PERFORMANCE AUGMENTATION & ANALYSIS OF ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM USING OPTIMIZED PAPR LESSENING ALGORITHMS

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By

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Transforming Education Transforming India

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DECLARATION

I hereby declare that the thesis entitled,” **PERFORMANCE AUGMENTATION & ANALYSIS OF ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM USING OPTIMIZED PAPR LESSENING ALGORITHMS**”, has been prepared by me under the guidance of Dr. H. Pal Thethi, Professor of ECE, Lovely Professional University (LPU), Punjab, India. This work is my own original work and all the ideas and references have been duly acknowledged. No part of this thesis has formed the basis for the award of any degree or fellowship previously at any other university.

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CERTIFICATE

I certify that Prabal Gupta has completed his thesis entitled, **PERFORMANCE AUGMENTATION & ANALYSIS OF ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM USING OPTIMIZED PAPR LESSENING ALGORITHMS**, for the award of Doctor of Philosophy (Ph.D.) degree in Electronics and Communication Engineering (ECE), Faculty of Technology and Science, Lovely Professional University, Punjab, India, under my guidance and supervision. To the best of my knowledge, the present work is the result of his original investigation, study and has not been submitted to any other university or institution for the award of any degree or diploma.

This thesis is fit for the submission and the partial fulfilment of the conditions for the award of the Ph.D. in ECE. He has carried out the work at the School of Electronics and Electrical Engineering, Lovely Professional University.

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ABSTRACT

The performance augmentation and analysis of orthogonal frequency division multiplexing (OFDM) system using optimized peak to average power ratio (PAPR) lessening algorithms have been studied. In chapter-3, OFDM is chosen for great speed information communications. It is spectrally highly systematic and well organized method. The performance study and PAPR assessment has been done for OFDM system of wireless communication system under diverse modulation schemes. We have substantially examined the effect of oversampling. Furthermore, the results of several simulations show that the PAPR of OFDM is totally depend upon number of subcarriers and conclude the importance that as the subcarriers increase then PAPR of OFDM system also increases.

In chapter-4, OFDM is the most encouraging multi-carrier modulation (MCM) system chosen for the high data rates but the objective is to resolve intrinsic common issue of PAPR. The projected algorithm is illustrated in this research study which is established upon Selected Mapping (SLM) with pseudo-random sequence under time domain μ law companding of signal. Besides the significant competitive characteristics of conventional SLM algorithm (ConvenSLM-Algo) [9], it undergoes the tedious complexity in generation of phase sequence and for the recovery of sequence, side information (SI) is mandatory. The key concern, thus, to eliminate the tedious problem of designing of phase sequence along with the aim of reducing the fluctuation of signal with high PAPR. Henceforth, in the projected algorithm (Projected-Algo) a noteworthy strategy has been investigated and followed for the designing of phase sequence which is very easy and for the recovery of information at receiver, side information of index of column of phase sequences can be used because of straightforwardness in its establishment. Hence, we demonstrate the effective overall excellent performance of Projected-Algo along with analysis and also comparative study of Projected-Algo outperforms the conventional OFDM system (Unchanged), ConvenSLM-Algo [9], SLM with new pseudo random phase sequences (ModSLM-Algo) given in literature [10].

In chapter-5, beginning with a description of modified partial transmitted sequence (MOPTS) algorithm by applying the normalized Riemann matrix (C) rows for phase sequences with discrete cosine transform (DCT) in time domain for diminishing of PAPR of several modulations under many subcarriers based OFDM after distributing the information into numerous blocks and optimizing with the assistance of phase sequences. Since, original PTS (ORIPTS) algorithm makes use of phase sequences which are random and designing of those phases are also tedious. Henceforth, in this thesis we are suggesting a MOPTS algorithm which has definite phase sequences of normalized Riemann matrix (C) along with DCT. Moreover, simulation outcomes clearly indicate the noteworthy PAPR performance of MOPTS in comparison with PAPR of original OFDM (OFDMORIPAPR) and ORIPTS. The authors have faith that this study will serve as the valuable pedagogical resource for better understanding the present research contributions in the most important area of PAPR lessening.

In chapter-6, OFDM is the highly spectrally well-organized method that has the difficulty of excessive PAPR it ultimately imposes constraints on the high power amplifier. Many practices have been projected to lessen PAPR of the OFDM systems. Amongst all the practices, SLM method has drawn more attention because of distortion-less behaviour. This technique uses unique phase sequences. It has been learnt that phase formation for SLM is very tedious. In the proposed work, SLM method has been used but phase arrangement formation is based on the usage of discrete cosine transform (DCT) matrix. In this proposed work, DCT matrix has been chosen based on the requirement of optimization so that the arrangement with lowest PAPR can be nominated for the transmission. MATLAB simulation depicts that the remarkable gain is achieved as compared with existing technique. In the proposed work, scheming of phase sequences are very informal due to the use of DCT matrix which has definite structure and can be generated at receiver side with the help of side information of the phases, are communicated from transmitter to the receiver.

In chapter-7, For lessening the trouble in OFDM of PAPR, a distinctive more efficient arrangement is projected with provision of clipping, hadamard matrix and PTS. Meanwhile, in original PTS designing of the phase sequence is very difficult and these phase sequences are highly required during division of data into multiple sub-blocks.

Therefore, in this research work of thesis, the main concept is that we are employing and presenting an approach which diminishes PAPR with the help of structured hadamard matrix in time domain along with clipping. Therefore, simulation outcomes are offered with modulation under numerous subcarriers. The performance of significantly enhanced planned method has been equated with OFDM, clipping, hadamard based PTS and it outperform all the conventional methods.

In chapter-8, OFDM has been most important mainstream technology considered for high data transmission speed. But, high PAPR diminishes system performance. Consequently, in this research work of thesis, pseudo random phase sequences based PTS algorithm (PRS-PTS-Algo) has been considered. In order to obtain information back at receiver only index value of column of the phase sequences can be utilized. In addition, 8-PSK (phase shift keying) and 16-PSK modulation methods and diverse subcarriers are considered. Simulation results clearly show that PRS-PTS-Algo provides remarkable reduction in the PAPR issue as compared with conventional OFDM system (Conv-OFDM) along with very efficient generation of phase sequences.

In chapter-9, an improved PTS algorithm is projected for diminishing PAPR of well accepted and effective OFDM system. OFDM is also considered as trustworthy method for several wireless communication applications and obtained a lot of the research interests but unfortunately, one of the most important concern is very high PAPR in OFDM signals which deteriorates system performance thus this is the most important drawback. To address this problem, a novel PTS algorithm is projected based upon centering phase sequences matrix (PTS-CPSM-Algo). These phase sequences are used for optimization of data so that minimum PAPR can be obtained. This algorithm obtains significant reduction in PAPR which leads to the enhancement in performance of OFDM system. From the developed analysis and simulation results supremacy can be clearly seen for proposed PTS-CPSM-Algo over already existing OFDM system, SLM and PTS algorithm.

In chapter-10, The SLM is one of the productive, predominant and distortion less algorithm for lessening of PAPR of the OFDM system. Therefore, this chapter presents the evaluation and assessment of SLM algorithm with Hadamard matrix as the phase sequences and also pseudo random phase sequences in comparison with OFDM system. These phase sequences are systematic in structure. The SLM algorithm with pseudo random phase sequences shows the remarkable performance and it outperforms SLM algorithm with hadamard matrix based phase sequences and conventional OFDM system as shown by the simulation results. On the foundation of estimated features, this chapter chooses excellent phase creation procedure for the production of phase sequences.

PREFACE

Performance augmentation and analysis of orthogonal frequency division multiplexing system using optimized PAPR lessening algorithms have been studied. In this work, we apply OFDM system, SLM with pseudo random phase sequences and μ law companding, MOPTS algorithm, conventional SLM algorithm, SLM algorithm using DCT matrix as phase sequences, conventional PTS algorithm, PTS algorithm with clipping technique and hadamard matrix, PRS-PTS-Algo, PTS-CPSM-Algo, SLM algorithm with Hadamard matrix as the phase sequences and also pseudo random phase sequences. PAPR reduction of the OFDM system is comprehensively studied by scientists and researchers so as to minimized the distortion in the data. In many applications like Long Term Evolution (LTE), Digital video broadcasting (DVB), Asymmetric digital subscriber line (ADSL), Multimedia over coax alliance (MOCA), IEEE 802.20, IEEE 802.11 a/g/n, IEEE 802.16 d, IEEE 802.15.3a, Digital audio broadcast (DAB) system etc. We have concentrated our attention on enhancing the OFDM system performance by diminishing the problem of PAPR. The enhancement in OFDM system performance has been perceived and described in the current study.

I would like to express my gratitude to my supervisor, Dr. H. Pal Thethi for the worthy guidance, suggestions, and supervision from the very early stage of this research work in order to complete this research work. I am truly fortunate to have opportunity to work with him and found his guidance to be tremendously valuable. I am thankful to Dr. Santosh Kumar Nanda, Dr. Rajiv Kumar Singh, Balpreet Singh and B. Arun Kumar for their valuable suggestions. I am also grateful to my family and friends for their moral support, cooperation and care during the complete period of this research work. Finally, I thank God for giving me the strength to keep going.

P Gupta

Prabal Gupta

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CHAPTER 1 INTRODUCTION AND OVERVIEW

1.1 INTRODUCTION

There is a lot of emphasis on recent development [1] in the current wireless communication technologies have come. This is in reply to the increasing demand for higher data rates. It is because of popularity of services like multimedia which include gaming, social media services and real time media streaming. However, over the past several years [2] there has been detailed analysis and focus. This is for enhancing the services available on the wired telecommunication networks to the movable non-wired telecommunication users. Additionally, the need for wireless broadband multimedia communication system (WBMCS) is required. It is because of its usability both in private sectors and public sectors.

For instance the mobile radio channel [2] is considered by multipath reception. Consequently, the wireless network must be designed to diminish the adverse effects. As well, the conventional single carrier systems modulation method obtained only limited data rate. It is because of multipath effect of channel of wireless and complexity in the receiver. In this system, as the increment in the data rates takes place then as a result, the duration of symbols diminished. However, it suffers with inter-symbol interference (ISI) created by dispersive channel impulse response. So it required a very significant complex equalization method. Orthogonal frequency division multiplexing (OFDM) is very efficient and useful multicarrier modulation (MCM) method for wireless communication method [1].Additionally, we note that, OFDM is the application of parallel transmission of data. It diminishes the effect of fading caused due to multipath and makes complex equalizers needless [2].

1.2 BACKGROUND OF OFDM SYSTEM

In OFDM [3] modulation method, several data bits are modulated simultaneously with the help of multiple carriers. Furthermore, this method partitioned transmission frequency band into the numerous narrower subbands. So that individually data symbol spectrum occupies one of the subbands. On the other hand, OFDM enhances spectral efficiency which is the major advantage after using subbands which overlap. In order to avoid any kind of interference among subands, these subbands are made orthogonal to the each other. It means these subbands are found to be independent mutually. Now, after breaking wide transmission band into narrower several subbands, OFDM method, for this reason, effectively fight the most common effect of fading known as frequency-selective. It is faced in channel of wireless. Also, OFDM ideally alters frequency selective channel of fading into the several flat fading channel. Thereby permits the utilization of very easy equalizers of frequency-domain. So as to overcome the problem. Henceforth, OFDM presents inter-symbol interferences (ISI) and inter-carrier interferences (ICI). ISI is the consequence which adjacent OFDM symbols apply on each other because of delay spread. ICI is the effect which subcarriers apply on each other. Now, both of these problem can be diminished by presenting a guard interval among the symbols of the OFDM. Subsequently, this interval is the cyclic extension of signal itself concatenated at starting of symbol of OFDM, known as cyclic prefix (CP).

As has been widely discussed, OFDM [2] can also be seen as a modulation method or a kind of multiplexing method. One of the most important reason for using OFDM is to enhance the robustness against frequency selective fading. For instance, Generally, in single carrier system, a single interferer or fade can make the complete link fail. But, in multicarrier system only very small subcarriers will be affected and for correction, finally, error correction coding can be utilized.

Let us consider, the most important word here is orthogonal which depicts that there exists the mathematics relationship between all the frequencies of the entire system. To better understand, hence, it is generally possible to arrange carriers in OFDM signal so that overlapping for sidebands can be seen. But still signals are obtained without causing any adjacent carrier interferences. Under this condition, the carriers must be orthogonal mathematically.

Meanwhile, the most basic principle of OFDM system originates from the important research work depicted by Chang [4]. We see that OFDM method was used in many high frequency military systems [2] like KATHRYN, ANDEFT, KINEPLEX. On the other hand, however, the best efforts were done by Weinstein and Ebert [5] to utilize the Discrete Fourier Transform (DFT) as the important part of modulation and demodulation processes. This could be the best alternative. In addition to remove the banks of sub-carrier oscillators and coherent demodulators required usually. Cooley and Tukey [6] explained methods in more details for the calculation of the complex Fourier Series. They are beneficial where number of data points can be selected as extremely composite number. The preceding discussion shows that the algorithm is derived and presented in different form. For this reason, making it possible to have strong motivation in order to use OFDM in various commercial communication systems.

1.3 APPLICATIONS OF OFDM SYSTEM

- IEEE 802.16 Worldwide interoperability for Microwave access (WiMAX) [1]
- Long Term Evolution (LTE) standards [1]
- IEEE 802.11 a/g/n/ac wireless LANs [1]
- Digital Audio Broadcasting (DAB) [1]
- Digital Video Broadcasting (DVB) [3]
- Digital Video Broadcasting-Terrestrial (DVB-T) [1]
- Digital Video Broadcasting by Satellite (DVB-S) [1]
- Multimedia over Coax Alliance (MOCA) home networking [7]
- IEEE 802.20 [7]

1.4 ADVANTAGES OF OFDM SYSTEM

- **Bandwidth saving:** The OFDM [7] system is much more efficient as compared with the frequency division multiplexing system. Usually, in OFDM system, subcarriers are overlapping in nature due to orthogonality among them. But in FDM different carriers are spaced apart.
- **Easy implementation using modulation and demodulation:** The [7] most important problem in multicarrier modulation (MCM) system is several modulators and demodulators at transmitter and receiver side respectively. But it can been seen that, in OFDM system data transmission is easily done using inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT).

- **Easy equalization:** We can see that, in single carrier system, equalization [7] makes frequency channel flat. But in frequency domain, equalization amplifies the noise where channel response is poor. So due to this its performance is affected because of very high attenuation in some bands. Since all utilized frequencies are provided with equal importance. But, on the other hand, in OFDM system, entire wideband channel is divided into flat fading sub-channels. Hence diminish the complexity of equalization.
- **Protection against ISI:** An interesting and most significant [7] usage of cyclic prefix in between successive OFDM symbols makes it insusceptible to ISI. And also, we note that, it is less sensitive to sampling timing offsets in comparison with single carrier system.

1.5 DISADVANTAGES OF OFDM SYSTEM

Despite possessing several advantages, OFDM system also has major problems like

- **Peak to Average Power Ratio (PAPR):** As has been widely discussed**,** the presence [7] of several number of subcarriers with varying amplitude consequences in high PAPR of system with very large dynamic range. Because of that it ultimately effects the efficiency of RF amplifier.
- **Synchronization (frequency and time) at receiver:** Carrier frequency [7] offset (CFO) and Symbol Timing offset (STO) affects the OFDM system performance. At the receiver side, correct timing between IFFT and FFT is necessary. For instance, OFDM system is highly sensitive to Doppler shift which disturb CFO and results in ICI.

1.6 OBJECTIVES OF THE THESIS

It is clear that the important objectives of this work is to alter the current PAPR reducing schemes which are well known as Selected Mapping (SLM) and Partial Transmitted Sequence (PTS) such that the complexity and its impact in designing the phase sequences can be reduced. The designing of the large number of phase sequences for the information needs large amount of time. So, by diminishing this problem with the condition that the performance of proposed system will be better in PAPR reduction as compared with traditional system. Thus making it suitable and it is the key idea. We are motivated to understand the objectives, the following studies, examinations and investigations which are undertaken,

- Investigations and mathematical formulation of the prevailing Orthogonal Frequency Division Multiplexing system.
- Analyzing numerous Peak to Average Power Ratio reduction methods like Selected Mapping and Partial Transmitted Sequence.
- To propose the efficient scheme for the lessening of Peak to Average Power Ratio of the system.
- Performance evaluation of the projected systems with the traditional orthogonal frequency division multiplexing system and already existing techniques

1.7 MOTIVATION

The PTS [1], [8] is an attractive algorithm and it has been adopted by several researchers because it shows an exceptional PAPR reduction. The advantage of introducing no distortion in the transmitted signal but designing several phase sequences which are utilized by this algorithm in the time domain is very important. So, the important steps must be taken while dealing with this algorithm significantly. Hence, the quality and advantages of this algorithm for the reduction of PAPR can be carry forwarded in several other aspects also.

After performing literature review, it is found that if the designing of phase sequences become easy then the high PAPR problem can be reduced easily. Hence, the performance of the OFDM system can be enhanced. And also, if time domain technique like clipping used then PAPR can also be diminished. However, this is very easy to implement. So, prime motivating factor of this work is diminish the PAPR using highly acceptable PTS algorithm.

The SLM [9], [10] algorithm has been studied by many researchers and given in the literature because it shows good reduction in the PAPR problem. It is a promising algorithm because of easy implementation. It does not introduce distortion into transmitted OFDM signal. But in this technique, frequency domain possesses the designing of several phase sequences. Also, data has been processed through these several phase sequences just before the IFFT. Now after generation of the time domain sequences, only the sequence which generate minimum PAPR will be selected for the transmission from transmitter side to receiver side.

As noted by the strong literature review based upon SLM clearly depicts the importance of many phase sequences for the reduction of PAPR. Several other researchers have shown many types of phase sequence. But still, we found that there exists complexity in designing it. And also, µ law companding which is one of the most widely explored PAPR reduction technique along with newly designed phase sequences. Motivation and idea came only after performing literature reviews of several research works. Finally, new algorithms have already been proposed. In future, another type of research work will also be designed which will be based upon these algorithms. This is the goal of this study which leads to the improvement in the drawback of the currently existing algorithms.

The OFDM system [1] generates signals for transmission, where output is found to be the superposition of several subcarriers with assistance of IFFT. It can obtain very high PAPR which is the most important implementation issue of OFDM system. If in any case transmitter possess high PAPR then the significant reduction is obtained in average power with reference to constant saturation power. Now, in modern system, PAPR issue is more in uplink. Because it is limiting link in range, coverage and battery power is also limited in mobile terminal. Hence, the efficiency of power amplifier (PA) is found to be very critical.

In the upcoming future 5G [1] smart phones with beamforming method, PAPR diminishing is very important. It is because of poor performance of battery and low power efficiency of mmWave PA. In addition to this, in the tactical communications, the critical point is coverage whereas in vehicle to vehicle communication needs very robust output power.

The most important issue here is that PA prepared with high scopes of power and have small cost efficiency. They are found to be very expensive. Moreover, as a result practical implementation must consider all measures and several steps to diminish high PAPR. So, this work also aims to design and develop the systematic algorithms for the diminishing of high PAPR. Henceforth, this is also the most important motivating factor of this work.

The combination of OFDM with multiple-input multiple-output (MIMO) results in MIMO-OFDM which is the most promising method. It can be considered for broadband wireless access method because of very high data rates situation of transmission. The OFDM diminishes receiver complexity just by transforming the frequency-selective MIMO channel into the set of parallel frequency flat channel of MIMO [1]. The realistic spectral efficient version of OFDM like orthogonal frequency division multiple access (OFDMA) are also under consideration. So that, the requirement of current and upcoming generation wireless communication system.

1.8 PROBLEM DEFINITION

A lot of research has been completed in the recent past which is related to the performance, investigation and improvement of OFDM system. But still it suffers with the problem of the high PAPR. As suggested by several researchers in many research works. In addition, due to the problem of high PAPR, high power amplifier starts working in the non-linear region. So, it introduces distortion in the information in the transmitter side itself. Keeping in the mind, past several researches, at first currently, this thesis aims to explore and investigate the performance of OFDM system.

Now, we start by exploring the already available PAPR reduction methods like conventional SLM and PTS algorithms. So as to obtain their most important advantages and disadvantages in order to implement OFDM system. Henceforth, analysis and investigation of well-organized PAPR reduction is considered as the significant area which is explored in this thesis.

Final aim of this thesis is to sufficiently recommend the novel algorithms so it become more suitable in the already systems. In addition, it leads to the efficient and significant reduction of PAPR of OFDM system.

CHAPTER 2 REVIEW OF LITERATURE

2.1 LITERATURE REVIEW

After the advent of OFDM system, the algorithms for the PAPR reduction in OFDM system are gaining much more interest among many researchers. This enhanced OFDM system with suitable algorithm leading to numerous number of applications. So from past few decades PAPR reduction has always been an attention-grabbing and eye-catching area of research.

Tang et al. [11] proposed a hybrid method in order to diminish the peak to average power ratio (PAPR). The clipping and companding method like iterative clipping and filtering (ICF) method and enhanced non-linear companding (ENC) method respectively were used. The computational complexity of the projected scheme was lower in comparison with ICF but higher than ENC as shown by results and also the projected method performed much better in diminishing the PAPR and bit error rate (BER) in comparison with ICF whereas the projected method in comparison with ENC obtained equal PAPR diminishing but better BER performance as shown by simulation results.

Thota et al. [12] demonstrated the reduction of PAPR using SLM, PTS, hybrid and projected method. Evaluation has been done in terms of power spectral density (PSD), efficiency and gain with the help of OFDM analysis along with high PAPR through high power amplifier (HPA) models. Very encouraging results were obtained by hybrid PAPR diminishing technique. HPA operated in linear region with high efficiency in comparison with non-hybrid PAPR diminishing method. It has also been suggested that hybrid PAPR diminishing technique can be utilized in 5G and beyond.

Hu et al. [13] analyzed the most important reasons for the error floor of the piecewise linear companding (PLC). Now, depending upon the analysis, authors proposed a generalized PLC technique to diminish the distortions in the decompanded signals along with the easing of the limitation on the preservation of average signal power. At last, authors formulated optimization problems in order to obtain most important parameters of the functions of companding in search of tradeoff between PSD and BER under the limitation on the PAPR. The projected generalized PLC improved the performance of BER while keeping same performance of PAPR as PLC.

Zhang and Shahrrava [14] projected a method which was hybrid PAPR method employed a cascaded structure of two stage. The first stage was known post Inverse Fast Fourier Transform (IFFT) stage which can build set of higher order sequences of quadrature amplitude modulation (QAM) sequences with the help of binary phase shift keying (BPSK) or quadrature phase shift keying (QPSK) sequences with minimum IFFTs. The second stage was depending upon optimal Class-III SLM method which contained the bank of parallel blocks. Now, these blocks created many candidate sequences from every QAM sequence after passing it with the help of a set of parallel sub-blocks which performed circular convolution along the perfect sequences and circular shifts with the assistance of optimum shift values. In the term of PAPR diminishing and lower complexity, projected method outperformed already existing methods as shown by simulation results.

Matsumine and Ochiai [15] proposed a novel joint channel coding and PAPR reduction technique for polar codes OFDM system. The most important idea was to present shaping indices to the polar encoder and create several OFDM symbol candidates in accordance with many shaping bit patterns and then choose the one which generate smallest PAPR as signal of transmission. Here, side information transmission was not needed because information and shaping bits can easily be jointly decoded with the help of polar code traditional decoding algorithm. For the well-organized PAPR reduction, the polar code design procedure has been demonstrated. The projected shaping technique offered a gain of additional 4.5 dB with respect to performance of PAPR without disturbing the complexity of decoding.

Zhou et al. [16] projected a low complexity PTS method which was dependent upon the dominant time-domain samples, and two novel metrics for selecting these samples were announced. The grouping scheme has also been involved for the further diminishing of computational complexity. The low complexity PTS method provided a good PAPR diminishing performance with more saving in the computational complexity as indicated by the simulation results.

Arbi and Geller [17] demonstrated PAPR diminishing method for OFDM using signal space diversity. The unique algorithm for the choosing of two rotated and cyclically Q-delayed (RCQD) QAM constellations was projected to together optimize the BER and blind detection performance of SLM method. Simulation results depicted that the projected scheme obtained very large reduction in the PAPR without any spectral spoilage and also improved the BER performance.

Liu et al. [18] proposed an efficient active constellation extension (ACE) which depends upon extension projection onto the convex sets (EPOCS-ACE) method for diminishing PAPR of OFDM system with very large subcarriers and constellations of higher order. The iterative process which was specially designed not only obtained gain of PAPR reduction in one iteration but also adjust to familiarize several necessities of OFDM system. In addition to this, both novel peaks-clipping method and specific extension rules were planned in order to ensure performance of BER while diminishing the PAPR. The derivation of theoretical analysis of selection criterion for compensation factor, correction factor optimization, CCDF reachable bound and analysis of complexity was presented. In comparison with ACE, the EPOCS-ACE obtained better performance for BER, PAPR and complexity for OFDM system as shown by simulation results.

Rateb and Labana et al. [19] projected a very low complexity method for diminishing of PAPR which was dependent upon linear scaling of the portion of the signal coefficient by the optimal factor. The research work was backed by the several performance metrics analysis which ultimately lead to the optimal high-quality of key parameters so that maximum gain can be obtained. The projected method reduced the PAPR effectively with negligible effect on BER which slightly diminish the data rates. Considering subcarriers equal to 1024, the PAPR reduced from 13 dB to 7.4 dB or 6.9 dB, in return for data rates reduction of 1% and 2% respectively. Further, PAPR differed very slightly with increasing number of the subcarriers. This provided the competitive flexible tradeoff in comparison with those given by present method provided in literature. Henceforth, this method has good potential for applications like LTE and 5G systems.

Wang et al. [20] proposed the parallel tabu search based method to obtain the sub-optimal peak reduction tone (PRT) set. After obtaining sub-optimal PRT set, authors applied it in the adaptive iterative clipping and filtering (AICF) technique for the reduction of PAPR. In addition to this, BER performance and reduction of PAPR awere compared among AICF technique, adaptive amplitude clipping, adaptive scaling and fast iterative shrinkage threshold algorithm method. The simulation results verified that parallel tabu search dependent PRT method obtained better secondary peaks with small computational complexity and AICF method diminish PAPR with fast convergence speed while its performance of BER was only marginally inferior than for the current techniques.

Hsu and Liao et al. [21] proposed the generalised precoding technique which preferred generalised precoding matrix (PM) to deliver the flexible method in order to create precoded data with small PAPR and complexity. The proposed generalised precoding OFDM system obtained close performance of BER with small PAPR reduction in comparison with system of OFDM. In addition to this, performance of BER of generalised precoding based OFDM was superior to that OFDM system at low signal to noise ratio. Now, the single-carrier frequency division multiple access was case of discrete fourier transform (DFT) based generalised precoding scheme, henceforth, the projected technique promised for obtaining small PAPR and complexity with better performance of BER.

Kim et al. [22] proposed a new method of PAPR reduction which was recognized as PAPR diminishing network (PRNet), depend upon the autoencoder architecture provided by deep learning. In the PRNet, the mapping and demapping of the constellation of symbols on every subcarriers was calculated with the help of deep learning method so that BER and PAPR can jointly be diminished. The planned method outperformed the traditional method in terms of PAPR and BER.

Anoh et al. [23] demonstrated the novel technique as a root-based μ law companding (MC) known as RMC method which concurrently expands and compress OFDM signals amplitudes unlike MC. Authors expressed a second transform which was independent of MC model. The results of two projected methods outperformed four companding method like MC, hyperbolic arc sine companding (HASC), exponential companding (EC) and log based modified (LMC). In addition to this, authors precoded OFDM signals with the help of discrete hartley transform (DHT) for further diminishing of PAPR limits obtained by RMC by phase distorting. While preserving BER, DHT-precoded RMC outperformed four different methods like (LMC, MC, HASC and EC) in the terms of the PAPR

Bi et al. [24] explained a joint low complexity and PAPR diminishing method based upon Luby transform (LT) codes. An already defined threshold was used to lessen complexity and also to control PAPR while doing LT codes ending process. In addition to this, authors used several IFFT operations to formulate and model the complexity of theoretical algorithm. Simulation results depicted that the projected method diminish the PAPR with large lessening of complexity. In comparison with prevailing method, reduction of complexity of 81% obtained concerning total numbers of operations of IFFT. The experimental curves were very much consistent analysis of mathematics with regard to the per degree IFFT operations.

Chen and Chung et al. [25] presented the modified PTS algorithm for PAPR lessening of M-ary-quadrature amplitude modulation (M-QAM) OFDM signals by dividing block of OFDM into non-disjoint sub-blocks of OFDM. The sum of many QPSK constellations can be depicted through M-QAM, authors applied altered disjoint partitioned on QPSK OFDM blocks, which ultimately results in equivalent non-disjoint partitioned on M-QAM OFDM block. The simulation results depicted that modified PTS with non-disjoint partitioned obtained better PAPR lessening in random, adjacent and interleaved methods in comparison to disjoint sub-block partition in traditional PTS.

Liu et al. [26] proposed the design which incorporated thoughtful error-correcting code and bit flipping with unequal error protection. The modified density evolution technique was utilized for getting suitable code degree distributions to the system of bit flipping. The projected design obtained effective lessening of PAPR with small degradation of BER in several cases as depicted by simulation results.

Wei and Shen et al. [27] demonstrated the PTS method with low-complexity known as N-PTS for the reduction of PAPR. After creating few sequences, time domain signals were achieved by uniting the original signal along with two circular signals. Hence the implementation of only one IFFT block was necessary. The N-PTS method obtained low computational complexity while losing the small bit of performance in comparison with traditional PTS method.

Hussaini et al. [28] presented the sub-blocks interleaving PTS (SBI-PTS) method with low complexity for the lessening of PAPR in OFDM system. In this method, every sub-block was interleaved form others as proposed by a new sub-blocks interleaver. In addition to this, a novel scheme of optimization has been proposed with the help of which number of iterations were made equal to the sub-blocks numbers only which results in diminishing time of processing and small computation leads to complexity reduction. This novel method diminished the complexity up to 99.95% (with number of sub-blocks M=16, IFFT size N=256) in comparison with traditional PTS, new existing PTS method and provided good performance of BER. This method also offered enhanced efficiency of transmission because it did not need side information.

Mazahir and Sheikh et al. [29] proposed two new methods which changed operation of companding in order to accommodate symbol power randomness. The analysis of probabilistic of average power of symbol in association with amplitude of constituent samples was carried out. This produced the theoretical framework employed in the designing of the projected small complexity solutions. The operation of companding became adaptive which actually adjusted with the change in symbol amplitude distribution during the runtime application as demonstrated by the proposed method.

Wu and Chung et al. [30] proposed a new correlative precoder to provide correlatively precoded waveform of OFDM with diminished PAPR along with improved intercarrier interference (ICI) self-cancellation or enhanced suppression of sidelobe either jointly or respectively. The correlative precoders can be considered to obtain joint characteristics performance in the lessening of PAPR, suppression of spectral sidelobe and ICI self-cancellation.

Renze et al. [31] projected a method with which candidate rotation vectors were created based upon the genetic and greedy algorithm. In order to obtain the further lessening of PAPR, authors combined projected technique and superimposed sequence of training technique. As depicted by simulation results and theory that projected technique obtained better lessening of PAPR along with the reduction in the computational complexity.

Bandara et al. [32] proposed nonlinear companding transform (NCT) function with suitable parameters compression and expansion weights can be easily applied. As an outcome, the projected function can maintain average power of the signal approximately unaffected during this process of the companding. Henceforth, proposed function was found be greater in comparison with earlier proposed method. The simulation results depicted the excellent performance of projected function. The projected method performed good with nonlinear transmitter amplifier and delivered best performance of error in comparison with function of error and exponential function dependent method.

Wang and Akansu [33] studied a low complexity lessening of PAPR framework to jointly alter amplitude and phase values of the original symbols in the alphabet. This framework utilised only one FFT/IFFT pair of operator for the transmultiplexing of the symbols without the side information(SI). The most important advantage of proposed technique was to design a symbol alphabet (SA) modifier matrix (SAM) for the lessening of PAPR as depicted through the comparison performance for the applications scenarios given in the study.

Zhou et al. [34] proposed a heuristic PTS selection technique, modified Chaos Clonal Shuffled Frog-leaping algorithm (MCCSFLA). It was dependent upon chaos theory and also inspired by the natural clonal selection of a frog colony. Authors also analyzed MCCSFLA with the assistance of theory of Markov chain and proved that the algorithm can also converged to global optimum. As shown by results of simulation, proposed technique obtained better PAPR reduction in comparison with several other quantum evolutionary, genetic and selection mapping algorithm. In addition to this, projected method converged faster than quantum evolutionary and genetic algorithms.

Hou et al. [35] proposed an algorithm dependent upon peak-windowing residual noise, which was created by windowing the samples of the signals which exceeded the predefined threshold. Filtering residual noise in order to satisfy tone reservation (TR) constraints and scaling with the help of the scaling factor determined to reduce out of range power creates the peak canceling signal (PCS). The simulation results depicted that projected algorithm obtained 6.9 dB reduction in PAPR with small complexity as compared with other methods.

Yang et al. [36] demonstrated that SLM method was considered for the reduction of PAPR but it has the drawback of high computational complexity. To diminish the complexity of the conventional SLM(C-SLM) method, real and imaginary parts of OFDM signals were used separately. The odd and even sequences of the imaginary and real parts were obtained with the help of properties of Fourier transform. Several candidates were created with the different combination of all the sub-carriers. The proposed method has small complexity by using only M IFFT operations to create M^4 candidates. The proposed method obtained best performance of PAPR reduction and also diminished the computational complexity as compared with C-SLM method.

Li et al. [37] formulated an optimization problem in order to enhance the joint decoding performance by optimizing the partitions. In addition to this, two greedy based methods were projected in order to provide the solution of the problem. The simulation results depicted that joint decoding method with projected partitioned method delivered suitable performance of error correcting for the large PTS groups than it did with partition which was known as pseudorandom. Thus, much better performance of PAPR can be maintained.

Hong et al. [38] presented the adaptive all pass filter (AAPF) based PAPR lessening method. AAPF method did not suffer increment in the mean power and decrement in the spectral efficiency unlike tone reservation (TR) method. The AAPF method can be used along with the rotation of constellations whereas the ACF method has limitation in it. The discussion and comparison was done with TR method for performance of PAPR and computational complexity. The AAPF method did not affect signal reception quality at the side of receiver demonstrated by BER performance.

Taspinar et al. [39] demonstrated PTS depend upon parallel tabu search (Parallel TS-PTS) method. PTS is the distortionless PAPR lessening method, but for the application its complexity related to find optimal phase factor is very high. Comparison of parallel TS-PTS was done with several PTS methods for the reduction of PAPR and performance of search complexity. The simulation results depicted that projected TS-PTS scheme provided best PAPR reduction and BER performance.

Park et al. [40] demonstrated that SLM is good PAPR reduction scheme for PAPR diminishing of OFDM system. For the recovery of data at the receiver side, SLM method required transmission of already chosen phase sequence index which is also known as side information (SI). Henceforth, authors proposed a novel pilot phase sequence enabling for the recovery of the data without SI and also with low complexity decoding method. The performance of BER of proposed method was similar to the SLM method with SI and much better than maximum likelihood (ML) decoding method and also the computation complexity of projected decoding method was small in comparison with ML decoding method.

Varahram and Ali [41] suggested that for the lessening of PAPR, PTS is the effective method. In conventional PTS (C-PTS) many IFFT operations and calculations were performed in order to get phases which are optimum so it increased the complexity. Henceforth, authors proposed a method to diminish the number of IFFT operations to just half but at the cost of little bit PAPR degradation. The simulations were done with OFDM signal under QPSK and also power amplifier of saleh model. The effects of digital predistortion (DPD) to enhance the efficiency and linearity of power amplifier (PA) saleh model were also observed.

Wei et al. [42] have considered the helmert sequence for the PAPR diminishing which is entirely different from the riemann, random and hadamard for SLM-OFDM system. Helmert-SLM didn't transmit any kind of information because of regular structure of helmert sequence. This proposed method provided an improvement of 3.5 dB in comparison with riemann based SLM-OFDM and obtained 4.5 dB improvement in comparison with cyclic hadamard sequence based SLM-OFDM.

Liang and Jiang [43] stated the modified scheme of artificial bee colony-based (ABC-SLM) method. The projected scheme known as gene algorithm (GA)-ABC-SLM. It is the combination of artificial bee colony dependent SLM with gene algorithm (GA). The simulation outcomes depict the better performance of projected work in comparison with ABC-SLM.

Wang [44] considered an additive scrambling PAPR diminishing with BPSK for OFDM system. In this work, the set of OFDM signals were generated after addition of scrambling sequence. At last, the sequence which generate the lowest PAPR was chosen. This proposed method leads to the reduction in the complexity and generated comparable performance of PAPR reduction in comparison with SLM method.

Liang et al. [45] examined a modified SLM technique for the improvement in the complexity. It can also be considered suboptimal SLM method for PAPR reduction. This projected technique created W signals with the help of phase factor so that the scrambling of input signal to generate $\frac{W}{2}$ signals, followed by IFFT and further, scrambling takes place for the remaining $\frac{W}{2}$ signals. In addition to this, the creation of phase factor was fully depending upon sub-code of the reed-muller codes with the random ordering. The simulation results showed that proposed method was much more improved in result in comparison with adopting SLM method.

Shankar et al. [46] discussed a new precoding technique which was purely based upon hadamard SLM (HSLM) and genetic algorithm (GA) for the lessening of PAPR in OFDM systems.

Pamungkasari et al. [47] analyzed the effect of the cyclic shift resolutions of OFDM along with low complexity cyclic SLM (C-SLM) method without the need of side information (SI) and use of delay correlation and match filter (C-SLM-DC-MF) based upon reducing PAPR, BER and accuracy. According to the authors, very high resolution leads to the smallest PAPR reduction with better BER and accuracy.

Cheng et al. [48] presented a new artificial bee colony dependent SLM method (ABC-SLM). The simulation outcomes clearly depicted very good PAPR diminishing along with the smallest computational complexity.

Sudha et al. [49] examined the different way for the generation of phases as lehmer random number generator or multiplicative congruential generator (MCG). PAPR performance comparison has been established in comparison with hadamard and riemann. Authors suggested that MCG can be a very good alternative for random sequence and hadamard sequence.

Sudha et al. [50] applied a new methodology in which the information sequences were divided into two sub-blocks so that circular convolution applied to the first sub-block and with the help of traditional SLM in second sub-block. Now, final signals were obtained by uniting both the sub-blocks signals. Consequently, marginal PAPR reduction along with computational complexity reduction was obtained. Several phases were considered like chaotic, new riemann and riemann phases sequences. Simulation results depict that modified-SLM with new riemann phase sequences creates largest PAPR lessening as compared with other phase sequences.

Rahman et al. [51] proposed a novel phase sequence creation method from the condex matrix that can obtain better lessening in PAPR in comparison with the bauml sequence. Authors depicted that proposed phases sequences obtained 4.0 dB higher decrease in PAPR in comparison with traditional SLM technique. It also diminished the computational overhead by about 59%.

Woo et al. [52] proposed a choosing technique of cyclic shift values which was used for the reduction of variance of correlation between several OFDM arrangements. In addition to this, a picking technique has been proposed for the proper rotation values when $U > N/8$ where N is size of the IFFT and U is several number of OFDM signals. The simulation results depicted that projected technique achieved optimal lessening in

PAPR. It required very small memory and side information in comparison with sequence which were random.

Haque et al. [53] examined the SLM technique with the assistance of hadamard matrix factor of row as it’s phases sequences in order to investigate the diminishing of PAPR. The projected method has shown the significant improvement in the performance of PAPR with the help of row factor of hadamard matrix.

Sudha et al. [54] discussed the modified SLM method with the help of perfect square or conversion vectors. In the technique, the information sequence was equally divided after that the first half was taken to IFFT and then circular convolution applied with perfect sequences whereas for the next half, traditional SLM was applied for the reduction of PAPR and complexity. Authors suggested that, the complexity of the proposed work has been reduced as compared with traditional SLM technique.

Adegbite et al. [55] proposed the prolate binary sequences for OFDM system which implement SLM. Through simulations, it was observed that the above mentioned sequences improved the performance of PAPR reduction and also lead to the reduction in computational complexity in comparison with riemann binary sequences.

Katam and Muthuchidambaranathan [56] presented a novel phase sequence which was totally dependent upon decimal sequences and after that proposed modified SLM algorithm to diminish high PAPR. Since, SLM improved the statistical characteristic of the PAPR distribution with the assistance of very less correlated phase sequence sets. The simulation outcomes depicted that PAPR performance of proposed work was far better than traditional SLM technique.

Wang and Liu [57] considered a partial phases weighting SLM (PPW-SLM) method for the diminishing of the PAPR. In the projected PPW-SLM technique, properties of IFFT and partial phases weighting method were utilized for easiness of calculation of IFFT and obtained very good PAPR diminishing performance. Computational complexity reduction in proposed PPW-SLM was very significant as compared with conventional SLM (CSLM).

Ji et al. [58] addressed the semi blind SLM method with small complexity transceiver for the PAPR reduction in OFDM. In the projected method, the phase rotation vectors along with the pilot vectors were separately designed which ultimately leads to small computational complexities along with embedding-side information (SI) into subcarriers of pilot. SI finding based algorithm was also designed. Simulation results depicted that proposed method can obtain small computation complexity than semi blind SLM method. The proposed work obtained slightly worst PAPR lessening and almost same BER along with exact SI at receiver.

2.2 RESEARCH GAP

Although several methods for the reduction of PAPR in OFDM system have been proposed by many researchers in this field. But still, this problem needs to be enumerated and addressed by research community in other ways like,

1) The most popular widely known method for the reduction of PAPR is SLM algorithm. But still it needs a lot of enhancement in the process for the easy generation of the phase sequences in frequency domain. So that, when the elementary product of phase sequences with data take place then it not only reduces PAPR but also leads to the easy designing of structured frequency domain phase sequences. Notably, this thesis aims to summarize and analyze its performance with several subcarriers, many phase sequences along with digital modulation techniques.
2) Several researchers have followed PTS algorithm. It optimizes the data in the time domain with the assistance of phase sequences along with the frequency domain partitioned data. Consequently, with the help of this well-organized thesis we explore, investigate and analyze the best partitioned of data. And also, easy and structured generation of phases sequences under many subcarriers, several phase sequences and also several digital modulation techniques.
3) From the foregoing discussions, it is well established by this thesis that it aims in suggesting, investigating, analyzing and exploring the hybrid technique for the diminishing of PAPR. So that, this hybrid technique must have the advantages of both existing techniques. Lastly, this issue of PAPR specifically can be reduced drastically.

CHAPTER 3 OFDM SYSTEM AND PAPR CONCEPTS

3.1 OFDM SYSTEM BLOCK DIAGRAM

The introduction about OFDM system has been covered in CHAPTER 1. Now, the performance study and PAPR assessment of OFDM system will be covered in this chapter. Hence, Figure 3.1 shows the block diagram representation of OFDM system. The transmitter and receiver of OFDM has the below mentioned procedures:

1. Information bits of source are modulated by digital modulation scheme (Mod.) like M-ary quadrature amplitude modulation (M-QAM) and M-ary Phase-Shift-Keying (M-PSK). In OFDM modulation which are utilized like BPSK,16-QAM, QPSK, 64-QAM and 8-PSK. Generally, it has been observed that higher order modulation leads to the improvement in the speed of data rates.

2. After performing the mapping of symbol, the data is converted into parallel with the assistance of serial-to-parallel (S/P).

3. Now, several orthogonal sub-carriers are generated with the help of IFFT hence, symbols can be transmitted easily. There are many sizes of IFFT depicted in the literature like 64,128,256,512,1024 and 2048. IFFT [3] diminished the computational complexity in contrast to IDFT (inverse discrete fourier transform), several DSP (digital signal processing) chips implementation of both IFFT and FFT are available.

4. Precisely, OFDM actually converts frequency selective-fading channel into numerous flat-fading sub-channels, hence allow the utilization of very easy frequency domain equalizers. Now, again converting from parallel to serial.

5. Both the Inter-symbol interferences (ISI) and Inter-carrier interferences (ICI) [3] can be diminished significantly, with the assistance of the guard intervals in between several symbols of OFDM. This particular interval is the cyclic-extension of signal and concatenated at starting of symbols of OFDM, known as cyclic prefix (CP).

6. Then digital to analog conversion (D/A) is applied and multiplied by carrier frequency, at last, passed through power amplifier (PA) and finally, through channel.

At receiver, all the above mentioned procedure which are performed at transmitter will be reversed like the down conversion, including conversion from analog to digital converter (A/D), then cyclic-prefix-removal is applied, then serial-to parallel (S/P), fast-fourier-transform (FFT), parallel-to-serial (P/S) & at last, bits will be obtained from the symbols after applying demapping of symbols known as digital demodulation (Demod.).

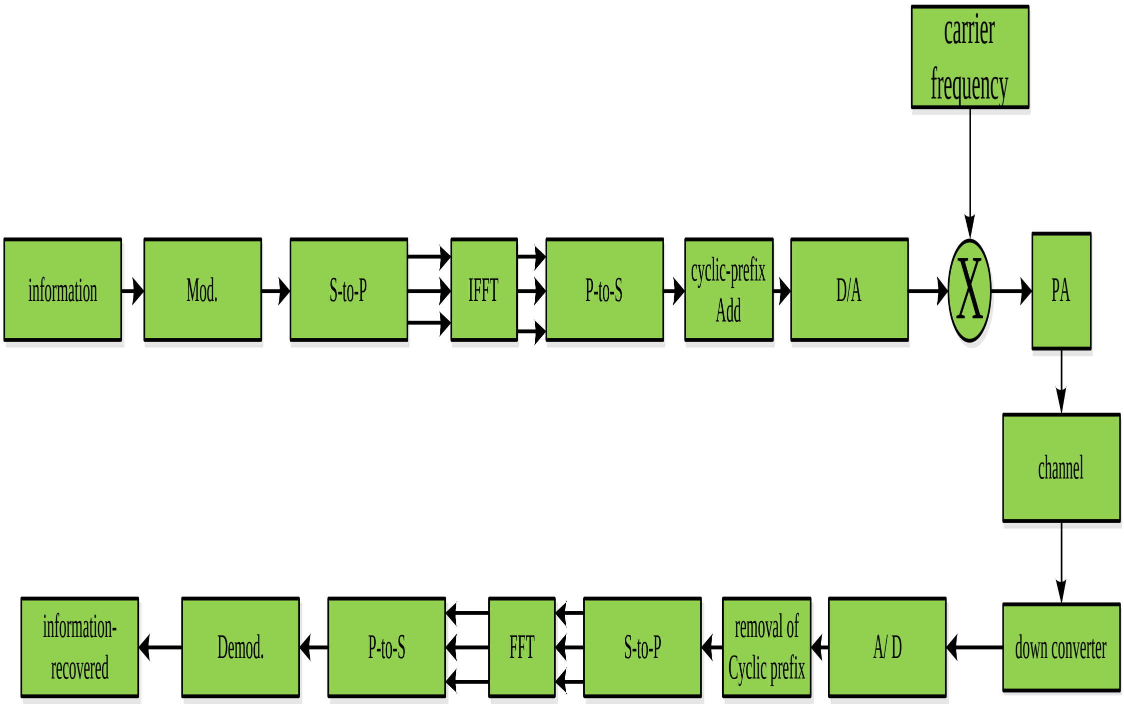

Figure 3.1 Block diagram representation of the OFDM [1]

3.2 MATHEMATICAL EQUATIONS OF OFDM SYSTEM MODEL AND PAPR

OFDM is a multicarrier modulation method [1] which divides the bandwidth into several number of orthogonal subcarriers which are transmitted with the assistance of equal intervals and gives several advantages like very easy integration with MIMO and also enhances spectral efficiency. Figure 3.1 depicts the block the diagram of the OFDM transmitter side and receiver side.

In OFDM system, a group of N complex symbols of data $S(\mathrm{k})$ which are modulated on the set of N orthogonal subcarriers. So, the input symbol vector on the frequency domain which is called as data block can be denoted by $S = [S(0), S(1), S(2) \ldots S(N-1)]^T$ and base band continuous-time OFDM signal $s(t)$, well-defined as the summation of all the N sub-carriers with spacing $\frac{1}{Nt_s}$, is represented by [1],

$$s(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S(k) e^{\frac{j2\pi kt}{Nt_s}},\ 0 \leq t \leq Nt_s \tag{3.1}$$

where t_s is the sampling period and $j = \sqrt{-1}$.

Frequently, the output of the OFDM signal has very large peaks which can be denoted as PAPR. The PAPR of baseband signal [1] of OFDM signal of continuous time $s(t)$ is defined as the ratio between maximum instantaneous power to the average power represented as:

$$PAPR\big(s(t)\big) = \frac{\max\limits_{0 \leq t \leq Nt_s} |s(t)|^2}{\frac{1}{Nt_s}\int_0^{Nt_s} E\{|s(t)|^2\} dt} \tag{3.2}$$

where $E[.]$ represents the expected value. If the $\mathrm{s(t)}$ signal is sampling at the rate of Nyquist rate $t = nt_s$, with integer n then the discrete-time OFDM signal [1] of baseband $x(n)$ can be represented as:

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S(k) e^{\frac{j2\pi kn}{N}}, \quad n = 0,1, \ldots . N-1 \tag{3.3}$$

and PAPR in the terms of the discrete-time OFDM signal [1] can be denoted as:

$$PAPR\big(x(n)\big) = \frac{\max\limits_{0 \leq n \leq N-1} |x(n)|^2}{\frac{1}{N}\sum_{n=0}^{N-1} |x(n)|^2} \tag{3.4}$$

In maximum cases, PAPR [1] of the OFDM signal of discrete time is less than the continuous time OFDM signal by $0.50\sim 1$ dB. Henceforth, the relationship in between PAPRs is denoted by

$$PAPR\big(x(n)\big) \leq PAPR\big(s(t)\big) \tag{3.5}$$

3.3 MATHEMATICAL EQUATION OF CCDF

The OFDM signal [1] of time domain $s(t)$ is a complex number. Now, assuming the real part and imaginary part which follows a gaussian distributions, with the variance of 0.50 and along with 0 mean, in promise with central limit theorem when N is appropriately very large, the amplitude of signal of OFDM $|s(t)|$ becomes a distribution of rayleigh and distribution of power becomes exponential.

The cumulative distribution function (CDF) of the amplitude of the signal sample is given by

$$F(z) = 1 - e^{-z} \tag{3.6}$$

Now, if we undertake the average power of $s(t)$ is equivalent to one, which means $E|s(t)|^2 = 1$, then the probability distribution function for PAPR is less than a certain threshold value given by

$$\begin{aligned} \Pr(PAPR \leq z) &= (F(z))^N \\ &= (1 - e^{-z})^N \end{aligned} \tag{3.7}$$

Though, when the PAPR diminishing performance is evaluated, then complementary cumulative distribution function (CCDF) is used most frequently. The probability which PAPR exceeds a threshold value (i.e., CCDF) [1] is explained by

$$\begin{aligned} \Pr(PAPR > z) &= 1 - \Pr(PAPR \leq z) \\ &= 1 - (1 - e^{-z})^N \end{aligned} \tag{3.8}$$

Now, in the literature, CCDF of the PAPR is generally denoted in the terms of the number of sub-carriers N. The expression for the CCDF of the PAPR with total sub-carriers N with L times oversampling can be denoted as [59]:

$$CCDF = \Pr(PAPR > z) = 1 - (1 - e^{-z})^{N \times L} \tag{3.9}$$

3.4 SIMULATION RESULTS AND DISCUSSIONS

The modern day requirement is more information so new wireless application have been created for the current technologies which ultimately, provides high speed data rates transmission along with better utilization of spectrum. Henceforth, OFDM is the excellent solution for the achievement of this goal. It provides the clear choice for the upcoming high data rates system. Precisely, In OFDM method, numerous data bits are simultaneously modulated with the assistance of numerous subcarriers. This method, divide the entire band of frequency into many smaller subbands. OFDM [3] enhances the spectrum efficiency because subbands are orthogonal to each other. This implies that each of the individual subbands are independent of each other. It has been analyzed that, the PAPR of discrete time signal which has undergone with oversampling provides an accurate approximations of the continuous time signal of OFDM only if the oversampling factor [60] is found to be atleast 4($L \geq 4$). In this projected work, we have chosen oversampling value L as 4,8, and N=32,64,128, OFDM blocks=3200, modulation= 8-PSK and 16-PSK.

Figure 3.2 to Figure 3.5 depict the comparison of CCDF performance for OFDM under numerous subcarriers, oversampling and modulations. The analysis shows that OFDM at N=32 achieve lowest PAPR and outperform the OFDM for N=64 and 128. The performance enhancement creates from the condition that as the number of subcarriers are increasing so as the corresponding increment in PAPR issue is observed.

It is obvious from Figure 3.2, that in order to obtain a *CCDF*=0.1%, for 8-PSK and L=4 based OFDM system over N=128 requires the PAPR of 10.50 dB, but this condition fall to 10.30 dB for OFDM system over N=64, for OFDM system over N=32 PAPR value further falls to 9.6 dB. The similar observations can also have obtained from Figure 3.3 to Figure 3.5.

The values of PAPR (dB) compulsory to attain a *CCDF*=0.1% for OFDM system over *N*=128,64 and 32 considering diverse number of modulation method and oversampling values are depicted in Table 3.1.

Table 3.1 CCDF performance analysis of OFDM system for diverse modulation methods, subcarriers and oversampling values

	PAPR (dB) to attain *CCDF*=0.1%		
	OFDM system		
Modulation and oversampling	*N*=128	*N*=64	*N*=32
L=4 and 8-PSK	10.50	10.30	9.60
L=8 and 8-PSK	10.90	10.10	10.00
L=4 and 16-PSK	10.40	10.30	9.90
L=8 and 16-PSK	10.98	10.10	10.01

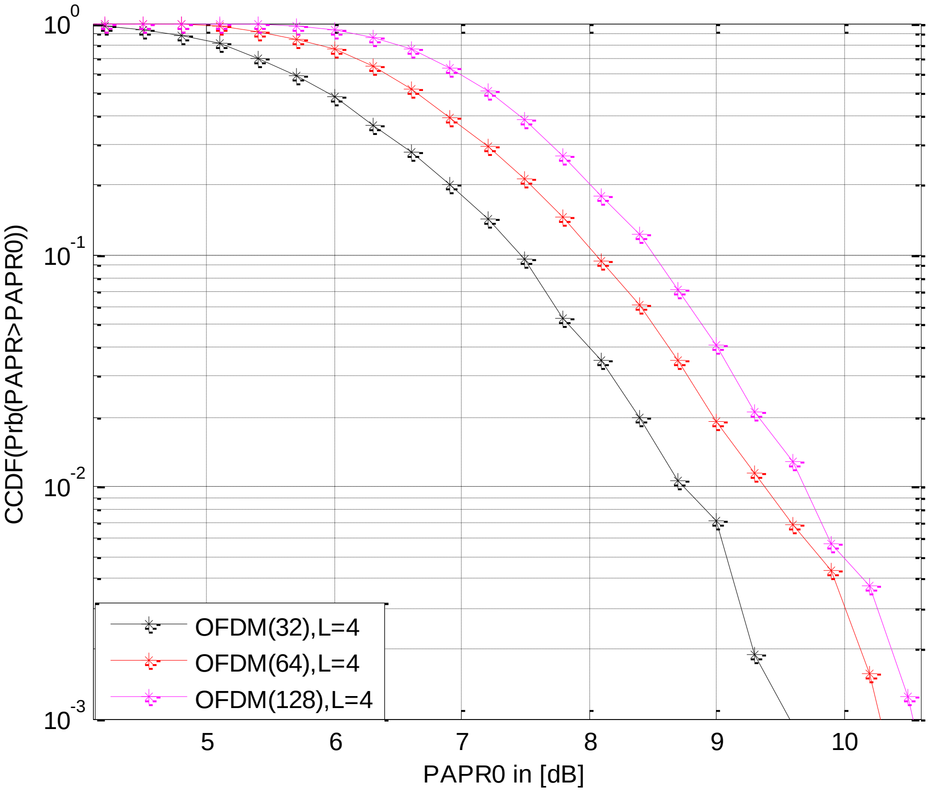

Figure 3.2 CCDF for *N*=32,64,128 under *L*=4 and 8-PSK modulation.

