PERFORMANCE EVALUATION OF PEAK-TO-AVERAGE POWER RATIO REDUCTION TECHNIQUES IN OFDM

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DECLARATION

I hereby declare that the work in this dissertation is an authentic study based on my work, except for quotation and summaries, which have been duly acknowledged.

10 January 2017 OTHMAN
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ABSTRACT

The high demand of using wireless communication leads to establish a new technique of modulation to enhance the throughput of the system and to have a high data rate communication. One of the modern wireless modulation technique is the Orthogonal Frequency Division multiplexing (OFDM) which considered a suitable technique of modulation in modern wireless application. But there is an important issue to make into consideration when designing OFDM, which is the Peak to Average Power Ratio Reduction (PARP). This study provides a full comparison between using several techniques of PARP reduction like Clipping and Filtering, Partial Transmit Sequence, DFT Spreading, and Selective Mapping techniques. These techniques are simulated and the PARP results are obtained for each technique. The comparison between the results is also obtained and verified experimentally using MATLAB. The simulation results show that Clipping and filtering technique is the simplest technique of reducing PARP ratio of the OFDM signal, it depends on the clipping level that satisfies the signal to quantization noise ratio SQNR. They also show that the partial transmit and selective mapping techniques depends on dividing the OFDM signal into subsignals which the result of transmission these subsignals is nearly to that obtained for the base band signal transmission. The use of selective mapping technique (SLM) leads to a PARP reduction in the simulation from nearly 18 for normal OFDM signal to 12.8 for SLM-OFDM signal. The PARP ratio from the clipping and filtering technique is 9.5 while the PARP from SLM is 16.4. The efficiency obtained from the simulation of the SLM technique and clipping and filtering technique are 28.6 and 58.4 respectively.

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ABSTRAK

Permintaan yang tinggi menggunakan komunikasi tanpa wayar membawa kepada mewujudkan satu teknik baru modulasi untuk meningkatkan daya pemprosesan sistem dan mempunyai komunikasi kadar data yang tinggi. Salah satu teknik modulasi wayarles moden adalah ortogon Bahagian Kekerapan pemultipleksan (OFDM) yang dianggap teknik yang sesuai modulasi dalam permohonan wayarles moden. Tetapi ada satu isu penting untuk membuat kira apabila mereka bentuk OFDM yang Peak untuk Pengurangan Nisbah Power Purata (PARP). Kajian ini menyediakan perbandingan penuh antara menggunakan beberapa teknik pengurangan PARP seperti Keratan dan Penapisan, Partial Transmit Sequence, DFT Menyebarkan, dan teknik Pemetaan Terpilih. Teknik-teknik ini adalah simulasi dan keputusan PARP diperolehi bagi setiap teknik. Perbandingan antara keputusan juga diperoleh dan disahkan secara eksperimen menggunakan MATLAB. Keputusan simulasi menunjukkan bahawa Keratan dan teknik penapisan adalah teknik yang paling mudah untuk mengurangkan nisbah PARP isyarat OFDM, ia bergantung kepada tahap keratan yang memenuhi isyarat untuk pengkuantuman bunyi nisbah SQNR. Mereka juga menunjukkan bahawa penghantar separa dan teknik pemetaan terpilih bergantung kepada membahagikan isyarat OFDM ke subsignals yang hasil daripada penghantaran subsignals ini adalah hampir dengan apa yang diperoleh untuk penghantaran isyarat jalur asas. Penggunaan teknik pemetaan terpilih (SLM) membawa kepada pengurangan PARP dalam simulasi daripada hampir 18 isyarat OFDM normal kepada 12.8 isyarat SLM-OFDM. Nisbah PARP daripada teknik menggunting dan penapisan ialah 9.5 manakala PARP dari SLM adalah 16.4. Kecekapan diperolehi daripada simulasi teknik SLM dan keratan dan penapisan teknik masing-masing 28.6 dan 58.4.

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LIST OF ABBREVIATIONS

ADC	analog signal to digital one
BER	Bit Error Rate
CCDF	Cumulative Distribution Function
CP	cyclic prefix
DFT	Discrete Fourier Transform
DSL	Digital Subscriber Line
FDD	Frequency Division Duplex
HPA	High-Power-Amplifier
MIMO	multiple-input multiple-output
OFDM	Orthogonal Frequency Division multiplexing
PARP	Peak to Average Power Ratio Reduction
PTS	Partial Transmit Sequence
SLM	selective mapping technique
SQNE	Quantization Noise Error
TDD	Time Division Duplex
WLANs	Wireless Local Area Networks

CHAPTER I

INTRODUCTION

1.1 MOTIVATION OF STUDY

The increasing demand of using wireless communication to communicate with high data rate with efficient spectral is the main issue in the modern life, such as Digital Television, Digital Audio Broadcasting, broadband internet access like Digital Subscriber Line (DSL), wireless networks like Wireless Local Area Networks (WLANs) and 4 G mobile communications. Orthogonal Division Multiplexing (OFDM) is one of the techniques which widely used as a modulation technique used in these systems due to its high data rate and spectral efficiency.

In this thesis, a comparison study between different techniques of OFDM PARP reduction has been introduces. This chapter contains the problem statement, Objective of the comparison study, contribution and research scope.

1.1.1 Peak to average power ratio

However, one of the most topics should be taken into consideration when using OFDM as a modulation technique is the peak to average power ratio (PAPR) of a transmitted signal. It is considered a challenge in wideband multi-carrier systems that use orthogonality or multiple-input multiple-output (MIMO) OFDM system (Müller&Huber 1997). The large peaks of the transmitted signal are the concept behind PARP since they affect the performance of transmission by introducing a serious degradation in performance when the signal passes through a nonlinear High-Power-Amplifier (HPA). This degradation leads to in-band distortion which increases Bit Error Rate (BER), and out-of-band radiation, which causes adjacent channel interference.

1.1.2 PARP reduction techniques

There are several techniques to deal with PARP issue called the PARP reduction techniques in MIMO OFDM systems (Wang et al. 2013). One of these techniques depends on reducing the amplitude of the peaks values by using clipping before transmission and some of them use the concept of divided the OFDM signal into sub-blocks or sub-signals before transmission. The first implementation method is clipping and filtering technique, which considered the simplest one in PARP reduction. It depends on clipping the high peaks values into a predetermine value before filtering and amplification (Patel 2016). This technique is a nonlinear process and may cause both in-band and out-of-band interference. The second method is the Partial Transmit Sequence (PTS) which depends on divided the original OFDM signal into sub-blocks. This technique causes no distortion and creates no out-of-band radiation, but it may be require transmission additional information to the receiver. The main concept of PTS is used in Selective Mapping technique (SLM) without increase in power and without any loss of data by multiplying the original OFDM signal into different phase which results in different transmitted signals. The Discrete Fourier Transform (DFT) is also used as a technique of PARP reduction because it uses the concept of Orthogonal Frequency Division Multiple Access (OFDMA) which transforms the transmission of multi-carrier OFDM signal to single carrier signal called SC-FDMA that yields to have a PARP value near to that obtained from the base band transmission (Al-Hussaini et al. 2016).

1.2 PROBLEM STATEMENT

OFDM system is known to have high PARP value due to the generation process of the OFDM signal which depends on having high peaks in the time domain since many subcarrier components are added via an IFFT operation. This high PARP value compared with single-carrier systems results in efficiency degradation of the power amplifier in the transmitter and reduction of the BER performance. The PAPR reduction techniques are critical and very important to use in the uplink transmission since the efficiency of power amplifier is critical due to the limited battery power in a mobile terminal.

Due to the importance of the PARP issue, this study aims to study different techniques of PARP reduction and perform a full comparison between using each technique.

1.3 RESEARCH OBJECTIVES

The main objective of this project is to investigate the performance of different PARP reduction algorithms used in OFDMA.

The main objectives are:

1. To simulate different types of techniques that used to reduce the PARP value of the OFDM transmitted signal.
2. To perform a brief comparison study between different types of techniques to reduce PARP considering the BER performance, power use, spectral efficiency and interference.
3. To compare the simulated PARP of each obtained from OFDM and with these obtained from the base band transmission and SC-FDMA transmitted signal.

1.4 DISSERTATION ORGANIZATION

This thesis contains five chapters. The first one is the introduction which gives an overview of the research objectives and the scope of the study. Chapter two introduces in details the PARP reduction techniques and their characteristics, when each one used, and how to determine the suitable technique to use. Chapter two also discussed theoretically the concept of OFDM, OFDMA and Signal to Quantization Noise Error (SQNE). Chapter three introduced the methodology used in this comparison study between techniques, some flow chart of the MATLAB code simulation are also introduced. The simulation results are introduced in chapter four. This chapter introduced the simulation results of the comparison study and the comments of all results. Chapter five concludes the thesis results and discussed some proposed future works. .

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

The peak to average power ratio (PARP) is the most issue when implemented OFDMA as a modulation technique over all the mobile generations. So, many researchers conducted many proposed solutions to settle this issue with making the signal more reliable. In this chapter, all thermotical concepts and related work will be reviewed and exhibited.

2.2 OVERVIEW OF LONG TERM EVOLUTION

3GPP Long Term Evolution represents one of the most standard that will lead to developing the cellular network technology. It was developed to meet the continuous great demands like (Sesia et al. 2015) :

1. High data rate
2. System capacity and coverage
3. Low user latency.
4. High user mobility.

The improved system performance ensures the competitiveness of LTE compared to other existing systems. Figure 2.1 provides the main revolution of cellular mobile generation over the period from 1999 to what is expected in 2020.

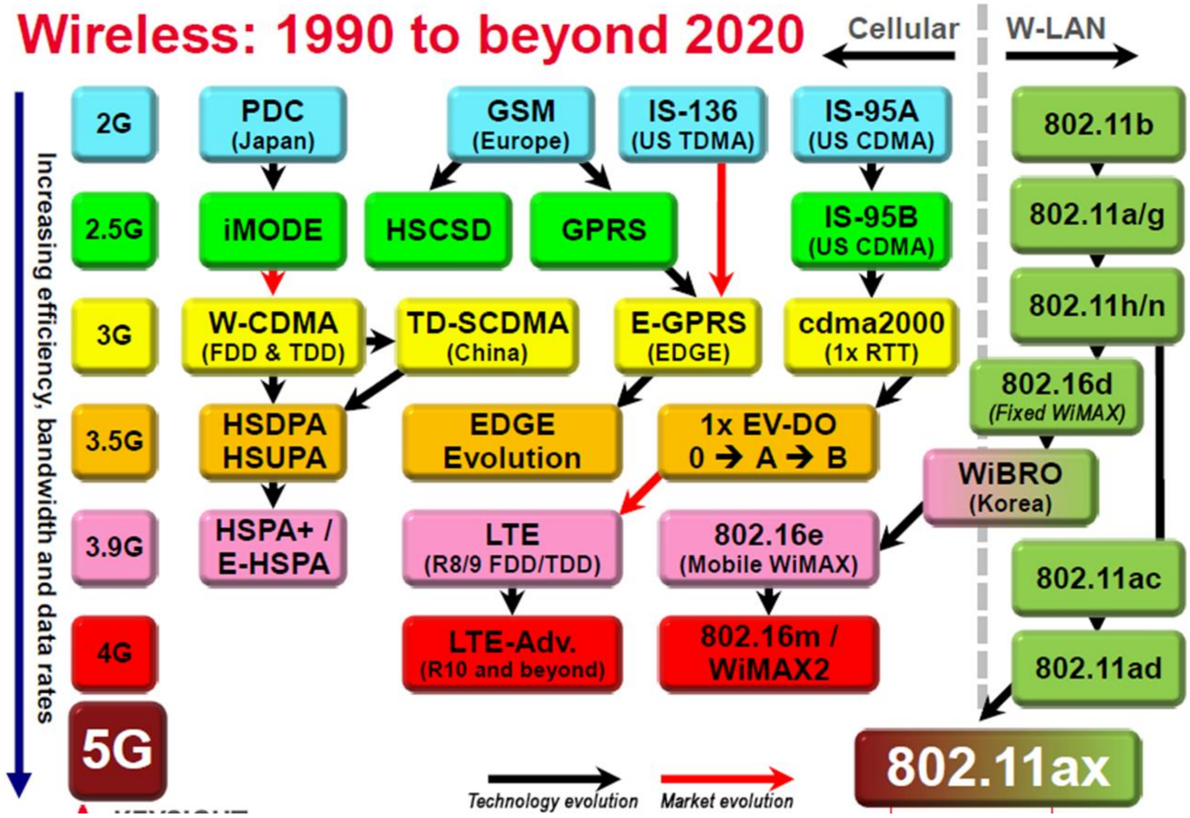


Figure 2.1 The overview of mobile revolution (Bands 2016).

As the OFDMA is developed basically to cover the demand of frequency spectrum which is considered as physical demand. An overview will be listed below regarding to physical layer.

2.2.1 LTE PHYSICAL LAYER

The LTE Physical Layer has responsibility of transferring both the data which may be voice or multimedia streaming and user's control data between the eNodeB and the cellular base station with highly efficient consideration. The synonym eNodeB is used in LTE terminology (Zyren&Mccoy 2007). The two common duplex mechanisms FDD (Frequency Division Duplex) and TDD (Time Division Duplex are implemented in LTE physical layer(Zhang, Pan, et al. 2016).

2.2.2 LTE Frame Structure

Figure 2.2 depicts the generic frame structure for uplink and downlink operation in LTE according to (Sesia et al. 2015). The duration of one frame in LTE system is 10 ms with each frame is divided into 10 sub-frames of 1 ms. Each sub-frame is further divided into two time slots, each with duration of 0.5 ms. Each time slot consists of either 7 or 6 OFDM symbols depending on the type of cyclic prefix (CP) employed.

