Islamic University of Technology (IUT)

PEAK TO AVERAGE POWER RATIO REDUCTION IN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM

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A thesis presented to
The Academic Faculty

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Declaration

This is to certify that the project entitled “**PEAK TO AVERAGE POWER RATIO REDUCTION IN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM”** is supervised by Dr. Mohammad Rakibul Islam. This project work has not been Submitted anywhere for a degree.

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Dedicated To Our Parents

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ABSTRACT

High data rate and speedy communication has become the ultimate goal of any communication research work. Multiplexing of signal bits is an important part of the wireless communication system. OFDM (Orthogonal Frequency Division Multiplexing) has become a promising technique at present days wireless communication technology due to its extraordinary features.

This thesis paper represents a total overview of OFDM system, basic principles of OFDM system, OFDM generation and reception. Though it has some salient and supreme features over other multiplexing techniques, still has some drawbacks which limit its performance in some cases.

So an investigation has been done to minimize the effects of these drawbacks, specially emphasis is put on to reduce the PAPR (Peak to Average Power Ratio) of OFDM signals. Several techniques to minimize PAPR has been investigated and finally some new techniques have been proposed to minimize PAPR.

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List of Abbreviations

OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak to Average Power Ratio
SLM	Selected Mapping
LPF	Low Pass Filter
DAC	Digital to Analog Converter
ADC	Analog to Digital Converter
GSM	Global System for Mobile Communication
UMTS	Universal Mobile Telecommunication System
GPRS	General Packet Radio Service
ITU	International Telecommunication Union

Chapter 1

Introduction

For the last few years, the advancement in wireless communication technology has been shooting up like a rocket to the sky. It is true that the extraordinary communication system is among the some of the few key issues for which the civilization has climbed up and is exploring at its peak now. Today's age is age of information technology and communication which could not be imagined except the radical change in communication technology.

The history of wireless communication technology is not very ancient one. The journey of it started at the mid of previous century. Gradually and rapidly this technology tree has enhanced its branches with immense opportunities like leaves and flowers and human civilization has started to enjoy its fruits. The evolution state is now transiting between the third and the fourth generation. Figure 1.1 shows the data rates of previous, current and future wireless communication technology [1]

In this introduction, we will try to have a glimpse over the major breakthroughs of wireless communication evolution.

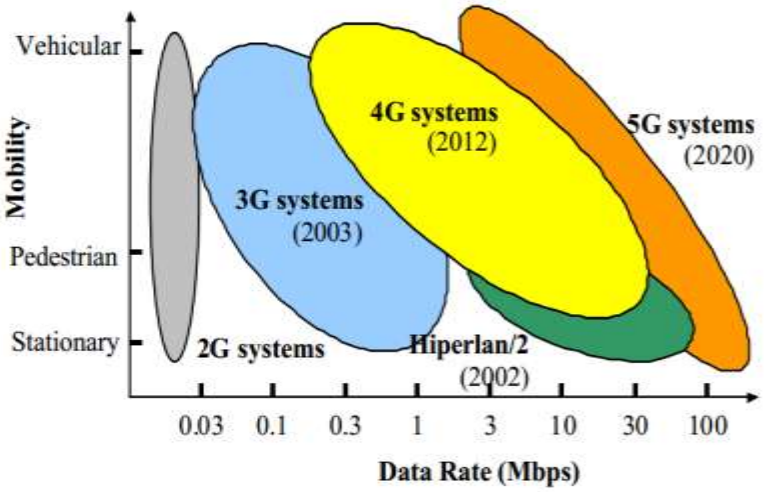


Figure 1.1: Previous, Current &Future Generation Mobile System

1.1 First Generation Wireless System

First-generation mobile systems used analog transmission for speech services. The two most popular analog systems were Nordic Mobile Telephones (NMT) and Total Access Communication Systems (TACS). Other than NMT and TACS, some other analog systems were also introduced in 1980s across the Europe. All of these systems offered handover and roaming capabilities but the cellular networks were unable to interoperate between countries. This was one of the undesired disadvantages of first-generation mobile networks. In the United States, the Advanced Mobile Phone System (AMPS) was launched in 1982. The system was allocated a 40-MHz bandwidth within the 800 to 900 MHz frequency range by the Federal Communications Commission (FCC) for AMPS. In 1988, an additional 10 MHz bandwidth, called Expanded Spectrum (ES) was allocated to AMPS. AMPS and TACS use the frequency modulation (FM) technique for radio transmission. Traffic is multiplexed onto an FDMA (frequency division multiple access) system [2-3].

1.2 Second Generation Wireless System

Second-generation (2G) mobile systems were introduced in the end of 1980s. Low bit rate data services were supported as well as the traditional speech service. Compared to first-generation systems, second-generation (2G) systems use digital multiple access technology, such as TDMA (time division multiple access) and CDMA (code division multiple access). Consequently, compared with first-generation systems, higher spectrum efficiency, better data services, and more advanced roaming were offered by 2G systems. In Europe, the Global System for Mobile Communications (GSM) was deployed to provide a single unified standard. Global System for Mobile Communications, or GSM, uses TDMA technology to support multiple users During development over more than 20 years, GSM technology has been continuously improved to offer better services in the market.

The next advancement in the GSM system was the addition of two platforms, called Voice Mail Service (VMS) and the Short Message Service Centre (SMSC). The move into the 2.5G world began with General Packet Radio Service (GPRS). GPRS is a radio technology for GSM networks that adds packet-switching protocols, shorter setup time for ISP connections, and the possibility to charge by the amount of data sent, rather than connection time. GPRS is the most significant step towards 3G. GSM and EDGE (Enhanced Data rates in GSM Environment) with both voice and data traffic moving on the system, the need was felt to increase the data rate. Thus the advent of third generation became important.

1.3 Third Generation Wireless System

The International Telecommunication Union (ITU) defined the demands for 3G mobile networks with the IMT-2000standard. An organization called 3rd Generation Partnership Project (3GPP) has continued that work by defining a mobile that fulfills the IMT-2000 standard. In Europe it was called UMTS (Universal Mobile Telecommunication System), which is ETSI-driven.

IMT2000 is the ITU-T name for the third generation system, while cdma2000 is the name of the American 3G variant. WCDMA is the air-interface technology for the UMTS. 3G networks enable network operators to offer users a wider range of more advanced services while achieving greater network capacity through improved spectral efficiency. Services include wide-area wireless voice telephony, video calls, and broadband wireless data, all in a mobile environment.

Additional also include HSPA (High Speed Packet Access) data transmission capabilities able to deliver speeds up to 14.4 Mbps on the downlink and 5.8 Mbps on the uplink. The first commercial 3G network was launched by NTT DoCoMoin Japan branded FOMA, based on W-CDMA technology on October 1, 2001 [4]. In fact, most of these applications will not be limited by the data rate provided by 3G systems, but by the cost of the service.

1.4 Fourth Generation System & Beyond

Research are going on the development of 4th generation (4G) mobile communication systems. The commercial rollout of these systems is likely to begin around 2008 - 2012, and will replace 3rd generation technology. Few of the aims of 4G networks have yet published, however it is likely that they will be to extend the capabilities of 3G networks, allowing a greater range of applications, and improved universal access. Ultimately 4G networks should encompass broadband wireless services.

1.5 History of OFDM

The origins of OFDM development started in the late 1950's [5] with the introduction of Frequency Division Multiplexing (FDM) for data communications. In1966 , the structure of was patented by Chang [6] and published [7] the concept of using orthogonal overlapping multi-tone signals for data communications. In 1971, Weinstein [8] introduced the idea of using a Discrete Fourier Transform (DFT) for of the generation and reception of OFDM signals, eliminating the requirement for banks of analog subcarrier oscillators. This presented an opportunity for an easy implementation of OFDM, especially with the use of Fast Fourier Transforms (FFT), which are an efficient implementation of the DFT. This suggested that the easiest implementation of OFDM is with the use of Digital Signal Processing (DSP), which can implement FFT algorithms. It is only recently that the advances in integrated circuit technology have made the implementation of OFDM cost effective. Reliance on DSP prevented the widespread use of OFDM during the early development of OFDM. It wasn't until the late 1980's that began on the development of OFDM for commercial use, with the introduction of the Digital Audio Broadcasting (DAB) system.

1.6 Thesis Layout

This thesis comprises of six chapters.

Chapter 1 represents the background of the present work, motivation, objectives and related work with this thesis.

Chapter 2 discusses about fundamental principles of orthogonal frequency division multiplexing technique and characteristics of this modulated transmitted signal.

Chapter 3 discusses on main drawback of OFDM that is Peak to Average Power Ratio problem and different techniques to reduce it.

Chapter 4 focuses on a specific technique that is Selected mapping technique to reduce PAPR.

Chapter 5 proposes a possible modified SLM technique to achieve a better performance.

Chapter 6 concludes the whole work with a brief summary and some future suggestions.

CHAPTER 2

Basic Principles of OFDM

2.1 What is OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is almost identical to the popular and used technique of Frequency Division Multiplexing (FDM). OFDM uses the proposition of FDM to entitle several messages to be sent over a single radio channel. It is however in a much more dominated manner, permitting an enhance spectral efficiency.

A general example of FDM is the use of various frequencies for each frequency modulation radio stations. Because of using different transmit carrier frequencies, all stations transmit at the same time but do not constrain with each other. Moreover, they are bandwidth bounded and are spaced adequately distant in frequency so that the signals processed do not overlap in the frequency domain. At the receiver side, each signal is especially received by using a frequency adjustable band pass filter to precisely remove all the signals except for the station of concern. This filtered signal can then be demodulated to recover the original processed data.

OFDM is unlike to FDM in various ways. In typical condition broadcasting each radio station permits on a different frequency, efficiently using FDM to maintain a distinction between the stations. There is however no synchronization between these stations. With an OFDM transmission such as Digital Audio Broadcasting (DAB), the information signals from several stations is combined into a single multiplexed stream of data. This data is then processed using an OFDM ensemble that is made up from a concentrated packing of many subcarriers. All the subcarriers within the OFDM signal are time and frequency synchronized to each other, permitting the intercession between subcarriers to be carefully controlled.

Due to the orthogonal essence of the modulation, do not cause Inter-Carrier Interference (ICI) yet these several subcarriers overlap in the frequency domain. Usually with FDM the transmission signals need to have a large frequency guard-band between channels for preventing intercession. This shrinks the inclusive spectral efficiency. Anyhow with OFDM the orthogonal packing of the subcarriers significantly lowers this guard band, enhancing the spectral efficiency. All the wireless telecommunication systems use a modulation scheme to map the data signal to a form that can be especially processed over the communications channel.

With the most acceptable one, a wider range of modulation arrangements has been improved, determined on if the signal information is an analogue waveform or a digital one. Some of the regular analogue modulation arrangements contain Frequency Modulation (FM), Amplitude Modulation (AM), Phase Modulation (PM), Single Side Band (SSB), Vestigial Side Band (VSB), Double Side Band Suppressed Carrier (DSBSC) [9], [10]**.** Whereas digital communications include, Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM) [9] – [11]

In a FDM transmission, each of the carriers can use both an analogue or digital modulation scheme. There is no synchronization between the transmission and so from one side it could be transmitted using FM and another in digital using FSK. In a single OFDM transmission all the subcarriers are synchronized to each other, regulating the transmission to digital modulation schemes.

OFDM is symbol based, and can be thought of as a large number of low bit rate carriers transmitting in parallel. To clinch that the orthogonal essence of the formation is sustained, all the carriers transmit in simultaneous using synchronized time and frequency, appearing a single block of spectrum. As these several carriers form a single OFDM transmission, they are recurrently represented to as ‘subcarriers’, with the terminology of ‘carrier’ retained for set out the RF carrier interlacing the signal from base band.

Orthogonality will be maintained if they are mutually substantive to each other. Orthogonality is a property that permits several data signals to be processed accurately over a regular channel and identified, without intercession. Dropping of orthogonality effects in obscuring between these information signals and desensitizing in communications. Several regular multiplexing arrangements are natively orthogonal. Time Division Multiplexing (TDM) permits transmission of several data signals over a single channel by allocating distinctive time slots to each separate data signal. In time of each time period only the signal from a single origin is processed intercepting any intercession between the multiple information sources. For the reason of this TDM is orthogonal in essence. In the frequency domain most FDM systems are orthogonal as each of the separate transmission signals are well expanded out in frequency intercepting intercession.

Since these methods are orthogonal, the terminology OFDM has been reserved for a special form of FDM. The subcarriers in an OFDM signal are expanded as well matched as is theoretically feasible while sustaining orthogonality between them. OFDM attains orthogonality in the frequency domain by assigning each of the distinct data signals onto various subcarriers. OFDM signals are done up from aggregate of sinusoids, with each accordance to a subcarrier. The baseband frequency of each subcarrier is selected to be an integer multiple of the inverse of the symbol time, developing in all subcarriers having an integer number of cycles per symbol.

As a consequence the subcarriers are orthogonal to each other. Figure 2-1 shows the formation of an OFDM signal with four subcarriers.

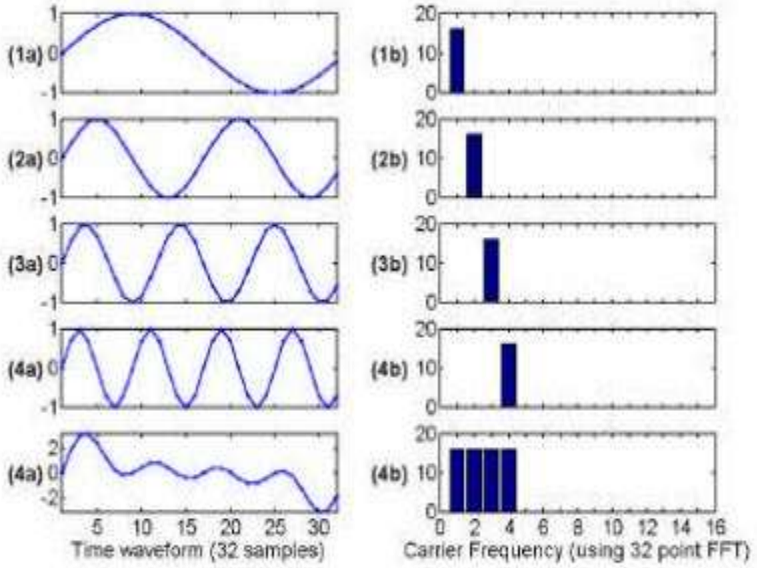


Figure 2-1: Time domain formation of an OFDM signal.