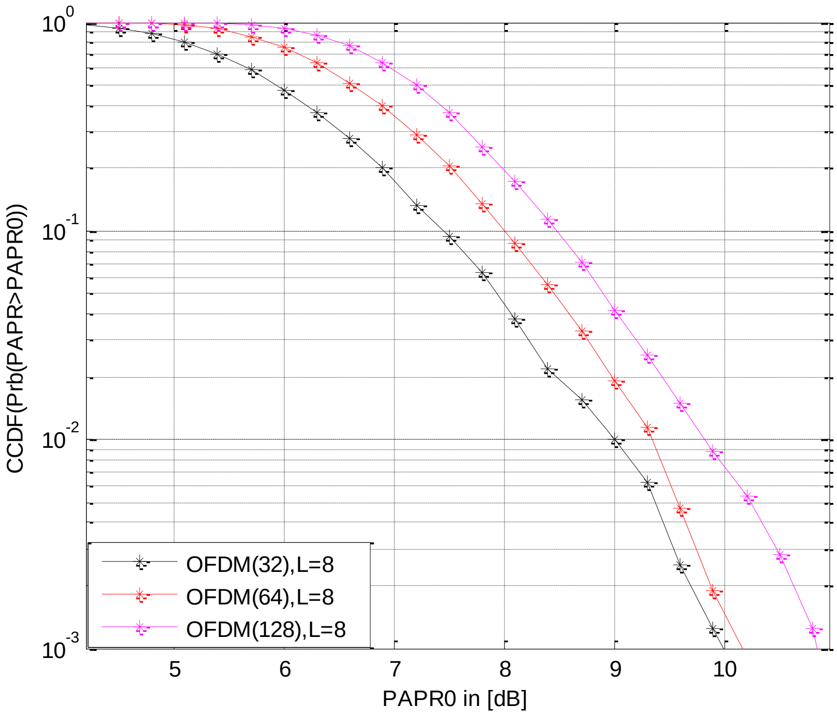

Figure 3.3 CCDF for N=32,64,128 under L=8 and 8-PSK modulation.

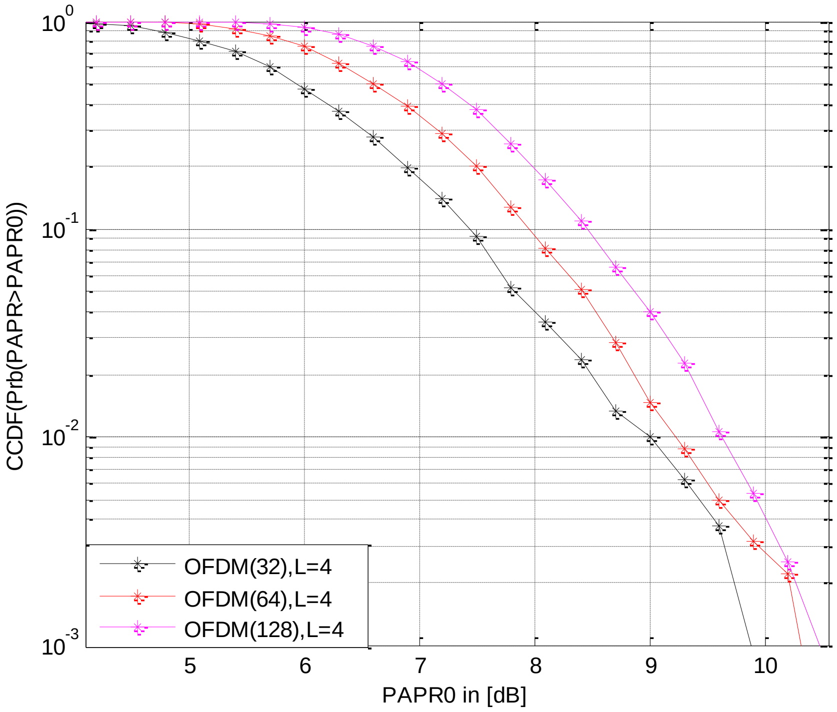

Figure 3.4 CCDF for N=32,64,128 under L=4 and 16-PSK modulation

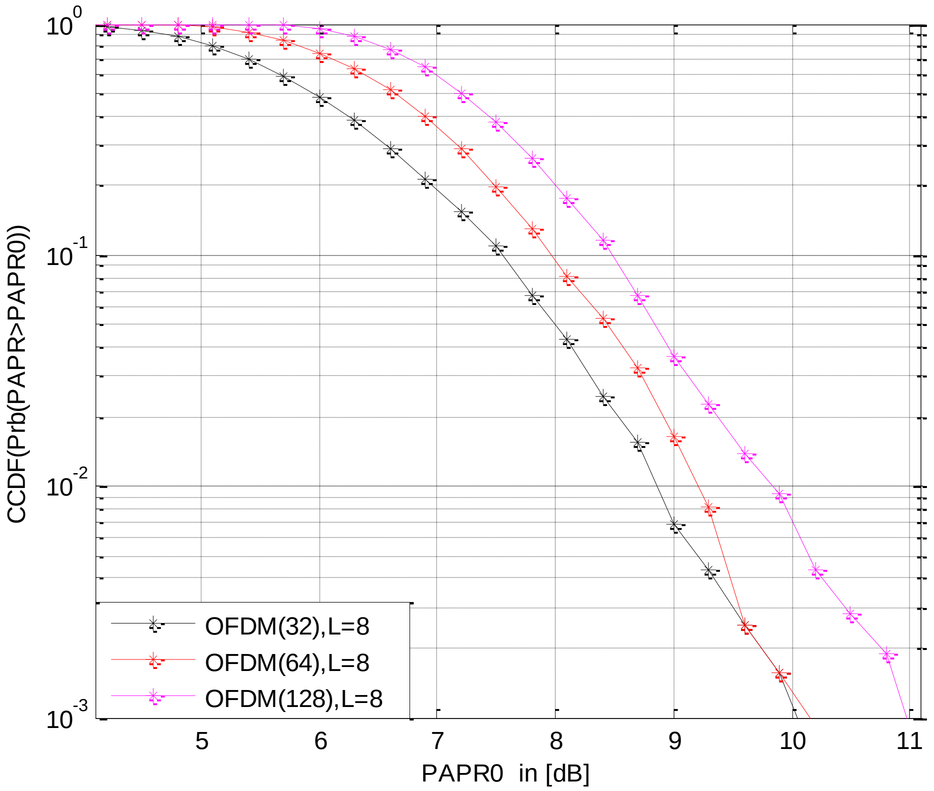

Figure 3.5 CCDF for *N*=32,64,128 under *L*=8 and 16-PSK modulation.

3.5 CONCLUSION

This chapter studied and analyzed the PAPR for diverse modulation procedures like 8-PSK, 16-PSK, oversampling factor for values 4 and 8 under subcarriers with values like 32,64 and 128. Performance of OFDM system at *N*=32 is better in all the cases because it achieves minimum PAPR in comparison with other subcarriers like 64 and 128 and also the best performance is achieved by OFDM system at *N*=32 under *L*=4 and 8-PSK modulation with the lowest PAPR of 9.60 dB. The most important conclusion which can be drawn from here is that as the *N* is increasing then corresponding increment in PAPR is also observed. This can be easily observed from all the figures and Table 3.1.

CHAPTER 4 PERFORMANCE INVESTIGATION AND PAPR REDUCTION ANALYSIS USING VERY EFFICIENT AND OPTIMIZED AMENDED SLM ALGORITHM FOR WIRELESS COMMUNICATION OFDM SYSTEM

4.1 INTRODUCTION

Orthogonal Frequency division multiplexing (OFDM) [61] which is excellent and desired as multicarrier modulation (MCM) has been extensively acknowledged and adopted in several areas like Long term Evolution (LTE), Digital video broadcasting (DVB), Multimedia over coax alliance (MOCA), IEEE 802.20, IEEE 802.11 a/g/n, IEEE 802.16 d, IEEE 802.15.3a, Digital audio broadcast (DAB) system, HIPERLAN/2 [7]. In the time domain when numerous components are added after passing through IFFT then high peak values are generated by signal because of this result, OFDM system suffers and characterized very high PAPR, this is the key disadvantage of OFDM system and which is like any modulation of multicarrier. The modern system of communication comprises of high power amplifier (HPA) which works very professionally efficient when functions near its nonlinear (NL) region but when signal is enlarged by NL-HPA then they create vulnerable distortions in phase and amplitude. In order to acquire maximum efficiency from HPA they must be functioned close to saturation region which is likely by the suppressing of PAPR issue.

Many approaches have been recommended to alleviate PAPR issue in OFDM are summarized like a new discrete artificial bee colony with PTS (DisABC-PTS) proposed in [62] obtain minor complexity and PAPR. This procedure deals with the discrete space and in this continuous to discrete space transformation is not required at all. It also not deals with any kind of loss of the information. In [59], precoding method is suggested which is based on discrete hartley matrix transform (DHMT) so that the PAPR can be reduced. The assessment of proposed method is done with vandermonde like matrix transform (VLMT), walsh hadamard matrix transform (WHMT), discrete cosine matrix transform (DCMT) and OFDM system. It is found that planned method acquires remarkable results. In [8], PTS with the blind side information detection is proposed which has a table between phase rotations and pilot tones. This proposed algorithm leads to the reduction of cost of calculation along with the PAPR. The phase rotation factors which were selected can be found straightforwardly with pilot tones. Few tones used for the estimation of channel apart from this no other tones were opted so due to this data rates and spectrum efficiency remains unaffected. In literature [63], for the lessening of PAPR, SLM with multiple-chaotics has been planned. This method advances the performance and BER of system. Literature [64] planned a novel PTS scheme using leading samples in time domain for OFDM signals. This scheme proposed a very efficient choosing method for these samples. This technique obtains optimal reduction in PAPR along with small complexity in comparison with conventional OFDM system.

Only recently, Adebisi et al. [65] suggested a new PAPR reduction method with the assistance of companding. The amplitude of OFDM signal compands to value of 1V. This procedure works as a limiter which decrease system complexity along with the PAPR. The authors also investigate out of band interference which shows that it's performance better by 5 dB. In literature [52], for the lessening of PAPR, Class III SLM technique was proposed with the capability of choosing the cyclic shifted values. This procedure diminishes the variance of correlation among OFDM signal. The main improvement here is best lessening of PAPR along with small memory and side data. Sohn et al.[66] recommended a new SLM scheme which practices conversion matrix (CM) and genetic algorithm (GA) which only involves one IFFT module whereas conventional SLM requires more IFFT blocks. This suggested work obtain good PAPR reduction with small computations complexity. In Ref. [7], authors planned a procedure which is the amalgamation of SLM and PTS both. This planned technique decreases the PAPR from 6 dB to 5 dB. Authors also reflected the results of the other procedure where the recommended procedure outperforms all the conventional methods.

Hajomer et al.[67] proposed a chaotic discrete hartley transform (DHT) which leads to the development of the OFDM system performance and physical layer security. Moreover, the projected procedure has very high spectrum efficiency with insignificant computation complexity. Sandoval et al. [1] suggested a optimization and evaluation of

PAPR lessening system for many applications like tactical, commercial and public safety. Authors accomplish the significance of hybrid system where goal was to advance both BER and diminish PAPR. Authors in [10], proposed a novel technique for constructing pseudo-random sequences based SLM procedure for diminishing PAPR. This proposed method is quite simple in generating phase sequence any needs only index of column as a side information whereas in conventional SLM needs the entire information to be transmitted for the retrieval of information. In [68], authors showed a new SLM-OFDM system which uses U IFFT where U different symbol waveforms are generated from the same data set, in order to create $U^2/4$ symbol candidates. The performance of proposed technique is superior than any other SLM-OFDM system.

Gautam et al. [69] recommended an analysis for PAPR reduction with amplitude clipping and effects of non-linear distortion. Authors also suggested that for the drop of PAPR, amplitude clipping can be establishing with insignificant distortion on signals. In [9], the authors projected a method for diminishing the PAPR of multi-carrier system which is known as SLM. It is shown that, SLM is quite good for several applications and also it obtained good gain with moderate computational complexity. An arrangement planned in [70], depicted a companding transform scheme which convert probability distribution function (PDF) of rayleigh distribution of OFDM signal into PDF of shape of quadrilateral so its name is quadrilateral companding transform (QCT).

The authors in [71] proposed a new very minor complexity PTS algorithm with its important basis in employment of differential evolution (DE) in general MBLX-DE which lead to the reduction of the PAPR. The novel non-linear companding transform (NCT) rules are used as a proposed method by authors in [72]. In [73], the investigations of PTS are performed with adaptive particles swarm optimizations. In order to diminish the PAPR, the signals which are available at the output of IFFT are divided into real and imaginary odd along with real and imaginary even sequences with the help of FFT properties, so a small complexity SLM algorithm using time domain sequence has been proposed in [74]. The authors of [75] presented the technique based on PTS which uses low complexity of phase weight so that the blocks can be optimized. A new small complexity PTS is investigated with random phase sequences matrix (RPSM) for the diminishing of PAPR in OFDM. The main condition is to obtain finest phase sequence matrix and to decrease complexity is proposed in [76]. PAPR lessening using a technique free from side information utilized the concept of random variables (RV) transformation. It changes the constellation henceforth, reduction of the PAPR is cited in [77]. The authors in [78], proposed a L_2 by 3 algorithm which depends upon discrete sliding norm transform for the reduction of PAPR. A suboptimal meta heuristics algorithm for the improvement of performance of phase sequences which is based upon improved harmony search is presented in [79]. Another approach is presented in [80], where authors introduced the novel sub-block division for the improvement of PAPR along with small complexity.

In [81], authors investigated several PAPR reduction algorithms like SLM, PTS, clipping and SLM with clipping. Authors concluded that the performance of SLM with clipping is better than conventional techniques. The authors in [82], proposed a partial selected mapping technique with small complexity. The performance of proposed technique is found to be better than conventional SLM technique. In [83], presented the amended MSD (Modified Sequence DHT) system for PAPR reduction and for the preservation of OBI (Out of Band Interference). In [84], the authors presented, a scaled particle swarm optimizations algorithm for finding the best phases in order to diminish the PAPR of the OFDM system.

Merah et al. [85] proposed a strategy which depends upon the analyzing the data in the random access memory (RAM). Moreover, the smallest PAPR is calculated and the address related to this is communicated to the receiver side for the recovery of the information. SLM with the assistance of several phase sequences generated through discrete cosine transform (DCT) matrix has been projected in [86].

Gupta et al. [87] projected a combined PAPR reduction scheme which is based upon higher order partitioned PTS and bose-chaudhuri-hocquenghem (BCH). In [60] authors projected the review of the PTS technique for the diminishing of PAPR. In [88], [89], the authors suggested μ law and square rooting companding (SQRT) as the simplest and very effective techniques for the PAPR reduction.

4.1.1 IMPORTANT DISCUSSIONS

Now, based upon the recent literature review, the following most significant objectives which are essential to be addressed:

- SLM algorithm can be applied significantly to improve the PAPR performance which is the main goal of OFDM system because of its distortionless action.
- Most of the already prevailing approaches have not considered very efficient SLM algorithm with pseudo-random sequence under time domain μ law companding.
- The outstanding performance investigations of SLM algorithm with optimized pseudo-random sequence under time domain μ law companding has never been done in comparison with SLM algorithm with pseudo-random sequence, conventional SLM algorithm and conventional OFDM system under diverse modulation schemes, phase sequences, subcarriers and μ values.

This chapter is well systematized as follows: Section 4.1, brief introduction is demonstrated. Section 4.2, projects the preliminaries, Conventional SLM method, Novel method pseudo random sequence based SLM, CCDF Analysis and μ law companding transform. Section 4.3, offers newly projected SLM Algorithm in details. Section 4.4, represents the simulation results and performance investigations whereas Section 4.5, presents the conclusion.

4.2 PRELIMINARIES

This section presents numerous characterizations which are essential for the Projected-Algo. At the first, brief review of OFDM, PAPR, μ law companding transform and CCDF are offered along with conventional SLM proposed in literature [9] (ConvenSLM-Algo) and SLM with new pseudo random phase sequences given in literature [10] (ModSLM-Algo).

4.2.1 OFDM and PAPR

In OFDM system, at the first, input data is modulated by phase shift keying (PSK) afterward, the frequency domain input symbols are converted into parallel from serial

$Y = [Y_{0,}Y_1Y_{2,\ldots..}\ Y_{N-1}\,]^T$. The time domain signal of OFDM is formed after the addition of N input symbols modulated into N orthogonal sub-carriers. The OFDM system of complex baseband [64] can be acquired as

$$y_t = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} Y_k\ e^{j2\pi k\Delta f t}\,, 0 \leq t \leq NT \tag{4.1}$$

where $j = \sqrt{(-1)},\ \Delta f$ characterizes bandwidth of sub-carriers, NT represents OFDM time period in which T is the time interval of individual element. For the orthogonality condition $\Delta f = 1/NT$.

The PAPR associated with OFDM signal is explained [64] as,

$$PAPR = \frac{\underset{0\leq t\leq NT}{max}|y_t|^2}{E[|y_t|^2]} \tag{4.2}$$

where $E[.]$ denotes the operator of expectation. Suppose L represents the oversampling factor with value greater than or equal to one. For the approximation of y_t along with $PAPR$, L times oversampled OFDM signals are considered with NL samples. The input oversampled symbol Y_L is converted to y_L oversampled signal vectors as $y_L = [y_0, y_1, \ldots\ldots.y_{LN-1}]^T$ of which y_n is denoted [64] by

$$y_n = \frac{1}{\sqrt{LN}}\sum_{k=0}^{NL-1} Y_k\ e^{j2\pi kn/LN}, 0 \leq n \leq LN - 1 \tag{4.3}$$

It is recognized that the OFDM undergo inverse discrete Fourier Transform (IDFT) for generating orthogonality among sub-carriers but for the diminishing of computation complexity of IDFT, OFDM communication system use IFFT. Generally, the estimation of PAPR is not done with the Nyquist rate sample OFDM signal with $L = 1$ rather OFDM system with oversampling factor $L = 4$ is considered [64].The oversampled OFDM with L generate the $PAPR$ which can be designed as

$$PAPR = \frac{\underset{0\leq n\leq NL-1}{max}|x_n|^2}{E[|x_n|^2]} \tag{4.4}$$

In general, high $PAPR$ is the main problem of OFDM communication system. In the subsequent subsection, PAPR problem can be solved with conventional SLM scheme suggested by [9].

4.2.2 CONVENTIONAL SLM METHOD

In the conventional SLM method [9], considering the fact of generating several OFDM frames representing similar information. Here, authors had proposed a fine solution for this problem. Designing N different vectors as $P_n = [{}_n^1P,\ {}_n^2P, \dots\dots {}_n^DP,]$, with ${}_n^{\mu}P = e^{j\emptyset_n^{\mu}},\ \emptyset_n^{\mu} \in [0, 2\pi)\ n = 1{:}N, \mu = 1{:}D.$

The mapping of data into carrier $Y[\mu]$, where carrierwise product OFDM signal with P_n, resulting into several N frames denoted by the following equation,

$$Y^{(n)}[\mu] = Y[\mu].e^{j\emptyset_n^{\mu}},\ n = 1{:}N, \mu = 1{:}D \tag{4.5}$$

Then, several N distinct frames are converted into time domain from frequency and selection of minimum PAPR sequence is done for transmission from transmitter to receiver side.

At the receiver, the straightforward technique is to send n as a side information for the vector because receiver must be aware with actual P_n.

4.2.3 NOVEL METHOD PSEUDO RANDOM SEQUENCE BASED SLM

The pseudo-random phase based SLM [10] denoted the systematic structure for phase designing defined a matrix as $F^0 \in \{+j, -j, +1, -1\}$. The possible combination of F^0 is:

$$F^0 = \begin{bmatrix} +1 & -1 \\ -j & +j \end{bmatrix}$$

For the creation of pseudo-random sequence F^0 is found to be base so that desired phase sequence for SLM can be originated easily. This phenomenon can be handled as follows:

$$F^m = \begin{bmatrix} F^{m-1} & F^{m-1} \\ F^{m-1} & F^{m-1^T} \end{bmatrix}, m = log_2 N - 1 \qquad (4.6)$$

where, the hermitian transpose of F^{m-1} matrix is F^{m-1^T}, and the total number of the sub-carriers is represented by $N = 2^n, n = 2,3,4,5,6$ ...

It must be taken into consideration that the matrix F^m is the matrix of size $l \times l$, where l is total number sub-carriers N.

The representation of $F^m = [a^{m1}, a^{m2}, \dots \dots . a^{ml}]$. After designing the desired phase sequence, the product of information vector $C(U) = [C_0(U)$, $C_1(U)$, $C_2(U), \dots$ $C_{N-1}(U)$] and chosen phases $a^{mk}(U)$ is represented as,

$$E_k(U) = C_k(U). a^{mk}(U) \qquad (4.7)$$

where $U = 1,2,3 \dots M$, $k = 0, 1,2,3, \dots \dots N - 1$.

Henceforth, the sequence related to time domain information vectors can be obtained as

$$D_n(U) = IFFT(E_k(U)) \qquad (4.8)$$

where n=$0, 1,2,3, \dots \dots N - 1$.

The main objective in SLM technique is to calculate:

$$D_n(opt) = min_{(a^{mk})} \left\{ \frac{max\{|D_n|^2, n=0,1,2,3,4 \dots\dots\dots L*N-1\}}{\frac{1}{LN} \sum_{n=0}^{NL-1} |D_n|^2} \right\} \qquad (4.9)$$

It is well understood that the side information (SI) is needed at the receiver for the recovery of sequence so with the given scheme [10] only utilized column index will be used as SI. The block diagram is shown in Figure 4.1.

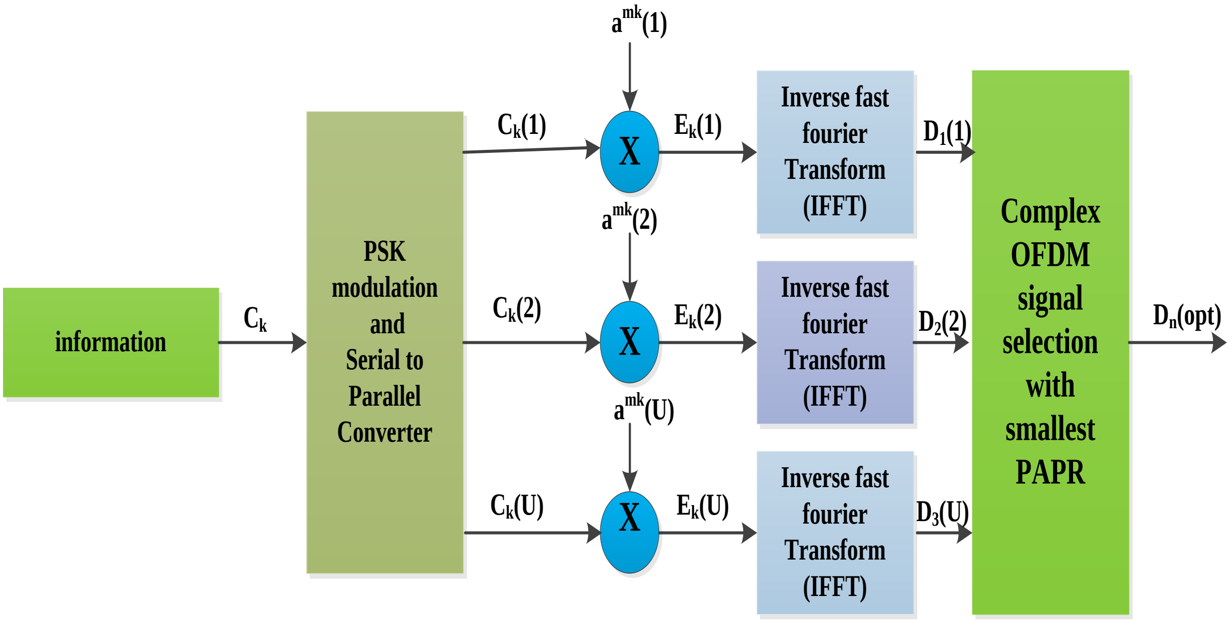

Figure 4.1 Novel method pseudo random sequence based SLM algorithm.

4.2.4 CCDF ANALYSIS

In literature [61], the important consideration of Complementary Cumulative Distribution Function (CCDF) is done for the analysis of PAPR. In general, It generates the probability of time domain OFDM signal surpassing a definite threshold $PAPR0$ $(in\ dB)$, and is denoted as,

$$CCDF_{D_{n(opt)}}(PAPR0) = Pr(PAPR_{D_{n(opt)}} > PAPR0) \tag{4.10}$$

where *Pr(.)* represents probability function.

4.2.5 μ LAW COMPANDING TRANSFORM

The μ law companding transform improves the small amplitude of the signal and stores the large peaks. This process rises the average power of the signal while maintain the peak power as it is. The companded signal $x^c(n)$ for the signal $x(n)$ is denoted as [3],

$$x^c(n) = \frac{Vsgn(x(n))log[1+\mu|x(n)/V|]}{log(1+\mu)} \tag{4.11}$$

where $V = \max|x(n)|$ is the normalization constant in such a way that $0 \leq |x(n)/V| \leq 1$, μ is a parameter of companding and $sgn(x(n))$ represents the sign of signal $x(n)$. Now, if in any case this companding transform applies to the complex signal then the sign function is equal to 1 for that envelope.

At the side of the receiver, received OFDM complex signal $r(n)$ is expanded for the retrieval of original signal previous to the demodulation. The received expanded OFDM envelope $r_e(n)$ is calculated according to [3]

$$r_e(n) = V\frac{exp\left[\frac{r(n)}{V\,sgn(r(n))}log(1+\mu)\right]-1}{\mu\,sgn(r(n))} \tag{4.12}$$

4.3 PROPOSED PROJECTED SLM ALGORITHM

The block diagram of projected SLM algorithm is shown in Figure 4.2. Now, let us describe U several reproductions of the complex modulated and up-sampled information vectors as $P^U = [P_0^U, P_1^U, P_2^U \ldots\ldots\ldots. P_{LN-1}^U]$, and R^U is the U different phase vectors that is $R^U = [R_0^U, R_1^U, R_2^U \ldots\ldots\ldots. R_{LN-1}^U]$, $U = 1,2,3..$, where, $R_k^U = e^{j\emptyset_k^U}$, and $\emptyset_k^U \in [0, 2\pi)$, $k = 0,1,2,3, \ldots.. LN-1$. More precisely, for the generation of U phase sequence, this process is defined as below:

$$F^m = \begin{bmatrix} F^{m-1} & F^{m-1} \\ F^{m-1} & {F^{m-1}}^T \end{bmatrix}, m = log_2 N - 1 \tag{4.13}$$

where, the hermitian transpose of F^{m-1} matrix is ${F^{m-1}}^T$, and the total number of the sub-carriers is represented by $N = 2^n, n = 1,2, \ldots.,$

Suppose, for the generation of 8×8 pseudo-random matrix through above equation (4.13), Therefore by linking together

$$F^2 = \begin{bmatrix} F^1 & F^1 \\ F^1 & {F^1}^T \end{bmatrix} \tag{4.14}$$

The most important criteria for the matrix F^2 has the following representation as

$$F^2 = \begin{pmatrix} +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 \\ -j & +j & -j & +j & -j & +j & -j & +j \\ +1 & -1 & +1 & +j & +1 & -1 & +1 & +j \\ -j & +j & -1 & -j & -j & +j & -1 & -j \\ +1 & -1 & +1 & -1 & +1 & +j & +1 & +j \\ -j & +j & -j & +j & -1 & -j & -1 & -j \\ +1 & -1 & +1 & +j & +1 & +j & +1 & -1 \\ -j & +j & -1 & -j & -1 & -j & -j & +j \end{pmatrix} \tag{4.15}$$

In the very same way, we can wisely generate optimized phases according to our desired information data vector length. It should be taken into consideration that is the matrix of size $l \times l$, where l is the total number of sub-carriers as LN. Consequently, it can be denoted and achieved by the total number of columns as $F^m = [a^{m1}, a^{m2}, \dots \dots . a^{ml}]$. Now $R_k^U = a^{m1}$ for the first consideration of phase vector and afterward it will take another column as a phase vector.

Hence, the product of phases vectors and information vectors are denoted through below equation:

$$\overline{P_k(U)} = P_k(U).R_k^U \tag{4.16}$$

where, $U = 1,2,3,..,$ and $k = 0,1,2,3, \dots .. LN - 1$.

Henceforth, perfectly adequate complex time domain OFDM signal can be computed as,

$$E_n^U = \frac{1}{\sqrt{LN}} \sum_{k=0}^{NL-1} \overline{P_k(U)}.e^{j2\pi kn/LN}, 0 \leq n \leq LN - 1 \tag{4.17}$$

where, $U = 1,2,3 \dots,$ and $n = 0,1,2,3, \dots .. LN - 1$.

Now, this time domain OFDM signal E_n^U(n) when passed through μ law companding to easily obtain the companded signal $E_n^{U^c}(n)$ is denoted as,

$$E_n^{U^c}(n) = \frac{Vsgn(E_n^U)log[1+\mu|E_n^U/V|]}{log(1+\mu)} \tag{4.18}$$

where $V = \max|E_n^U|$ is the normalization constant must be kept in such a way that $0 \leq |E_n^U/V| \leq 1$, μ is a parameter of companding and $sgn(E_n^U)$ represents the sign of signal E_n^U. Now, if in any case this companding transform applies to the complex signal then the sign function is equal to 1 for that envelope.

Last but not the least, the main objective of SLM algorithm is to find out the minimum PAPR which is investigated in details and represented as:

$$min_{(R_k)}\left\{\frac{max\{|E_n^{U^C}(n)\ |^2, n=0,1,2,3,4 \ldots\ldots\ldots L*N-1\}}{\frac{1}{LN}\sum_{n=0}^{NL-1}|E_n^{U^C}(n)\ |^2}\right\} \tag{4.19}$$

Conceptually, it is well significant that the SLM algorithm necessitates side information which should be send to the receiver. Henceforth, when we pick to produce phase vectors for the sub-carriers *(N)* like 256 then with this technique, we can create several phase vectors out of which we have to choose efficiently that phase vector which leads to the generation of lowest PAPR. In the conventional SLM entire vector will be transmitted as a side information (SI) which is very crucial however in proposed algorithm only the index value of column will be send to the receiver after thorough investigations. Apart from obtaining smallest PAPR, this time domain complex OFDM signal is further processed wisely through μ law companding. Indeed, this time domain companded sequence which is obtained for numerous phases will be kept and Hence, out of these precalculated companded sequences which generate lowermost PAPR will be selected for the transmission. In this way, our main goal to obtain too smallest PAPR will be easily achieved.

4.4 SIMULATION RESULTS AND PERFORMANCE INVESTIGATIONS

In this particular section, we evaluate the performance of the projected SLM algorithm with time domain μ law companding technique, new pseudo random phase sequence created SLM deliberated in [10], the random phase sequences based SLM deliberated in [9] and OFDM system in the term of several digital modulation techniques, many sub-carriers.

In our simulations, we consider $N = 32{,}64{,}128{,}256\ and\ 512$ random input information vectors mapped using digital modulation schemes like BPSK,8-PSK,32-PSK. Furthermore, the generated symbols undergo an oversampling of L=4 for the estimation of PAPR of continuous domain from discrete domain. Now size of $IFFT/FFT$ is 128 for N =32 and $L = 4$ and likewise for the other sub-carriers. The time domain values for μ are 4,7,10,16,32,64 and to acquire the $CCDF$, 4.1×10^3 generation of OFDM symbols has been considered.

In the simulation results, in fact, Unchanged= conventional OFDM system, ConvenSLM-Algo= conventional SLM proposed in literature [9],ModSLM-Algo= SLM with new pseudo random phase sequences given in literature [10],Projected-Algo= projected SLM algorithm with μ law companding applied in time domain OFDM complex symbols for U=16, 32 and 64.

From Figure 4.3 to Figure 4.14, the plot of $CCDF$ for $N = 32{,}64{,}128{,}256$ and 512 with total number of phase sequence $U = 16, 32\ and\ 64$, for μ=8 and BPSK, $8-$PSK, $32-$PSK are investigated for the performance analysis of $PAPR$. Figure 4.3 illustrates the results of Projected-Algo and other arrangements under some specific defined attention. Although all technique diminishes PAPR, some overtake other. However, upon equating the Projected-Algo with Unchanged at 0.1% (10^{-3}) $CCDF$, the Projected-Algo is significantly better than unchanged by up-to 5.89 dB while considering the case of N=64,BPSK, $\mu = 8$ and U=16.

In addition, the Projected-Algo achieves smallest PAPR among all the prevailing schemes under examination. Specifically, at $0.1\%(10^{-3})$ $CCDF$ for the Projected-Algo we can easily notice the gains of 3.79 dB than ConvenSLM-Algo and 3.40 dB better than ModSLM-Algo and this value of gain is considered as the most significant gain. The improvement in the performance originates from the condition that the use of SLM algorithm based upon new pseudo random phase sequences [10] helps in the optimization of data along with the μ law companding [3] which actually, rises the average power of the signal while maintain the peak power as it is.

Figure 4.4 shows the comparison between Unchanged, ConvenSLM-Algo, ModSLM-Algo, Projected-Algo, after taking into the account for N=128, U=16, $\mu = 8$ and BPSK. Remarkable gain has been achieved by the Projected-Algo. Specifically, gain of 4.00 dB, 4.39 dB and 5.49 dB has been found as compared to ModSLM-Algo, ConvenSLM-Algo and Unchanged at 0.1% (10^{-3}) $CCDF$.

Additionally, it can be observed that growth in sub-carriers and phases justifies the best performance of Projected-Algo. Similarly, from Figure 4.5 to Figure 4.6, It is also of great interest that Projected-Algo outperforms the other arrangements while maintaining the superiority of our proposed model when N is either small or large. Thus, the comparative results are summarized in Table 4.1.

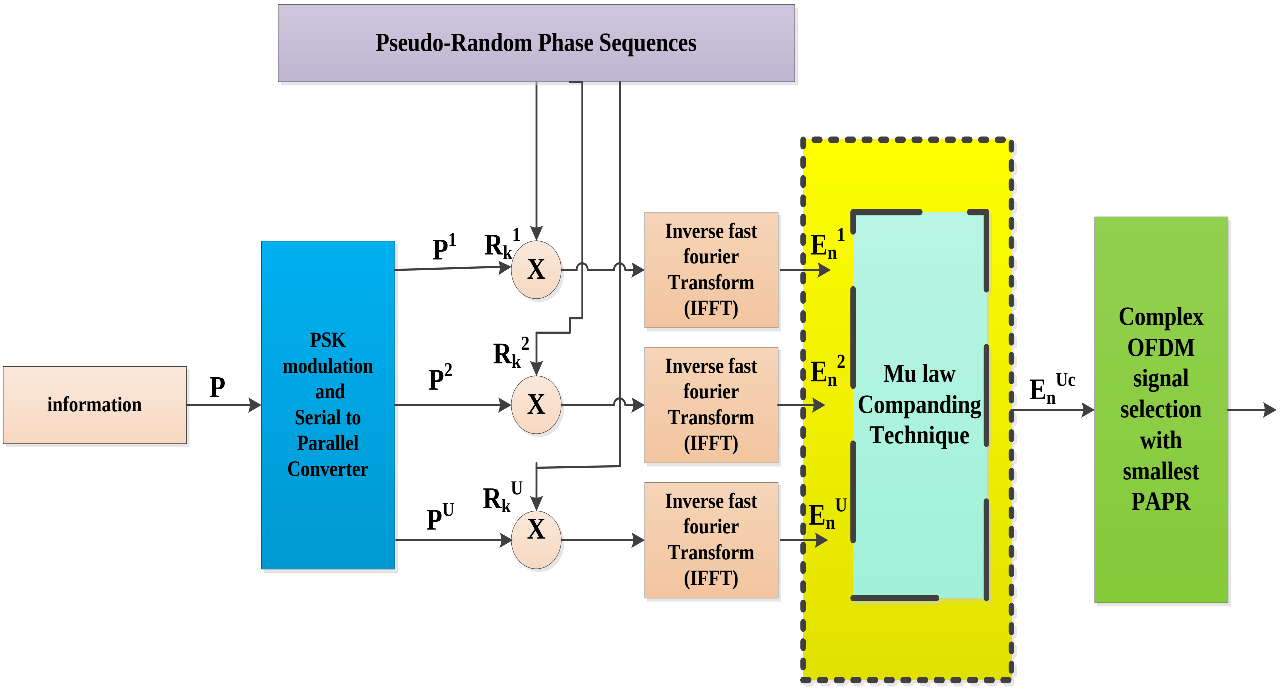

Figure 4.2 Proposed SLM algorithm using pseudo random phase sequence and μ law companding technique.

Table 4.1 CCDF performance analysis of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=64, 128, 256, 512 CCDF at 0.1 % (10^{-3}) under BPSK, U=16 and μ=8

Sub-carriers	Unchanged	ConvenSLM-Algorithm	ModSLM-Algorithm	Projected-Algorithm
64	10.90	8.80	8.41	5.01
128	10.50	9.40	9.01	5.01
256	11.00	9.80	9.21	5.01
512	11.40	10.00	9.40	5.07

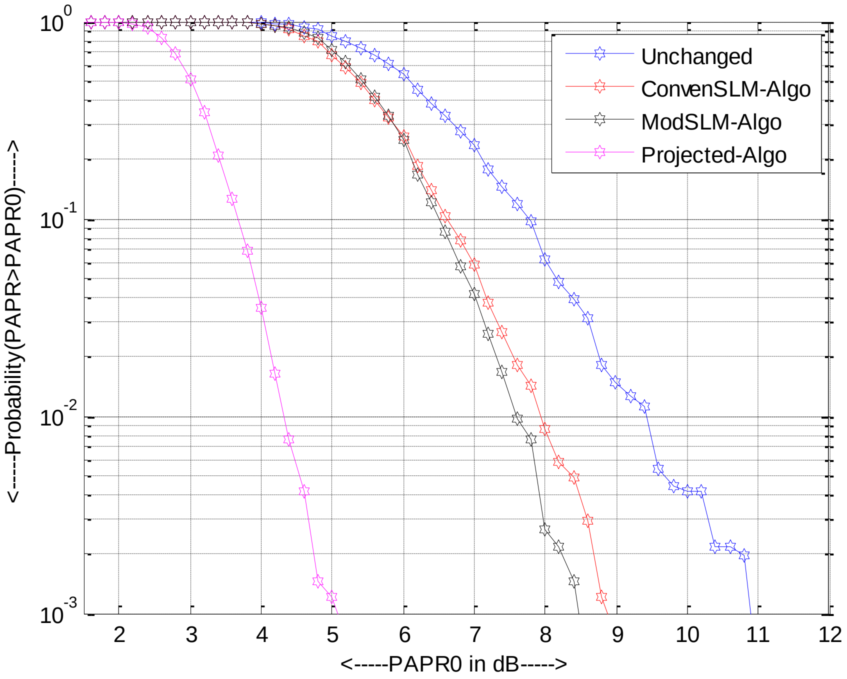

Figure 4.3 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected Algo for N=64, U=16, BPSK and μ=8.

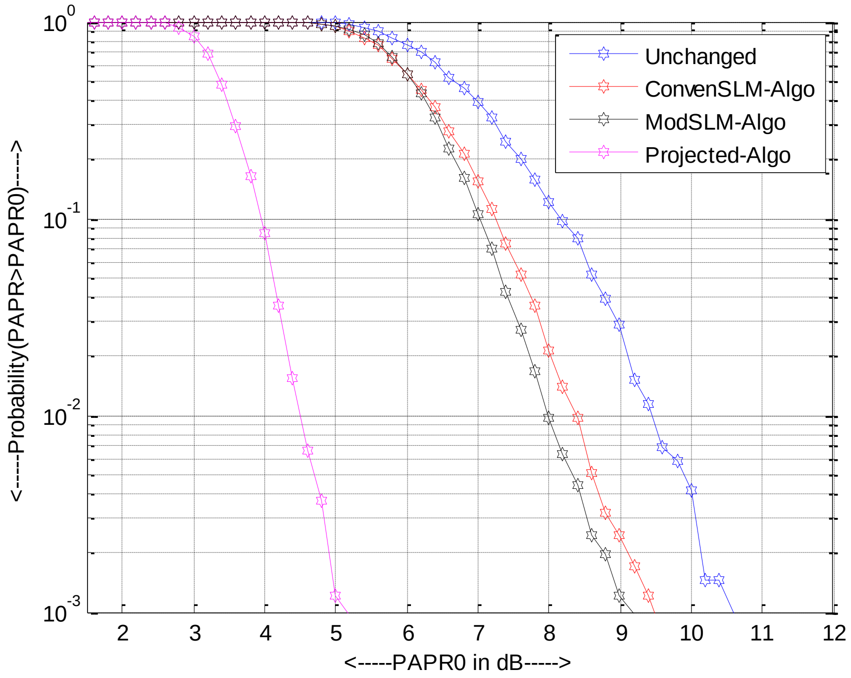

Figure 4.4 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=128, U=16, BPSK and μ=8.

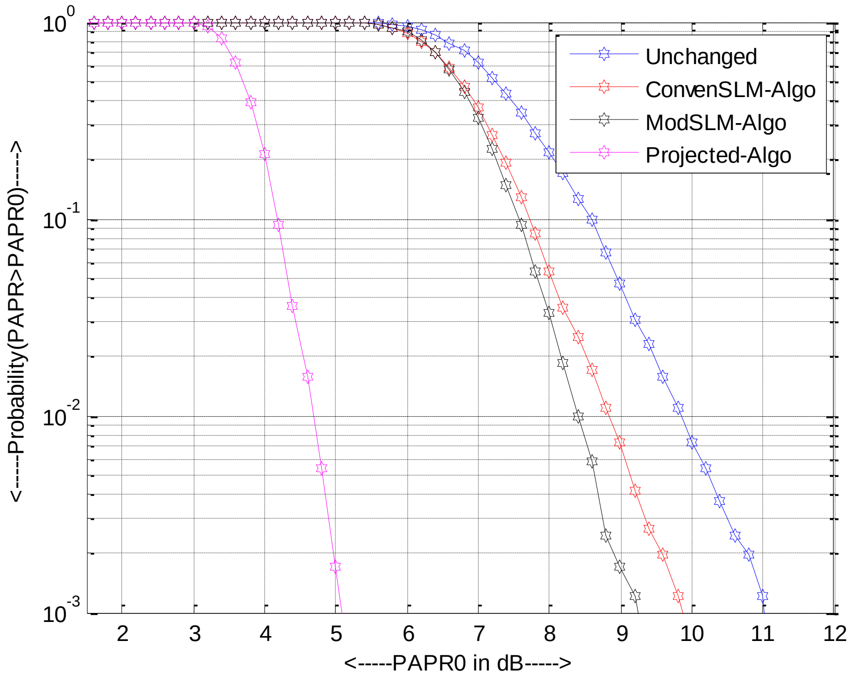

Figure 4.5 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=256, U=16, BPSK and μ=8.

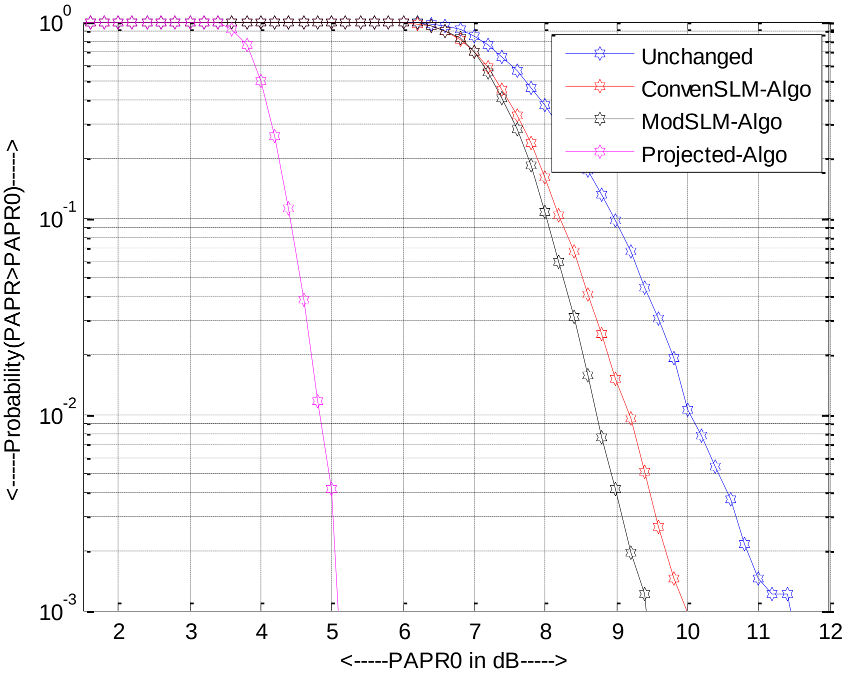

Figure 4.6 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=512, U=16, BPSK and μ=8.

Figure 4.7 shows the performance analysis of PAPR of Unchanged, ConvenSLM-Algo, ModSLM-Algo, Projected-Algo for N=64, U=16, $\mu = 8$ and 8-PSK. The several values of PAPR for comparison is depicted in Table 4.2.

Analyzing Table 4.2 reveals that for N=64, the performance of Projected-Algo is excellent in comparison with Unchanged, ConvenSLM-Algo, ModSLM-Algo.

Here, we have understood that PAPR (dB) needed to obtain 0.1% $CCDF$ for N=64 at U=16, $\mu = 8$ and 8-PSK is 10.00, 9.40, 8.50 and 4.68 dB for the Unchanged, ConvenSLM-Algo, ModSLM-Algo, Projected-Algo respectively. Similarly, we can observed the reduction of PAPR for Projected-Algo under N=128,256 and 512, U=16, $\mu = 8$ and 8-PSK (Table 4.2).

Table 4.2 CCDF performance analysis of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=64, 128, 256, 512 , CCDF at 0.1 % (10^{-3}) under 8-PSK, U=16 and μ=8

Sub-carriers	Unchanged	ConvenSLM-Algorithm	ModSLM-Algorithm	Projected-Algorithm
64	10.00	9.40	8.50	4.68
128	10.80	9.32	8.70	5.02
256	11.01	9.81	9.10	5.12
512	11.10	10.00	9.32	5.10

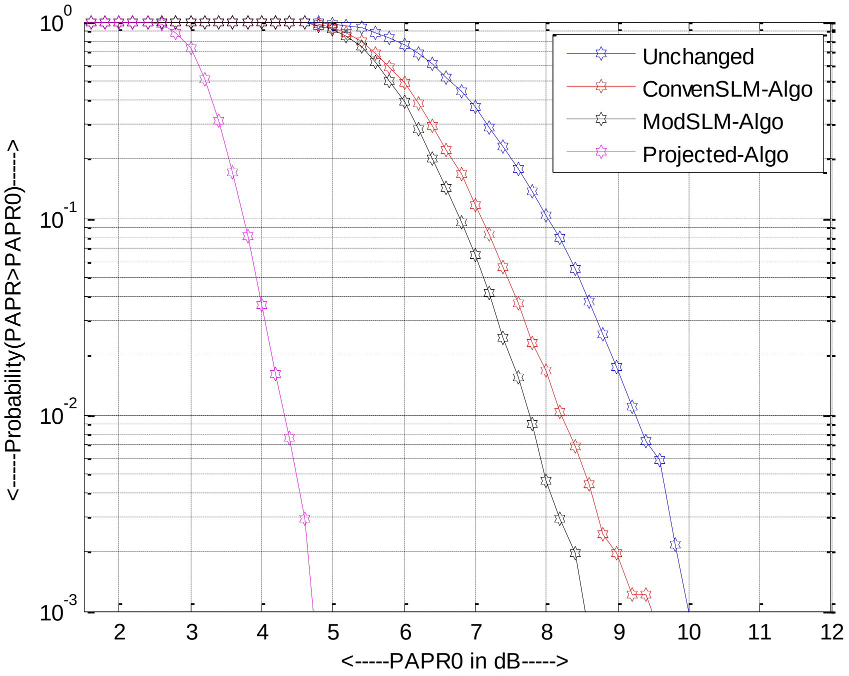

Figure 4.7 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=64, U=16 , 8-PSK and μ=8.

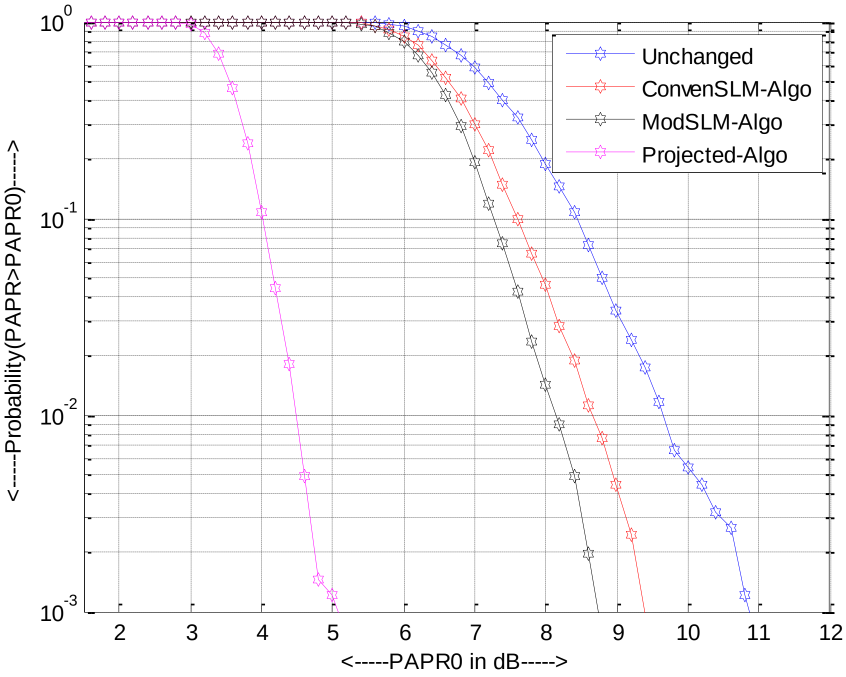

Figure 4.8 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=128, U=16, 8-PSK and μ=8.

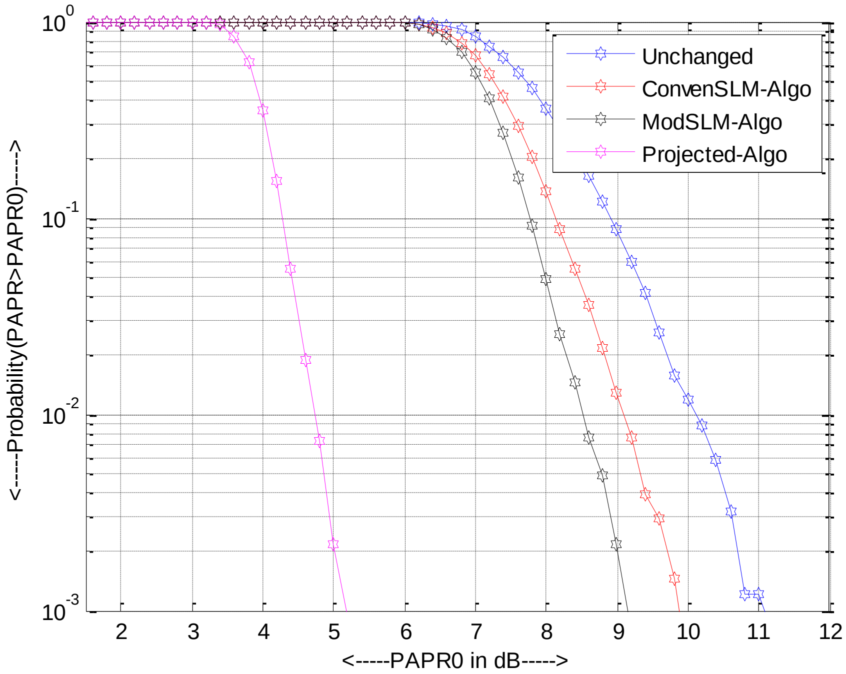

Figure 4.9 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=256, U=16, 8-PSK and μ=8.

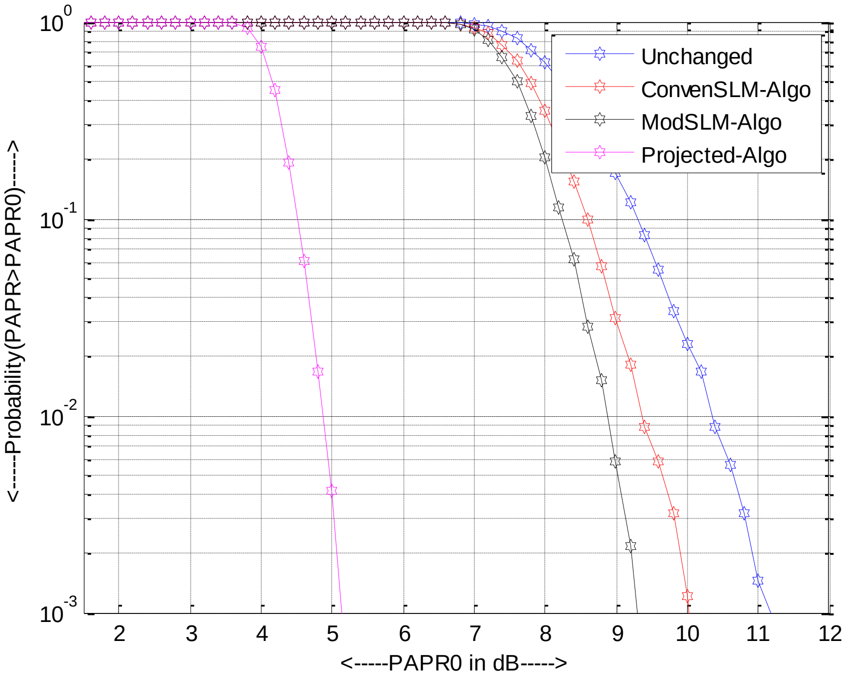

Figure 4.10 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=512, U=16, 8-PSK and μ=8.

Figure 4.11 to Figure 4.14 shows the PAPR analysis of Unchanged, ConvenSLM-Algo, ModSLM-Algo, Projected-Algo for N=64,128,256,512, U=16, $\mu = 8$ and 32-PSK. The performance of all the algorithm is shown in Table 4.3. It is understandable for Table 4.3 the performance of Projected-Algo, for N=64, U=16, $\mu = 8$ and 32-PSK, is excellent in contrast with Unchanged, ConvenSLM-Algo, ModSLM-Algo.

Here we have observed that PAPR (dB) needed to obtain 0.1% CCDF for N=64 at U=16, μ=8 and 32-PSK is 10.40, 9.30,8.45 and 4.82 dB, for Unchanged, ConvenSLM-Algo, ModSLM-Algo and Projected-Algo respectively. Similarly, we have observed for the higher number of subcarriers for the estimation of PAPR reduction of Projected-Algo in comparison with Unchanged, ConvenSLM-Algo, ModSLM-Algo (Table 4.3).

Table 4.3 CCDF performance analysis Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for *N*=64, 128, 256, 512, CCDF at 0.1 % (10^{-3}) under 32-PSK, *U*=16 and μ=8

Sub-carriers	Unchanged	ConvenSLM-Algorithm	ModSLM-Algorithm	Projected-Algorithm
64	10.40	9.30	8.45	4.82
128	10.61	9.60	9.05	4.83
256	11.01	9.50	9.30	5.10
512	11.02	10.10	9.42	5.10

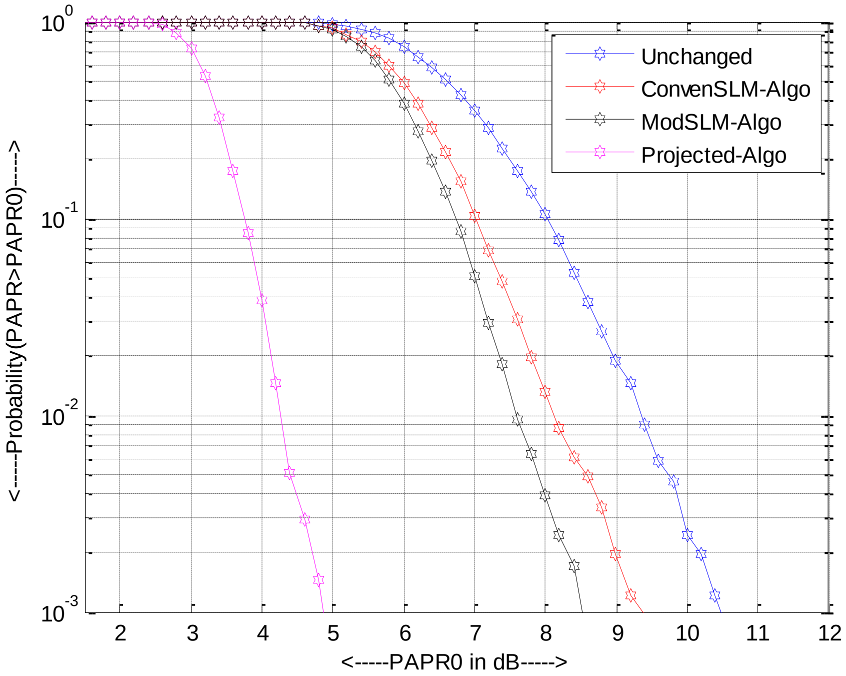

Figure 4.11 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for *N*=64, *U*=16, 32-PSK and μ=8.