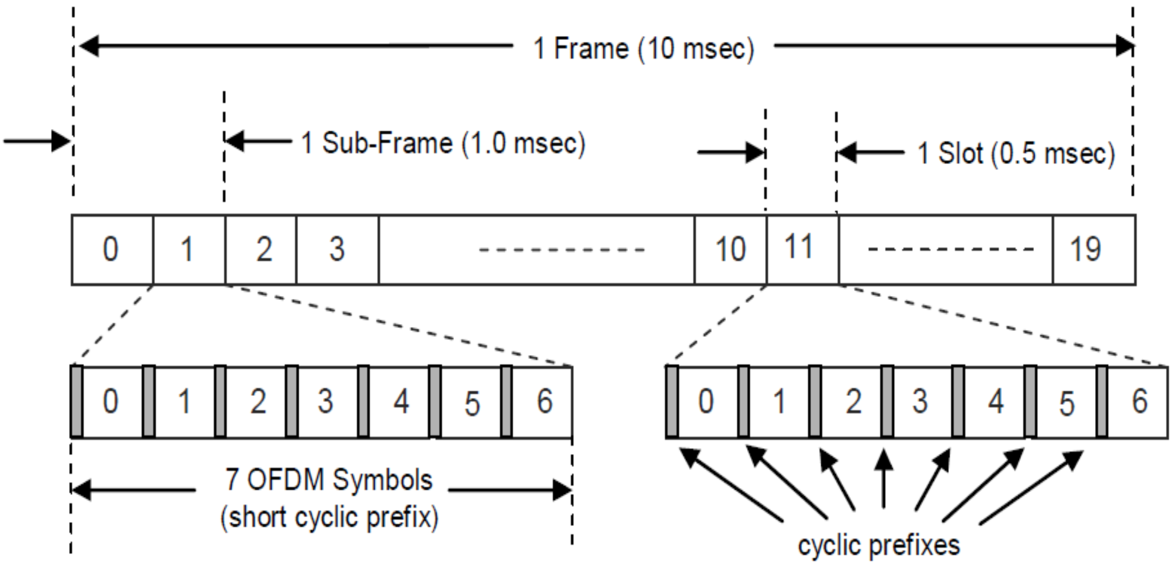


Figure 2.2 LTE Frame Structure with 7 OFDM symbols per time slot(Zhao&Haggman 2001).

The duplication of the last part of the data symbol is called Cyclic prefix (CP). The CP is embedded before similar data symbol during the monitor interval (Pham et al. 2016). The LTE technology utilized two sorts of cyclic prefix, called normal CP and extended CP. The duration of normal CP and extended CP is given in Table 2.1. Ts is the standard sampling time unit used throughout the LTE specification documents and l is the index of OFDM symbol in a slot (Zhang, Walker, et al. 2016).

Table 2.1 Cyclic Prefix Duration.

Configuration		Cyclic Prefix Length	
		Ts	μsec
Normal CP	$\Delta f = 15kHz$	160 for l = 0	5.21 for l = 0
		144 for l = 1,2,…5	4.69 for l = 1,2,5
Extended CP		512	16.67
		1024	33.33

In the case of FDD (Frequency Division Duplex), all sub frames are assigned either for downlink or uplink transmission as shown in Figure 2.3. The blue arrow represents downlink transmission and the black arrow represents uplink transmission (Marzetta et al. 2016).

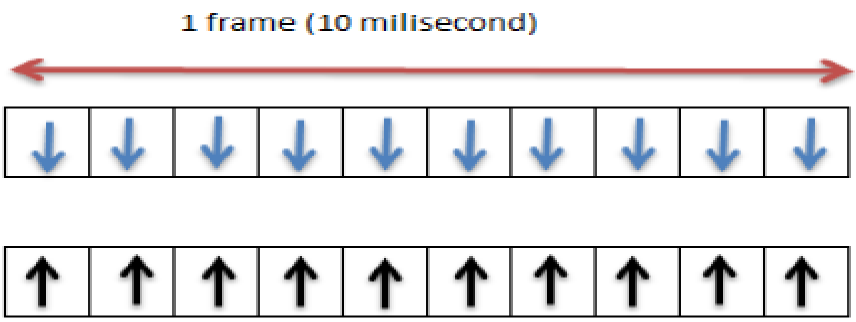


Figure 2.3 Uplink-Downlink Configurations for LTE FDD.

As mentioned above, LTE uses OFDM as one of the key technologies. In OFDM, the whole transmission bandwidth is divided into subcarriers (Hui et al. 2016). Furthermore, one PRB is consist of 12 consecutive subcarriers which are grouped together in LTE physical layer and called (Physical Resource Block). A PRB has period of 1 time slot. Within one PRB there are 12x7 or 12x6 resource elements as depicted in Figure 2.4. A PRB is the smallest element allocated to a user (Chendamarai Kannan et al. 2016).

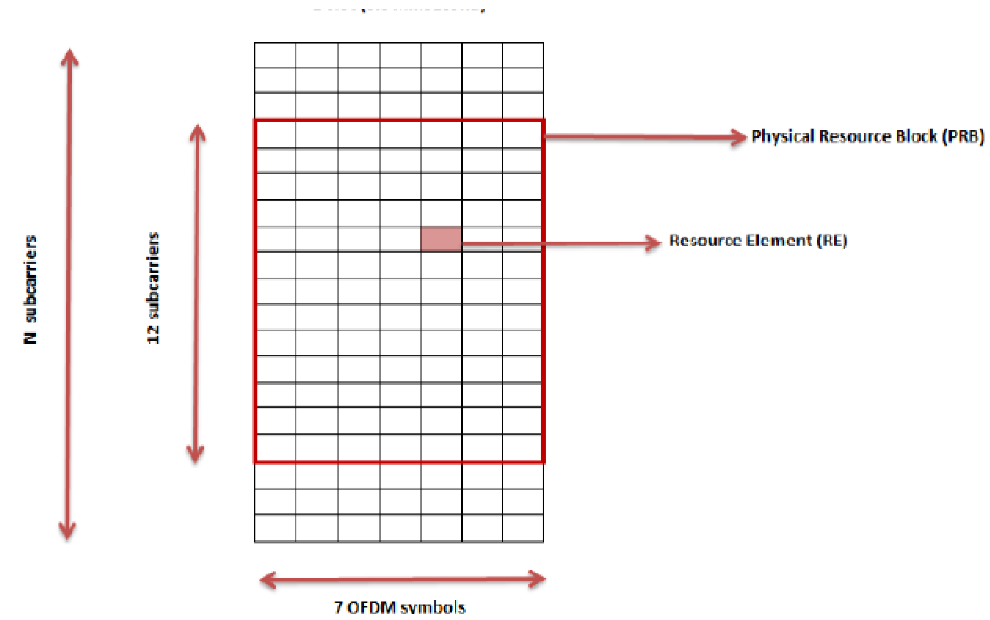


Figure 2.4 LTE downlink resource grid (Ghosh et al. 2010).

2.3 ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

Because of the increasing demand of wireless applications due to the increase of tablets and Internet of things, and because the need for high data rat transmission and using the spectrum available in an efficient way, the Orthogonal frequency division multiplexing (OFDM) is considered one of modern techniques used to satisfy this demands. OFDM is a form of modulation using multicarrier signals. It is a combination of modulation and multiplexing, figure 2.5 and 2.6 respectively (Sustek et al. 2016).

The carrier in OFDM is first split into independent signals modulated by data and then re-multiplexed to create the OFDM carrier as shown in figure 2.1(Nee&Prasad 2000).

The first condition of using OFDM is the linearity of the transmitting and receiving systems since any non-linearity will cause interference between the carriers as a result of inter-modulation distortion which impair the orthogonality of the system (Jiang&Wu 2008).

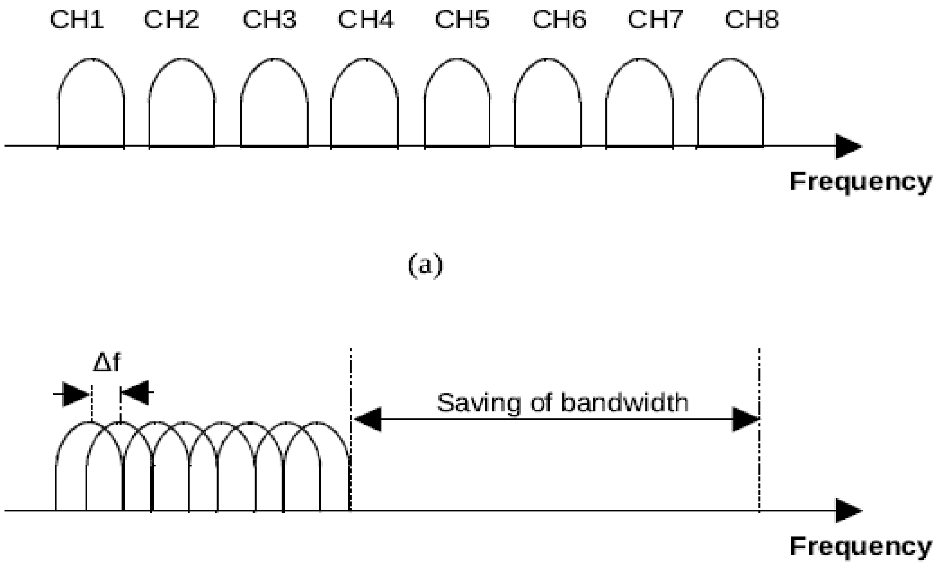


Figure 2.5 theoretical concept of OFDM signal. (a) Conventional multi-carrier technique. (b) OFDM technique(El Ayach et al. 2010).

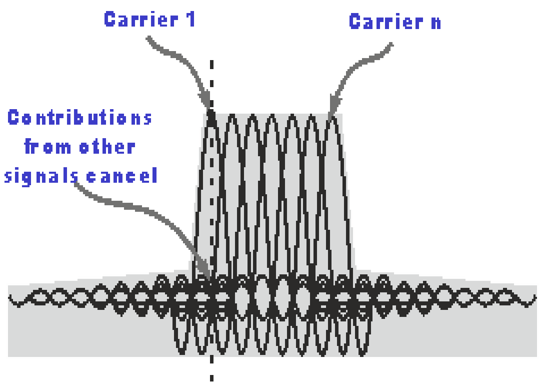


Figure 2.6 Subcarrier of the OFDM signal.

The Advantages of using OFDM as a modulation scheme are (Benvenuto&Tomasin 2002):

- ***Invulnerability to selective fading:*** since the OFDM divides the whole channel into multiple narrowband signals that are less affected by the selective fading.
- ***Less interference:*** because of the subdivided of the overall channel.

- ***Spectrum efficiency:*** using the available spectrum to send several signals because of the concept of orthogonality.
- ***Less ISI:*** Because the low data rate on each of the sub-channels.
- ***Simpler channel equalization:*** using multi-channel in OFDM results on less equalization required and the equalization process become much simpler (Bolea et al. 2014).

However, the OFDM has some disadvantages and they should be into consideration when using OFDM process. The disadvantages are (Li et al. 2005).

- ***High PARP:*** the amplitude variation of the sub-carriers results a high PARP value. This impacts the linearity of the RF amplifier efficiency.
- ***Sensitive to carrier offset and drift:*** Each carrier should has a specific offset and drift to satisfy orthogonality.

Figure 2.7 shows the block diagram of the OFDM transmitter and receiver, the process starts from transforming the input bit stream from serial to parallel and then mapped to the suitable sub-carrier. To create the OFDM symbol and to be sure that it is orthogonal to other symbols, IFFT process is obtained by the equation below.

$$c(t) = \sum_{n=1}^{N} m_n(t) \sin(2\pi n t) \tag{2.1}$$

The channel is to be determining according to the surrounding environment and the receiver performs the inverse operations of the transmitter as shown in figure 2. That is, the receiver starts from down converter and A/D. the FFT process is then performed to recover the transmitted symbols by applying the equation below:

$$x(k) = \sum_{n=0}^{N-1} x(n) \sin\left(\frac{2\pi kn}{N}\right) + j \sum_{n=0}^{N-1} x(n) \cos\left(\frac{2\pi kn}{N}\right) \tag{2.2}$$

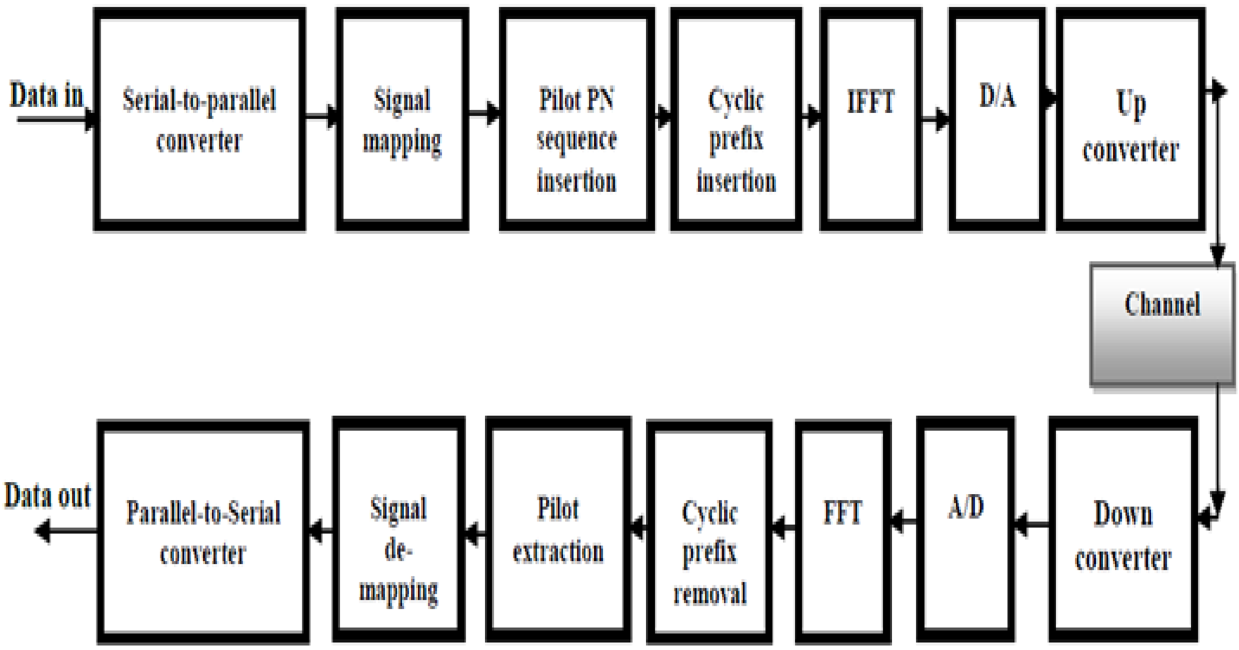


Figure 2.7 OFDM block diagram

The multiple access of the OFDM is the OFDMA which is a scheme used to provide a multiple access capability when using OFDM technologies, and also used to reduce the PARP value (Rahmatallah&Mohan 2013).