(1a), (2a), (3a) and (4a) show individual subcarriers, with 1, 2, 3, and 4 cycles per symbol accordingly. The phase on all these subcarriers is zero.

(1b), (2b), (3b) and (4b) show the FFT of the time waveforms in (1a), (2a), (3a) and (4a) accordingly.

(4a) and (4b) shows the result for the summation of the 4 subcarriers.

If any two different functions within the set are multiplied, and integrated over a symbol period, then the result will be zero, for orthogonal functions.

Further way of reasoning of this is that, at a matched receiver for one of the orthogonal functions, a subcarrier in the case of OFDM, then the receiver will only see the result for that function. The results from all other functions in the set integrate to zero, and hence have no effect.

Sets of functions are orthogonal to each other if they match the criterions in equation (2-1).

$$\int_0^T s_i\,(t) s_j(t) dt = \begin{cases} C\ i = j \\ 0\ i \neq j \end{cases} \tag{2-1}$$

Equation (2-2) shows a set of orthogonal sinusoids, which represent the subcarriers for an unmodulated real OFDM signal.

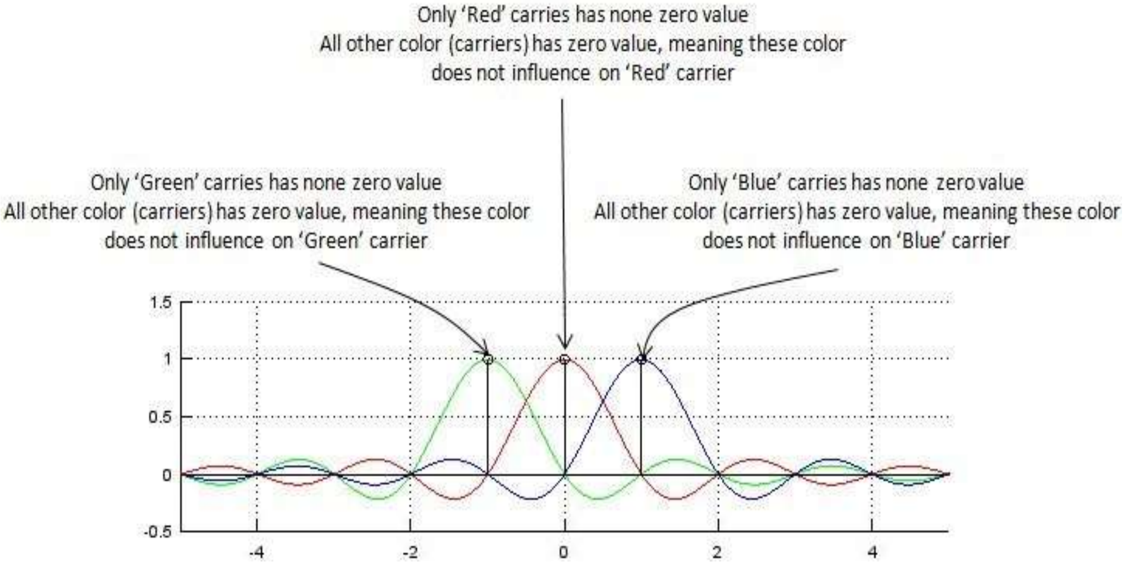
$$s_k(t) = \begin{cases} \sin(\,2\pi k f_0 t) & {\scriptstyle 0<t<T \quad k=1,2,\ldots M} \\ 0 & {\scriptstyle otherwise} \end{cases} \tag{2-2}$$

where, f_o is the carrier spacing, M is the number of carriers, T is the symbol period. Since the highest frequency component is Mf_o the transmission bandwidth is also Mf_o.

2.2 Frequency Domain Orthogonality

Another way to view the orthogonality property of OFDM signals is to look at its spectrum. In the frequency domain each OFDM subcarrier has a sinc, sin(x)/x, frequency response, as shown in Figure 2-2. This is a result of the symbol time corresponding to the inverse of the carrier spacing. As far as the receiver is concerned each OFDM symbol transmitted for a fixed time (TFFT) with no tapering at the ends of the symbol. This symbol time corresponds to the inverse of the subcarrier spacing of 1/TFFT Hz 1. This rectangular, boxcar, waveform in the time domain results in a sinc frequency response in the frequency domain. The sinc shape has a narrow main lobe, with many side-lobes that decay slowly with the magnitude of the frequency difference away from the centre. Each carrier has a peak at the centre frequency and nulls evenly spaced with a frequency gap equal to the carrier spacing.

The orthogonal nature of the transmission is a result of the peak of each subcarrier corresponding to the nulls of all other subcarriers. When this signal is detected using a Discrete Fourier Transform (DFT) the spectrum is not continuous as shown in Figure 2-2 (a), but has discrete samples. The sampled spectrum are shown as ‘o’s in the figure. If the DFT is time synchronized, the frequency samples of the DFT correspond to just the peaks of the subcarriers, thus the overlapping frequency region between subcarriers does not affect the receiver. The measured peaks correspond to the nulls for all other subcarriers, resulting in orthogonality between the subcarriers.



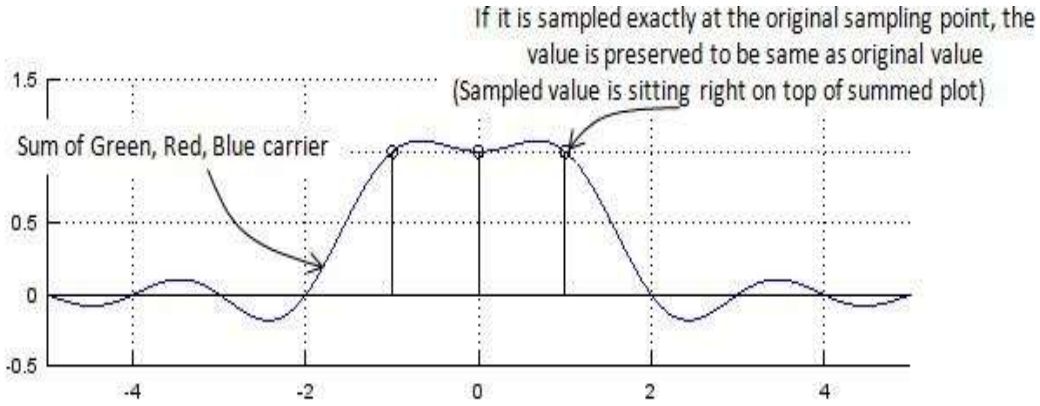


Figure 2-2: Frequency response of the subcarriers in a 3 tone OFDM signal.

2.3 OFDM Generation and Reception

OFDM signals are typically generated digitally due to the difficulty in creating large banks of phase lock oscillators and receivers in the analog domain. Figure 2-3 shows the block diagram of a typical OFDM transceiver. The transmitter section converts digital data to be transmitted, into a mapping of subcarrier amplitude and phase. It then transforms this spectral representation of the data into the time domain using an Inverse Discrete Fourier Transform (IDFT). The Inverse Fast Fourier Transform (IFFT) performs the same operations as an IDFT, except that it is much more computationally efficiency, and so is used in all practical systems. In order to transmit the OFDM signal the calculated time domain signal is then mixed up to the required frequency.

The receiver performs the reverse operation of the transmitter, mixing the RF signal to base band for processing, then using a Fast Fourier Transform (FFT) to analyze the signal in the frequency domain. The amplitude and phase of the subcarriers is then picked out and converted back to digital data. The IFFT and the FFT are complementary function and the most appropriate term depends on whether the signal is being received or generated. In cases where the signal is independent of this distinction then the term FFT and IFFT is used interchangeably.

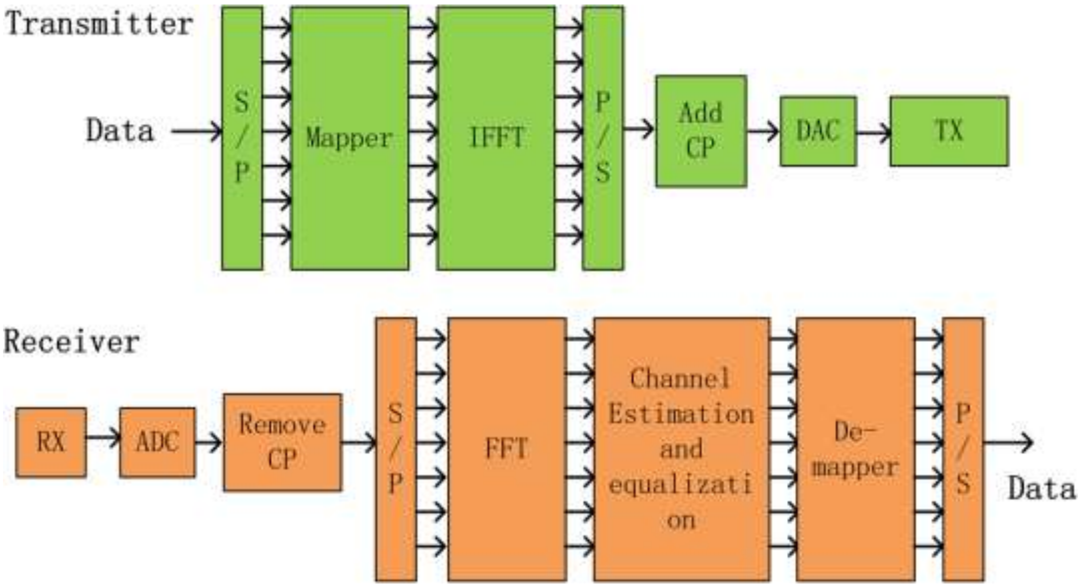


Figure 2-3: Block diagram showing a basic OFDM transceiver.

2.4 Serial to Parallel Conversion

Data to be transmitted is typically in the form of a serial data stream. In OFDM, each symbol typically transmits 40 - 4000 bits, and so a serial to parallel conversion stage is needed to convert the input serial bit stream to the data to be transmitted in each OFDM symbol. The data allocated to each symbol depends on the modulation scheme used and the number of subcarriers. For example, for a subcarrier modulation of 16-QAM each subcarrier carries 4 bits of data, and so for a transmission using 100 subcarriers the number of bits per symbol would be 400.

For adaptive modulation schemes such as described in section 4.2, the modulation scheme used on each subcarrier can vary and so the number of bits per subcarrier also varies. As a result the serial to parallel conversion stage involves filling the data payload for each subcarrier. At the receiver the reverse process takes place, with the data from the subcarriers being converted back to the original serial data stream.

When an OFDM transmission occurs in a multipath radio environment, frequency selective fading can result in groups of subcarriers being heavily attenuated, which in turn can result in bit errors. These nulls in the frequency response of the channel can cause the information sent in neighboring carriers to be destroyed, resulting in a clustering of the bit errors in each symbol. Most Forward Error Correction (FEC) schemes tend to work more effectively if the errors are spread evenly, rather than in large clusters, and so to improve the performance most systems employ data scrambling as part of the serial to parallel conversion stage. This is implemented by randomizing the subcarrier allocation of each sequential data bit. At the receiver the reverse scrambling is used to decode the signal. This restores the original sequencing of the data bits, but spreads clusters of bit errors so that they are approximately uniformly distributed in time. This randomization of the location of the bit errors improves the performance of the FEC and the system as a whole.

2.5 Frequency to Time Domain Conversion

After the subcarrier modulation stage each of the data subcarriers is set to an amplitude and phase based on the data being sent and the modulation scheme; all unused subcarriers are set to zero. This sets up the OFDM signal in the frequency domain. An IFFT is then used to convert this signal to the time domain, allowing it to be transmitted. Figure 2-5 shows the IFFT section of the OFDM transmitter. In the frequency domain, before applying the IFFT, each of the discrete samples of the IFFT corresponds to an individual subcarrier. Most of the subcarriers are modulated with data. The outer subcarriers are unmodulated and set to zero amplitude. These zero subcarriers provide a frequency guard band before the nyquist frequency and effectively act as an interpolation of the signal and allows for a realistic roll off in the analog anti-aliasing reconstruction filters.