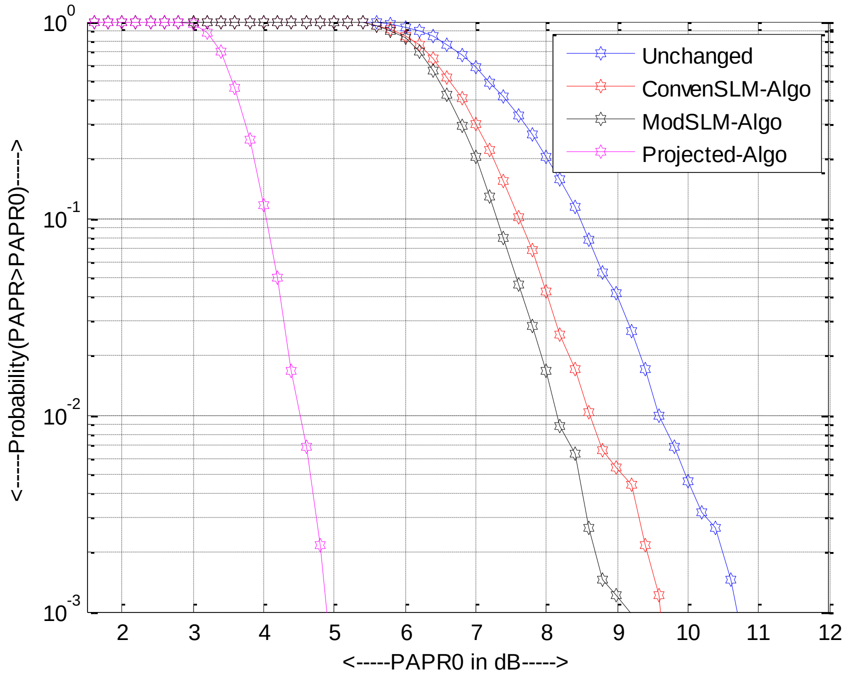

Figure 4.12 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=128, U=16, 32-PSK and μ=8.

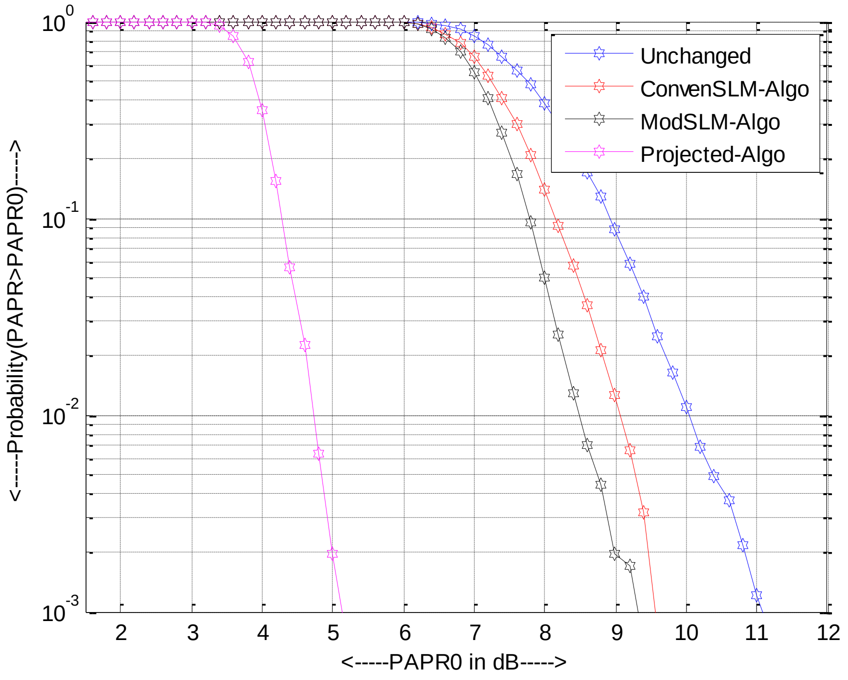

Figure 4.13 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=256, U=16, 32-PSK and μ=8.

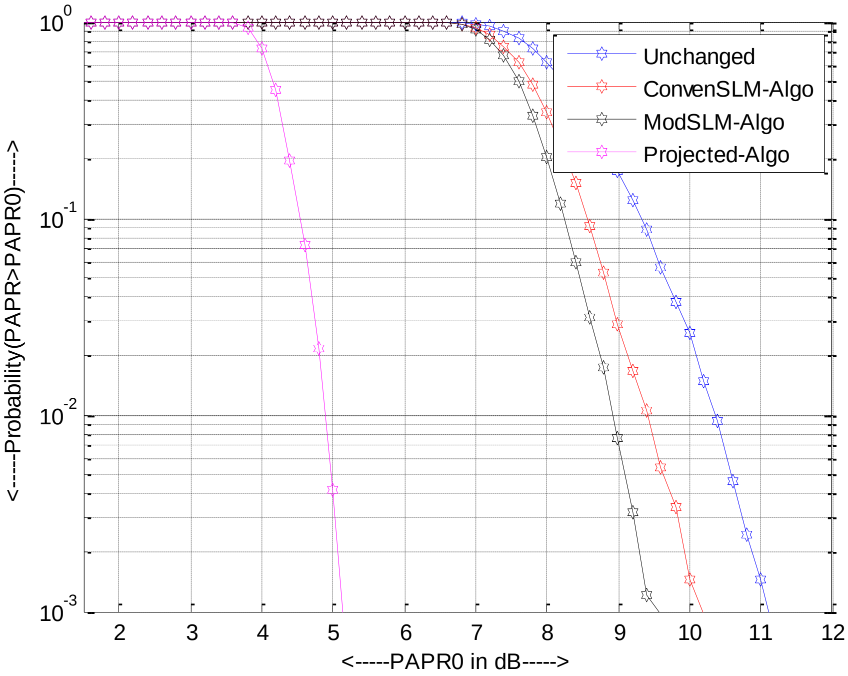

Figure 4.14 Comparison of Unchanged, ConvenSLM- Algo given in [9], ModSLM-Algo given in [10] and Projected-Algo for N=512, U=16 , 32-PSK and μ=8.

Figure 4.15 to Figure 4.17 show the PAPR analysis for the Unchanged and Projected Algorithm for several $\mu = 4,7,10,16,32,64$, U=16 and N=32 under BPSK, 8-PSK and 32-PSK. The performance comparison is depicted in Table 4.4. For N=32, U=16 and $\mu = 4$, the performance of the Projected Algorithm (Projected-Algo-mulaw-4) is remarkable in comparison with Unchanged (Conventional OFDM system) and also for $\mu = 7,10,16,32,64$.

Here we have observed that PAPR (dB) needed to attain 1% (10^{-2}) $CCDF$ for N=32, U=16 at BPSK is 9.00, 4.81,4.40,4.00,3.50,3.10 and 2.60 dB, for the Unchanged and Projected-Algo under $\mu = 4, 7,10,16,32,64$, respectively (Table 4.4). Similarly, we can obtain for the higher modulation like 8-PSK and 32-PSK in order to find out the PAPR analysis for the Unchanged in comparison with Projected-Algo under several values of μ (Table 4.4).

The improvement in the performance originates from the condition that the use of SLM algorithm based upon new pseudo random phase sequences [10] helps in the optimization of data along with the μ law companding [3] which actually, rises the average power of the signal while maintain the peak power as it is.

Table 4.4 CCDF performance analysis of Unchanged, Projected-Algo for N=32 ,CCDF at 1% (10^{-2}) under BPSK,8-PSK and 32-PSK, U=16, μ=4,7,10,16,32,64

Modulation	Projected-Algo for several μ						
	Unchanged	μ=4	μ=7	μ=10	μ=16	μ=32	μ=64
BPSK	9.00	4.81	4.40	4.00	3.50	3.10	2.60
8-PSK	8.80	4.70	4.20	3.80	3.42	3.00	2.51
32-PSK	8.81	4.62	4.20	3.91	3.40	3.00	2.50

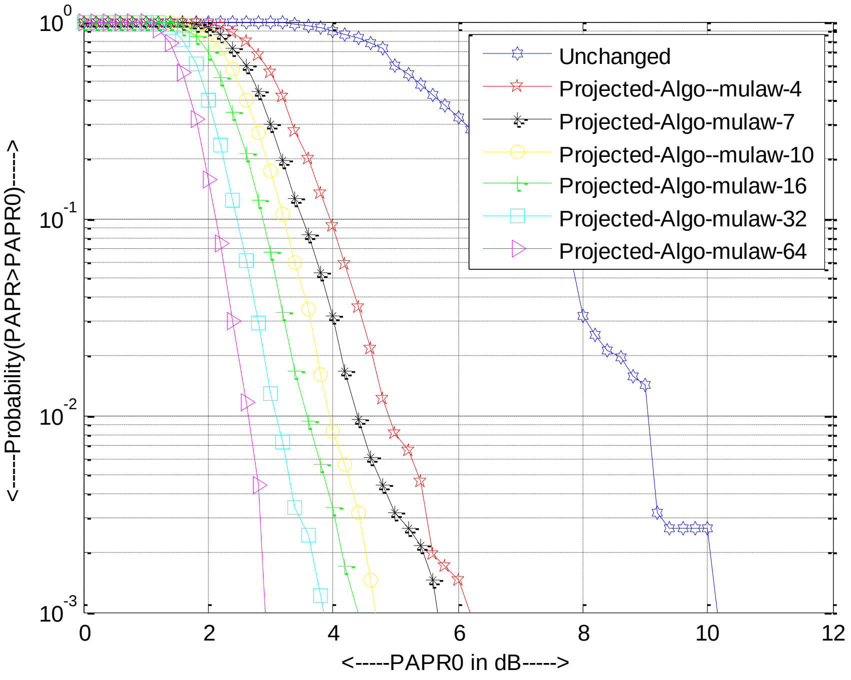

Figure 4.15 Comparison of Unchanged, Projected-Algo with μ = 4,7,10,16,32 and 64 for N=32, U=16 and BPSK.

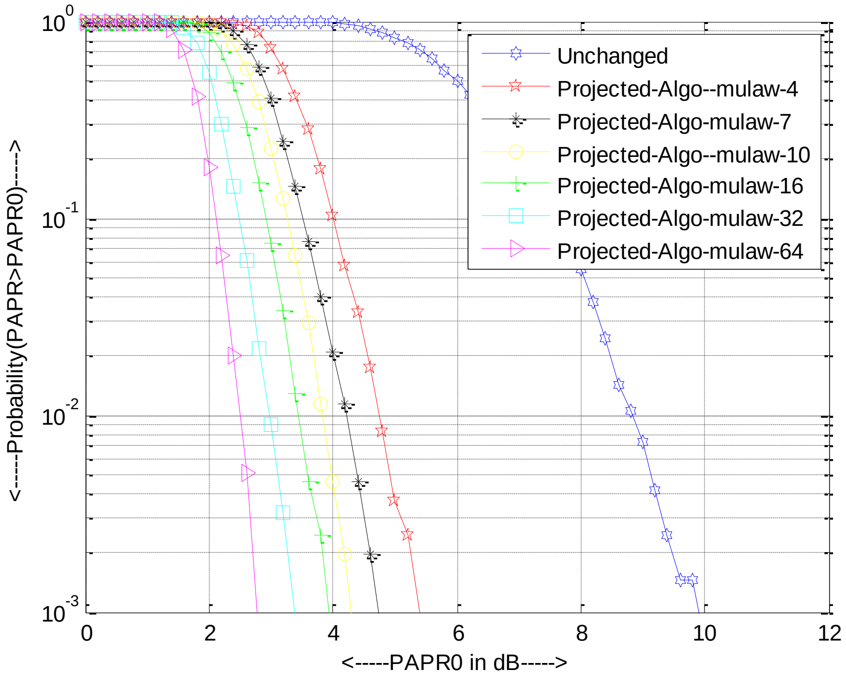

Figure 4.16 Comparison of Unchanged, Projected-Algo with μ = 4,7,10,16,32 and 64 for N=32, U=16 and 8-PSK.

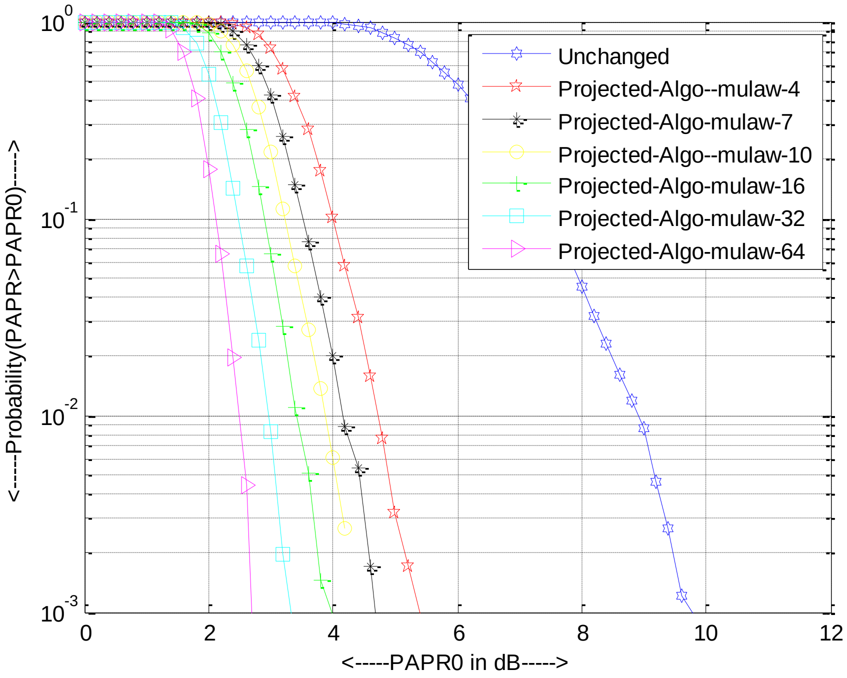

Figure 4.17 Comparison of Unchanged, Projected-Algo with μ = 4,7,10,16,32 and 64 for N=32, U=16 and 32-PSK.

Figure 4.18 to Figure 4.20 show the PAPR analysis for the Unchanged and Projected Algorithm for several $\mu = 4,7,10,16,32,64$, U=32 and N=32 under BPSK, 8-PSK and 32-PSK. The performance comparison is depicted in Table 4.5.

For N=32, U=32 and $\mu = 4$, the performance of the Projected Algorithm (Projected-Algo-mulaw-4) is remarkable in comparison with Unchanged (Conventional OFDM system) and also for $\mu = 7,10,16,32,64$.

Here we have observed that PAPR (dB) needed to attain $1\%(10^{-2})$ $CCDF$ for N=32, U=32 at BPSK is 9.00, 4.50,3.90,3.60,3.20,2.80 and 2.40 dB, for the Unchanged and Projected-Algo under $\mu = 4, 7,10,16,32,64$, respectively (Table 4.5).

Similarly, we can obtain for the higher modulation like 8-PSK and 32-PSK in order to find out the PAPR analysis for the Unchanged in comparison with Projected-Algo under several values of μ (Table 4.5).

Table 4.5 CCDF performance analysis of Unchanged, Projected-Algo for N=32 ,CCDF at 1% (10^{-2}) under BPSK,8-PSK and 32-PSK, U=32 and μ= 4,7,10,16,32,64

Modulation	Projected-Algo for several μ						
	Unchanged	μ=4	μ=7	μ=10	μ=16	μ=32	μ=64
BPSK	9.00	4.50	3.90	3.60	3.20	2.80	2.40
8-PSK	8.80	4.10	3.70	3.40	3.02	2.60	2.20
32-PSK	8.80	4.20	3.70	3.40	3.00	2.52	2.15

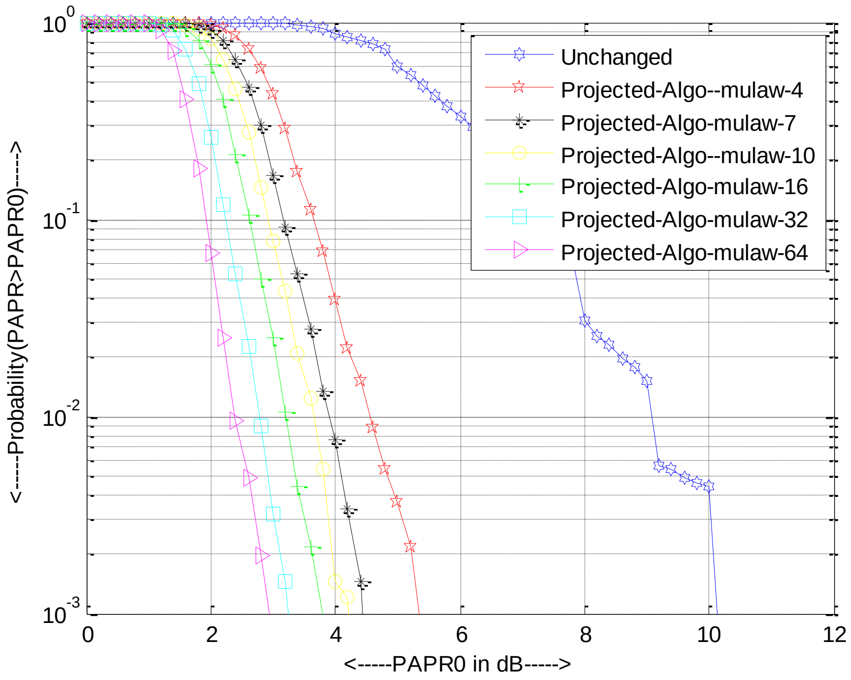

Figure 4.18 Comparison of Unchanged, Projected-Algo with μ = 4,7,10,16,32 and 64 for N=32, U=32 and BPSK.

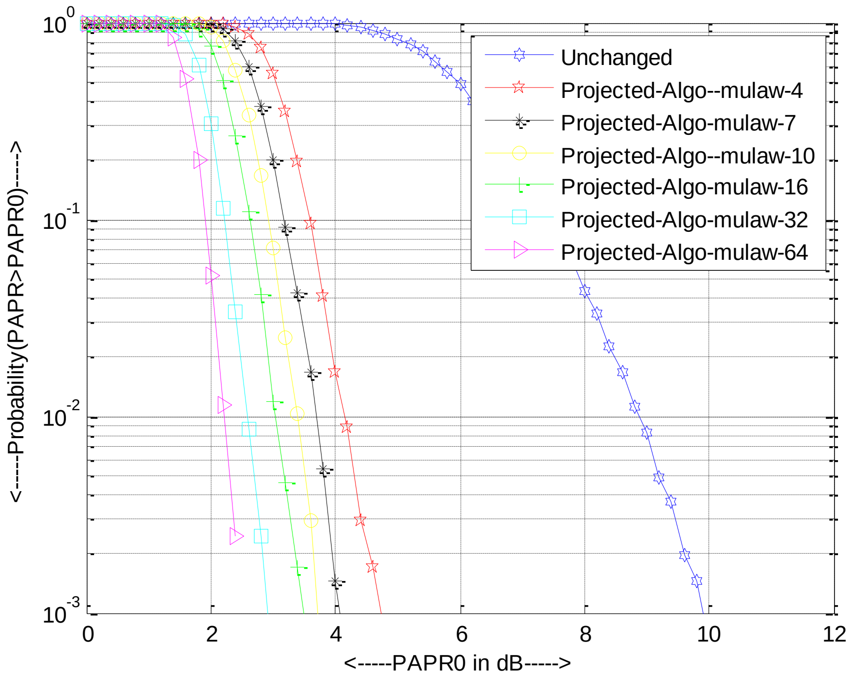

Figure 4.19 Comparison of Unchanged, Projected-Algo with μ = 4,7,10,16,32 and 64 for N=32, U=32 and 8-PSK.

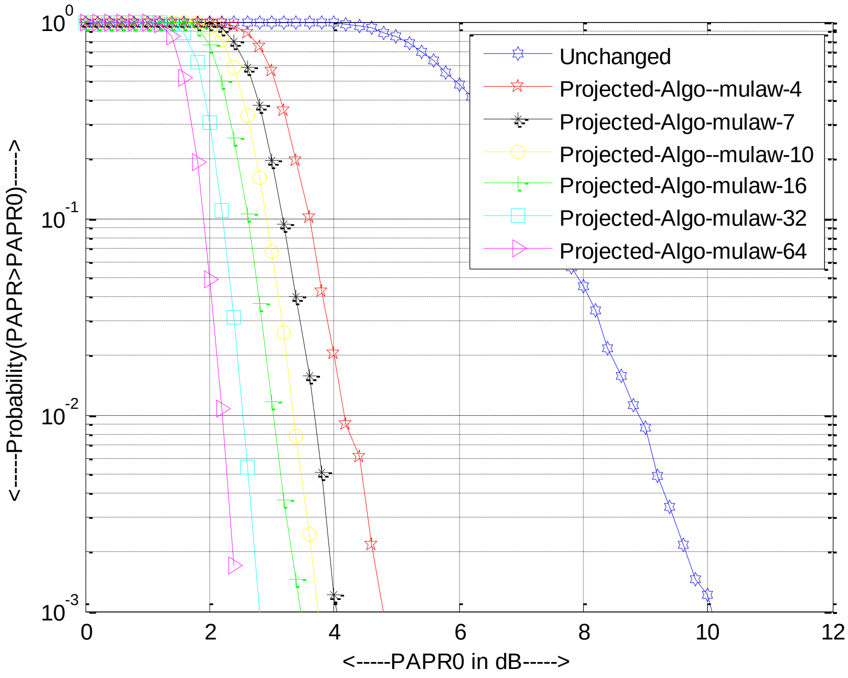

Figure 4.20 Comparison of Unchanged, Projected-Algo with μ = 4,7,10,16,32 and 64 for *N*=32, *U*=32 and 32-PSK.

Figure 4.21 to Figure 4.23 show the PAPR analysis for the Unchanged and Projected Algorithm for several $\mu = 4,7,10,16,32,64$, *U*=64 and *N*=32 under BPSK, 8-PSK and 32-PSK.

The performance comparison is depicted in Table 4.6. For *N*=32, *U*=64 and $\mu = 4$, the performance of the Projected Algorithm (Projected-Algo-mulaw-4) is remarkable in comparison with Unchanged (Conventional OFDM system) and also for $\mu = 7,10,16,32,64$.

Here we have observed that PAPR (dB) needed to attain 1% $CCDF$ for *N*=32, *U*=64 at BPSK is 9.00, 4.20,3.70,3.40,3.10,2.50 and 2.20 dB, for the Unchanged and Projected-Algo under $\mu = 4, 7,10,16,32,64$, respectively (Table 4.6).

Similarly, we can obtain for the higher modulation like 8-PSK and 32-PSK in order to find out the PAPR analysis for the Unchanged in comparison with Projected-Algo under several values of μ (Table 4.6).

Table 4.6 CCDF performance analysis of Unchanged, Projected-Algo for N=32 ,CCDF at 1% (10^{-2}) under BPSK,8-PSK and 32-PSK, U=64 and μ=4,7,10,16,32,64

Modulation	Projected-Algo for several μ						
	Unchanged	μ=4	μ=7	μ=10	μ=16	μ=32	μ=64
BPSK	9.00	4.20	3.70	3.40	3.10	2.50	2.20
8-PSK	9.00	3.72	3.21	3.00	2.62	2.30	2.00
32-PSK	8.80	3.70	3.21	3.00	2.70	2.30	2.00

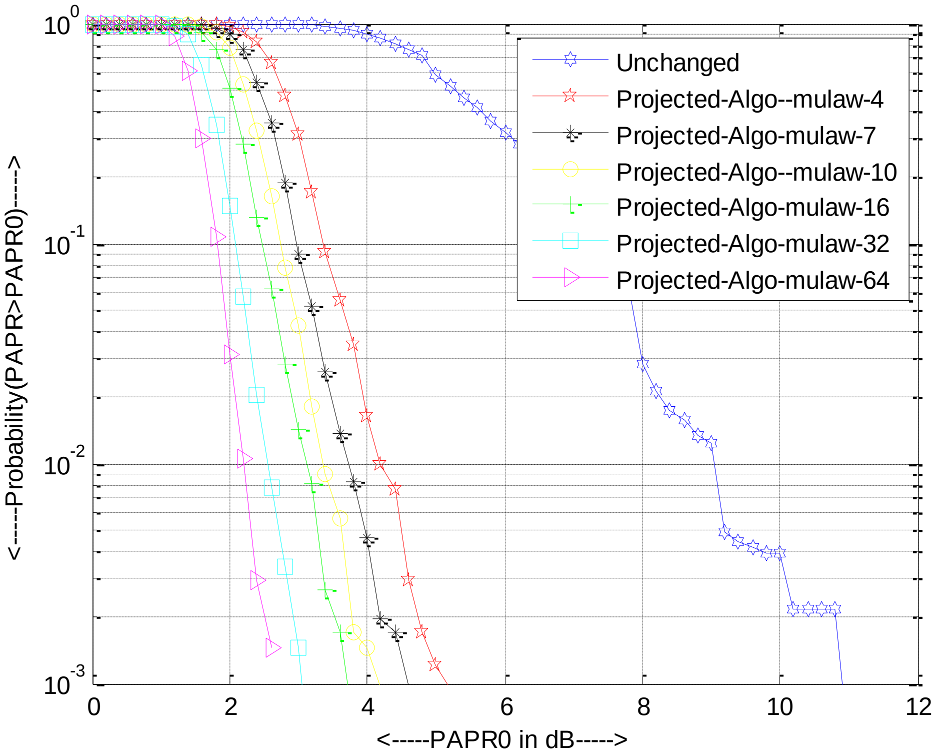

Figure 4.21 Comparison of Unchanged, Projected-Algo with $\boldsymbol{\mu}$= 4,7,10,16,32 and 64 for N=32, U=64 and BPSK.

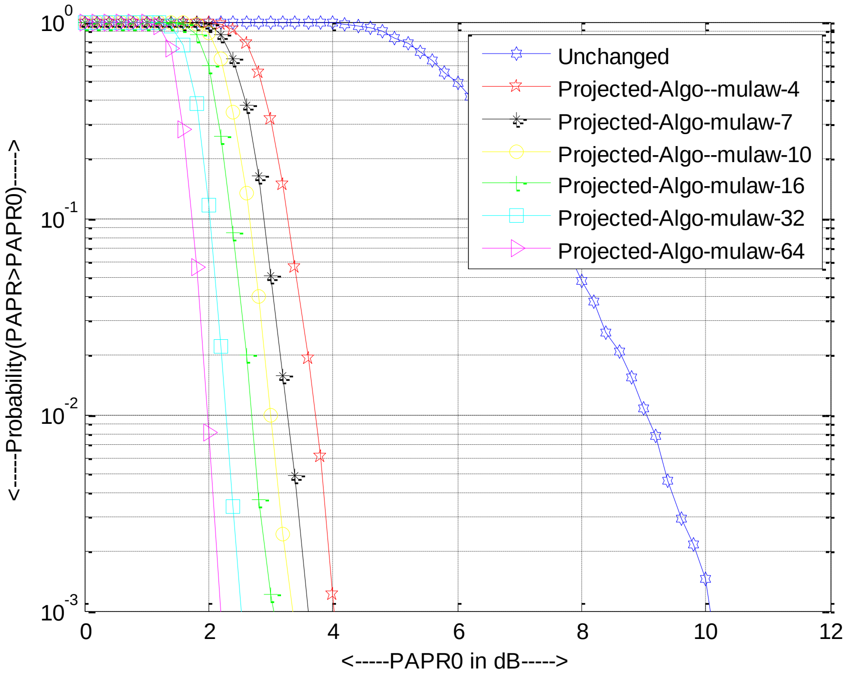

Figure 4.22 Comparison of Unchanged, Projected-Algo with $\boldsymbol{\mu}$ = 4,7,10,16,32 and 64 for N=32, U=64 and 8-PSK.

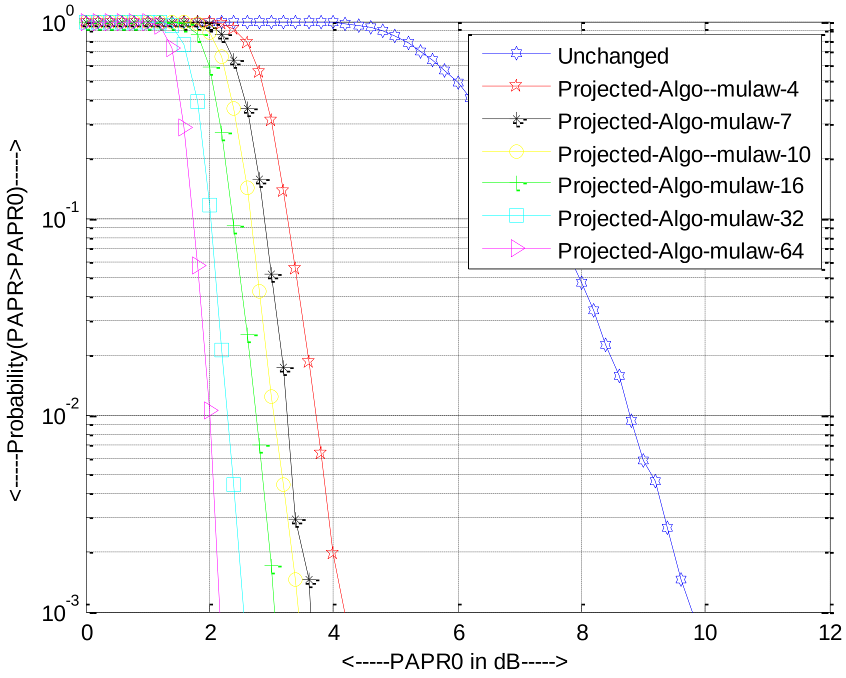

Figure 4.23 Comparison of Unchanged, Projected-Algo with $\boldsymbol{\mu}$ = 4,7,10,16,32 and 64 for N=32, U=64 and 32-PSK.

4.5 CONCLUSION

This paper presents the process for the lessening of PAPR issue by using the underlined more efficient SLM algorithm with the assistance of pseudo random phase sequence of frequency domain and μ law companding for μ=4,7,10,16,32,64 in the time domain with numerous sub-carriers (N)=32,64,128,256,512 and BPSK, 8-PSK and 32-PSK modulation schemes. SLM algorithm suffers the inherent difficulty for the generation of phase sequence. So this is the relevant concern which requires innovative solution. Hence, with this type of objective in our mind, a Projected-Algo has been granted in this study. Now, the generation of the pseudo-random phase sequence is purely based upon the seed matrix, F^0. This Projected-Algo offers the organized and very informal phase sequences generation monitored by time domain μ law companding desirable only very slightest side information for the transmission to be utilized at the receiver. Simulations results, in essence, noticeably portrays the significant, excellent performance as established by the expressive results of Projected-Algo in comparison with Unchanged, ConvenSLM-Algo [9] and ModSLM-Algo given in literature [10]. However, we can discover that proposed algorithm guarantees the optimal reduction of PAPR issue. Hence, making it much more appropriate for applications.

CHAPTER 5 PERFORMANCE ENHANCEMENT OF OFDM SYSTEM USING MODIFIED PTS (MOPTS) PAPR REDUCTION ALGORITHM

5.1 INTRODUCTION

The technique which is based upon multiple signal representation or probabilistic method such as PTS algorithm which acts on the phase of the data sub-carriers in order to diminish the problem of PAPR in OFDM [85]. OFDM has got significant interest due to very high data rates along with the trusted performance of spatial multiplexing and diversity. Moreover, OFDM system possesses smooth equalization [60], good spectral power efficiency along with the easy implementation on hardware by assistance of FFT. In [60], authors demonstrated the analytical review of the PTS algorithm. The numerical calculations and simulation results depicted that row exchange interleaving method is the excellent method for diminishing the PAPR issue. OFDM procedure has been adopted by several wireless and wire-line system like wireless local-area network (WLAN). Authors also depicted [90] that number of sub-carriers, modulations technique and oversampling rate influence the PAPR performance. Authors explained new sub-block partitioned method after combining two conventional techniques adjacent and pseudo random. They also depicted the utilization of OFDM in LTE [60],[91], European telecommunication standards institute (ETSI) [92],Digital audio-broadcasting (DAB) [93], DVB [94], worldwide interoperability for microwave access (WiMAX) IEEE-802.16 [60], [95], Asynchronous digital subscriber line (ADSL) [60], [96].Since, OFDM has numerous advantages but high PAPR is considered as the key disadvantage of OFDM because of this, it suffers from out of band-radiations (OOB) and in band-distortions (IB) [60] and high PAPR leads to non-linearity in high power amplifier (HPA). Moreover, high PAPR enhance complexity of both analog-to-digital converters (ADC) and digital-to-analog converters (DAC).

The several solutions for the lessening of PAPR is to adopt the appropriate method which can reduce PAPR just before sending signals from transmitter side. Many procedures have been presented in literatures to diminish value of PAPR like trellis assisted constellation subset selection (TACSS) [97] in which authors depicted the control of signal transition after choosing the subset of costellation with controlling bits which are subject to the trellis dependent constraint imposed by the bank of memories. Another important methods are clipping [98],non- linear companding transforming [99]–[101] ,peak windowing [102] , clipping and filtering [103] active constellation extension (ACE) [104] the above mentioned procedures be appropriate to group of signals distortion whereas other techniques which belong to the category of scrambling practices of signal like PTS [80], [105], tone-reservation (TR) [106], [107], SLM [108]–[110], block coding [111], interleaving technique [112], tone injection [113]. This chapter is prepared as follows: Section 5.1, brief introduction is demonstrated. Section 5.2, provides the comprehensive summary of the works supported for PAPR reduction. Section 5.3, briefly shows OFDM, DCT and original PTS technique. In Section 5.4, we show the proposed modified PTS (MOPTS) algorithm. Then simulation results are implemented in Section 5.5 whereas in Section 5.6, conclusions are drawn.

5.2 RELATED WORKS

In literature, numerous papers have been discussed related to high PAPR in OFDM like, In 2019, Gokceli et al. [114] introduced an effective technique for the diminishing of PAPR where clipping noise can be easily filtered and controlled inside passband of the transmitter which ultimately control signal which going to be transmitted. Several results suggested in 5G new radio (NR) mobile network context which demonstrate the efficiency of presented work. In 2019, Sandoval et al. [115] presented the novel hybrid PAPR diminishing method which uses three techniques like iterative modified companding and filtering, convolutional codes, successive sub-optimal cross antenna-rotations and inversion (SS-CARI). Significant reduction in PAPR is attained with help of hybrid technique.

Tang et al. [116] proposed a clipping noise method of compression in which modification is done in time domain signal. The reduction in computation complexity has been obtained because it utilizes only one FFT. The presented work demonstrated better BER and PAPR reduction performance as compared with traditional ICF method.

In [117], an effective PAPR lessening method proposed which deals with time domain kernel matrix in order to generate signal with minimum PAPR. It also employed the curve fitting approaches to optimize the scaling factor. The projected method is found to be more efficient as equated with traditional clipping and filtering technique. However, our prior research [86], [87], [118], [119] have documented several schemes such as, In [86], SLM technique has been proposed which uses DCT matrix based phase sequences. Remarkable gain obtained in comparison with conventional SLM technique. In [87], a combination of PTS and BCH have been projected to reduce PAPR. Simulation results revealed the significant improvement in the performance with the assistance of proposed work as compared with the conventional PTS and OFDM system. In [118], a highly optimized phases are obtained and applied in SLM algorithm. Simulations results obtained show the extraordinary performance of planned work in contrast with OFDM. In [119], Gupta et al. presented the SLM algorithm along with the usage of hadamard matrix as a phase sequences which help in diminishing the PAPR. The performance of proposed work is better in contrast with traditional OFDM. In [120], authors projected a different method which is based upon iterative clipping and filtering (ICF) with easy clipping of signals along with filters so that small error vector magnitude and minimum PAPR can be achieved.

In this chapter, a modified PTS (MOPTS) algorithm has been proposed which uses riemann matrix (C) rows as the phase sequences along with DCT in time domain for the lessening of PAPR. In this chapter, we will propose the algorithm so that smallest PAPR based OFDM signals can be created. The simulation results clearly show the best performance of MOPTS algorithm in comparison with conventional PTS technique and original OFDM system.

5.3 OFDM, DCT AND ORIGINAL PTS ALGORITHM

5.3.1 SYSTEM MODEL

In OFDM [116] input information is modulated by PSK as sub-carriers in frequency domain. Now, frequency domain OFDM signals consist of N sub-carriers are represented as $X = [X^0, X^1, X^2, \dots X^k, \dots . X^{N-1}]$ where X^k represents block of data for kth sub-carriers.

The discrete signal in time domain of OFDM [60] can be represented as,

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X^k \, e^{\frac{j2\pi kn}{N}}, n = 0,1,2 \ldots\ldots N-1 \tag{5.1}$$

where n represents discrete sampling-index, k is index of frequency, N denotes total number of sub-carriers.

Oversampling [94], [116] is generally considered for the better approximation of continuous-time OFDM for PAPR. Now, if the oversampling factor is denoted by L then information can be extended by inserting $(L-1)N$ zeros with LNpoints data block of IFFT. For [60] the enhancement in the accuracy of PAPR, sampling of discrete baseband signal must be under $L \geq 4$.

The time domain conversion [116] of oversampled $X(k)$ is obtained by IFFT module to obtain $x(n)$:

$$x(n) = \frac{1}{\sqrt{NL}} \sum_{k=0}^{NL-1} X^k \, e^{\frac{j2\pi kn}{NL}}, n = 0,1,2 \ldots\ldots NL-1 \tag{5.2}$$

where X^k represents block of data for the kth subcarriers.

The range of the time domain signal $x(n)$ is evaluated with the assistance of $PAPR$. It is represented as

$$PAPR(x(n)) = 10log_{10} \frac{\max\limits_{0 \leq n \leq NL-1} (|x(n)|^2)}{E[|x(n)|^2]} \tag{5.3}$$

where $E[.]$ represent operator of expectation [116]. The $PAPR$ lessening of any technique is calculated by complementary cumulative distribution function $CCDF$ denoted by [41], [86]:

$$CCDF = Prob\{PAPR > PAPR^0\} \tag{5.4}$$

where $CCDF$ estimates probability of OFDM signal PAPR that exceeds provided threshold $PAPR^0$.

5.3.2 DCT EQUATION

The discrete cosine transform (DCT) is represented [121] as

$$d^n = \sqrt{\frac{2}{N}}\beta^n \sum_{m=0}^{N-1} x^m \cos(\frac{\pi n(2m+1)}{2N}) \tag{5.5}$$

where N different symbols of data.

$$\beta^n = \begin{cases} \frac{1}{\sqrt{2}}, & n = 0 \\ 1, & n = 1,..N-1 \end{cases} \tag{5.6}$$

5.3.3 RIEMANN MATRIX

The rows of normalized Riemann matrix (C) are preferred as phase sequences for PTS algorithm. Now, Riemann matrix (M) [122], [123] is attained by eliminating first column and first row of matrix B, where

$$B(i,j) = \begin{cases} i-1 \; if \; i \; divides \; j \\ -1 \; otherwise \end{cases} \tag{5.7}$$

By using the equation (5.7), Riemann matrix (M) [124] of the order 4 can be presented as:

$$\text{Riemann matrix } (M) = \begin{pmatrix} 1 & -1 & 1 & -1 \\ -1 & 2 & -1 & -1 \\ -1 & -1 & 3 & -1 \\ -1 & -1 & -1 & 4 \end{pmatrix} \tag{5.8}$$

If the Riemann matrix (M) with size $D \times D$, then the values of the normalized Riemann matrix (C) will be $\left\{\frac{1}{D}\right\} M$.

5.3.4 TRADITIONAL PTS METHOD

In traditional PTS arrangement [64] an oversampled input information symbols X is segregated into numerous sub-blocks $X^v = [X^{v,0}, X^{v,1}, X^{v,2} \dots\dots, X^{v,NL-1}]^T$, $0 \le v \le V-1$, with the condition that

$$X = \sum_{v=0}^{V-1} X^v \tag{5.9}$$

Now, by using $IFFT$ to individual sub-blocks, the vectors of sub-signals $x^v = [x^{v,0}, x^{v,1}, \dots\dots. x^{v,LN-1}]^T, 0 \le v \le V-1$ are created. The phase rotating factors $b^v = e^{j\emptyset^v}$, where $\emptyset^v \in [0, 2\pi)$ for $v = 1,2, \dots V-1$. The phase rotating factors are generally the elements of predefined set denoted as $b^v \in \left\{ e^{\frac{j2\pi l}{W}} \right| l = 0,1,2, \dots. W-1\}$, where W denoted as size of phase rotating factors. The phase factors are $b_u = [b_u^0, b_u^1, \dots. b_u^{V-1},], u = 0,1 \dots. U-1$, where U signifies total OFDM signals created. Now, with the uth phase vector, the uth OFDM signal is denoted as

$$x_u = [x_u^0, x_u^1, \dots\dots, x_u^{LN-1}]^T \tag{5.10}$$

$$= \sum_{v=0}^{V-1} b_u^v x^v, u = 01,2 \dots U-1 \tag{5.11}$$

Since, all the first factors of phase rotating $b_0^v, 0 \le v \le V-1$ are generally assigned with value 1, $U = W^{V-1}$ signals of the OFDM are created in the traditional PTS method. Lastly, best OFDM signal x_{opt} with smallest PAPR worth among U OFDM signal is chosen for transmission, that is,

$$x_{opt} = \underset{u=0,1,2\dots U-1}{argmin} \; PAPR(x_u) \tag{5.12}$$

Block diagram of above mentioned traditional PTS method is denoted by Figure 5.1.

5.4 PROPOSED MODIFIED PTS (MOPTS) ALGORITHM

The MOPTS algorithm which uses Riemann matrix *(C)* as phase sequences along with DCT for the diminishing of the PAPR (Figure 5.2).

Steps for projected MOPTS algorithm are denoted as:

Step 1: Information Y possesses length N, after passed through digital modulator, is denoted as $G = [G_0, G_1, G_2, \ldots . G_{N-1}]$ where N being total number of the sub-carriers. Oversampling represented by L is performed for the better approximation of the PAPR.

Step 2: The oversampled information symbols is divided into several sub-clocks $G^v = [G^{v,0}, G^{v,1}, G^{v,2} \ldots .., G^{v,NL-1}]^T$ with $0 \leq v \leq V - 1$ as condition given by

$$G = \sum_{v=0}^{V-1} G^v \tag{5.13}$$

Step 3: Now, after applying IFFT to the separate sub-blocks, time domain OFDM signal is denoted as

$$g(n) = \frac{1}{\sqrt{NL}} \sum_{k=0}^{NL-1} G[k]\, e^{\frac{j2\pi kn}{NL}}, n = 0,1,2 \ldots .. NL - 1 \tag{5.14}$$

The vectors for several sub-signals

$$g^v = [g^{v,0}, g^{v,1}, \ldots \ldots . g^{v,LN-1}]^T, 0 \leq v \leq V - 1 \tag{5.15}$$

Step 4: Taking the DCT of the time domain sequence using equation (5.5) and represented

$$s^v = DCT(g^v) \tag{5.16}$$

The vectors for the numerous sub-signals,$s^v = [s^{v,0}, s^{v,1}, \ldots \ldots . s^{v,LN-1}]^T, 0 \leq v \leq V - 1$.

Step 5: The phase rotation vectors are chosen in time domain for the optimization of the data from normalized Riemann matrix (C) obtained by considering $\left\{\frac{1}{4}\right\} M$ from equation (5.8).

Step 6: The phase factors which are selected from rows of normalized Riemann matrix (C) are $p_u = [p_u^0, p_u^1, \ldots . p_u^{V-1},], u = 0,1 \ldots . U - 1$, where U denotes total number of OFDM signals is denoted as

$$s_u = [s_u^0, s_u^1, \ldots\ldots, s_u^{LN-1}]^T \tag{5.17}$$

$$= \sum_{v=0}^{V-1} p_u^v \, s^v, \quad u = 01,2 \ldots U-1 \tag{5.18}$$

Step 7: Now, calculate and find out the smallest $PAPR$ which is represented as

$$PAPR\big(s_u(n)\big) = 10log_{10}\frac{\underset{0\le n\le NL-1}{max}(|s_u(n)|^2)}{E[|s_u(n)|^2]} \tag{5.19}$$

$$s_{opt} = \underset{u=0,1,2\ldots U-1}{argmin} \; PAPR(s_u(n)) \tag{5.20}$$

*Step 8:*Finally, $CCDF$ for the PAPR is calculated as

$$CCDF\big(PAPR\big(s_{opt}\big)\big) = Prob\big\{PAPR\big(s_{opt}\big) > PAPR^0\big\} \tag{5.21}$$

where $CCDF$ denotes the probability of the symbols that exceeds the provided threshold $PAPR^0$.

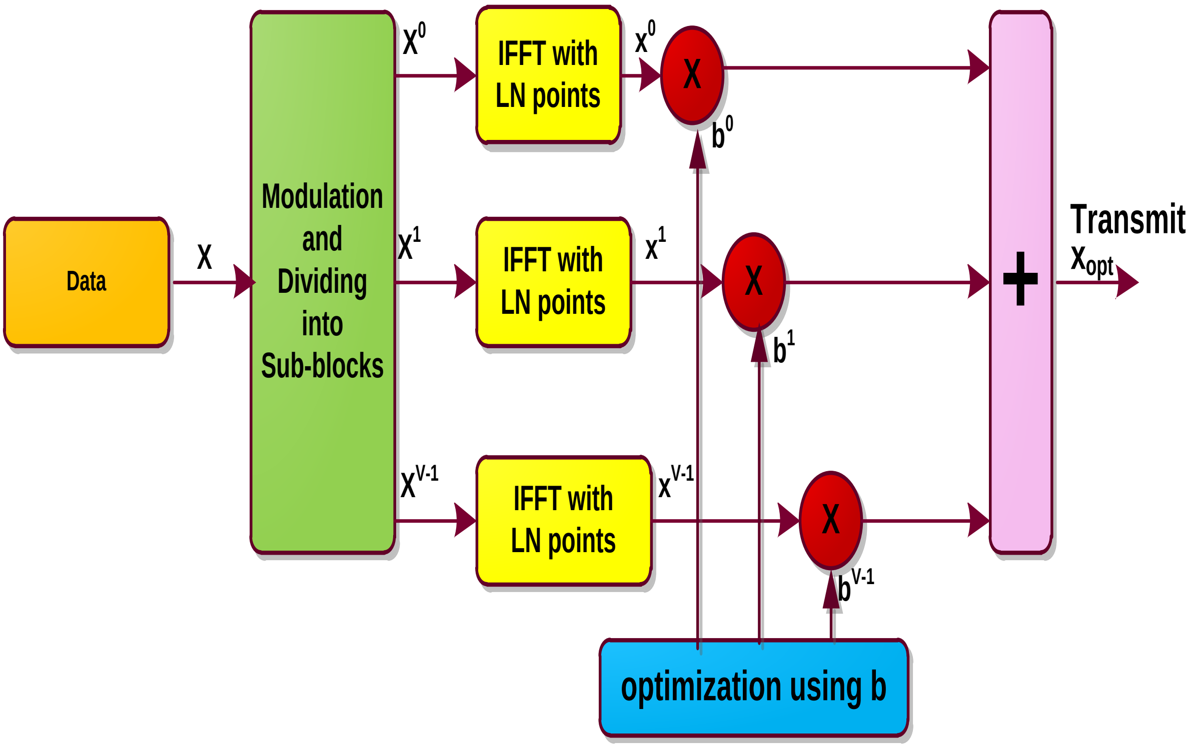

Figure 5.1 The block diagram of traditional PTS method [64].

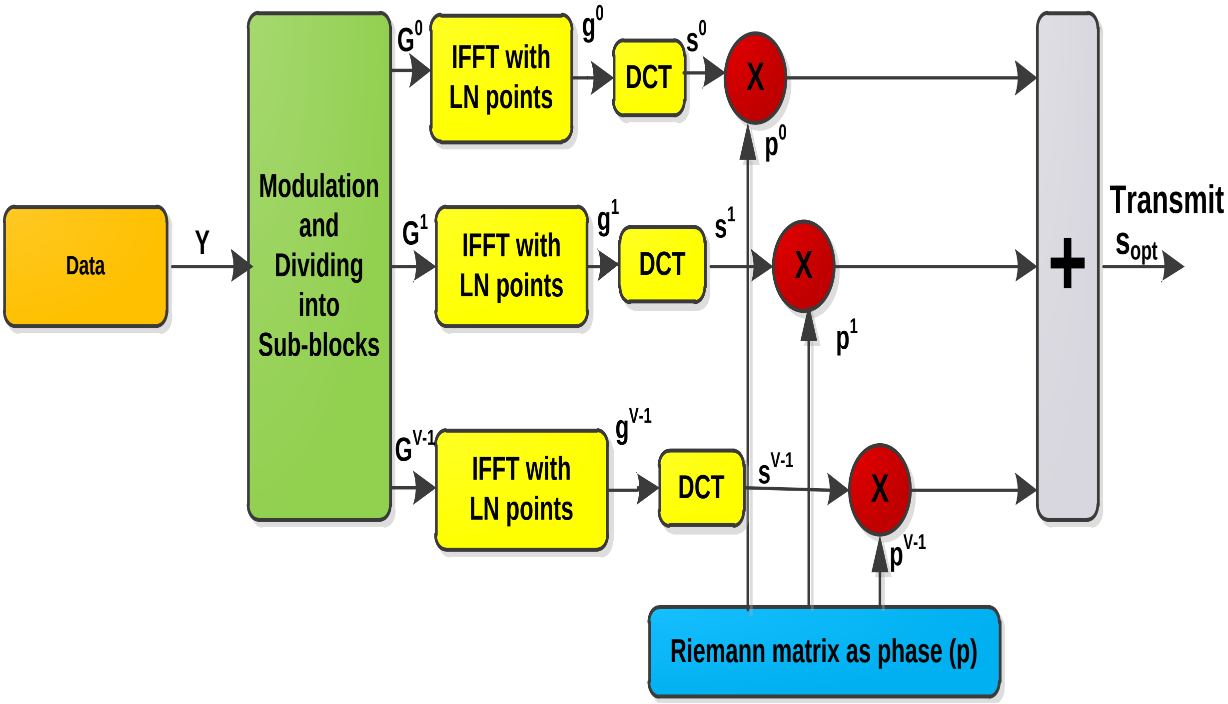

Figure 5.2 The block diagram of proposed modified PTS (MOPTS) algorithm.

5.5 SIMULATION RESULTS

The significant factors considered for the performance investigation of MOPTS algorithm such as oversampling value (L), sub-blocks partition (V) and rows (U) of normalized Riemann matrix (C) are 4 each whereas sub-carriers (N) are 64,128 and 256. The iterations of 9000 OFDM blocks are also considered. The modulation schemes which are considered for the simulations are 16-PSK,32-PSK and 64-PSK.

From Figure 5.3 to Figure 5.11 depict CCDF of the PAPR of original OFDM (OFDMORIPAPR), original PTS (ORIPTS), Modified PTS (MOPTS). In Figure 5.3 with 64 sub-carriers and 16-PSK, MOPTS has remarkable PAPR reduction in comparison with ORIPTS and OFDMORIPAPR which is about 0.70 dB and 2.1 dB better than ORIPTS, OFDMORIPAPR respectively similarly it can be easily understood for Figure 5.4 and Figure 5.5.

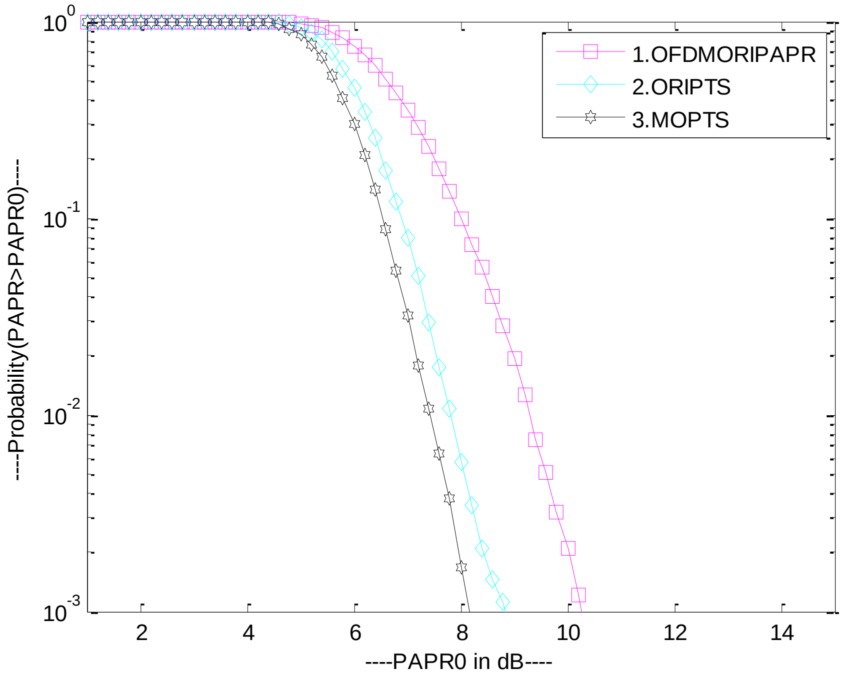

Figure 5.3 PAPR diminishing comparison of MOPTS, ORIPTS and OFDMORIPTS under 64 sub-carriers and 16-PSK.

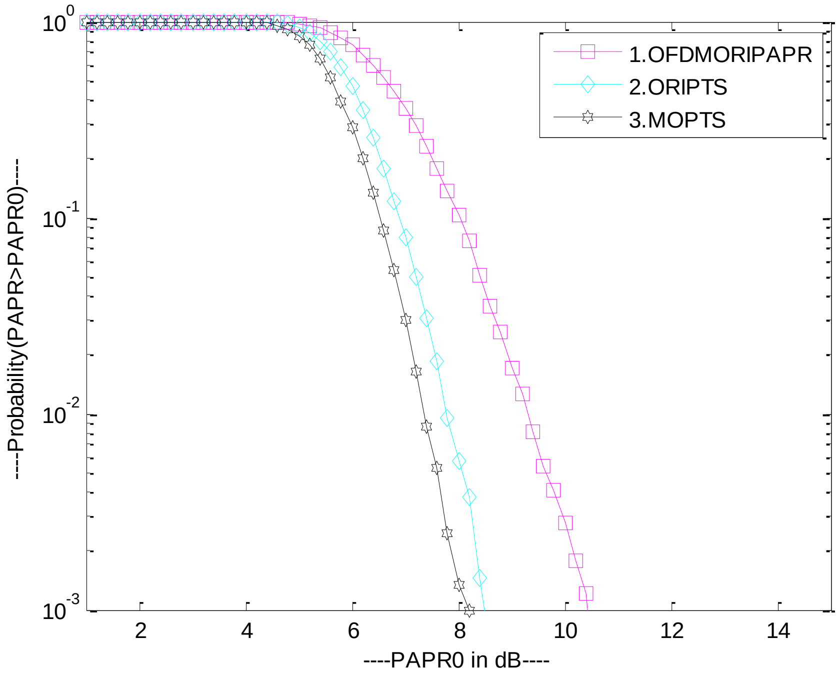

Figure 5.4 PAPR diminishing comparison of MOPTS, ORIPTS and OFDMORIPTS under 64 sub-carriers and 32-PSK.

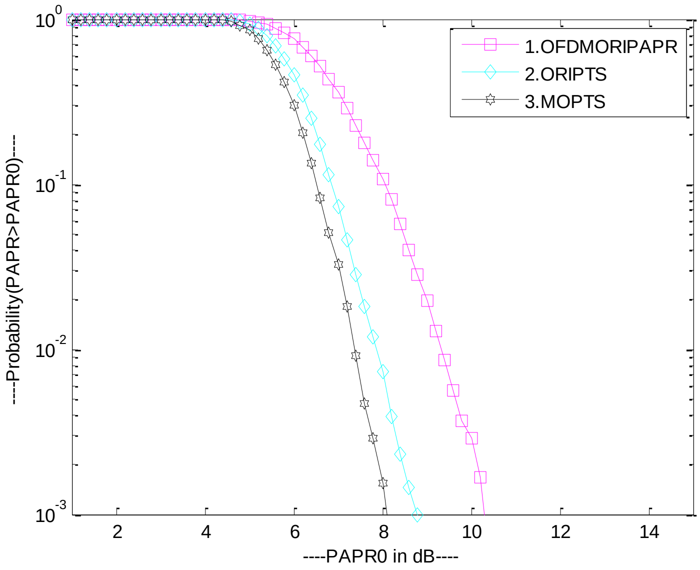

Figure 5.5 PAPR diminishing comparison of MOPTS, ORIPTS and OFDMORIPTS under 64 sub-carriers and 64-PSK.

In Figure 5.6 with 128 sub-carriers and 16-PSK, MOPTS has remarkable PAPR reduction in comparison with ORIPTS and OFDMORIPAPR which is about 0.60 dB and 1.82 dB better than ORIPTS, OFDMORIPAPR respectively similarly it can be easily understood for Figure 5.7 and Figure 5.8.

