Sudan University of Science and Technology

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PEAK TO AVERAGE POWER RATIO (PAPR) REDUCTION IN OFDM BASED RADIO SYSTEM

A Research Submitted in Partial Fulfillment for the Requirements of the Degree B.SC (Honor) in Electronics Engineering

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الآيـــــة

﴿وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ
وَالْمُؤْمِنُونَ وَسَتُرَدُّونَ إِلَى عَالِمِ الْغَيْبِ وَالشَّهَادَةِ
فَيُنَبِّئُكُمْ بِمَا كُنْتُمْ تَعْمَلُونَ﴾

صدق الله العظيم

التوبة (105)

DEDICATION

To

Endless love

Our mothers

To

Man who teach me to be man

Our fathers

To

Our brothers and Sisters

To

Our teachers &our colleagues

AKNOWLEDGMENT

First we need to thank fully our god (Allah) that without his blessing this work will not complete.

Then all thanks for our supervisor Dr. Mohamed Hussain to his patience with us and countless hours and valuable efforts to guide and advise us to complete the work in her fair way.

Lastly we need to thank our teachers in electronic engineering school to their efforts in helping and support

Abstract

A non-constant envelope with high peaks is a main disadvantage of Orthogonal Frequency Division Multiplexing (OFDM). These high peaks produce signal excursions into non-linear region of operation of the Power Amplifier (PA) at the transmitter, thereby leading to non-linear distortions and spectral spreading. Many Peak to Average Power Ration (PAPR) reductions methods have been proposed in the literature. The objective of this review is to give a clear understanding of different techniques to reduce PAPR of the signal and that mathematically analyzed . finally compare PAPR before and after clipping , selective mapping and partial transmit sequence . The numerical analysis and computer simulation show that PTS is the best for reducing PAPR

المستخلص

الظروف الغير مستمره للقمم العالية هو العيب الرئيسي في التقسيم الترددي المتعامد هذه القمم العالية تنتج رحله الإشارة الى منطقة غير خطية لتشغيل مكبر القوة في الإرسال بذلك يؤدي الى تشوهات الغير الخطية والإنتشار الطيفي ,وقد إقترحت العديد من التقنيات للحد من القيم العالية والمتوسطة للقدرة.

الهدف من هذا البحث هو إعطاء فهم واضح للتقنيات المختلفة للحد من النسبة للحد الاعلى والمتوسطة للقدره للإشارة وتحليلها رياضيا.

وأخيرا مقارنة النسبة بين القيم الأعلى والمتوسطة للقدرة قبل وهذا بطرق معينة وهي القص ورسم إنقائي للخرائط وإرسال التسلسل الجزئي.

التحليل العددي والمحاكاة الحاسوبية توضح أن إرسال التسلسل الجزئي هو الأفضل للحد من النسبة الاعلى والمتوسطة للقدرة.

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LIST OF Symbols

Symbols	Meaning
$X(t)$	ratio between the maximum instantaneous power and average power
E[ ]	Statistical expectation function
Max[ ]	Highest value among the samples
N	Number of subcarrier
X_k	Complex number representing a BPSK,QPSK or QAM symbol
E	Exponential
J	Imaginary number j= -1
K_{th}	Subcarrier
$\triangle f$	Subcarrier spacing
T	Time
X_k	The frequency bin argument

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LIST OF ABBREVIATIONS

LTE	Long Term Evolution
3G	The Third Generation Of Mobile Telecommunications Technology
3GPP	The 3rd Generation Partnership Project
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
FFT	Fast Fourier Transform
MATLAB	Matrix Laboratory
CRC	*Cyclic Redundancy Check*
BER	Bit Error Rate
IFFT	Inverse Fast Fourier Transform
PAPR	Peak To Average Power Ratio+
SNR	Signal To Noise Ratio
FM	Frequency Modulation
AMPS	*Advanced Mobile Phone System*
ETACS	Extended Total Access Communications System
GSM	*Global System for Mobile*

3GPP2	The *3rd Generation Partnership Project 2*
TDMA	Time Division Multiple Access
IEEE	Institute Of Electrical and Electronic Engineering
EUTRA	Evolved Universal Terrestrial Radio Access
FDMA	Frequency Division Multiple Access
BER_T	Bit Error Rate Target
DSP	Digital Signal Processing
HARQ	*Hybrid Automatic Repeat Request*
VHDL	*Very high Hardware Description Language*
DFT	Discrete Fourier Transform
AWGN	Additive White Gaussian Noise
FDM	Frequency Division Multiplexing
ISA	International Society of Automation
QPSK	Quadrature Phase Shift Keying
SINR	Signal To Interference Noise Ratio
AMC	Adaptive Modulation And Coding

SC-FDMA	Single Carrier Frequency Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
W-CDMA	Wideband Code Division Multiple Access
UMTS	The *Universal Mobile Telecommunications System*
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
MBMS	*Multimedia Broadcast Multicast Services*
LAN	Local Area Network
HSPA	High Speed Packet Access
QOS	*Quality Of Service*
IMT	International Mobile Telecommunications
ISI	Inter Symbol Interference
ITU	International Telecommunications Union
PHY	Physical Layer
MIMO	Multiple Input Multiple Output
ICI	Inter Carrier Interference

Chapter one

INTRODUCTION

1.1 preface

The Internet communication service is being extended beyond its traditional frontiers of fixed wired infrastructure through the gradual addition of a broad range of Complex networks and autonomous devices. In particular, the introduction of the Smartphone and subsequently the Tablets has produced a demand for mobile data services that has been growing rapidly[1]. From traditional wireless networks to opportunistic networks of mobile devices in dense environments, new hardware platform requirements are becoming increasingly more complex, due to the necessary processing and computation power. The need for revolutio-nary or evolutionary architectures with multiple processors designed using different types of processors and technologies, and thus managing a range of heterogeneous components in order to support new multi-media services are only a subset of the wide range of existing new technologies that require high levels of processing power.[2]

The consequence of the evolution of the mobile wireless standards is an increased need for the system to support multiple standards and multi-component devices for backward compatibility. These two require-ments greatly complicate the development of telecommunication systems, imposing the optimization of device parameters over numerous cons-traints, such as performance, area and power[3].

Achieving device optimization requires a deep understanding of application complexity and the choice of an appropriate architecture to support this application. Of particular note, the new, feature-rich wireless standard called long-term evolution (LTE) is a complex application that needs a large amount of processing power. LTE is the next evolutionary step after The Third Generation (3G) for mobile wireless communication, and is aimed at increasing the wireless network capacity while improving the spectral efficiency. LTE unites many technological innovations from diverse research areas such as digital signal processing, Internet protocols, network architecture, and security, and, as such, will drastically change the way that the worldwide mobile network is used in the future. LTE is anticipated to be the first truly global wireless standard, as it may be deployed in a variety of spectrum and operating scenarios, and has the capability to support wireless applications. Numerous operators and service providers around the world have deployed LTE on their networks or have announced LTE as their intended next generation technology. Base stations developed according to The 3rd Generation Partnership Project Long Term Evolution (3GPP -LTE) standard require unprecedented processing power. 3GPP LTE enables data rates beyond hundreds of Mbits/s by using advanced technologies, a highly complex LTE physical layer. Understanding LTE and its Performance is of great value to anyone who is interested in 3GPP LTE or wireless broadband networks more generally[4].

This thesis provides a step by step study for of an LTE physical layer and its major blocks, and provides some performance analysis to some important features.

One of the major problems of OFDM is high peak to average power ratio (PAPR) of the transmit signal. If the peak transmit power is limited by either regulatory or application Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation (MCM) technique which seems to be an attractive candidate for fourth generation (4G) wireless communication systems. The additional increasing demand on high data rates in wireless communications systems has arisen in order to carry broadband services. OFDM offers high spectral efficiency, immune to the multipath fading, low inter-symbol interference (ISI), immunity to frequency selective fading and high power efficiency. OFDM has been adopted by Digital Audio Broadcasting (DAB), Digital Video Broadcasting-Terrestrial (DVB-T) and Wireless LAN (WLAN) systems. Additionally, OFDM has been used in the mobility mode of IEEE802.16 WiMAX. Furthermore, it is currently a working specifications in 3GPP Long Term Evolution (LTE) downlink, and is the candidate access method for the IEEE 802.22 Wireless Regional Area Networks (WRAN) [1].

the major problem in OFDM and the topic of this paper, is its is the PAPR . the sum of N orthogonal sinusoids results in a signal having large amplitude fluctuations.

1.2 PROBLEM STATEMENT

In OFDM system the output is the super preposition of multiple subcarriers . In this case ,some instantaneous power output might increase greatly and become far higher than the mean power of the system when the phases of these carriers are same ,This is also defined as large peak-to average power ratio (PAPR) .

1.3 PROPOSED SOLUTION

the simplest distortion technique is the clipping , which limits the instantaneous signal peak to a present threshold period to sending the signal to a power amplifier . depending on the level of threshold the signal is distorted more or less severely . although a low pass filter can be used along with the clipping to alleviate splattering effect , sometimes the problem of peak growth may occur after the low pass filtering .

Also Selective Mapping (SLM) is used and compared with clipping .

1.4 AIM AND OBJECTIVES

PAPR reduction using clipping and filtering:

1- Applying clipping , Selective Mapping (SLM) , partial transmit sequence(PTS) method.

2-Evaluate PAPR before and after applying the three methods.

3-Compare PAPR results for the three methods .