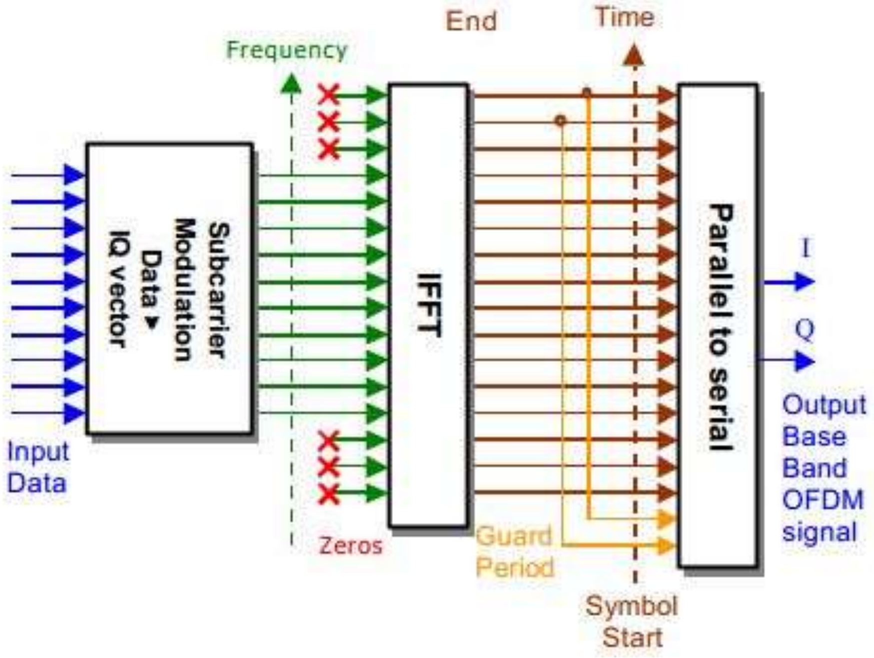


Figure 2-4: OFDM generation, IFFT stage

2.6 RF Modulation

The output of the OFDM modulator generates a base band signal, which must be mixed up to the required transmission frequency. This can be implemented using analog techniques as shown in Figure 2-7 or using a Digital Up Converter as shown in Figure 2-8. Both techniques perform the same operation, however the performance of the digital modulation will tend to be more accurate due to improved matching between the processing of the I and Q channels, and the phase accuracy of the digital IQ modulator.

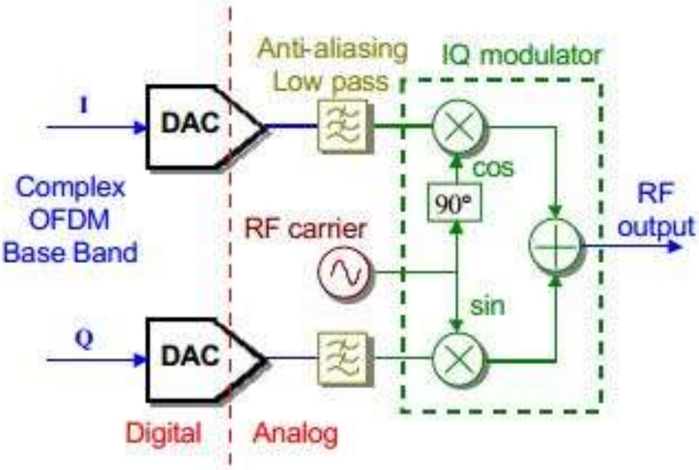


Figure 2-5: RF modulation of complex base band OFDM signal, using analog techniques.

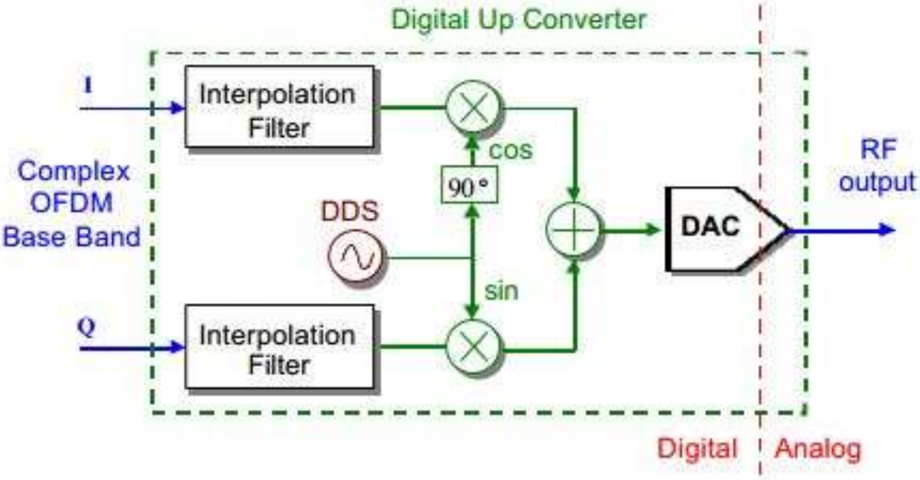


Figure 2-6: RF modulation of complex base band OFDM signal, using digital techniques.

Chapter 3

PAPR In OFDM

3.1 Concept of PAPR

The high PAPR is one of the most detrimental aspects in the OFDM system, as it decreases the SQNR (Signal-to-Quantization Noise Ratio) of ADC (Analog-to-Digital Converter) and DAC (Digital-to-Analog Converter) while degrading the efficiency of the power amplifier in the transmitter. The PAPR problem is more important in the uplink since the efficiency of power amplifier is critical due to the limited battery power in a mobile terminal. The ratio between the maximum power and the average power of the complex passband signal $\tilde{s}(t)$ is represented by PAPR [12], that is,

$$PAPR\{\tilde{s}(t)\} = \frac{\max\left|Re\left(\tilde{s}(t)e^{j2\pi f_c t}\right)\right|^2}{E\ \{|Re(\tilde{s}(t)e^{j2\pi f_c t})|^2\}}$$
$$= \frac{\max|s(t)|^2}{E\ \{|s(t)|^2\}} \qquad (3-1)$$

The above power characteristics can also be described in terms of their magnitudes by defining the crest factor (CF) as

Passband Condition : $CF = \sqrt{PAPR}$

Baseband Condition : $CF = \sqrt{PMEPR}$

Where PMEPR is the ratio between the maximum power and the average power , that is,

$$PMEPR\{\tilde{s}(t)\} = \frac{\max|\tilde{s}(t)|^2}{E\{|\tilde{s}(t)|^2\}} \qquad (3\text{-}2)$$

The maximum power occurs when all of the N subcarrier components are added with identical phases in case of OFDM. The maximum power will be equivalent to N times the average power that is PAPR=N for the assumption $E\{|s(t)|^2\} = 1$. Whereas, the probability of the occurrence of the maximum power signal increases as N decreases [13]. Considering M^2 OFDM signals with the maximum power among M^N OFDM signals, the occurrence probability of the largest $PAPR$ is $M^2/M^N = M^{2-N}$, that turns out to be 4.7 x 10^{-38} in the case of OFDM with N=64. [14]. This indicates rare occasion of largest PAPR. While the input signals of N-point IFFT have the uniformly distributed independent and finite magnitudes which are for QPSK and QAM, we can assume that the real and imaginary parts have asymptotically Gaussian distributions for a sufficiently large number of subcarriers by the central limit theorem. The amplitude of the OFDM signal $s(t)$ then follows a Rayleigh distribution. Let $\{\boldsymbol{Z}_n\}$ the magnitudes of complex sample $\{|s(nT_s/N|\}_{n=0}^{N-1}$ .Assuming that the average power of $s(t)$ is equal to one, that is, $E\{|s(t)|^2\} = 1$, then$\{\boldsymbol{Z}_n\}$ are the independent and identically distributed Rayleigh random variables normalized with its own average power, which has the following probability density function:

$$fz_n(z) = \frac{z}{\sigma^2} e_{2\sigma^2}^{-z^2} = 2ze^{-z^2}, n = 0, 1, 2, \cdots, N-1 \qquad (3\text{-}3)$$

Where $E\{\boldsymbol{Z}_n^2\} = 2\sigma^2 = 1$. Let $\boldsymbol{Z}_{max}$denote the crest factor.$(\text{i.e.}, \boldsymbol{Z}_{max} = max_{n=0,1,\cdots,N-1}\, \boldsymbol{Z}_n)$

Now, the cumulative distribution function (CDF) of $\boldsymbol{Z}_{max}$is given as:

$$\begin{aligned} F_{\mathbf{Z}_{max}}(z) &= P(\mathbf{Z}_{max} < z) \\ &= P(\mathbf{Z}_0 < z) \cdot P(\mathbf{Z}_1 < z) \ldots P(\mathbf{Z}_{N-1} < z) \\ &= \left(1 - e^{-z^2}\right)^N \qquad (3-4) \end{aligned}$$

Where $P(\mathbf{Z}_n < z) = \int_0^2 f_{\mathbf{Z}_n}(x)dx,\ n = 0,1,2,\cdots, N-1$

In order to find the probability that the crest factor (CF) exceeds z, considering the following complementary CDF (CCDF):

$$\begin{aligned} \tilde{F}_{\mathbf{Z}_{max}}(z) &= P(\mathbf{Z}_{max} > z) \\ &= 1 - P(\mathbf{Z}_{max} \le z) \\ &= 1 - F_{\mathbf{Z}_{max}}(z) \\ &= 1 - (1 - e^{-z^2})^N \qquad (3\text{-}5) \end{aligned}$$

Since earlier equations are derived assuming that N samples are independent and N is sufficiently large, they do not hold for the band limited or for oversampled signals. However, deriving the exact CDF for the oversampled signals is difficult and therefore, the following simplified CDF will be used:

$$F_z(z) \approx (1 - e^{-z^2})^{\alpha N} \tag{3-6}$$

Where α has to be determined by fitting the theoretical CDF into the actual one [15]. The PAPR defined earlier deals with the passband signal with a carrier frequency of $f_c$in the continuous time domain. A continuous time baseband OFDM signal$x(t)$with the symbol period $T_s$and the corresponding passband signal $\tilde{x}(t)$with the carrier frequency f_c have almost the same PAPR since$f_c$in general is much higher than $1/T_s$, [16]. However, the PAPR for the discrete-time baseband signal$x[n]$may not be the same as that for the continuous-time baseband signal$x(t)$.

In order to see the effect of oversampling or interpolation on PAPR, considering the PAPRs of the specific sequences, such as, Chu sequence and IEEE 802.16e preamble sequences.

3.2 Sampling Effect on PAPR:

The PAPR defined in Equation (3.7) deals with the passband signal with a carrier frequency of fc in the continuous time domain. Since fc general is much higher than 1=Ts, a continuous time baseband OFDM signal x(t) with the symbol period Ts and the corresponding passband signal~   x(t) with the carrier frequency fc have almost the same PAPR . However, the PAPR for the discrete-time baseband signal x½n may not be the same as that for the continuous-time baseband signal x(t).In fact, the PAPR for x½n is lower than that for x(t), simple because x½ may not have all the peaks of x(t) [17-18]. In practice, the PAPR for the continuous-time baseband signal can be

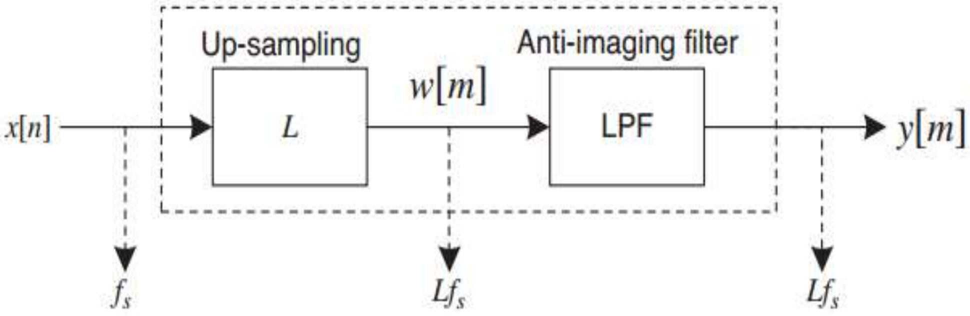


Figure 3-1: Block diagram of L-times interpolator.

measured only after implementing the actual hardware, including digital-to-analog convertor (DAC). In other words, measurement of the PAPR for the continuous-time baseband signal is not straightforward. Therefore, there must be some means of estimating the PAPR from the discrete-time signal x½n. Fortunately, it is known that x½n can show almost the same PAPR as x(t) if it is L-times interpolated (oversampled) .

Figure 3-1 shows the block diagram of interpolator with a factor of L it was citation 170. It inserts L-1 zeros between the samples of x[n] to yield w[m] as follows:

$$w[m] = \{x[{}^{m}\!/\!_{L}], \quad \text{for m=0,} \pm \text{L,} \pm \text{2L,...} \\ 0 \quad \text{elsewhere} \tag{3-7}$$

A low pass filter is used to construct the L-times-interpolated version of x[n] from w[m]. For the LPF with an impulse response of h[m], the L-times-interpolated output y[m] can be represented as

$$y[m] = \sum_{k=-\infty}^{\infty} h[k]w[m-k] \tag{3.8}$$

Figures 3.2 and 3.3 illustrate the signals and their spectra appearing in the oversampling process with a sampling frequency of 2kHz to yield a result of interpolation with L=4.