2.4 PARP CONCEPT

The Peak-to-average power reduction of OFDM signals is defined as the ratio between the maximum instantaneous power and its average power (Yu et al. 2013).

$$PAPR = \frac{max|s(t)|^2}{mean|s(t)|^2} \tag{2.3}$$

where s(t) is the amplitude of the signal.

The results when substitution will lead to the what is called the Complementary Cumulative Distribution Function (CCDF) of PAPR which can be utilized to evaluate the bounds for the minimum number of redundancy bits required to identify the PAPR sequences. The second utilization is investigating the efficiency of any PAPR reduction schemes. A proper output back-off of HPA to minimize the total degradation according to CCDF can also be determined (Ahmed et al. 2015).

A maximum expected PAPR of OFDMM signals can be derived by assuming:

Xn= 1

in Equation 2.1 for all sub-carriers (Cimini&Sollenberger 2000).

2.5 PARP REDUCTION TECHNIQUES

With the increasing popularity of OFDM, there have been numerous attempts to reduce the PAPR of this type of signals. This section presents 4 typical techniques for PAPR reduction in OFDM systems

2.5.1 Clipping and filtering technique

This technique is the simplest technique of reducing PARP ratio of the OFDM signal, it depends on the clipping level that satisfies the signal to quantization noise ratio SQNR and the oversampling level L which is normally greater than or equal to 4 to meat Nyquist rate of the up-sampling signal (Lee&Kim 2013) as shown in figure 2.8.

The passband modulated signal X^p[m] with carrier frequency *fc* is transformed to the clipped and filtered signal X_c^p[m] which expressed as:

$$X_c^p[m] = \begin{cases} -A & X^p[m] \leq -A \\ X^p[m] & |X^p[m]| < A \\ A & X^p[m] \geq A \end{cases} \tag{3.1}$$

where the clipping level is A and the clipping ratio to have a powerful transmission of clipped OFDM is (CR) which equal:

$$CR = \frac{A}{\sigma} \tag{3.2}$$

where σ is the RMS amplitude of the OFDM signal and equal to $\sigma = \sqrt{N/2}$

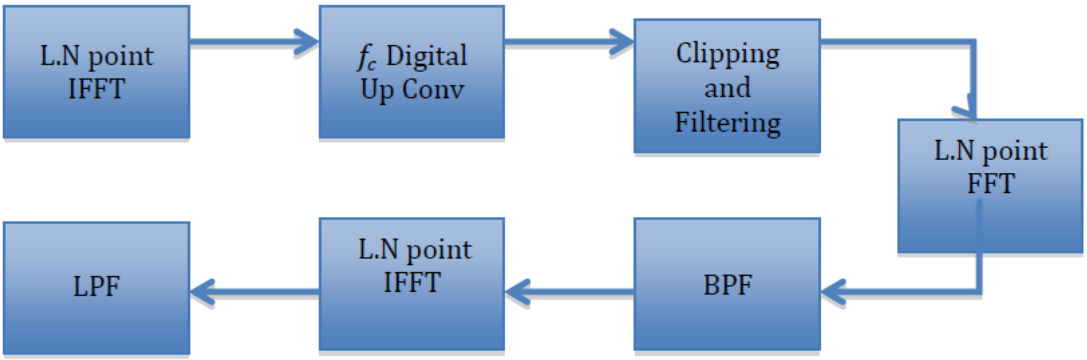


Figure 2.7 Clipping and filtering technique block diagram.

Moreover, clipping is performed at the transmitter then the receiver is imposed in this case to evaluate and measure the clipping value that has been occurred and remunerate the received OFDM symbol appropriately (Myung et al. 2006). Ordinarily, at most one clipping occurs per OFDM symbol, the OFDM receiver has to evaluate the two followed the size of clipping and its location which is difficult to determine these values. So, clipping strategy present both in band distortion and out of band radiation into OFDM signals, which degrades the system performance including BER and spectral efficiency (Zhu et al. 2013) (Park et al. 2000).

The second stage, the filtering, can deduct out of band radiation after clipping although it cannot reduce in-band distortion. Nonetheless, some peak surpass could be caused form clipping method, so the peak signal value exceeds the threshold value at some points in clipping and filtering method(Qualcomm). To deduct peak regrowth, a reputation of clipping-and-filtering mechanisms can be implemented until get a desirable value, but as a result the computational PAPR cost will be complexity increase. The advent of peak windowing schemes which is improved clipping algorithm can minimize the out of band radiation by using narrowband windows like Gaussian window (Jiang and Wu 2008).

2.5.2 Partial Transmit Sequence

The OFDM signal X is entered the process of the Partial Transmit Sequence (PTS)(Baxley&Zhou 2007). The X signal is partitioned into V disjoint sub blocks as follows:

$$X = [X^0, X^1, X^2, \ldots\ldots, X^{V-1}]^T \qquad (3.3)$$

All sub blocks are combined with each other by applying the phase rotation factor $b_v=e^{j\Phi}$ to the IFFT. The transmitted signal X will be X' as:

$$X'(b) = \sum_{v-l}^{M} b_v x_v \qquad (3.4)$$

Figure 4 shows the block diagram of the PTS technique which used in the simulation.

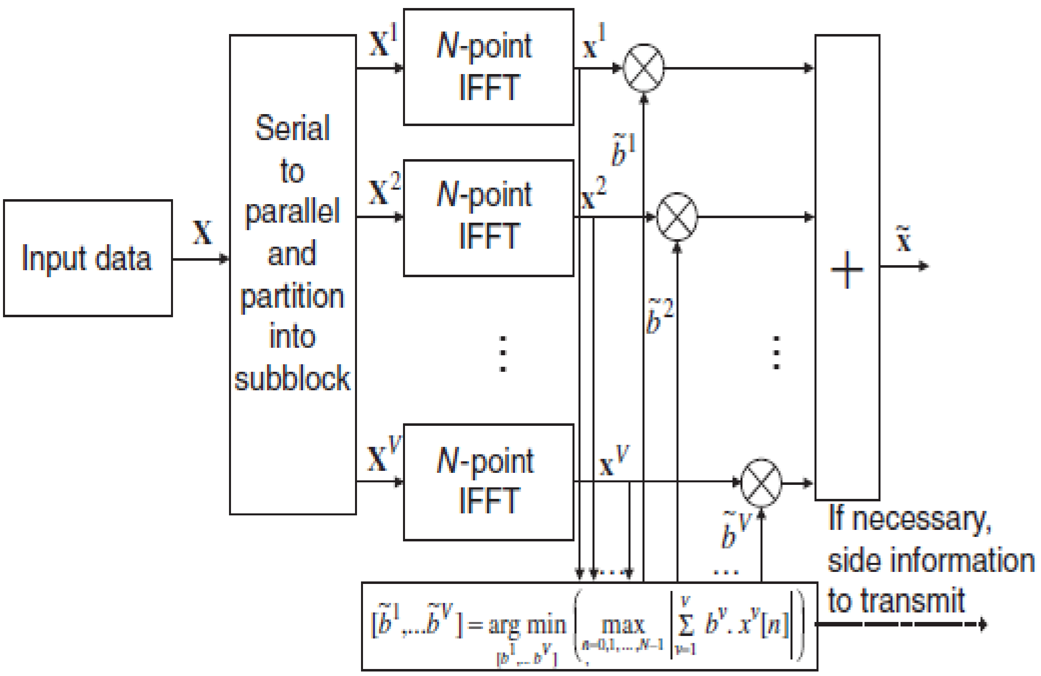


Figure 2.8 Block diagram of Partial Transmit Sequence (PTS)

Therefore, there are two important issues should be solved in PTS: high computational complexity for searching the optimal phase factors and the overhead of the optimal phase factors as side information needed to be transmitted to receiver for the correct decoding of the transmitted bit sequence (Alavi et al. 2005).

2.5.3 Selective Mapping technique (SLM)

Selective Mapping technique is the technique which depends on transforming the normal OFDM signal into a signal multiplied by a phase shift between each sub-carrier(Han&Lee 2004). The efficiency of this technique is directly proportional to the number of phase different used. But when the phases increased the simulation computation is also increased and this is considered a drawback of this technique. The block diagram of the SLM technique is shown in figure 2.9 (Abdullah et al. 2016).

Each data block is multiplied by V different phase factors, each of length N, Bv = [bs,0, bs,1, ... , bs,N-1]^T (s=0,1,....,V-1), resulting in V different data blocks. Thus, the vth phase sequence after multiplied is Xv = [$X_0b_{s,0}$, $X_1b_{s,1}$, ... , $X_{N-1}b_{s,N-1}$]^T (s=0,1,....,V-1). Therefore, OFDM signals becomes as

$$x^v(t)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} X_n b_{s,n} e^{j2\pi f_n t}$$

where 0 <t<NT , s = 1,2,....,V-1.

Among the data blocks Xv (s =0,1,....,V-1), only one with the lowest PAPR is selected for transmission and the corresponding selected phase factors bs,n also should be transmitted to receiver as side information (Kenneth&Neelakanta 2016; Ryu&Joo 2016). For implementation of SLM OFDM systems, the SLM technique needs IFFT operation and the number of required bits as side information is [log2 v] for each data block. Therefore, the ability of PAPR reduction in SLM depends on the number of phase factors and the design of the phase factors. Some extension of SLM also have been proposed to reduce the computational complexity and number of the bits for side information transmission (Han and Lee 2004).

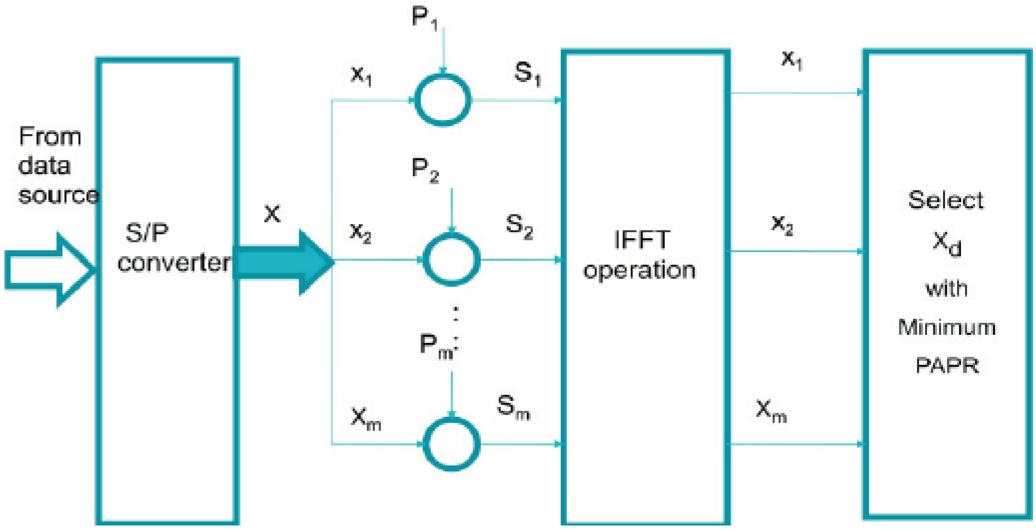


Figure 2.9 The process of SLM-OFDM signal transmission

2.5.5 DFT spreading

This technique deals with passband signal as a baseband one by converting the OFDM signal to OFDMA one which depends on transmitting the subcarriers one after the other in serial communication instead of the parallel form of the OFDM (An&Ryu 2016). The result PARP of the OFDM signal after using this technique is near to that obtained from the SC-FDMA. The DFT spread system as shown in figure 2.10 consists of serial to parallel converter, DFT and IDFT, parallel to series operation, cyclic prefix and A\D converter (Shedashale&Patil 2016).

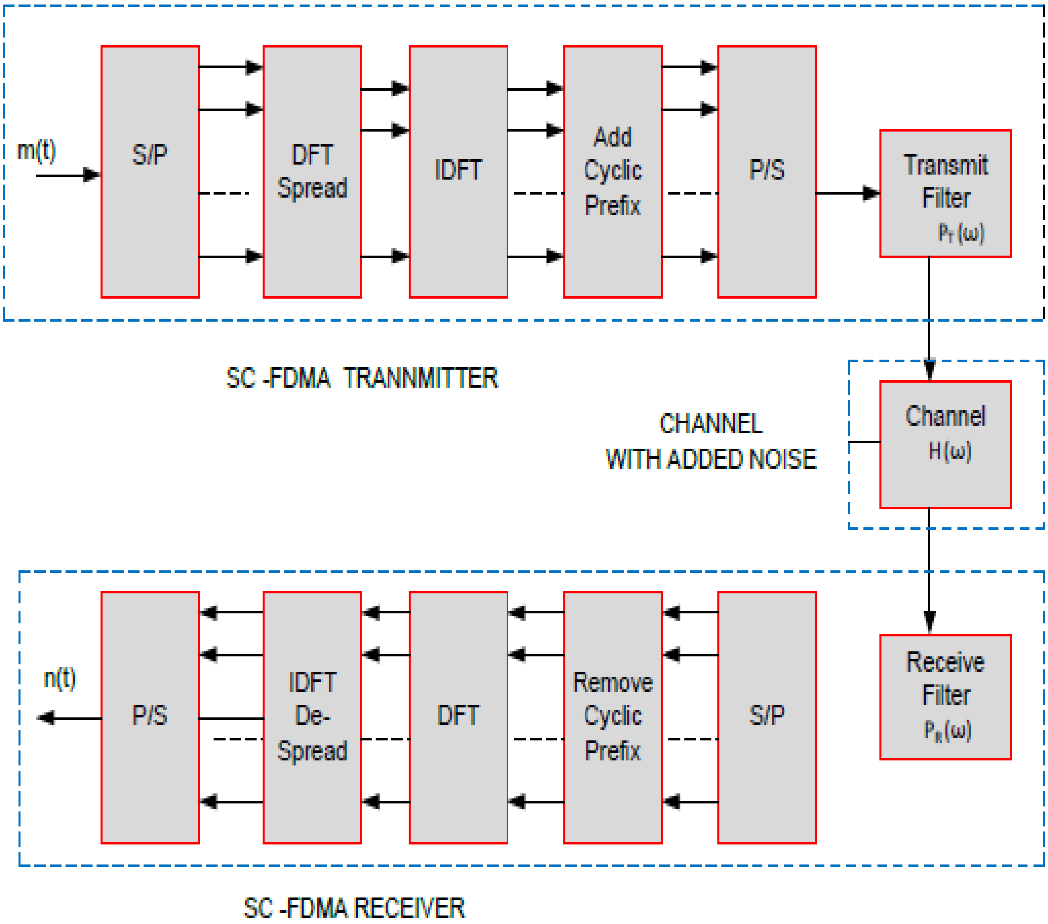


Figure 2.10 Block diagram of DFT spread technique

2.6 RELATED WORK

The eldest paper in my related work is for Armstrong (2002) which developed repeated clipping and frequency domain filtering for the ODFM signal. His development is significantly reducing the PARP value for the transmitting signal and the method did not cause any increase regarding out-of-band power.