1.5 Methodology

The proposal is based on Matrix Laboratory (MATLAB) simulation different types of input data must be apply . The signal then enters the OFDM transmitter where an Inverse Fast Fourier Transform (IFFT) is performed before transmission. A channel model is then applied to the transmitted signal. The model allows for the signal to noise ratio, multipath, and peak power clipping , selective mapping and partial transmit sequance to be controlled. At the Orthogonal Frequency Division Multiplexing (OFDM) receiver the data is received a Fast Fourier Transform (FFT) is applied to convert the signal back to the frequency domain and demodulation , decoding procedures is performed. Depending on the channel factors , code rate and modulation scheme are observed when channel factors changed. Based on the state of the received signal . finally compare PAPR before and after clipping , selective mapping and partial transmit sequence .

CHAPTER TWO

LTE PHYSICAL LAYER DOWNLINK

Chapter Two

LTE physical layer downlink

2.1 Literature Review

Wireless communication networks were significantly advanced by the introduction of the cell concept by Bell Lab which provided a practical enhancement of mobile telecommunications system capacity. This can be achieved by dividing the coverage area into a given number of cells and assigning a specific frequency to each cell

The first generations of mobile communication networks were analog cellular systems that used Frequency Modulation (FM) for radio transmission. *Advanced Mobile Phone System* (AMPS) and Extended Total Access Communications System (ETACS) were the most popular first generation mobile communication systems employed around 1983.The 2nd generations of mobile communication standards were developed around 1995; these standards used digital modulation and provided three times more spectrum efficiency compared to the first generation. The Global system mobile (GSM) and The Code Division Multiple Access 2000 (CDMA 2000) are two well known 2nd generation standards that were introduced by 3GPP and The *3rd Generation Partnership Project 2 (*3GPP2) standard development groups. GSM is based on Time Division Multiple Access (TDMA) while CDMA 2000 uses Code Division Multiple Access (CDMA). The 2nd generation was the beginning of the evolution toward 3G and 4G standards. 3GPP, Institute Of Electrical and Electronic Engineering (IEEE) and 3GPP2 are three major standard development groups that are in tight competition to satisfy 4th generation requirements.

LTE, also called Evolved Universal Terrestrial Radio Access

(EUTRA), introduced by 3GPP is a 3rd generation of mobile communication standard that uses (OFDM) in downlink and Single Carrier-Frequency Division Multiple Access (SC-FDMA) in uplink, whereas previous 3rd generation standards using CDMA. Another adaptation of LTE is in packet-switched networks, which do not follow the circuit switching of preceding standards. The most frequent rival of LTE is the 802.16e standard, also called Worldwide Interoperability for Microwave Access (WiMAX) that was developed by IEEE.

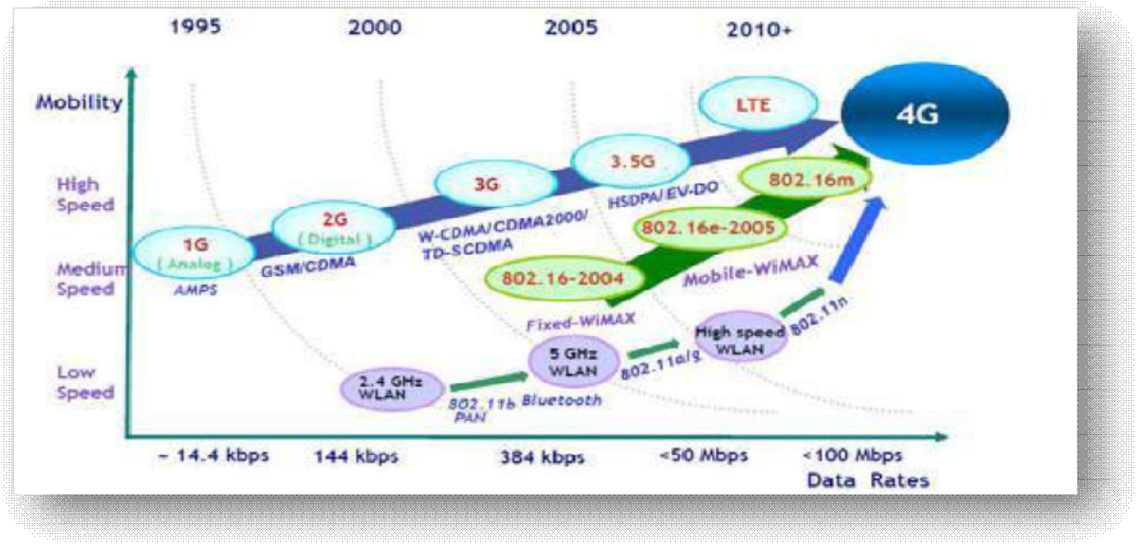

Figure 2.1: Evolution Track of 3G toward 4G [1].

The main objectives of this evolution track are improvements in data rate, spectral efficiency, power consumption of the terminal, cell edge bit rate; and reductions in transmission latency, connection establishment latency and cost. The first release of 3G provided by 3GPP in 2000 was called Release 99 for defining Wideband Code Division Multiple Access (W-CDMA) and The *Universal Mobile Telecommunications System* (UMTS) standards. This evolution was followed by Release 4 in 2001,which added a given feature to Release 99 called all-IP core network‘. Release 522 introduced High Speed Downlink Packet Access (HSDPA) in 2002 followed by Release 6 that introduces High Speed Uplink Packet Access (HSUPA) and adds more features to the preceding release such as *Multimedia Broadcast Multicast Services* (MBMS) and integrated operation with Wireless LAN in 2005 . Release 7 (from 2005 to 2007) introduced HDPA+, which focuses on developing specifications like latency and Quality Of Service(QOS) improvement, and real time applications.

Release 8 is the first LTE release and was published in 2008. Release9 includes enhancement, WiMAX and LTE interoperability. Release 10 is under development to satisfy International Mobile Telecommunications (IMT)-advanced requirements for 4th generation broadband mobile communications. IMT-Advanced, previously known as system beyond IMT-2000 is a concept Introduced by the International Telecommunications Union (ITU).

The main objective of IMT-Advanced is to develop a wireless communication technology that supports high data rates with high mobility and can be deployed in some areas by 2015. The requirements of IMT-Advanced are a peak data rate of 100 Mbps in high mobility (300 km/h) and 1 Gbps in low mobility (3 km/h).

Literature Review

M. JunaidArshad, Amjad Farooq and Abad Shah provided a detailed comparison of the different generations of the mobile communication technologies in a tabular form to have a better knowledge and understanding in the advancement of mobile communication systems [1].

There is significant interest worldwide in the development for broadband cellular wireless (BCW) system. SRikanth S.Kumaran V.Manikandan C.Murugesapandian discussed the reasons for the popularity of OFDMA and outlines some of important concepts which are used in OFDMA as applied to BCW system [2].

Jim Zyren provided An overview of the LTE physical layer (PHY), including technologies that are new to cellular such as OFDM and Multiple Input Multiple Output (MIMO) data transmission [3].

Qi Wang, Christian Mehlf¨uhrer, and Markus Ruppinvestigated carrier frequency synchronization in the downlink of 3GPP Long Term Evolution (LTE). A complete carrier frequency offset estimation and compensation scheme based on standardized synchronization signals and reference symbols is presented [4].

The dense deployment of femtocells however, makes interference and hence resource management both critical and extremely challenging. R. Van Nee and R. Prasad designed and implemented one of the first resource management systems, FERMI, for OFDMA-based femtocell networks [5].

With the consumer drive for more and more data, worldwide operators are experiencing an ultimate need for wireless bandwidth growth.Zhihong Lin and Greg wood introduced the development cycle for manufacturers, and demonstrates the potential for eNodeB solutions with competitive differentiation, lower capital expenditure, and operating expenses to high-performance LTE [7].

The time variations of the channel during one OFDM frame destroy the orthogonality of different subcarriers and results in power leakage among the subcarriers, known as Inter-carrier Interference (ICI), which results in a degradation of system performance. Tiejun (Ronald) Wang, John G. Proakis, and James R. Zeidlerchannel used state information to minimize the performance degradation caused by ICI. A simple and efficient polynomial surface channel estimation technique is proposed to obtain the necessary channel state information [8].

Table 2.1: Data Rates and Latency for 3GPP Standards.

3GPP standards	DOWNLINK peak data rate	UPLINK peak data rate	Latency round trip time
WCDMA (UMTS)	384 Kbps	128 Kbps	150 ms
HSDPA/ HSUPA	14Mbps	5.7 Mbps	100 ms
HSPA +	28 Mbps	11 Mbps	50 ms
LTE	300 Mbps	75 Mbps	10 ms
LTE advanced	1 Gbps	500 Mbps	Less than 5 ms

2.2 LTE Physical Layer

2.2.1 Design Goals

The LTE PHY is designed to meet the following goals [1]:

1. Support scalable bandwidths of 1.25, 2.5, 5.0, 10.0 and 20.0 MHz
2. Peak data rate that scales with system bandwidth
   a. Downlink peak rate of 100 Mbps in 20 MHz channel.
   b. Uplink peak rate of 50 Mbps in 20 MHz channel.
3. Supported antenna configurations .
4. Spectrum efficiency.
5. Mobility A. Optimized for low speeds (<15 km/hr) B. High performance at speeds up to 120 km/hr C. Maintain link at speeds up to 350 km/hr.
6. Coverage a. Full performance up to 5 km b. Slight degradation 5 km – 30 km c. Operation up to 100 km should not be precluded by standard

2.2.2 Uplink

The LTE PHY uses Single Carrier - Frequency Division Multiple Access (SC-FDMA) as the basic transmission scheme for the uplink. The principle advantage of SC-FDMA over conventional OFDM is a lower Peak to Average Power Ratio (PAPR) (by approximately 2 dB) than would otherwise be possible using OFDM.