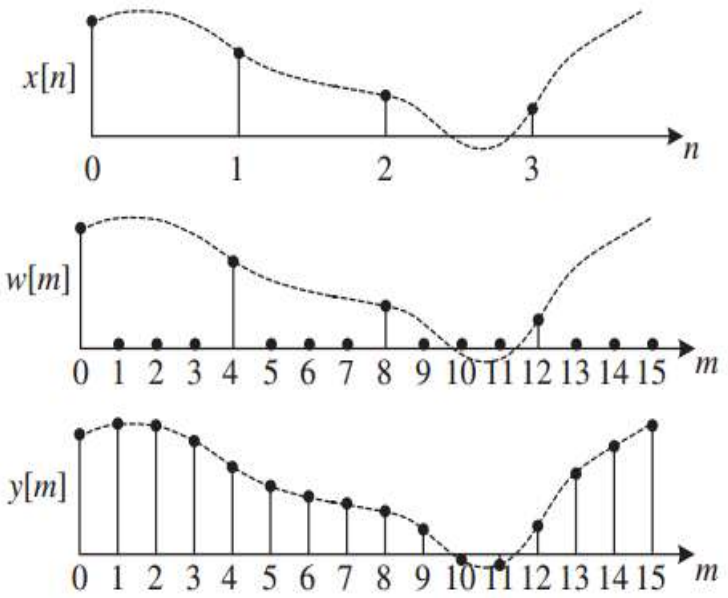


Figure 3-2: Time Domain Interpolation (L=4)

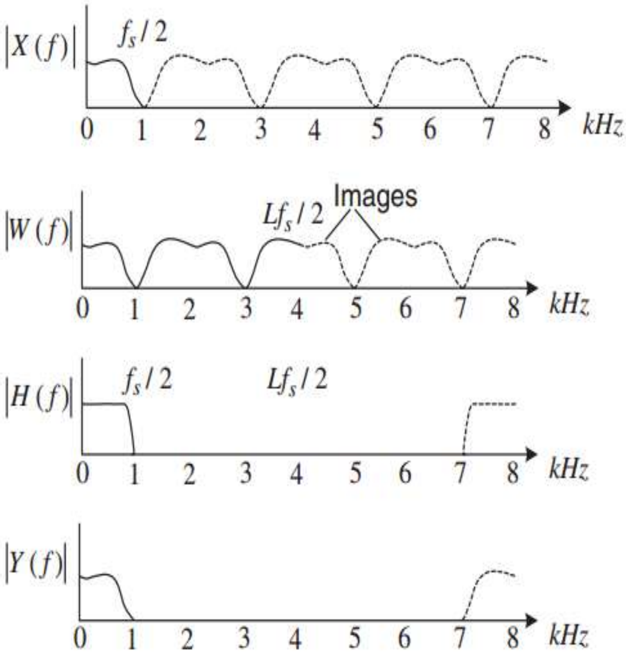


Figure 3-3: Frequency Domain Interpolation (L=4)

In point of fact, simply because $x[n]$may not have all the peaks of$x(t)$, the PAPR for $x[n]$is lower than that for $x(t)$. For an L-times-interpolated signal, the PAPR is now redefined as

$$PAPR = \frac{\max_{m=0,1,\ldots,NL}|x'[m]|^2}{E\{|x'[m]|^2\}} \tag{3-9}$$

3.3 Concept of CCDF:

The cumulative distribution function (CDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. In our thesis work, the complementary CDF (CCDF) is commonly used instead of the CDF itself. The CCDF of the PAPR denotes the probability that the PAPR of a data block exceeds a given threshold. In [19] a simple approximate expression is derived for the CCDF of the PAPR of a multicarrier signal with Nyquist rate sampling. From the central limit theorem, the real and imaginary parts of the time domain signal samples follow Gaussian distributions, each with a mean of zero and a variance of 0.5 for a multicarrier signal with a large number of subcarriers. Hence, the amplitude of a multicarrier signal has a Rayleigh distribution, while the power distribution becomes a central chi-square distribution with two degrees of freedom. The CDF of the amplitude of a signal sample is given by

$$F(z) = 1 - \exp(z). \tag{3-10}$$

What we want to derive is the CCDF of the PAPR of a data block. The CCDF of the PAPR of a data block with Nyquist rate sampling is derived as

$$\begin{aligned} P(PAPR > z) &= 1 - P(PAPR \leq z) \\ &= 1 - F(z)N(6) \\ &= 1 - (1 - \exp(-z))N \end{aligned} \tag{3-11}$$

This expression assumes that the N time domain signal samples are mutually independent and uncorrelated. This is not true, however, when oversampling is applied. Also, this expression is not accurate for a small number of subcarriers since a Gaussian assumption does not hold in this case. Therefore, there have been many attempts to derive more accurate distribution of PAPR. Refer to [20–23] for more results on this issue.

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3.4 Different Techniques For PAPR Reduction:

Different techniques to reduce peak to average power ratio of OFDM transmitted signal which have been proposed upto now are shown in tabulated form.

3.4.1 Clipping Technique:

Clipping is the simplest technique to reduce PAPR in OFDM system. Within a particular threshold value different parts of signal are clipping. As a result out of band distortion occurs. Due to this orthogonality of subcarriers changes therefore rise in bit error rate. To avoid this, the clipped signal is desired to be a narrowband. At transmitter, clipping is performed so that receiver will have to determine the signal clipping by calculating location and size of the signal. Doing filtering process repeatedly reduce re-peak growth. Some clipping processes are Block-scaling, Clipping & Filtering, Peak windowing, Peak cancellation, Fourier projection, Decision-aided reconstruction.

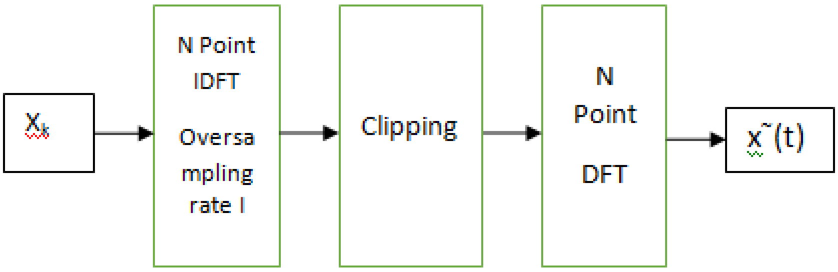


Figure 3-4: Block diagram of a PAPR reduction scheme using clipping

3.4.2 Coding Technique:

The coding scheme is used to minimize PAPR of OFDM signals with appropriate block coding and set of code words. Unlike signal distortion techniques it creates no out-of-band radiation therefore we also get a minimum bit error rate. On the other hand, it is troubled with inefficient bandwidth when the code rate gets reduced . Finding the best codes and storing tables in order to encode and decode create difficulties in particularly for large number of subcarriers.

The technique is done by adding a Simple Odd Block Code at the last bit across the channels. When N signals having the same phase added together therefore results in the peak power which is N times the average power. There we get code words with good PAPR and bad PAPR too. We have to select the codeword which gives the best PAPR reduction reducing the occurrence . To select the better code we need to consider M-ray phase, modulation scheme, any type of coding rate, which are suitable for encoding decoding. Error correction or error decoding is also a major concern.

3.4.3 Adaptive predistiorion technique:

Adaptive predistorter is an efficient scheme to compensate for nonlinear distortion in a power amplifier. As a method to improve the parameter convergence speed in the predistorter, a series expansion technique having orthogonal polynomials has been investigated. To achieve the parameter optimization speed improvement of the predistorter, a method is needed to determine step-size in a recursive calculation. The parameter convergence performance of the predistorter is investigated in OFDM systems with and without peak-to-average power ratio (PAPR) reduction, where the partial transmit sequence (PTS) technique is employed to reduce PAPR . Computer simulation results show that the proposed adaptive predistorter achieves faster parameter convergence time than that of non-orthogonal one in OFDM systems with nonlinear power amplifier affected by memory effect, even though PAPR of OFDM signal is reduced by using PTS. It is also confirmed that power added efficiency is further improved by combining the adaptive predistortion with PAPR reduction technique.

3.4.4 DFT-spreading technique:

DFT-spread OFDM (DFTS-OFDM) is a transmission scheme that can combine the desired properties for uplink transmission i.e.; small variations in the instantaneous power of the transmitted signal, possibility for low-complexity high-quality equalization in the frequency domain, possibility for FDMA with flexible bandwidth assignment. Due to these properties, DFTS-OFDM has been selected as the uplink transmission scheme for LTE, which is the long-term 3G evolution. Because of the single carrier property, it is also known as single carrier FDMA (SC-FDMA) system. As in OFDMA, the transmitters in an SC-FDMA system use different orthogonal frequencies (subcarriers) to transmit information symbols. However, they transmit the subcarriers sequentially, rather than in parallel. Relative to OFDMA, this arrangement reduces considerably the envelope fluctuations in the transmitted waveform . Therefore, SC-FDMA signals have inherently lower PAPR than OFDMA signals.

3.4.5 Signal Scrambling Technique:

Signal scrambling technique is mainly based on phase rotation method. The fundamental rule of this technique is to generate multiple signal waveforms which carry the same information and then choose the waveform from those candidates with the smallest PAPR for transmission. Details of this technique is discussed in next chapter.

Chapter 4

Signal Scrambling Techniques

4.1 Concept of Phase rotation:

The overlapping of different sub-carrier signals results in high peak power signal in OFDM. If a transmission process can be designed in which multiple sequences carry same information and each of them represents that same transmission process, then the best perform signal among different output signal can be selected out considering condition like PAPR assigned value. So reduction of signal with significant number of peaks can be achieved. In signal scrambling technique, peak to average power of a signal is reduced by a phase rotation approach. This type of multi signal representation technology first generate multiple signal waveforms that carry same information and then choose the waveform from those candidates with smallest PAPR value. So probability of getting high peak power signal can effectively be reduced which result in low PAPR value. So this approach can be an alternative of distortion techniques for reduction of PAPR.

A skeleton of this multi-signal representation can be formed by involvement of a serial to parallel converter, a phase rotation module and parallel output signals which can be obtained by executing IFFT operation simultaneously. Then the optimal signal value that has lowest PAPR value is transmitted to the receiving section of the communication system. A plurality of reserved sub-carriers can be used to transmit the encoded side-band information.

Actually equivalency can be found like performing a linear transformation on modulated data symbols in this technique. This process can be written as

$$X_{m,n} = A_{m,n}.X_n (n = 0,1,...,N-1; m = 1,2,...,M) \qquad (4\text{-}1)$$

where X_n represents an element of modulated data symbols X in frequency domain, $X_{m,n}$ is the N-point data symbols before applying IFFT transform. The final goal of this transform is going to find N-point weighting factors $A_{m,n}$. It has the ability to reduce the appearance probability of high peak value $X_n = IFFT(X_{m,n})$ in time domain. Block diagram of phase rotation PAPR reduction scheme as shown in Fig. 4.1.

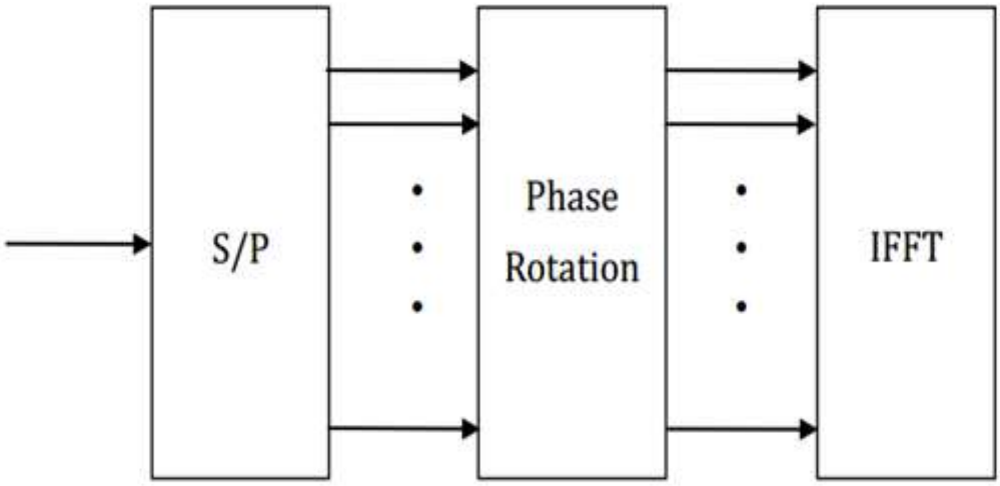


Figure 4-1: Block Diagram of Phase Rotation

This idea of signal scrambling phase rotation paves the way to achieve high coding rate, low redundancy although it only optimizes the statistical characteristics of PAPR in OFDM system. So techniques based on this principle can achieve prospective results.

By using the idea of phase rotation, different scrambling techniques like selected mapping, partial transmit sequence, tone reservation, tone injection have been proposed. In our thesis work, we keep our focus only between selected mapping and partial transmit sequence technique.

4.2 SLM Technique:

4.2.1 Principle of SLM Technique:

Selected Mapping (SLM) technique is one of the most promising reduction techniques to reduce Peak to Average Power Ratio (PAPR) of Orthogonal Frequency Division Multiplexing (OFDM) system. PAPR reduction through SLM scheme was brainchild of Bauml, Fischer and Huber.The basic idea of this technique is based on the phase rotation. The lowest PAPR signal will be selected for transmission from a number of different data blocks which have independent phase sequences but same information at the transmitter. Figure 4.1 shows a block diagram of SLM scheme [24] where serial to parallel conversion of data streams, multiplication with sequences, IFFT operation are illustrated.

