# PAPR REDUCTION USING DCT AND IDCT BASED MODIFIED SLM AND PTS TECHNIQUES IN OFDM AND MIMO-OFDM

**THESIS**

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# CERTIFICATE

Certified that this thesis entitled **“PAPR REDUCTION USING DCT AND IDCT BASED MODIFIED SLM AND PTS TECHNIQUES IN OFDM AND MIMO-OFDM”** submitted for the award of the degree of **DOCTOR OF PHILOSOPHY** in ELECTRONICS AND COMMUNICATION ENGINEERING of the Pondicherry University, Puducherry is a record of original research work done by **Mrs. S. SUJATHA.** during the period of study under my supervision and that the thesis has not previously formed the basis for the award to the candidate of any Degree, Diploma, Associateship, Fellowship or other similar titles. This thesis represents independent work on the part of the candidate.

**Supervisor**
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**Date:**
**Place: Puducherry**

# ABSTRACT

The demand for high data rate wireless multi-media applications has increased significantly over the past few years in the market because of the tremendous growth in network mobility, scalability and connectivity to different networks. The wireless users have put pressure on designers where they need to fulfill their requirements without compromise. However, the designers are facing problem in limited availability of Radio Frequency (RF) spectrum and the time variation of the channel strengths due to the multipath fading. Hence, they have an uphill task to address these challenges. The present wireless systems aim for two conflicting goals, viz., providing quality of service such as delay, fairness to users, and maximizing the throughput of the system.

Several techniques have been developed for increasing bandwidth with high data rate. Among these techniques, Orthogonal Frequency Division Multiplexing (OFDM) is a special form of multicarrier technique where all the subcarriers are orthogonal to each other. OFDM offers higher data rate and high immunity to the multipath fading channel without degrading the Bit Error Rate (BER) performance. It has gained popularity for broadband communication system because of its high spectral efficiency and capacity to combat multipath fading. At the same time, it has some limitations such as Inter-Symbol Interference (ISI), Inter-Carrier Interference (ICI) and high Peak-to-Average Power Ratio (PAPR).

The limitations of ISI and ICI are avoided by guard band insertion. The major problem in OFDM system is large PAPR, which is the ratio of peak to average power. The operating point of the linear power amplifier reaches the saturation region due to the high PAPR which leads to in-band distortion and out-band noise. This can be avoided with increasing the dynamic range of power amplifier which leads to high cost and high power consumption at the base station. Practically, it is not possible to operate the power amplifier in linear region. To reduce the PAPR, several techniques such as clipping, interleaving, block coding,

Selective Mapping (SLM) and Partial Transmit Sequences (PTS) are in practice. The basic idea of these methods is to achieve better PAPR reduction at the cost of high transmit signal power, degradation of BER and large computational complexity.

Among the various PAPR reduction techniques, Modified SLM and PTS technique is very flexible to work with arbitrary number of subcarriers and suitable to all types of modulation applied to them. In this approach discrete cosine transform (DCT) is used along with modified SLM and PTS. The modified SLM and PTS (MPTS) technique has been proposed. To improve the power amplifier efficiency, the modified SLM and PTS has been combined with various PAPR reduction techniques such as DCT, constant modulus algorithm (CMA),interleaving and Pulse shaping in OFDM and MIMO-OFDM systems. This cascading approach provides better PAPR reduction. The CMA technique is an efficient PAPR reduction technique which uses two methods steepest decent and unit circle. To minimum computational complexity and protects the data sequence from fading channel. On the other hand, latency is a major drawback in interleaving technique because it takes long time and hides all kinds of error structures which affect the performance of the system. This can be overcome by modified PTS combined with interleaving technique because it has an optimum set of phase rotation factors which leads to achieve better PAPR reduction performance. However, modified PTS with interleaving technique has no inherent error control.

The modified SLM with interleaving and pulse shaping method is based on proper selection of the different subcarriers. Each subcarrier has different pulse shapes which are derived from cyclic shift of the same pulse. This will reduce the PAPR of the transmitted signal because the peak amplitude of the different pulse shapes will never occur at the same time. Here, the use of IDCT stages has been avoided and the transmitter power is effectively used. This makes this approach to be suitable for the high data rate MIMO-OFDM system such as a digital multimedia wireless broadband mobile communication system.