2.2.3 Downlink

The LTE physical layer downlink consists of several stages [11] as follows:

2.2.4 OFDM

- **OFDM VS. FDM**

OFDM is a digital modulation scheme that is used in both wire line and wireless systems to transmit numerous modulated carriers that are mathematically orthogonal to each other. In other words, the subcarriers ideally exhibit zero mutual inference.

OFDM is similar to frequency division multiplexing (FDM) in that it multiplexes carriers across frequency, but with two important differences. First, FDM is the traditional method to separate signals intended for different radios. When it is used to allow multiple users to share the same channel it is called frequency-division multiple access (FDMA). OFDM is often used for multiple accesses as well, but the primary motivation for using OFDM is to increase performance over using a single carrier modulation. Secondly, OFDM differs from traditional FDM in its subcarrier spacing.

In OFDM, the carriers overlap to a great degree, as shown in Figure 2.3 each carrier is ideally represented mathematically by a sin(x)/x pulse, which have nulls at a spacing of 1/Ts where Ts is the symbol time of each subcarrier. In OFDM, the carrier spacing is 1/Ts, which is precisely the location of nulls in a sin(x)/x pulse and thus, ideally, there is zero inter-carrier interference (ICI). This is a secondary advantage of OFDM, in that it is more spectrally efficient than standard FDM. The spectrum and power spectral density of OFDM and FDM are contrasted in Figure2.3 and Figure 2.4.

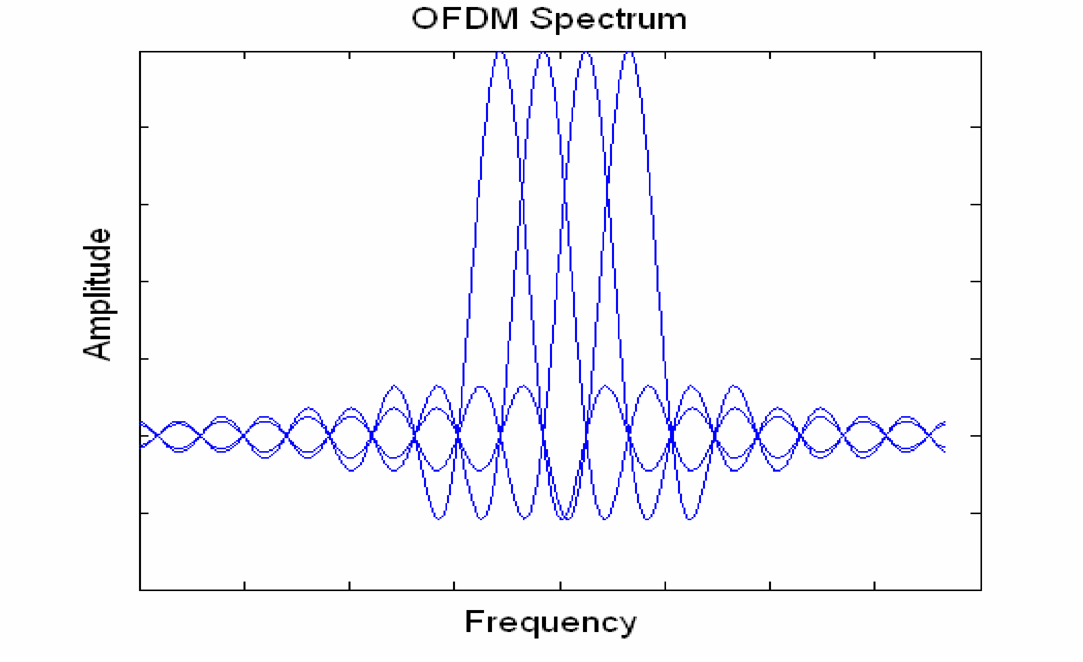

Figure 2.2: OFDM Spectrum.

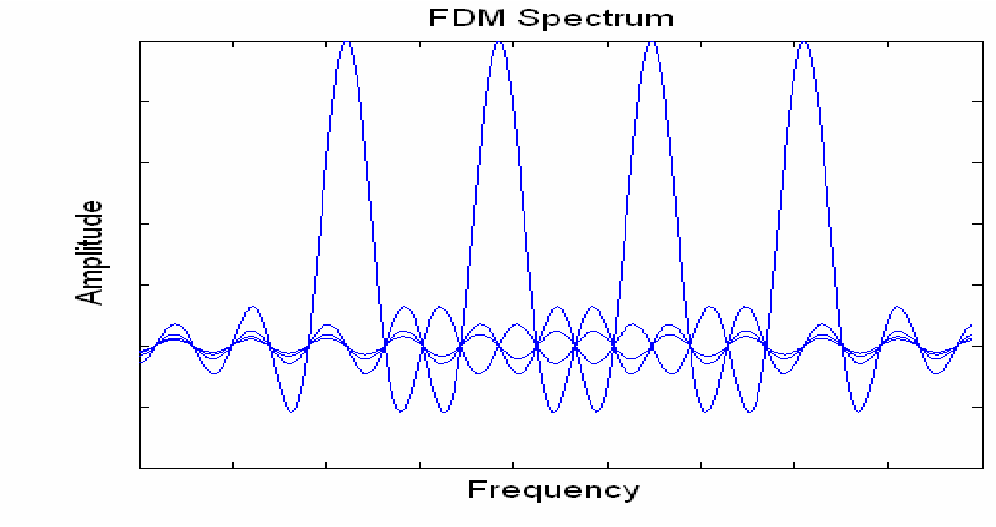

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Figure 2.3: FDM Spectrum.

2.3 Advantages and Drawbacks of OFDM

2.3.1 Advantages

- By using the parallel multicarrier transmission, OFDM converts frequency selective fading channels to non-selective fading sub-channels (flat fading).
- OFDM is good for broadcasting applications because it allows single frequency networks to be used.
- OFDM flexible to the channel conditions without the need of channel equalization algorithms and it is also easy in meeting various design requirements, such as complexity.
- OFDM is robust to *i*nter symbol interference (ISI) and inters carrier interference (ICI) by using Cyclic prefix technique

2.3.2 Drawbacks

- The OFDM system is sensitive to the carrier frequency offset and Doppler shift.
- High peak to average power ratio reduces the power efficiency of the RF power amplifier and because of that makes the design of RF amplifier becomes more difficult.

The next chapter will discuss some popular techniques that use to reduce the effect of high peak to average power ratio.

2.4 Multipath Interference

Multipath interference is a phenomenon in the physics of wave where by a wave from a source travels to a detector via two or more paths and, under the right condition; the two (or more) components of the wave interfere. Multipath interference is a common cause of "ghosting" in analog television broadcasts. The condition necessary is that the components of the wave remain coherent throughout the whole extent of their travel.

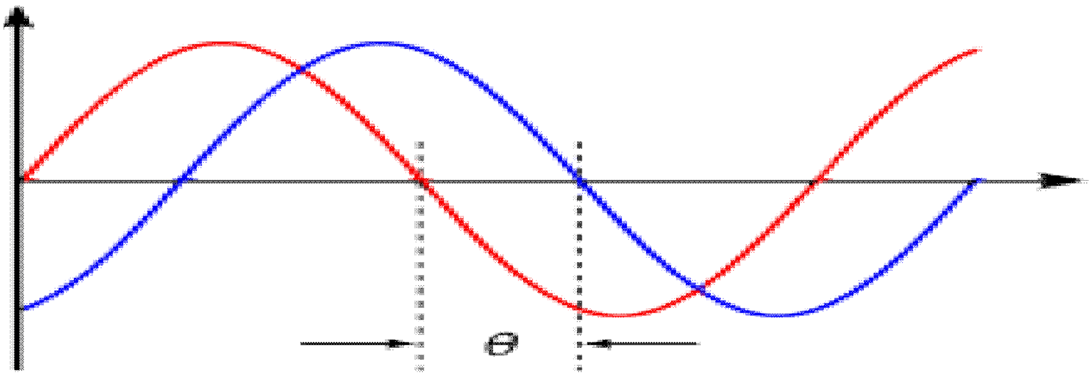


Figure 2.4: Coherent Waves along Two Different Paths.

The interference will arise owing to the two (or more) components of the wave having, in general, travelled a different length (as measured by optical path length geometric length and diffraction (differing optical speed), and thus arriving at the detector out of phase with each other.

The signal due to indirect paths interferes with the required signal in amplitude as well as phase which is called multipath fading.

2.5 Related Work

Juan J. Sánchez, D. Morales-Jiménez and G. Gómez,provided performance evaluation of LTE downlink physical layer according to the latest 3GPP specifications. Particularly, the main features at the LTE physical layer (like spatial multiplexing or adaptive modulation and coding) are described and analyzed [9].

Christian Mehlf uhrer, Martin Wrulich and Josep Colom Ikunopresented a MATLAB-based down- link physical-layer simulator for LTE. Different research applications are covered by simulator. Depending on the research focus, the simulator offers to carry out single-downlink, single-cell multi-user , and multi-cell multi-user simulations[10]. Pelcat, M., Aridhi, S., Piat, J., Nezan, J.-F.providedA Dataflow-Based as an Approachfor LTE eNodeB based on PHY layer and provides a clear introduction to the 3GPP LTE physical layer and to dataflow-based prototyping and programming. The difficulties in the process of 3GPP LTE physical layer porting are outlined, with particular focus on automatic partitioning and scheduling, load balancing and computation latency reduction, specifically in systems based on heterogeneous multi-core Digital Signal Processors [11].