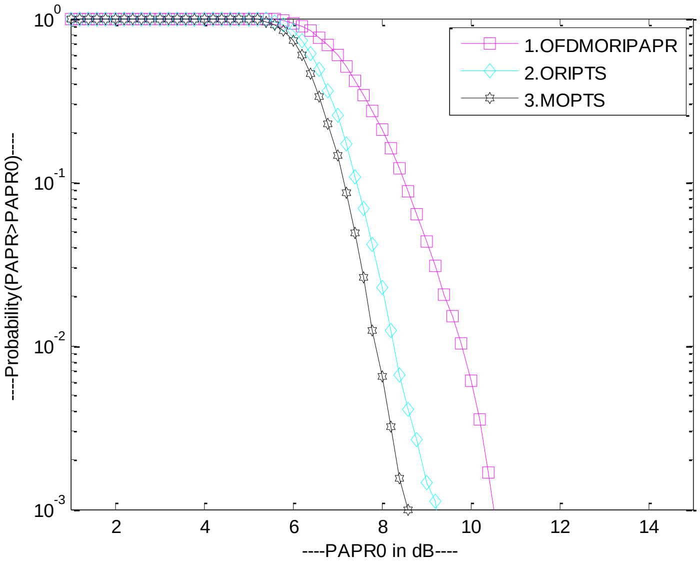

Figure 5.6 PAPR diminishing comparison of MOPTS, ORIPTS and OFDMORIPTS under 128 sub-carriers and 16-PSK.

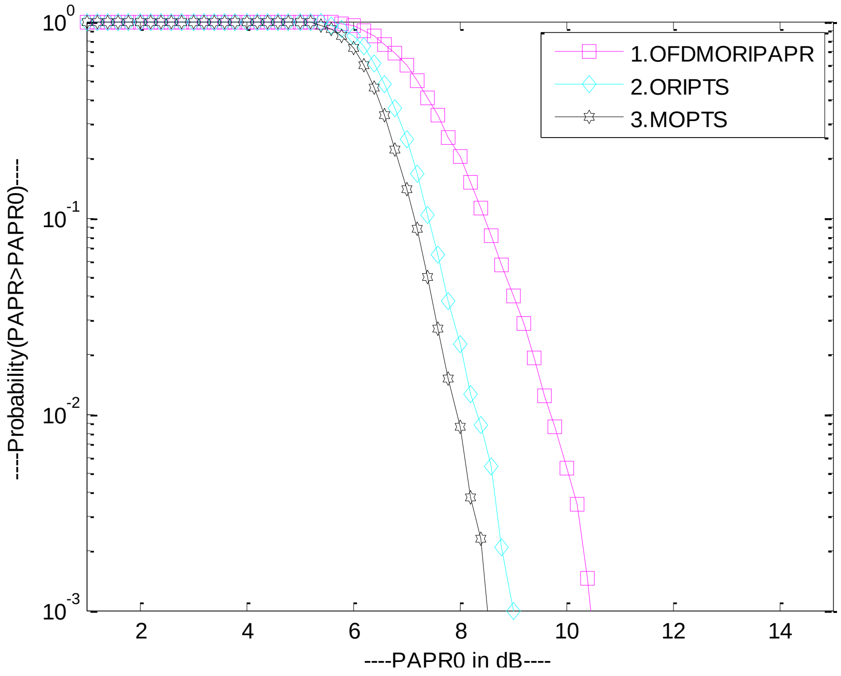

Figure 5.7 PAPR diminishing comparison of MOPTS, ORIPTS and OFDMORIPTS under 128 sub-carriers and 32-PSK.

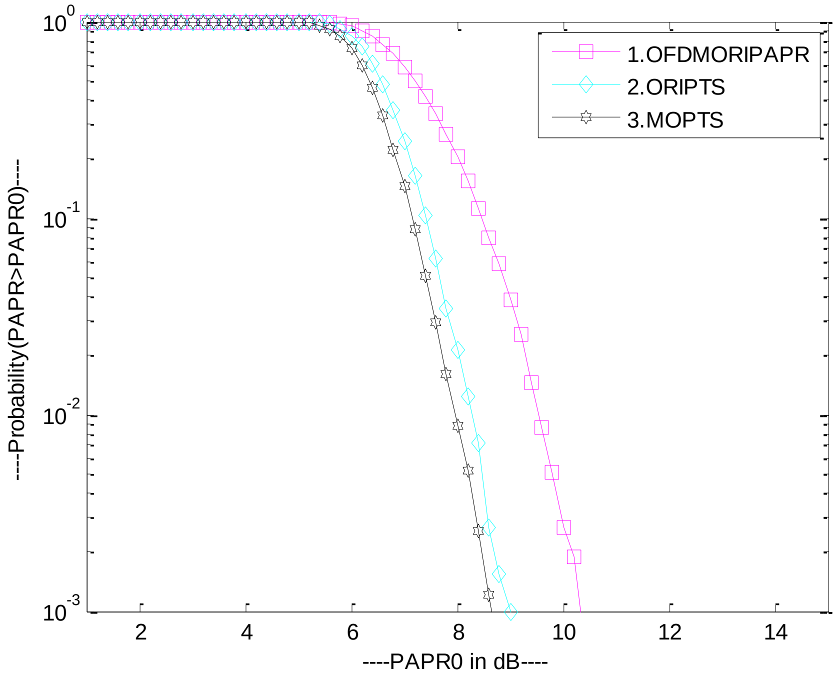

Figure 5.8 PAPR diminishing comparison of MOPTS, ORIPTS and OFDMORIPTS under 128 sub-carriers and 64-PSK.

In Figure 5.9 with 256 sub-carriers and 16-PSK, MOPTS has remarkable PAPR reduction in comparison with ORIPTS and OFDMORIPAPR which is about 0.39 dB and 2.19 dB better than ORIPTS, OFDMORIPAPR respectively similarly it can be easily understood for Figure 5.10 and Figure 5.11.

It is easily agreed from the Table 5.1 that performance of the MOPTS for N=64 and 64-PSK is best in contrast with 32-PSK and 16-PSK.

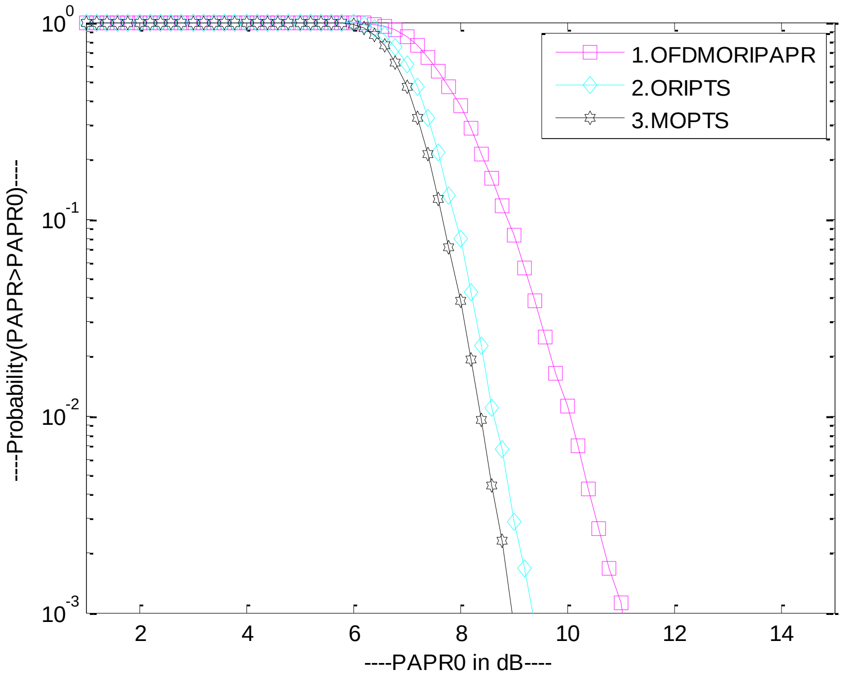

Figure 5.9 PAPR diminishing comparison of MOPTS, ORIPTS and OFDMORIPTS under 256 sub-carriers and 16-PSK.

As number *N* depicted in Table 5.1 is increasing from 64,128, and 256 for 16-PSK then the corresponding increase in the PAPR is also observed as 10.21 dB, 10.42 dB and 11.00 dB respectively but remarkable PAPR reduction is achieved by MOPTS algorithm as 8.11 dB,8.60 dB and 8.81 dB respectively.

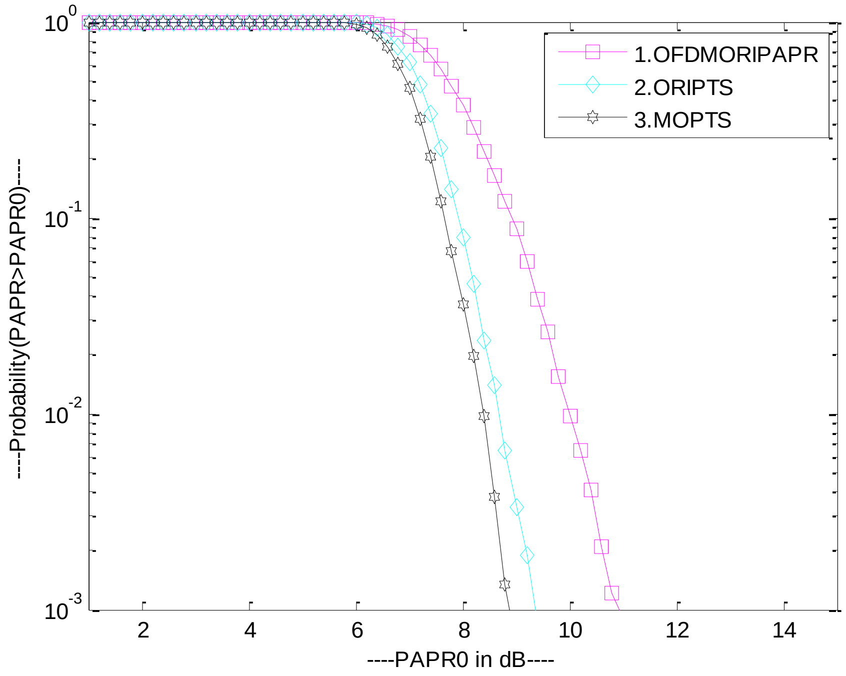

Figure 5.10 PAPR diminishing comparison of MOPTS, ORIPTS and OFDMORIPTS under 256 sub-carriers and 32-PSK.

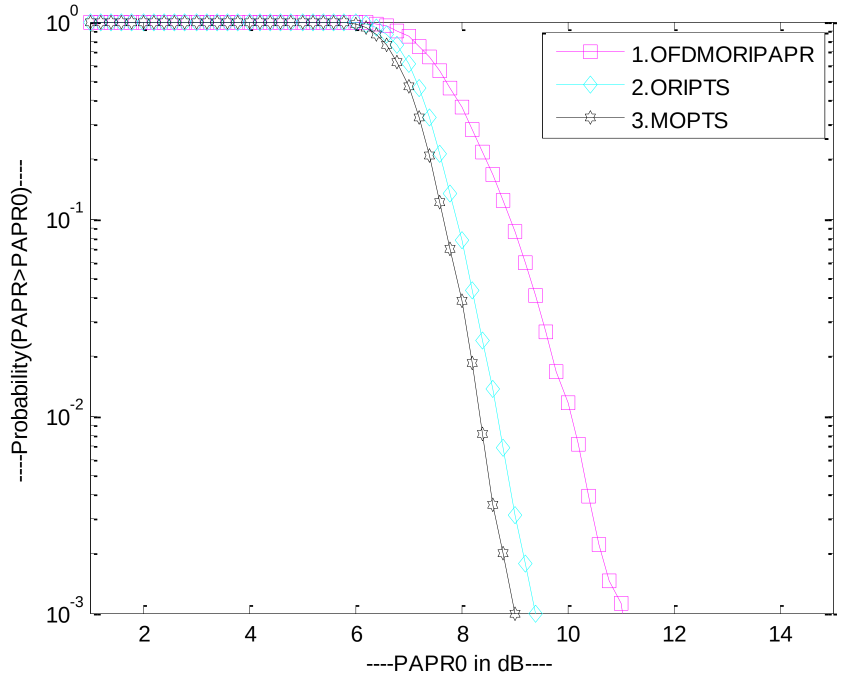

Figure 5.11 PAPR diminishing comparison of MOPTS, ORIPTS and OFDMORIPTS under 256 sub-carriers and 64-PSK.

Table 5.1 CCDF Performance Analysis of MOPTS,ORIPTS and OFDMORIPAPR for N=64,128,256 under 16-PSK, 32-PSK, 64-PSK

PAPR (dB) in order to accomplish $Prob\{PAPR > PAPR^0\} = 10^{-3}$				
Sub-Carriers	Modulations	OFDMORIPAPR	ORIPTS	MOPTS
64	16-PSK	10.21	8.81	8.11
	32-PSK	10.40	8.40	8.20
	64-PSK	10.22	8.80	8.05
128	16-PSK	10.42	9.20	8.60
	32-PSK	10.40	9.00	8.41
	64-PSK	10.21	9.00	8.61
256	16-PSK	11.00	9.20	8.81
	32-PSK	10.81	9.21	8.80
	64-PSK	11.00	9.40	9.00

5.6 CONCLUSION

In this chapter, PTS scheme has been emphasized to diminish PAPR difficulty of OFDM. Though, PTS scheme undergoes the difficulty of designing and obtaining phase sequences which help in diminishing this problem of PAPR. So, this is the most significant concern which requires the advanced solution. Focusing on this objective, a modified PTS (MOPTS) algorithm has been designed in this paper, which uses normalized Riemann matrix *(C)* and DCT in time domain whereas the main aim behind using normalized Riemann matrix *(C)* is the optimization which assists in finding the best phase sequences for the PAPR reduction. Additionally, the proposed MOPTS algorithm can easily generate phase sequences which was difficult in the traditional PTS scheme. Simulation results have been accomplished by comparing MOPTS, ORIPTS and OFDMORIPAPR. The final results, in principle, have depicted that proposed MOPTS algorithm is robust as compared with ORIPTS and OFDMORIPAPR. Furthermore, the futuristic aim of the proposed work is that, it can also be implemented using M-QAM.

CHAPTER 6 DISCRETE COSINE TRANSFORM MATRIX BASED SLM ALGORITHM FOR OFDM WITH DIMINISHED PAPR FOR M-PSK OVER DIFFERENT SUBCARRIERS

6.1 INTRODUCTION

OFDM is favourable for very speedy communication of the information. It has many advantages like high spectral efficiency because of orthogonality among sub-carriers, strong impact on inter symbol interference (ISI) and easier channel estimation. Besides all these, it has disadvantage of high PAPR. Many PAPR depletion techniques like PTS, coding, clipping, SLM, tone injection, and tone reservation [87], [92], [125] have been proposed. Among all these techniques SLM has been found to be very efficient due to its distortion-less behaviour. It chooses the phase sequence which leads to the generation of minimum PAPR.

Selected mapping proposed in [122] uses Riemann matrix where Riemann matrix is nominated as the phase sequences and thus remarkable gain has been achieved. Selected mapping proposed in [9] uses only randomly generated phase sequences. But designing of random phase sequences up to length equal to data length is very difficult. In [126], authors proposed a SLM system that leads to the reduction of PAPR, improvement in BER and also does not necessitate side information transmission. Chaotic sequence projected for the lessening of PAPR outperforms conventional methods like Shapiro-Rudin and Walsh Hadamard sequence [127].

The pseudo random interferometry codes have been preferred as the phase sequences for the SLM to lessen PAPR and also to enhance BER performance that yields better results as compared to Walsh-Hadamard arrangement and Golay arrangement [128]. Monomial phase sequence for SLM for the lessening of the PAPR has been proposed in [129] and the cubic phase sequence is found suitable for the PAPR reduction. A new method for controlling the PAPR has been demonstrated in [125] in which authors have used standard array of linear codes. This organization can be understood as a revised SLM algorithm which ultimately the probabilistic system to diminish PAPR after opting the signals with less PAPR from many candidates for transmission. Since, the coset leader of the linear block codes are preferred in this method, hence no information is needed as syndrome decoding can be used for the received signals recovery. In [87], the hybridization of higher order segregated PTS with BCH have been suggested to lessen PAPR. This method diminishes the PAPR by choosing the signal with small PAPR as compared with many signals. For the recovery of transmitted signal, syndrome decoding is preferred. The simulation results of suggested work are superior as related with OFDM system and existing PTS method. In Reference [130], authors suggested an ICF algorithm for minimization of PAPR of OFDM. ICF is implemented with window which is rectangular in domain of frequency and needs iterative condition for the particular threshold in CCDF. In this study, the authors have developed an ICF optimized technique which find out filter frequency response for every ICF repetition using convex optimization. For the reduction of signal distortion, the designing of optimal filter is required. After 1 or 2 repetitions, the suggested technique obtains decline in CCDF graph and diminishes in PAPR whereas conventional ICF needs 8 to 16 repetitions to get same lessening in PAPR. Moreover, the obtained symbol of OFDM have less out of band radiation and lower distortion as compared with available techniques.

In Reference [41], the authors concentrated on the effective technique preferred for diminishing of the PAPR is PTS. In the C-PTS many IFFT operations are performed in order to get optimum sequence of phase which leads to the increment of complexity. In this research, authors have proposed a method for the reduction of half IFFT calculations but at the small cost of degradation of PAPR. The simulation results are obtained with modulation of QPSK and Saleh power amplifier. The examination of digital predistortion (DPD) to enhance the efficiency of Saleh power amplifier (PA) are also performed.

The research by Tan and Beaulieu [121] focused on the calculation of BEP of DCT based OFDM with AWGN channels in the existence of frequency offset, is considered. These consequences of BEP performance of the discrete cosine transform-OFDM method and the discrete Fourier transform-OFDM technique are related. Many digital techniques like BPSK, QPSK and 16-PSK are considered. The zero padded discrete cosine transform-OFDM method and zero padded discrete Fourier transform-OFDM technique are compared with the MMSE detections and the MMSE decisions feedback finding over Rayleigh channel. Simulation results and analysis show that DCT-OFDM outperforms DFT-OFDM.

Han and Lee [131] suggested the improved selected mapping system for PAPR lessening of coded OFDM. In this method, the authors have embedded phases which reduce the PAPR of information blocks of coded OFDM. Improvement in error performance and PAPR can be easily obtained with absolutely no damage in data rates. Further, CCDF of PAPR is originated and related with the simulation results.

In [7], there exist several benefits of OFDM such as good spectral efficiency but it has many disadvantages. The main issue in the OFDM system is very high PAPR. There are numerous techniques present to diminishing the PAPR like PTS, tone reservation (TR), SLM and interleaving. During large number of sub carriers clipping technique is not suitable at all. The important methods which are used for PAPR lessening are SLM and PTS. In this study, authors have proposed the hybrid combination of the PTS technique and SLM technique. It diminishes PAPR from 6 to 5 and at last, the results obtained from hybrid technique obtains better results as compared with existing technique.

In [132], a novel phase updating algorithm has been proposed. With the help of random increment, the phase of several subcarriers is reorganized till the PAPR goes below the particular near of threshold. There exists the examination of distinct distributions for the increment in phase and variance for distribution fluctuation on both mean and variance for PAPR. In this, after changing the shifts of phases, threshold is found to be reduced. This random phase updating algorithm deliver best results and diminish mean power variance of the OFDM.

In [133], Hosseini et al. proposed the algorithm which is dependent on companding for diminishing the PAPR. In this algorithm, IFFT works with a compressing polynomial at the both side i.e. transmitter and receiver. The reverse extending function with Jacobi's method works with FFT. This procedure has very low complexity as related with other systems. It needs fewer increases in the signal to noise ratio (SNR) for BER as compared with another companding approaches. There exists a compromise between the performances and complexities which can established the polynomial compressing order and the number of repetition.

In [134], the usage of PTS has been shown for diminishing the PAPR. Generally, the original PTS technique involves a finding over several phase factors, which ultimately results in the increment of computation complication with many sub-blocks. In order to find perfect phase factor, it undergo combinatorial optimization with some constraint. Now, the authors presented an approach which depends on simulated annealing, and it is characterized as a nonlinear optimization. This proposed technique works with very low complexity. To justify the outcomes, several simulations have been performed which represent that the proposed technique can obtain less complexity with good PAPR lessening. In [119], the SLM algorithm has been studied with Hadamard matrix for lessening the PAPR. Due to the use of Hadamard matrix, phase sequences generation and choice have become very easy. Numerous outcomes clearly depicted the outstanding performance of suggested algorithm with conventional system of OFDM.

In this current proposed work, discrete cosine transform (DCT) matrix have been used for SLM as a phase arrangement for the lessening of the PAPR. The arrangement of this chapter is as follows: Section 6.1, a general overview of related work. Section 6.2 incorporates description of OFDM and SLM technique. Section 6.3 represents proposed scheme whereas simulation results exhibition is followed by conclusion inferred in Section 6.5 based upon the opinion from the simulation results.

6.2 DESCRIPTION OF OFDM

6.2.1 THE SYMBOL OF OFDM

Let $c \in \mathbb{C}^N$be the OFDM symbol of frequency domain and $c(i), i = 0,2, \dots . N - 1$be the value of symbol supported by the sub-carrier. Then, OFDM symbol of time domain, $x \in \mathbb{C}^{lN}$associated with c with l times oversampling is given as [130]

$$x(k) = \frac{1}{\sqrt{lN}} \sum_{i=0}^{lN-1} c(i) * e^{j*2*\pi*k*i/lN} \tag{6.1}$$

where $k = 0,1,2,3, \ldots\ldots lN - 1$ is the time index.

6.2.2 PARAMETERS OF OFDM SYSTEM

Let us describe two parameters associated with OFDM arrangement: PAPR and Complementary Cumulative Distribution Function (CCDF). For suitability, we will consider c^0 and x^0 to signify symbols of domain of frequency and symbols of domain of time , respectively, c and x for OFDM symbol of the frequency domain and the time domain.

PAPR: The PAPR of OFDM , x^0, can be well-defined as [130]

$$PAPR = \frac{max_{k=1,..lN} |x^0|^2}{\frac{1}{lN}\sum_{k=1}^{lN} |x^0|^2} \tag{6.2}$$

CCDF: In order to calculate the depletion in $PAPR$, CCDF of $PAPR$ is employed and is given as [41]

$$CCDF\left(PAPR(x^0)\right) = Pr(PAPR(x^0) > PAPR^0) \tag{6.3}$$

Equation (6.3) represents the probability that $PAPR$ of symbols top the threshold $PAPR^0$.

The IDCT vector of $N \times 1$ vector κ, and DCT of $N \times 1$ vector ν, can be given as [121]

$$\begin{aligned} \nu &= M^T * \kappa \\ k &= M * \nu \end{aligned} \tag{6.4}$$

respectively, where the unitary $N \times N$ matrix. M is the matrix of DCT, and IDCT matrix is M^T. The $M(r, c)$ of DCT matrix M is given as

$$M(r,c) = \sqrt{\frac{2}{N}}\ \beta cos(\frac{\pi * r(2c+1)}{2N}) \tag{6.5}$$

where

$$\beta = \begin{cases} \frac{1}{\sqrt{2}}, for\ \ n = 0, \\ 1,\ \ for\, n = 1,..N-1,\ \ 0 \le r \le N-1, 0 \le c \le N-1 \end{cases} \tag{6.6}$$

6.3 SLM TECHNIQUE

In conventional SLM technique [131] , at first, the data is divided into the information block $\mathfrak{R}$ having size N. Then the information block of OFDM is multiplied with several phase sequence $\mathcal{B}_u = [b^{u,0}, b^{u,1}, b^{u,2} \dots\dots b^{u,N-1}]^T,\ u = 1 \dots..U$, to generate the U phase alternated OFDM blocks of information $\mathfrak{R}^u = [\,\mathfrak{R}^{u,0}, \mathfrak{R}^{u,0}, \dots\dots\dots\dots.\mathfrak{R}^{u,N-1}]^T$ where $\mathfrak{R}^{u,m} = \mathfrak{R}^m * b^{u,m},\ m = 0,1, \dots..,N-1$ and phase sequence $b^{u,m} = e^{\varphi(n)}$, $\varphi(n) \in [0,2\pi)$[9]. All of the several U phase rotation block of OFDM signify the similar information as the unchanged information of OFDM block given that the phase sequence is well recognized. To contain unchanged block of information in the given set of phase interchanged OFDM blocks, $\mathcal{B}_1$ is chosen as single vector having size N. After application of SLM method to $\mathfrak{R}$, equation (6.1) develops with the assistance of inverse fast fourier transform (IFFT) as

$$r^u(n) = \frac{1}{\sqrt{lN}} \sum_{m=0}^{lN-1} \mathfrak{R}^m * b^{u,m} * e^{j*2*\pi*k*m/lN} \tag{6.7}$$

where $k = 0,2,3, \dots..lN-1$, and $u = 1,2,3,4 \dots..U$.

PAPR is designed for U phase rotation blocks of OFDM information by equation (6.2)

$$PAPR = \frac{max_{k=1,..lN}|r^u\,|^2}{\frac{1}{lN}\sum_{k=1}^{lN}|r^u\,|^2} \tag{6.8}$$

Among the several phase rotation data blocks of OFDM blocks, the single with smallest PAPR is picked and communicated. The data about the chosen phase sequence must be conveyed as an information to the receiver. Converse operation at receiver side must be performed to recover unchanged OFDM blocks of data. The phase sequences are chosen so that phase rotation OFDM blocks are adequately different.

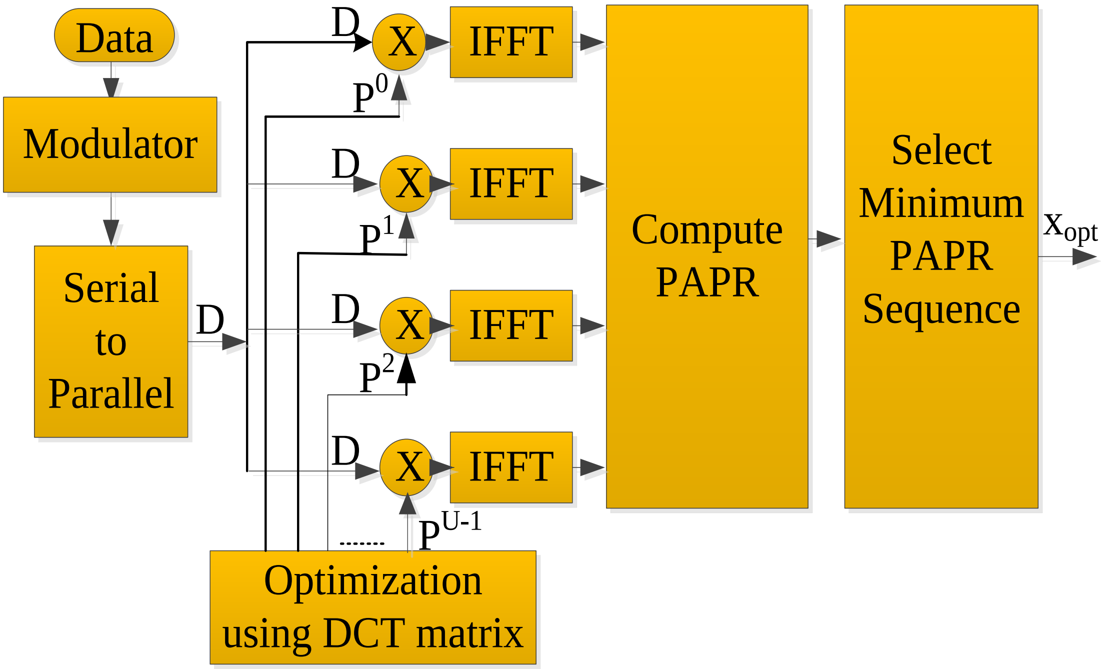

Figure 6.1 Proposed SLM Technique using DCT for OFDM System.

6.4 PROPOSED SCHEME

Proposed scheme uses discrete cosine transform matrix as the phase sequence for SLM for the lessening of the PAPR (Figure 6.1).

Discrete cosine matrix (M) is an orthogonal matrix and follows $M * M^T = I$,where I is an identity matrix. Due to the definite structure of DCT matrix, it has been opted for proposed work. Steps for the offered procedure are as follows:

1. Data sequence D having length N, after passing through modulator is represented by $D = [D_0, D_1, D_2, .. D_{N-1},]^T$, N being number of sub-carriers. For better approximation of exact PAPR, oversampling by L of each signal is required. To

upsample a signal $L-1$ zeros are added in the information vector which is $D = [D_0, 0,0,0, D_1, ..D_{LN-1},]^T$ for $L = 4$.

2. In order to optimize and reduce PAPR the data blocks $D^v = [\, D_0^1, D_1^2, \dots \dots \dots \dots . D_{LN-1}^U]^T,\ 1 \le v \le U$ are multiplied with phase sequence P^v which is represented as

$$P^v = \begin{bmatrix} P_0^1 & P_1^1 & P_2^1 & \dots & P_{LN-1}^1 \\ P_0^2 & P_1^2 & P_2^2 & \dots & P_{LN-1}^2 \\ & & \vdots & & \\ & & \vdots & & \\ P_0^U & P_1^U & P_2^U & \dots & P_{LN-1}^U \end{bmatrix} \tag{6.9}$$

where U is the number of rows as a phase sequence of DCT matrix which is designed for phase rotation of blocks of OFDM system.

3. Phase alternated OFDM symbol is generated with the help of multiplication of modulated information and phase sequence and is given as

$$X_{LN}^v = \begin{bmatrix} D_0^1 * P_0^1 & D_1^1 * P_1^1 & D_2^1 * P_2^1 & \dots & D_{LN-1}^1 * P_{LN-1}^1 \\ D_0^2 * P_0^2 & D_1^2 * P_1^2 & D_2^2 * P_2^2 & \dots & D_{LN-1}^2 * P_{LN-1}^2 \\ & & \vdots & & \\ & & \vdots & & \\ D_0^U * P_0^U & D_1^U * P_1^U & D_2^U * P_2^U & \dots & D_{LN-1}^U * P_{LN-1}^U \end{bmatrix} \tag{6.10}$$

4. Time domain transformation of the altered data block of OFDM (X^v) is implemented with the assistance of IFFT and is characterized by

$$x_{LN}^v = \frac{1}{\sqrt{lN}} \sum_{m=0}^{lN-1} X_{LN}^v * e^{j*2*\pi*k*\frac{m}{lN}} \tag{6.11}$$

5. Now, PAPR is obtained as

$$PAPR = \frac{max_{k=1,..lN}|x_{LN}^v\,|^2}{\frac{1}{lN}\sum_{k=1}^{lN}|x_{LN}^v\,|^2} \tag{6.12}$$

6. Among several phase sequence rotated OFDM blocks of data, the data block which generate tiniest PAPR is chosen; i.e., x_{opt} for the transmission. In this way, the side information about phases will be trasmitted to the receiver.

7. In order to compute the lessening of PAPR, CCDF of PAPR is calculated as

$$CCDF\left(PAPR(x_{opt})\right) = Pr\left(PAPR(x_{opt}) > PAPR^0\right) \qquad (6.13)$$

which represents the probability that the PAPR of symbols top the threshold $PAPR^0$.

6.5 SIMULATION RESULTS

MATLAB has been used for simulation of OFDM system taking sub-carriers *(N)* = 128, 64 and 32, phase sequence *(U)* = [1, 2, 4, 8, 16, 32, 64, 128], modulation scheme =BPSK, 4-PSK, 8-PSK, 16-PSK, and 32 PSK. CCDF curve has been utilized for the calculating of PAPR of the OFDM. Figure 6.2 depicts the comparison of conventional SLM given in [9] with the proposed SLM technique. Comparable result is obtained at *U*=1 due to consideration of less number of phase sequences. As the phase sequences are improved from *U*=1 *to U*=8, considerable growth in the gain has been observed. Particularly at *U*=8, gain of 1.35 dB at *CCDF*=.001% has been achieved as compared to [9]. Hence, it can be concluded that growth in the quantity of phase sequences lead to the enhancement of performance of the proposed work.

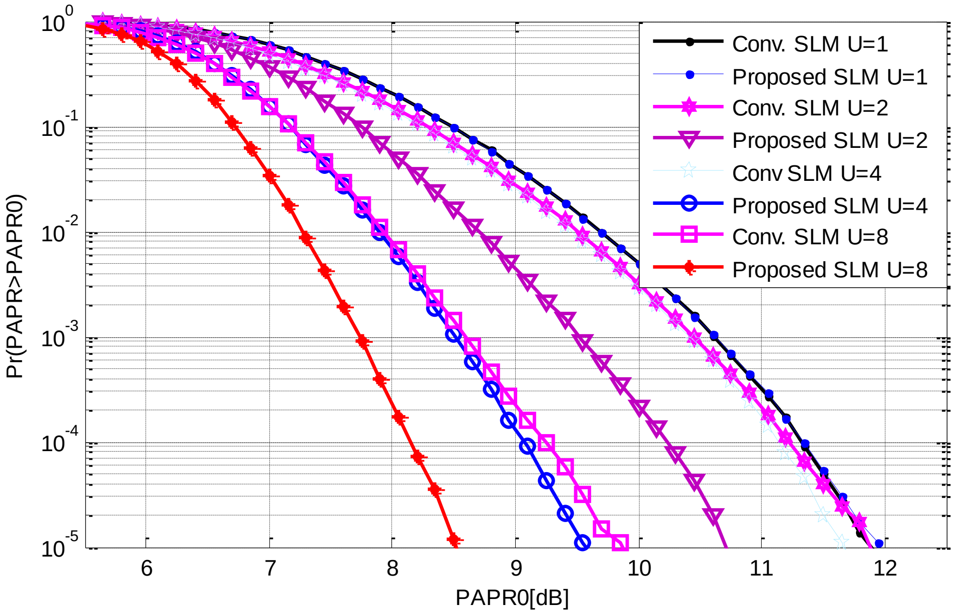

Figure 6.2 Comparison of SLM given in [9] with proposed SLM for *U*=1, 2, 4, 8, *N*=128 and 4-PSK.

Figure 6.3 shows the comparison of conventional SLM [9] with the proposed SLM for higher number of phases *U*=16, 32, 64, and 128. Remarkable gain has been achieved by the proposed scheme in comparison with the [9], i.e., 1.36, 1.25, 1.4, 1.27 dB while comparing at *CCDF*=.001% for *U*=16, 32, 64, and 128 phase sequences, respectively.

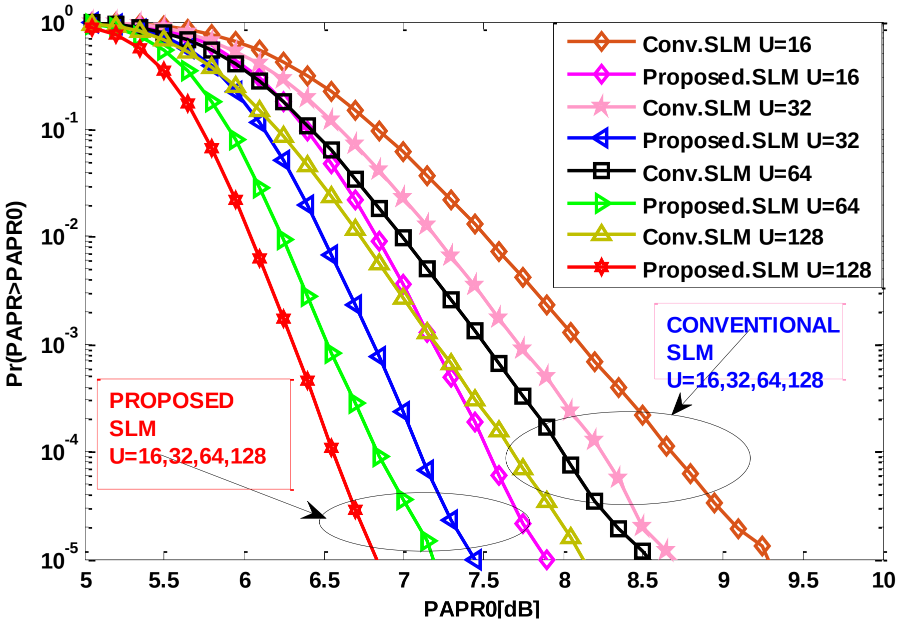

Figure 6.3 Comparison of SLM given in [9] with proposed SLM for *U*=16, 32, 64,128, *N*=128 and 4-PSK.

Figure 6.4 to Figure 6.5 depict PAPR for Conv. SLM (conventional SLM) and proposed SLM for *U*=1, 2, 4, and 8 under *N*=32 and 64. The comparison is also shown in Table 6.1. For *N*=32 and *N*=64, the presentation of projected SLM system for *U*=8 is tremendous in comparison with proposed SLM for *U*=1, 2, 4 and the Conv. SLM scheme for *U*=1, 2, 4, 8 (Figure 6.4 to Figure 6.5). Here, it is perceived that PAPR (dB) required to accomplish the $P(PAPR > PAPR_0) = 10^{-4}$ for *N*=32 at 4-PSK is: 10.60, 10.30, 10.15, 8.21 dB, respectively for Conv. SLM for *U*=1, 2, 4, 8 whereas it is 10.60, 9.25, 8.20, 7.10 dB, respectively for proposed SLM for *U*=1, 2, 4, 8 (Table 6.1). Similarly, we can perceive for *N*=64 and *N*=128 in order to estimate the PAPR lessening of proposed SLM system in contrast with the Conv. SLM system (Table 6.1).

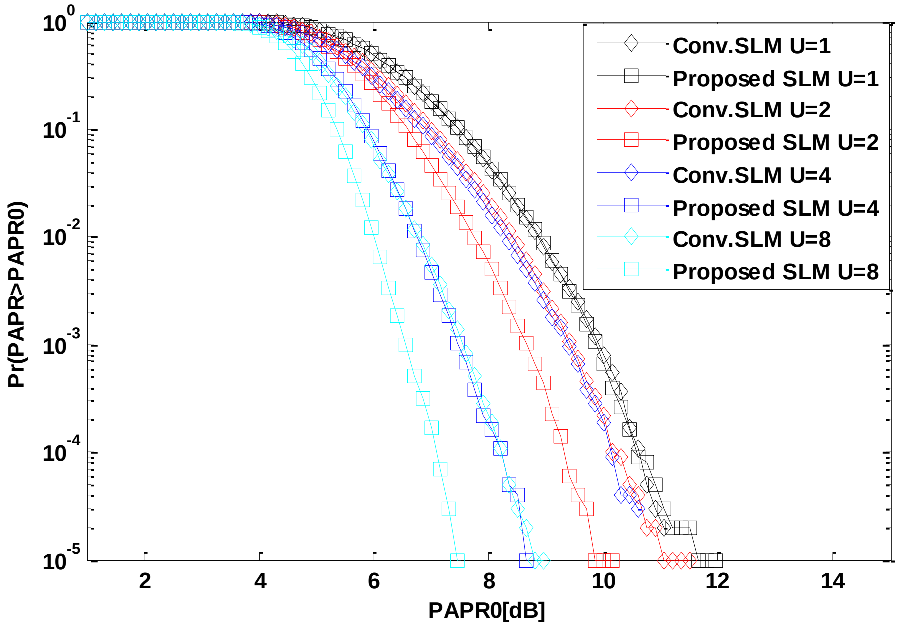

Figure 6.4 Comparison of SLM given in [9] with proposed SLM for *U*=1, 2, 4, 8 and *N*=32 and 4-PSK.

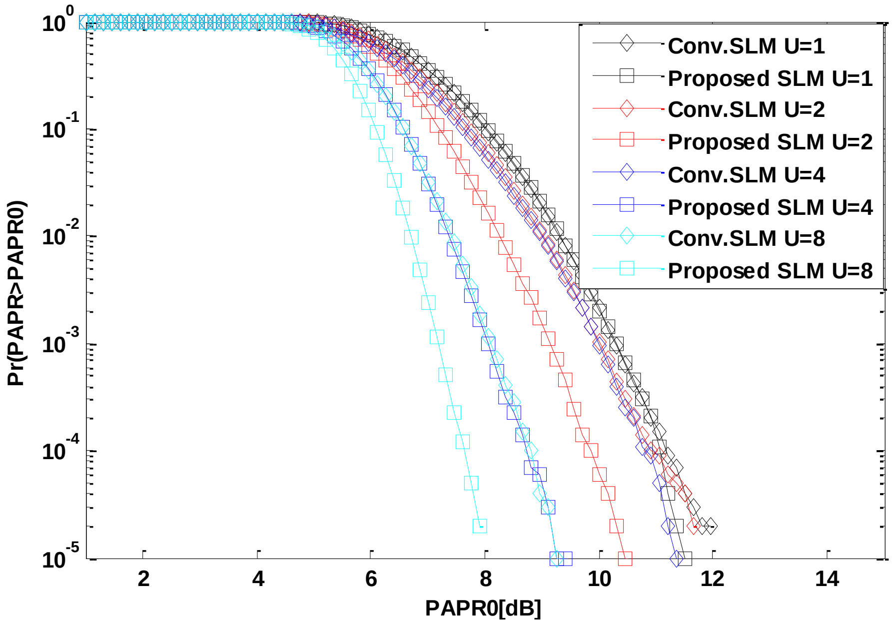

Figure 6.5 Comparison of SLM given in [9] with proposed SLM for *U*=1, 2, 4, 8 and *N*=64 and 4-PSK.

Table 6.1 CCDF performance investigation of conventional SLM and proposed SLM for *N*=32,64 and 128 under *U*=1,2, 4 and 8

	PAPR (dB) value to attain $P(PAPR > PAPR_0) = 10^{-4}$							
	Conventional SLM				Proposed SLM			
N	*U*-1	*U*-2	*U*-4	*U*-8	*U*-1	*U*-2	*U*-4	*U*-8
32	10.60	10.30	10.15	8.21	10.60	9.25	8.20	7.10
64	11.20	10.90	10.75	8.80	11.05	9.85	8.70	7.60
128	11.35	11.20	11.18	9.25	11.35	10.25	9.14	8.10

Figure 6.6 to Figure 6.7 depict the PAPR performance analysis for conventional SLM and proposed SLM for *U*=16, 32, 64 and 128 under *N*=32 and 64. The PAPR value for comparison purpose is also shown in Table 6.2. Close observation of Table 6.2 reveals that for *N*=32, the performance of the proposed SLM scheme for *U*=128 is tremendous in comparison with Conv. SLM scheme for *U*=16, 32, 64, 128 and also with the proposed SLM for *U*=16, 32, 64.

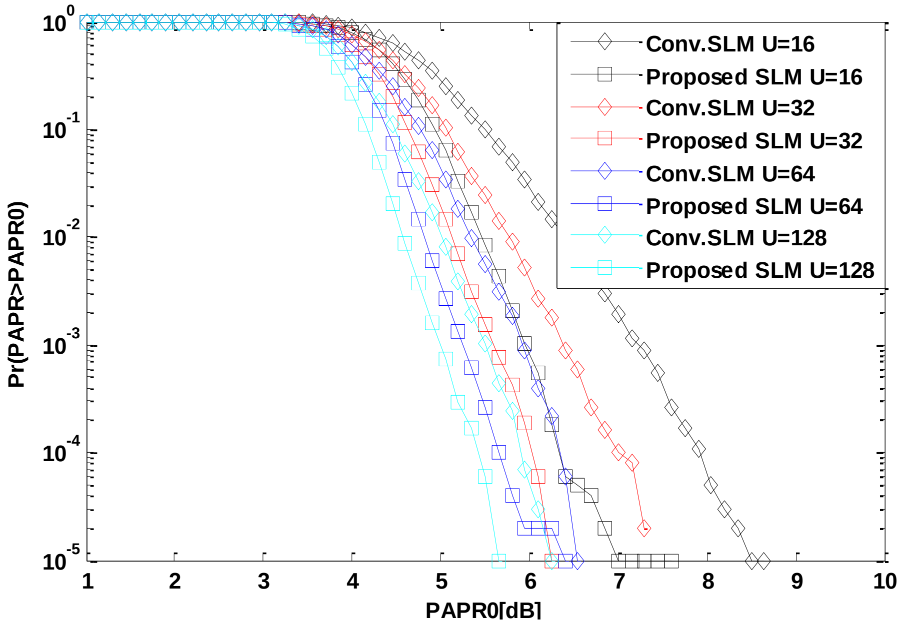

Figure 6.6 Comparison of SLM given in [9] with proposed SLM for *U*=16, 32, 64, 128 and *N*=32 and 4-PSK.

Here, we have perceived that PAPR (dB) required to accomplish the $P(PAPR > PAPR_0) = 10^{-4}$ for *N*=32 at 4-PSK is: 7.90, 7.00, 6.26, 5.82 dB for Conv. SLM for *U*=16, 32, 64, 128, respectively whereas it is 6.25, 5.96, 5.65, 5.36 dB for proposed SLM for *U*=16, 32, 64, 128, respectively (Table 6.2). Similarly, we can perceive the performance of PAPR lessening of proposed SLM scheme in comparison with Conv. SLM scheme for *N*=64 and *N*=128. (Table 6.2).

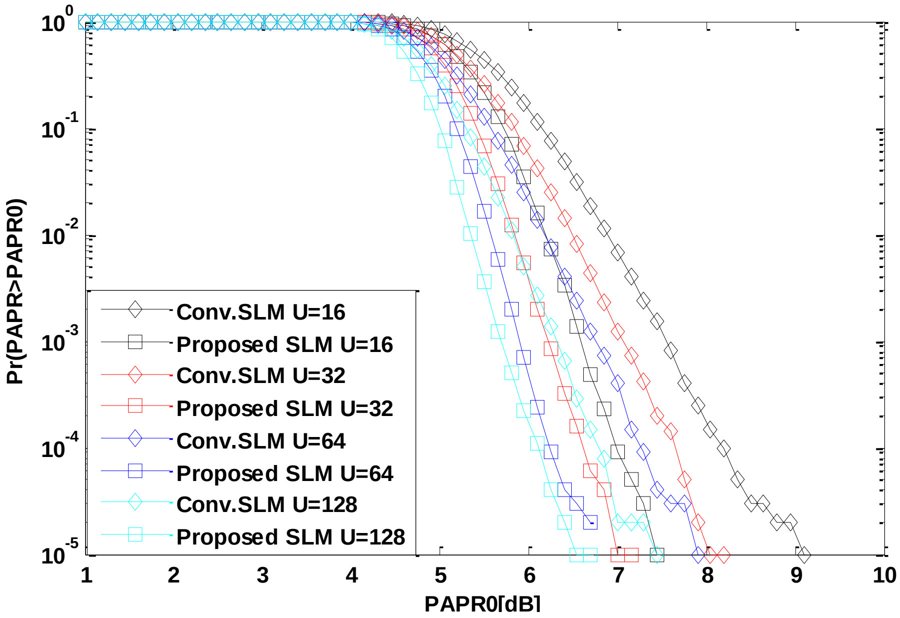

Figure 6.7 Comparison of SLM given in [9] with proposed SLM for *U*=16, 32, 64, 128 and *N*=64 and 4-PSK.

Table 6.2 CCDF performance investigation of conventional SLM and proposed SLM for *N*=32,64 and 128, *U*=16,32, 64 and 128

	PAPR (dB) value to attain $P(PAPR > PAPR_0) = 10^{-4}$							
	Conventional SLM				Proposed SLM			
N	*U*-16	*U*-32	*U*-64	*U*-128	*U*-16	*U*-32	*U*-64	*U*-128
32	7.90	7.00	6.26	5.82	6.25	5.96	5.65	5.36
64	8.20	7.60	7.15	6.85	7.00	6.55	6.25	6.10
128	8.65	8.20	7.92	7.62	7.45	7.10	6.85	6.55

Figure 6.8 to Figure 6.12 depict PAPR performance analysis of Conv. SLM and proposed SLM for *U*=1, 2, 4 and 8 under *N*=128 for various higher order modulation schemes like BPSK, 4-PSK, 8-PSK, 16-PSK, and 32-PSK. The performance of PAPR for the Conv. SLM and the proposed SLM is displayed in Table 6.3. It is obvious from Table 6.3 that the performance of proposed SLM scheme, for *N*=128 and BPSK, for *U*= 8 is marvelous in contrast with the Conv. SLM system for *U*=1, 2, 4, 8 and also with the proposed SLM for *U*=1, 2, 4.

Here, we have perceived that PAPR (dB) required to accomplish the $P(PAPR > PAPR_0) = 10^{-3}$ for *N*=128 and BPSK modulation is: 10.90, 10.45, 10.75, and 9.10 dB, respectively for Conv. SLM for *U*=1, 2, 4, 8 whereas it is 10.60, 9.10, 8.35, and 7.30 dB, respectively for the proposed SLM for *U*=1 , 2, 4, 8. Similarly, we can perceive for higher order of modulation in order to estimate the performance of PAPR lessening of proposed SLM system in comparison with Conv. SLM scheme (Table 6.3).

Table 6.3 CCDF performance investigation of conventional SLM and proposed SLM for *N*=128, M-PSK, *U*=1,2, 4 and 8

	PAPR (dB) value to attain $P(PAPR > PAPR_0) = 10^{-3}$							
	Conventional SLM				Proposed SLM			
M-PSK	*U*-1	*U*-2	*U*-4	*U*-8	*U*-1	*U*-2	*U*-4	*U*-8
2	10.90	10.45	10.75	9.10	10.60	9.10	8.35	7.30
4	10.60	10.30	10.45	8.50	10.30	9.25	8.60	7.78
8	10.60	10.31	10.35	8.65	10.45	9.71	8.35	7.63
16	10.45	10.45	10.31	8.66	10.60	9.27	8.36	7.62
32	10.45	10.30	10.32	8.52	10.46	9.40	8.50	7.75

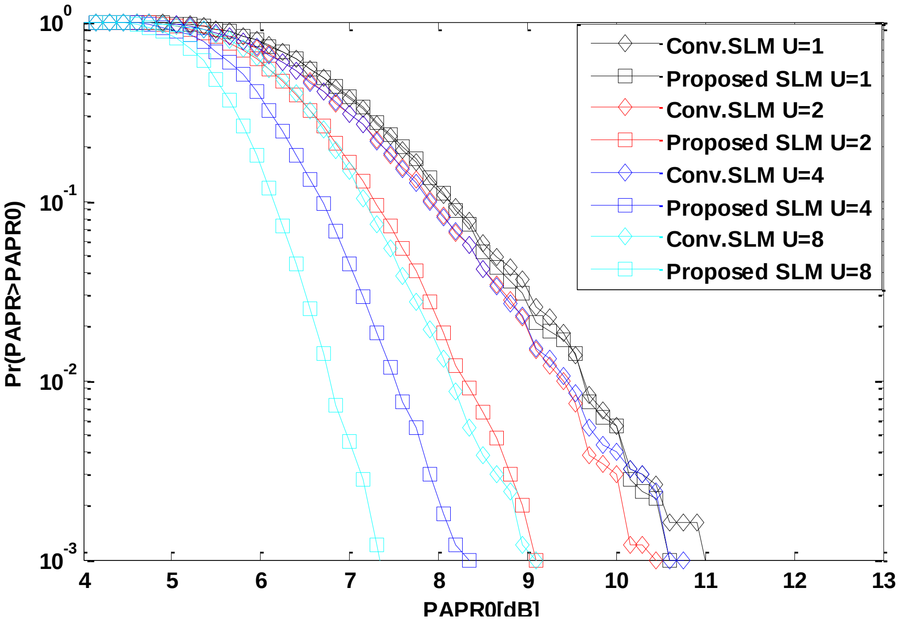

Figure 6.8 Comparison of SLM given in [9] with proposed SLM for *U*=1, 2, 4, 8 and *N*=128 and BPSK.

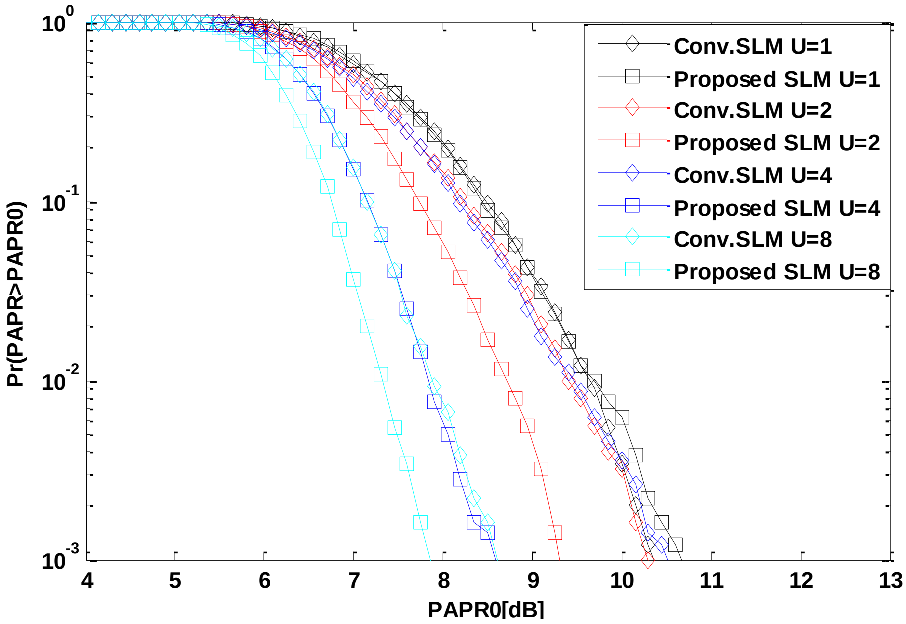

Figure 6.9 Comparison of SLM given in [9] with proposed SLM for *U*=1, 2, 4, 8 and *N*=128 and 4-PSK.

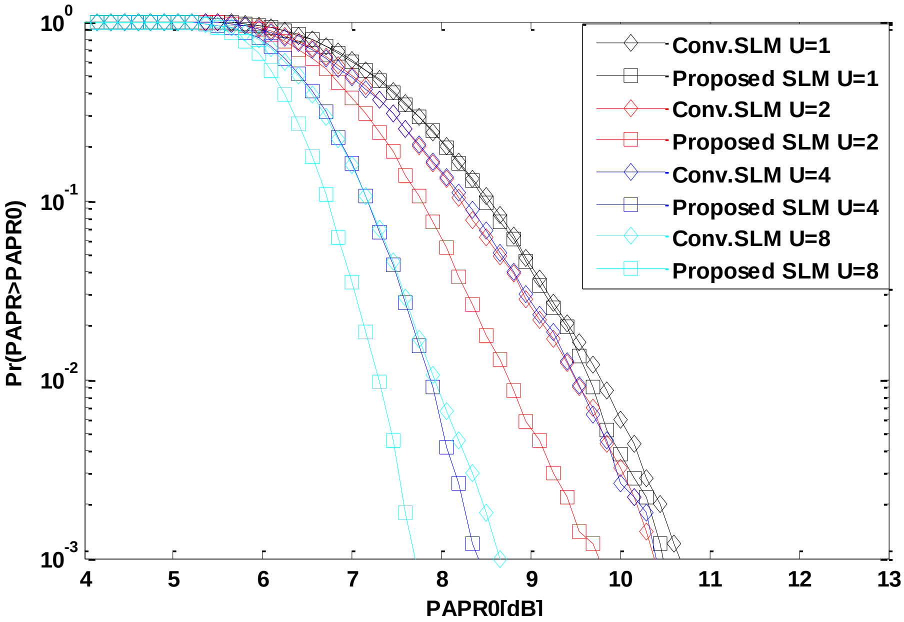

Figure 6.10 Comparison of SLM given in [9] with proposed SLM for *U*=1, 2, 4, 8 and *N*=128 and 8-PSK.

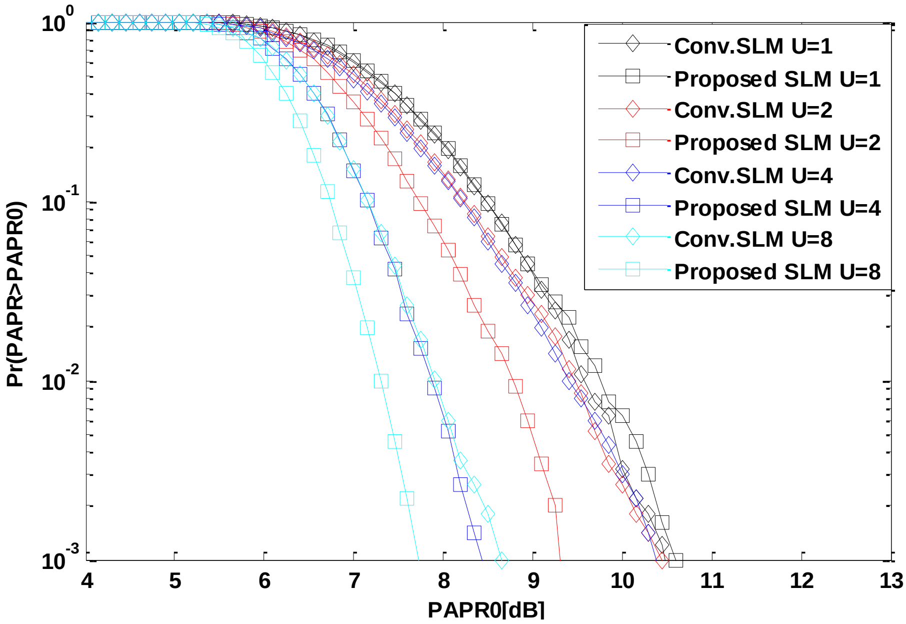

Figure 6.11 Comparison of SLM given in [9] with proposed SLM for *U*=1, 2, 4, 8 and *N*=128 and 16-PSK.