The study of HanandLee (2005) introduce some reduction technique of PARP whichis considered the main drawback of OFDM. The review summarized the advantages and disadvantages of PARP reduction techniques like clipping and filtering, coding, partial transmit sequence, selected mapping, interleaving, tone reservation, tone injection, and active constellation extension.

The work of JiangandWu (2008) introduced and analysed different algorithms related to OFDM PAPR reduction. The results were depending on practical complexity, spectral spillage, bandwidth extension, and overall performance. The study also presented some techniques of PAPR reduction for the new revolution multiuser OFDM broadband communication technology.

RahmatallahandMohan (2013) provide comprehensive understanding of the PARP problem in broad banding communication. The study defined the most effected parameters that impact the PARP performance over OFDM.

The study Prabhu et al. (2014) proposed a low-complex method to solve the PARP problem in OFDM. The smart solution is based on sending part of the signal from one antenna and the compensate of it is sending from revered antenna. The results show the reduction is 25% of power with only 15% of overhead weight.

The study of Ahmed et al. (2015) is modified anew PARP reduction based on selecting mapping technique. The idea was dividing the signal to different block and from full comparative study analysis, the PARP value can be reduced. The results show complementary cumulative distributive function (CCDF) became better.

The work of Gupta et al. (2015) proposed a combination of higher order partitioned partial transmitted sequence (PTS) along with Bose Chaudhuri Hocquenghem Code (BCH). This combination aims to reduce the PARP significantly. The results show the proposed technique impact the PARP reduction better than the conventional one.

The study of Wang et al. (2015) introduced a new developed PARP reduction technique which is based on precoding matrix with an inverse discrete combination and called T-OFDM. The simulation results show the BER versus the SNR with different frequency carrier.

The study of PandeyandPoladia (2015) developed a novel technique to reduce the PARP value by reduction the carrier power. The results show the method deduct the PARP value by 22%.

The work Ghassemlooy et al. (2017) presented a novel PARP reduction technique reduction scheme for the asymmetrically clipped optical orthogonal frequency division multiplexing (ACO-OFDM). The results show a significant improvement of PARP value by 6 dB for 256 users.

Table 2.10 Recently related works

Author	**year**	**Main objective**
Armstrong	2002	Developing repeated clipping and frequency domain filtering for the ODFM signal
HanandLee	2005	Introduce some reduction technique of PARP
JiangandWu	2008	Introduced and analysed different algorithms related to OFDM PAPR reduction
RahmatallahandMohan	2013	Provide comprehensive understanding of the PARP problem in broad banding communication
Prabhu et al.	2014	Proposed a low-complex method to solve the PARP problem in OFDM.
Ahmed et al.	2015	Modified anew PARP reduction based on selecting mapping technique
Gupta et al.	2015	Proposed a combination of higher order partitioned partial transmitted sequence (PTS) along with Bose

		Chaudhuri Hocquenghem Code (BCH)
Wang et al.	2015	Introducing a new developed PARP reduction technique
PandeyandPoladia	2015	Developing a novel technique to reduce the PARP value by reduction the carrier power
Ghassemlooy et al.	2017	Presenting a novel PARP reduction technique reduction scheme for the asymmetrically clipped optical orthogonal frequency division multiplexing (ACO-OFDM)
This work	2017	Investigate the performance of different PARP reduction algorithms used in OFDMA.

2.7 SUMMARY

In this chapter, all related theoretical concepts and basics are introduced with all related figures and diagrams. The related studies show the significant impact of the selective peak to average power reductions techniques that are chosen in this project.

CHAPTER III

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the methodology of studying and simulating the PARP reduction techniques of OFDM signal is introduced. First of all the method used in this study is the comparison study between different techniques of PARP reduction of OFDM signal. This comparison is performed refer to the normal OFDM signal, and a simulation of all the applied techniques are introduced. Some of the PARP reduction techniques depend on clipping the amplitude of the OFDM signal before filtering, reshape the transmitted OFDM signal to be several transmitted blocks instead of one, DFT spreading technique is also considered one of the most techniques used, and the Selective Mapping technique is also used which depends on multiplying the OFDM signal with phase sequence. All these techniques are simulated and compared between each other. In this chapter an overview of these techniques are discussed and a flow chart of the simulation process are also introducing.

3.2 OVERALL METHODOLOGY

The overall methodology here is the study of different techniques of PARP reduction by performing several simulations as:

- Generating the bit stream to be transmitted.
- Perform OFDM modulation.
- Evaluate the PARP of the OFDM signal without using any reduction technique.
- Perform the reduction technique.

- Evaluate the PARP value after reduction and compare the result with other reduction techniques.
- Compute the BER performance of the OFDM signal with and without PARP reduction.

3.3 THE FLOW CHART OF THE SIMULATIONS

The flow chart of the first section of simulation is as shown in figure 3.1:

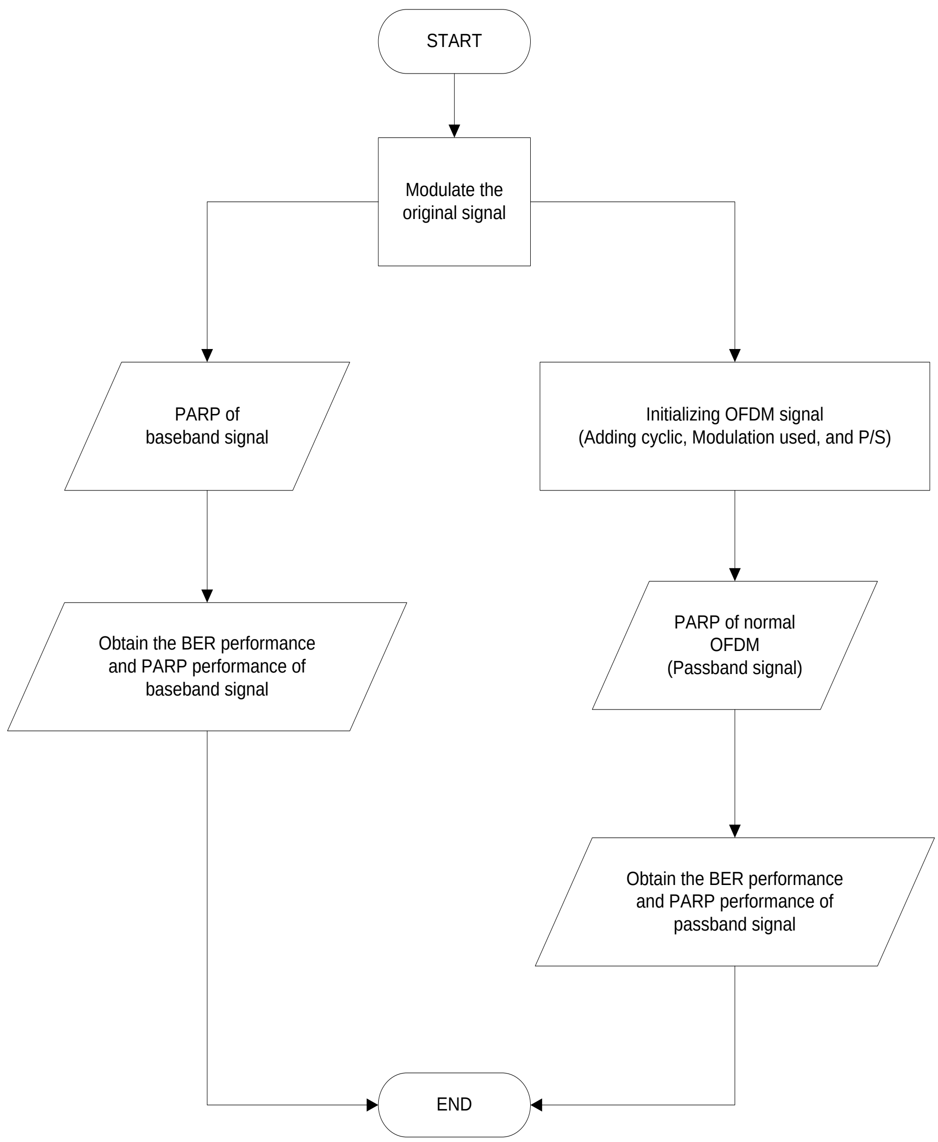


Figure 3.1 The flowchart of the first simulation section as performed in section 4.2

The flow chart of the second simulation section obtained in section 4.3 is as shown in figure 3.2:

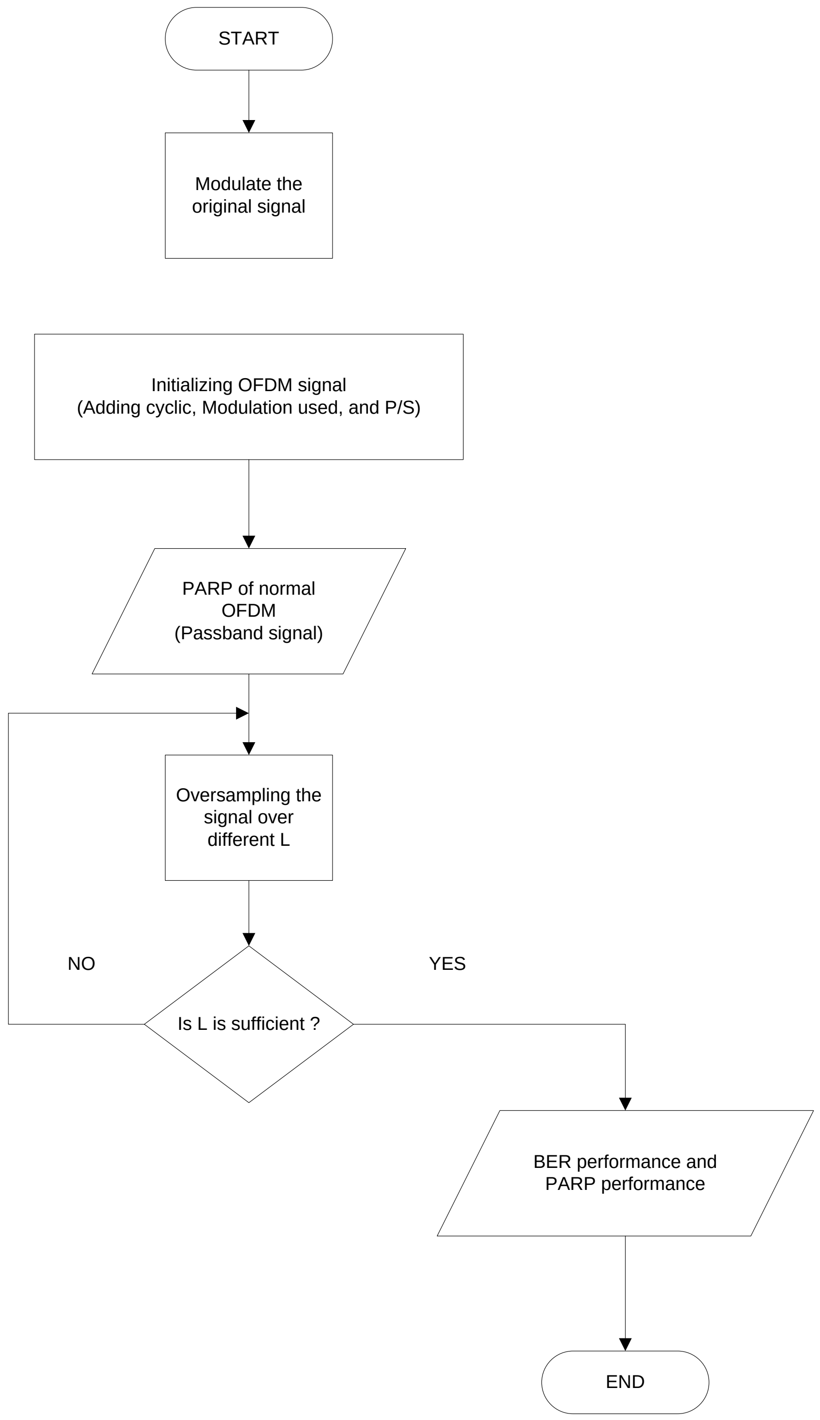


Figure 3.2 The flowchart of the second simulation section as performed in section 4.3

The flow chart of the comparative simulation section obtained in section 4.4 is as shown in figure 3.3:

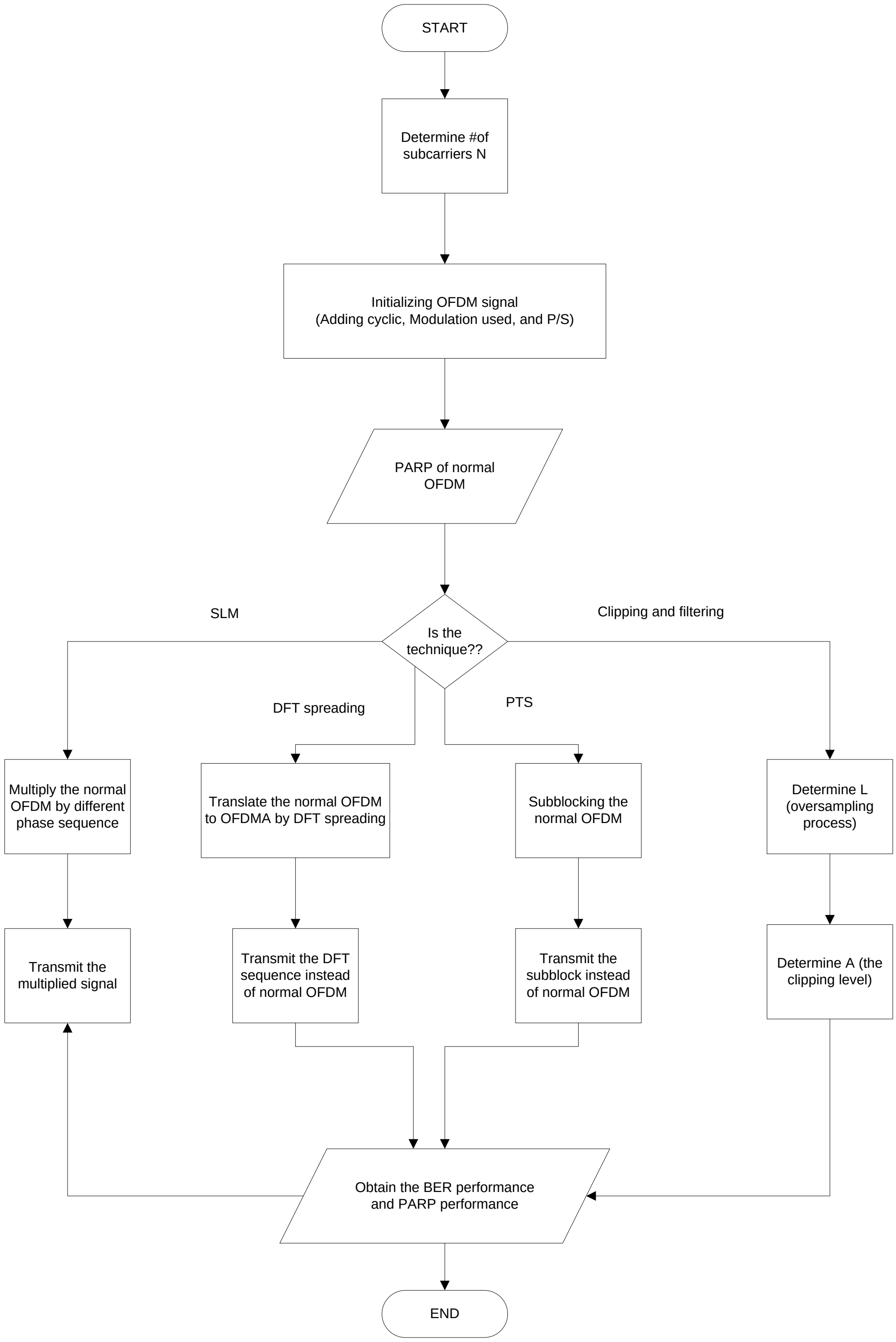


Figure 3.3 The flowchart of the comparative simulation as performed in section 4.4

Table 3-1 Simulation Parameters for the first scenario

Parameters	Setting/ value
Clipping ratio	1.2
Modulation order	QPSK
Number of subcarriers	128
Carrier frequency	2 MHz
Sampling frequency	8 MHz (to make oversampling)
Bandwidth	1 MHz
Number of guard interval samples	32
Interpolation L	4
Number of subblocks V	1 to 16
Roll of factor for pulse shaping	0 to 1
Clipping ratio	1.2
Modulation order	QPSK
Number of subcarriers	128
Carrier frequency	2 MHz
Sampling frequency	8 MHz (to make oversampling)

3.4 MATLAB CODE SETUP

As mentioned before in section 3.3, the MATLAB simulator is used in this comparative study. The code is divided into several sub-codes, each one perform a simulation for a technique. There are several functions used to generate normal OFDM signal like cyclic prefix (CP), adding zeroes, zero padding, clipping function to clip the OFDM signal when using clipping and filtering technique, IFFT-oversampling function to perform oversampling with suitable interpolation L, and the function modulation to perform modulation of signals used. After the technique simulation is finished and the PARP reduction performance is technique, the result is compared with the PARP obtained from the normal OFDM. At the end of chapter 4, a comparison between clipping and filtering technique and the Selective Mapping technique is performed to make sure that the clipping and filtering technique is the simplest technique to perform to reduce PARP if the interpolation level L of the oversampling equal or greater than 4 and the clipping level A is determined accurately.

3.5 SUMMARY

This chapter studied in briefly and details the methodology used in this comparative study. It starts from giving a short overview about the PARP reduction techniques used in this study, and then the flow charts of the three sections of the simulation are obtained. And finally some parameters used in simulation are listed. All simulation results and comparison between techniques are obtained in chapter 4

CHAPTER IV

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, many simulation results are obtained to study the PARP reduction in OFDM MIMO systems using several techniques of reduction like Clipping and Filtering, Partial Transmit Sequence, and DFT Spreading. These techniques are simulated and the PARP results are obtained for each technique. The comparison between results are also obtained and verified experimentally. The proposed algorithms start with OFDM generation signal and perform the reduction technique on the generated signal to obtain the result. The proposed algorithms are simulated using MATLAB environment. This simulation divided into three sections, the first one is the initialization of the OFDM signal and performing a comparison between the PARP reduction between basic OFDM and single carrier signals and between the base band signals and the pass band one. The second section is to compare the basic OFDM signal PARP with the PARP result obtained from clipping the signal to show how clipping affect the performance of signal especially in quantization to be sure that there are techniques to reduce PARP of OFDM. The third section discussed the performance differences between PARP reduction techniques.

4.2 SIMULATION INITIALIZATION

The concept behind the OFDM transmission is that using multi subcarriers where their components were added via an IFFT operation and have high peak values. Because of these high peak values, OFDM signal has great value of PARP higher than the PARP obtained from single-carrier systems. Besides of all the efficient features of OFDM in transmission, the PARP problem is very important to be in the consideration in the Uplink transmission since the limitation of battery power available for the mobile terminal that affects the efficiency of power amplifier.

To initialize the simulation to have an experimentally overview about the response of PARP in OFDM, the generation of OFDM signal is obtained in figure 1 and 2 and the complementary CDF of OFDM is in figure 3.

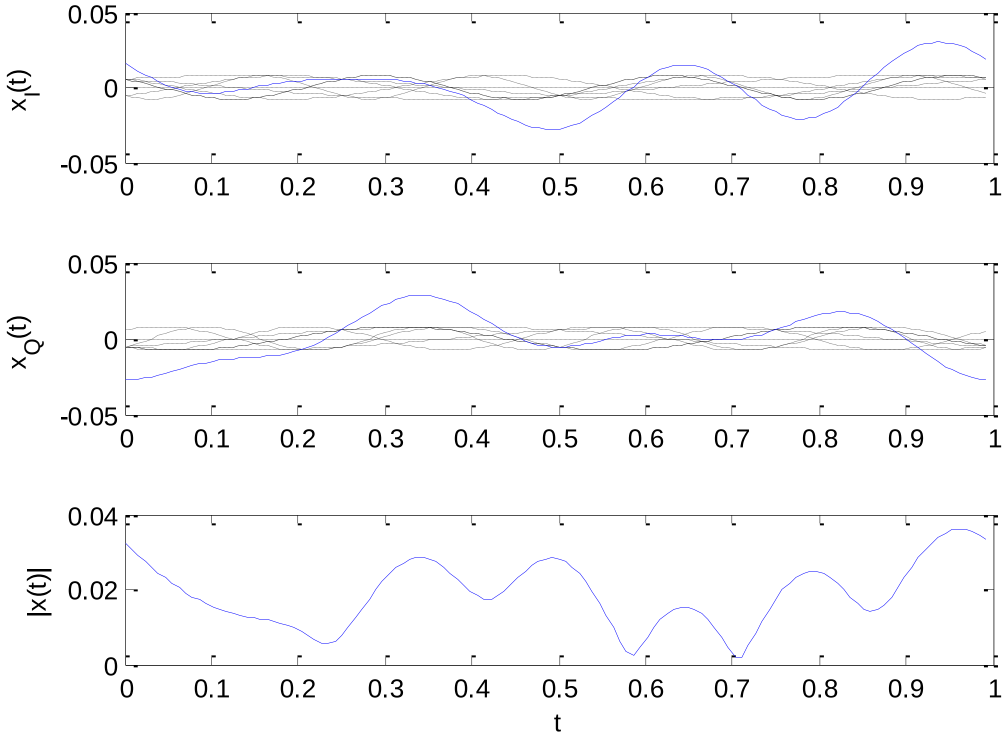


Figure 4.1 Time domain OFDM signal with N=16 and QPSK as modulation

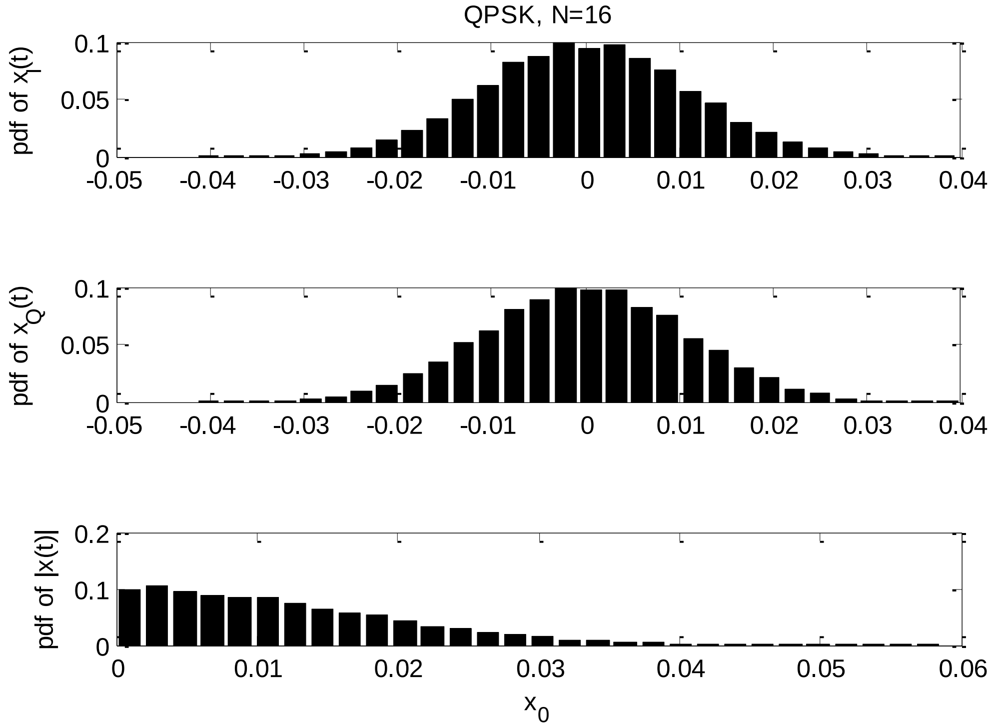


Figure 4.2 OFDM Magnitude distribution

From figures 4.1 and 4.2, the PAPR response of OFDM is increased as N increase. Meanwhile, figure 2 shows that the distribution of the OFDM signal x(t) follows a Gaussian distribution while the magnitude of x(t) |x(t)| follows a Rayleigh distribution.

Figure 4.3 shows the complementary CDF of OFDM to show the effect of N in the OFDM signal. As said before, the PARP response increases as N increase. Figure 3 shows the response of N equals 64, 128, 256, 512, and 1024 respectively. The response shows that there are 1 dB difference from N=64 and N=256 and so on.

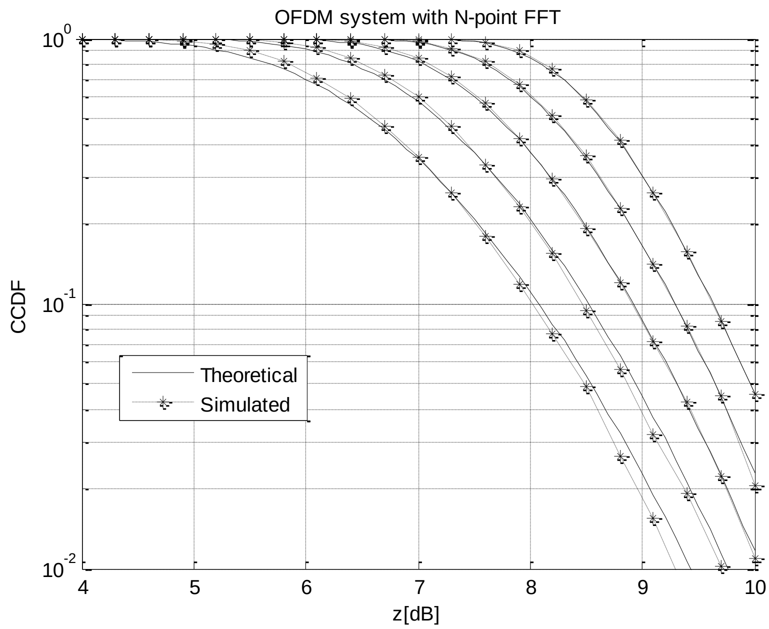


Figure 4.3 OFDM signals distribution with different values of N (64, 128, 256, 512, and 1024).

The PARP distribution of Orthogonal FDM increases as a pass band signal, while the PARP distribution of the base band signals is usually equals zero.

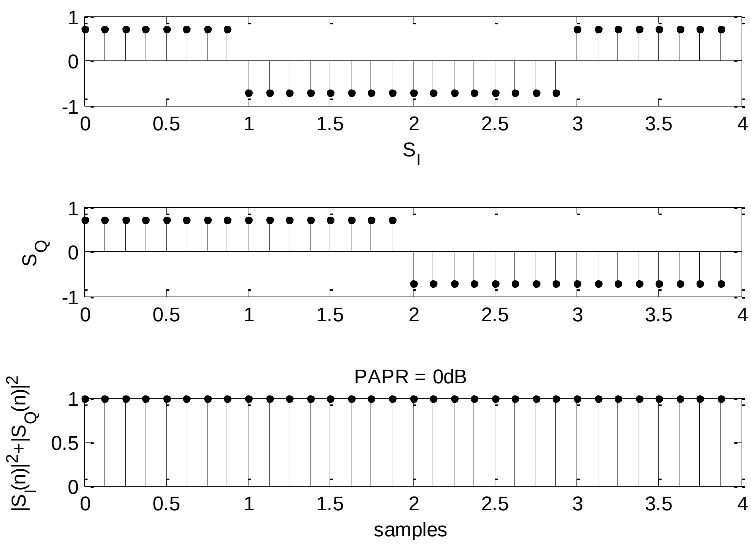


Fig. 4: Baseband signal for QPSK-modulated symbols.

This simulation shows that the PARP response is appeared when the transmitted signal is modulated. Figure 4 shows the base band distribution of the transmitted signal of a single carrier (N=1) while figure 5 shows the pass band distribution of the transmitted signal. The modulation used is QPSK with carrier frequency fc = 1[Hz]. The result shows that the baseband signal has the value of PARP reaches 0dB while the pass band signal has a 3.01 dB of PAPR value. In general, and unlike OFDM, the modulation scheme can use to predict the value of PARP in the single carrier system directly.