Jordan Douglas Guffey introduced in details the development of an Orthogonal Frequency Division Multiplexing (OFDM) reference design system based off of the IEEE 802.16-2004 OFDM PHY standard. His system consisted of a separate transmitter and receiver and which have been implemented in VHDL for use on the Kansas University Agile Radio (KUAR).

The KUAR is an experimental software-defined radio platform that was intended for research in frequency-agile and cognitive radios [12]. Shahram Zareiconsidered channel coding and link adaptation in addition to discussion of circular buffer, which is used in the rate matching module and Hybrid Automatic Repeat Request (HARQ) based on LTE PHY layer study [13].

MaximePelcat Introduced LTE PHY layer as base to start a good study of data flows computation algorithms and Rapid Prototyping and Programming Multi-core Architectures and Digital Signal Processing (DSP) [14].

CHAPTER THREE

SIMULATION USING MATLAB

Chapter Three

Simulation Using MATLAB

3.1 Simulation Background

Mobile network technologies have been experiencing great progress. Simulations and analysis of these systems are challenging tasks. Different network simulation and modeling tools have already been developed. However, these simulation and modeling tools are commercial, they are focused on the physical layer simulations or they are simply unavailable. Hence, the own simulation program was created in Mat lab. MATLAB (matrix laboratory) is a numerical computing environment and fourth-generation programming language. Developed by Math Works, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and FORTRAN. MATLAB had around one million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics. MATLAB is widely used in academic and research institutions as well as industrial enterprise. The simulation includes a code written in MATLAB to study the performance of the LTE physical layer under various variations of operating parameters including clipping, noise, multipath, FFT size and different coding and modulation schemes.

3.2 LTE Simulator

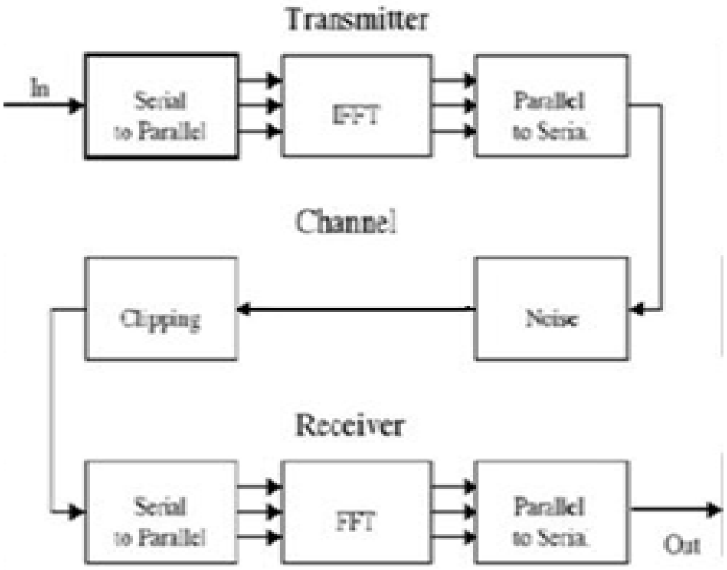


Figure 3.1: LTE physical Layer Simulation.

3.2.1 Transmitter

- **FFT Size**

In choosing the FFT size different FFT sizes are demonstrated and the BER is observed to choose a suitable FFT size for transmission according to the channel conditions. The FFT size varies from (128-2048) based on the IEEE 802.16e-20055 standard.

3.2.2 Channel Model

The channel simulation allows examination of common wireless channel characteristics such as noise, multipath, and clipping [5]. By adding random data to the transmitted signal, simple noise is simulated. Multipath simulation involves adding attenuated and delayed copies of the transmitted signal to the original. This simulates the problem in wireless communication when the signal propagates on many paths. For example, a receiver may see a signal via a direct path as well as a path that bounces off a building. Finally, clipping simulates the problem of amplifier saturation. This addresses a practical implementation problem in OFDM where the peak to average power ratio is high.

3.2.3 Receiver

- **OFDM Receiver**

The receiver performs the inverse of the transmitter. First, the OFDM data are split from a serial stream into parallel sets. The Fast Fourier Transform (FFT) converts the time domain samples back into a frequency domain representation. The magnitudes of the frequency components correspond to the original data. Finally, the parallel to serial block converts this parallel data into a serial stream to recover the original input data.

3.3 Mathematical Representation of OFDM

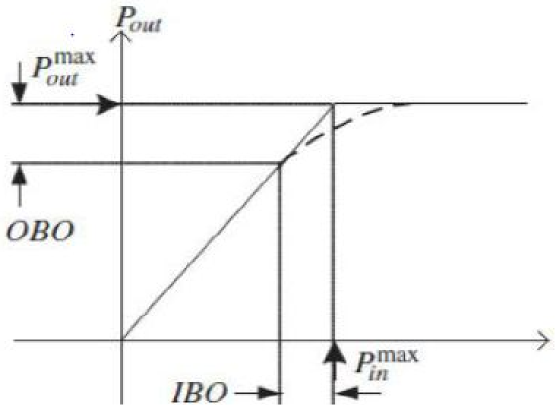
3.3.1 PAPR

Various works has been done on OFDM. In OFDM, as all the carriers are added using an IFFT operation, this may lead to a signal with large peaks and dynamic range in time domain [1]. For an OFDM signal x(t), the PAPR is given as:

$$PAPR\ \{x(t)\} = \frac{\max\limits_{0 \le t \le T}\ \{|x(t)|^2\}}{E\{|x(t)|^2\}} \qquad (3.1)$$

x(t) : ratio between the maximum instantaneous power and average power
$E[\cdot]$: denotes the statistical expectation function
$\max[\cdot]$: highest value among the samples

.High value of PAPR is serious concern when OFDM signal pass through nonlinear devices such as in 4G systems where OFDM is a downlink method and on-board high power amplifier have non-linear input output characteristics at high power values as shown in Figure



Reduction of peak- to- average power ratio is always a concern for researchers. Various methods has been implemented to reduce PAPR like clipping , companding , SLM , PTS , tone injection , tone reservation , active constellation extension and coding

3.3.2 OFDM Transmission

At baseband, an OFDM signal can be represented by a sum of modulated complex exponential

$$S(t) = \sum_{k=0}^{N-1} X_k \, e^{(\mathrm{j2\pi k\Delta ft})} \qquad (3.2)$$

N : number of subcarriers

X_k : complex number representing a BPSK, QPSK, or QAM symbol

e : exponential

J : imaginary number j= -1

kth : subcarrier

Δf : subcarrier spacing

T : time

If this signal is sampled as in Equation 3.2

$$S(nt) = \sum_{k=0}^{N-1} X_k \, e^{(\mathrm{j2\pi k\Delta fnT_s})} \qquad (3.3)$$

Then the sampled signal is exactly equivalent to an inverse N-point discrete Fourier transform (DFT)

X_k: as the frequency bin arguments

The DFT and the inverse DFT are given in Equation 3.3

$$X_l = \sum_{l=0}^{N-1} X_n \, e^{(\frac{-\mathrm{j}2\pi \mathrm{nl}}{\mathrm{N}})} \qquad \mathrm{l} = 0, \dots., \mathrm{N}-1 \tag{3.4}$$

$$x_n = \frac{1}{N} \sum_{n=0}^{N-1} X_l \, e^{(\frac{\mathrm{j}2\pi \mathrm{nl}}{\mathrm{N}})} \qquad \mathrm{n} = 0, \dots., \mathrm{N}-1 \tag{3.5}$$

The Fast Fourier Transform (FFT) is simply a computationally efficient implementation of the DFT. The IFFT and FFT are the core modulation and demodulation operations used in OFDM.

3.3.3 Clipping

Clipping is a technique in which the signal is clipped by a certain ratio to reduce the power. However, an over clipping to the signal may degrade the performance due to the distortion of the original signal.

$$Z(t) = x(t) + n(t) \tag{3.6}$$

Where n noise level and Z (t) received signal, $r_x(t) = |x(t)|$ the magnitude $r_z(t) = |z(t)|$

$$r_z(r_x) = \begin{cases} r_x & r_x \leq A \\ A & r_x > A \end{cases} \tag{3.7}$$

A : is the clip level

$r_x(t) = |x(t)|$: the magnitude

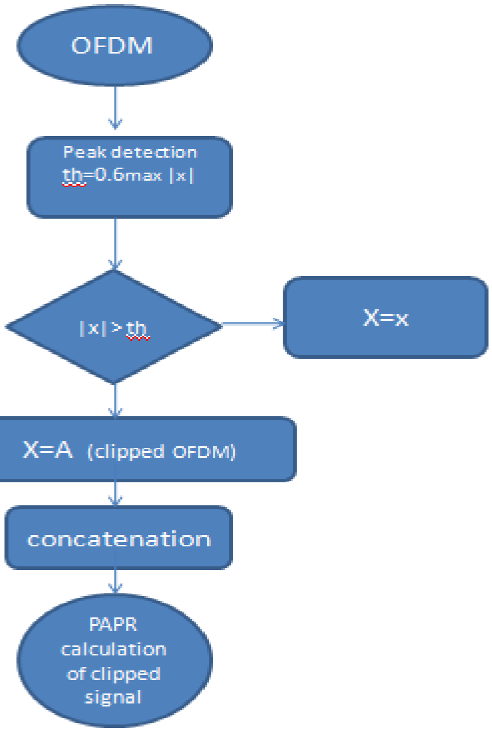


figure 3.2 flow chart of clipping technique

3.3.4 Selective Mapping

In selective mapping (SLM) technique [8-10] the actual transmit signal lowest PAPR is selected from a set of sufficiently different signals which all represents the same information. SLM Technique are very flexible as they do not impose any restriction on modulation applied in the subcarriers or on their number.