4.2.2 Block Diagram of SLM Technique:

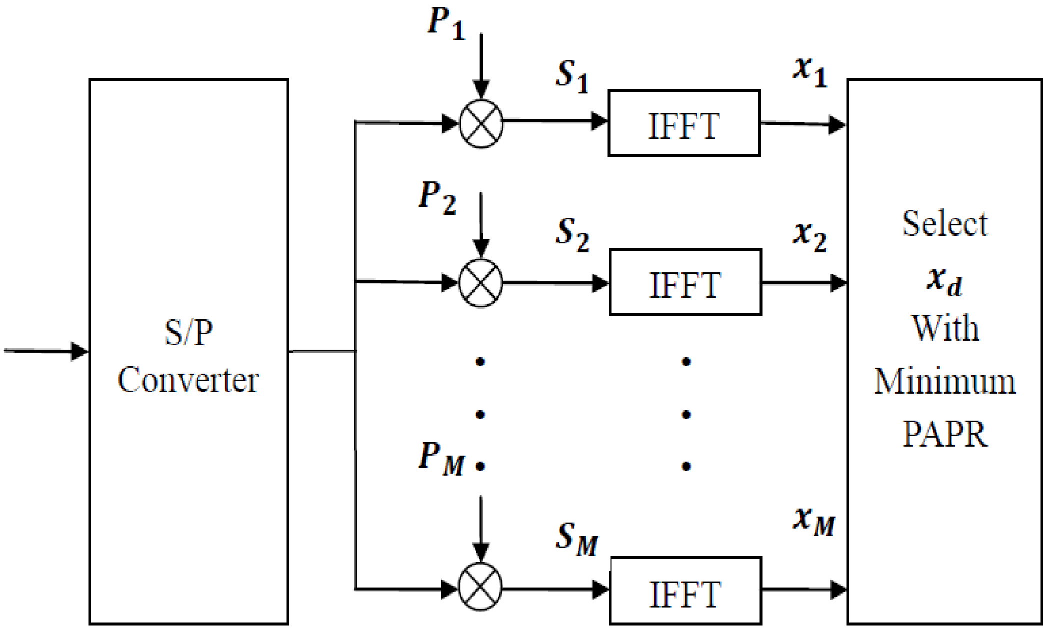


Figure 4-2: Conventional SLM block diagram

4.2.3 Procedure of SLM Technique:

The total selected mapping procedure can be divided into a number of steps. First of all, the transmitter generates a set of sufficiently different candidate data blocks where all of them represent the same information as the original data block, we assume input data set is $X = [X_0, X_1, X_2, X_3, ...X_{N-1}]^T$ .In the next step, Each data block is multiplied by U number of different phase sequences $P^{(u)} = [P_0^{(u)}, P_1^{(u)}, P_2^{(u)}, P_3^{(u)}, ...P_{N-1}^{(u)}]$, both the input data and phase sequence have the same length N. After multiplication, we get *U* no of modified data blocks. To include the unmodified data block in the set of modified data blocks, we set $P^{(1)}$ as the all-one vector of length *N*. Let us denote the modified data block for the *u*th phase sequence $X^{(u)} = [X_0 P_{u,0}, X_1 P_{u,1}, X_2 P_{u,2}, X_3 P_{u,3}, ..., X_{N-1} P_{u,N-1}]^T$ u = 1, 2, …,*U*. After applying SLM to **X**, the multicarrier signal becomes $x^{(u)}(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n P_{u,n} . e^{j2\pi n \Delta f t}, 0 < t < NT, u = 1, 2, ...U$ Among the modified data blocks $X^{(u)}$, *u* = 1, 2,…, *U*, the one with the lowest PAPR is selected for transmission. Information about the selected phase sequence should be transmitted to the receiver as side information. At the receiver, the reverse operation is performed to recover the original data block. For implementation, the SLM technique needs *U* number of IDFT operations, and the number of required side information bits is $\log_2 U$ for each data block. This approach is applicable with all types of modulation and any number of subcarriers. The amount of PAPR reduction for SLM depends on the number of phase sequences U and the design of the phase sequences.

4.2.4 Simulation Analysis of SLM Technique:

The theoretical CCDF curves as a function of PAPR distribution is shown in Fig. 3.3 when SLM method is used. The number of N sub-carriers is chosen as 128. M takes the value of 1 (without adopting SLM method), 2, 8, 32 and 128. It can be easily illustrated from Fig. 4.3 that PAPRs CCDF distribution gets smaller and smaller with increase of branch number M.

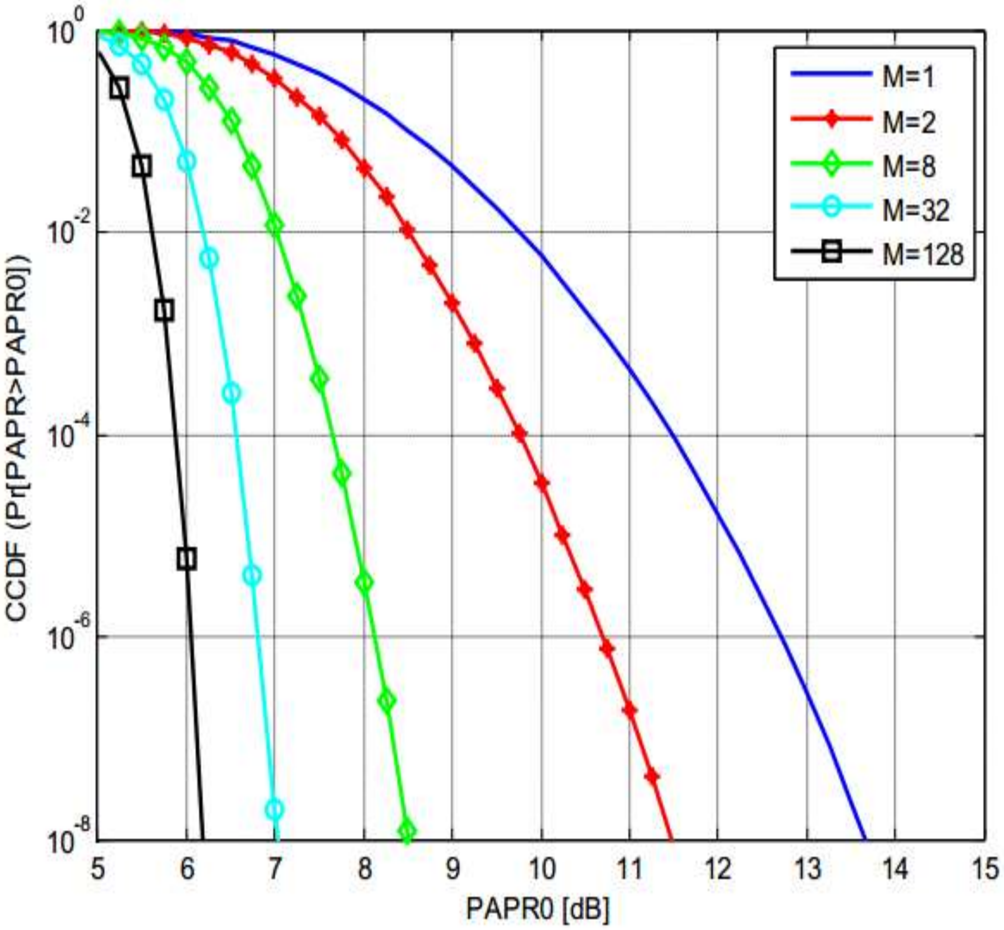


Figure 4-3: CCDF vs PAPR performance curve for theoretical SLM

The salient feature of selected mapping method lies in how to generate multiple OFDM signals when the information is the same. Initially different pseudo-random sequences $[P_{m,0,}P_{m,1,}.......P_{m,n-1}]^T$, where $m = 1,2, \dots , M$ and $P_{m,n} = e^{j\Phi_{m,n}}$ are defined and stands for the rotation factor. $P_{m,n}$ is also known as the weighting factor . $\Phi_{m,n}$ is uniformly distributed in $[0\ 2\pi]$.The N different sub-carriers are modulated with these vectors respectively so as to generate candidate OFDM signals. From another point of view, this method can be seen as performing dot product operation on a data block $\boldsymbol{X}n$ with rotation factor $\mathrm{P}m$.

In the reality, all the elements of phase sequence P_1 are set to 1 so as to make this branch sequence the original signal. The symbols in branch m is expressed as

$$S_m = [X_0 P_{m,0}, X_1 P_{m,1}, ..., X_{N-1} P_{m,N-1}]^T \qquad \text{m=1,2,...,M} \qquad (4\text{-}2)$$

and then transfer these M OFDM frames from frequency domain to time domain by performing IFFT calculation. The entire process is given by

$$x_m(t) = \frac{1}{\sqrt{N}} \sum_{0}^{n-1} X_n P_{m,n} . e^{j2\Pi n\Delta ft}, \qquad 0 \le \text{y} \le \text{NT, m=1,2,..M} \qquad (4\text{-}3)$$

Finally, the one which possess the smallest PAPR value is selected for transmission. Its mathematical expression is given as

$$x_d = \arg\min_{1\le m\le M} (PAPR(x_m)) \qquad (4\text{-}4)$$

Where $\arg_{\min}$ represent the argument of its value is minimized.

In order to correctly demodulate the received signal, it is essential to know which sequence is linked to the smallest PAPR among M different candidates after performing the dot product at the receiver. Hence, the receiver is required to learn information about selected phase vector sequence and ensure that the vector sequence is received correctly. An intuitive approach is to select the whole sequence of branch number m as side information transmitted to the receiving end. However, in practice, the process does not necessarily require the delivery of the entire vector sequence. It can be realized by sending the route number of the vector sequence instead. This is only possible when the receiving end is able to restore the random phase sequence *Pm* by means of look-up table or any other method. As the side information plays a vital role for signal restoration at the receiver, channel coding is used to guarantee a reliable transmission. Once channel coding technique is adopted during the data transmission process, sending of any additional side information is not required. In this way, all possible routes are detected at the receiving end from which the most likely one is chosen as the optimum.

4.2.5 Performance Key factors:

There are some factors that influence the PAPR performance curve in SLM reduction technique. Parameters like modulation type, oversampling rate, route number and subcarrier number are such key factors in this case [25]

For different modulation types:

Different modulation types do not give exactly same PAPR performance curves. Slight variation in performance have been observed if we use different schemes like Binary Phase Shift Keying (BPSK), Quadrature Phase Shift keying (QPSK), 16QAM, 64QAM.

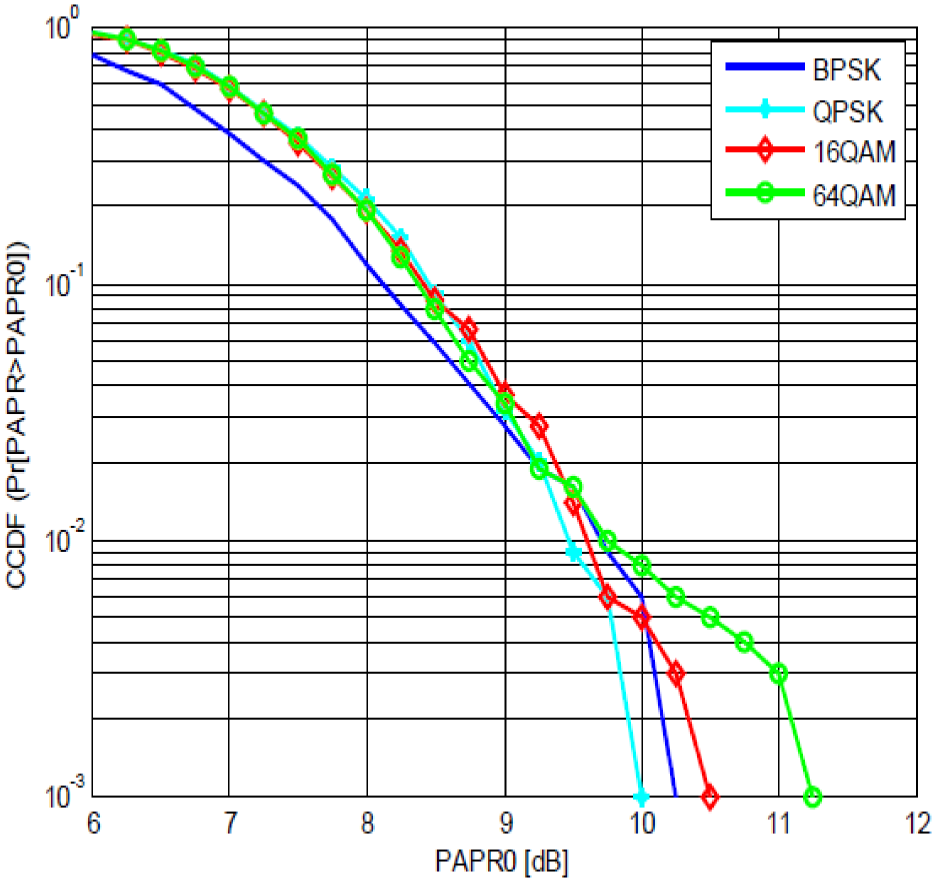


Figure 4-4: Comparison of PAPR reduction performances with different modulations types.

For different values of route numbers:

We define rotation factor as $Pm, \in[\pm 1,\pm j]$ that reduces calculation complexity dramatically compared to performing miscellaneous complex multiplication. The algorithm executes 10000 times, over-sampling factor is 8 and QPSK mapping is adopted as modulation scheme in each sub-carrier. Route numbers M=2, M=4, M=8, M=16 and M=32 are used. From Fig., it can be observed that the proposed SLM method displays a better PAPR reduction performance than the original OFDM signal which is free of any PAPR reduction scheme. The probability of high PAPR is significantly decreased. Increasing M leads to the improvement of PAPR reduction performance. If the probability is set to 1% and then the CCDF curves with different M values are compared. The PAPR value of case M=2 is about 1dB smaller than the unmodified one M=1. Under the same condition, the PAPR value of case M=16 is about 3dB smaller than the original one M=1. However, from the comparison of the curve M=8 and M=16, we learned that the performance difference between these two cases is less than 0.5dB. This proves that we will not be able to achieve a linear growth of PAPR reduction performance with further increase the value of M (like M>=8), the PAPR reduction performance of OFDM signal will not be considerably improved.

Moreover, if we want to judge performance by execution time, we can see that execution time will last longer with the increase of M. Therefore, in practical application, we usually take M=8, thereby not only improve the system performance, but also avoid introducing too much computational complexity so as to save the limited resource successfully.