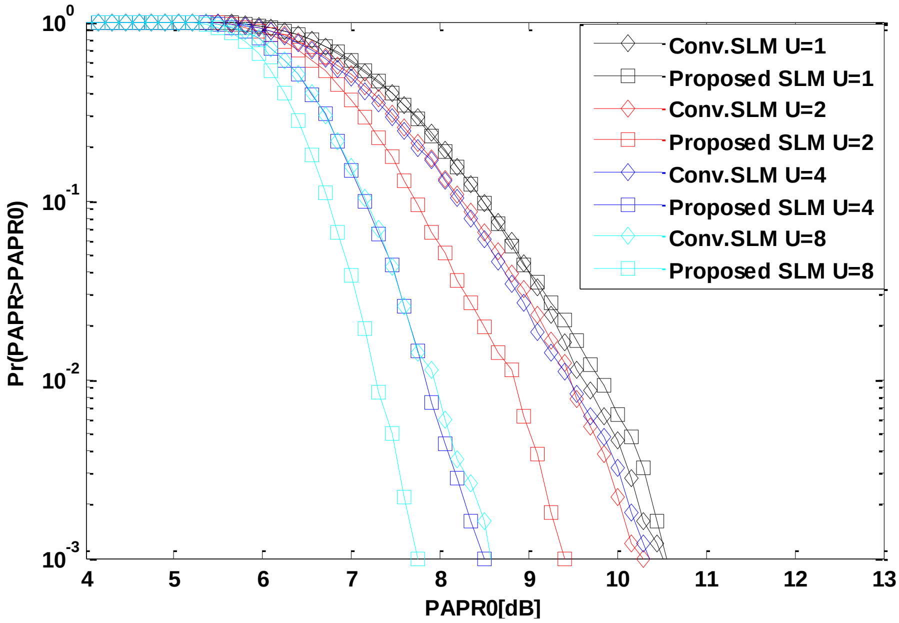

Figure 6.12 Comparison of SLM given in [9] with proposed SLM for *U*=1, 2, 4, 8 and *N*=128 and 32-PSK.

Figure 6.13 to Figure 6.17 depict the PAPR performance analysis for Conv. SLM and proposed SLM for *U*=16, 32, 64, 128 under *N*=128 for various higher order modulation scheme like BPSK, 4-PSK, 8-PSK, 16-PSK, and 32-PSK. The PAPR performance comparison is shown in Table 6.4. For *N*=128 and BPSK modulation scheme, the performance of proposed SLM scheme for *U*= 128 is impressive in comparison with the performance of proposed SLM for *U*=16, 32, 64 and also with the Conv. SLM scheme for *U*=16, 32, 64, 128 (Table 6.4).

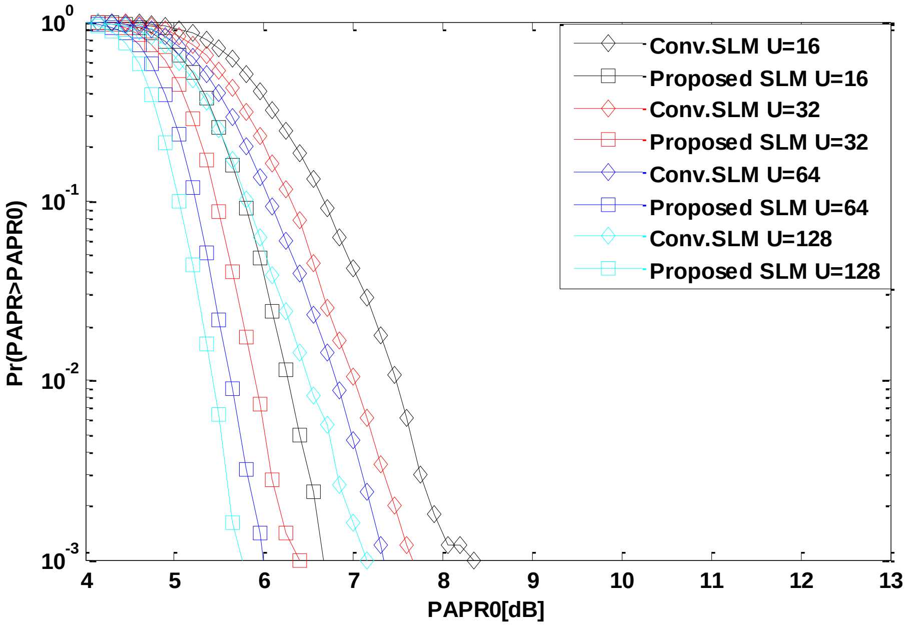

Figure 6.13 Comparison of SLM given in [9] with proposed SLM for *U*=16, 32, 64, 128 and *N*=128 and BPSK.

Here, we have perceived that PAPR (dB) required to accomplish the $P(PAPR > PAPR_0) = 10^{-3}$ for *N*=128 at BPSK is: 8.35, 7.61, 7.30 and 7.15 dB, respectively for Conv. SLM for *U*=16, 32, 64, 128 whereas it is 6.57, 6.40, 5.95 and 5.67 dB for the proposed SLM for *U*=16, 32, 64, 128, respectively (Table 6.4). Similarly, we can perceive for higher order of modulation in order to estimate the performance of PAPR lessening of proposed SLM system in contrast with Conv. SLM system (Table 6.4).

Table 6.4 CCDF performance investigation of conventional SLM and proposed SLM for *N*=128, M-PSK, *U*=16,32, 64 and 128

	PAPR (dB) value to attain $P(PAPR > PAPR_0) = 10^{-3}$							
	Conventional SLM				Proposed SLM			
M-PSK	*U*-16	*U*-32	*U*-64	*U*-128	*U*-16	*U*-32	*U*-64	*U*-128
2	8.35	7.61	7.30	7.15	6.57	6.40	5.95	5.67
4	8.20	7.75	7.60	7.10	7.10	6.85	6.40	6.25
8	7.90	7.76	7.30	7.15	7.30	6.86	6.41	6.25
16	8.08	7.77	7.45	7.10	7.15	6.72	6.41	6.25
32	8.07	7.75	7.60	7.16	7.01	6.70	6.41	6.27

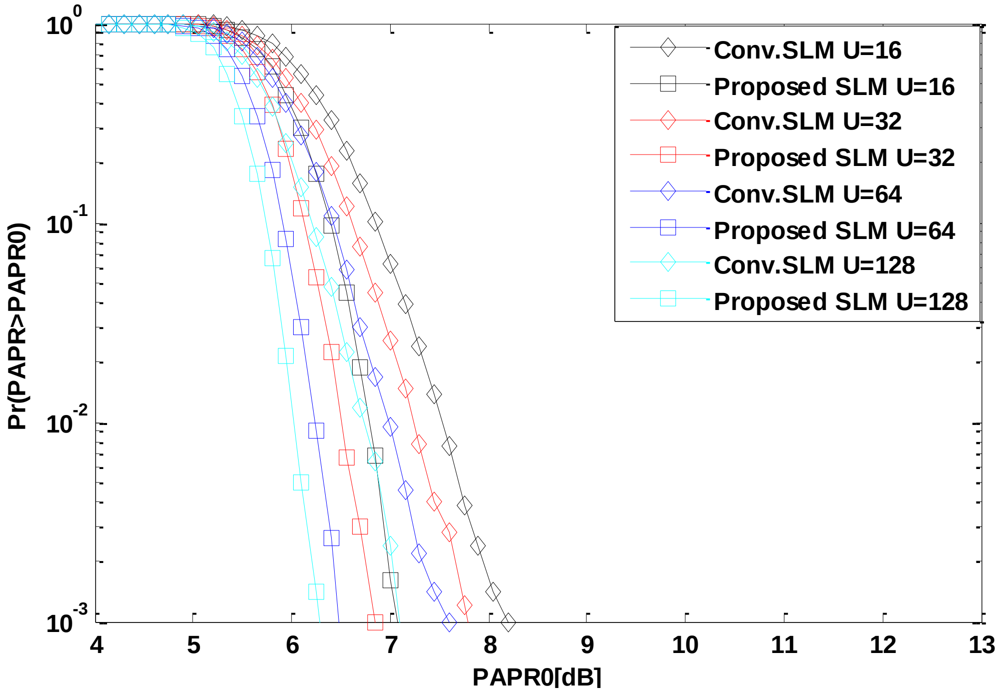

Figure 6.14 Comparison of SLM given in [9] with proposed SLM for *U*=16, 32, 64, 128 and *N*=128 and 4-PSK.

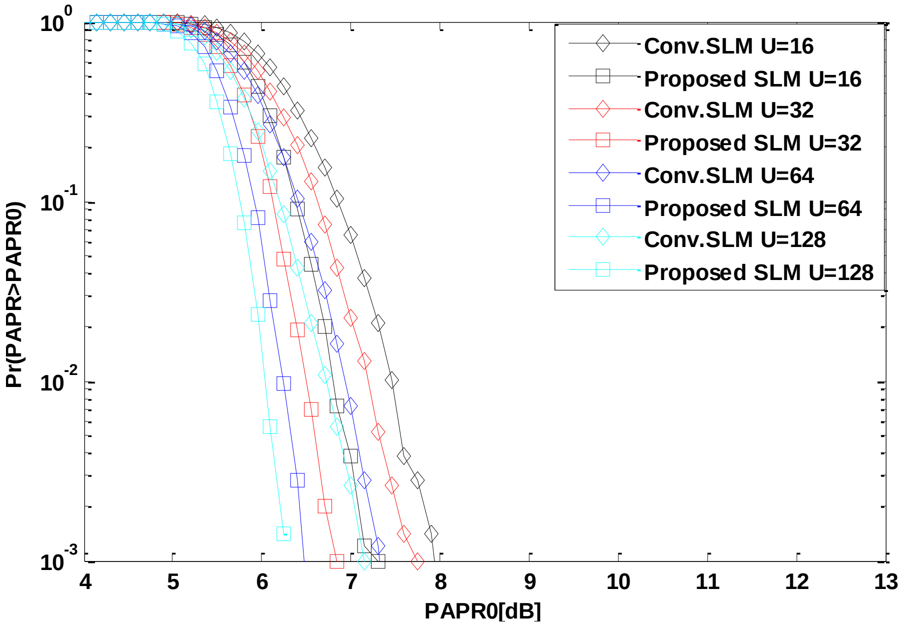

Figure 6.15 Comparison of SLM given in [9] with proposed SLM for *U*=16, 32, 64, 128 and *N*=128 and 8-PSK.

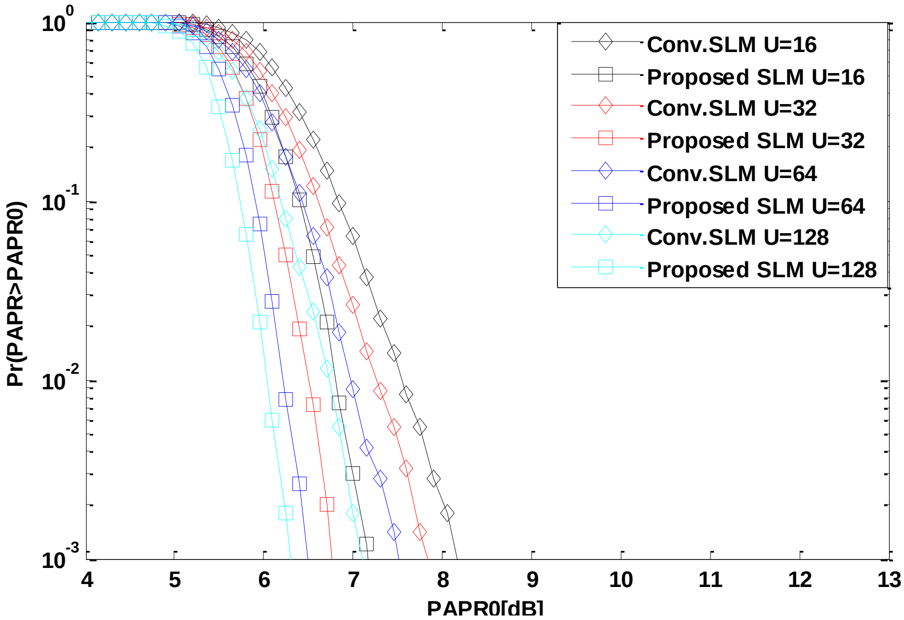

Figure 6.16 Comparison of SLM given in [9] with proposed SLM for *U*=16, 32, 64, 128 and *N*=128 and 16-PSK

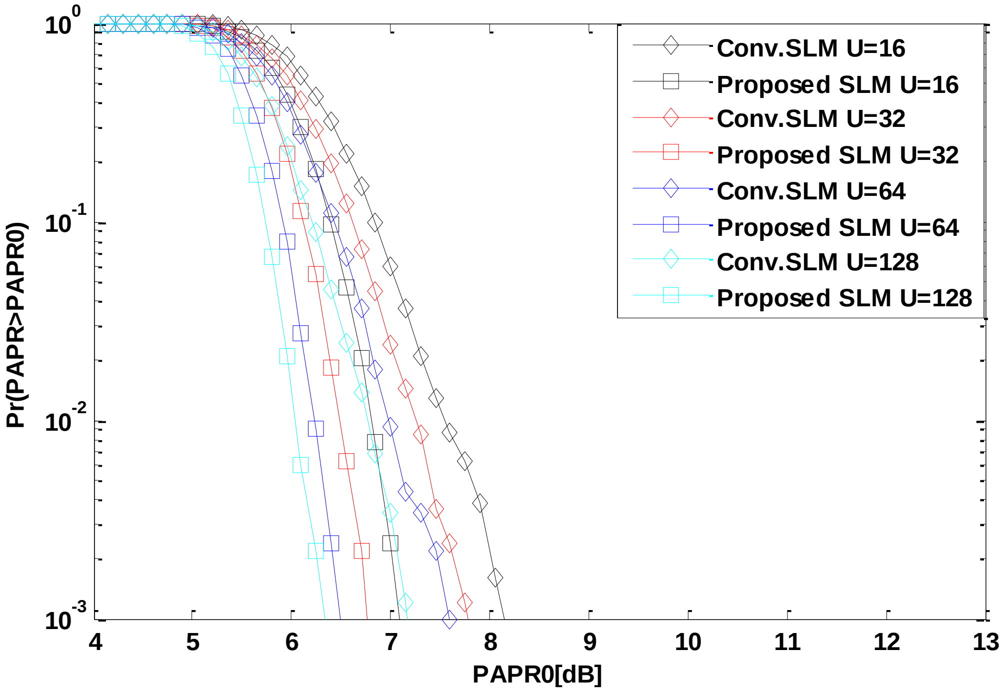

Figure 6.17 Comparison of SLM given in [9] with proposed SLM for *U*=16, 32, 64, 128 and *N*=128 and 32-PSK.

6.6 CONCLUSION

The proposed SLM method using DCT for the selection of phase sequences is found to be better than the work presented in literature. In conventional SLM, randomized phase sequence criterion has been adopted whereas in the proposed work, designing of phase sequence is based on the use of DCT matrix which needs less computational efforts. Moreover, in the proposed work, very small information about phase is required to be sent because of specific structure of DCT matrix so that the data can be easily reproduced at the receiver. In future, the proposed work can also be simulated using other modulation schemes like QAM.

CHAPTER 7 PAPR CLIPPING UNITED WITH ALTERED PTS TO LESSEN PAPR IN OFDM

7.1 INTRODUCTION

For attaining a great speed in the data, recent developments are taking place in wireless communications. OFDM which is a wireless communication system used in the IEEE 802.16 (WIMAX) and LTE standards, pointed out by [1]. Authors have studied theories like PAPR, OFDM and condition for the lessening of PAPR in the multi carrier signals. Authors finally, conclude that the usage of combined technique can be beneficial because it can take the advantage of the many different techniques while diminishing PAPR along with development in BER presentation, Hence, it has become the necessity to reduce this PAPR. Many methods are recommended in works similar to discrete hartely matrix transform (DHMT) precoding to lessen the elevated PAPR in OFDM is explained by [59]. In this manuscript, the DHMT based OFDM is utilized. The performance is equated with walsh-hadamard matrix transform (WHMT), OFDM, discrete cosine matrix transform (DCMT) and vandermonde-like matrix transfor (VLMT) based OFDM, in one of the study [67] has proposed a chaotic discrete hartley transform (DHT) to increase security and transmission of optical OFDM in passive optical network (PON). Authors have proposed analysis that present DHT matrix with permutation of rows and columns for diminishing PAPR. Henceforth, the proposed method generate complexity which is small and leads to good spectrum efficiency.

A novel methodology [7] has been suggested for diminishing the PAPR in which combination of PTS is combined with SLM technique and it was observed that the reduction in PAPR was found to be from 6 dB to 5 dB. At, last the results obtained from proposed algorithm are compared with pre-defined techniques and it performs better in comparison with other techniques. Another technique [66] is proposed for diminishing PAPR. In this proposed technique SLM along with conversion matrices (CM) and genetic algorithm (GA) has been deployed. So, due to this, it requires only single IFFT module. Simulation results clearly, portrays the noteworthy performance of projected technique along with small complexity. In one of the advance revision [76] projected a PTS algorithm which possess low complexity along with random phase sequence matrix (RPSM) for the PAPR lessening in OFDM system. The optimum sequences of phases sequence matrix are designed for the diminishing PAPR and concurrently lessen the usage of IFFT operations. There exists a condition of tradeoff between complexity and diminishing PAPR. The improved PTS perform better as compared with traditional PTS (T-PTS). OFDM is also known as multicarrier system.

Many advantages of OFDM are there like high spectrum efficiency, protection in frequency selective channels of fading. Now, it also experiences the problem of high PAPR. Since PAPR is very high so High Power Amplifier (HPA) begin working in the nonlinear regions. Henceforward, it has become very significant to perform in depth research in this topic and diminish PAPR so that the amazing characteristics of OFDM system can be used as presented by [94], whereas peak interference to carrier ratio (PICR) to measure the subsequent intercarrier interference (ICI). The PICR can be diminished by PTS and SLM as discussed by [135] whereas authors in [136] used sub-optimal PTS united with the preset threshold in order to obtain low complexity to discover optimum weighting factors. A particular bit in weighting factors which leads to slight peak to average power ratio is obtained from sub-optimum technique and also a particular threshold which obtained from OFDM frames probability, applied to diminish complexity. In order to diminish peak to average power ratio by employing easy symbols transform in OFDM-CDMA. This method is very easy because of no extra complexity and worked without any kind of limits after allocating spreading codes and maintain original efficiency. The outcomes showed that investigated method gave peak to average power ratio lessening. It can also provide further diminishing by uniting SLM and PTS which are very less complex as compared with ordinary SLM and PTS methods as presented by [137].

The technique based upon modified iterative amplitude clipping and filtering (IACF) method to diminish the PAPR as demonstrated by [138]. BCH codes along with the PTS is selected for the minimization of PAPR which is presented by [87] & authors designed [139] lower bound for the error of mean square estimation in between intercarrier interference (ICI) least square estimator by utilizing several training sequences. They proposed many sequences based upon matrix of hadamard whereas authors utilized [140] phase sequence based on chaotic sequences. So, for diminishing PAPR chaotic sequences is added for specific optimization. The simulation outcomes showed that projected method improved PAPR lessening performance of SLM method more successfully as compared with other phase sequences. The planned PTS algorithm based on discrete Artificial Bee Colony (DiscABC-PTS) for diminishing the same problem. In comparison with ABC-PTS, this projected algorithm has good efficiency in high computation and also it obtains small PAPR as compared with available PTS is explained by [62]. One of the study revealed, a leading samples of time domain in the same manner as available PTS techniques. But authors projected a good criterion for the choosing of leading samples of time domain. It diminished PAPR along with lesser complexity is presented by [64] whereas [141] projected a novel approach with the addition of two operations so that efficiency and linearity can be upgraded. The important idea here is to form a signal of correction in the manner of ping pong in between pre-distortion and diminishing of PAPR. The projected method provides an improvement in comparison with conventional techniques.

In [21], authors planned a precoding process practice a generalize precoding matrix (PM) to deliver a scheme which generate a data with small PAPR and complexity. The planned method attained the BER which is superior as compared with OFDM along with smaller PAPR. In [65], authors planned a method which compand amplitude of OFDM signal. Along with the diminishing PAPR, this scheme reduces the complexity. In [142], authors planned PAPR diminishing algorithm with perturbation assisted method with the help of degree of freedom inherent array of antenna. In this manuscript, perturbation signals are used in frequency domain for diminishing the PAPR.

The Figure 7.1 demonstrates the transmitter and receiver fragments with the assistance of block diagram of OFDM. This chapter is arranged in five sections where Section 7.1, represents general introduction. Section 7.2, represents equations related to conventional OFDM system and it is followed by Section 7.3 of projected procedure whereas another Section 7.4, presents simulation results and final Section 7.5, offers the conclusion of our work.

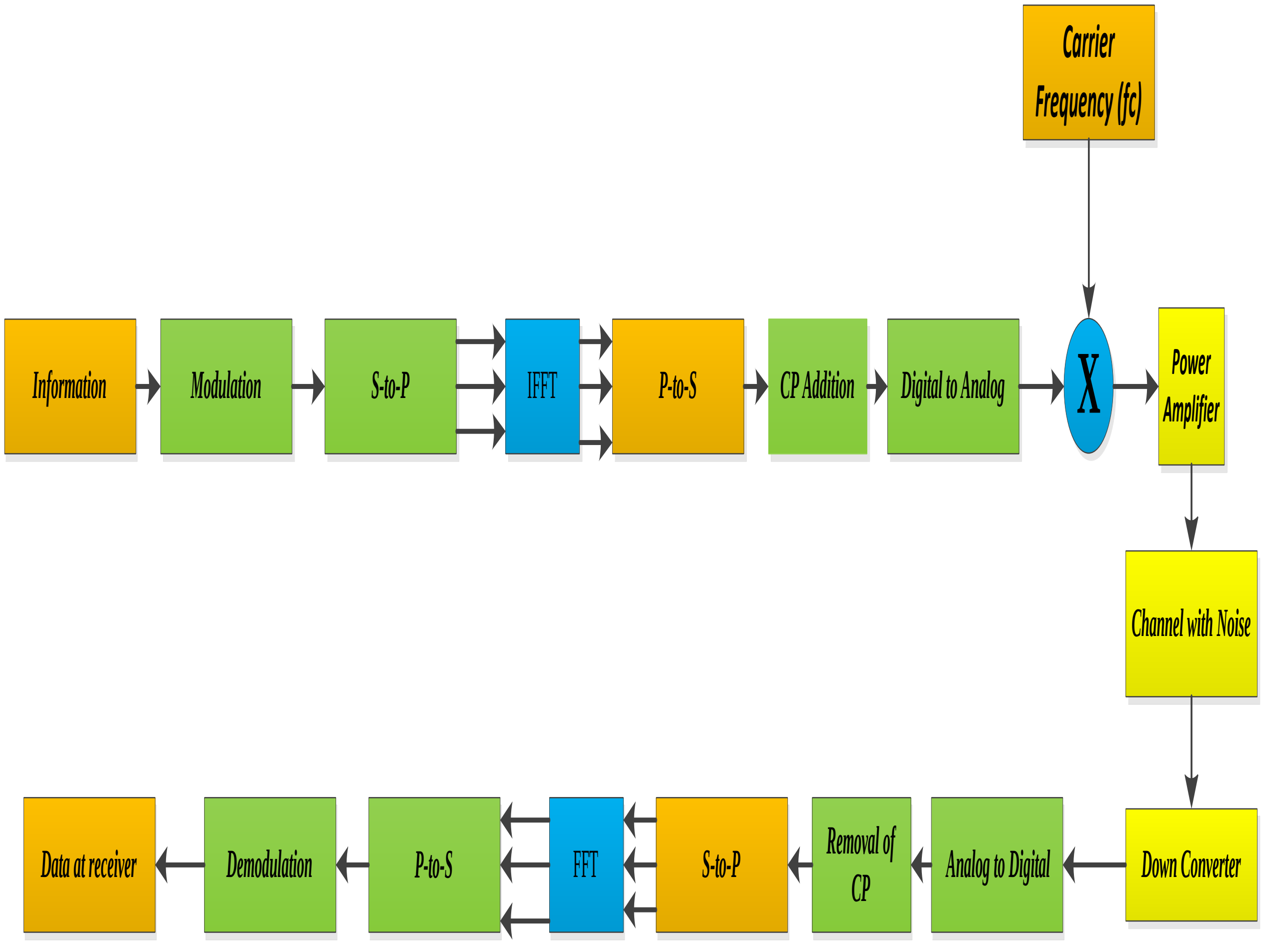

Figure 7.1 Block plan of OFDM structure [1].

7.2 EQUATIONS FOR OFDM SYSTEM

The data w[n] after modulation undergo the process of transformation using IFFT is demonstrated by [87] with the following equation,

$$w[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{k=(N-1)} W[k] e^{\frac{(2.jk.n.\pi)}{(N)}} \qquad 0 \leq \ n \leq N-1 \tag{7.1}$$

where N= subcarriers; n=time domain; k= frequency domain

PAPR: It can be calculated as the highest power of time domain signal taken division by the average power after IFFT transformation is presented by [87] ,

$$PAPR(z[n]) = \frac{max(|z[n]|^2|)_{0 \leq n \leq N-1}}{E(z[n]^2)} \tag{7.2}$$

where *E[.]* is operator of expectation.

Complementary Cumulative Distribution Functions (CCDF): It is calculated as likelihood that PAPR can be originated larger than specific edge value revealed by [87],

$$PAPR(z[n]) = Pr(PAPR\ (z[n]) > specific\_threshold\_value) \tag{7.3}$$

Walsh Hadamard Sequence: It is an orthogonal codes presented by [140] which can be created recursively by a method known as Sylvester technique,

$$H_{2*N}^{W} = \begin{bmatrix} H_N^W & H_N^W \\ H_N^W & -(H_N^W) \end{bmatrix} \text{ and } H_2^W = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \tag{7.4}$$

Clipping Procedure: The signal x is clipped and can be explained by [138] as,

$$y(n)_{clip} = \begin{Bmatrix} x * e^{j\varphi}, & |x| \leq Bo \\ Bo * e^{j\varphi}, & |x| > Bo \end{Bmatrix} \tag{7.5}$$

where *Bo* is the predefined level.

Conventional PTS: The technique which was preferred for the lessening of PAPR for OFDM system generally added several fractional arrangements was presented in [1].

In this PTS arrangement, the contribution information *X* was segregated and V non-overlapping sequences were obtained. The IFFT had been applied to individual sequence and afterward subsequent sequences were multiplied by several vectors of rotations known as phases $\{b_1, b_2, b_3\}$ etc.

After processing all the sequences, they were added and PAPR was computed. At last, the sequence with slight PAPR was communicated. Figure 7.2 depicted the conventional PTS scheme.

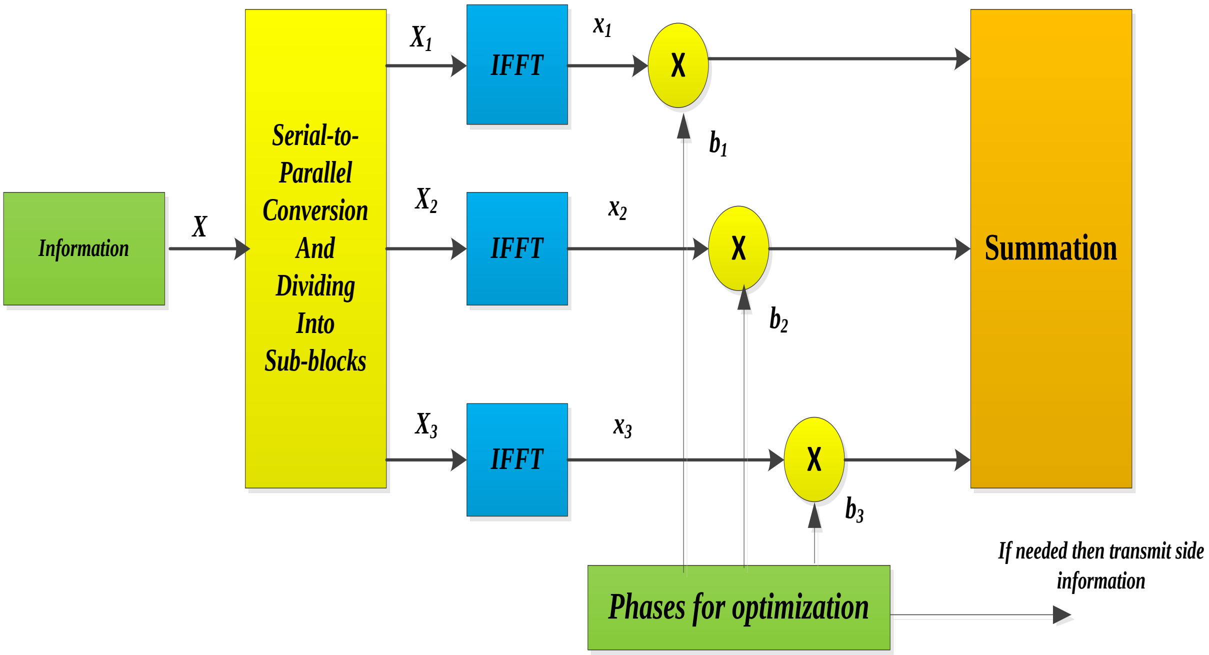

Figure 7.2 Block diagram of PTS technique [1].

7.3 PROJECTED PROCEDURE

The information W which will undergo the process of modulation can be represented by $[W(0), W(1), W(2) \ldots \ldots \ldots \ldots ..]^T$. It undergoes the process of digital modulation. Once it is passed through BPSK modulation then it can be depicted by $W_m = [W_m(0), W_m(1), W_m(2) \ldots \ldots \ldots \ldots ..]^T$.Now, this information before IFFT is divided into numerous small blocks.

$$W_m = [ph_0, ph_1, ph_{2,} \ldots \ldots . ph_{D-1,}] \tag{7.6}$$

$$W_m = \sum_{j=0}^{D-1} ph_J \tag{7.7}$$

Here D=4 is considered which represents total number of segments data. Hence, these equations tell us that we can get the same data only by adding small sub-segments.

Once data with is segregated then IFFT is applied so that time domain data can be obtained as:

$$w_m[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{k=(N-1)} W_m[k] * e^{\frac{(2.j.\pi.k.n)}{(N)}} \qquad 0 \leq \ n \leq (N-1) \tag{7.8}$$

where N=32 to 1024 are considered.

For the reduction of PAPR we require the below defined matrix as:

$$H_{2*N}^{W} = \begin{bmatrix} H_N^W & H_N^W \\ H_N^W & -(H_N^W) \end{bmatrix} \text{ and } H_2^W = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \tag{7.9}$$

Now, the multiplication of rows of matrix is done after IFFT with the help of information sequence which is given by:

$$h(n) = \sum_{j=0}^{D-1} r * w_m \tag{7.10}$$

where r=4 are the total number of rows considered.

After crossing the particular pre-defined threshold of 0.90, the signal is clipped and given as:

$$h(n)_{clip} \ = \begin{Bmatrix} Cpe^{j\varphi} & |h(n)| > Cp \\ he^{j\varphi} & |h(n)| \leq Cp \end{Bmatrix} \tag{7.11}$$

Finally, the data which generate smallest PAPR is chosen for communication and index of rows are preserved for retrieval of information at receiver.

In the above recommended procedure, we have shown the entire organization which benefit in improving the data in such a way that it's PAPR diminished along with easy scheming of phases for the algorithm. This projected procedure is depicted by Figure 7.3.

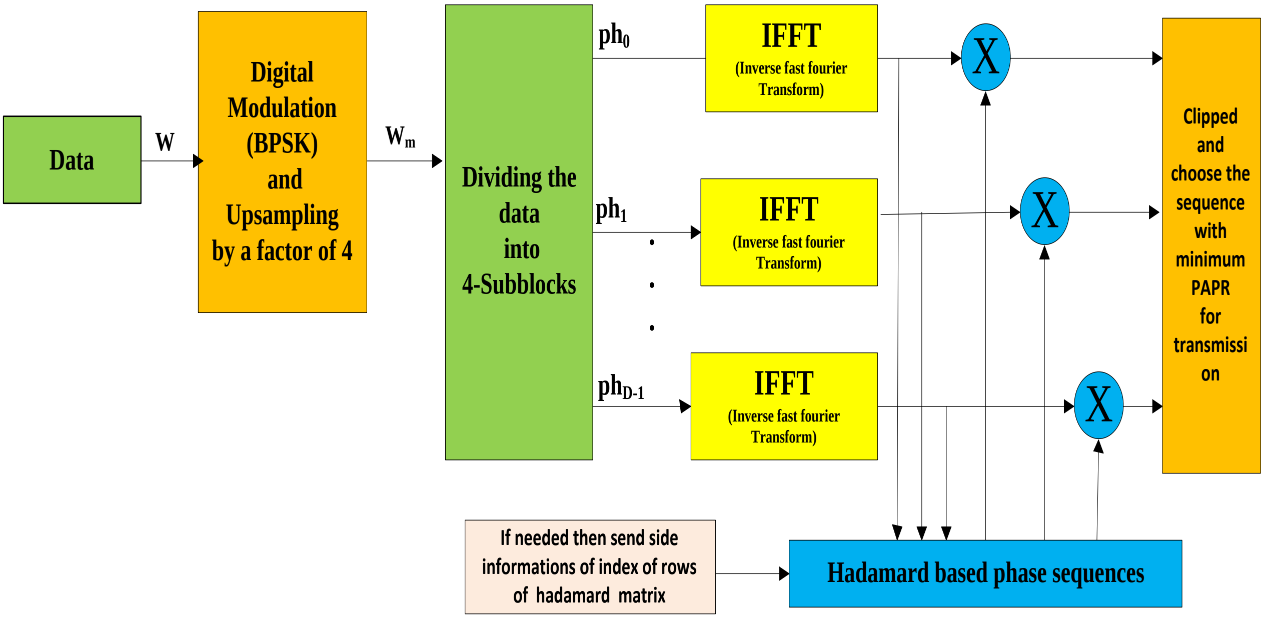

Figure 7.3 Block diagram of projected procedure.

7.4 SIMULATION RESULTS

The important parameters for the performance evaluation of projected procedure are total number of rows of matrix are 4 and data divisions are also 4. Level of the clipping is 0.90 where as several number of subcarriers are used along with the oversampling of 4. The iteration of 10^4 OFDM blocks are considered. From Figure 7.4 to Figure 7.9 PAPR assessment is performed for BPSK under 32 to 1024 sub-carriers between A= Conventional OFDM, B= PTS under hadamard phase sequences, C= Clipping algorithm and D= PTS under hadamard matrix hybridized with Clipping algorithm. Now, considering for Figure 7.4 with N=32 where A possess PAPR of 10.9 dB where PAPR of the B, C and D are 7.6, 10.3 and 7 dB respectively. Hence, D lessen the PAPR at very agreeable level. Similarly, it performs quite well in the conditions while considering for 64,128,256,512 and 1024 sub-carriers as shown by Figure 7.5 to Figure 7.9. The performance of PAPR for A, B, C and D algorithms are displayed in Table 7.1.

Table 7.1 Performance Evaluation of CCDF at 0.1 % for PAPR (dB) of A, B, C and D under BPSK modulation

Serial No.	No.Sub-carriers	A	B	C	D
1	32	10.9	7.6	10.3	7
2	64	10.8	8	10.1	7.2
3	128	11	8.31	10.2	7.6
4	256	11.2	8.7	10.4	7.82
5	512	11.1	9.01	10.2	8.1
6	1024	11.01	9.30	10.1	8.5

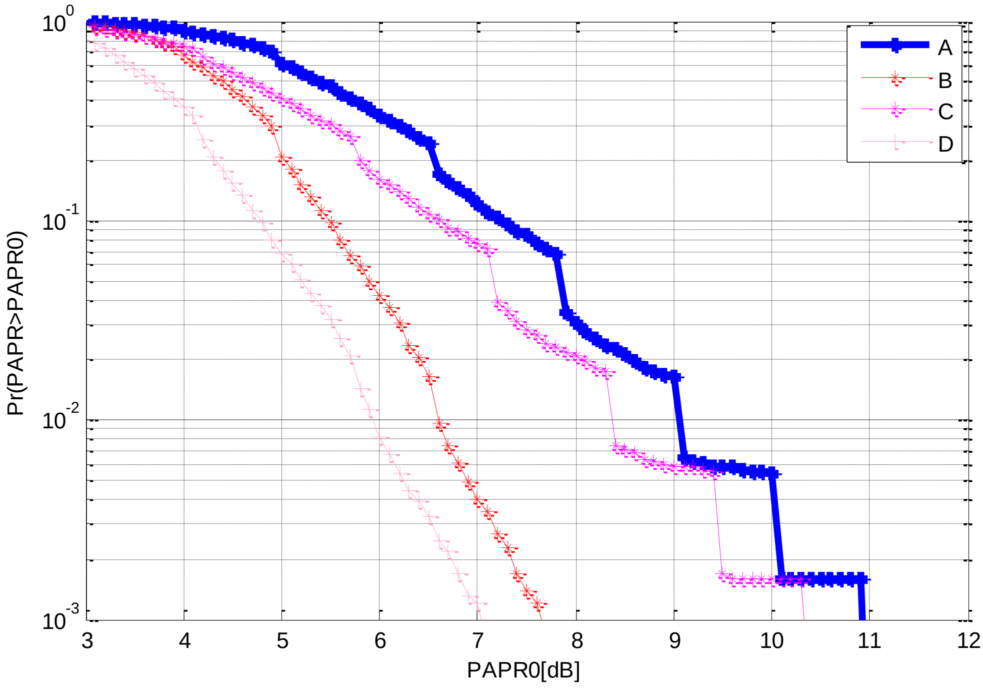

Figure 7.4 Simulation result of CCDF for 32 subcarriers under BPSK modulation technique.

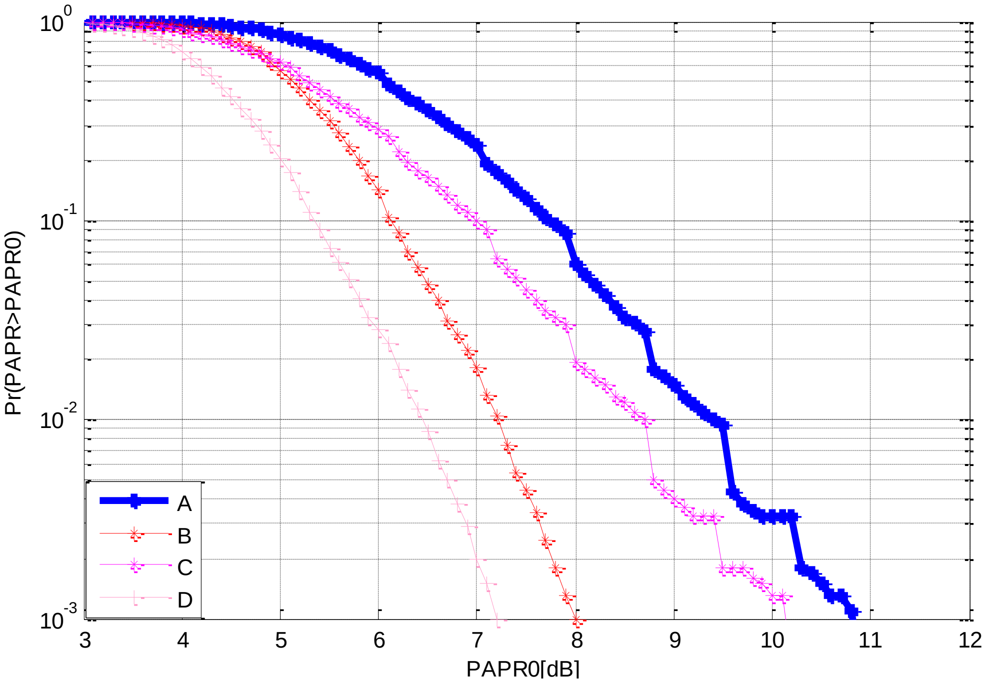

Figure 7.5 Simulation result of CCDF for 64 subcarriers under BPSK modulation technique.

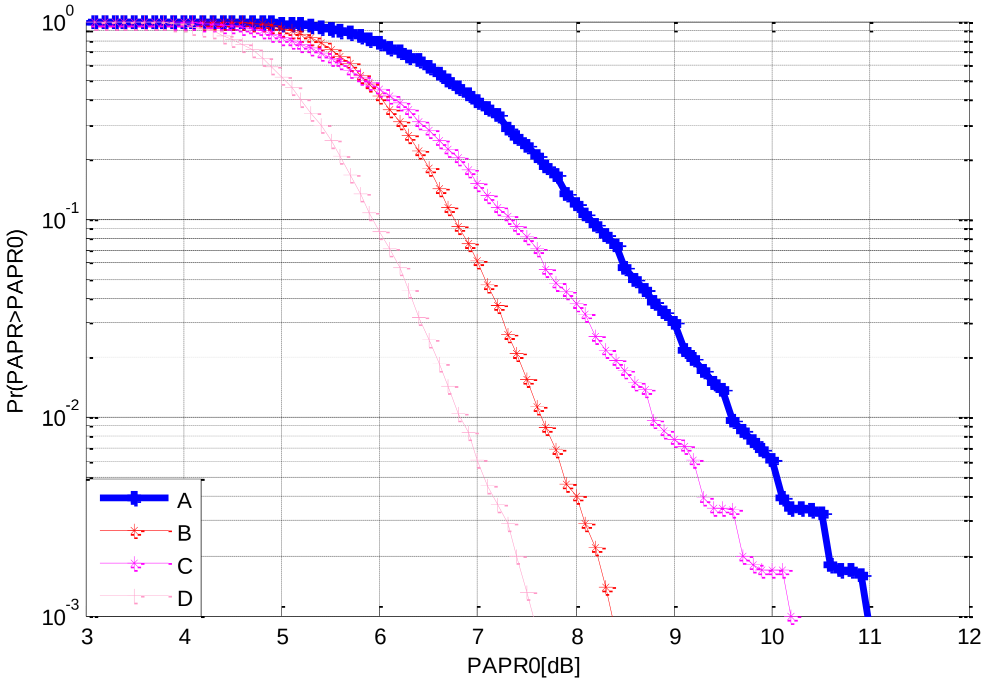

Figure 7.6 Simulation result of CCDF for 128 subcarriers under BPSK modulation technique.

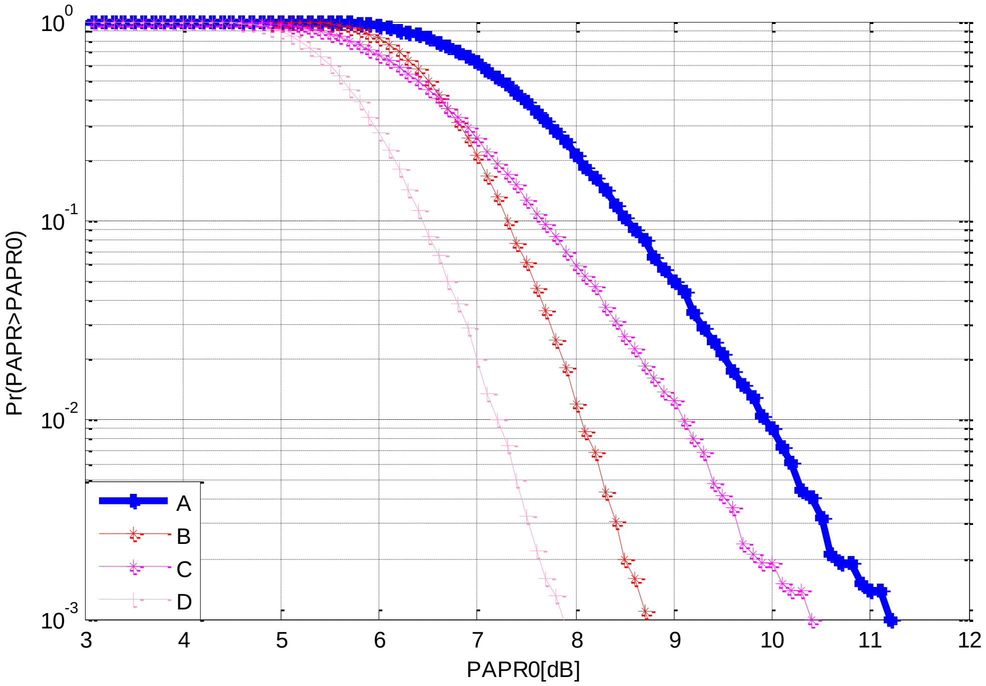

Figure 7.7 Simulation result of CCDF for 256 subcarriers under BPSK modulation technique.

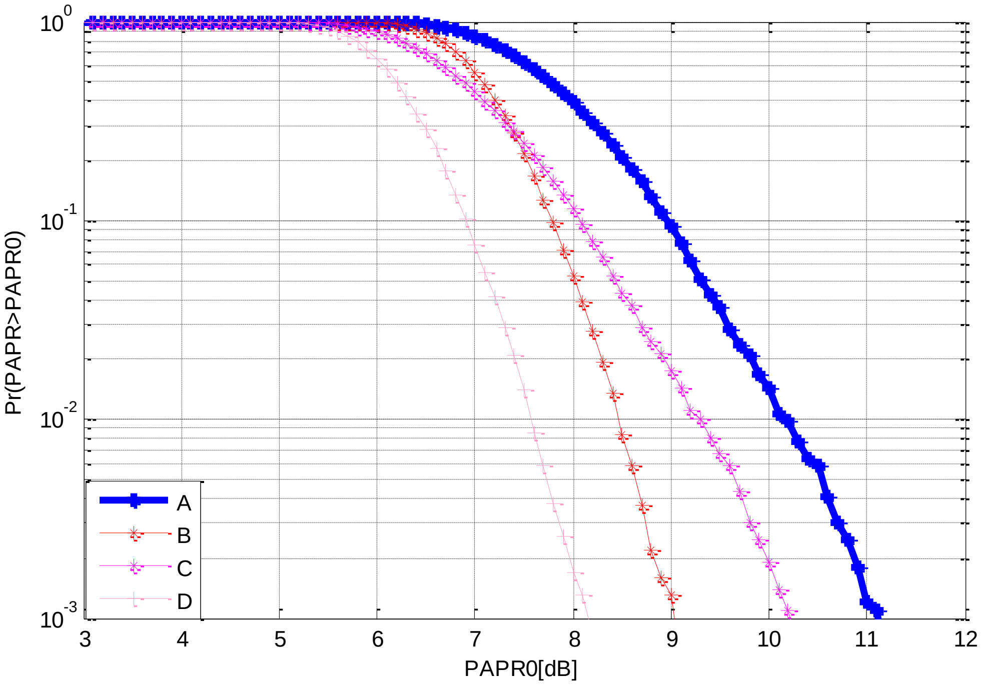

Figure 7.8 Simulation result of CCDF for 512 subcarriers under BPSK modulation technique.

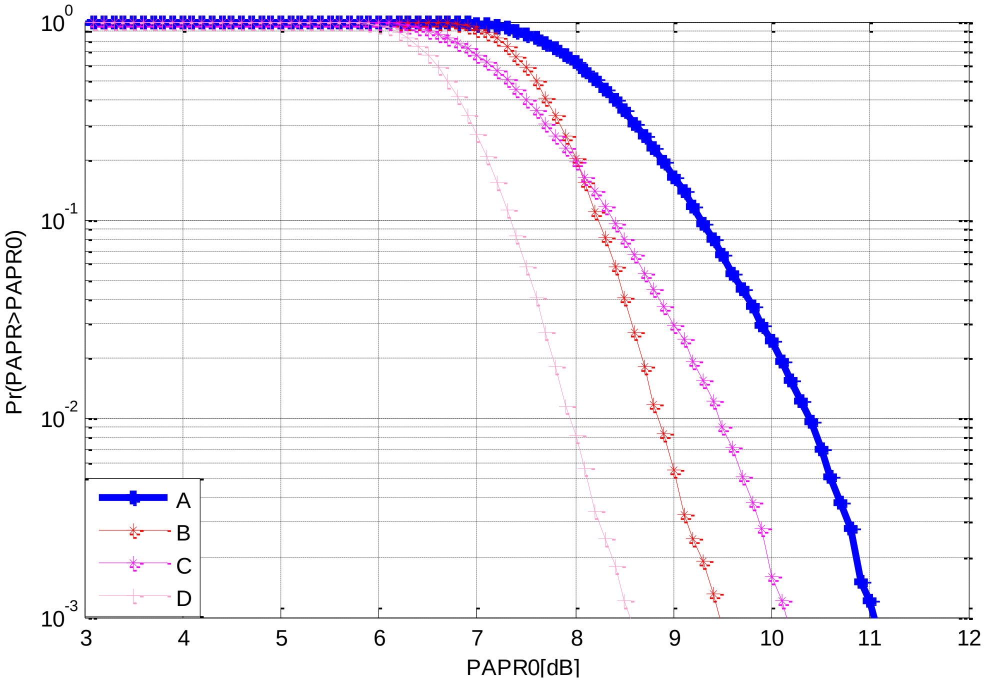

Figure 7.9 Simulation result of CCDF for 1024 subcarriers under BPSK modulation technique.

7.5 CONCLUSION

An innovative method is presented through this research manuscript in which PTS, hadamard matrix and clipping play their role in diminishing PAPR. Generally, conventional PTS technique faces the problem of phase designing while our proposed techniques presents the methodology by which phase generation become quite easy. The most important advantage of this proposed algorithm is that even after optimization using several phases the information is further clipped. The performance of our proposed procedure outperform all the conventional techniques. Such type of remarkable performance can be easily understood from the above presented simulation results. At last, we have accomplished a well-established PAPR lessening algorithm which not only enhanced the information with the assistance of phases in time domain but also clip the information if found greater then threshold. In the above revealed table it can be easily obtained that minimum PAPR i.e. 7 dB is always accomplished by D algorithm which is less in contrast with conventional algorithms during 32 sub-carriers whereas 8.5 dB in 1024 sub-carriers less in contrast with conventional algorithms. Hence, the remarkable property of our procedure can be easily acceptable.

CHAPTER 8 PAPR ASSESSMENT OF OFDM AND PSEUDO RANDOM PHASE SEQUENCES BASED PTS ALGORITHM OVER DIVERSE SUBCARRIERS

8.1 INTRODUCTION

OFDM is the most important approach due to robustness on the multipath fading channel, large spectral efficiency and reduced inter symbol interference. Since it uses the multi-carrier method due to that it has very high bandwidth efficiency. The reduction in the multi-path delay and multi-path fading is obtained due to numerous subcarriers which are orthogonal [143]. OFDM has been adopted in areas [144] like LTE and DVB. High PAPR is the main problem in OFDM. Hence, when OFDM signal goes through high power amplifier (HPA) at side of transmitter then non-linear distortions are perceived on it in form of out of band (OOB) noise and in-band (IB) noise, which ultimately worsens the performance [10].

Many techniques have been projected to diminish PAPR issue are summarized such as, Kumar et al. [143], PTS method has been taken into consideration because PAPR problem was diminished by this PTS algorithm without creating any kind of signal distortions. Authors used PTS and hybridized algorithm such as PS-GW so as to obtain minimum performance on computational complexity and PAPR. PS-GW is found to be combination of the PSO and GWO which find best combinations of phase rotational factors very efficiently. The exploitation capacity was improved in PSO along with investigations in the GWO to generate two variations. The outcomes showed the effective reduction in both computational complexity and PAPR.

Gupta and Thethi [144], authors proposed SLM along with pseudo random sequences under μ law companding in time domain. The excellent performance demonstrated by the projected algorithm in comparison with original OFDM and other existing techniques. Ali et al. [10] demonstrated SLM method with new pseudo random sequences for the lessening of PAPR. Traditional random sequences generally faced the shortage of structure of systematic nature due to that complexity increased. For the recovery of original signal, SLM required side information (SI) at the receiver. But in this projected method SI diminished to the single index value of the column of phase sequences matrix. Hence, the simulation outcomes depicted projected method nearly obtained same PAPR performance as compared with traditional sequence.

Zhou [16] projected the PTS method with low complexity projected which depended upon samples of dominant time domain and two novel matrices for selecting samples. Along with this, for the diminishing of computational complexity, grouping technique used in projected method. Simulation outcomes depicted that projected technique provided a perfect PAPR lessening with more saving in computation complexity. In [73], PTS algorithm based upon adaptive swarm optimization has been proposed. This proposed algorithm worked fine in order to search phases for the reduction of computation complexity. The experimental results depicted that projected algorithm has diminished PAPR and computational complexity.

Thota et al.[12] discussed that PAPR is diminished by SLM, PTS, hybrid and projected technique. The high PAPR analysis has been performed through diverse HPA models in term of gain, efficiency and PSD. The encouraging results obtained with the assistance of hybrid technique of PAPR reduction. HPA operated in linear region for better efficiency in comparison with non-hybrid PAPR reduction technique. Henceforth, PAPR lessening technique of hybrid nature can be utilized in system of future wireless communication. Prasad and Jayabalan [84] applied algorithm known as scaled PSO to the PTS method in order to obtain phase factors for lessening of PAPR problem at very fast convergence rate and small complexity of computational. The velocity updating equation of traditional PSO along with scaling factor so that velocity and inertia weight and velocity of particles can be increased consequently, getting faster convergence to best value along with lessening of PAPR problem. From obtained simulation outcomes, it can be easily noticed that projected scaled method of PSO-PTS diminished PAPR issue and appropriate for application having 64-QAM.

Jawhar et al. [80] recommended a new subblock partition method in order to enhance the reduction capacity of PAPR along with small computation complexity since the fundamental obstacle in OFDM system which is obtained as PAPR due to which system suffers IB distortions and OOB radiations. The results clearly indicated that proposed method can enhance PAPR diminished performance than interleaving PTS (IL-PTS), adjacent PTS (Ad-PTS) method. In addition to this, computation complexity of proposed method is much smaller than pseudorandom PTS (PR-PTS) and Ad-PTS.

Zhang and Shahrrava [14] projected a PAPR reduction method with small complexity. The projected method is a hybrid method with two stages structure in cascade. First stage is post IFFT stage which can form high order QAM with assistance of QPSK or BPSK with less number of IFFT where as another stage is depend upon SLM algorithm of class-III with parallel blocks. Every block creates sequences from every QAM sequences after passing through the parallel sub-blocks which performed circular convolution with the help of perfect sequences and shift in circular way with the shift values of optimal nature. The simulation results depicted proposed method outperformed existing method in PAPR lessening along with lesser complexity.

Madhavi and Patnaik [72] projected a novel NCT set of rules. Inflexion points and variable slopes were presented inside PDF, BER and PAPR are matched in order to obtain efficiency in performance and also flexibility in non-linear companding (NCL) form. Theoretical study of such set of rules were provided with signal attenuation factor and transform gain. The evaluation totally dependent on selection criteria of the parameters of transform which focused on execution and robustness aspect. The simulink used for the exploration. Hao et al. [145] suggested three subblock partitioned methods for PTS algorithm. GSD, BGSD, and QPP method all had performance of PAPR near to the random partition method but with small computation complexity. The numerical simulation of proposed scheme solved issue of very high complexity and obtained essential PAPR reduction.

Jun et al. [146] suggested multi population genetic PTS method. This method brought in artificial selection operator, migration operator and used multiple population to find the optimal factors for PTS, henceforth it diminished computation complexity. The simulation experiments showed that in comparison with conventional PTS method, the enhanced multi-population genetic PTS method diminished complexity without producing any loss of PAPR performance.

Cai et al. [147] introduced a class of PAPR diminishing technique based upon PTS algorithm. In these techniques, some properties of FFT are utilized in order to enhance signal sequences at cost of small computation. Simulation results showed these techniques obtained much better performance as compared with traditional PTS algorithm.

Mata et al. [148] proposed the PAPR diminishing method which depend upon enhanced PTS algorithm along with ABC method. The ability of projected method is PAPR lessening along with small complexity which lead to further enhancement in the quality of signals. The remarkable PAPR lessening along with small computation complexity of the projected method confirmed by the simulations.

Cheng et al. [62] demonstrated new discrete artificial bee colony scheme which dependent upon PTS (DisABC-PTS) method. As equated to ABC scheme based PTS method (ABC-PTS) projected before, DisABC-PTS method worked in discrete space, which had very high computational efficiency. Simulation outcomes indicated that DisABC-PTS method obtained small PAPR as compared with already available PTS method and had small computational complexity.

Lee et al. [64] suggested a new-fangled PTS algorithm with help of dominant samples of time-domain of OFDM signals. The projected method used dominant samples of time-domain in a manner which is very same to many already available low complexity PTS algorithm, authors proposed very efficient selection technique for dominant samples of time-domain. The achievement of lower computational complexity in comparison to traditional PTS method while obtained best PAPR reduction performance.

Sandoval et al. [1] proposed classification, evaluation of performance and optimization of reduction of PAPR method for public safety, commercial and tactical applications. Authors also included a new category, namely, hybrid method. In addition to this, authors compared characteristic through CCDF and evaluation of BER and also concluded the significance of hybrid method with the aim to enhance BER and diminish PAPR.

Wei and Shen [27], authors demonstrated that PTS is encouraging method for PAPR reduction because it presented no distortions. A small complexity PTS method termed N-PTS projected for the lessening of PAPR. By creating some sequences, time domain signals were achieved by combining original signals with the two circular signals. Henceforth, one IFFT block is mandatory to design. Simulation results and analysis showed that N-PTS method achieved small computation complexity while losing a slight of the performance in comparison with traditional PTS.