OFDM is an orthogonal modulation and multiplexing scheme which is used mainly to overcome the problem of selective fading effects. In spite of its many advantages it has a main drawback of PAPR problem. Many PAPR reduction techniques are present in which signal distortion less technique reduces PAPR efficiently. PTS is one of those techniques which have less hardware complexity comparatively. In the proposed work, characteristics of DCT are utilized in PTS technique to reduce the PAPR further. The proposed work uses DCT before and after PTS in order to reduce PAPR. The modified PTS technique which has less computational complexity compared to conventional PTS is also combined with DCT to reduce PAPR in the same configuration as that with conventional PTS. The proposed work is simulated with MATLAB 2010a which shows reduction in PAPR compared to conventional schemes. In the proposed work both in conventional PTS and modified PTS, application of DCT before the technique shows more PAPR reduction compared to application of DCT after the PTS techniques. In DCT before PTS techniques, the autocorrelation between every modulated data bits are reduced whereas in DCT after PTS techniques, the autocorrelation between processed OFDM signals are reduced. Because of the application of DCT in PTS techniques increases the hardware complexity of the OFDM system.

MIMO technology, which multiplies capacity by transmitting different signals over multiple antennas, and OFDM, which divides a radio channel into a large number of closely spaced sub channels to provide more reliable communications at high speeds. In future work, the DCT with PTS techniques are proposed to be applied in MIMO OFDM system to overcome the PAPR problem in it.

In summary, an attempt has been made in this research work to enhance the power amplifier efficiency and reduce the high PAPR of the OFDM and MIMO-OFDM systems through modified SLM and PTS approach combined with some PAPR reduction techniques.

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ADC | - | Analog-to-Digital Converter |
| BER | - | Bit Error Rate |
| BPSK | - | Binary Phase Shift Keying |
| CCDF | - | Cumulative Distribution Function |
| DAC | - | Digital-to-Analog Converter |
| DCT | - | A discrete cosine transform |
| DFT | - | Discrete Fourier Transform |
| FFT | - | Fast Fourier Transform |
| IDCT | - | Inverse discrete cosine transform |
| IFFT | - | Inverse Fast Fourier transform |
| IP | - | Internet Protocol |
| LTE | - | Long-Termed Evolution |
| MIMO | - | Multiple Input Multiple Output |
| MSE | - | Mean Square Error  Multiplexing |
| OFDM | - | Orthogonal Frequency Division |
| OSNR | - | Optical Signal-to-Noise Ratio |
| PAPR | - | Peak-to-Average Power Ratio |
| QAM | - | Quadrature Amplitude Modulation |
| QoS | - | Quality-of-Service |
| QPSK | - | Quadrature Phase Shift Keying |
| SNR | - | Signal-to-Noise Ratio |
| UWB | - | Ultra Wide Bandwidth |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $C_t$ | - | Antennas |
| $\beta$ | - | Average transmit power |
| V | - | Channel matrix |
| $s(\tau)$ | - | Current estimate |
| $(.)^T$ | - | Denotes Transpose |
| $\beta K_t$ | - | Fixed total transmit power |
| $x$ (t) | - | Gaussian Distributed |
| $\nabla s(\tau)$ | - | Gradient Vector |
| $\Psi$ | - | Kronecker properties |
| N | - | Length of data sequence |
| S | - | Neighborhood search algorithm until PAPR |
| U | - | Number of subcarriers |
| $f_m$ | - | OFDM data block |
| $O(N^2)$ | - | Operations |
| $\varnothing$ | - | Point-wise division |
| $T_s$ | - | Sampling Interval |
| $\Delta s$ | - | Set to be the function of PAPR |
| $D_i$ | - | Takes the Value |
| $C_N$ | - | The Discrete Cosine Transformed data sequence |
| $\psi_n$ | - | The optimum weight vector |
| A | - | The phase modulated data bits |
| $\hat{\psi}_e$ i | - | The update error |
| $W = Z^I G$ | - | Time Domain data Matrix |
| N | - | Total number of data sequence |
| M | - | Total number of phase factor used |
| \|.\| | - | vector argument |
| $Y_{N-1}$ | - | where N is equal to the number of subcarriers |

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

With the modernization of the technologies wireless communication systems are facing several demands for high-speed wireless services such as switched traffic, Internet Protocol (IP) data packets and multimedia. This implies that a future generation system will be aiming at wideband, broadband and Ultra Wide Bandwidth (UWB), which are capable of achieving the high spectral efficiency by using the various wireless techniques. However, the system design should satisfy the customer's requirements without any compensation. A well-balanced complexity, flexibility, data rate, Quality-of-Service (QoS) and cost are the important considerations for commercial applications particularly. The great progress made in the fields of microelectronics, signal processing, mobile computing, etc., thrive in achieving spectral efficiency with high flexibility [1].

