filter coefficients should be transmit to the receiver for kindly rebuilding. In backward adaptive LPC, no need to any side information be sent, because the filter coefficients can be recomputed at the receiver therefore it keep the bandwidth. This leads to overall Computational Complexity is then double the Computational Complexity of forward LPC.

Through the results obtained in this thesis by applied LPC in OFDM for PAPR reduction, we notes the following:

The simulation shows that at Figures (4.7) and (4.9) the proposed method get same achievement and comparable performances, therefore, it could be realize that the

LPC_OFDM reduction method is do not depend of modulation systems and could be utilized to big order modulation method.

The simulation shows that at Figures (4.9) to (4.15) the LPC_OFDM reduction method could be utilized to each number of subcarriers mandatory for the standard.

The simulation shows that at Figures (4.10) to (4.13) the LPC_OFDM reduction method degrades the error performance and could achieve well BER performance than the overall OFDM (4.3).

The simulation shows that at Figures (4.12) and (4.13) increasing filter order without power equalization leads to BER performance degrades, So, it have to be realize which for small number of M, the PAPR reduction could still be important without cooperation to the BER.

REFERENCES

[1] M. M. Hasan, "A new PAPR reduction technique in OFDM systems using linear predictive coding," *Wireless personal communications*, vol. 75, pp. 707-721, 2014.

[2] S. B. Meshram and S. Rathkanthiwar, "An Overview: Peak-to-Average Power Ratio Reduction in OFDM System Using Block Coding Technique," *International Journal of Engineering Innovations and Research*, vol. 2, p. 63, 2013.

[3] S. Weinstein and P. Ebert, "Data transmission by frequency-division multiplexing using the discrete Fourier transform," *IEEE transactions on Communication Technology*, vol. 19, pp. 628-634, 1971.

[4] R. Salmanzadeh and B. M. Tazehkand, "A modified method based on the discrete sliding norm transform to reduce the PAPR in OFDM systems," *ETRI Journal*, vol. 36, pp. 42-50, 2014.

[5] M. I. Abdullah, "Comparative study of PAPR reduction techniques in OFDM," 2011.

[6] H. B. Mishra, "PAPR reduction of OFDM signals using selected mapping technique," 2012.

[7] Y. Rahmatallah and S. Mohan, "Peak-to-average power ratio reduction in OFDM systems: A survey and taxonomy," *IEEE communications surveys & tutorials*, vol. 15, pp. 1567-1592, 2013.

[8] P. Liu, "New peak-to-average power ratio reduction schemes for OFDM systems," Concordia University, 2004.

[9] H. Joshi, "Performance augmentation of OFDM system," 2012.

[10] A. Goel, "Improved PAPR Reduction in OFDM Systems," 2013.

[11] G. Hill, "Peak power reduction in orthogonal frequency division multiplexing transmitters," Victoria University, 2011.

[12] C. Choudhary and V. Gupta, "A Study of Performance Enhancement Schemes for Multicarrier Transmission," *International Journal of Computer Applications,* vol. 68, 2013.

[13] S. H. Muller and J. B. Huber, "OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequences," *Electronics letters,* vol. 33, pp. 368-369, 1997.

[14] A. B. Narasimhamurthy, M. K. Banavar, and C. Tepedelenliouglu, "OFDM systems for wireless communications," *Synthesis Lectures on Algorithms and Software in Engineering,* vol. 2, pp. 1-78, 2010.

[15] M. A. Islam, N. Ahmed, N. U. Ahamed, M. Rahman, and S. Aljunid, "PAPR Reduction in an OFDM system using Recursive Clipping and Filtering Technique," *WSEAS Transactions on communications,* vol. 13, pp. 291-297, 2014.

[16] M. Bala, M. Kumar, and K. Rohilla, "PAPR Reduction in OFDM Signal Using Signal Scrambling Techniques," *International Journal of Engineering and Innovative Technology (IJEIT),* vol. 3, pp. 140-143, 2014.