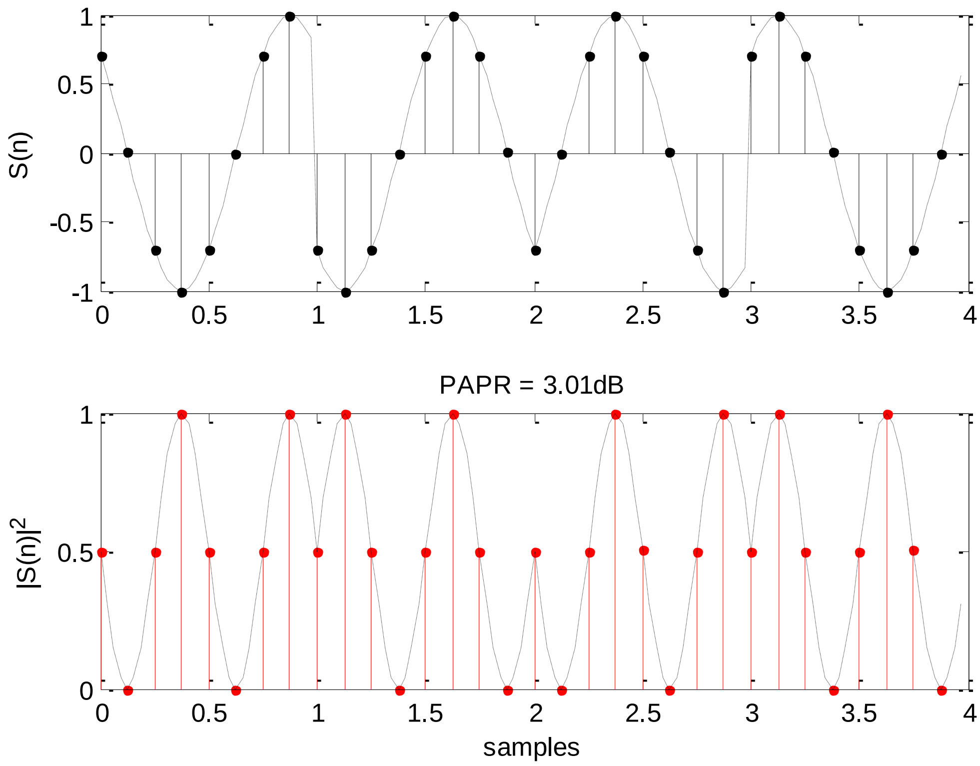


Figure 4.5 Pass band signal for QPSK-modulated symbols.

The MATLAB output:

PAPRs_of_baseband_passband_signals = [0 3.0103]

4.3 THE EFFECT OF OFDM PARP ON SQNR

To reduce the PARP of OFDM, there are several techniques to do this; one of them is the oversampling and its effect on SQNR. Oversampling is done when converting analog signal to digital one (ADC). The PARP of the baseband signal in the continues-time domain is not easy to determine, it is not a straightforward process. Because of this, the measurement is performed in the discrete-time signal x[n]. To have an acceptable PARP from the discrete signal near to that from the continues one, the L-times interpolated (oversampled) should be L≥4. The practical technique to perform oversampling is the use of Chu sequence as shown in figure 4.6.

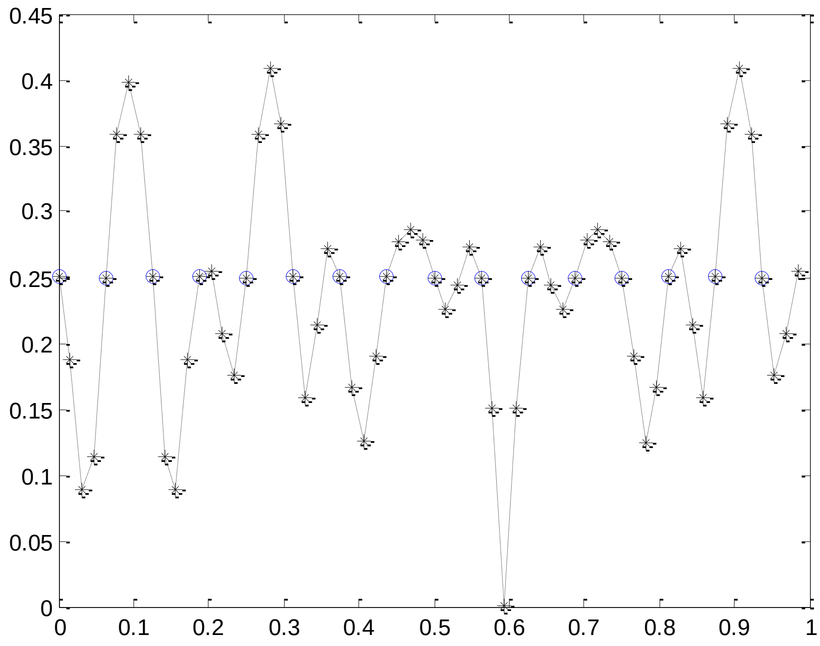


Figure 4.6 Magnitude of IFFT for Chu sequences without and with 4-times oversampling.

Figure 4.6 shows the Chu sequence simulation of number of IFFT equals 16 without the oversampling and with L=4. The values of PAPR obtained from MATLAB calculation is 0dB and 4.27 dB respectively for without and with oversampling. IEEE 802.16e sequence is another sequence shown in figure 7. The figure shows the oversampling of 114 preambles. The result shows that the PARP value with presence of oversampling is 0.4 dB greater than that PARP without oversampling. From figures 6 and 7, it's clear that oversampling process is an important process in the PARP reduction in the baseband transmission.

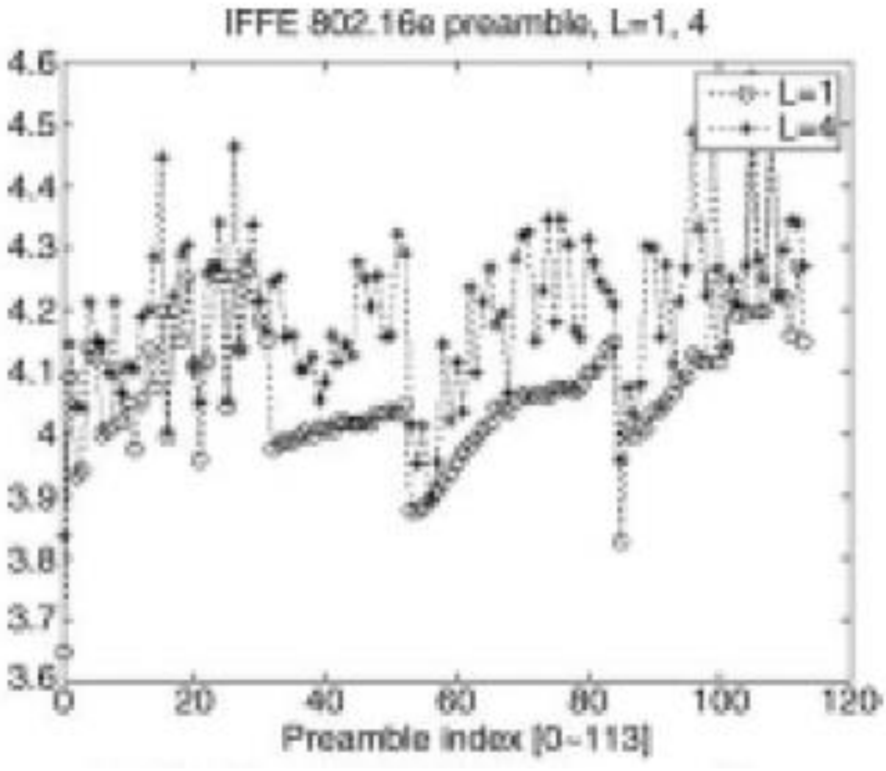


Figure 4.7 PARP of IEEE 802.16e preambles without and with 4-times oversampling

The clipping of the OFDM signal is a very important issue in the PARP reduction. It is affects the quantization process of converting analog signal to digital which affects the SQNR. But the relation between the clipping level and the PARP and quantization noise is critical because when the clipping level is low, the clipping distortion is increased but the quantization noise decreases and vice versa.

Figure 4.8 shows the SQNR response with respect to clipping level. The OFDM signals quantized with different levels as 6, 7, 8, and 9 bits. It is cleared from the figure that the clipping level depends on the quantization level, but it is usually around 4σ in most cases. From the figure, the surrounding area around the maximum point of SQNR is varied according to the clipping level and distortion.

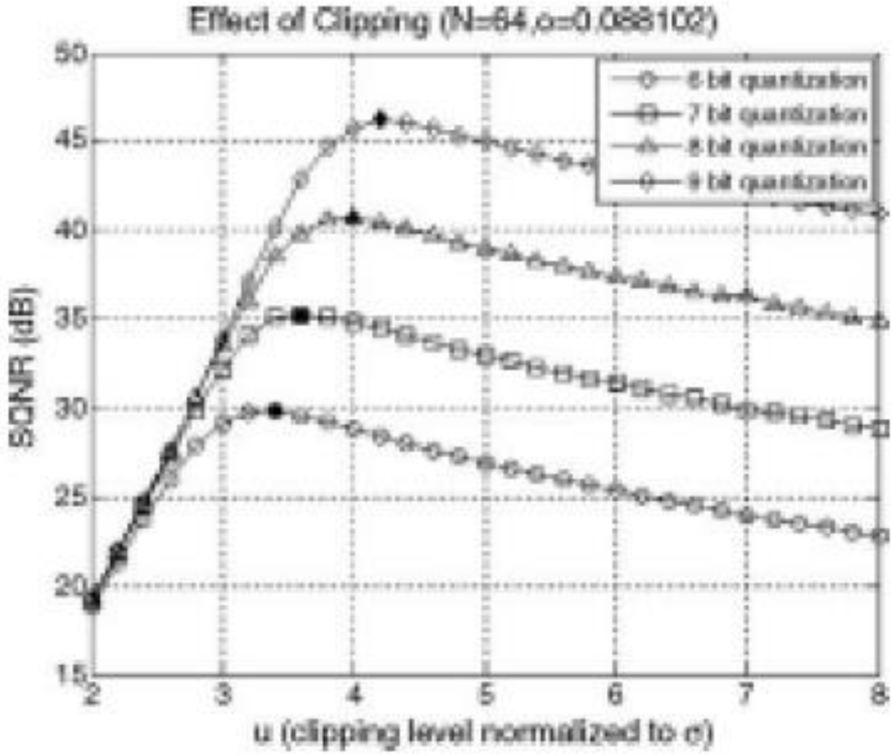


Figure 4.8 Quantized OFDM with different values with respect to the clipping level.

4.4 PARP REDUCTION TECHNIQUES

This part is to study the PARP reduction techniques which are discussed before in previous chapters. These techniques in summary are:

- The clipping technique employs clipping or nonlinear saturation around the peaks to reduce the PAPR.
- The coding technique is to select such code-words that minimize the PAPR.

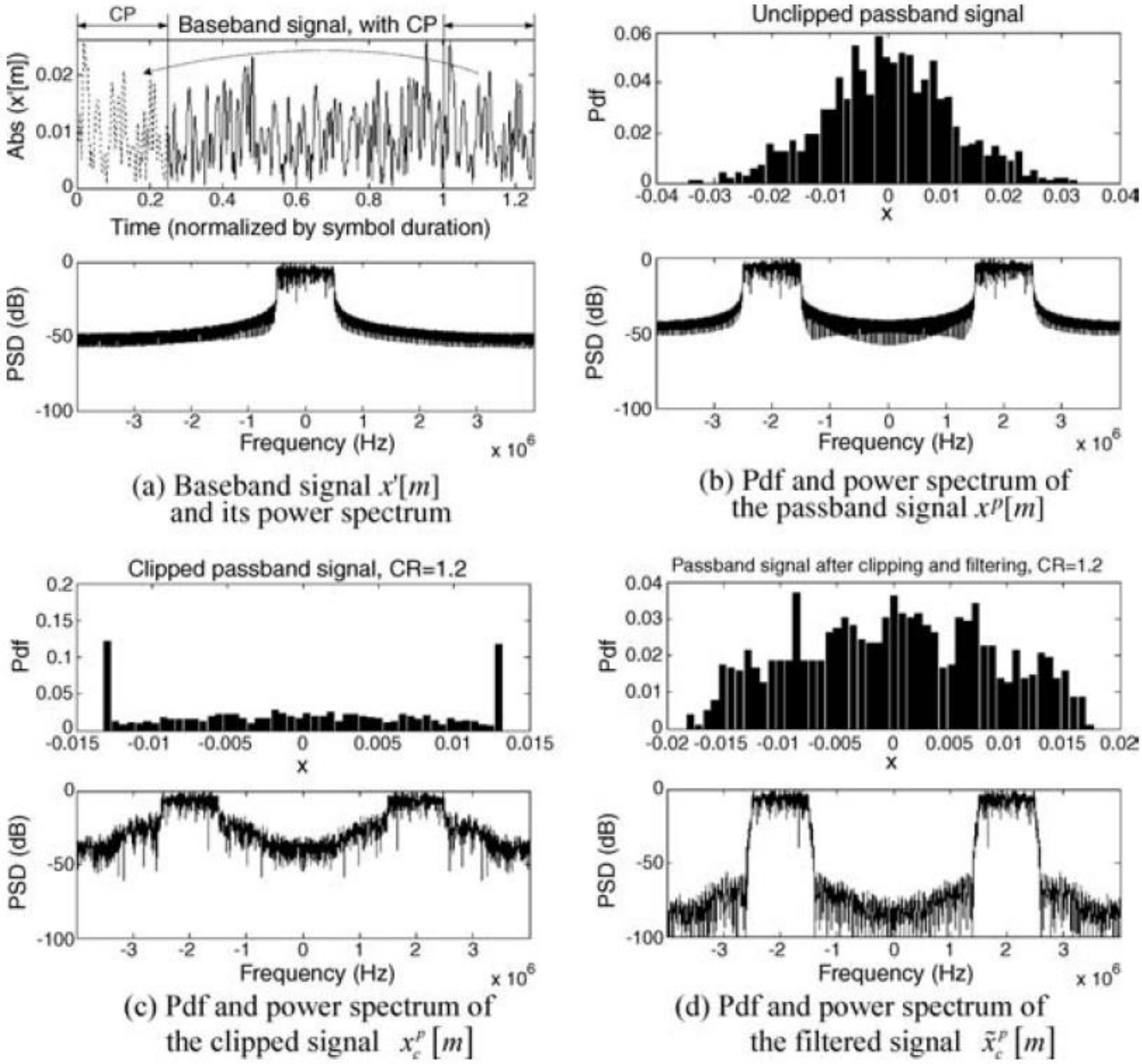
- The probabilistic technique scramble an input data block of the OFDM symbols and transmit one of them with the minimum PAPR to reduce high PARP.
- The adaptive pre-distortion technique
- The DFT-spreading technique

In the following subsections, a simulation study of clipping and filtering, Partial Transmit Sequence, and DFT Spreading are performed and compared between each other.