Gupta and Thethi [149], authors proposed modified PTS (MOPTS) algorithm after using normalized riemann matrix rows as sequences of phases along with DCT under many modulations methods and subcarriers along with distributing information into many blocks and utilizing phase sequences for optimization. Generally, original PTS (ORIPTS) method used random phase sequences which are difficult to design. Simulations results depicted the remarkable performance of MOPTS as compared with original OFDM (OFDMORIPAPR) and ORIPTS.

Gupta et al. [87] demonstrated a perfect hybridization of PTS along BCH codes. This method selected the signal with reduced PAPR from many signals. At the side of transmitter, the process of scrambling used coset leader of BCH codes and technique of syndrome decoding in order to recover the sequence which was transmitted at the side of receiver. At last, simulations results revealed that improved PTS method had decent reduction in PAPR in comparison with traditional OFDM and already available PTS method.

Gupta et al. [86] projected SLM technique based upon the use of DCT matrix. In this demonstrated work, DCT matrix had been selected which depend upon optimization requirement in such a way that small PAPR arrangement can be chosen for the purpose of transmission. Simulations of MATLAB depicted remarkable gain obtained as compared with already available method. The DCT matrix had certain structure and can be created at receiver with assistance of SI of phase.

Muller and Huber [105], authors proposed new scheme which worked with any sub-carrier and unconstrained sets of signal. The most important core is to combine PTS to reduce the PAPR. Prasad and Jayabalan [150], modified SLM was proposed to diminish computational complexity in SLM method. Authors applied many phase sequences like riemann, centering, centered riemann and new centered to modified SLM method and effects on PAPR lessening are examined. The modified SLM new centered method is most appropriate for the application of 64-QAM as it provided decent reduction in PAPR at smaller computational complexity.

This chapter is systematized as: in Section 8.1, brief introduction is demonstrated based upon earlier work. Section 8.2 depicts preliminaries, OFDM System and PAPR, analysis of CCDF, pseudo random sequences. Section 8.3 offers Pseudo Random Phase Sequences based Partial Transmit Sequence Algorithm (PRS-PTS-Algo). Section 8.4 depicts simulations results and Section 8.5 depicts conclusion.

8.2 PRELIMINARIES

This particular section shows many mandatory definitions for PRS-PTS-Algo. Brief review of OFDM system, PAPR, CCDF are introduced and also pseudo random sequences are explained.

8.2.1 OFDM SYSTEM AND PAPR

In OFDM system, at beginning, input information is first modulated by PSK and after that symbols of frequency domain are transformed to the parallel from serial $Z = [Z_{0,}Z_1, Z_{2,....}\ Z_{N-1}\ ]^T$. The signal of time domain is made after addition of modulated N input symbols to subcarriers which are orthogonal. The complex baseband signal of OFDM z_t can be represented [64], [144] as

$$z_t = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} Z_k\ e^{j2\pi kt\Delta f}\ , \qquad 0 \leq t \leq NT \tag{8.1}$$

where $j = \sqrt{(-1)},\ \Delta f$ symbolizes subcarriers bandwidth, NT signifies time period of the OFDM in which individual element is of time interval T. For the condition of orthogonality $\Delta f\ = 1/NT$.

The PAPR problem is described [64], [144] as,

$$PAPR = \frac{\max\limits_{0 \le t \le NT} |z_t|^2}{E[|z_t|^2]} \tag{8.2}$$

where the operator of expectation is denoted by $E[.]$. Now, Let us suppose L signifies the value of oversampling factor with the value either equal to one or greater than one. For approximation of z_t along PAPR, oversampled signals with L times are taken into consideration with NL samples. Henceforth, the input oversampling $Z_L = [Z_{0,}Z_1, Z_{2,....} \; Z_{LN-1}]^T$ is converted to $z_L = [z_0, z_1, z_2 \ldots \ldots . z_{LN-1}]^T$ of which z_n is represented [64], [144] by

$$z_n = \frac{1}{\sqrt{LN}} \sum_{k=0}^{NL-1} Z_k \; e^{\frac{j2\pi nk}{LN}}, \qquad 0 \le n \le LN - 1 \tag{8.3}$$

It is finally well acknowledged that OFDM uses inverse discrete fourier transform (IDFT) for creating orthogonality in sub-carriers but for reduction in computation complexity of IDFT, it uses IFFT [64], [144]. Now, assessment of problem PAPR is not completed with nyquist rate sample of OFDM signal with the value of $L = 1$ rather OFDM with value of $L = 4$ is taken into consideration. The oversampled signal of OFDM with L times creates PAPR is shown as

$$PAPR = \frac{\max\limits_{0 \le n \le NL-1} |z_n|^2}{E[|z_n|^2]} \tag{8.4}$$

8.2.2 ANALYSIS OF CCDF

In literature, analysis of PAPR is done with CCDF. It delivers probability of OFDM signal of time domain exceeding certain threshold $PAPR0(dB)$ is represented by [61], [144],

$$CCDF_{G_{n(opt)}}(PAPR0) = Pr(PAPR_{G_{n(opt)}} > PAPR0) \tag{8.5}$$

where $Pr(.)$ represents probability function and $G_{n(opt)}$ is the best sequence which is finally chosen for the transmission.

8.2.3 PSEUDO RANDOM SEQUENCES

These sequence is based upon concatenating matrices [10]. At first, let us represent matrix $A^0 \in \{+1, -1, +j, -j\}$. One of the possible realization of A^0 is given as:

$$A^0 = \begin{bmatrix} +1 & -1 \\ -j & +j \end{bmatrix}$$

Now, in order to create the phase sequence then A^0 becomes main seed for creating pseudo random sequences. This is process is demonstrated as:

$$A^m = \begin{bmatrix} A^{m-1} & A^{m-1} \\ A^{m-1} & A^{m-1^T} \end{bmatrix} \tag{8.6}$$

where, A^{m-1^T} is Hermitian transpose of the matrix $A^{m-1}$and value of m is considered as 1. Now, considering the concatenating of A^0 as controlled by above equation, The construction of A^1 as:

$$A^1 = \begin{bmatrix} A^0 & A^0 \\ A^0 & A^{0^T} \end{bmatrix}$$

The matrix A^1 can be given by

$$A^1 = \begin{bmatrix} +1 & -1 & +1 & -1 \\ -j & +j & -j & +j \\ +1 & -1 & +1 & +j \\ -j & +j & -1 & -j \end{bmatrix}$$

It should be well understood that matrix A^m is $l \times l$ matrix, where l holds value according to matrix and can be denoted by several number of columns such as, $A^m = [b^{m1}, b^{m2}, \dots \dots . b^{ml}]$. Finally, these columns will be used as phase sequences for PTS algorithm.

8.3 PSEUDO RANDOM PHASE SEQUENCES BASED PARTIAL TRANSMIT SEQUENCE ALGORITHM (PRS-PTS-ALGO)

The information Z of length N, passed through digital modulator and is represented by $H = [H_0, H_1, \ldots . H_{N-1}]$ where subcarriers are denoted by N. Now for the better approximation of PAPR oversampling given by L is performed . The oversampled symbols of information is partitioned into numerous sub-blocks denoted as $H^v = [H^{v,0}, H^{v,1}, H^{v,2} \ldots \ldots, H^{v,NL-1}]^T$ with $0 \leq v \leq V-1$ the condition is demonstrated as

$$H = \sum_{v=0}^{V-1} H^v \tag{8.7}$$

Now, by using IFFT to each sub-blocks, OFDM signal in time domain is given by $h^v = [h^{v,0}, h^{v,1}, \ldots \ldots . h^{v,LN-1}]^T$. The pseudo random phase sequences are explained as

$$A^1 = \begin{bmatrix} +1 & -1 & +1 & -1 \\ -j & +j & -j & +j \\ +1 & -1 & +1 & +j \\ -j & +j & -1 & -j \end{bmatrix}$$

Here, several columns of the above defined matrix are given by $A^m = [b^{m1}, b^{m2}, \ldots \ldots . b^{ml}]$ with m=1. Now, $c_u^v = b^{m1}$ for the consideration of first phase sequences with $u = 0$ and after that it will select another column as phase sequences, where $u = 0,1,2, .. U-1$, and U denotes total number of OFDM signals generated. Now, along with uth phase sequences, uth OFDM signal is represented by

$$\begin{aligned} h_u &= [h_u^0, h_u^1, \ldots \ldots, h_u^{LN-1}]^T \\ &= \sum_{v=0}^{V-1} c_u^v \, h^v, \ \ u = 0,1, \ldots U-1 \end{aligned} \tag{8.8}$$

At last, best signal of OFDM $h_{u(opt)}$with lowest PAPR value among U signals of OFDM is selected for the transmission, where $u(opt)$ represents index of optimal OFDM signal, that is,

$$u(opt) = \underset{u=0,1,2\ldots U-1}{arg\,min}\ PAPR(h_u) \tag{8.9}$$

The block diagram for the above explained PRS-PTS-Algo is represented by Figure 8.1.

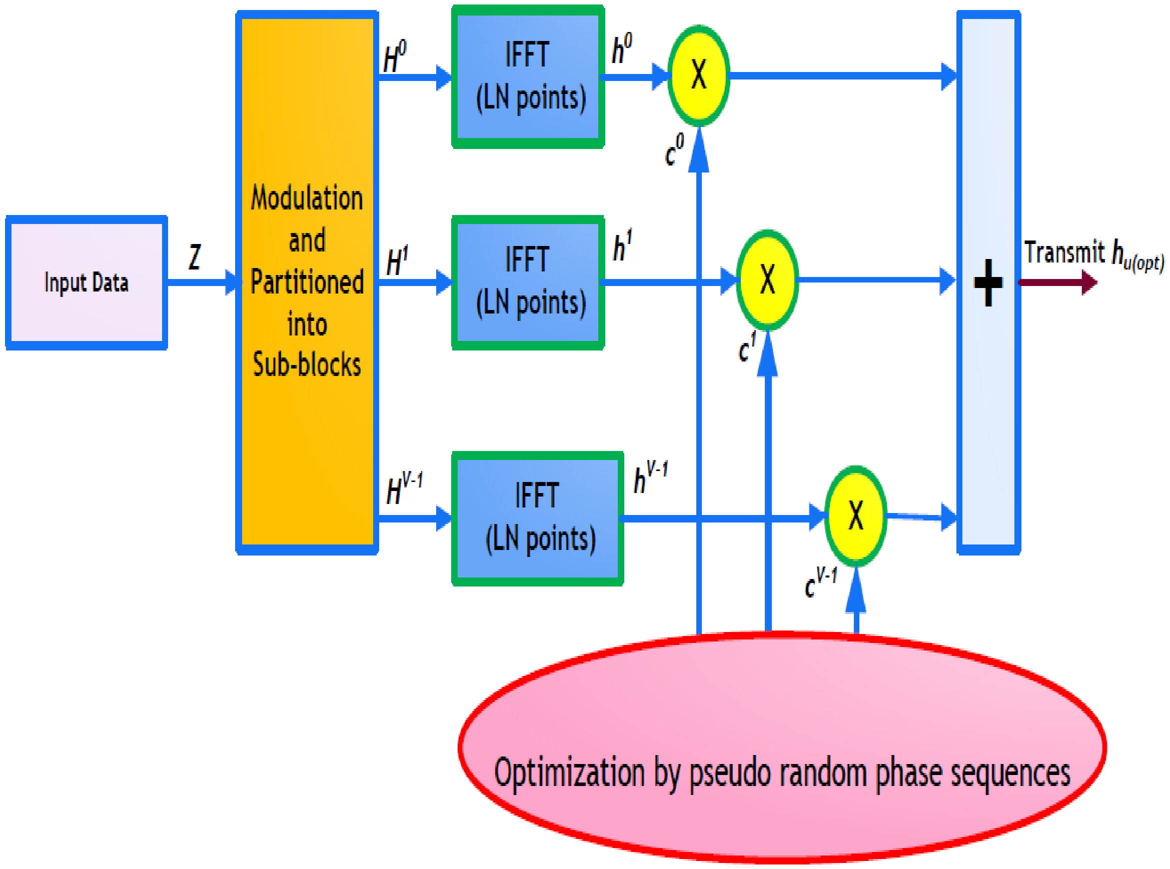

Figure 8.1 Block diagram of PRS-PTS-Algo.

8.4 SIMULATION RESULTS

This section presents performance of Pseudo Random Phase Sequences based PTS Algorithm (PRS-PTS-Algo) and conventional OFDM system (Conv-OFDM) in the term of diverse sub-carriers *(N)* and modulation methods. The important factors which are considered for the investigation of performance such as value of oversampling factor *(L)* =4 from [86], [149], sub-block partition *(V)* =4 from [149], subcarriers *(N)* are 32,64,128,256,512 and 1024, *U*=4, the iteration of 5200 OFDM blocks and also modulation methods are 8-PSK, 16-PSK. Now, From Figure 8.2 to Figure 8.13 show plot of CCDF for numerous N and modulations methods.

Figure 8.2 to Figure 8.7 demonstrates the PAPR analysis of PRS-PTS-Algo and Conv-OFDM for N=32,64,128,256,512 and 1024 with 8-PSK. The performance of PRS-PTS-Algo and Conv-OFDM is presented in Table 8.1. It can be easily perceived from Table 8.1 that performance of PRS-PTS-Algo is noteworthy in comparison with Conv-OFDM.

For Figure 8.2, it can be perceived that PAPR (dB) required to attain CCDF at 0.1% (10^{-3}) for N=32, 8-PSK is 9.69 dB and 8.28 dB for Conv-OFDM and PRS-PTS-Algo respectively. For Figure 8.3, it can be perceived that PAPR (dB) required to attain *CCDF* at 0.1% (10^{-3}) for N=64, 8-PSK is 10.38 dB and 8.67 dB for Conv-OFDM and PRS-PTS-Algo respectively.

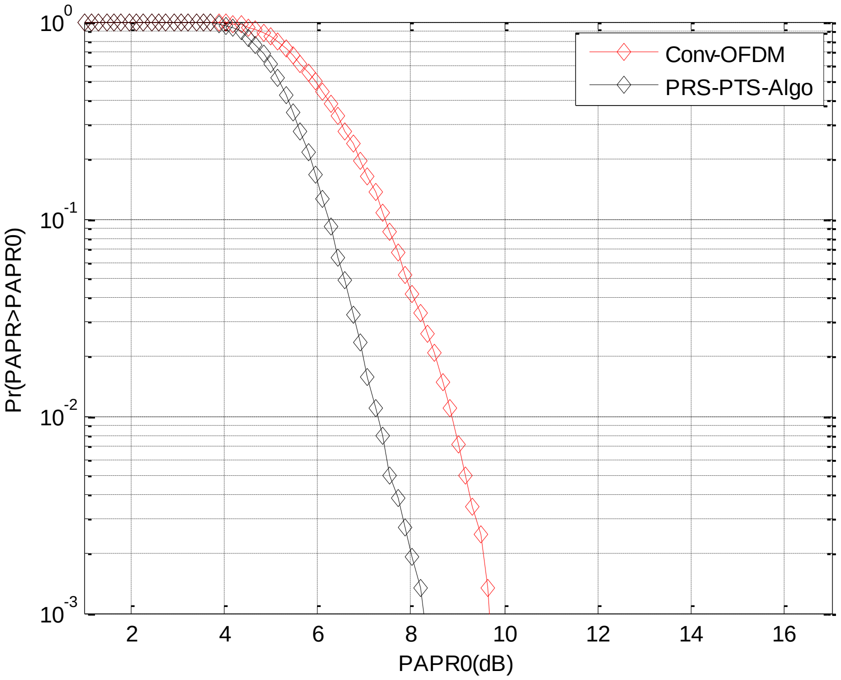

Figure 8.2 Assessment of Conv-OFDM and PRS-PTS-Algo for N=32 and 8-PSK.

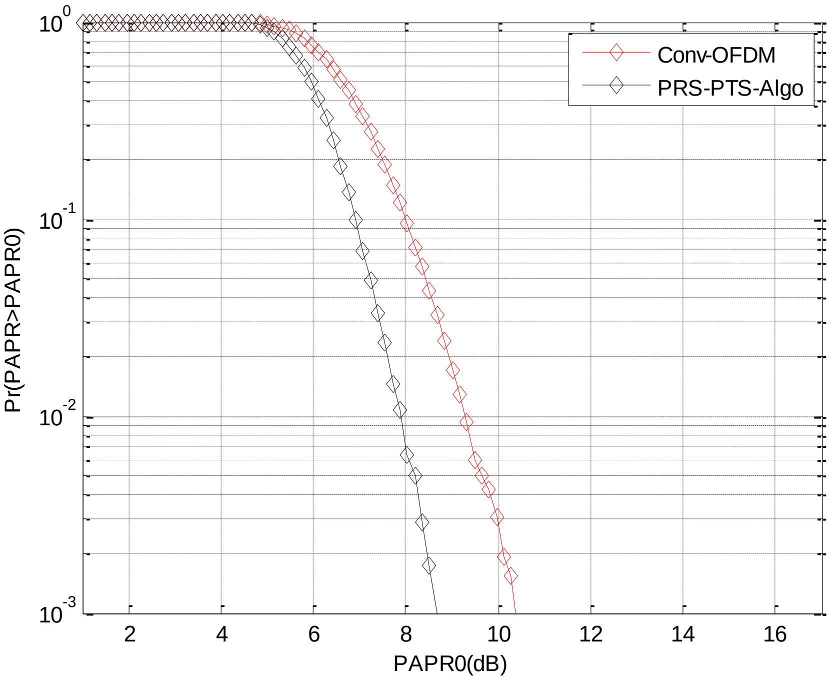

Figure 8.3 Assessment of Conv-OFDM and PRS-PTS-Algo for *N*=64 and 8-PSK.

For Figure 8.4, it can be perceived that PAPR (dB) required to attain *CCDF* at 0.1% (10^{-3}) for *N*=128, 8-PSK is 10.95 dB and 8.87 dB for Conv-OFDM and PRS-PTS-Algo respectively. It can be easily observed that PRS-PTS-Algo outperforms Conv-OFDM along with the maintenance of excellent performance for numerous values of *N* and 8-PSK. Similarly, we can find out PAPR analysis for Conv-OFDM and PRS-PTS-Algo for the higher values of *N* and 8-PSK from Table 8.1.

Table 8.1 CCDF performance assessment and analysis of Conv-OFDM and PRS-PTS-Algo for diverse values of *N*, *CCDF* at (0.1%)10^{-3} and 8-PSK

N	Conv-OFDM (dB)	PRS-PTS-Algo (dB)
32	9.69	8.28
64	10.38	8.67
128	10.95	8.87
256	10.95	9.39
512	11.18	9.58
1024	11.13	9.91

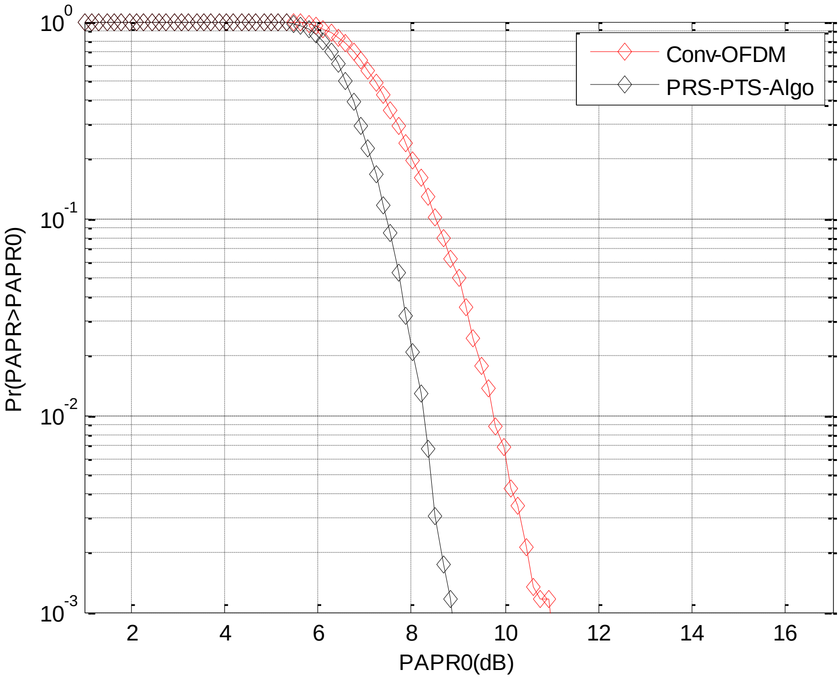

Figure 8.4 Assessment of Conv-OFDM and PRS-PTS-Algo for *N*=128 and 8-PSK.

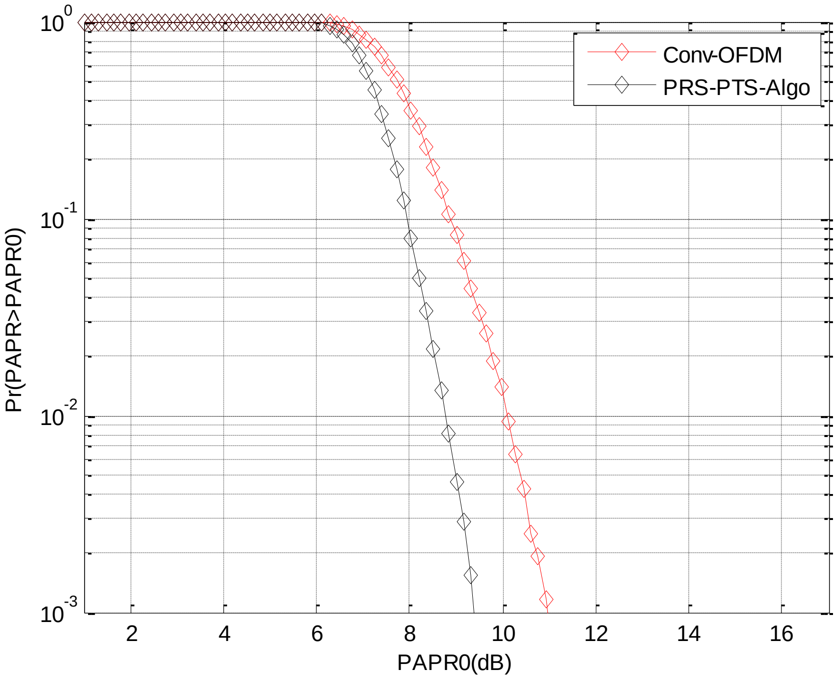

Figure 8.5 Assessment of Conv-OFDM and PRS-PTS-Algo for *N*=256 and 8-PSK.

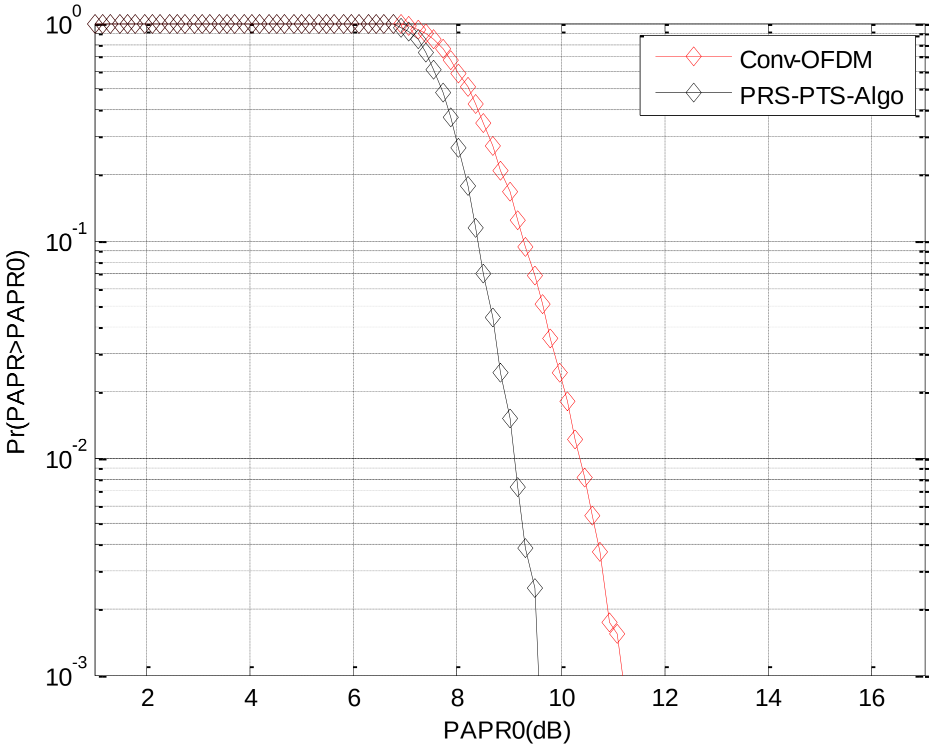

Figure 8.6 Assessment of Conv-OFDM and PRS-PTS-Algo for *N*=512 and 8-PSK.

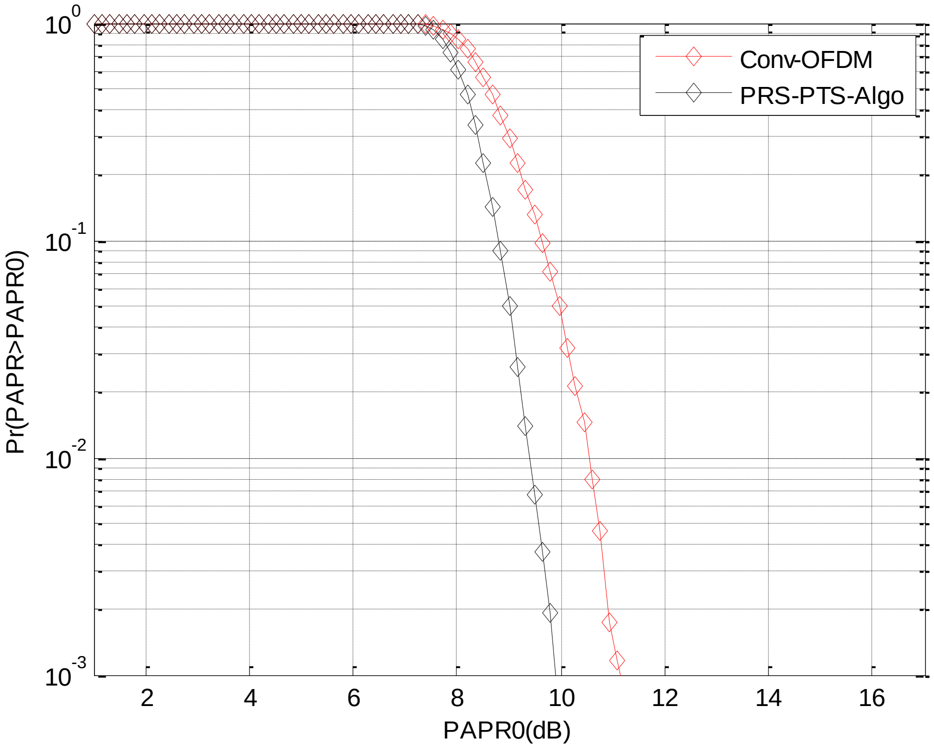

Figure 8.7 Assessment of Conv-OFDM and PRS-PTS-Algo for *N*=1024 and 8-PSK.

Figure 8.8 to Figure 8.13 demonstrates the PAPR analysis of PRS-PTS-Algo and Conv-OFDM for *N*=32,64,128,256,512 and 1024 with 16-PSK. The performance of PRS-PTS-Algo and Conv-OFDM is presented in Table 8.2. It can be easily perceived from Table 8.2 that performance of PRS-PTS-Algo is noteworthy in comparison with Conv-OFDM.

For Figure 8.8, it can be perceived that PAPR (dB) required to attain CCDF at 0.1% (10^{-3}) for *N*=32, 16-PSK is 10.14 dB and 8.23 dB for Conv-OFDM and PRS-PTS-Algo respectively. For Figure 8.9, it can be perceived that PAPR (dB) required to attain *CCDF* at 0.1% (10^{-3}) for *N*=64, 16-PSK is 10.42 dB and 8.71 dB for Conv-OFDM and PRS-PTS-Algo respectively.

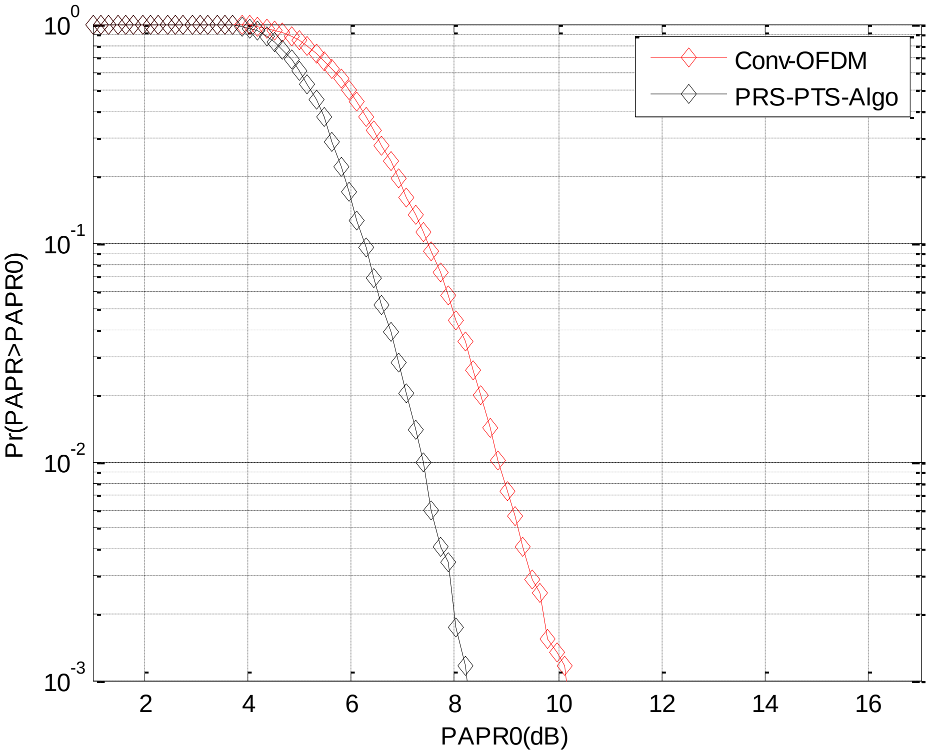

Figure 8.8 Assessment of Conv-OFDM and PRS-PTS-Algo for *N*=32 and 16-PSK.

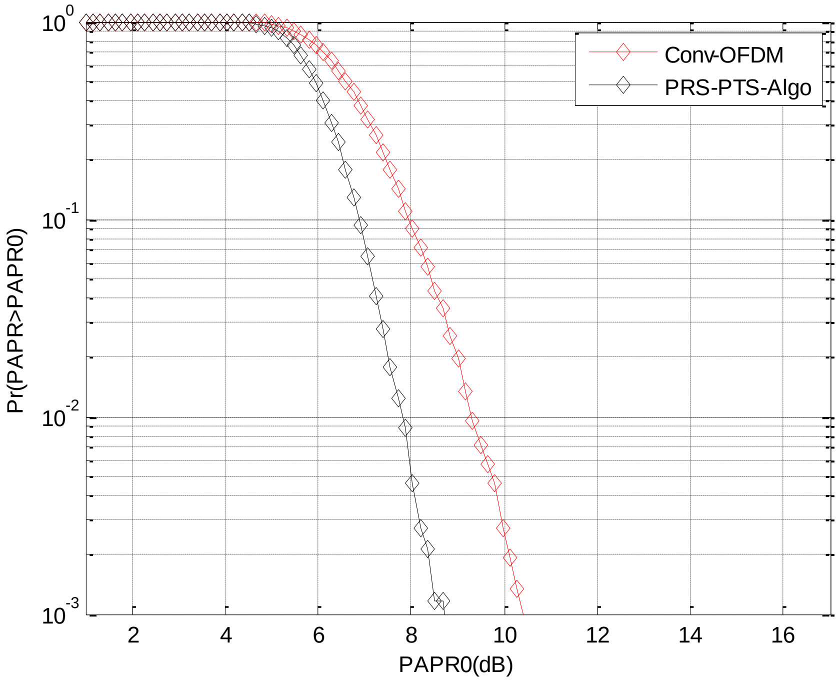

Figure 8.9 Assessment of Conv-OFDM and PRS-PTS-Algo for *N*=64 and 16-PSK.

For Figure 8.10, it can be perceived that PAPR (dB) required to attain CCDF at 0.1% (10^{-3}) for *N*=128, 16-PSK is 10.43 dB and 9.06 dB for Conv-OFDM and PRS-PTS-Algo respectively. It can be easily observed that PRS-PTS-Algo outperforms Conv-OFDM along with the maintenance of excellent performance for numerous values of *N* and 16-PSK. Similarly, we can find out PAPR analysis for Conv-OFDM and PRS-PTS-Algo for the higher values of *N* and 16-PSK from Table 8.2.The enhancement in performance originates from condition that PTS algorithm does not introduce distortion in the data [27], [143] and its uses pseudo random phase sequences [10].

Table 8.2 CCDF performance assessment and analysis of Conv-OFDM and PRS-PTS-Algo for diverse values of *N*, *CCDF* at (0.1%)10^{-3} and 16-PSK

N	Conv-OFDM (dB)	PRS-PTS-Algo (dB)
32	10.14	8.23
64	10.42	8.71
128	10.43	9.06
256	10.88	9.31
512	10.97	9.63
1024	11.36	9.94

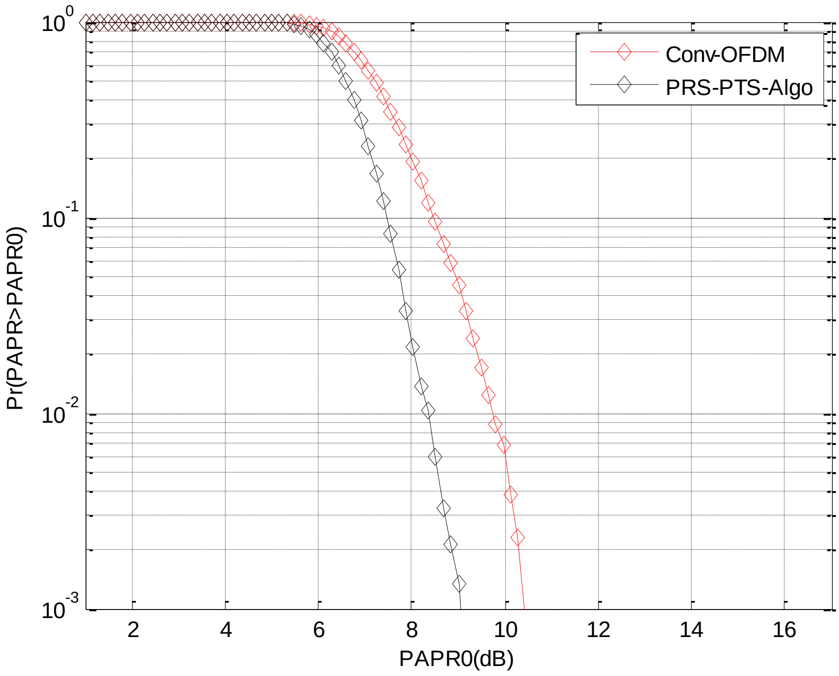

Figure 8.10 Assessment of Conv-OFDM and PRS-PTS-Algo for *N*=128 and 16-PSK.

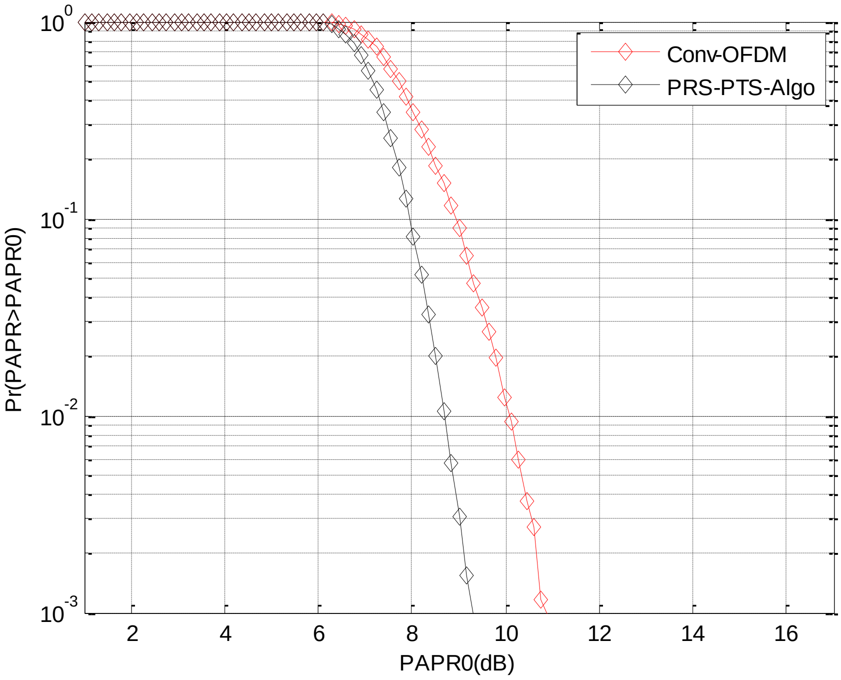

Figure 8.11 Assessment of Conv-OFDM and PRS-PTS-Algo for *N*=256 and 16-PSK.

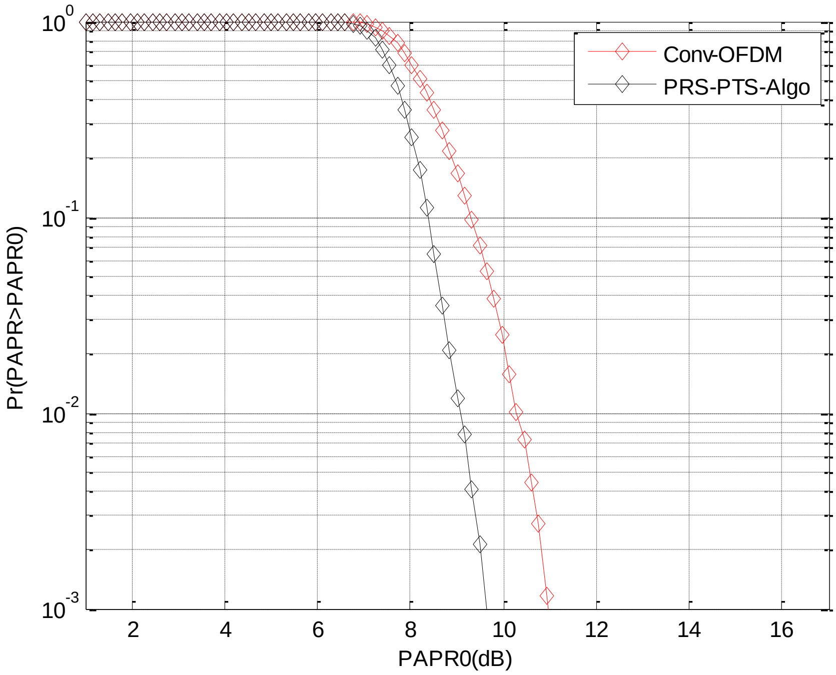

Figure 8.12 Assessment of Conv-OFDM and PRS-PTS-Algo for *N*=512 and 16-PSK.

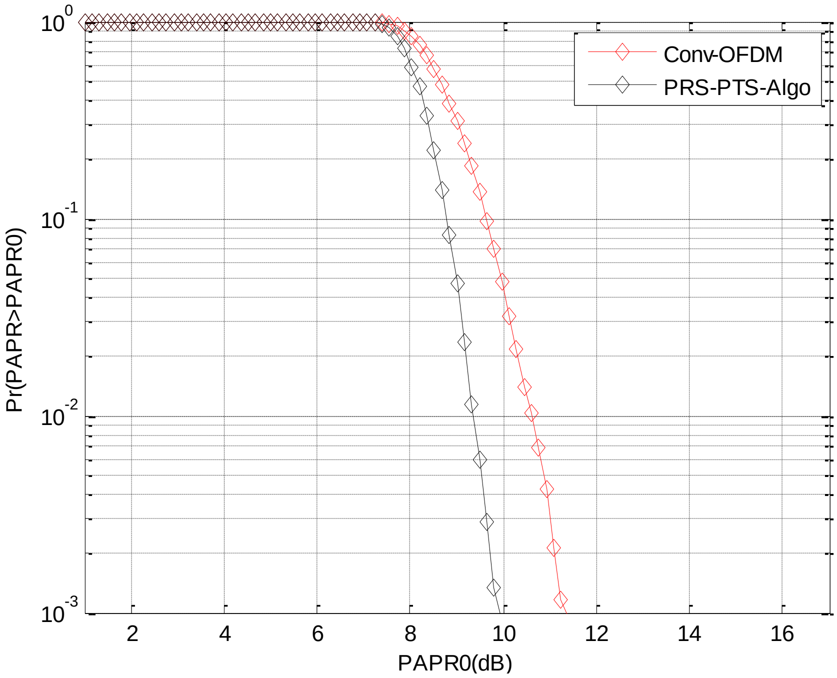

Figure 8.13 Assessment of Conv-OFDM and PRS-PTS-Algo for *N*=1024 and 16 PSK.

8.5 CONCLUSION

In this paper, PRS-PTS-Algo is presented, examined and it shows very good reduction in PAPR problem. Furthermore, two diverse modulation methods such as 8-PSK and 16-PSK are used along with numerous subcarriers. Generally, the phase sequences generation is very difficult but it becomes very systematic and easy with help of pseudo random phase sequences and in addition, also very small side information in the form of index value of the column will be transmitted to receiver for the recovery of sequences. The above analysis and simulation results show that PRS-PTS Algo achieves decent reduction in the issue of PAPR and it also outperforms Conv-OFDM system. Henceforth, making it suitable for several applications.

CHAPTER 9 AN EFFICIENT AND IMPROVED PTS ALGORITHM FOR PAPR REDUCTION IN OFDM SYSTEM

9.1 INTRODUCTION

OFDM [151] has been adopted in many wireless communication systems like Wireless Local Area Networks (WLAN) and Long Term Evolution (LTE) [150] because of its high spectral efficiency and sturdiness to the multipath fading channels. More recently, discrete fourier transform spread OFDM as one of the most popular uplink modulation method. Now, 3GPP has decided to utilize OFDM with cyclic prefix in 5G New-Radio (5G NR). But, OFDM system has disadvantage of high PAPR which ultimately needs a non-linear High Power Amplifier (HPA) in order to work in very ineffective region [151]. Although, back off of the power can be utilized to diminish nonlinear distortions but it will lead to the reduction in the efficiency of power. It is because of the fact that power amplifier (PA) is generally estimated to operate close to saturation region. Henceforth, as substitute technology that can be utilized to enhance the efficiency of PA, PAPR reduction has turn out to be an eye-catching research [11]. Recently, in order to diminish the issue of high PAPR, numerous methods have been suggested in the literatures containing coding methods, multiple signaling and probabilistic method and also signal distortion methods [3] and [115].

Coding method obtained PAPR reduction by selecting codewords, but it results in the loss of coding rate [152]. Multiple signaling and probabilistic methods like SLM and PTS, are realized by creating several signals and choosing the one with smallest PAPR [60] and [153]. Signal distortions methods diminish the PAPR by adjusting the signal which generally caused in-band and out of band distortions. However, they are easy to realize and do not need side information. Clipping is well known signal distortion technique for the reduction of PAPR [11]. Among all the already available methods, PTS algorithm is competitive because of its simplicity and effectiveness. The organization of this research work is: Sec. 9.1, a brief introduction to OFDM system and possibility that the different algorithms could be used to improve performance of OFDM system. Section 9.2 provides understanding to preceding work carried out on

PAPR reduction. Section 9.3 incorporates description of preliminaries. Section 9.4 represents newly proposed algorithm in details whereas Sec. 9.5 demonstrates simulation results and discussions followed by conclusion presented in Sec. 9.6.

9.2 RELATED WORKS

In [151], authors projected a new well-organized continuous and piecewise non-linear companding method for reduction in PAPR. In this projected companding transform, Large amplitude signal samples were clipped for lessening in peak power, medium amplitude signal samples were transformed non-linearly with power compensation along with small amplitude signal samples remain unchanged. Under such type of the arrangement, this method could obtain important reduction in PAPR and it caused very small enhancement in Bit Error Rate (BER) and Power Spectral Density (PSD). In [150], authors applied diverse phase sequences like centered Riemann, Riemann, Centering and new centered to the revised SLM method and thus effects were analyzed. The revised SLM with new centered method was appropriate for the 64-QAM applications since it provided decent reduction in PAPR at small computation complexity.

In [154], authors proposed a new nonlinear companding transform (NCT) for the reduction in PAPR. The companding function based upon continuous differentiable reshape of the Probability Density Function (PDF) of amplitude of signals was considered. The innovative PDF was cut off for the lessening in PAPR and along with this, lower segments were generally scaled whereas medium segments were linearized for preserving power and constraint of cumulative distribution. Finally, authors also proposed a novel receiving technique in order to enhance BER.

In [155], authors projected triangular-distribution (TR) based on companding which reduced PAPR very effectively compared with existing methods. The proposed method presented for several modulation methods. Simulation results demonstrated that projected companding method outperformed the existing method in term of PAPR reduction for every modulation method. In [156], authors proposed the Harmonious Kernel adaptive filters with slepian based flat top window. This projected technique elucidated OFDM issue like PAPR. In [157], authors demonstrated a new PAPR minimization method which was based upon combined clipping and tangent-rooting companding. The projected method offered decent reduction of PAPR with small complexity compared with other methods.

In [158], authors proposed a companding function for PAPR lessening. This function actually altered signals into the PDF along with cumulative distribution function which was anti-trigonometric function. After wisely selection of factors of transform, the BER enhanced considerably during the diminishing of PAPR. In [159], authors demonstrated vandermonde matrix as the new phase sequences for Selected Mapping (SLM) with interleaver. In fact, authors explained that no side information was required. Moreover, substantial reduction in PAPR was also obtained. In [160], authors proposed a very easy side information (SI) deletion method using pilot which was related with the channel estimation. In [161], authors proposed a new PTS method for the search of phase rotation factors.

In [13], authors proposed a generalized piecewise linear companding (PLC) method to diminish the distortions in the decompanded signals along with easing of constraint on maintenance of average power of the signal. At last, authors formulated the optimizations problem in order to find parameters of function of compading. In [14], authors projected the hybrid PAPR method that employed the two stages structures. The very first stage was the post IFFT stage which could form higher order QAM from BPSK or QPSK with very less numbers of IFFT whereas second stage was dependent upon class-III SLM algorithm which contained the bank of parallel blocks.

In [162], authors compared several PAPR reduction companding transforms. Simulation results depicted that companding transform which compressed very large signals without disturbing small signals were far superior than others. Authors also shown that Log companding transform can be used as the excellent transform. In [11], authors proposed a hybrid method with iterative clipping and filtering (ICF) method and improved non-linear companding (ENC). In [163], authors proposed two different novel methods using Reed Solomon (RS) codes under GF (65537) and GF (257) in coded OFDM. In [164], authors introduced a novel SLM algorithm using interleavers for the reduction of PAPR. This projected method considered as modified SLM method.

Simulation results showed that projected algorithm obtained better PAPR performance than traditional SLM for the provided IFFT with no extra side information. In [165], authors discussed a swarm intelligence algorithm for the optimization of phases based upon firefly algorithm (FF). Simulation results depicted that FF based PTS (FF-PTS) algorithm was efficient because of best PAPR characteristics when equated to the traditional algorithms.

In [166], authors derived a new, low complexity PAPR reduction and demodulation method. In addition to this, authors also established a novel time domain technique for sending side information. In [167], authors proposed an adaptive threshold value for evaluation of characteristic of input signals. This research paper selected optimal generation of phase mechanism to generate phase sequences. Through this projected technique, generation of phases were recognized in according to reed-muller codes, henceforth obtaining systematic structures which normal creation method lacked. In [86], authors projected an algorithm which was based upon SLM and DCT matrix.

In [144], authors projected SLM method with pseudo-random phase sequences and also μ-law companding. In [87], authors proposed PTS with bose chaudhuri hocquenghem code (BCH). In [168], authors demonstrated a system which was an arrangement of two different techniques such as SLM and Clipping. Simulation results specified that offered method acquired appropriate reduction of PAPR with small complexity. The PAPR reduction was also analyzed for several subcarriers and compared with existing methods.

In [169], authors demonstrated comparative study of conventional and current PAPR reduction techniques in wavelet based OFDM to create excellent system. The optimization of PAPR was obtained through integration of clipping, companding and wavelet. Authors also analyzed several modulation methods for the projected hybrid system. In [170], authors proposed tail biting convolution coding (TBCC) method using bit by bit (BYB) and look up table (LUT) approaches on free scale starcore sc140 based platform of DSP and projected an excellent algorithm by comparing memory requirements and machine cycles. Authors also analyzed TBCC for PAPR in order to get overall results.

9.2.1 IMPORTANT DISCUSSIONS, KEY CONTRIBUTIONS AND INNOVATION CHARACTERISTICS

Based on the comprehensive study of the prevailing approaches that were described in the literature review, the following points explain innovation characteristics along with the significant objectives which are vital to be addressed for the proposed work:

- PTS algorithm can be used significantly because of its distortion-less behavior. Moreover, it also enhances the PAPR performance which is the most important goal of OFDM system.
- Most of the existing algorithms have not utilized PTS algorithm with centering phase sequence matrix (PTS-CPSM-Algo). The proposed algorithm will select the best phase sequences so that minimum PAPR can be obtained. This depicts that proposed algorithm is very easy to implement and possesses high potential.
- Furthermore, the excellent performance investigations of PTS-CPSM-Algo has never been done in comparison with original OFDM, SLM, original PTS under different phase sequences, subcarriers, oversampling factors and modulation methods.

9.3 PRELIMINARIES

9.3.1 CENTERING PHASE SEQUENCE

Centering matrix [150] is the idempotent and symmetric which multiplied with the vectors then it create effects which are same as deducting the mean components of matrix. The most important advantage of centering matrix is that it eliminates mean of the signal vector and multiple vectors kept in columns and rows of matrix. Henceforth, this centering matrix is known as centering phase sequence matrix (CPSM). The rows of this CPSM is considered as the phase sequences. The CPSM is given by $n \times n$ matrix. Now, CPSM (C) of order 8 can be given by

$$C = \begin{bmatrix} +0.8750 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 \\ -0.1250 & +0.8750 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 \\ -0.1250 & -0.1250 & +0.8750 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 \\ -0.1250 & -0.1250 & -0.1250 & +0.8750 & -0.1250 & -0.1250 & -0.1250 & -0.1250 \\ -0.1250 & -0.1250 & -0.1250 & -0.1250 & +0.8750 & -0.1250 & -0.1250 & -0.1250 \\ -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & +0.8750 & -0.1250 & -0.1250 \\ -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & +0.8750 & -0.1250 \\ -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & -0.1250 & +0.8750 \end{bmatrix} \tag{9.1}$$

The ratio of maximum power to the average power is called as PAPR [87]. Now, the OFDM with L times oversampled create PAPR for signal s_n with sub-carriers *(N)* which can be given by [144],

$$PAPR = \frac{\underset{0 \le n \le NL-1}{max} |s_n|^2}{E[|s_n|^2]} \tag{9.2}$$

where *E[.]* signifies operator of expectation.

The performance [150] of PAPR lessening algorithm is evaluated by the most important informative metric which is known as complementary cumulative distribution function (CCDF).

The PAPR diminishing ability is calculated by the amount of CCDF lessening is accomplished. It denotes probability that PAPR tops threshold PAPRn [86].

9.4 PARTIAL TRANSMIT SEQUENCE WITH CENTERING PHASE SEQUENCE MATRIX ALGORITHM (PTS-CPSM-ALGO)

The information R with length N when passed through modulation then it is depicted by $S = [S_0, S_1, \dots . S_{N-1}]$ with N as sub-carriers. Now, oversampling is executed for estimation of PAPR denoted by L.

These oversampled symbols is distributed into numerous sub-blocks as represented by $S^v = [S^{v,0}, S^{v,1}, S^{v,2} \dots \dots, S^{v,NL-1}]^T$ where $0 \le v \le V-1$ is represented by

$$S = \sum_{v=0}^{V-1} S^v \tag{9.3}$$

Now, after using the IFFT to every sub-blocks, the time domain OFDM signal is represented by $s^v = [s^{v,0}, s^{v,1}, \dots \dots . s^{v,LN-1}]^T$.

The CPSM (C) (9.1) can also be given by

$$C = \begin{bmatrix} b^{11}, b^{12}, \ldots\ldots\ldots . b^{18} \\ b^{21}, b^{22}, \ldots\ldots\ldots . b^{28} \\ b^{31}, b^{32}, \ldots\ldots\ldots . b^{38} \\ . \\ . \\ . \\ b^{81}, b^{82}, \ldots\ldots\ldots . b^{88} \end{bmatrix} \tag{9.4}$$

Now, $c_u^v = [b^{11}, b^{12}, b^{13} \ldots\ldots b^{18}]$ with $u = 0$, for the first phase sequences and just after that it will choose another row as a phase sequences, where $u = 0,1,2,..U - 1$, and U represents total signals of OFDM created.

Now with uth phase sequences, uth OFDM signal is denoted by

$$\begin{aligned} s_u &= [s_u^0, s_u^1, \ldots\ldots, s_u^{LN-1}]^T \\ &= \sum_{v=0}^{V-1} c_u^v s^v, \ \ u = 0,1, \ldots U - 1 \end{aligned} \tag{9.5}$$

Finally, the excellent OFDM signal $s_{u(opz)}$ with smallest value of PAPR among U signals OFDM is chosen for the purpose of transmission, where $u(opz)$ denotes index of the optimal signal of OFDM which is represented by

$$u(opz) = \underset{u=0,1,2\ldots U-1}{arg\ min}\ PAPR(s_u) \tag{9.6}$$

The PTS-CPSM-Algo is represented by the block diagram given by Figure 9.1.

9.5 SIMULATION RESULTS AND DISCUSSIONS

In this section several parameters have been taken into consideration like N=32,64,128 and 256, information mapped with the assistance of modulations such as 8-PSK, 16-PSK and 32-PSK [144]. Furthermore, symbols undergone the oversampling with value of L=4 [144] & 8 for approximation of continuous from the discrete domain. The 5.4×10^3 OFDM symbols, V=8, U=2&8 have been considered. The size of IFFT/FFT is 256 for N=64 with L=4 and similarly for numerous other sub-carriers. Due to the increasing request for wireless communication and improvement of signal processing methods the broad band communications are utilizing OFDM with several sub-carriers and modulation methods [11]. In the simulation results, ORIGINAL-OFDM= Original OFDM system, SLM-2= SLM Algorithm with 2 rows as phase sequences, ORPTS-2= PTS with U=2, SLM-8= SLM Algorithm with 8 rows as phase sequences, PROPOSED-PTS-ALGO-PH-2= PTS-CPSM-Algo with U=2, ORPTS-8= PTS with U=8 and PROPOSED-PTS-ALGO-PH-8=PTS-CPSM-Algo with U=8.

The ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 have been simulated and overall performance is evaluated for PAPR using CCDF.

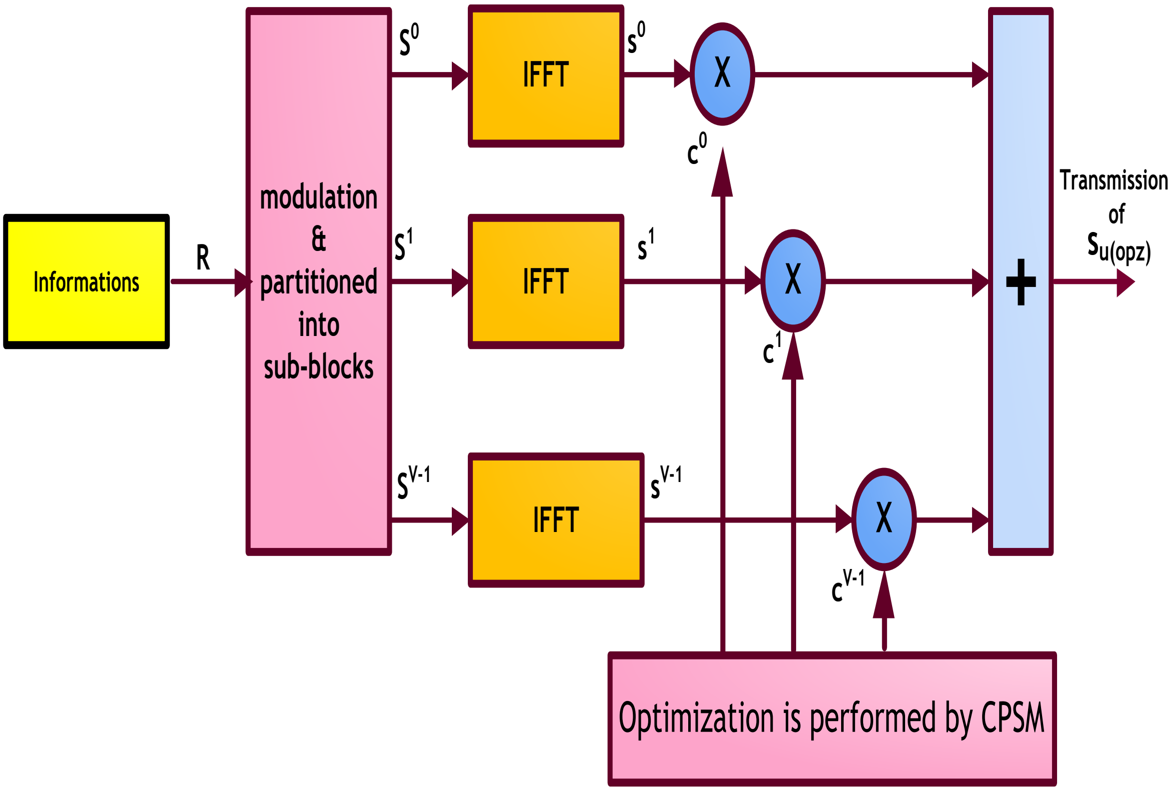

Figure 9.1 Block diagram of PTS-CPSM-Algo.