In wireless network, the communication usually takes place by parallel data system, where the signal is essentially categorized in specific number of non-overlapping channel, which are called as sub-channel with specific frequency. A modulation technique is adopted for each such sub-channel using different types of symbol and then the system performs multiplexing with respect to frequency for all these sub-channels [2]. However, there was an evolution of a new problem called as spectral overlapping [3] in between such sub-channels in order to address the interference related issues. Therefore, the researchers during 1960 have come up with an idea for designing a multiplexing technique using frequency factor for such overlapping sub-channels. Their solution makes proper arrangement of such overlapping sub-channels in order to overlap the sidebands of the individual signal carriers without raising any possibility of interference. The utility of the frequency division multiplexing dates more than 100 years back when it was found to use in transmitting message in telegraph. However, the resource utilization was quite poor as only a small rate of signal is transmitted over a large bandwidth channel with an aid of separate carrier frequency allocated for each signals. There were significant spacing between the carrier frequency in order to resist being in the condition of overlapping. It also supports the use of filters for enhancing the signal quality as well as spectral efficiency. Although the researchers have evolved up with an idea of frequency division multiplexing but the affectivity of such technique was missing. The prime reason behind this was ignorance of the fact that such forms of carriers must bear the orthogonal property in order to address the problem in multiplexing. It was in this time that OFDM took birth and took the shape in the form of multiple standards e.g. 802.11 g/a [4-6]. The preliminary scheme of Orthogonal Frequency Division Multiplexing (OFDM) was launched during 1966 under the supervision of Robert W. Chang [7] who received a patent in 1970 for his significant contribution in design and development of OFDM in wireless communication system.

The prime idea of using OFDM was normally to use multiple sub-carriers to transmit the signal in order to avoid either carrier or symbol related interference. The design principle of OFDM is quite simple as it incorporates the features of narrowband in its sub-channels for ensuring flat fading. Apart from its usage in audio and video broadcasting [8,9], OFDM is currently used in 4G networks [10,11], LTE (Long-Termed Evolution) network [12], and upcoming 5G network [13]. Although, OFDM is one of the most demanding technology for present day multi-carrier based communication system, but still the technique suffers from certain pitfalls. This chapter discusses about one of the potential and an unaddressed problem in OFDM called as PAPR (Peak-to-Average Power Ratio) and proposes a solution to overcome it.

## 1.2 ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

Orthogonal Frequency Division Multiplexing is one type of the multicarrier modulation technique that supports transmission of the data packet using multiple sub-carriers for better utilization of the channel capacity. There are various forms of modulated carriers used in OFDM that are quite spaced closely with each other. In such carriers, the sidebands normally spread out from both the side during the modulation process that can be of any forms e.g. data or voice applied to carrier. Moreover, for an effective transmission as well as demodulation, it is essential to have a good spacing among the signals during the transmission stage.

An effective demodulation can be ensured by providing a good spacing among the signals during the transmission stage so that it is feasible for the receiver for segregating the signals using certain filters. However, such processes are found to be missing in OFDM. It was seen that a sidebands could be received without any presence of interference even if they overlaps with each other by using the orthogonal properties. This problem occurs owing to the orthogonal properties of OFDM [14].

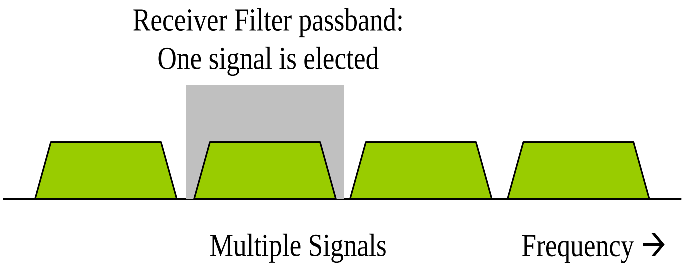


**Fig. 1.1 Conventional Forms of Modulated Signal**

The receiver in OFDM works like an aggregated system of demodulators that performs translation of each carrier. As shown in Fig.1.1, in order to regenerate the transmitted information from the signal sub-carrier, it is essential for the yielding signal to be jointly integrated considering the symbol period. As the theory states that the spacing of the signal carriers are equivalent to the inverse of the symbol period hence such carrier spacing will possess the entire cycles of the symbol period that will finally result in negative interference. Fig.1.2 shows the conventional spectrum generated by the OFDM for *n* number of signal carrier.