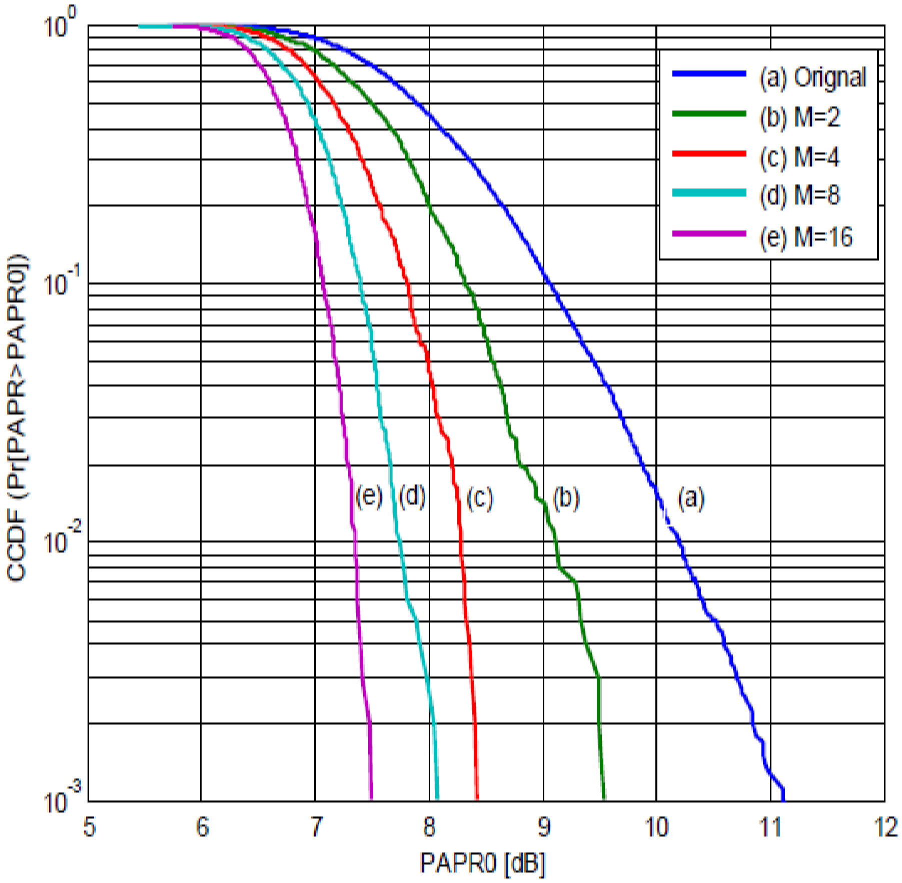


Figure 4-5: Comparison of PAPR reduction performances with different values of M.

For different values of sub-carrier numbers:

We keep the number of OFDM signal frame *M* equals to 8 in this case, the number of sub-carrier *N* equals to 256, 128, and 64, respectively. In the Fig. 4.5, the CCDF curve of original sequence's PAPR is given as the reference of comparison to the others which SLM method been used. It can be seen from Fig. that SLM algorithm particularly suitable for the OFDM scenario with larger number of sub-carriers, and it also shows the PAPR reduction performance of OFDM signal is not significantly deteriorated when the number of sub-carriers is greater than 128, even if the number of carriers doubled after the adoption of SLM algorithm.

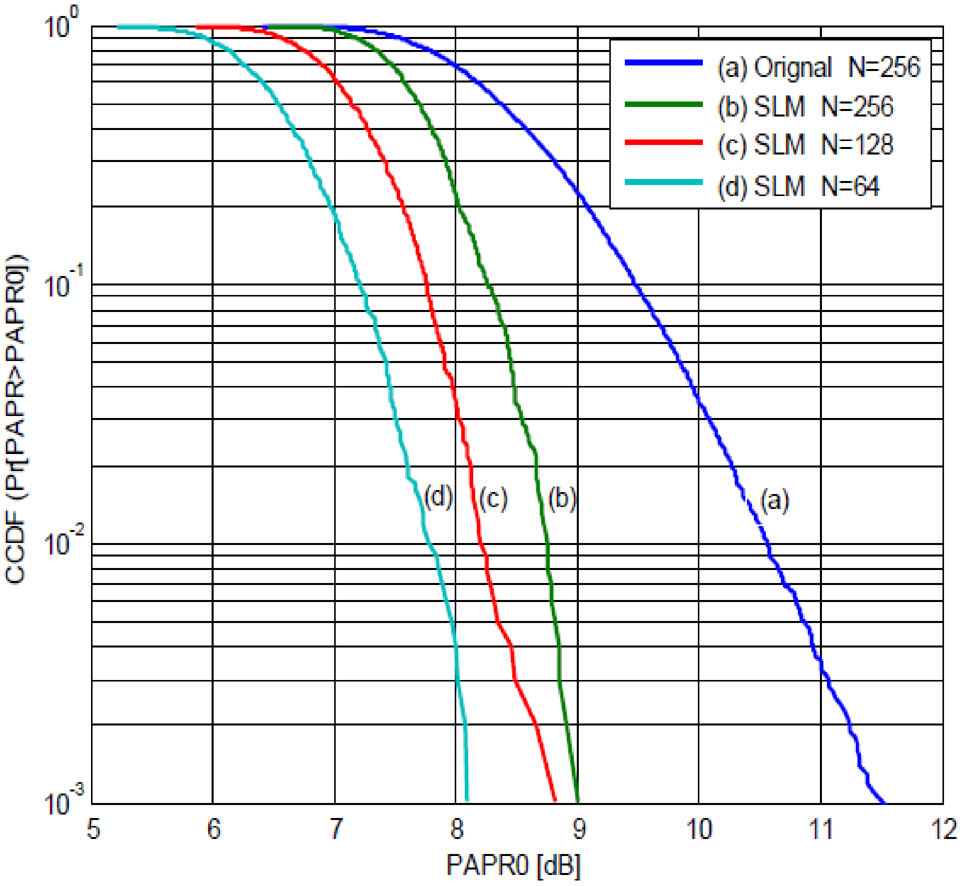


Figure 4-6: Comparison of PAPR reduction performances with different values of N

For different values of oversampling rate:

Oversampling is done because continuous-time OFDM signal cannot be described precisely with the insufficient *N* points sampling. Some of the signal peaks may be missed and PAPR reduction performance is unduly accurate [6666]. To avoid this problem, oversampling is usually employed, which can be realized by taking *L*·*N* point IFFT/FFT of original data with (*L*-1)·*N* zero-padding operation. Over-sampling plays an important role for reflecting the variation features of OFDM symbols in time domain like higher over-sampling rate leads to higher PAPR value and good PAPR reduction performance which is illustrated in Fig 4.7

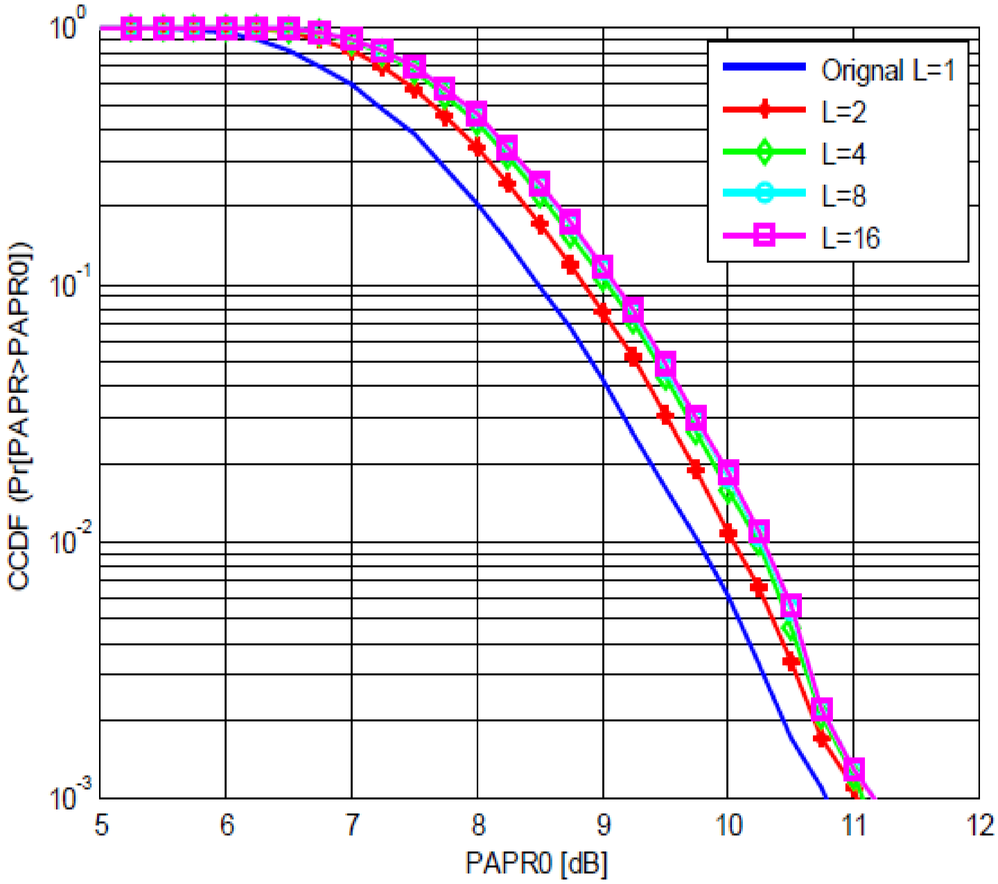


Figure 4-7: Comparison of PAPR reduction performances with different values of L

Chapter 5

Modified SLM Techniques

5.1 Idea Behind Modification of SLM:

From the previous chapter discussion and description on SLM technique, it is obvious that how it reduce the peak to average power ratio in OFDM transmission. Though it gives a supreme performance over the other techniques considering some important parameters, in some cases it may not give a satisfactory performance. Some key issues are to be kept in mind in case of using different techniques to reduce PAPR in OFDM system. These issues are PAPR reduction capability, power increase in transmit signal, bit error rate increase at the receiver, loss in data rate, computational complexity, effect on digital to analog converter, transmit filter, transmit power amplifier etc. Protecting data from transmitter to receiver end is very much important otherwise whole data block could be corrupted for single data bit error. Error in sideband information will result in reception failure and degradation in BER(bit error rate) in receiver. If some protecting code techniques like channel coding is not employed then there will be significant amount of loss. Considering all these issues, researches are going on to improvise this conventional SLM performance for reduction of PAPR in OFDM system.

In our thesis work ,we have designed several modified SLM and found out simulations in Matlab. These things are discussed elaborately in next section.

5.2 Proposed Scheme 1:

In this modified scheme, first of all, a sufficient number of modulated data are generated and then data sets first are divided into a number of sub-blocks say

$P_1, P_2, P_3, ..., P_M$. Then, the successive operations like in conventional scheme such as multiplication with the phase sequence, inverse fast Fourier transforms are done to the data.

After phase sequence multiplication, we get $S_1, S_2, S_3, ..., S_M$. The Fourier transformed data are denoted as $x_1, x_2, x_3, ..., x_M$ at the end, these data are combined and their peak to average power ratio is calculated. The signal with lowest PAPR value is chosen. Dividing the generated data into sub-blocks and add them at end after several operations are some similar approaches that are applied in another signal scrambling technique called Partial Transmit Sequence (PTS) . But the main difference between these two techniques is that in case of PTS technique, after sub-dividation, instead of multiplying the partitions with phase sequences which is done in the proposed modified scheme, ifft operation is done and then the signal streams are multiplied with some assigned weighted values. Fig. 4.1 shows the block diagram of the proposed modified SLM scheme.

Simulation has been run for this proposed scheme in matlab. We will discuss it in detail in the simulation analysis part.

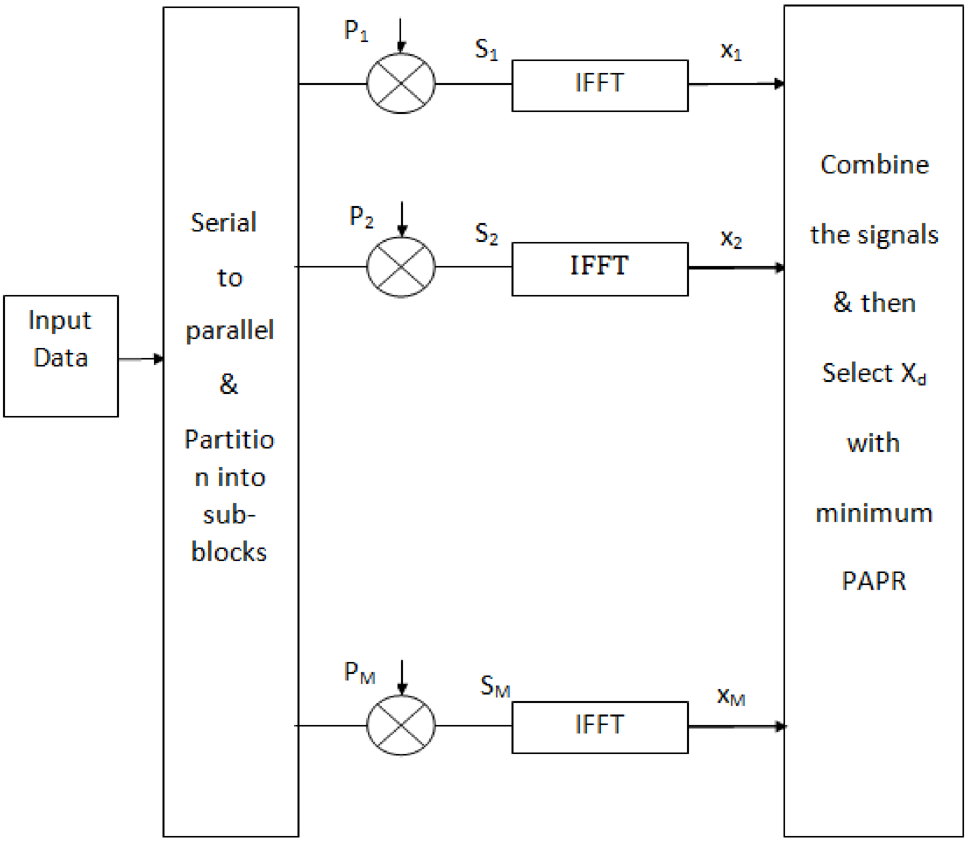


Fig. 5.1: Modified SLM scheme 1 block diagram

5.3 Proposed Scheme 2:

In this part, a modified Selected Mapping Technique is applied to reduce PAPR of the OFDM signal used as input. Through this method, PAPR reduction performance gets improved than the conventional one though it occupies a bit higher computation complexity.