It is obvious from Figure 9.2 to Figure 9.25 that PROPOSED-PTS-ALGO-PH-8 yields better performance as compared with ORIGINAL-OFDM and many existing techniques for numerous sub-carriers and modulation methods because it utilizes excellent phase sequences from CPSM [150] and also PTS algorithm is suitable due to the distortionless characteristics [64].

It is evident from Figure 9.2 that in order to obtain the CCDF at $(0.1\%)10^{-3}$, the PAPR (dB) can be perceived for *N*=64, 32-PSK, *L*=4 is 10.42 dB for ORIGINAL-OFDM, but it is 7.93 (dB) for PROPOSED-PTS-ALGO-PH-2 and also it reduces further to 6.22 (dB) for PROPOSED-PTS-ALGO-PH-8. It is perceived that the PAPR performance enhances as the number of rows of phase sequences increase with U=2 and 8. For this reason, PROPOSED-PTS-ALGO-PH-8 is much better than PROPOSED-PTS-ALGO-PH-2. For, Figure 9.3, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$ for PAPR (dB) can be perceived for *N*=128, 32-PSK, *L*=4 is 10.91 (dB) for ORIGINAL-OFDM, but it is 8.68 (dB) for PROPOSED-PTS-ALGO-PH-2 and also it falls to 6.79 (dB) for PROPOSED-PTS-ALGO-PH-8.

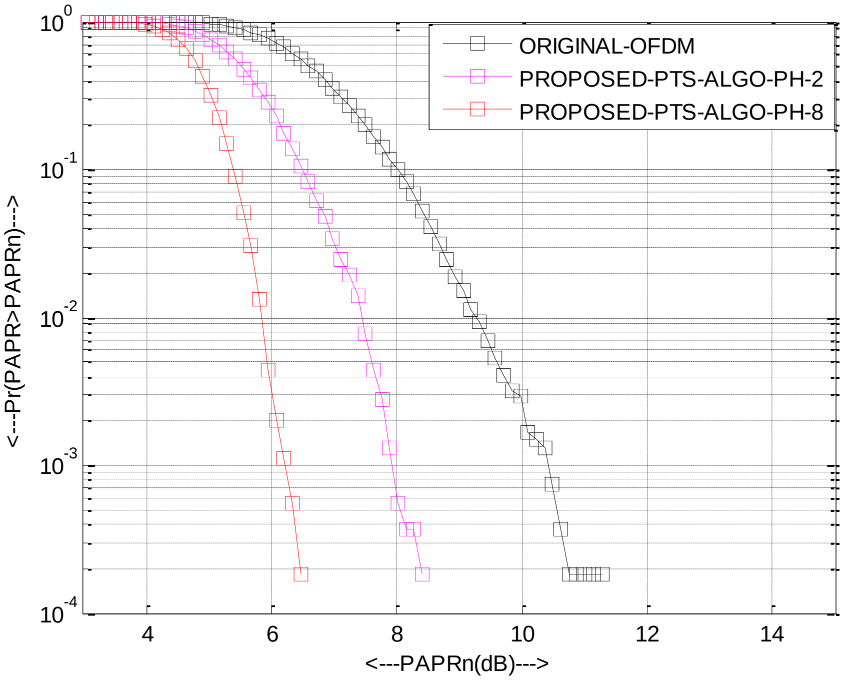

Figure 9.2 Performance comparison ORIGINAL-OFDM, PROPOSED-PTS-ALGO-PH-2 and PROPOSED-PTS-ALGO-PH-8 for N=64,32-PSK and L=4.

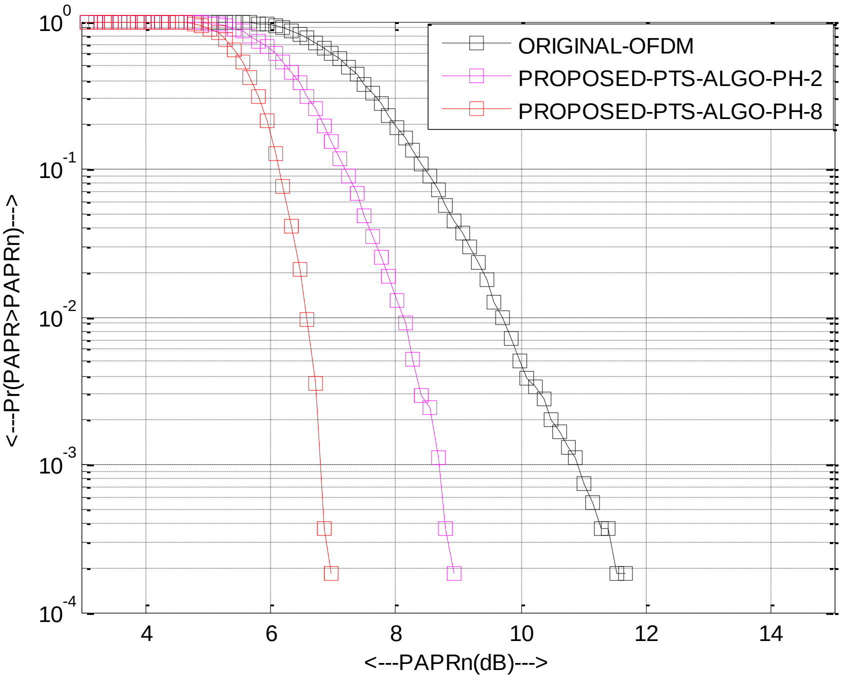

Figure 9.3 Performance comparison ORIGINAL-OFDM, PROPOSED-PTS ALGOPH-2 and PROPOSED-PTS-ALGO-PH-8 for N=128,32-PSK and L=4.

For, Figure 9.4, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$for PAPR (dB) can be perceived for *N*=256, 32-PSK, *L*=4 is 10.78 (dB) for ORIGINAL-OFDM, but it is 9.13 (dB) for PROPOSED-PTS-ALGO-PH-2 and also it falls to 7.46 (dB) for PROPOSED-PTS-ALGO-PH-8. Similar, observations can be obtained for Figure 9.5.

It is evident from Figure 9.6 that in order to obtain the CCDF at $(0.1\%)10^{-3}$, the PAPR (dB) can be perceived for *N*=64, 32-PSK, *L*=8 is 10.16 dB for ORIGINAL-OFDM, but it is 8.05 (dB) for PROPOSED-PTS-ALGO-PH-2 and also it reduces further to 6.25 (dB) for PROPOSED-PTS-ALGO-PH-8. For, Figure 9.7, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$for PAPR (dB) can be perceived for *N*=128, 32-PSK, *L*=8 is 10.60 (dB) for ORIGINAL-OFDM, but it is 8.74 (dB) for PROPOSED-PTS-ALGO-PH-2 and also it falls to 6.93 (dB) for PROPOSED-PTS-ALGO-PH-8.

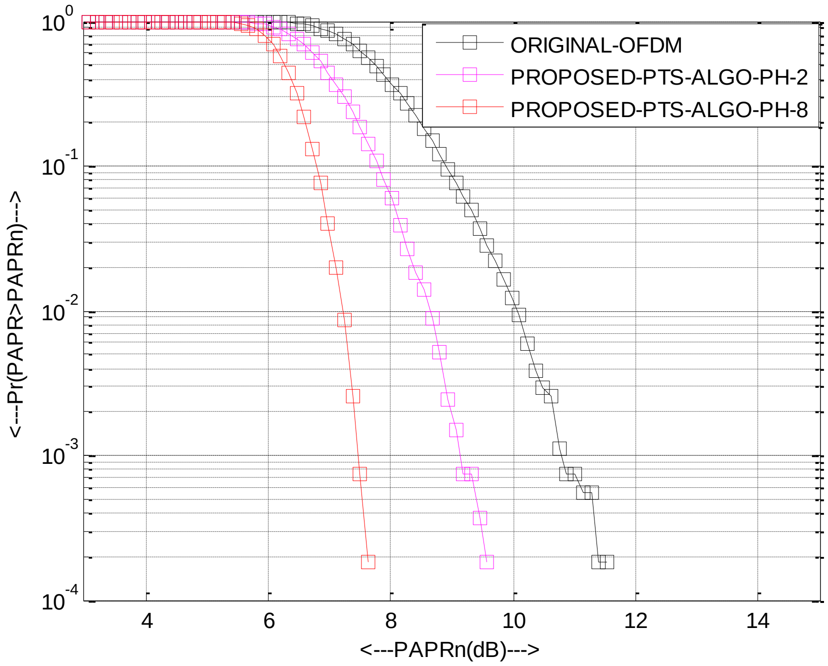

Figure 9.4 Performance comparison ORIGINAL-OFDM, PROPOSED-PTS-ALGO-PH-2 and PROPOSED-PTS-ALGO-PH-8 for N=256,32-PSK and L=4.

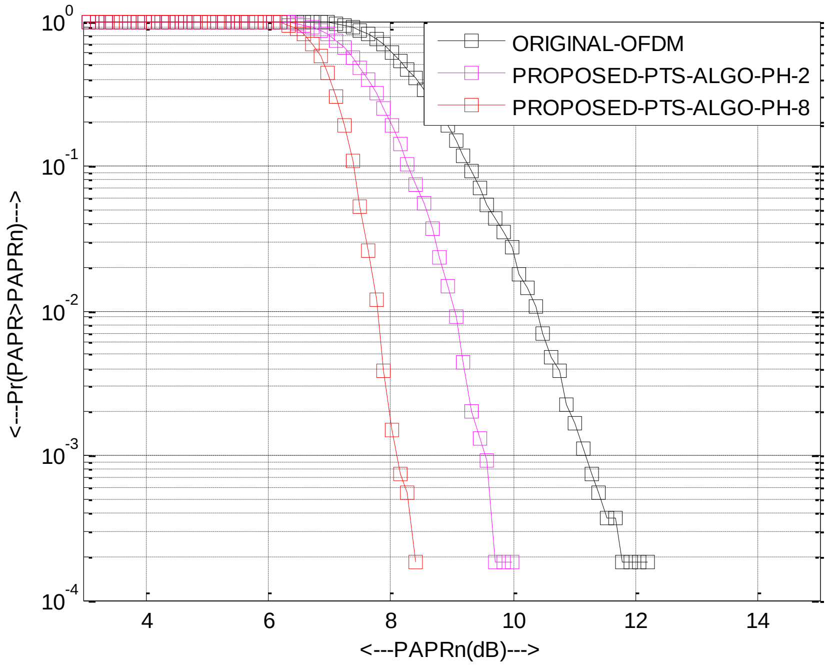

Figure 9.5 Performance comparison ORIGINAL-OFDM, PROPOSED-PTS-ALGO-PH-2 and PROPOSED-PTS-ALGO-PH-8 for N=512,32-PSK and L=4.

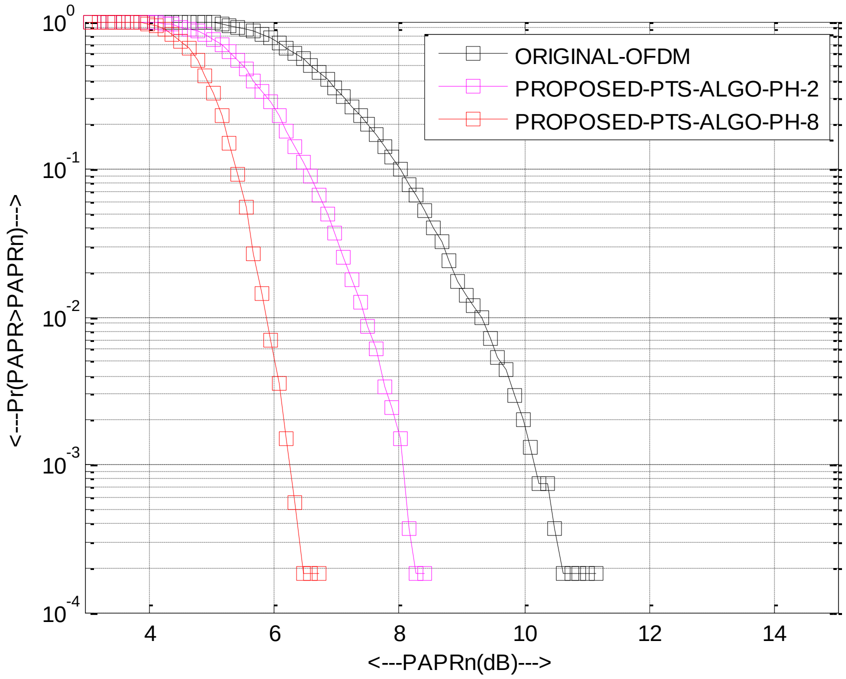

Figure 9.6 Performance comparison ORIGINAL-OFDM, PROPOSED-PTS-ALGO-PH-2 and PROPOSED-PTS-ALGO-PH-8 for N=64,32-PSK and L=8.

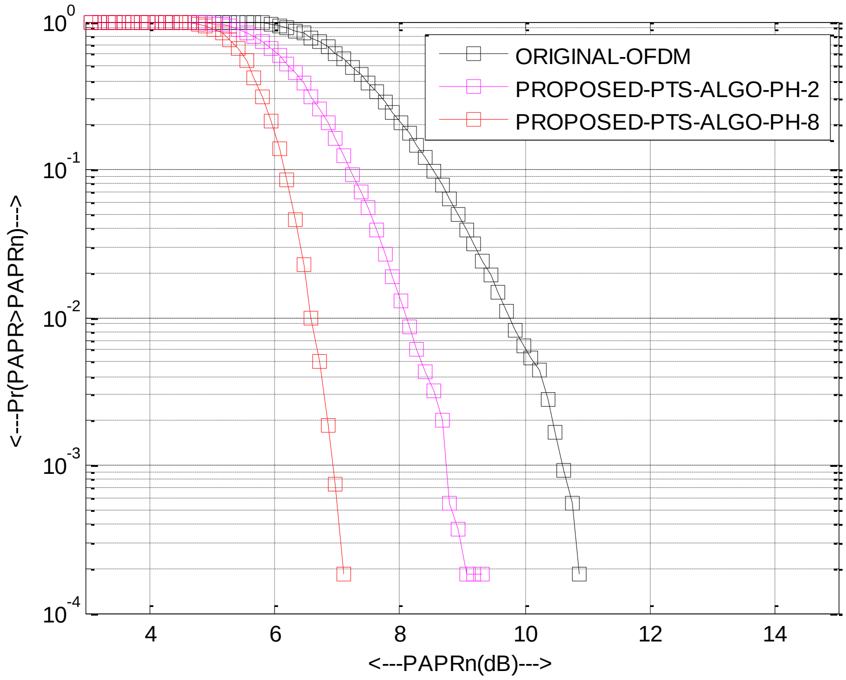

Figure 9.7 Performance comparison ORIGINAL-OFDM, PROPOSED-PTS-ALGO-PH-2 and PROPOSED-PTS-ALGO-PH-8 for N=128,32-PSK and L=8.

For, Figure 9.8, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$for PAPR (dB) can be perceived for *N*=256, 32-PSK, *L*=8 is 10.72 (dB) for ORIGINAL-OFDM, but it is 9.17 (dB) for PROPOSED-PTS-ALGO-PH-2 and also it falls to 7.54 (dB) for PROPOSED-PTS-ALGO-PH-8. Similar, observations can be obtained for Figure 9.9.

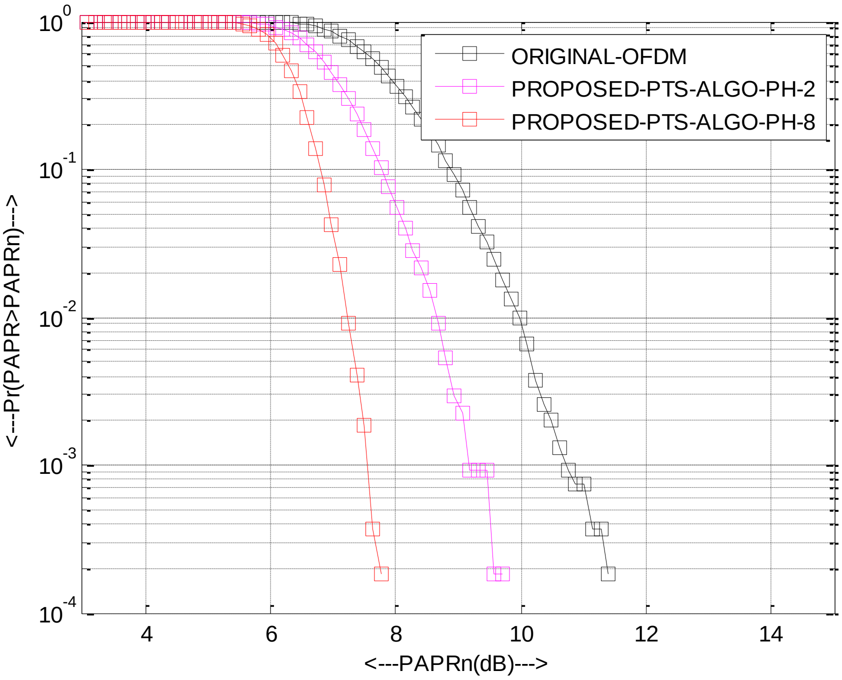

Figure 9.8 Performance comparison ORIGINAL-OFDM, PROPOSED-PTS-ALGO-PH-2 and PROPOSED-PTS-ALGO-PH-8 for N=256,32-PSK and L=8.

CCDF performance evaluation of ORIGINAL-OFDM, PROPOSED-PTS-ALGO-PH-2 and PROPOSED-PTS-ALGO-PH-8 for numerous sub-carries under 32-PSK with CCDF at $(0.1\%)10^{-3}$ is tabulated in Table 9.1 which clearly shows that PROPOSED-PTS-ALGO-PH-8 outperforms PROPOSED-PTS-ALGO-PH-2 and ORIGINAL-OFDM in all the cases.

It is evident from Figure 9.10 that in order to obtain the CCDF at $(0.1\%)10^{-3}$, the PAPR (dB) can be perceived for N=64, 16-PSK, L=4 is 10.39 dB for ORIGINAL-OFDM, 10.00 dB for SLM-2, 9.26 dB for ORPTS-2, 9.09 dB for SLM-8, 8.26 dB for PROPOSED-PTS-ALGO-PH-2, 7.57 dB for ORTPTS-8 and also it reduces further to 6.13 dB for PROPOSED-PTS-ALGO-PH-8.It is perceived that the PAPR performance enhances as the number of rows of phase sequences increase with U=2 and 8. For this reason, PROPOSED-PTS-ALGO-PH-8 is much better than PROPOSED-PTS-ALGO-PH-2. The very similar kind of observations can be obtained for ORPTS-8 and ORPTS-2 and also for SLM-8 and SLM-2.

Table 9.1 CCDF performance evaluation of ORIGINAL-OFDM, PROPOSED-PTS-ALGO-PH-2 and PROPOSED-PTS-ALGO-PH-8 for numerous sub-carries under 32-PSK with CCDF at (0.1%)10^{-3}

N	*L*	ORIGINAL-OFDM(dB)	PROPOSED-PTS-ALGO-PH-2(dB)	PROPOSED-PTS-ALGO-PH-8(dB)
64	4	10.42	7.93	6.22
128	4	10.91	8.68	6.79
256	4	10.78	9.13	7.46
512	4	11.17	9.55	8.09
64	8	10.16	8.05	6.25
128	8	10.60	8.74	6.93
256	8	10.72	9.17	7.54
512	8	11.11	9.69	7.99

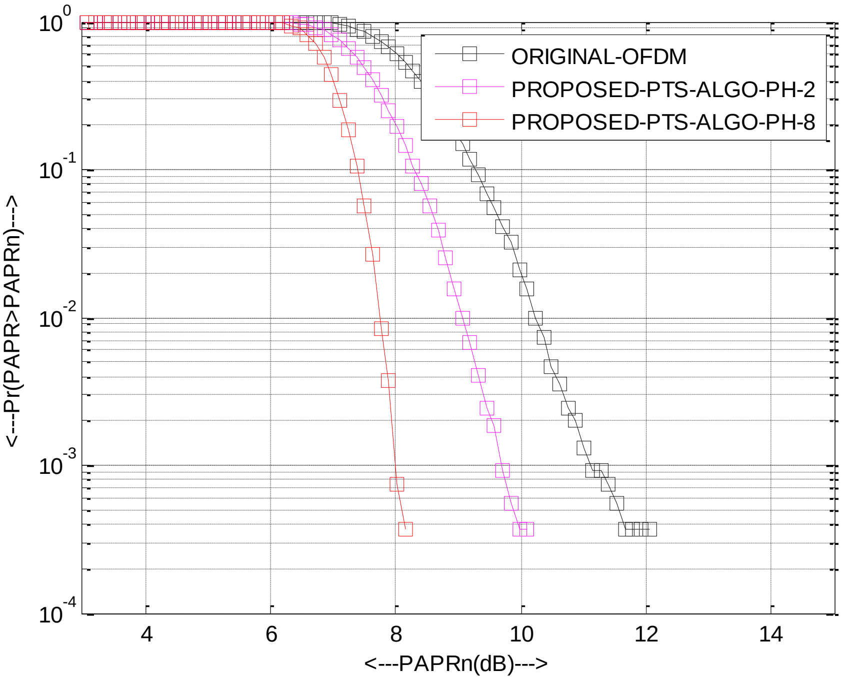

Figure 9.9 Performance comparison ORIGINAL-OFDM, PROPOSED-PTS-ALGO-PH-2 and PROPOSED-PTS-ALGO-PH-8 for N=512,32-PSK and L=8.

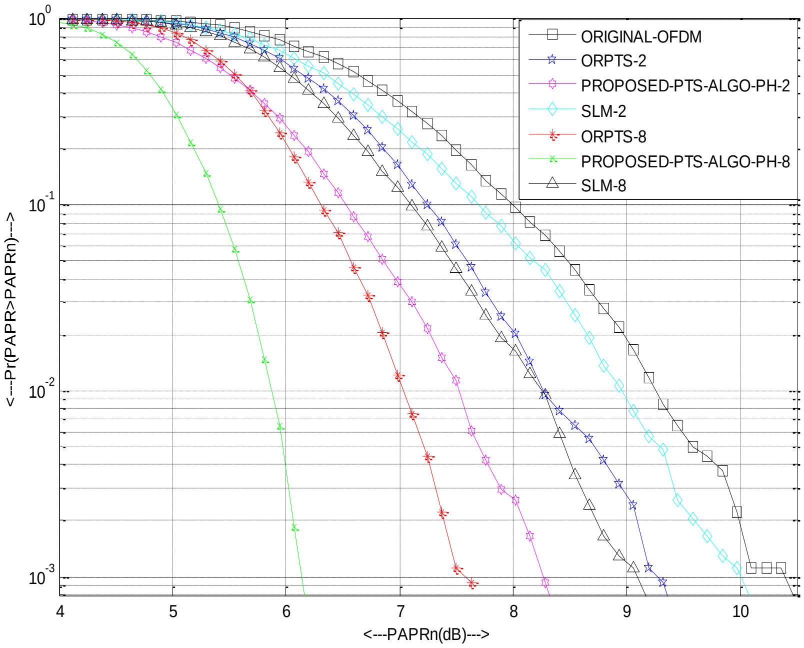

Figure 9.10 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=64,16-PSK and L=4.

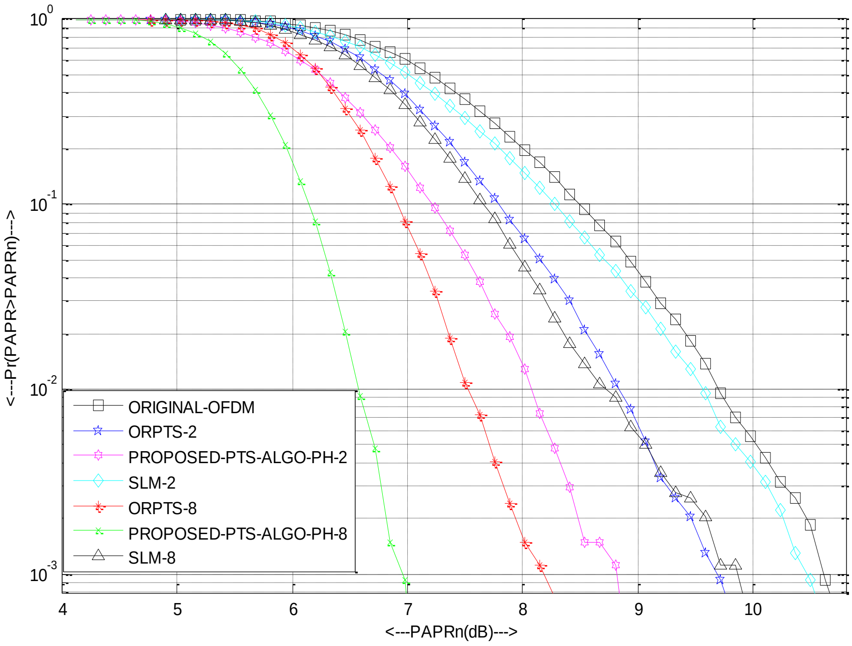

Figure 9.11 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=128,16-PSK and L=4.

For, Figure 9.11, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$ for PAPR (dB) can be perceived for N=128, 16-PSK, L=4 is 10.60 dB for ORIGINAL-OFDM, 10.46 dB for SLM-2, 9.68 dB for ORPTS-2, 9.85 dB for SLM-8, 8.81 dB for PROPOSED-PTS-ALGO-PH-2, 8.18 dB for ORTPTS-8 and also it reduces further to 6.95 dB for PROPOSED-PTS-ALGO-PH-8.

For, Figure 9.12, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$ for PAPR (dB) can be perceived for N=256, 16-PSK, L=4 is 11.04 dB for ORIGINAL-OFDM, 10.98 dB for SLM-2, 10.13 dB for ORPTS-2, 9.63 dB for SLM-8, 9.17 dB for PROPOSED-PTS-ALGO-PH-2, 8.55 dB for ORTPTS-8 and also it reduces further to 7.61 dB for PROPOSED-PTS-ALGO-PH-8. Similar, observations can be obtained for Figure 9.13.

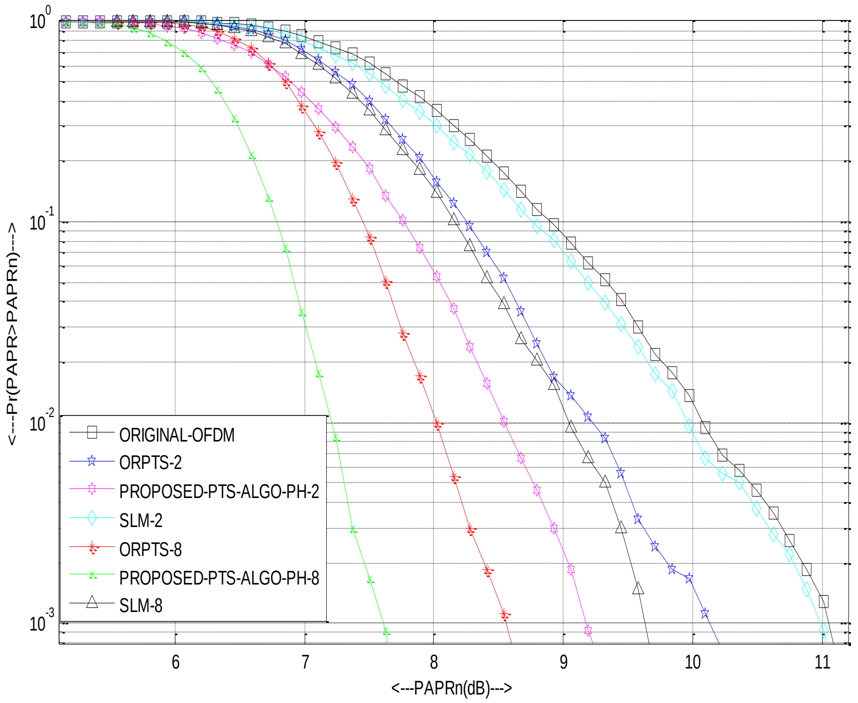

Figure 9.12 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=256,16-PSK and L=4.

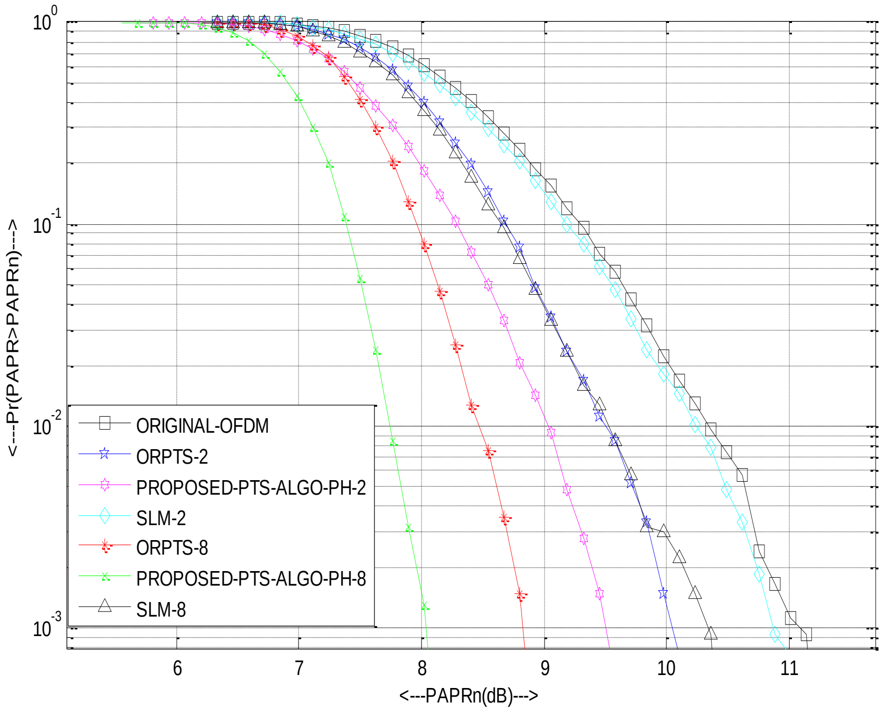

Figure 9.13 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=512,16-PSK and L=4.

It is evident from Figure 9.14 that in order to obtain the CCDF at $(0.1\%)10^{-3}$, the PAPR (dB) can be perceived for N=64, 16-PSK, L=8 is 10.17 dB for ORIGINAL-OFDM, 9.90 dB for SLM-2, 9.16 dB for ORPTS-2, 9.46 dB for SLM-8, 8.13 dB for PROPOSED-PTS-ALGO-PH-2, 7.60 dB for ORTPTS-8 and also it reduces further to 6.27 dB for PROPOSED-PTS-ALGO-PH-8. For, Figure 9.15, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$for PAPR (dB) can be perceived for N=128, 16-PSK, L=8 is 10.50 dB for ORIGINAL-OFDM, 10.26 dB for SLM-2, 9.78 dB for ORPTS-2, 9.52 dB for SLM-8, 8.78 dB for PROPOSED-PTS-ALGO-PH-2, 8.03 dB for ORTPTS-8 and also it reduces further to 6.93 dB for PROPOSED-PTS-ALGO-PH-8.

For, Figure 9.16, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$for PAPR (dB) can be perceived for N=256, 16-PSK, L=8 is 10.91 dB for ORIGINAL-OFDM, 10.73 dB for SLM-2, 9.91 dB for ORPTS-2, 9.56 dB for SLM-8, 9.15 dB for PROPOSED-

PTS-ALGO-PH-2, 8.57 dB for ORTPTS-8 and also it reduces further to 7.43 dB for PROPOSED-PTS-ALGO-PH-8. Similar, observations can be obtained for Figure 9.17.

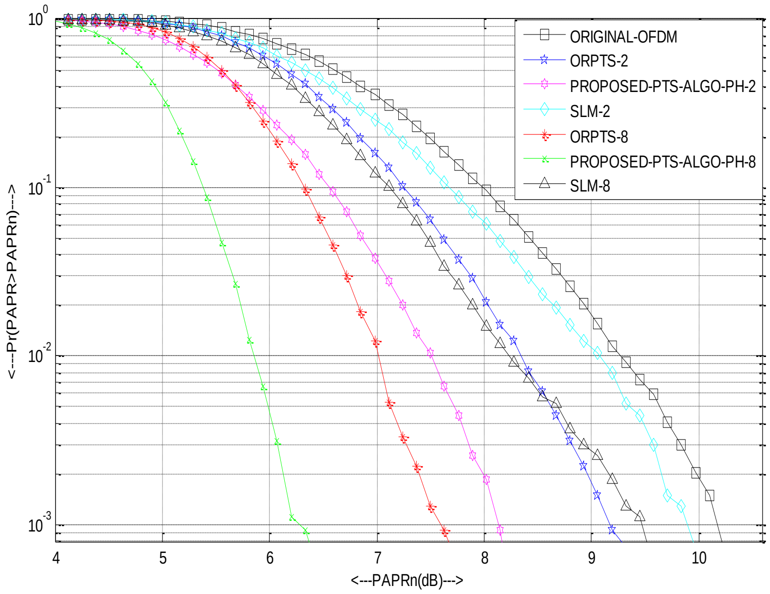

Figure 9.14 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=64,16-PSK and L=8.

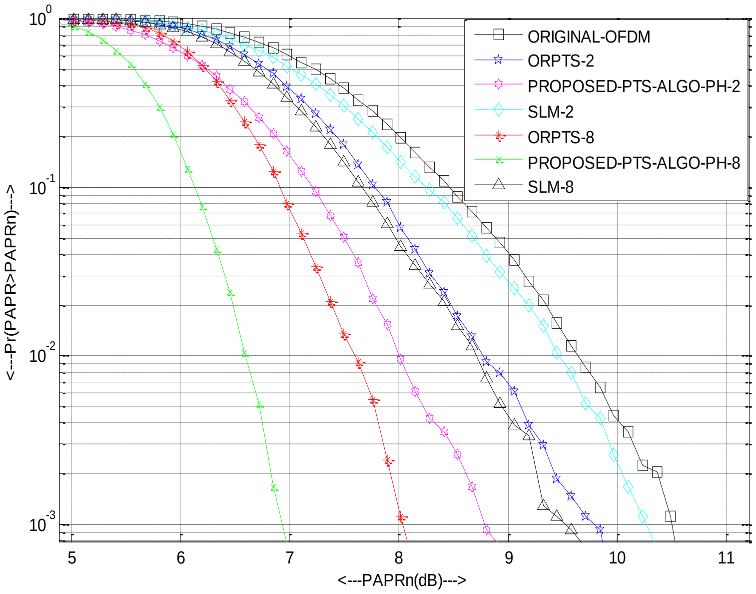

Figure 9.15 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=128,16-PSK and L=8

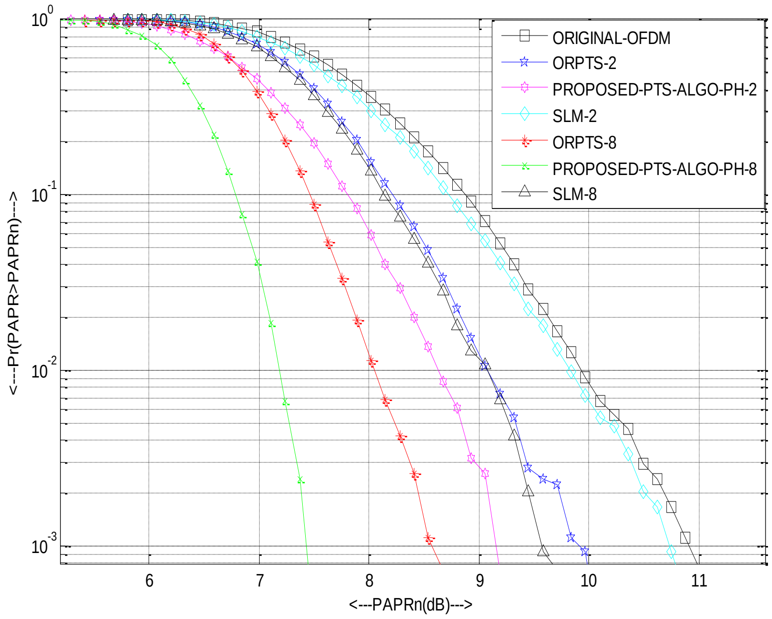

Figure 9.16 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=256,16-PSK and L=8.

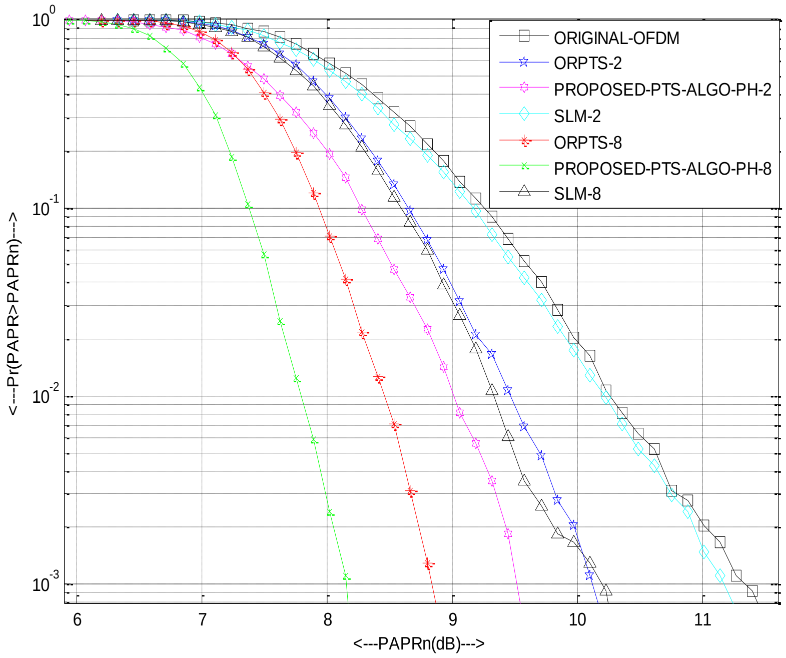

Figure 9.17 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=512,16-PSK and L=8.

CCDF performance evaluation of ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for numerous sub-carries under 16-PSK with CCDF at $(0.1\%)10^{-3}$ is tabulated in Table 9.2 which clearly shows that PROPOSED-PTS-ALGO-PH-8 outperforms ORIGINAL-OFDM and many existing techniques in all the cases.

Table 9.2 CCDF performance evaluation of ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for numerous sub-carries under 16-PSK with CCDF at $(0.1\%)10^{-3}$

N	L	ORIGINAL-OFDM (dB)	SLM-2	ORPTS-2	SLM-8	PROPOSED-PTS-ALGO-PH-2(dB)	ORPTS-8	PROPOSED-PTS-ALGO-PH-8(dB)
64	4	10.39	10.00	9.26	9.09	8.26	7.57	6.13
128	4	10.60	10.46	9.68	9.85	8.81	8.18	6.95
256	4	11.04	10.98	10.13	9.63	9.17	8.55	7.61
512	4	11.08	10.86	10.04	10.33	9.50	8.82	8.03
64	8	10.17	9.90	9.16	9.46	8.13	7.60	6.27
128	8	10.50	10.26	9.78	9.52	8.78	8.03	6.93
256	8	10.91	10.73	9.91	9.56	9.15	8.57	7.43
512	8	11.34	11.17	10.11	10.20	9.51	8.83	8.15

It is evident from Figure 9.18 that in order to obtain the CCDF at $(0.1\%)10^{-3}$, the PAPR (dB) can be perceived for N=64, 8-PSK, L=4 is 10.42 dB for ORIGINAL-OFDM, 10.39 dB for SLM-2, 9.33 dB for ORPTS-2, 9.07 dB for SLM-8, 8.05 dB for PROPOSED-PTS-ALGO-PH-2, 7.60 dB for ORTPTS-8 and also it reduces further to 6.25 dB for PROPOSED-PTS-ALGO-PH-8. For, Figure 9.19, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$for PAPR (dB) can be perceived for N=128, 8-PSK, L=4 is 10.63 dB for ORIGINAL-OFDM, 10.33 dB for SLM-2, 9.91 dB for ORPTS-2, 9.55 dB for SLM-8, 8.73 dB for PROPOSED-PTS-ALGO-PH-2, 8.16 dB for ORTPTS-8 and also it reduces further to 6.90 dB for PROPOSED-PTS-ALGO-PH-8.

For, Figure 9.20, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$for PAPR (dB) can be perceived for N=256, 8-PSK, L=4 is 10.82 dB for ORIGINAL-OFDM, 10.76 dB for SLM-2, 9.91 dB for ORPTS-2, 9.87 dB for SLM-8, 9.39 dB for PROPOSED-

PTS-ALGO-PH-2, 8.31 dB for ORTPTS-8 and also it reduces further to 7.41 dB for PROPOSED-PTS-ALGO-PH-8. Similar, observations can be obtained for Figure 9.21.

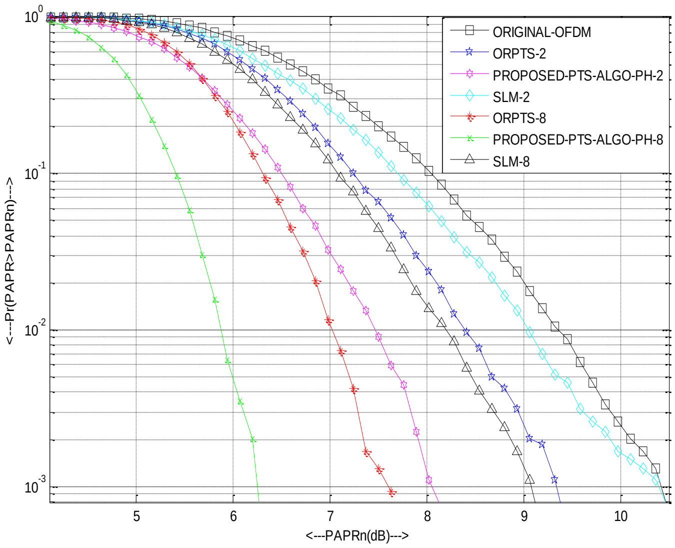

Figure 9.18 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=64,8-PSK and L=4.

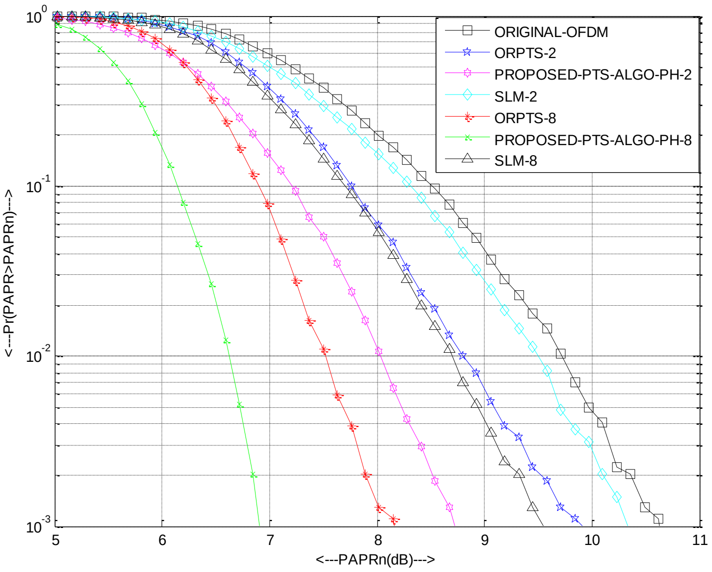

Figure 9.19 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=128,8-PSK and L=4.

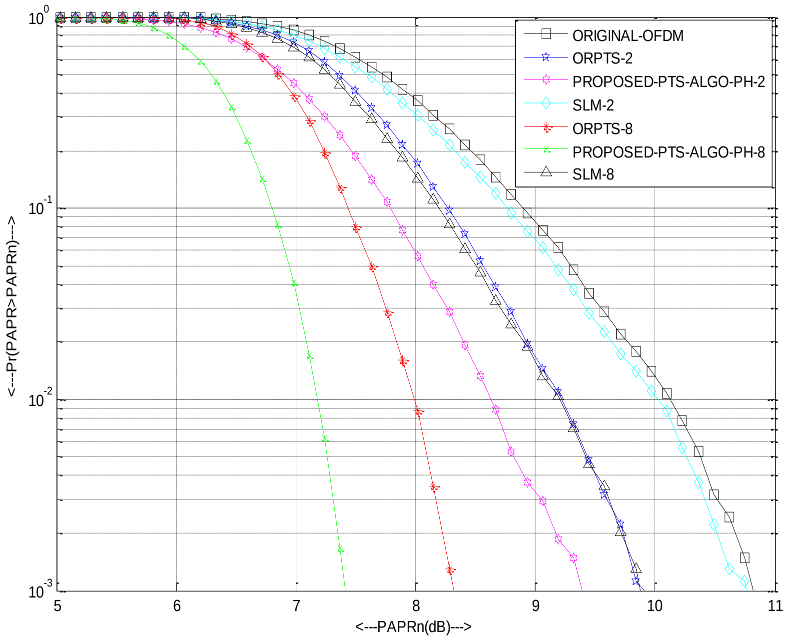

Figure 9.20 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=256,8-PSK and L=4.

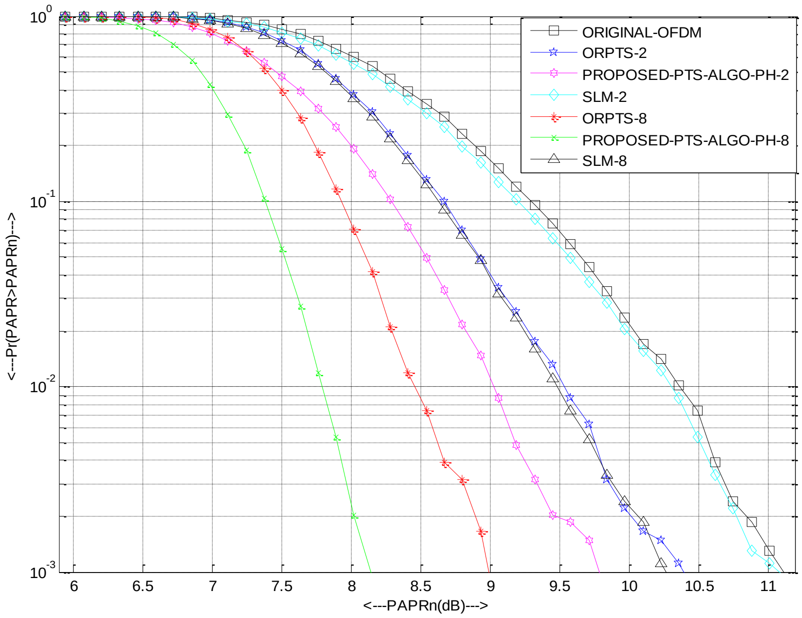

Figure 9.21 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=512,8-PSK and L=4.

It is evident from Figure 9.22 that in order to obtain the CCDF at (0.1%)10^{-3}, the PAPR (dB) can be perceived for N=64, 8-PSK, L=8 is 10.13 dB for ORIGINAL-OFDM, 9.85 dB for SLM-2, 9.17 dB for ORPTS-2, 9.16 dB for SLM-8, 8.05 dB for PROPOSED-PTS-ALGO-PH-2, 7.64 dB for ORTPTS-8 and also it reduces further to 6.21 dB for PROPOSED-PTS-ALGO-PH-8.

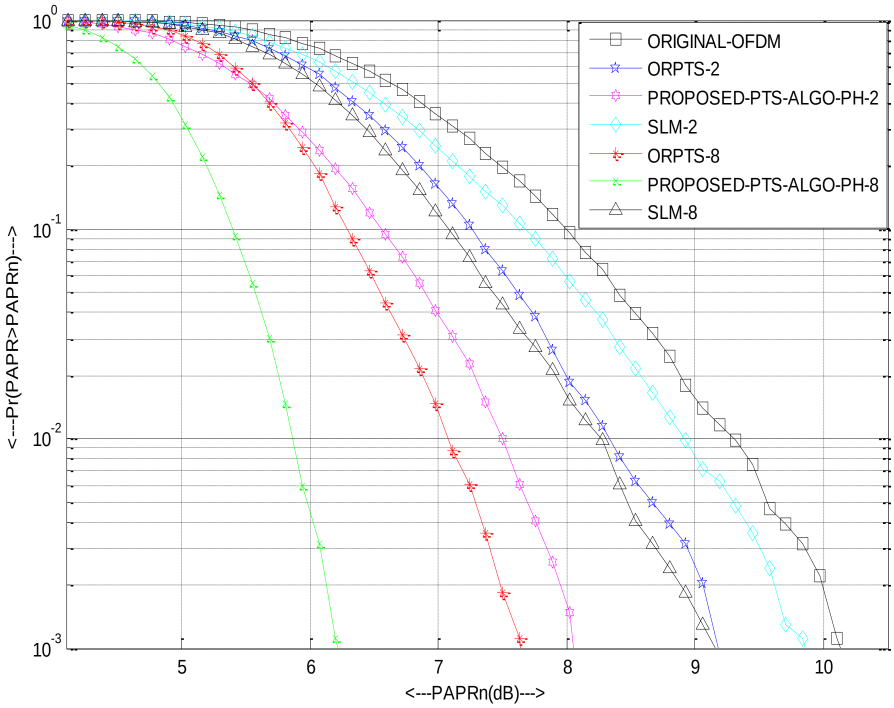

Figure 9.22 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=64,8-PSK and L=8.

For, Figure 9.23, it can be easily observed that the CCDF at (0.1%)$10^{-3}$for PAPR (dB) can be perceived for N=128, 8-PSK, L=8 is 10.46 dB for ORIGINAL-OFDM, 10.24 dB for SLM-2, 9.61 dB for ORPTS-2, 9.64 dB for SLM-8, 8.78 dB for PROPOSED-PTS-ALGO-PH-2, 8.20 dB for ORTPTS-8 and also it reduces further to 6.88 dB for PROPOSED-PTS-ALGO-PH-8.

For, Figure 9.24, it can be easily observed that the CCDF at (0.1%)$10^{-3}$for PAPR (dB) can be perceived for N=256, 8-PSK, L=8 is 10.81 dB for ORIGINAL-OFDM, 10.72 dB for SLM-2, 10.13 dB for ORPTS-2, 9.81 dB for SLM-8, 9.27 dB for PROPOSED-

PTS-ALGO-PH-2, 8.61 dB for ORTPTS-8 and also it reduces further to 7.45 dB for PROPOSED-PTS-ALGO-PH-8. Similar, observations can be obtained for Figure 9.25.

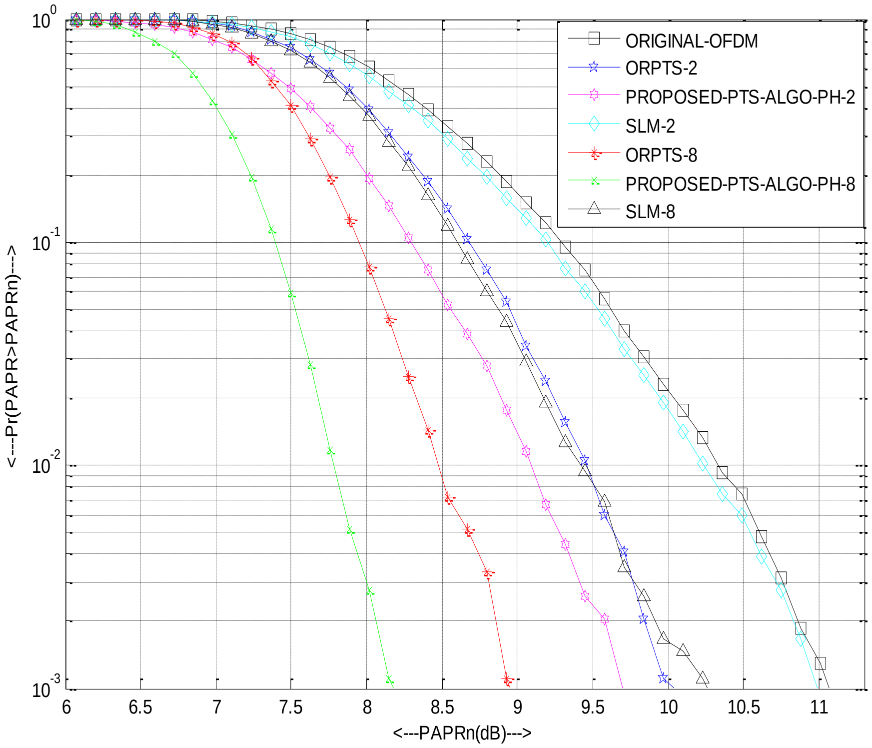

Figure 9.25 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=512,8-PSK and L=8.

CCDF performance evaluation of ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for numerous sub-carries under 8-PSK with CCDF at $(0.1\%)10^{-3}$ is tabulated in which clearly shows that PROPOSED-PTS-ALGO-PH-8 outperforms ORIGINAL-OFDM and many existing techniques in all the cases.

Table 9.3 CCDF performance evaluation of ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for numerous sub-carries under 8-PSK with CCDF at $(0.1\%)10^{-3}$

N	L	ORIGINAL-OFDM (dB)	SLM-2	ORPTS-2	SLM-8	PROPOSED-PTS-ALGO-PH-2(dB)	ORPTS-8	PROPOSED-PTS-ALGO-PH-8(dB)
64	4	10.42	10.39	9.33	9.07	8.05	7.60	6.25
128	4	10.63	10.33	9.91	9.55	8.73	8.16	6.90
256	4	10.82	10.76	9.91	9.87	9.39	8.31	7.41
512	4	11.11	11.08	10.39	10.26	9.78	8.99	8.13
64	8	10.13	9.85	9.17	9.16	8.05	7.64	6.21
128	8	10.46	10.24	9.61	9.64	8.78	8.20	6.88
256	8	10.81	10.72	10.13	9.81	9.27	8.61	7.45
512	8	11.07	10.99	10.04	10.26	9.69	8.94	8.18

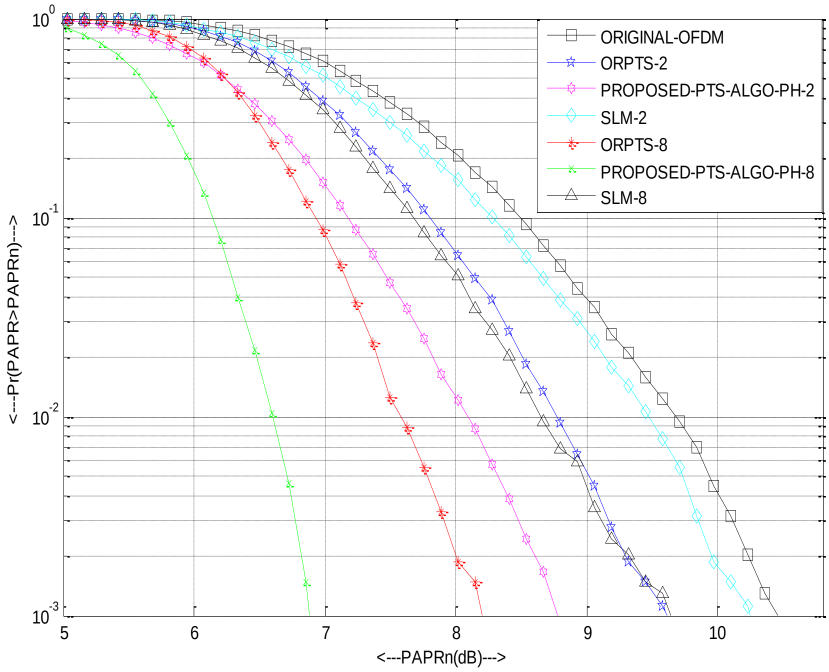

Figure 9.23 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=128,8-PSK and L=8.