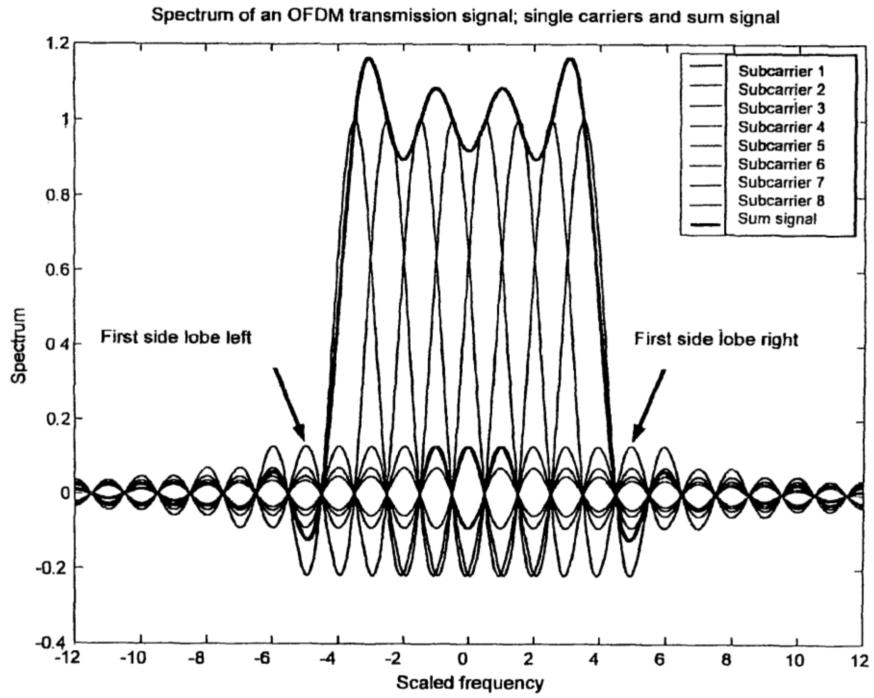


**Fig. 1.2 Spectrum of Orthogonal Frequency Division Multiplexing [15]**

A significant characteristic that can be visualized in Fig.1.2 is the linearity feature of the signal generated by the OFDM. If the signals are found to be non-linear than it will represent the case of either interference or distortion during inter-modulation. Non-linearity in the signal generation process will also result in unnecessary interference that will finally lead to damage the orthogonality feature of the transmission process. The peak of the carrier (as seen from the spectrum in Fig.1.2) also leads to generation of significant power problems in OFDM. The transmitter involved in the modulation process will require depending on amplification for the signals so that the resultant signals in the receiver side are maintained with proper peaks in the spectrum. However, such process also results in inefficiency owing to lowering of the average power involved in the process of transmission.

The information or payload is distributed among the signal that uses in OFDM. Hence, every signal carrier in this process significantly controls the value of the data rate. Lower possibilities of interference can be expected from the minimal value of the data rate thereby ensures higher transmission quality. The system controls the data rate by adding a guard band time (also called as guard interval) that guarantee stability of the signal during the sampling process of the data without any occurrences of the delay factor. Fig.1.3 shows the process using guard interval and sampling window.

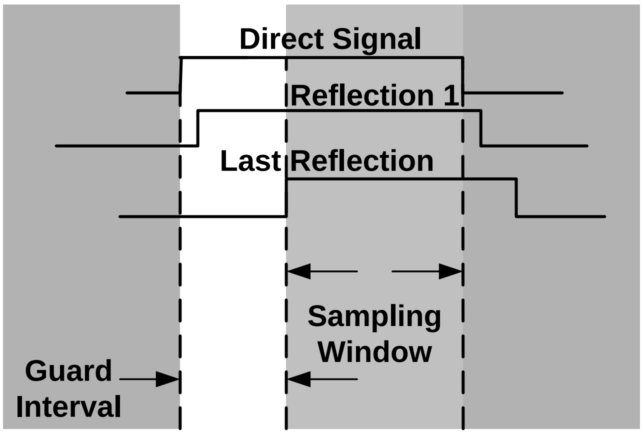


**Fig. 1.3 Guard Intervals in Orthogonal Frequency Division Multiplexing**

As the payload is distributed across the bulky number of channels in OFDM, so such transmission have some potential advantages. The occurrences of the null owing to the effect of the multi-path or due to interference have a minor effective on the smaller number of sub-carriers only. The system makes use of error coding procedures that adds explicit data to the forwarded payload for ensuring reconstruction of the damaged data within a receiver.