[17] A. Skrzypczak, J.-P. Javaudin, and P. Siohan, "Reduction of the peak-to-average power ratio for the OFDM/OQAM modulation," in *Vehicular Technology Conference, 2006. VTC 2006-Spring. IEEE 63rd*, 2006, pp. 2018-2022.

[18] Y. S. Cho, J. Kim, W. Y. Yang, and C. G. Kang, *MIMO-OFDM wireless communications with MATLAB*: John Wiley & Sons, 2010.

[19] M. Sundararajan and U. Govindaswamy, "Multicarrier Spread Spectrum Modulation Schemes and Efficient FFT Algorithms for Cognitive Radio Systems," *Electronics,* vol. 3, pp. 419-443, 2014.

[20] N. Chide, S. Deshmukh, and P. Borole, "Implementation of OFDM System using IFFT and FFT," *International Journal of Engineering Research and Applications (IJERA),* vol. 3, pp. 2009-2014, 2013.

[21] M. Z. Parvez, M. Baki, and A. Al, "Peak to average power ratio (PAPR) reduction in OFDM based radio systems," ed, 2010.

[22] T. Jiang and Y. Wu, "An overview: Peak-to-average power ratio reduction techniques for OFDM signals," *IEEE Transactions on broadcasting*, vol. 54, pp. 257-268, 2008.

[23] E. Y. Q. Al-Dalakta, "PAPR and ICI reduction techniques for OFDM based satellite communication systems," 2012.

[24] A. Chacko and J. Jeevitha, "PAPR reduction techniques for performance improvement in OFDM systems," in *Electronics and Communication Systems (ICECS), 2014 International Conference on*, 2014, pp. 1-4.

[25] K. Mhatre and U. P. Khot, "Efficient selective mapping PAPR reduction technique," *Procedia Computer Science*, vol. 45, pp. 620-627, 2015.

[26] P. K. Pradhan, "On Efficient Signal Processing Algorithms for Signal Detection and PAPR Reduction in OFDM Systems," 2016.

[27] C. Johri, P. Asthana, and S. Mishra, "Review paper on PAPR reduction techniques in OFDM system," 2014.

[28] Y. Wang and A. N. Akansu, "Low-complexity peak-to-average power ratio reduction method for orthogonal frequency-division multiplexing communications," *IET Communications*, vol. 9, pp. 2153-2159, 2015.

[29] K. Fazel and S. Kaiser, *Multi-carrier Spread-spectrum: Proceedings from the 5th International Workshop, Oberpfaffenhofen, Germany, September 14-16, 2005*: Springer Science & Business Media, 2006.

[30] F. Classen and H. Meyr, "Frequency synchronization algorithms for OFDM systems suitable for communication over frequency selective fading channels," in *Vehicular Technology Conference, 1994 IEEE 44th*, 1994, pp. 1655-1659.

[31] B. S. K. Reddy and B. Lakshmi, "Concatenated coding in OFDM for WiMAX using USRP N210 and GNU radio," *International Journal of Wireless & Mobile Networks*, vol. 5, p. 55, 2013.

[32] C. Tellambura, "Upper bound on peak factor of N-multiple carriers," *Electronics letters*, vol. 33, pp. 1608-1609, 1997.

[33] B. S. Atal, "The history of linear prediction," *IEEE Signal Processing Magazine*, vol. 23, pp. 154-161, 2006.

[34] J. Benesty, M. M. Sondhi, and Y. Huang, *Springer handbook of speech processing*: Springer Science & Business Media, 2007.

CURRICULUM VITAE

PERSONAL INFORMATION

Name, Surname : Mohanad Mahdi Abdulkareem ABDULKAREEEM

Date and Place of Birth : / Iraq –Baghdad

Marital Status : Married

Phone : 05319852116

Email : engelecommohanad@gmail.com

EDUCATION

High School: AL Gomhoria for Boys**.**

Undergraduate: B.S. degree in Electronic and Communications engineering from Baghdad University in 2005.