Block diagram of SLM Technique is shown below

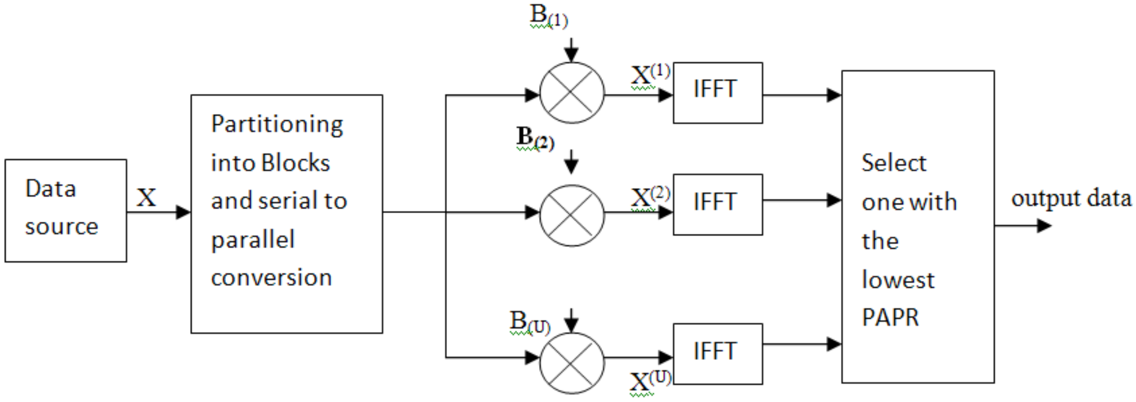


figure3.3 : Block Diagram of OFDM transmitter with the SLM Technique

All U phase rotated OFDM data blocks represented the same information as the unmodified OFDM data block provided that the phase sequence is $(x+a)^n = \sum_{k=0}^{n} \binom{n}{k} x^k a^{n-k}$known. After applying the SLM technique, the complex envelope of the transmitted OFDM signal becomes here , NT is the duration of an OFDM data block.

Output data of the lowest PAPR is selected to transmit. PAPR reduction effect will be better as the copy block number U is increased. SLM method effectively reduce PAPR without any signal distortion. But it has higher

system complexity and computational burden. This complexity can less by reducing the number of IFFT block

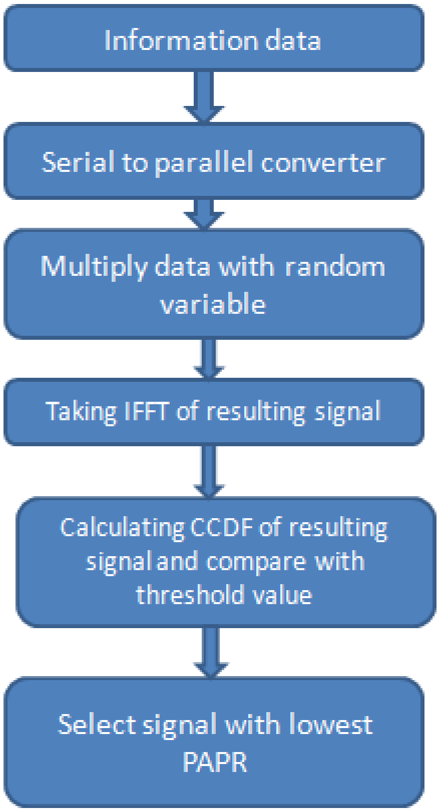


figure3.4 Flow Chart Of Selective Mapping Technique

3.3.5 Partial Transmit Sequence (PTS)

In PTS, an input data block of length N is partitioned into a number of disjoint sub-blocks. Then each of these sub-blocks are padded with zeros and weighted by a phase factor. The schematic is shown in Figure

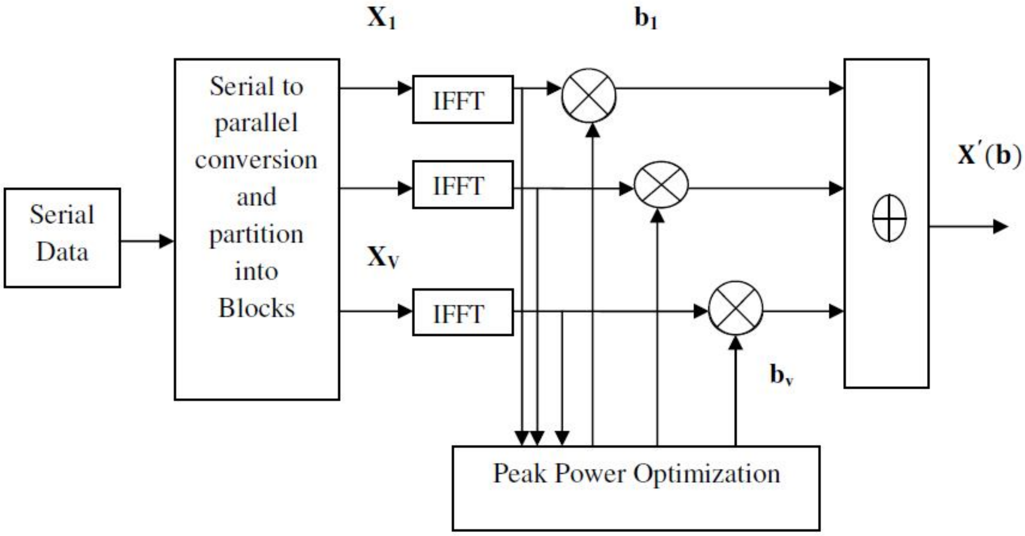
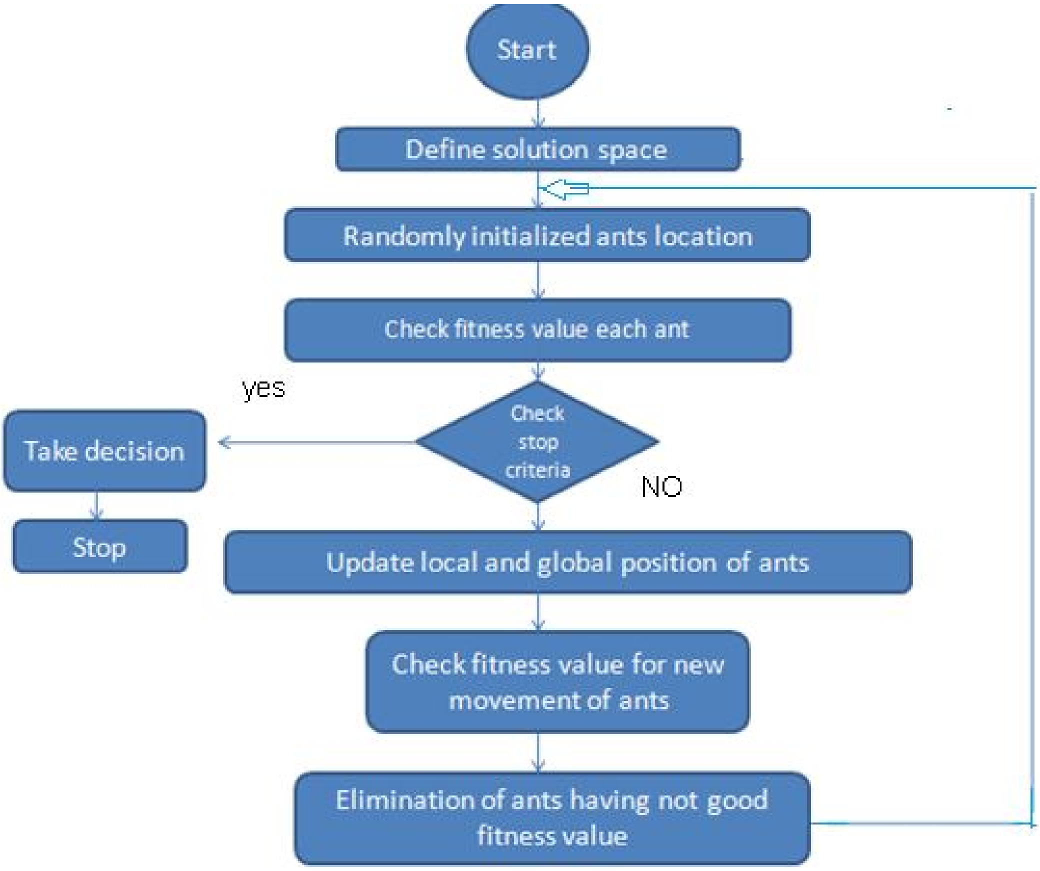


figure 3.5 block diagram or (PTS)

The phase factor is chosen such that PAPR of candidate signal is minimum. For V sub-blocks and W phase weights, we have to search WV-1 possible candidates, as for the first block phase factor is always chosen as 1. In calculation of each candidate V-1 additions and multiplication takes place.

To reduce the complexity of the PTS method by converging to a sub-optimal choice of the phase factors. Algorithms are described in for combining partial transmit sequences with reduced complexity and very little performance degradation. A gradient descent search for phase factors is proposed in which reduce search complexity at the expense of some performance degradation too. proposed a PTS scheme based on listing the phase factors into multiple subsets table and to reduce computational complexity, utilize the correlation among phase factors in each subset.



3figure3.6 Flow Chart of PTS technique

CHAPTER FOUR

Chapter Four

4.1 Simulation Result

This chapter represents and illustrate the output of this research and divided to two part first part represent the description of signal that generated by simulation and the second is result off applied various algorithm in the simulation.