An interesting fact about OFDM is that it allows overlapping of the subcarriers of the signal that is not entertained in conventional frequency division multiplexing. The principle of overlapping of sub-carriers is rendered possible in OFDM as it always guarantees superior spectral efficiency by separating sub-carriers at the receiver side. It also make truncates all the possibility of using maximized band pass filters. The problems of transmission that are encountered in single-carrier transmission are completely wiped out using OFDM transmission scheme in wireless networks. It gives an extensive privilege to distribute the frequency selective fading across multiple symbols and thereby enhance the quality of transmission. Such procedures randomize the burst errors generated due to fading effect as well as interference of impulse type so that it can reduce the impact of distortion on the symbols. By doing this operation, it allows the highest possibility of corrupted signal reconstruction. It can do that sometimes without any aid of forward error correction process. Due to the conventional principle of OFDM, the complete channel capacity is divided into multiple narrow sub-bands that flatten up the individual sub-bands relatively as compared to the coherence channel capacity of the channel. Due to this reason, OFDM is currently adopted in multiple wireless communication system that demands high data rate. The significant characteristics of OFDM are:

- **Potential to mitigate Interference**: The OFDM has the capability to address the significant amount of interference that safeguards the sub-channels with an assurity for negative data loss.

- **Resilience against Selective Fading**: As the OFDM can divide the entire channel into narrowband multiple signals, hence it can significant mitigate the problems of selective fading in wireless environment.

- **Cost Effective Equalization process**: Owing to the usage of multiple narrowband signals in the form of sub-carriers, therefore, OFDM offers better equalization process compared to any signal channel or any CDMA (Code Division Multiple Access) system.

- **Addresses Inter-Symbol Interference**: The transmission mechanism of the OFDM from low data rate from each individual channel offers better resistivity against both symbol and carrier related interference.

- **Better Spectrum Efficiency**: The mechanism of OFDM allows overlapping of sub channels and at the same time it offers better spectrum efficiency with an aid of spacing that are close to each other in the overlapping sub-carriers.

- **Effective towards effect of narrowband signals**: The transmission of OFDM ensures that there are no payloads or symbols lost with an aid of frequency selectivity, interleaving operation, and efficient channel coding.

Hence, it can be seen that there are significant levels of advantages offered by the inherent characteristics of OFDM. This potential advantages are not only limited to conventional version of OFDM, but it also extends its advantageous features towards the other versions of OFDM e.g. COFDM (Coded Orthogonal frequency division multiplexing), WOFDM (Wideband OFDM), VOFDM (Vector OFDM), Flash OFDM, OFDMA (Orthogonal frequency division multiple access) too [16]. COFDM ensures the incorporation of the error correction codes in the signal whereas WOFDM incorporates the degree of spacing and is used in WLAN system explicitly. Flash OFDM makes utility of multiple tones as well as enhanced hopping principle for signal distribution. OFDMA is used over cellular communication using OFDM methodology, whereas VOFDM implies the MIMO (Multiple Input Multiple Output) standards.

### 1.2.1 OFDM-MIMO

The capability of OFDM is further enhanced by adding the multiple numbers of antennas over the wireless links that is essential to enhance the spectral efficiency as well as superior reliability factor of a link in next generation of mobile networks and communication system. Fig.1.4 shows the strategy of the OFDM-MIMO where the figure represents two important blocks i.e. OMOD (OFDM Modulation) and ODEMOD (OFDM Demodulation). The fundamental strategy behind this design principle is the insertion of the guard interval that is called as CP (Cyclic Prefix). CP is essentially a replica of final segment of OFDM symbol. The diagram shows the utility of the CP that controls the transmitted signal into cyclic convolution from linear convolution. This result in diagonalization of the cumulative transfer function using IFFT (sender) and FFT (destination)