4.4.1 Clipping and Filtering technique

It is the simplest PAPR reduction technique. It depends on limit the level of the transmitted signal to a pre-specified one. Because it’s simple in construction and because the tradeoff between clipping and SQNR, there are some drawbacks in this technique:

- The BER performance degraded because of the clipping distortion.
- Because of the out-of-band radiation caused by the clipping process, interference between adjacent channels is appeared. This interference can be reduced by reducing the out-of-band radiation by using filtering, but with using a sufficient oversampling to avoid aliasing between signals.



(a) Baseband signal $x'[m]$ and its power spectrum

(b) Pdf and power spectrum of the passband signal $x^p[m]$

(c) Pdf and power spectrum of the clipped signal $x_c^p[m]$

(d) Pdf and power spectrum of the filtered signal $\tilde{x}_c^p[m]$

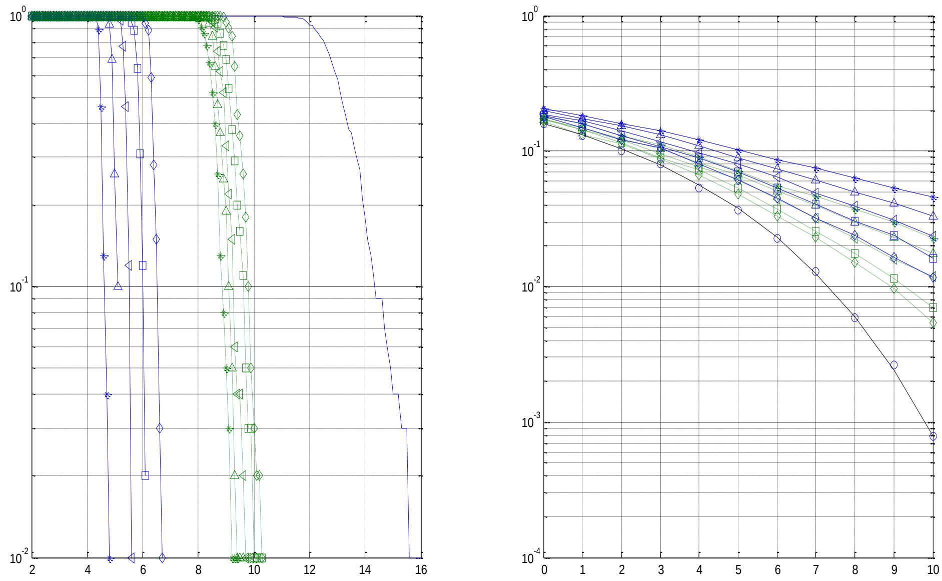
Figure 4.9 Histograms and power spectra of OFDM signal with clipping and filtering.

Figure 4.9 shows the simulation results for this technique with the use of the parameters listed in table 4.1 below. Figure 4.9(c) approved that the clipping level is suitable because all amplitudes of the new signal has values below the clipping level, and also this appeared in figure 9(d) after filtering the clipped signal.

Table 4.1: parameters of clipping and filtering technique

Parameters	Value
Clipping ratio	1.2
Modulation order	QPSK
Number of subcarriers	128
Carrier frequency	2 MHz
Sampling frequency	8 MHz (to make oversampling)
Bandwidth	1 MHz
Number of guard interval samples	32

To simulate the PARP of the clipped and filtered signal, Figure 4.10(a) is obtained. It shows that the PAPR value of the OFDM signal decreases with the use of clipping/filtering technique. The clipping ratio (CR) and PARP reduction is directly proportional. That means the smaller CR result a greater PAPR reduction. From Figure 10(b), the BER performance becomes worse as the CR decreases.



BER response

Figure 4.10 PAPR and BER performance of the OFDM signal with clipping/filtering technique

4.4.2 Partial Transmit Sequence (PTS)

It is simply make the whole signal of N symbols as a one block separated into V disjoint subblocks as follows:

$$X = [X^0, X^1, X^2, \ldots\ldots, X^{V-1}]^T \qquad (4.1)$$

where X^i are the subblocks that are consecutively located and also are of equal size. Figure 11 shows the PARP response of this technique using a 16-QAM modulation of the OFDM signal. It is clear that the PARP performance improves when number of subblocks increases.

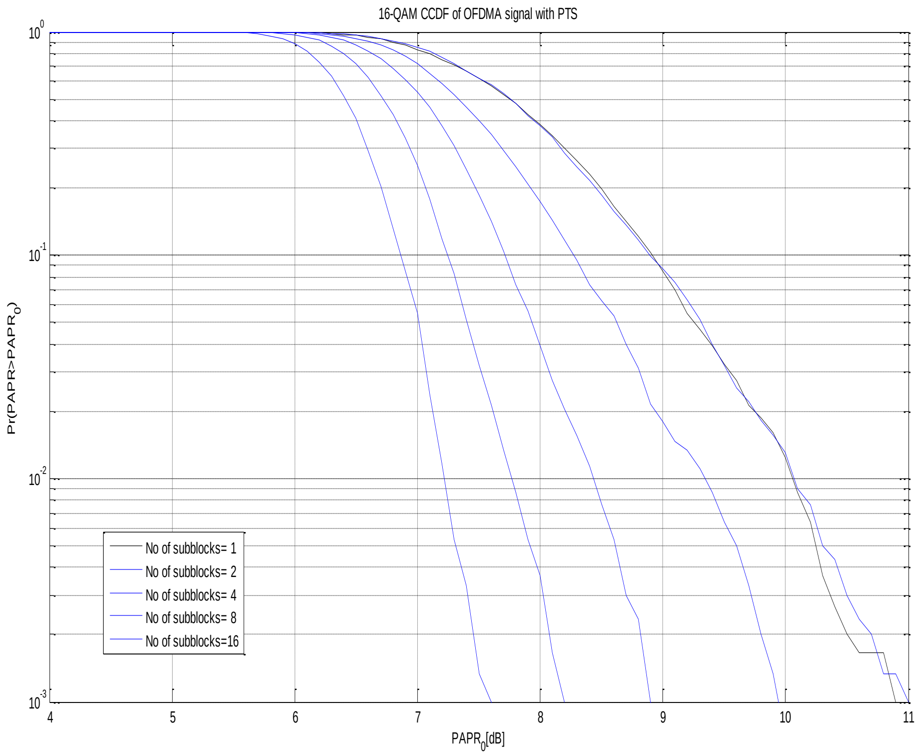


Figure 4.11 PAPR performance when the number of sub blocks varies.

4.4.3 DFT spreading

Suppose that you make DFT of the same size of IFFT as a spreading code to generate the OFDM signal. In this case, the signal is performed with OFDMA and results a good reduction of PARP because ODFMA can process as Single Carrier FDMA system where DFT and IDFT cancel each other virtually. This will improve PARP reduction because the resulted signal is as in a single-carrier system.

Figure 4.12 shows a comparison of several systems used DFT-spreading technique to reduce PARP. These systems are IFDMA, LFDMA, and OFDMA use QPSK, 16-QAM, and 64-QAM as a modulation technique. The figure shows that the PARP in the case of 16-QAM at 10^{-1} are 3.5dB, 8.3dB, and 10.8dB, respectively for IFDMA, LFDMA, and OFDMA with no DFT spreading for OFDMA.

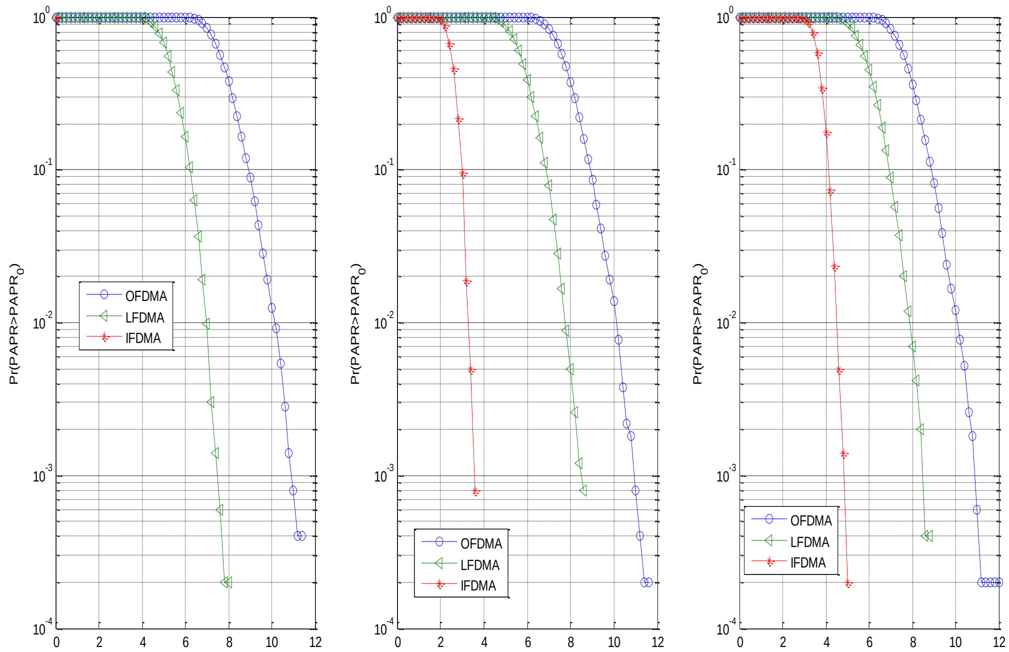


Figure 4.12 PAPR performances of IFDMA, LFDMA, and OFDMA.

Pulse shaping of the DFT-spreading affects the PARP performance as shown in figure 4.13. The figure shows that the pulse shaping improving the performance of IFDMA as α increased from 0 to 1 as the roll-off factor. But this improving does not appears in LFDMA.

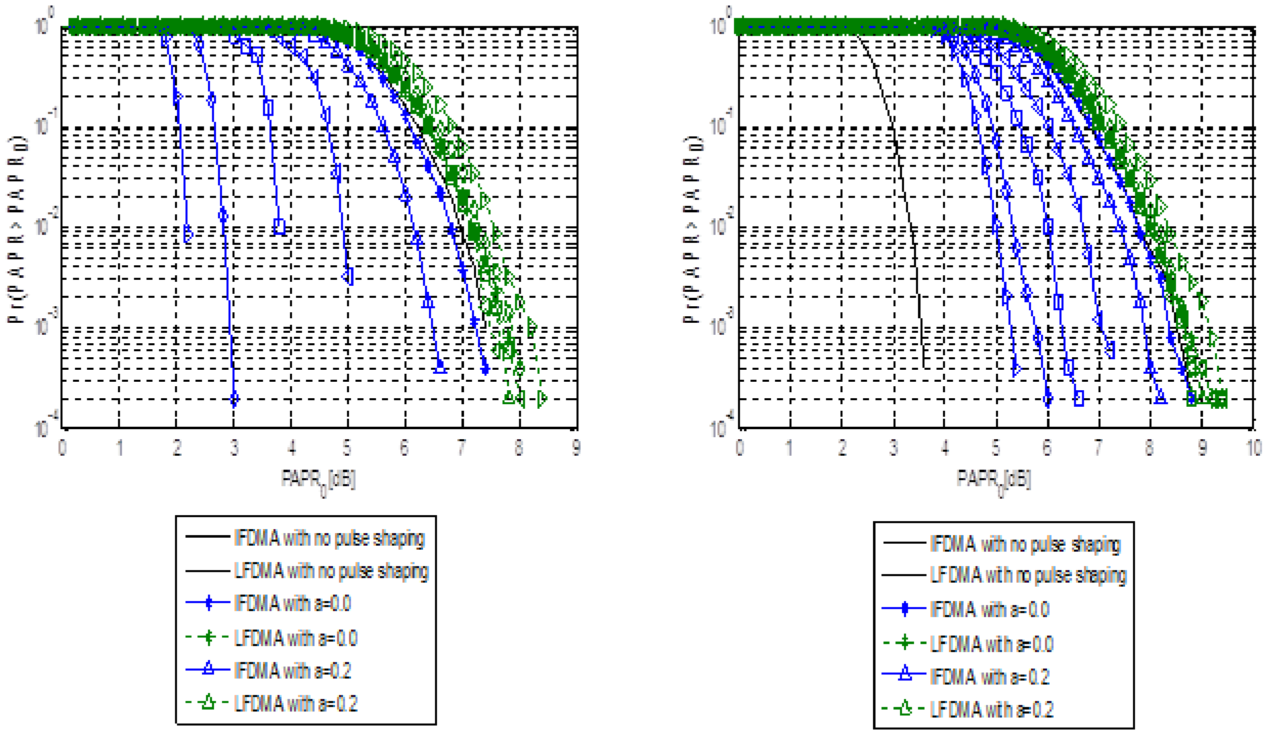


Figure 4.13 PAPR performances of pulse shaping DFT-spreading for QPSK and 16QAM.

As mentioned before, the PARP performance is increased as the number of subcarrier increase. By applying this term to the DFT-spreading technique, figure 14 shows that the PAPR performance of DFT-spreading technique is degraded as number of subcarriers increase.

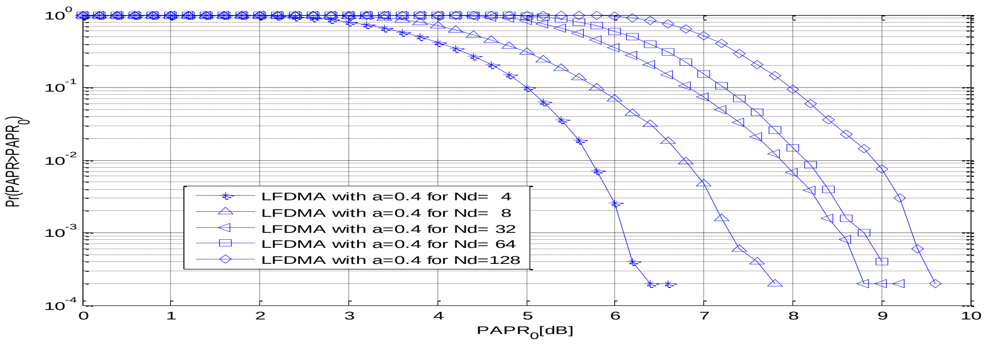


Figure 4.14 PAPR performance of DFT-spreading technique when subcarriers vary.