Table 4.1 Simulation Parameters

IFFT bin length	1024
carrier count	128
bits per symbol	3,4,6
symbols per carrier	100
SNR	20

In this simulation PSK modulator is applied for various type of PAPR reduction technique and the figure below show the constellation for BPSK, QPSK and 8PSK.

4.2.2 FFT Subcarrier Representation

The figure 4.1 show the signal power in frequency domain the horizontal and vertical axis represent the IFFT Bin and the magnitude ,in the 450 and 600 presented the max magnitude.

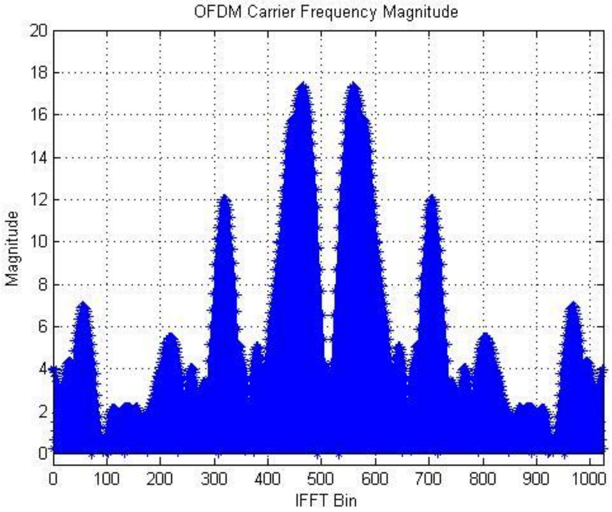
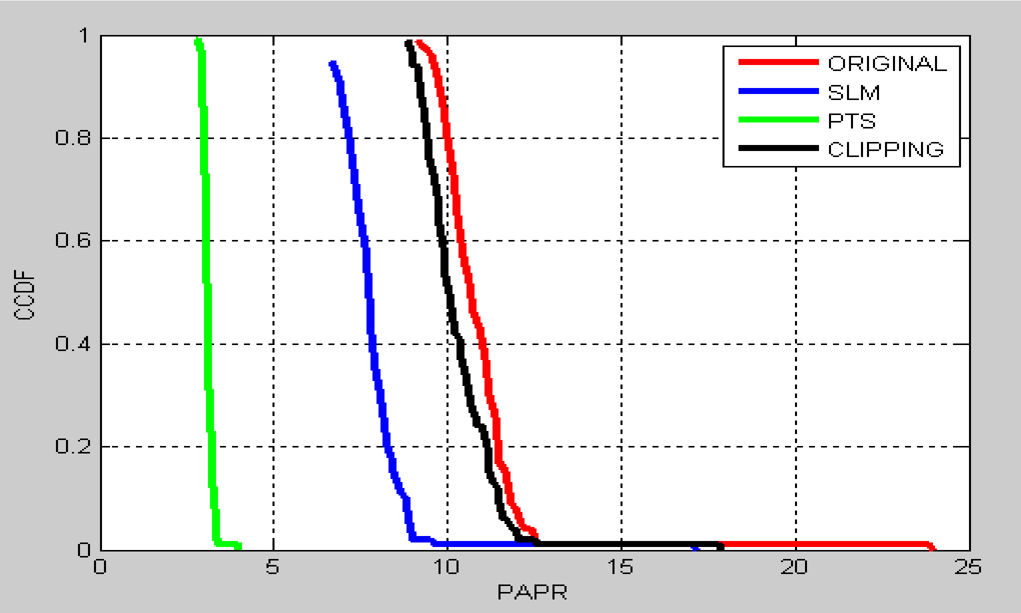


Figure 4.1 bandwidth representation in frequency domain versus power

Three scheme are applied in this research first one is clipping, SLM, PTS. Simulation are presented OFDM samples with phase shift keying (PSK) modulation the performance of the several PAPR schemes is presented in term of CCDF.

After simulation and comparison we found that PTS is the best technique over clipping and SLM



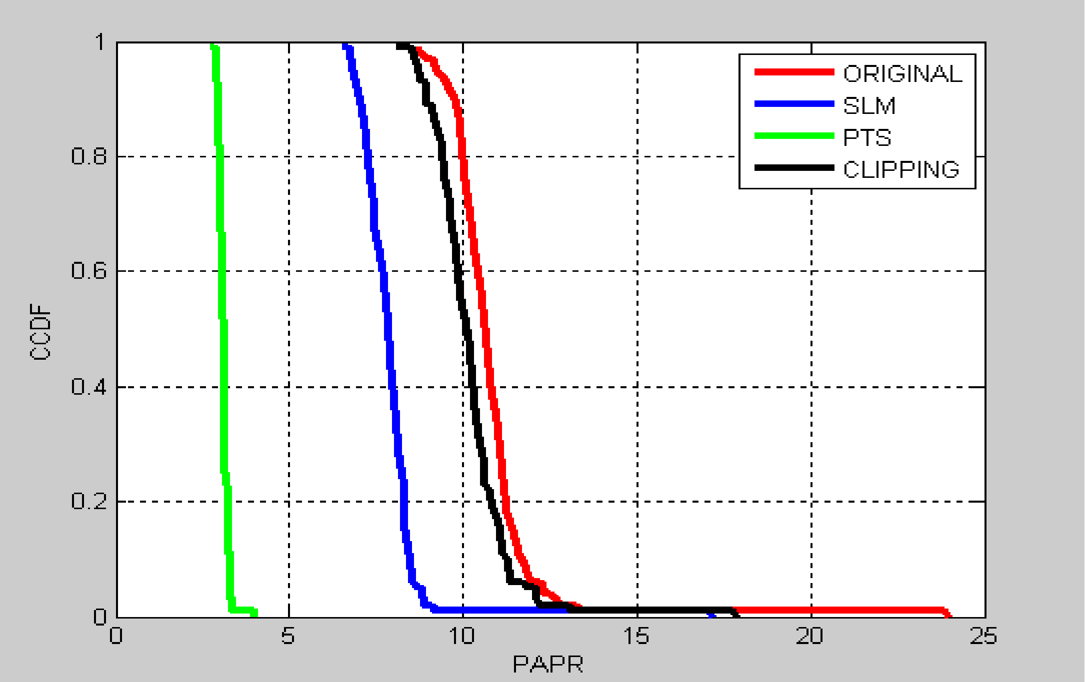
This figure 4.2 present and compare between reduction technique versus original signal before and after applied these scheme for bits per symbol = 3

The table 4.2 show the percentage of the reduction for these three techniques and it is clear that PTS given the highest reduction percentage

Table 4.2 PAPR result 8PSK

NO.	Reduction Technique	PAPR Reduction (%)
1	Original (without reduction technique)	0
2	Clipping	19.2
3	SLM	27.96
4	PTS	79.4

For the figure below 4.3 applying 4 bit per symbol the reduction of PAPR for the clipping and SLM is increase but PTS still have the best reduction



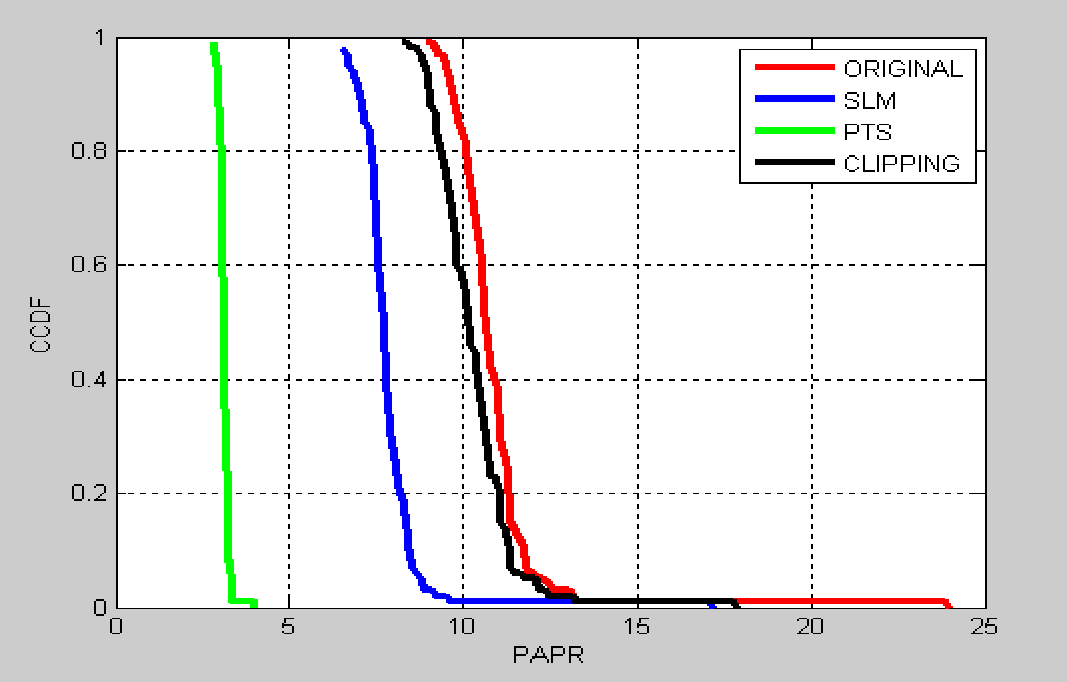
This figure 4.3 present and compare between reduction technique versus original signal before and after applied these scheme for bits per symbol = 4

This table 4.3 seen that percentage of SLM higher than clipping but the PTS is the highest.