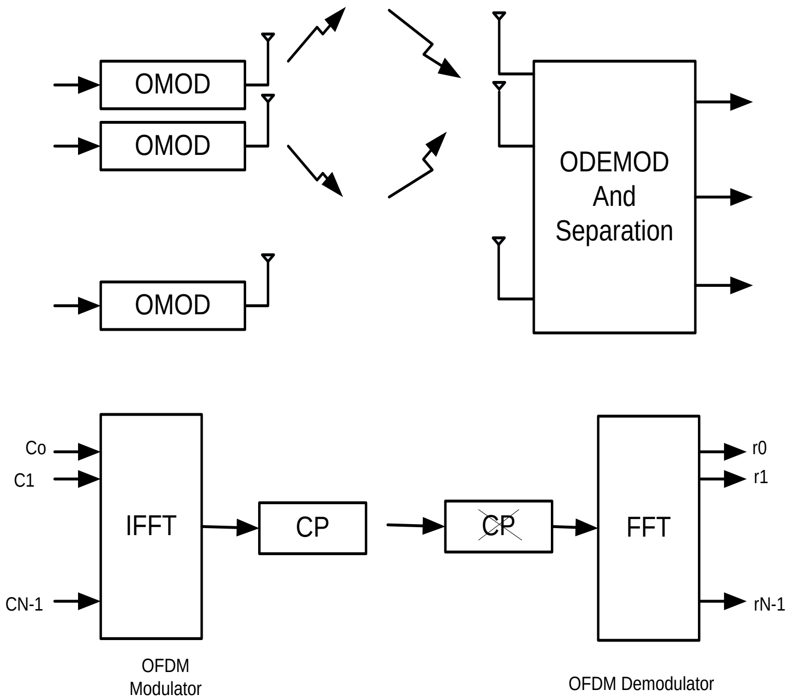


**Fig. 1.4 Strategy used in OFDM-MIMO**

The MIMO system is helpful for increasing the data rate as well as capacity of the system, whereas conventional OFDM system assists in minimizing the multipath fading, interference, etc. Hence, the joint integration of MIMO and OFDM mechanism allows better capacity, flexibility, and efficiency with maximized rate of data transmission with minimal bit error rate [17]. Therefore, the multiple antennas are utilized for cancelling the interference as well as to realize the diversity and gain in array using coherent combination.

There is a significant amount of hostility in the wireless medium that is found to be highly prone to fading and interference. Usage of MIMO concept incorporates the principle of diversity that gives multiple replicas of the communicated signal thereby strengthening to resist interference/fading effect with more reliability of the link [19]. Existing system uses time and frequency diversity frequently in its approach of design methodology [20]. The concept of spatial diversity in MIMO is increasingly adopted owing to its capability of enhanced spectral efficiency [20]. There are also concepts in MIMO called as receive diversity that pertains to the enhance capability of the receiver [21]. However, the biggest challenge is to deploy the multiple antennas in the handheld communication device. Such issues are addressed by using network coding and signal processing on the transmit side using space-time coding [21]. There are various studies to prove that data rates could be significantly increased due to usage of multiple antennas in both transmitters as well as receiver module. The mechanism of spatial multiplexing also enhances the spectral efficiency. Usage of Orthogonal Frequency Division Multiplexing can potentially minimize the complexity of the receiver in wireless communication system and the literatures have witnessed a significant level of research work by jointly using both MIMO and OFDM.

Hence, OFDM-MIMO offers an effective mechanism of signal propagation between the two nodes over wireless medium in presence of interference and noise. The combination of OFDM-MIMO offers better networking and communication privilege that are highly essential as well as mandatory for the existing wireless network to cater up the communication and resource requirement of future mobile networks.

### 1.2.2 Issues in OFDM

Although, there are significant positive features of OFDM, but it also suffers from many pitfalls. The significant pitfalls of OFDM system are as follows:

- Compared to single carrier-based communication system, OFDM suffers from high sensitivity to drift and offset of carrier frequency owing to Discrete Fourier Transform (DFT) leakage.
- Because of usage of guard interval, the capacity as well as loss of power is highly significant in OFDM system.

- The Peak-To-Average Power Ratio is quite high in OFDM.
- The principle of OFDM has higher degree of dependency with linear power amplifiers.
- OFDM is also highly sensitive to the Carrier Frequency Offset.