Block diagram of the proposed scheme is shown below:

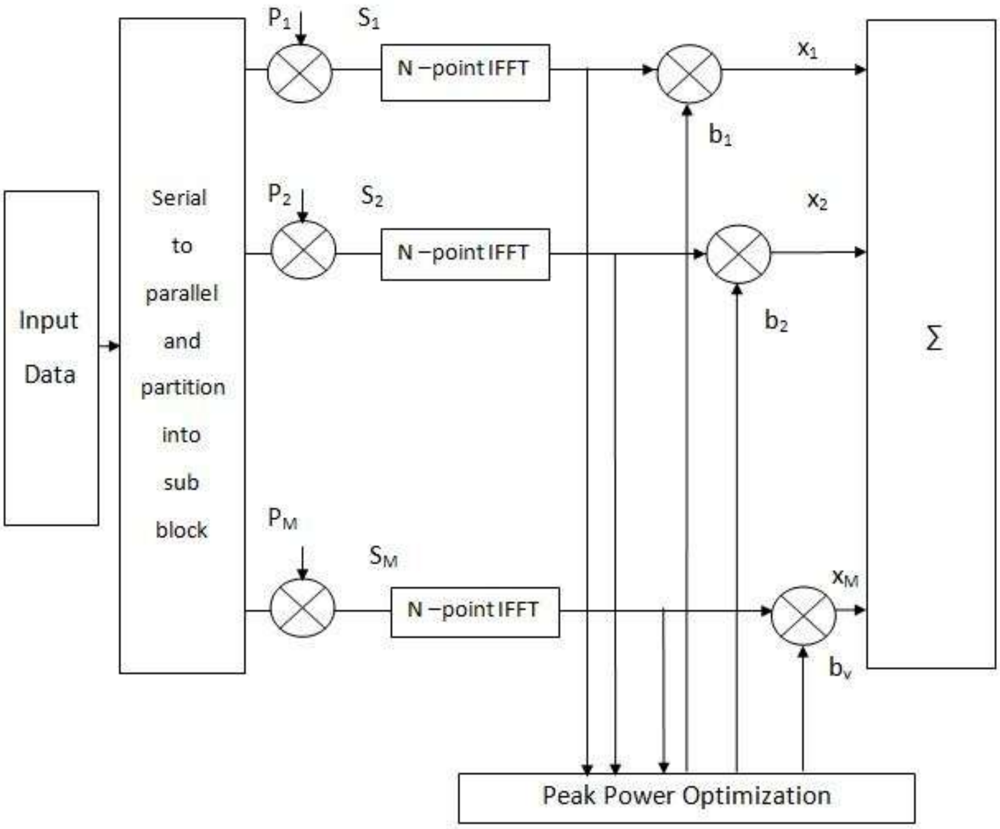


Figure 5-2: Block Diagram of Modified SLM Scheme 2

We take a OFDM signal as input which is passing through a serial to parallel connection and thus generate M number of sub blocks each assuming of length N. Now like in conventional SLM technique, M number of phase sequences are multiplied with each of the sub-blocks respectively. These sub-blocks are still in frequency domain. Again we multiply each sub-block with independent sub sequences from peak power optimization. Therefore we apply IFFT to the sub-block we got. As a result, the sub-blocks transform from frequency domain to time domain. PAPR of each block is compared and hence the one with the lowest PAPR is selected and used for actual transmission.

5.4 Proposed Scheme 3:

The previous one is differently modified to produce a reduced PAPR of the OFDM signal input. In this method PAPR reduction performance gets improved than the previous one.Block diagram of the proposed scheme is shown in the figure given below:

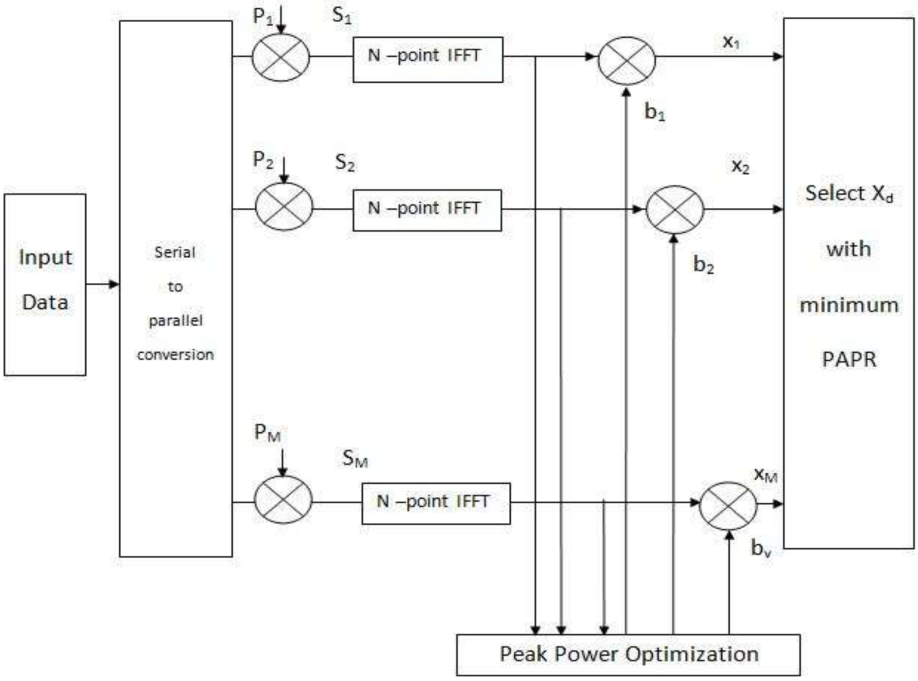
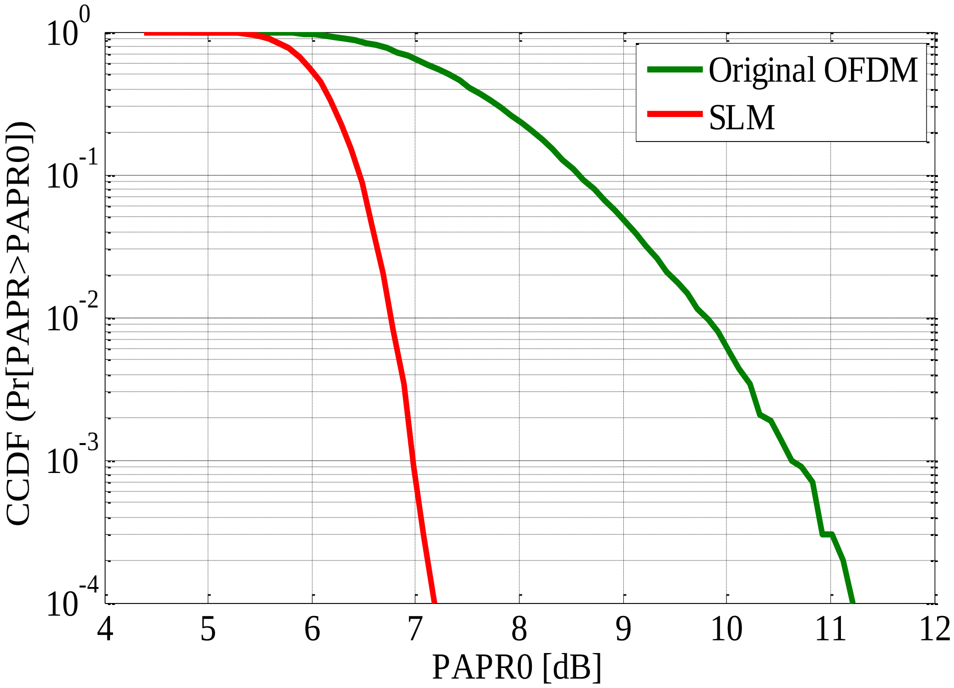


Figure 5-.3: Block Diagram of Modified SLM Scheme 3

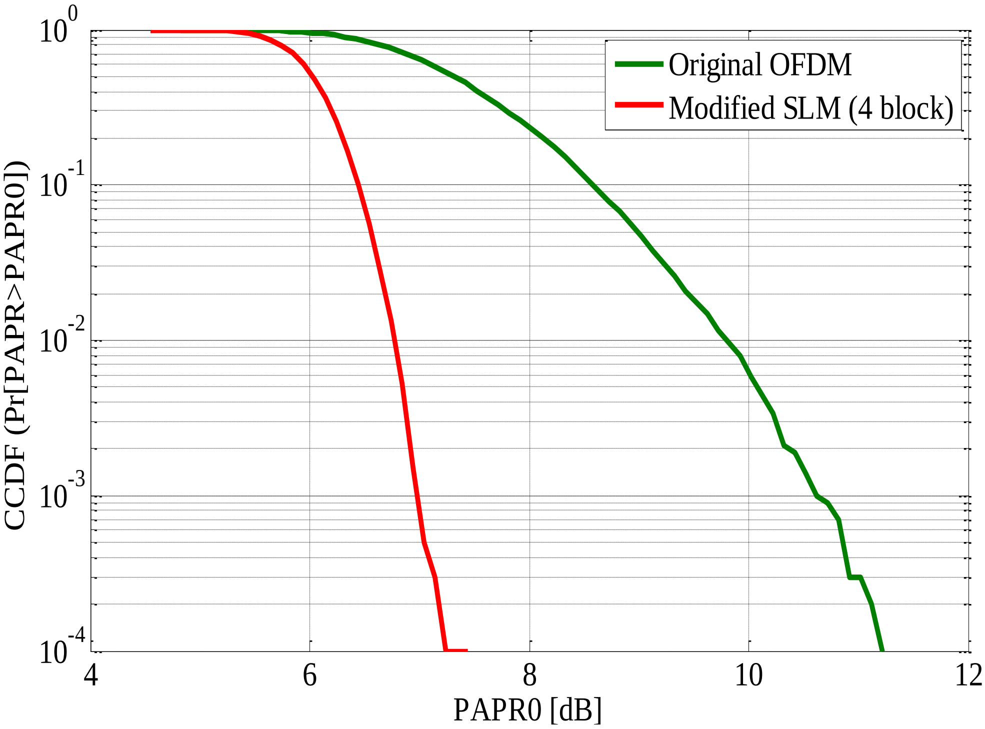
We take a OFDM signal as input which is passes through a serial to parallel connection and thus generate M number of sub blocks each of length N. Now like in conventional SLM technique, M number of phase sequences generated are multiplied with each of the sub blocks. These sub-blocks are still in frequency domain. After that we multiply each sub-block with independent sub sequence from peak power optimization. So we apply IFFT to the sub-blocks we got. As a result, the sub-blocks go to time domain from frequency domain. We integrate all the values and get the output with lowest PAPR.

5.5 Simulation Analysis:

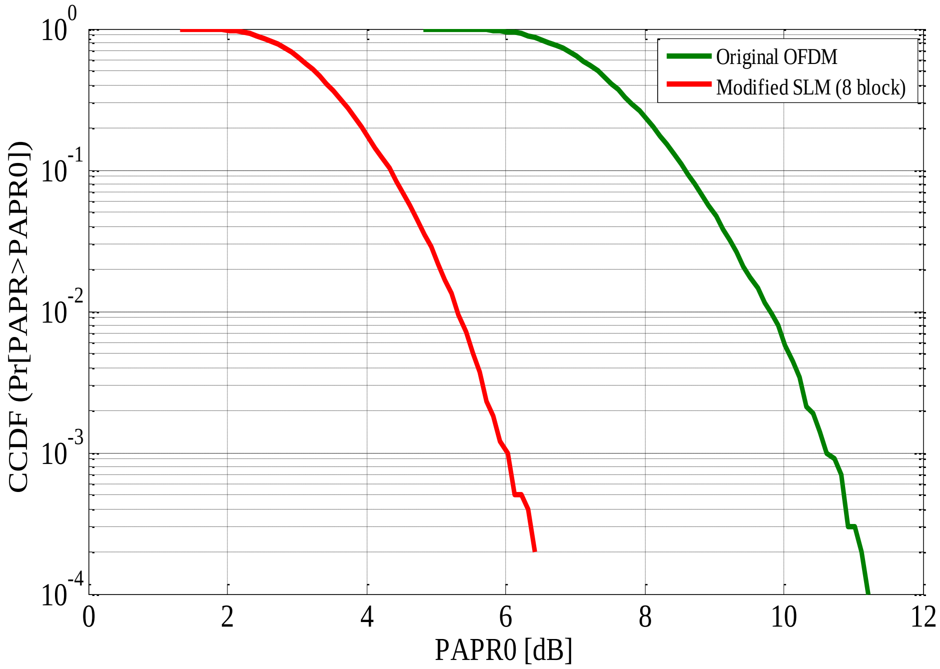
Matlab software has been used to plot the described conventional and modified schemes. Fig. 1 shows the PAPR performance of conventional SLM scheme. We take ten thousand data from the generated quadrature amplitude modulated data. The number of sub-bands we choose for our cases in this paper is 64. Phase factor possible values are taken as 1,-1, j, -j. The number of OFDM symbol candidates is sixteen with the mentioned sub-band numbers and the phase sequence. Data are oversampled with factor 4. Now, firstly, the PAPR of original PAPR is plotted using the equation (). The green solid line in Fig. 3 is indicating that original OFDM PAPR performance. The PAPR value (db) is found as 8.5, 9.8, 10.6, 11.2 for the CCDF values at .1,.01,.001,.0001 respectively. After applying SLM technique to the original signal, we get improved PAPR performance as 6.4,6.7,6.9,7.2 for the corresponding CCDF points. In case of our modified scheme 1, we applied sub-block partitioning. The simulation is conducted for 4, 8 and 16 sub-blocks. The 4-block scheme performance which is illustrated in Fig. 3(b), is remarkably less than the previous performance. For more number of sub-block partitioning like 8 and 16 sub-blocks in Fig. 3(c) and Fig. 3(d), even better performance with less PAPR value has been achieved. In case of proposed scheme 2, there is not any remarkable change with respect to the conventional SLM approach (figure 5.4(e)). But the proposed scheme 3 gives a better performance as we got the value of CCDF as 4.5, 5.5, 6.2 in .1, .01, .001 respectively. Though proposed scheme 1 for a large no of sub-blocks and proposed scheme 3 give low PAPR values, computational complexity increase in those cases. Values tabulated in Table I indicates the comparison of different simulated schemes.