Table 4.3 PAPR result for 16PSK

NO.	**Reduction Technique**	**PAPR Reduction (%)**
1	Original (without reduction technique)	0
2	Clipping	20.48
3	SLM	27.39
4	PTS	79.36

For the figure below 4.4 applying 4 bit per symbol the reduction of PAPR for the clipping and SLM is increase but PTS still have the best reduction



This figure 4.4 present and compare between reduction technique versus original signal before and after applied these scheme for bits per symbol = 6

The percentage of PTS is highest than clipping and SLM

Table 4.4 PAPR result for 64PSK

NO.	**Reduction Technique**	**PAPR Reduction (%)**
1	Original (without reduction technique)	0
2	Clipping	20.61
3	SLM	28.08
4	PTS	79.25

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

Chapter five

Conclusion

OFDM system has been discussed in this project. It indicated that OFDM is a popular communication system due to the advantages this system

. Peak to average power ratio issue was also discussed, showing how it affected the transmitted signal. There were many reduction techniques presented to solve high peak to average power ratio such as, clipping , partial transmit sequence(PTS) , Selective mapping (SLM) technique .

the main focus of the project is to compare the PAPR before and after applying this techniques the result showed that PTS is the most promising reduction technique. It was also mentioned that power saving could be achieved through partial transmit sequence(PTS) .

This project also shown the simulation results of OFDM symbol with and without SLM , PTS, CLIPPING. The simulation results indicated that large PAPR reduction is possible. also the result shown compare between the techniques and its cleared that PTS is the best for reducing PAPR .

Future Work & Recommendation

It is recommended for a complete analysis of the Quality of Services (QOS) in LTE Advanced to study the effect of other Key Performance Indicator (KPI) like throughput ,Bit error rate , signal to noise ratio, Delay , Jitter...........etc,