4.4.4 Selective mapping technique (SLM)

It is a PARP reduction technique for OFDM signal used to reduce the PARP value without increase in power and without any loss of data. So it is a distortion less technique. Figure 15 shows the block diagram of the selective mapping technique. It shows that the OFDM signal **X**=[X[0], X[1], ………, X[N-1]] is multiplied with phase sequence U which its phase vary from [0,2π). This will produce a new sequence $\mathbf{X^u}$=[X^u[0], X^u[1], ….., X^u[N-1]]^T, where the lowest PARP of $\mathbf{X^u}$ is selected for transmission. In receiver, additional information $\mathbf{X^u}$ added to the sequence as a phase index about the selected lowest PARP.

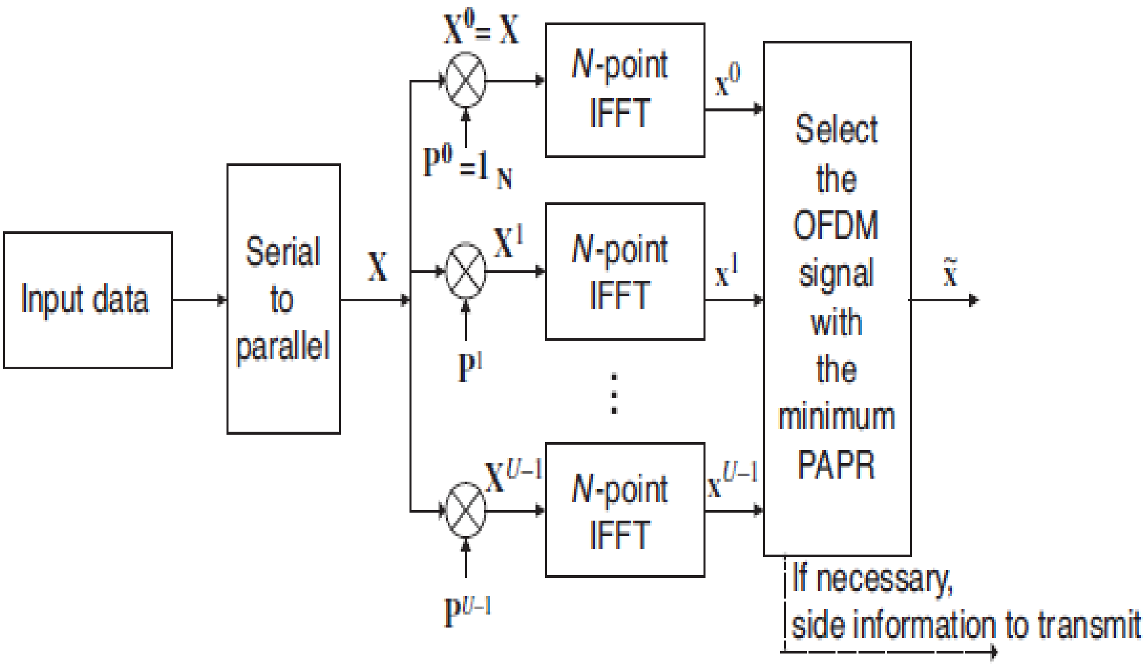


Figure 4.15 Block diagram of SLM technique

Figure 4.16 shows the output of the OFDM signal amplitude for 64 FFT sequence before and after the PARP reduction using selective Mapping. The figure shows that all amplitudes of the OFDM signal are reduced to less than 0.1 which leads a PARP reduction from nearly 18 for normal OFDM signal to 12.8 for SLM-OFDM signal.

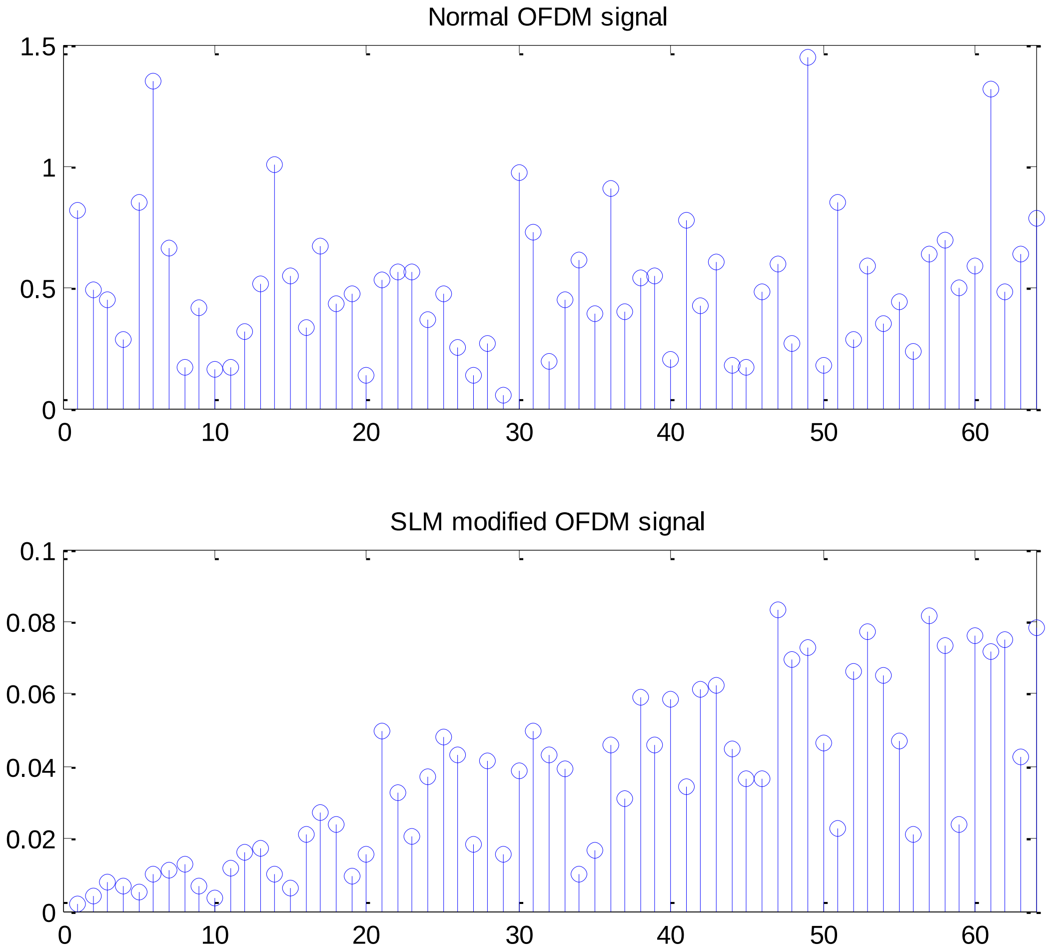


Fig. 16: Comparison between normal OFDM signal PARP with SLM-OFDM signal

From MATLAB output:

PAPR of normal OFDM = 17.9969

PAPR of SLM modified OFDM = 12.8242

4.5 COMPARISON BETWEEN PARP TECHNIQUES

As the number of phases set increases, the efficiency of the SLM method is also increases. This is in general considered a drawback of the SLM technique because increasing the phase amount will increase the computation at the transmitter's and receiver's sides. Another drawback of SLM appears from that the receiver must know phases' sets. It means that the transmitter should send extra sets besides the transmitted signal to let receiver knows the original one.

These drawbacks do not appear in the clipping and filtering technique because this technique depends on only the level of clipping the order of filtering. Also depends on the oversampling ratio L.

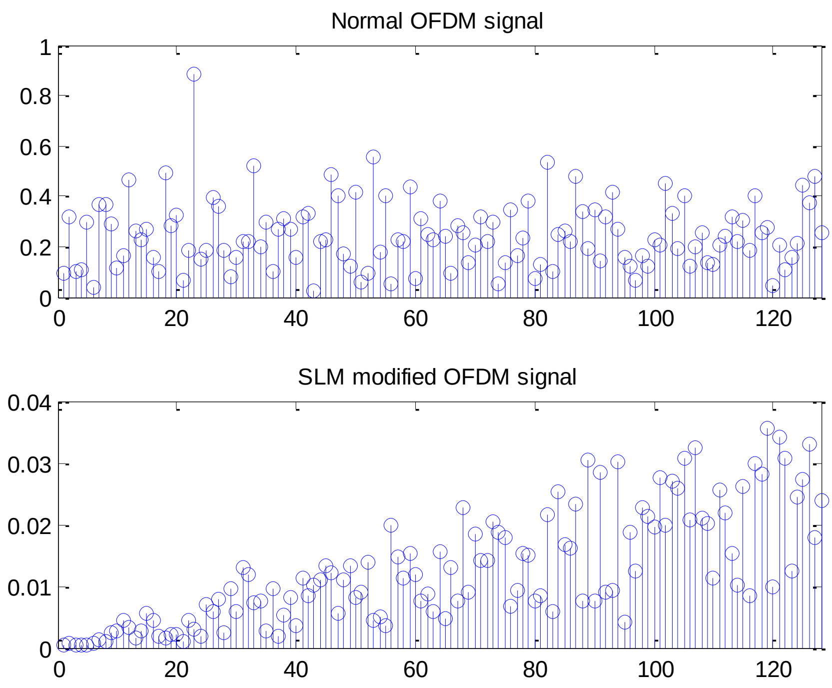


Figure 4.17 SLM-OFDM signal

Figure 4.17 and figure 4.18 show the output result of the SLM technique and clipping and filtering technique respectively. Figure 17 shows the SLM output where all OFDM signal amplitudes lie behind the 0.04 which reduces the PARP ratio. But there are samples of transmission, and when the samples increase the computational process also increases. Figure 18 shows OFDM output signal after clipping and filtering technique. The output shows that the amplitudes of the output signal lies below 0.2 but there are more samples than SLM. The output from the simulation shows that the PARP reduction obtained from the clipping and filtering ratio of 128 FFT sequence is less than this obtained from the SLM technique. The PARP ratio from the clipping and filtering technique is 9.5 while the

PARP from SLM is 16.4. The efficiency of the SLM technique and clipping and filtering technique are 28.6 and 58.4 respectively.

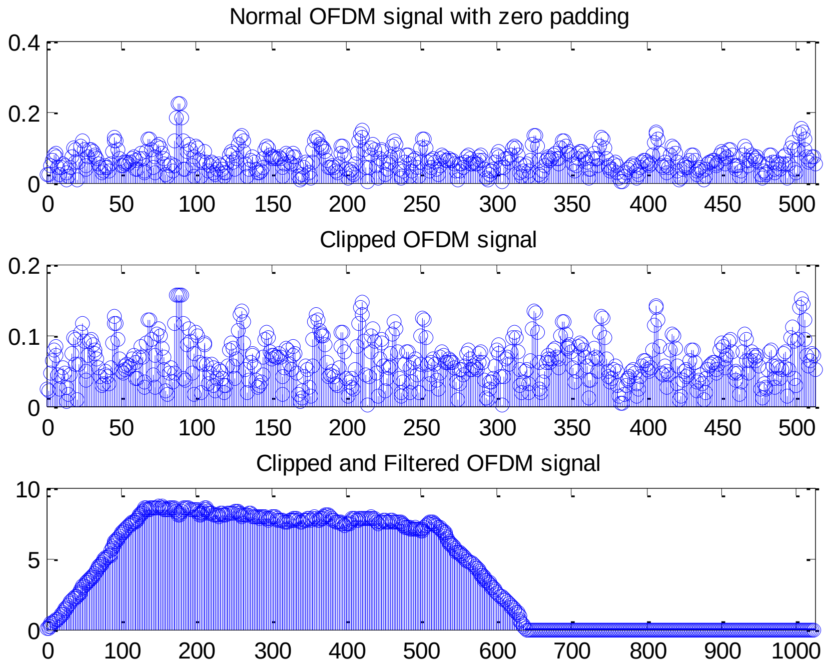


Figure 4.18 Clipping and filtering of OFDM

4.6 SUMMARY

This chapter simulates different techniques to reduce PARP in OFDM. These techniques depend on how the original signal will treat before transmission. The clipping and filtering technique is the simplest technique to improve PARP, it depends on how to choose the suitable value of clipping to reduce clipping distortion and improved PARP. The partial transmit sequence is considered a high technique of reducing PARP, it depends on how the whole signal subdivided into subsignals to transmit each subsignal individually. the phenomena of DFT is cancelled IFFT virtually is also considered one of the attractive way to improve PARP. It depends on transmit the OFDM signal by OFDMA system which result transmitting the OFDM signal as a base band signal (single carrier). Finally, the selective Mapping technique (SLM) is also simulated and compared with clipping and filtering technique. There are also different techniques to reduce OFDM PARP like PAPR Reduction Code, Tone Reservation, and Tone Injection.

CHAPTER V

CONCLUSION AND FUTURE WORKS

5.1 CONCLUSION

The goal of this thesis is to make a full comparison study about the PARP reduction in OFDM. It uses several techniques for reducing PARP in the OFDM system. This thesis generalized the concept of PARP reduction of OFDM instead of single-carrier in most PARP reduction techniques. In addition, this thesis also makes a comparison of PARP reduction in single- carrier signals as a base band signal and an OFDM signal as a passband signal, and how to transform the passband to base band signal to reduce PARP.

The simulation results show that the clipping and filtering technique is the simplest technique to improve PARP, it depends on how to choose the suitable value of clipping to reduce clipping distortion and improved PARP. In the other hand, the partial transmit sequence is considered a high technique of reducing PARP, it depends on how the whole signal subdivided into subsignals to transmit each subsignal individually and this subdivided transmission is generalized to selective Mapping technique. Using OFDMA concept transfer the transmission of OFDM to be like transmission a single-carrier signal which means reduction of PARP. This transformation performed by using the phenomena of DFT which cancelled IFFT virtually. All supposed techniques of reducing PARP are simulated and their results are compared together.

5.2 FUTURE WORK

There are several possible future works like:

- Reducing the out-of-band radiation which affects the transmitted signal in a way without using filtering.
- Enhance the trade-off between PAPR reduction, BER and spectral spreading.

- Using the PARP reduction techniques in different channel response like fading channel and compared the results.
- Using hybrid techniques by combining two or more methods of PARP reduction together.

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