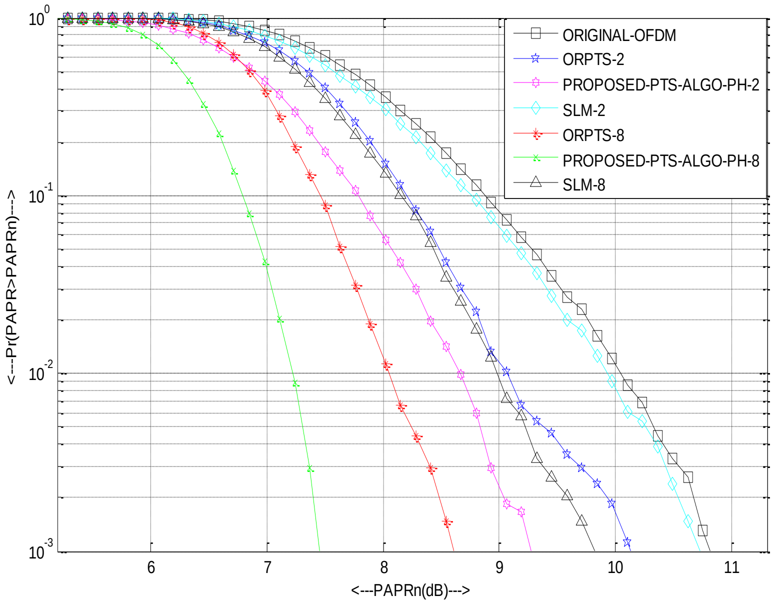

Figure 9.24 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=256,8-PSK and L=8.

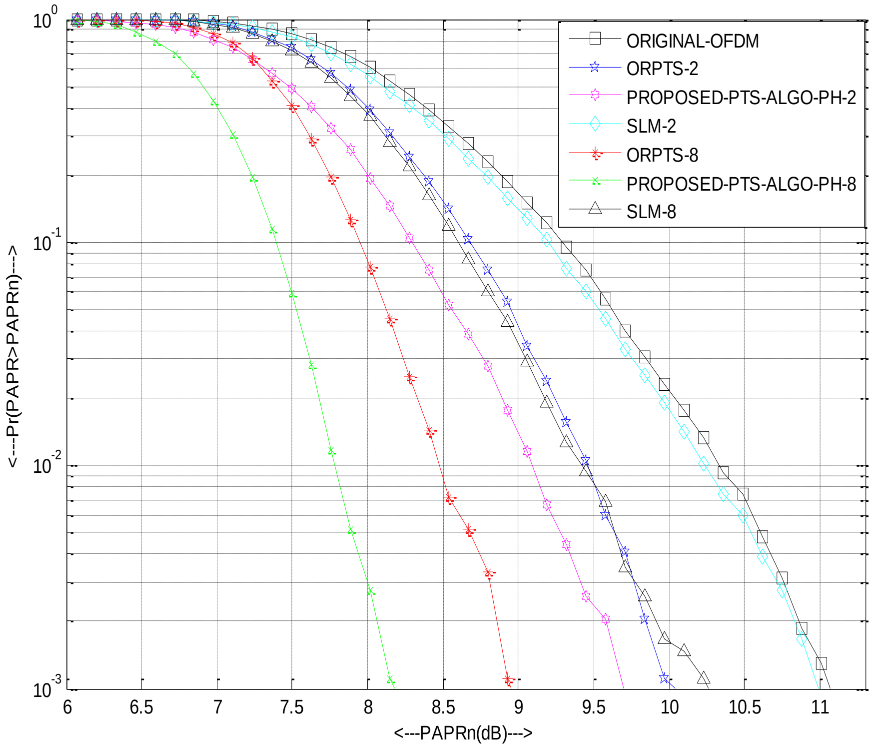

Figure 9.25 Performance comparison ORIGINAL-OFDM, SLM-2, ORPTS-2, SLM-8, PROPOSED-PTS-ALGO-PH-2, ORPTS-8 and PROPOSED-PTS-ALGO-PH-8 for N=512,8-PSK and L=8.

9.6 CONCLUSION

This paper depicts practice for reduction of PAPR concern after utilizing well-organized PTS algorithm with CPSM for several N like 64,128,256 and 512 with 32-PSK,16-PSK and 8-PSK under L=4,8 and also U=2,8. PTS algorithm undergoes difficulty in the creation of phase sequences. For this reason, this particular issue needs advanced solution. The performance explorations disclose that PROPOSED-PTS-ALGO-PH-2 and PROPOSED-PTS-ALGO-PH-8 are better in PAPR reduction as compared with Original OFDM system because they utilize the CPSM. It has been observed that creation of the several phase sequences are very systematic and easy. Moreover, the system performance of PROPOSED-PTS-ALGO-PH-2 is further enhanced by PROPOSED-PTS-ALGO-PH-8 because it uses larger number of phase sequences. This has already been justified with excellent simulation results. It can be seen from Figure 9.2 to Figure 9.25 that the PROPOSED-PTS-ALGO-PH-8 has superior PAPR reduction than PROPOSED-PTS-ALGO-PH-2, numerous existing techniques and ORIGINAL-OFDM. Moreover, the PROPOSED-PTS-ALGO-PH-8 can meritoriously work with numerous amount of subcarriers and modulation methods. Therefore, this proposed algorithm is eligible to act as a strong and more suitable algorithm for many applications like LTE, WLAN, digital video broadcasting (DVB), digital audio broadcasting (DAB), IEEE 802.16d.

CHAPTER 10 PERFORMANCE ASSESSMENT AND ANALYSIS OF PAPR FOR DIVERSE PHASE SEQUENCES BASED SLM ALGORITHM AGAINST OFDM SYSTEM

10.1 INTRODUCTION

OFDM is the method which divides the high data rate stream [167] into the low data rates streams and converts these particular streams into the signals of the time domain with the support of inverse fast fourier transform (IFFT). As the multicarrier transmission method, it depicts the advantage with very efficient frequency spectrum utilization and great opposition towards interference from the selective-fading-channels. In addition to this, it has been adopted as the transmission communication technologies for IEEE 802.11 (Wi-Fi). Regardless of utilized among wireless communication methods, OFDM has drawback of high PAPR. This problem not only diminishes efficiency of high power amplifier but also make difficulties for operations of analog to digital converters (ADC). Several methods have been projected to meritoriously diminish the high PAPR issue like Wei et al. [42] proposed helmert sequences based SLM algorithm which is different from other methods using numerous phase sequences. Moreover, this proposed algorithm does not transfer any kind of side information because these phase sequences have regular structure and also showed extremely low PAPR. Akurati et al. [171] demonstrated the hybridization of methods like companding and SLM. The authors obtained encouraging results which can be utilized in the future communication systems.

Liang and Jiang [43] projected a modified artificial-bee-colony (ABC) SLM algorithm for the enhancement in the performance of PAPR reduction of ABC-SLM algorithm. Hu et al. [172] planned a modified SLM algorithm for enhancing PAPR reduction performance. At first, it utilizes two phase factors sets which are orthogonal in order to create two groups of traditional OFDM signals. In addition to this, more signals are attained by employing linear combinations of two group of original signals established on the most important property of IFFT which is known as linear property.

Lekouaghet et al. [173] explained two different phase sequences for the SLM algorithm such as the rows of the normalized riemann matrix (RM) and also diagonal elements of the modified RM. Moreover, novel phase factors sets after utilizing rows of the symmetric toeplitz matrix is projected. Authors obtained the significant diminishing in the PAPR issue. Zhang and Shahrrava [14] proposed a hybrid PAPR method which employed two stage structure in cascade. The very first stage is the post IFFT stage which constructed set of higher order QAM sequences from QPSK or BPSK with the minimum IFFT whereas the second stage is depend upon class-III SLM method which consist of bank of the parallel blocks. Each and every blocks created many sequences from every QAM method after passing it through the set of the parallel sub-blocks which performed circular convolution with the perfect sequences and then shifting in circular with the shifting principles.

Xing et al. [158] projected the small complexity companding function for reduction of PAPR. This particular function transformed signals into the probability-density-function with the cumulative distribution function an anti-trigonometric function. After wisely, selecting the transform parameters, bit error rate (BER) can be enhanced during the diminishing of PAPR. In addition to this, projected companding function offered flexibility in the design.

Xing et al. [174] demonstrated a novel non-linear companding method in order to diminish PAPR for OFDM system with small BER and out of band (OOB) radiation. This projected method maintained constant average power of signal by choosing parameters. Tang et al. [11] proposed an amalgam method to diminish PAPR. An iterative clipping and filtering (ICF) method and improved nonlinear companding (ENC) method are utilized. The results showed that computational complexity of projected technique is somewhat higher than that of ENC, but much smaller than ICF. Gao et al. [175] explained a novel joint method, iterative partial transmit sequence (IPTS) and clip technique. The results showed that PAPR performance of this method is far better than single technology.

Iwasaki and Ohuchi [176] proposed a precoding technique for the diminishing of PAPR. With the help of this matrix, a small PAPR signal is created through the multiplication with the matrix created from sequences and data symbol vectors. Another method is partial transmit sequence (PTS) for the diminishing of PAPR. Authors also projected a combined method for the further diminishing of PAPR. The PAPR diminishing of projected technique is far superior than PTS and precoding technique independently.

Bharati and Podder [168] offered an arrangement of two different techniques like SLM and Clipping. This paper incorporates SLM with clipping method. The simulation results specified that presented method acquired performance of appropriate PAPR diminishing with small complexity of the computation. Geetha and Mahadevaswamy [156] proposed the harmonious kernel adaptive filter with slepian depend upon flat top window for limiting BER after optimizing the signals in order to maintain most important orthogonality and also elimination of noise. This particular window averages out of noise in the spectrum and reduce loss in the information by using method in the same amplitude measurement thus diminishing PAPR. This projected method explained problems like BER, PAPR, computational issues, complication in bandwidth and spectral usefulness.

Singal and Kedia [177] derived a novel small complexity equation for the combination of SLM with Additive Mapping (SLM-AM) and SLM with U^2 (SLM- U^2) method the help of M-PSK and M-QAM in MIMO-OFDM. In projected MIMO-OFDM, authors analysed PAPR lessening and complexity of computation of many approaches like SLM- U^2, C-SLM, SLM-AM and SLM-AM- U^2. The best PAPR diminishing performance has been obtained by SLM-AM- U^2. The computational complexity is small in this particular case also. Yadav and Prajapati [157] presented a new PAPR minimization method which depend upon hybrid combination of clipping and tangent rooting companding. Gupta and Thethi [144] demonstrated an algorithm which is based upon SLM with pseudo-random phase sequences and μ-law companding. Gupta and Thethi [149] proposed modified PTS (MOPTS) algorithm with RM and discrete cosine transform (DCT). Gupta et al. [86] proposed SLM algorithm with DCT matrix. This matrix will be used as phase sequences for the SLM algorithm.

Gupta et al. [178] presented an approach which is based upon PTS with hadamard matrix as a phase sequence with clipping. Authors depicted that the proposed algorithm outperformed several conventional techniques. Gupta et al. [119] analyzed SLM with hadamard matrix as phase sequences. Authors observed better performance of the projected method as compared with traditional OFDM. Gupta et al. [87] projected a hybrid technique of PTS and bose chaudhuri hocquenghem (BCH) code. Authors obtained better PAPR reduction performance in contrast with traditional PTS algorithm and OFDM. Gupta et al. [179] proposed SLM algorithm with Qth Sub-Optimal Circular Shifting phase sequences created matrix (QSCPM) with DCT. Authors obtained remarkable performance in several cases.

Ma et al. [180] proposed a novel SLM algorithm which employed matrix transformation, cyclic shifting, linear combining algorithm in order to create novel candidates. The new method needed one IFFT and obtained many candidates transmission signals throughout the complete process. This proposed algorithm diminished the complexity of the computation. Ghassemi and Gulliver [181] considered the performance and development of distortionless method in combination with small complexity IFFT algorithm to diminish the PAPR. Presently, projected IFFT-dependent method were depicted to diminish the complexity and enhance performance of PAPR. Kumar and Santitewagul [182] proposed a OFDM-OP (optimum transform) for the reduction of PAPR and it did not introduce any kind of distortion and required decrease in bandwidth and provided PAPR which was very near to single carrier modulation thus removing PAPR incurred by multicarrier OFDM system. Authors also proposed a hybrid OFDM-OP- DSI (dummy symbol insertion) which consist of multiple transform.

Ali et al. [10] projected SLM algorithm with novel technique of creating pseudo random sequences. Authors depicted that side information needed at the received reduced to single index value of utilized column and proposed algorithm is found to be very simple. Cheng et al. [140] demonstrated a novel criterion which depend upon correlationship in between another signals was proposed at first, in order to scrutinize effect of the different phase sequences set in SLM method. In agreeing to this condition, chaotic phase sequences set got united for optimization of PAPR diminishing performance.

Mohammad et al. [183] proposed a distortionless PAPR diminishing method which combined PTS and SLM (CPS). The simulation results showed that the CPS obtained better BER and PAPR performance than PTS. Moreover, CPS created PAPR performance near to that of SLM. Kim [184] projected SLM algorithm which utilized phase rotation along with sliding amplitude weighting factor in the domain of frequency in order to create independent OFDM group of symbols. Therefore, the important opinion of the projected method was that some subcarriers with small frequency provided to the high amplitude weighting-factor and some subcarriers with the high frequency was provided with low amplitude weighting factor.

Ji and Ren [185] demonstrated a new set of conversion matrices (CMs) for enhanced SLM method and signal processing method to eliminate weighted-factors on each subcarrier are also derived. Mohammed et al. [186] proposed a novel method for the reduction of very high PAPR with smallest effect on the performance of system. This method utilizes image adjust (IMADJS) function to diminish the very high PAPR of OFDM signals just by compressing very large signals and expanding very small signals. Xing et al. [187] depicted that OFDM system can be deployed in 5G system and even it can also be considered for beyond 5G (B5G). Sun and Ochiai [188][189] explained that major drawback of OFDM system is high PAPR. Authors also depicted that clipping and filtering is the most efficient approach [188].

In this chapter, the analysis of SLM algorithm based upon hadamard matrix established phase sequences and also centered upon pseudo random phase sequences against OFDM system is presented. The organization of this research work is: Sec. 10.1, an introduction of the related work is presented. Section 10.2 incorporates description of preliminaries. Section 10.3 represents SLM algorithm based upon numerous phase sequences whereas Sec. 10.4 demonstrates simulation results followed by conclusion presented in Sec. 10.5

10.2 PRELIMINARIES

10.2.1 HADAMARD MATRIX

The hadamard matrix [140] is generated recursively through Sylvester technique such as

$$J_{2*N}^{W} = \begin{bmatrix} J_N^W & J_N^W \\ J_N^W & -(J_N^W) \end{bmatrix} \text{ and } J_2^W = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \tag{10.1}$$

Then, the column of this matrix will be utilized by SLM algorithm as the phase sequences.

10.2.2 SLM BASED UPON PSEUDO RANDOM SEQUENCE (PRS)

The SLM based upon PRS [10], [144] represented a systematic structure for the designing of phases explained a matrix $M^0 \in \{+j, -j, +1, -1\}$. The probable arrangement of the M^0 is:

$$M^0 = \begin{bmatrix} +1 & -1 \\ -j & +j \end{bmatrix}$$

Now, for generation of the PRS, M^0 is obtained to be the most important base so that preferred phase sequence for the SLM algorithm can be generated. This occurrence can be controlled as given by:

$$M^m = \begin{bmatrix} M^{m-1} & M^{m-1} \\ M^{m-1} & {M^{m-1}}^T \end{bmatrix}, m = \log_2 N - 1 \tag{10.2}$$

where, hermitian transpose of the M^{m-1} matrix is ${M^{m-1}}^T$, and several number of subcarriers are denoted by $N = 2^n, n = 2,3, \ldots$

The most important consideration here is that M^m is matrix with size $l \times l$ and l denotes total number of subcarriers N. Moreover, the representation of several columns of $M^m = [b^{m1}, b^{m2}, \ldots \ldots . b^{ml}]$.

These columns will be used by SLM algorithm as the phase sequences.

10.2.3 PEAK TO AVERAGE POWER RATIO (PAPR)

The [144] oversampled OFDM with L creates the $PAPR$ which can be denoted by

$$PAPR = \frac{\underset{0 \le n \le NL-1}{max} |w_n|^2}{E[|w_n|^2]} \tag{10.3}$$

where $E[.]$ represents the operator of expectation.

10.2.4 CCDF FOR THE PURPOSE OF ANALYSIS

The CCDF curve is generally used for PAPR issue. It delivers that probability of the OFDM signals exceeding a particular threshold $PAPRm(dB)$ is denoted by [144]

$$CCDF_{H_{n(opt)}}(PAPRm) = \Pr(PAPR_{H_{n(opt)}} > PAPRm) \tag{10.4}$$

where $Pr(.)$ denotes function of probability and $H_{n(opt)}$ is the excellent sequence which is at last, selected for the transmission.

10.3 SLM ALGORITHM BASED UPON NUMEROUS PHASE SEQUENCES

The SLM is the most important PAPR diminishing algorithm which converts original OFDM signal into the numerous independent signals after performing the multiplication with numerous phase sequences and sends that one which creates small PAPR [150]. SLM is distortionless PAPR diminishing algorithm. SLM generally requires transmission of the index of the chosen signal along with the OFDM symbols. The final PAPR enhancement depends upon type of the phase sequences and number of candidates. Moreover, the choice of phase sequences generally plays the most significant role in the diminishing of PAPR. The Figure 10.1, depicts block diagram of the SLM algorithm.

The steps of the following SLM algorithm are as follows:

Step 1: The information data bits are mapped into the points of the constellation M-PSK (M-ary-Phase Shift Keying) to deliver the symbols Z_0, Z_1, Z_2 .....Z_{N-1}. For the approximation of the exact PAPR, L times oversampling is needed. So, symbols can be represented by Z_0, Z_1, Z_2, Z_{NL-1}.

Step 2: The symbol sequences lead to the creation of numerous OFDM frames depicting same information of length NL, where N depicts several number of the subcarriers.

Step 3: Every block of $Z = [Z_0, Z_1, Z_2 \ldots . Z_{NL-1}]$ is multiplied with the numerous U number of the phase sequences vectors represented by $S^u = [S_0^u, S_1^u, S_2^u, S_{3 \ldots\ldots}^u S_{NL-1}^u]$ where u denotes to the column values of that particular matrices.

Step 4: The phase sequences vectors $S^u = [S_0^u, S_1^u, S_2^u, S_{3 \ldots\ldots}^u S_{NL-1}^u]$ are generated with assistance of the column of Hadamard matrix given by equation (10.1) and pseudo random phase sequences depicted by equation (10.2).

Step 5: Now, the sets of the U different OFDM blocks of the information are created as represented by $Z^u = [Z_0^u, Z_1^u, Z_2^u, Z_3^u, \ldots \ldots, Z_{NL-1}^u]^T$, where $Z_n^u = Z_n . S_n^u$, $n = 0,1, \ldots NL - 1$, $u = 1,2,3 \ldots U$.

Step 6: Furthermore, transform Z^u into the time domain in order to obtain $z^u = IFFT\ \{Z^u\}$.

Step 7: Choose the one from z^u, $u = 1,2,3 \ldots U$ which has smallest PAPR and transmit that sequence.

10.4 SIMULATION RESULTS

In the simulation results, OFDMTRAD= Original OFDM system, SLMHADA= SLM algorithm based upon hadamard matrix phase sequences, SLMPSEUDO= SLM algorithm based upon pseudo random phase sequences. The OFDMTRAD, SLMHADA and SLMPSEUDO algorithms has been simulated and performance investigation along with assessment is done for the PAPR with the assistance of CCDF. For the simulations of OFDMTRAD, SLMHADA and SLMPSEUDO systems numerous parameters have already been taken into the consideration like *N*=32,64,128 and 256 information mapped with diverse digital modulations such as 16-PSK and 8-PSK. In addition to this, the oversampling has been undertaken with value of *L*=4 [144]. The 6.3×10^3 OFDM symbols and *U*=16 have also been considered.

The CCDF performance of OFDMTRAD is compared with SLMHADA and SLMPSEUDO. It is obvious from Figure 10.2 to Figure 10.9 that, SLMHADA and SLMPSEUDO yield better performance as compared with the OFDMTRAD for diverse subcarriers since it is utilizing remarkable hadamard matrix based phase sequences [140], pseudo random phase sequences [10] and SLM is the excellent distortionless algorithm used for the lessening of PAPR [86], [144], [150].

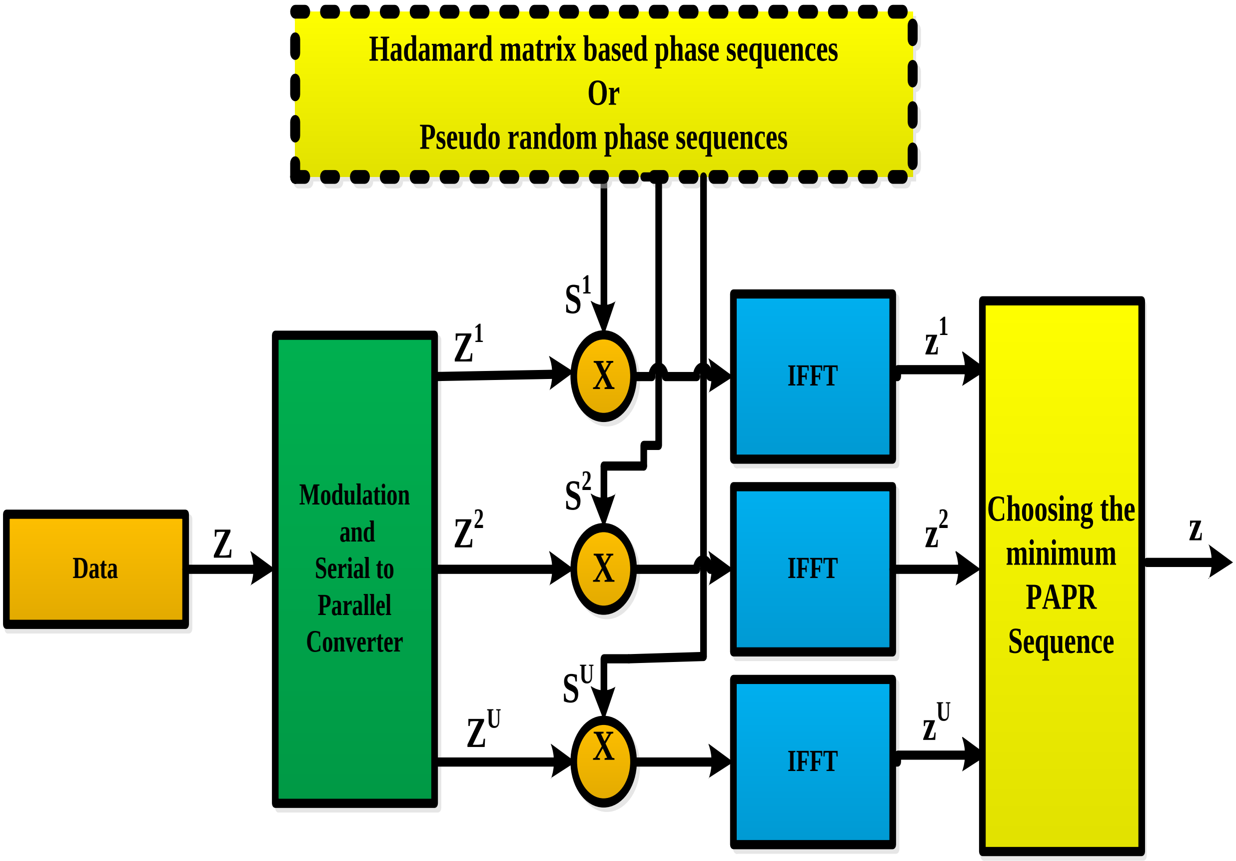

Figure 10.1 Block diagram of SLM algorithm based upon numerous phase sequences.

It is evident from Figure 10.2 that in order to get the CCDF at $(0.1\%)10^{-3}$, the PAPR (dB) can be observed for N=32, 8-PSK is 10.00 dB for OFDMTRAD, but it is 9.23 dB for the SLMHADA and also it diminish to 8.18 dB for the SLMPSEUDO. For, Figure 10.3, it can be easily perceived that the CCDF at $(0.1\%)10^{-3}$, the PAPR (dB) can be observed for *N*=64, 8-PSK is 10.30 dB for OFDMTRAD, but it is 9.37 dB for the SLMHADA and also it diminish to 8.32 dB for the SLMPSEUDO.

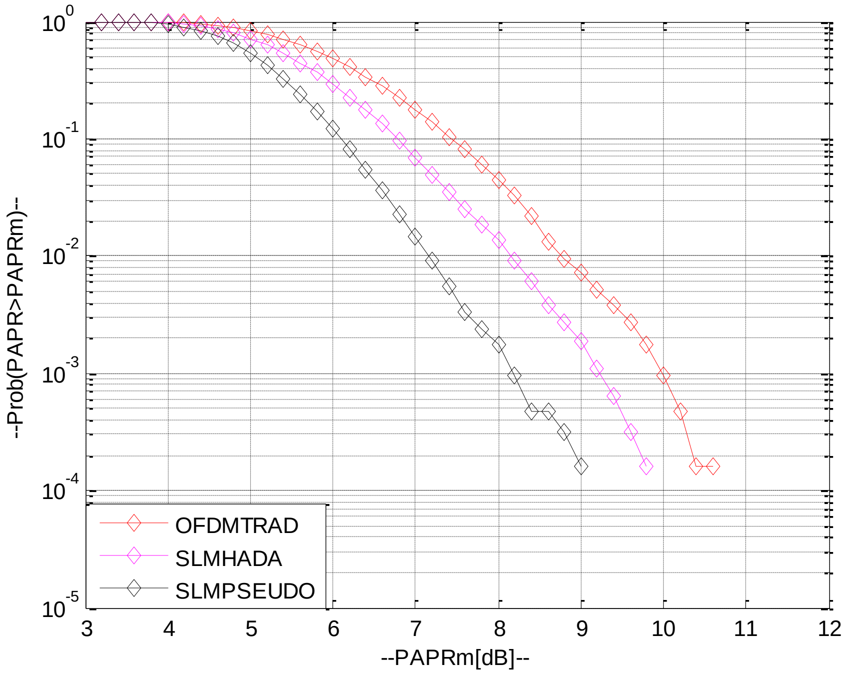

Figure 10.2 Performance comparison OFDMTRAD, SLMHADA and SLMPSEUDO for N=32,8-PSK and L=4.

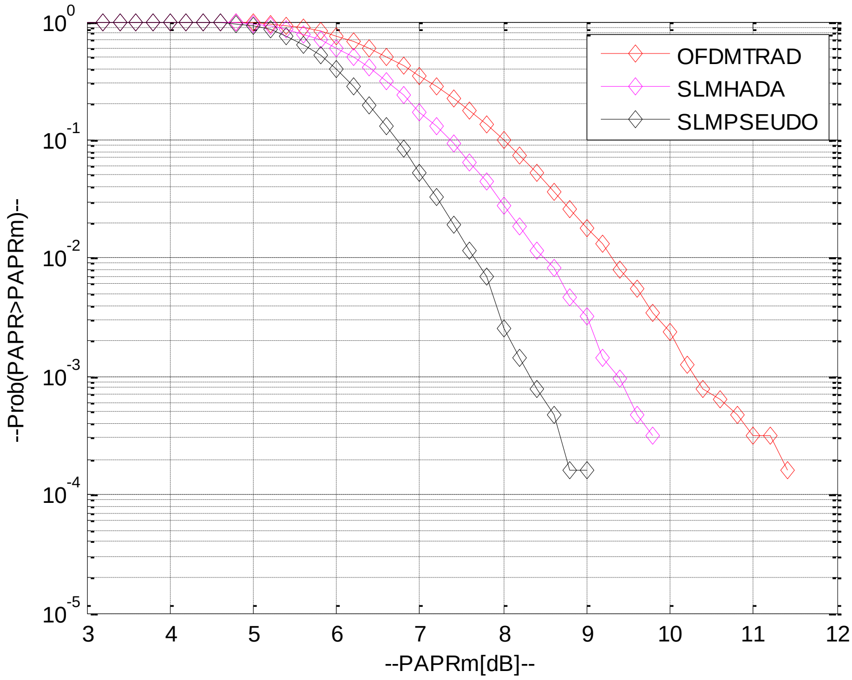

Figure 10.3 Performance comparison OFDMTRAD, SLMHADA and SLMPSEUDO for N=64,8-PSK and L=4.

For, Figure 10.4, it can be easily perceived that the CCDF at $(0.1\%)10^{-3}$, the PAPR (dB) can be observed for *N*=128, 8-PSK is 10.58 dB for OFDMTRAD, but it is 9.70 dB for the SLMHADA and also it diminish to 8.90 dB for the SLMPSEUDO.

For, Figure 10.5, it can be easily perceived that the CCDF at $(0.1\%)10^{-3}$, the PAPR (dB) can be observed for *N*=256, 8-PSK is 10.84 dB for OFDMTRAD, but it is 10.17 dB for the SLMHADA and also it diminish to 9.08 dB for the SLMPSEUDO.

It is evident from Figure 10.6 that in order to get the CCDF at $(0.1\%)10^{-3}$, the PAPR (dB) can be observed for *N*=32, 16-PSK is 10 dB for OFDMTRAD, but it is 9.00 dB for the SLMHADA and also it diminish to 8 dB for the SLMPSEUDO.

For Figure 10.7, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$ for PAPR (dB) can be perceived for *N*=64, 16-PSK is 10.46 dB for OFDMTRAD, but it is 9.50 dB for SLMHADA and also falls to 8.24 dB for SLMPSEUDO.

For Figure 10.8, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$ for PAPR (dB) can be perceived for *N*=128, 16-PSK is 10.56 dB for OFDMTRAD, but it is 9.51 dB for SLMHADA and also falls to 8.76 dB for SLMPSEUDO. For Figure 10.9, it can be easily observed that the CCDF at $(0.1\%)10^{-3}$ for PAPR (dB) can be perceived for *N*=256, 16-PSK is 10.81 dB for OFDMTRAD, but it is 10.00 dB for SLMHADA and also falls to 9.00 dB for SLMPSEUDO.

The SLMPSEUDO provides maximum reduction of the PAPR when compared with SLMHADA and OFDMTRAD. The reduction in PAPR for SLMHADA is greater than OFDMTRAD but it is less than SLMPSEUDO. The CCDF performance investigations, assessment and analysis of OFDMTRAD, SLMHADA and SLMPSEUDO for diverse subcarriers and modulation schemes such as 8-PSK and 16-PSK with CCDF at $(0.1\%)10^{-3}$ is tabulated in Table 10.1 which clearly depicts that SLMPSEUDO outperforms SLMHADA and OFDMTRAD in all the cases.

Table 10.1 CCDF performance assessment of OFDMTRAD, SLMHADA and SLMPSEUDO for diverse modulations and sub-carries with CCDF at (0.1%)10^{-3}

N	Modulation	OFDMTRAD (dB)	SLMHADA (dB)	SLMPSEUDO (dB)
32	8-PSK	10.00	9.23	8.18
64	8-PSK	10.30	9.37	8.32
128	8-PSK	10.58	9.70	8.90
256	8-PSK	10.84	10.17	9.08
32	16-PSK	10.00	9.00	8.00
64	16-PSK	10.46	9.50	8.24
128	16-PSK	10.56	9.51	8.76
256	16-PSK	10.81	10.00	9.00

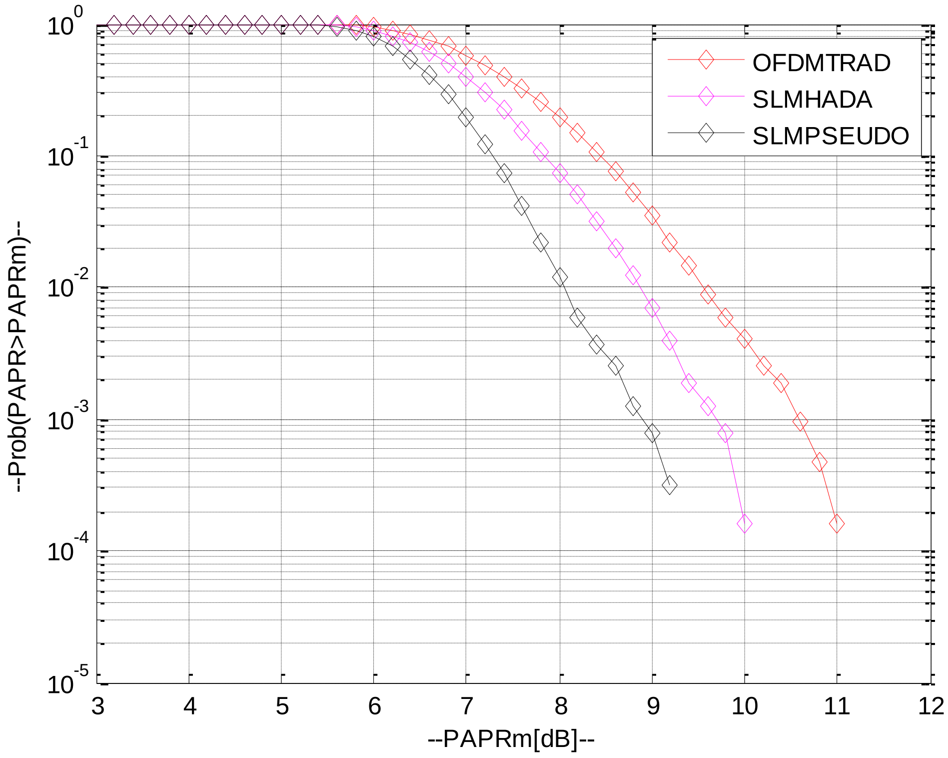

Figure 10.4 Performance comparison OFDMTRAD, SLMHADA and SLMPSEUDO for N=128,8-PSK and L=4.

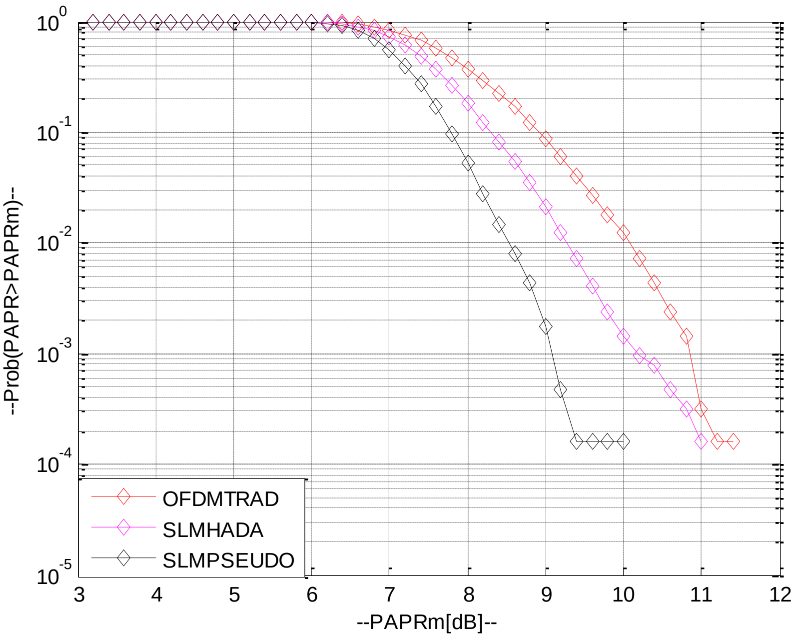

Figure 10.5 Performance comparison OFDMTRAD, SLMHADA and SLMPSEUDO for N=256,8-PSK and L=4.

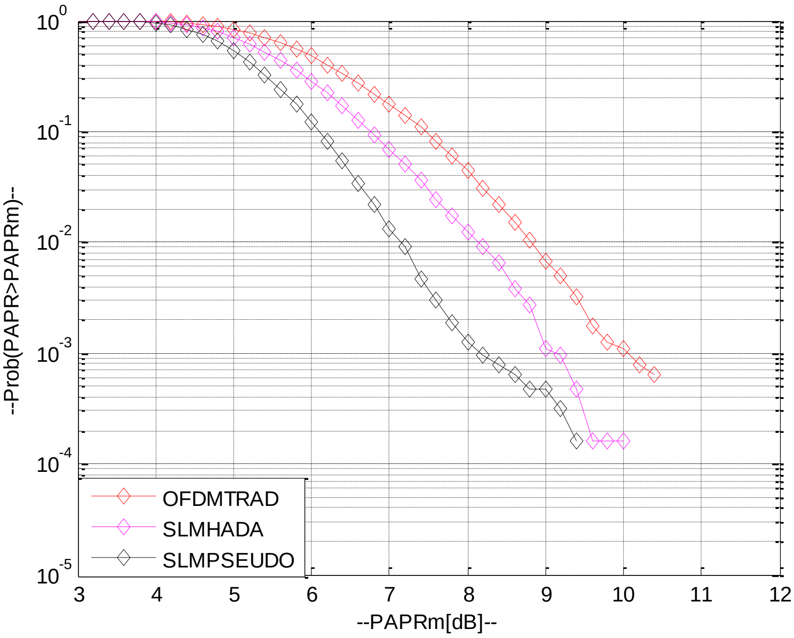

Figure 10.6 Performance comparison OFDMTRAD, SLMHADA and SLMPSEUDO for N=32,16-PSK and L=4.

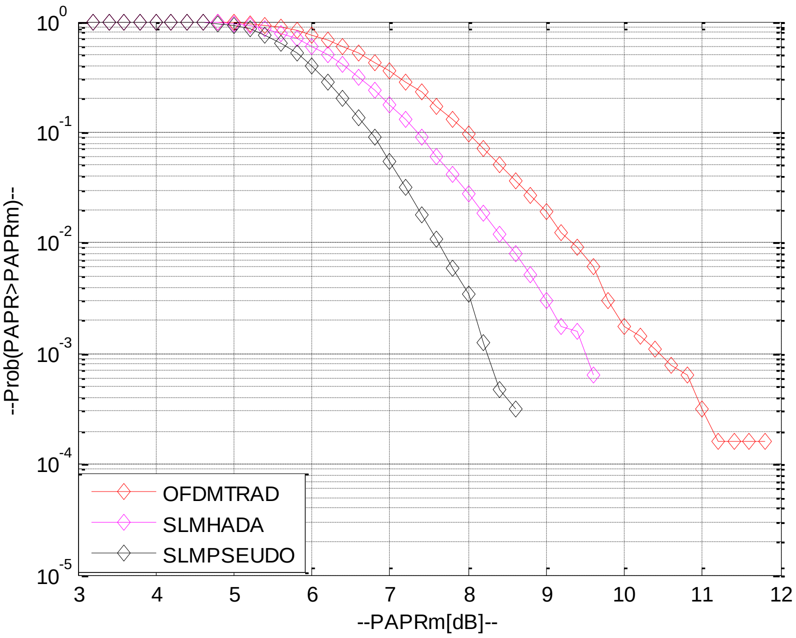

Figure 10.7 Performance comparison OFDMTRAD, SLMHADA and SLMPSEUDO for N=64,16-PSK and L=4.

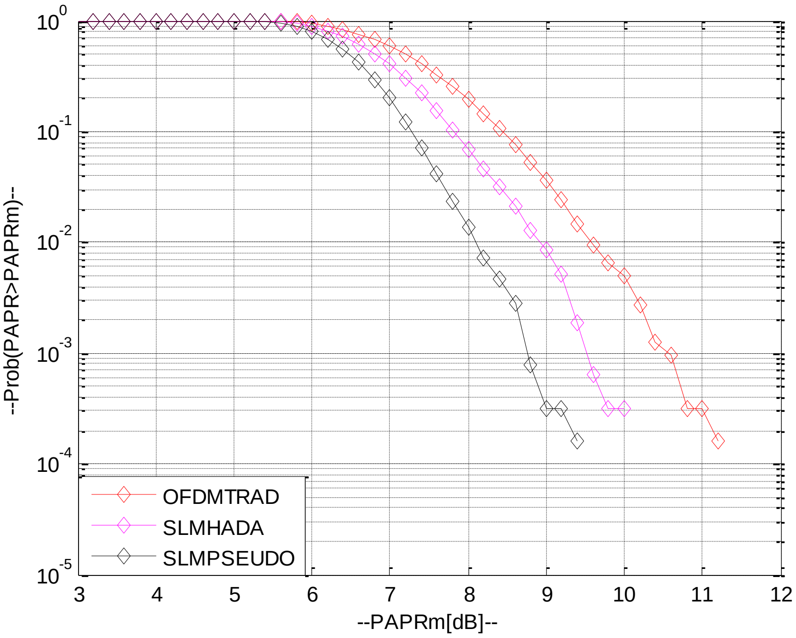

Figure 10.8 Performance comparison OFDMTRAD, SLMHADA and SLMPSEUDO for N=128,16-PSK and L=4.

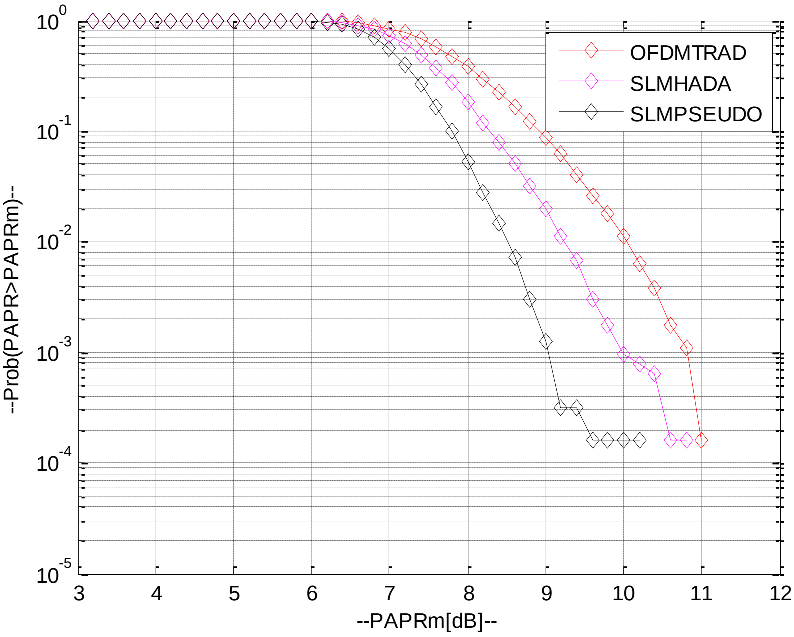

Figure 10.9 Performance comparison OFDMTRAD, SLMHADA and SLMPSEUDO for N=256,16-PSK and L=4.

This chapter now proposes a methodology as given by flow chart (Figure 10.10) in order to verify the effectiveness of two different phase sequences namely hadamard matrix based phase sequences and pseudo random phase sequences in SLM algorithm for the reduction of PAPR. For this reason, the projected system simulations, as explained by given algorithm works on the principle of obtaining best phase sequences so that smallest PAPR can be obtained. Also, it is clear that the use of these phase sequences lead to the reduction in the PAPR value and obtain smallest PAPR value. The exact PAPR values are shown in Table 10.1.

10.4.1 ALGORITHM ILLUSTRATIONS

This chapter shows and utilizes SLM algorithm with two different phase sequences like hadamard matrix phase sequences and pseudo random phase sequences. This section depicts illustrations of this algorithm. Since, this algorithm is excellent and effective in the field of PAPR reduction but every time when it comes to generate those phase sequences which will lead to the reduction in PAPR values then the search for those phase sequences came into picture. However, after studying numerous research papers so that the best phase sequences can be obtained. At last, for this reason these two different phase sequences can be considered along with SLM algorithm.

Finally, after implementing this algorithm with these two different phase sequences in this chapter, it is noticed and understandable that PAPR values start decreasing. Additionally, this chapter clearly shows the remarkable performance by SLMPSEUDO.

10.4.2 COMPREHENSIVE DISCUSSION OF RESULTS

The overall PAPR performance of the projected work has been depicted by numerous figures from Figure 10.2 to Figure 10.9. The SLM algorithm is simulated over two different phase sequences while incorporating diverse modulations techniques and sub-carriers.

The analysis clearly depicts that SLMPSEUDO performs far better than SLMHADA and OFDMTRAD. SLMPSEUDO performs better because it uses best phase sequences [10]. While considering the case of 8-PSK from Table 10.1 after analyzing,

It is clear that SLMPSEUDO obtains 8.18 dB which is the lowest in comparison with SLMHADA with 9.23 dB and OFDMTRAD with 10.00 dB along with CCDF at $(0.1\%)10^{-3}$ for N=32. Subsequently, while considering the case of 16-PSK from Table 10.1, It is clear that SLMPSEUDO obtains 8.00 dB which is the lowest in comparison with SLMHADA with 9.00 dB and OFDMTRAD with 10.00 dB along with CCDF at $(0.1\%)10^{-3}$ for N=32.

Hence, it can be easily observed that minimum value of PAPR is obtained by SLMPSEUDO. Finally, this chapter shows the excellent performance which comes under N=32 for both modulation schemes.

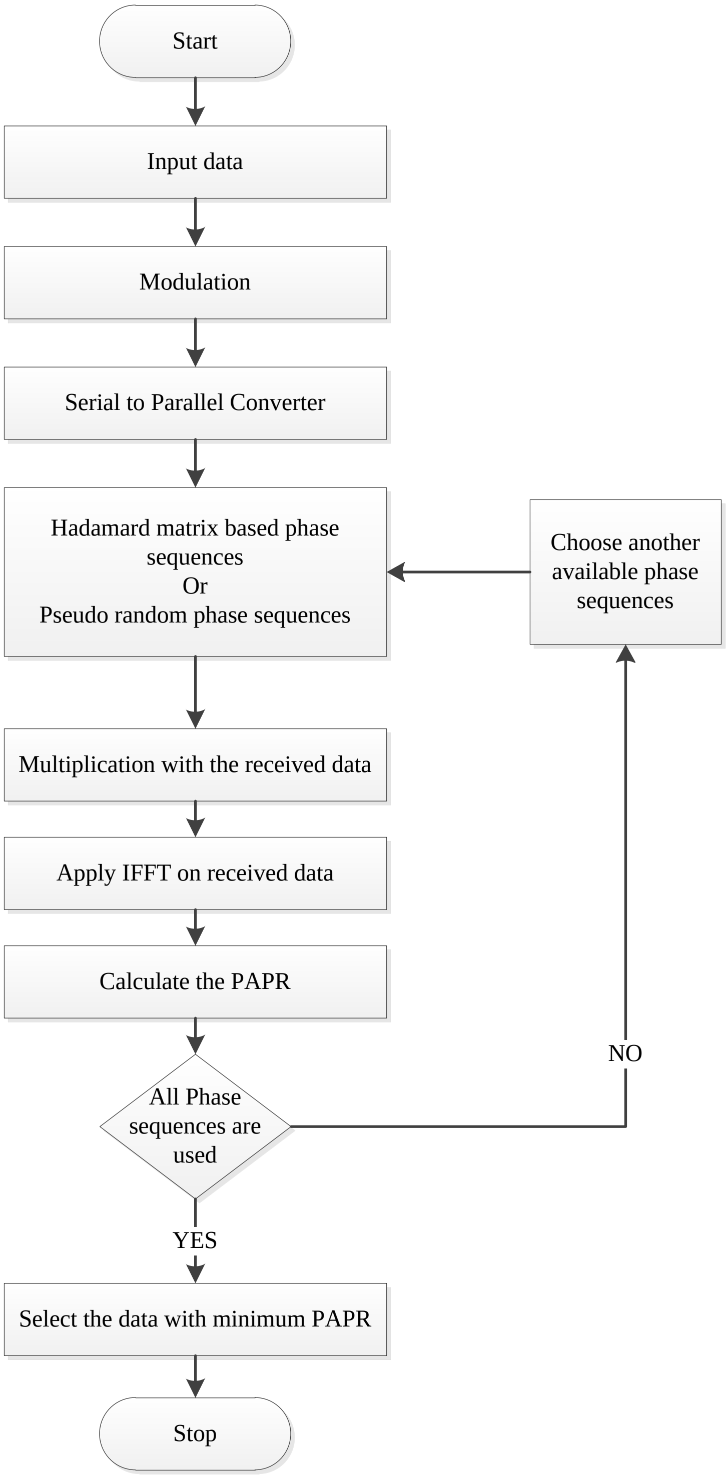

Figure 10.10 Flow chart of the proposed methodology

10.5 CONCLUSION

This research paper shows practice for the diminishing of PAPR concern after utilizing well established SLM algorithm with hadamard matrix based phase sequences and pseudo random phase sequences for diverse *N* like 64,128,256,512 with 8-PSK, 16-PSK under *L*=4 and also *U*=16. SLM algorithm needs highly optimized phase sequences. So, this particular problem needs highly advanced and innovative solution. The performance assessment, investigations and analysis disclose that SLMHADA, SLMPSEUDO is far better in PAPR reduction as compared with OFDMTRAD because these algorithm uses excellent phase sequences. It has already been shown that generation of the numerous phase sequences are very easy and systematic. In addition to this, the system performance of the SLMHADA is further improved by using SLMPSEUDO because of its phase sequences. This has been justified with the remarkable simulation results. The SLMPSEUDO algorithm is eligible to act as the strongest and more suitable algorithm for numerous applications.

CHAPTER 11 CONCLUSION AND FUTURE SCOPE

In past few decades the PAPR reduction in OFDM system has become very attractive and fascinating area of research. The OFDM system leads to several number of applications. In this work, we study and apply concepts like OFDM system, SLM algorithm with pseudo random phase sequences and μ law companding, MOPTS algorithm, conventional SLM algorithm, SLM algorithm with DCT matrix as phase sequences, conventional PTS algorithm, PTS algorithm with clipping technique and hadamard matrix, PRS-PTS-Algo , PTS-CPSM-Algo, SLM algorithm with hadamard matrix as the phase sequences and also pseudo random phase sequences. We have substantially concentrated our attention on diminishing the PAPR of OFDM system by proper choosing several parameters of various algorithms. Finally, the enhancement in the performance of OFDM system has been observed after reducing PAPR and also reported in the present study.

In this thesis we have proposed SLM algorithm with the assistance of pseudo random phase sequences of frequency domain and μ law companding for μ=4,7,10,16,32,64 in the time domain with numerous sub-carriers *(N)*=32,64,128,256,512 and BPSK, 8-PSK and also 32-PSK modulation schemes. Now, the generation of the pseudo-random phase sequences is purely based upon the seed matrix, F^0. This Projected-Algo offers the organized and very informal phase sequences generation monitored by time domain μ law companding desirable only very slightest side information for the transmission to be utilized at the receiver and excellent performance as established by expressive results of Projected-Algo in comparison with Unchanged, ConvenSLM-Algo [9] and ModSLM-Algo given in literature [10].

In the current thesis we have also understood the MOPTS algorithm which plays an important role and uses normalized Riemann matrix *(C)* and DCT in time domain. As a result, it has been observed that MOPTS algorithm can easily generate phase sequences which was difficult in the traditional PTS scheme. Finally, it is noticed that MOPTS algorithm is robust and also underline great impact as compared with ORIPTS and OFDMORIPAPR.

In the present study, it is demonstrated and found that in conventional SLM [9] randomized phase sequence criterion has been adopted whereas proposed work reveals its huge potential in such a way that the designing of phase sequences for SLM algorithm is based on the use of DCT matrix which needs less computational efforts and also very small information about phase is required to be sent because of specific structure of DCT matrix so that data can be easily reproduced at the receiver. In the present thesis we have also considered as well as seen that PTS, hadamard matrix and clipping play their role in diminishing PAPR. It is also examined and observed that our proposed technique presents the methodology by which phase generation become quite easy. In this manner the most important advantage of this proposed algorithm is that even after optimization using several phases the information is further clipped. The performance of our proposed procedure outperforms all the conventional techniques and offers improved efficiency. Above all, such type of remarkable performance can be easily understood from the above presented simulation results. At last, we have accomplished a well-established PAPR lessening algorithm which not only enhanced the information with the assistance of phases in time domain but also clip the information if found greater then threshold. Hence, it facilitates the remarkable property of our procedure which can be easily recognized. Also, it is important to note that in the current thesis, it is examined that as subcarriers are significantly increasing then corresponding increment in PAPR is observed.

In the present work, phase sequences generation is very difficult but it becomes very systematic and easy with help of pseudo random phase sequences and in addition, also very small side information in the form of index value of the column will be transmitted to receiver for the recovery of sequences. The PRS-PTS Algo is more attractive, efficient and achieves decent reduction in the issue of PAPR and it also outperforms Conv-OFDM system. In the present thesis, we have also considered as well as seen well-organized PTS algorithm with CPSM for several N like 64,128,256 and 512 with 32-PSK,16-PSK and 8-PSK under L=4,8 and also U=2,8. PTS algorithm undergoes difficulty in the creation of phase sequences. For this reason, this particular issue needs advanced solution. The performance explorations disclose that PROPOSED-PTS-ALGO-PH-2 and PROPOSED-PTS-ALGO-PH-8 are better in PAPR reduction as compared with Original OFDM system because they utilize the CPSM. It has been observed that creation of the several phase sequences are very systematic and easy. Moreover, the system performance of PROPOSED-PTS-ALGO-PH-2 is further enhanced by PROPOSED-PTS-ALGO-PH-8 because it uses larger number of phase sequences. This has already been justified with excellent simulation results. It can be seen from Figure 9.2 to Figure 9.25 that the PROPOSED-PTS-ALGO-PH-8 has superior PAPR reduction than PROPOSED-PTS-ALGO-PH-2, numerous existing techniques and ORIGINAL-OFDM. Moreover, the PROPOSED-PTS-ALGO-PH-8 can meritoriously work with numerous amount of subcarriers and modulation methods. In the present thesis, we have demonstrated the well-established SLM algorithm with hadamard matrix based phase sequences and pseudo random phase sequences for diverse N like 64,128,256,512 with 8-PSK, 16-PSK under L=4 and also U=16. The performance assessment, investigations and analysis disclose that SLMHADA, SLMPSEUDO is far better in PAPR reduction as compared with OFDMTRAD because these algorithm uses excellent phase sequences. It has already been shown that generation of the numerous phase sequences are very easy and systematic. In addition to this, the system performance of the SLMHADA is further improved by using SLMPSEUDO because of its phase sequences. The SLMPSEUDO algorithm is eligible to act as the strongest algorithm and future work can be to find out excellent phase sequences which can further diminish the PAPR issue with the assistance of proposed algorithms. The future scope of this research work can be in the field of finding new phase sequences which can be used with these kind of proposed algorithms for the efficient reduction of PAPR in OFDM system.

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LIST OF PUBLICATIONS

International Journal Publications

[1] **P. Gupta** and H. P. Thethi, “Performance Investigations and PAPR Reduction Analysis Using Very Efficient and Optimized Amended SLM Algorithm for Wireless Communication OFDM System,” *Wirel. Pers. Commun.*, no. 0123456789, Jun. 2020, doi: 10.1007/s11277-020-07563-0**. (Springer Publication, SCIE and SCOPUS Indexed)**

[2] **P. Gupta**, R. K. Singh, H. P. Thethi, B. Singh, and S. K. Nanda, “Discrete Cosine Transform Matrix Based SLM Algorithm for OFDM with Diminished PAPR for M-PSK over Different Subcarriers,” *J. Comput. Networks Commun.*, vol. 2019, pp. 1–10, Mar. 2019, doi: 10.1155/2019/2893207. **(Hindawi Publication, SCOPUS and ESCI Indexed)**

[3] **P. Gupta** and H. Pal Thethi, “PAPR assessment of OFDM and pseudo random phase sequences based PTS algorithm over diverse sub-carriers,” Mater. Today Proc., vol. 42, pp. 909–915, 2021, doi: 10.1016/j.matpr.2020.11.829. **(Elsevier Publication, SCOPUS Indexed)**

[4] **P. Gupta**, H. P. Thethi, and A. Tomer, “An Efficient and Improved PTS Algorithm for PAPR Reduction in OFDM System,” Int. J. Electron., Aug. 2021, doi: 10.1080/00207217.2021.1966671. **(Tylor and Francis, SCI, SCIE and SCOPUS Indexed)**

[5] **P. Gupta**, H. P. Thethi and A. Tomer, “Performance Assessment and Analysis of PAPR for diverse phase sequences based SLM Algorithm against OFDM system,” Wireless Networks (WINE), **Communicated (Under Review)**. **(Springer, SCIE and SCOPUS Indexed)**

International Conference Publications

[1] **P. Gupta** and H. P. Thethi, “Performance Enhancement of OFDM System Using Modified PTS (MOPTS) PAPR Reduction Algorithm,” in *2019 International Conference on Communication and Electronics Systems (ICCES)*, Jul. 2019, pp. 349–356, doi: 10.1109/ICCES45898.2019.9002045. **(IEEE-EXPLORE Publication, SCOPUS Indexed)**

[2] **P. Gupta**, H. P. Thethi, B. Singh, and S. K. Nanda, “PAPR Clipping United with Altered PTS to Lessen PAPR in OFDM,” in *2019 International Conference on Computer Communication and Informatics (ICCCI)*, Jan. 2019, pp. 1–6, doi: 10.1109/ICCCI.2019.8821846. **(IEEE-EXPLORE Publication, SCOPUS Indexed)**

[3] **P. Gupta** and H. P. Thethi, “A performance study and PAPR assessment of OFDM system for the diverse modulation schemes,” in Intelligent Circuits and Systems, London: CRC Press, 2021, pp. 505–510.