10^0
10^-1
10^-2
10^-3
10^-4
CCDF (Pr[PAPR>PAPR0])
4
5
6
7
8
9
10
11
12
PAPR0 [dB]
Original OFDM
SLM

(a)

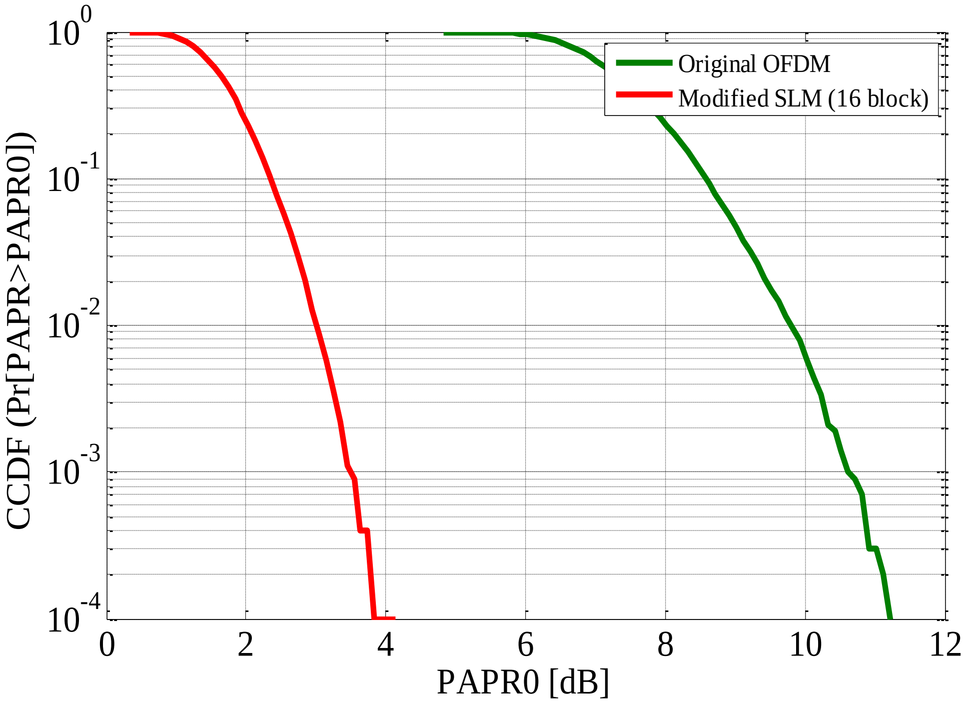

10^0
10^-1
10^-2
10^-3
10^-4
CCDF (Pr[PAPR>PAPR0])
4
6
8
10
12
PAPR0 [dB]
Original OFDM
Modified SLM (4 block)

(b)



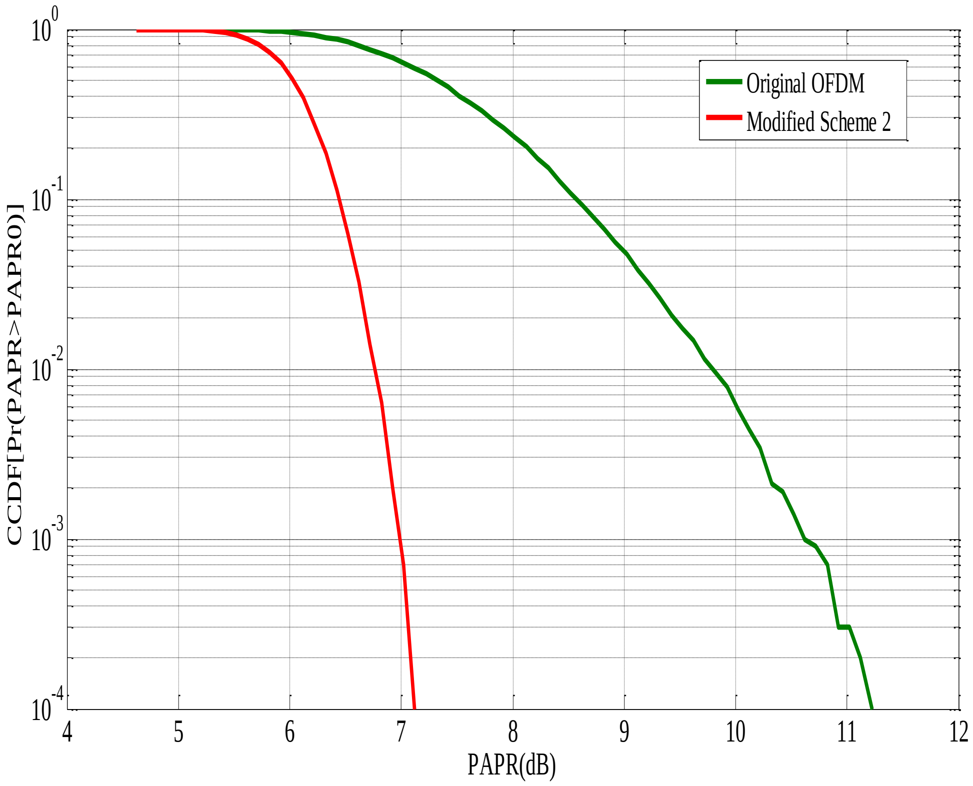
10^0
10^-1
10^-2
10^-3
10^-4
CCDF (Pr[PAPR>PAPR0])
0
2
4
6
8
10
12
PAPR0 [dB]
Original OFDM
Modified SLM (8 block)

(c)



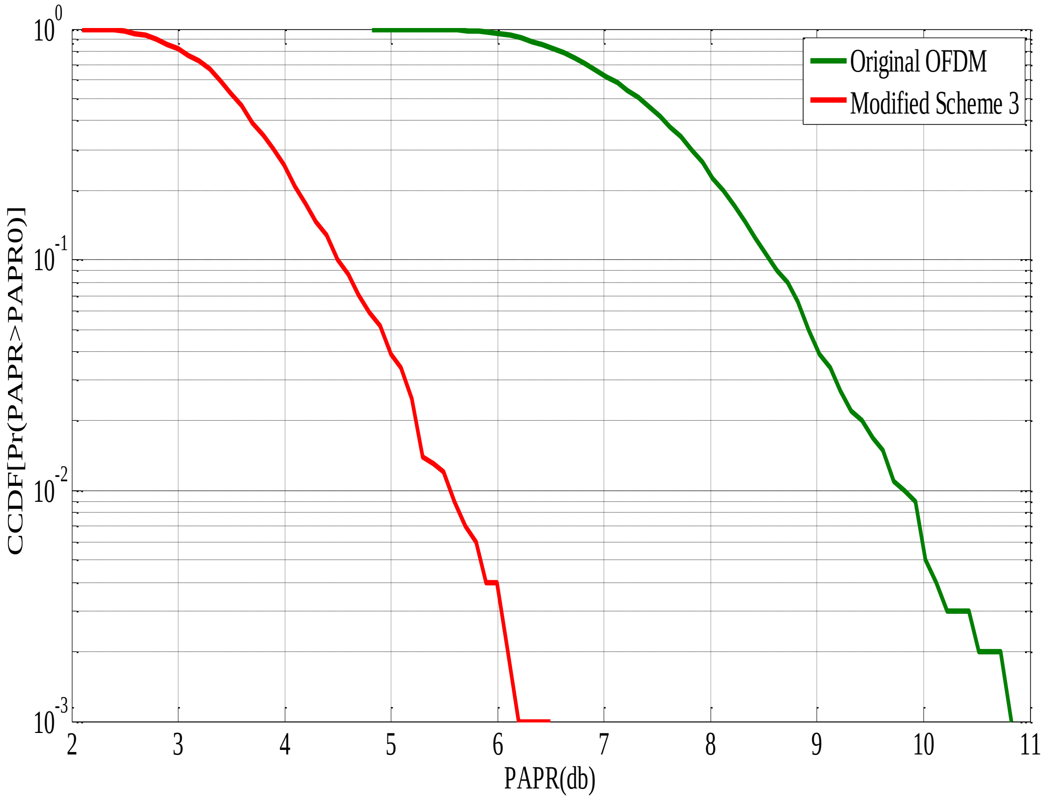
10^0
10^-1
10^-2
10^-3
10^-4
CCDF (Pr[PAPR>PAPR0])
0
2
4
6
8
10
12
PAPR0 [dB]
Original OFDM
Modified SLM (16 block)

(d)



10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
CCDF[Pr(PAPR>PAPR0)]
4
5
6
7
8
9
10
11
12
PAPR(dB)
Original OFDM
Modified Scheme 2

(e)



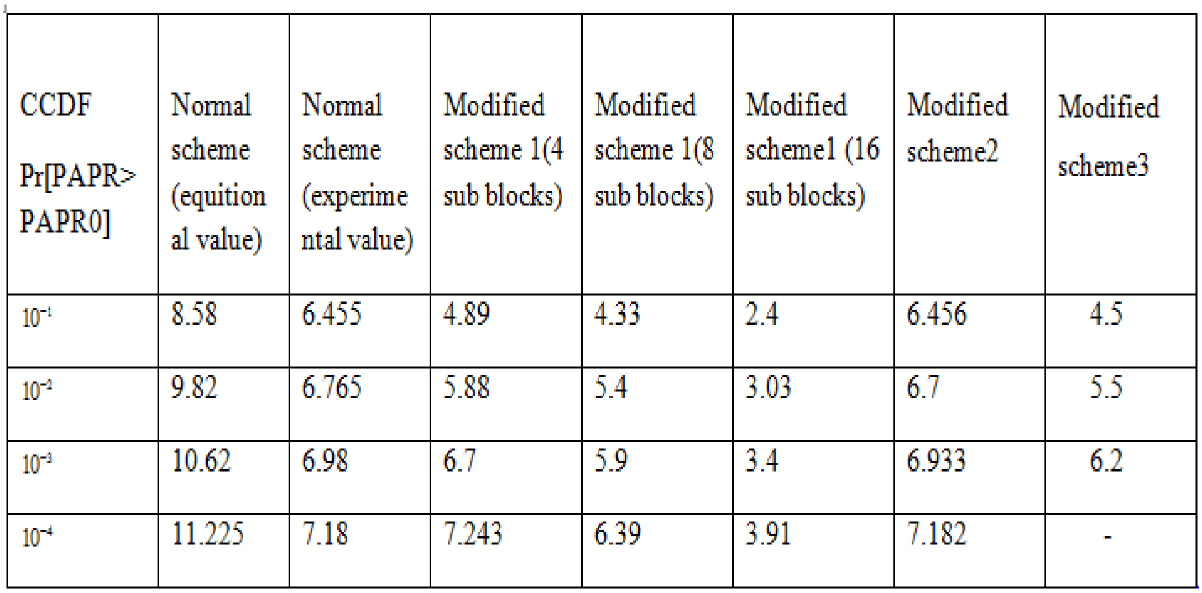
10^0
10^{-1}
10^{-2}
10^{-3}
CCDF[Pr(PAPR>PAPR0)]
2
3
4
5
6
7
8
9
10
11
PAPR(db)
Original OFDM
Modified Scheme 3

(f)

Figure 5-4: PAPR reduction performance of different schemes (a) CCDFs of PAPR of conventional scheme (b) CCDFs of PAPR of modified scheme 1 (4 block partitions) (c) CCDFs of PAPR of modified scheme 1 (8 block partitions) (d) CCDFs of PAPR of modified scheme 1(16 block partitions) (e) CCDFs of PAPR of modified scheme 2 (f)CCDFs of PAPR of modified scheme 3

TABLE 5.1

PAPR VALUES AT DIFFERENT CCDF



CCDF Pr[PAPR> PAPR0]	Normal scheme (equitional value)	Normal scheme (experimental value)	Modified scheme 1(4 sub blocks)	Modified scheme 1(8 sub blocks)	Modified scheme1 (16 sub blocks)	Modified scheme2	Modified scheme3
10^{-1}	8.58	6.455	4.89	4.33	2.4	6.456	4.5
10^{-2}	9.82	6.765	5.88	5.4	3.03	6.7	5.5
10^{-3}	10.62	6.98	6.7	5.9	3.4	6.933	6.2
10^{-4}	11.225	7.18	7.243	6.39	3.91	7.182	-

Chapter 6

Conclusion & Future work

6.1 Summary

The unique and potential features of OFDM make it the chosen multiplexing technique for the upcoming fourth generation technology. But goal of these technologies of high spectral efficiency could not be achieved without the optimum performance from OFDM technique. High peak to average power ratio is one of the major obstacles to achieve the goal. Thus different kinds of techniques to overcome these problem are being proposed. It is obvious that maximum performance could not be acquired without sacrificing any parameter performance degradation. Our proposed modified techniques could show better performance in some cases but complexity will increase in those cases. So some trade off for optimum performance may be considered.

6.2 Suggestions for Future Work:

In this thesis, we have implemented sub-block partition concept and introduction of weight factor concept in the modification of SLM technique. Actually, these concepts are parts of another technique to reduce PAPR named partial transmit sequence. So combination of different techniques can be done experimentally to realize better PAPR performance. Secondly, power saving analysis can also be performed for the proposed modified techniques.

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