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Appendix :

```
%  MTECH DIGITAL AND INSTRUMENTATION 1ST SEM
PROJECT
% BY SHIRSHENDU ROY AND RAHUL DAS
% OFDM SIMULALTION BY MATLAB CODE AND PAPR
REDUCTION TECHNIQUE
%
clear all;
close all;
fprintf ('OFDM Analysis Program\n\n');
defaults = input('press any key for entering the
parameter value for IFFT_bin_length=1024:\n ');
    IFFT_bin_length =1024
    carrier_count = input('carrier count = ');
    bits_per_symbol = input('bits per symbol = ');
    symbols_per_carrier = input('symbols per
carrier =');
    SNR = input('SNR = ');
% Derived parameters
baseband_out_length =  carrier_count *
symbols_per_carrier * bits_per_symbol;
carriers = (1:carrier_count) +
(floor(IFFT_bin_length/4) -
floor(carrier_count/2));
conjugate_carriers = IFFT_bin_length - carriers +
2;
display(carriers);
display(conjugate_carriers);
% TRANSMIT
baseband_out = round(rand(1,baseband_out_length));
convert_matrix = reshape(baseband_out,
bits_per_symbol,
length(baseband_out)/bits_per_symbol);
for k = 1:(length(baseband_out)/bits_per_symbol)
    modulo_baseband(k) = 0;
    for i = 1:bits_per_symbol
        modulo_baseband(k) = modulo_baseband(k) +
convert_matrix(i,k)*2^(bits_per_symbol-i);
```

```
    end
end

% Serial to Parallel Conversion
carrier_matrix = reshape(modulo_baseband,
carrier_count, symbols_per_carrier)';
carrier_matrix =
[zeros(1,carrier_count);carrier_matrix];
for i = 2:(symbols_per_carrier + 1)
    carrier_matrix(i,:) =
rem(carrier_matrix(i,:)+carrier_matrix(i-
1,:),2^bits_per_symbol);
end
% Convert the differential coding into a phase
carrier_matrix = carrier_matrix *
((2*pi)/(2^bits_per_symbol));
% Convert the phase to a complex number
[X,Y] = pol2cart(carrier_matrix,
ones(size(carrier_matrix,1),size(carrier_matrix,2))
);
complex_carrier_matrix = complex(X,Y);
% Assign each carrier to its IFFT bin
IFFT_modulation = zeros(symbols_per_carrier + 1,
IFFT_bin_length);
IFFT_modulation(:,carriers) =
complex_carrier_matrix;
IFFT_modulation(:,conjugate_carriers) =
conj(complex_carrier_matrix);
ofdm_symbol=IFFT_modulation;
%display(IFFT_modulation)
%z=IFFT_modulation';
%frame_guard1 = [z;zeros(1,carrier_count-1)];
%frame_guard=frame_guard1';
%display(frame_guard);
%
% PLOT BASIC FREQUENCY DOMAIN REPRESENTATION
% figure (1)
% stem(0:IFFT_bin_length-1,
abs(IFFT_modulation(2,1:IFFT_bin_length)),'b*-')
% grid on
% axis ([0 IFFT_bin_length -0.5 1.5])
```

```
% ylabel('Magnitude')
% xlabel('IFFT Bin')
% title('OFDM Carrier Frequency Magnitude')
% figure (2)
% plot(0:IFFT_bin_length-1,
(180/pi)*angle(IFFT_modulation(2,1:IFFT_bin_length)
), 'go')
% hold on
% stem(carriers-1,
(180/pi)*angle(IFFT_modulation(2,carriers)),'b*-')
% stem(conjugate_carriers-1,
(180/pi)*angle(IFFT_modulation(2,conjugate_carriers
)),'b*-')
% axis ([0 IFFT_bin_length -200 +200])
% grid on
% ylabel('Phase (degrees)')
% xlabel('IFFT Bin')
% title('OFDM Carrier Phase')
% Transform each period's spectrum (represented by
a row of carriers) to the
% time domain via IFFT
time_wave_matrix = ifft(IFFT_modulation');
time_wave_matrix = time_wave_matrix';
%ofdm_symbol=time_wave_matrix;
display(time_wave_matrix);
%
% PLOT OFDM SIGNAL FOR ONE SYMBOL PERIOD
% figure (3)
% plot(0:IFFT_bin_length-1,time_wave_matrix(2,:))
% grid on
% ylabel('Amplitude')
% xlabel('Time')
% title('OFDM Time Signal, One Symbol Period')
% Apply a Window Function to each time waveform
for i = 1:symbols_per_carrier + 1

    windowed_time_wave_matrix(i,:) =
real(time_wave_matrix(i,:));
end
% Serialize the modulating waveform
```

```
ofdm_modulation =
reshape(windowed_time_wave_matrix', 1,
IFFT_bin_length*(symbols_per_carrier+1));
 %PLOT OFDM SIGNAL (time)
temp_time =
IFFT_bin_length*(symbols_per_carrier+1);
% figure (4)
% plot(0:temp_time-1,ofdm_modulation)
% grid on
% ylabel('Amplitude (volts)')
% xlabel('Time (samples)')
% title('OFDM Time Signal')
 %PLOT OFDM SIGNAL (spectrum)
symbols_per_average = ceil(symbols_per_carrier/5);
avg_temp_time =
IFFT_bin_length*symbols_per_average;
averages = floor(temp_time/avg_temp_time);
average_fft(1:avg_temp_time) = 0;
for a = 0:(averages-1)
    subset_ofdm =
ofdm_modulation(((a*avg_temp_time)+1):((a+1)*avg_te
mp_time));
    subset_ofdm_f = abs(fft(subset_ofdm));
    average_fft = average_fft +
(subset_ofdm_f/averages);
end
display(average_fft)
average_fft_log = 20*log10(average_fft);
% figure (5)
% plot((0:(avg_temp_time-1))/avg_temp_time,
average_fft_log)
% hold on
% plot(0:1/IFFT_bin_length:1, -35, 'rd')
% grid on
% axis([0 0.5 -40 max(average_fft_log)])
% ylabel('Magnitude (dB)')
% xlabel('Normalized Frequency (0.5 = fs/2)')
% title('OFDM Signal Spectrum')
% Upconversion to RF
Tx_data = ofdm_modulation;
```

```
% CHANNEL

% The channel model is Gaussian (AWGN) only
Tx_signal_power = var(Tx_data);
linear_SNR = 10^(SNR/10);
noise_sigma = Tx_signal_power/linear_SNR;
noise_scale_factor = sqrt(noise_sigma);
noise = randn(1,
length(Tx_data))*noise_scale_factor;
Rx_Data = Tx_data + noise;
% RECEIVE
% Convert the serial input data stream to parallel
(according to symbol length
Rx_Data_matrix = reshape(Rx_Data, IFFT_bin_length,
symbols_per_carrier + 1);
Rx_spectrum = fft(Rx_Data_matrix);%
% PLOT BASIC FREQUENCY DOMAIN REPRESENTATION
% figure (6)
% stem(0:IFFT_bin_length-1,
abs(Rx_spectrum(1:IFFT_bin_length,2)),'b*-')
% grid on
% axis ([0 IFFT_bin_length -0.5 1.5])
% ylabel('Magnitude')
% xlabel('FFT Bin')
% title('OFDM Receive Spectrum, Magnitude')
% figure (7)
% plot(0:IFFT_bin_length-1,
(180/pi)*angle(Rx_spectrum(1:IFFT_bin_length,2)),
'go')
% hold on
% stem(carriers-1,
(180/pi)*angle(Rx_spectrum(carriers,2)),'b*-')
% stem(conjugate_carriers-1,
(180/pi)*angle(Rx_spectrum(conjugate_carriers,2)),'
b*-')
% axis ([0 IFFT_bin_length -200 +200])
% grid on
% ylabel('Phase (degrees)')
% xlabel('FFT Bin')
% title('OFDM Receive Spectrum,  Phase')
Rx_carriers = Rx_spectrum(carriers,:)';
```

```
% PLOT EACH RECEIVED SYMBOL
figure (8)
Rx_phase_P = angle(Rx_carriers);
Rx_mag_P = abs(Rx_carriers);
polar(Rx_phase_P, Rx_mag_P,'bd');
Rx_phase = angle(Rx_carriers)*(180/pi);
phase_negative = find(Rx_phase < 0);
Rx_phase(phase_negative) =
rem(Rx_phase(phase_negative)+360,360);
Rx_decoded_phase = diff(Rx_phase);
phase_negative = find(Rx_decoded_phase < 0);
Rx_decoded_phase(phase_negative) =
rem(Rx_decoded_phase(phase_negative)+360,360);
% Convert phase to symbol
base_phase = 360/2^bits_per_symbol;
delta_phase = base_phase/2;
Rx_decoded_symbols =
zeros(size(Rx_decoded_phase,1),size(Rx_decoded_phas
e,2));
for i = 1:(2^bits_per_symbol - 1)
    center_phase = base_phase*i;
    plus_delta = center_phase+delta_phase;
    minus_delta = center_phase-delta_phase;
    decoded = find((Rx_decoded_phase <= plus_delta)
& (Rx_decoded_phase > minus_delta));
    Rx_decoded_symbols(decoded)=i;
end
% Convert the matrix into a serial symbol stream
Rx_serial_symbols =
reshape(Rx_decoded_symbols',1,size(Rx_decoded_symbo
ls,1)*size(Rx_decoded_symbols,2));
% Convert the symbols to binary
for i = bits_per_symbol: -1: 1
    if i ~= 1
        Rx_binary_matrix(i,:) =
rem(Rx_serial_symbols,2);
        Rx_serial_symbols =
floor(Rx_serial_symbols/2);
    else
        Rx_binary_matrix(i,:) = Rx_serial_symbols;
```

```
    end
end
baseband_in =
reshape(Rx_binary_matrix,1,size(Rx_binary_matrix,1)
*size(Rx_binary_matrix,2));
%
% Find bit errors
%
bit_errors = find(baseband_in ~= baseband_out);
bit_error_count = size(bit_errors,2);
%%%%%%%%%%%%  DIFFERENT PAPR REDUCTION TECHNIQUES
%%%%%%%%%%%%%%%
%%%%%%%%%%%%  AMPLITUDE CLIPING TECHNINQUE
%%%%%%%%%%%%%%%
avg=0.05;
for K=1:4
clipped(K,:)=time_wave_matrix(K,:);
for i=1:length(clipped)
if clipped(:,i) > avg
        clipped(:,i) = avg;
    end
    if clipped(:,i) < -avg
        clipped(:,i) = -avg;
    end
end
end
display(clipped)
% figure(9)
% plot(real(clipped(2,:))); xlabel('Time');
ylabel('Amplitude');
% title('clipped Signal');grid on;


    % --------------calculate  papr of original
ofdm------------
   for i=1:4
     time_domain_signal1=abs(clipped(i,1:1024));
     meano=mean(abs(time_domain_signal1).^2);
     peako=max(abs(time_domain_signal1).^2);
     papr1(i)=10*log10(peako/meano);
   end
```

```
figure(10)
subplot(2,2,3);
title('AMP CLIPPING');
%papr=[1 2 3 4 5 6 7 8 9 10 11 13 14 15 16 17 18 19
20 21 22 23]
[N,X] = hist(papr1,100);
plot(X,1-cumsum(N)/max(cumsum(N)),'-.black',
'LineWidth',2, 'MarkerEdgeColor', 'r',
'MarkerSize',8);
grid on;
xlabel('papr1....AMP CLIPPING, x dB')
ylabel('ccdf')


%%%%%%%%%%%%%  PARTIAL TRANSMIT SEQUENCE TECHNIQUE
%%%%%%%%%%%%%%%

%close all
%clear

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% All permutations of phase factor B
p=[1 -1 i -i]; % phase factor possible values
B=[];
for b1=1:4
for b2=1:4
for b3=1:4
for b4=1:4
for b5=1:4
B=[B; [p(b1)  p(b2)  p(b3) p(b4)]]; % all possible
combinations
end
end
end
end
end
NN=symbols_per_carrier;  % the test is achieved on
10000 OFDM symbols only. It is
           % possible to use all of the 100000
symbols, but it will
           % take more time.
```

```
N=IFFT_bin_length;  % number of subbands
L=4;  % oversampling factor

for i=1:NN

    % calculate  papr of original ofdm

time_domain_signal1=abs(ifft([ofdm_symbol(i,1:512)
zeros(1,(L-1)*N) ofdm_symbol(i,513:1024)]));
     meano=mean(abs(time_domain_signal1).^2);
     peako=max(abs(time_domain_signal1).^2);
     papro(i)=10*log10(peako/meano);

    % Partition OFDM Symbol
     P1=[ofdm_symbol(i,1:256) zeros(1,768)];
     P2=[zeros(1,256) ofdm_symbol(i,257:512)
zeros(1,512)];
     P3=[zeros(1,512) ofdm_symbol(i,513:768)
zeros(1,256)];
     P4=[zeros(1,768) ofdm_symbol(i,769:1024)];

     % Transform Pi to Time Domain
     Pt1=abs(ifft([P1(1:512) zeros(1,(L-1)*N)
P1(513:1024)]));
     Pt2=abs(ifft([P2(1:512) zeros(1,(L-1)*N)
P2(513:1024)]));
     Pt3=abs(ifft([P3(1:512) zeros(1,(L-1)*N)
P3(513:1024)]));
     Pt4=abs(ifft([P4(1:512) zeros(1,(L-1)*N)
P4(513:1024)]));


    % Combine in Time Domain and find papr_min
    papr2(i)=papro(i);
    for k=1:256

final_signal=B(k,1)*Pt1+B(k,2)*Pt2+B(k,3)*Pt3+B(k,4
)*Pt4;
      meank=mean(abs(final_signal).^2);
      peak=max(abs(final_signal).^2);
      papr=10*log10(peak/meank);
```

```
      if papr < papr2(i)
         papr2(i)=papr;
         sig=final_signal;
      end
    end

end
subplot(2,2,1);
title('ORIGINAL signal');
[N,X] = hist(papro,100);
plot(X,1-cumsum(N)/max(cumsum(N)),'-ro',
'LineWidth',2, 'MarkerEdgeColor', 'r',
'MarkerSize',8);
grid;
xlabel('paprO...original signal, x dB')
ylabel('ccdf')
subplot(2,2,2);
title('PTS');
[N,X] = hist(papr2,100);
plot(X,1-cumsum(N)/max(cumsum(N)),'-.green',
'LineWidth',2, 'MarkerEdgeColor', 'r',
'MarkerSize',8);
grid;
xlabel('papr2....PARTIAL TRANSMIT, x dB')
ylabel('ccdf')


%%%%%%%%%%%%%  SELECTIVE MAPPING TECHNIQUE
%%%%%%%%%%
N=IFFT_bin_length;
%L=4;  % oversampling factor
C=4; % number of OFDM symbol candidate
% phase factor matrix [B] generation
%p=[1 -1 j -j]; % phase factor possible values
%randn('state', 12345);
%B=randsrc(C,N,p); % generate N-point phase factors
for each one of the
size(B)
D=B'
%size(ofdn_symbol)
```

```
for i=1:NN
      %calculate  papr of original ofdm

time_domain_signal1=abs(ifft([ofdm_symbol(i,1:512)
zeros(1,(L-1)*N) ofdm_symbol(i,513:1024)]));
     meano=mean(abs(time_domain_signal1).^2);
     peako=max(abs(time_domain_signal1).^2);
     papro(i)=10*log10(peako/meano);
    % B*ofdm symbol
    p=[];
    for k=1:C
        p=[p; D(k,:).*ofdm_symbol(i,:)];
    end
     % Transform Pi to Time Domain and find paprs
     for k=1:C
         pt(k,:)=abs(ifft([p(k,1:512) zeros(1,(L-
1)*N) p(k,513:1024)]));

papr(k)=10*log10(max(abs(pt(k,:)).^2)/mean(abs(pt(k
,:)).^2));
     end

    % find papr_min
    papr_min(i)=min(papr);
end
subplot(2,2,4);
[N,X] = hist(papr_min,100);
plot(X,1-cumsum(N)/max(cumsum(N)),'-.b',
'LineWidth',2, 'MarkerEdgeColor', 'r',
'MarkerSize',8);
grid;
xlabel('papr3....SELECTIVE MAPPING, x dB')
ylabel('ccdf=pr(papr>papr0')
%%
% plot all the papr reduction technique
%
figure(11)
[N,X] = hist(papro,100);
plot(X,1-cumsum(N)/max(cumsum(N)),'-ro',
'LineWidth',3, 'MarkerEdgeColor', 'r',
'MarkerSize',8);
```

```
axis([0 10 -0.025 1]);
hold on
[N,X] = hist(papr_min,100);
plot(X,1-cumsum(N)/max(cumsum(N)),'blue',
'LineWidth',3, 'MarkerEdgeColor', 'r',
'MarkerSize',8);
hold all
[N,X] = hist(papr2,100);
plot(X,1-cumsum(N)/max(cumsum(N)),'green',
'LineWidth',3, 'MarkerEdgeColor', 'r',
'MarkerSize',8);
hold all;
[N,X] = hist(papr1,100);
plot(X,1-cumsum(N)/max(cumsum(N)),'black',
'LineWidth',3, 'MarkerEdgeColor', 'r',
'MarkerSize',8);
grid;
hold all;

logy=linspace(0,1,6)
set(gca,'YTick',logy);
xlabel('PAPR')
ylabel('S')
hleg=legend('ORIGINAL','SLM','PTS','CLIPPING');grid
on;
```