## 1.3 PROBLEM IDENTIFICATION

There is a possibility of higher values of peaks present over the time domain in OFDM as it is possible for adding the sub-carriers using inverse Fast Fourier Transformation procedure. Because of this reason, OFDM posses maximum Peak-to-Average Power Ratio or commonly known as PAPR problem in contrast to single-carrier transmission system. The presence of higher values of PAPR causes potentially negative effect on the OFDM system as it minimized the signal-to-quantization nose ratio for both Digital-to-Analog Converter (DAC) and Analog-to-Digital Converter (ADC). Such operation tremendously degrades the performance as well as effectiveness of the power amplifiers present in the transmitter. Hence, a higher value of the PAPR may significant increase the complexity of the usual processes of both DAC and ADC.

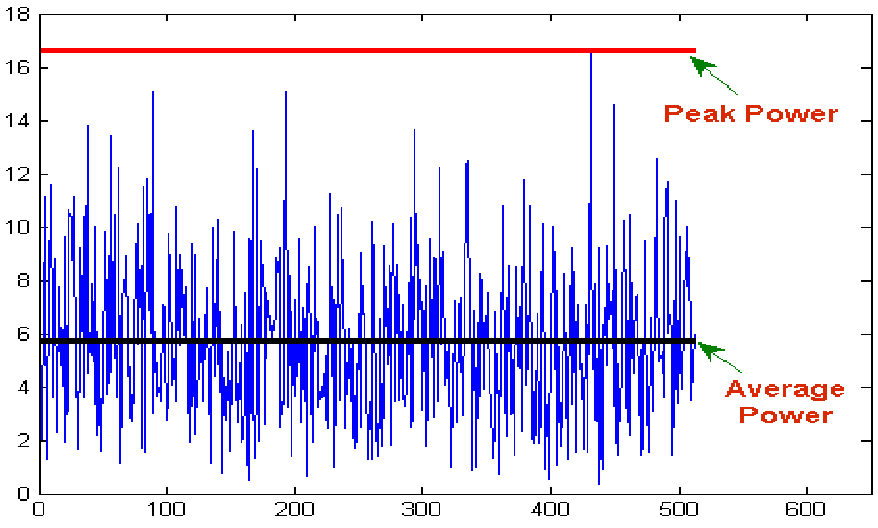


**Fig. 1.5 Visualization of PAPR Problem [23]**

Fig. 1.5 shows the presence of two trends of curves in spectral analysis of OFDM i.e. peak power (red trend of curve) and average power (black trend of curve). In such case of evolution of trends, the system depends on power amplifiers to be functioning over linear region. Although clipping is one possible solution to minimize PAPR problem only at the transmitter, but it minimizes the performance of OFDM. Apart from conventional OFDM, OFDM with MIMO also suffers from the potential problem of PAPR in spite of its inherent characteristics of the enhanced spectral efficiency. One of the potential flaws of the OFDM-MIMO is its complication towards the front end of the radio frequency. In order to address such issues, various solutions has been discussed and presented till date to enhance the performance of OFDM signals. However, such techniques are found to address the problems of PAPR but at the cost of bit error rate, loss of data rate, maximized transmits signal power, and computational complexity. Therefore, the problem statement of the proposed study can be stated as –"*It is a computationally challenging task to evolve up with a computational model that can significant address the problem of PAPR in OFDM and equivalently enhance the communication performance.*" The next section discusses about the research aim and objectives of the proposed study.

## 1.4 RESEARCH AIM AND OBJECTIVES

The prime objective of research is to propose a simple and cost-effective computational framework that can significantly minimize the PAPR in OFDM-MIMO system.

Following are the research objectives.

i. To study a novel framework using *Enhanced Selective Level Mapping* for minimizing PAPR using the principle of discrete cosine transformation.

ii. To develop a simple framework using *Constant Modulus Algorithm* with an aid of *modified Selective Level Mapping* for PAPR minimization.

iii. To propose an *Interleaving and pulse shaping Mechanism* with an aid of pulse shaping method for further minimizing the PAPR.

iv. To propose a *Partial Transmit Sequence mechanism* applicable using the principle of discrete cosine transformation for PAPR minimization.

v. To *Jointly Implement Interleaving* and *Pulse Shaping Method* over *modified Partial Transmit Sequence* for minimizing PAPR.

The above mentioned research aim is implemented over both conventional OFDM as well as OFDM with MIMO. Each objective has its own contribution towards minimizing the PAPR problems in both OFDM and OFDM with MIMO principles. The next section discusses about the brief description of the research methodologies undertaken to implement the research goal.

## 1.5 RESEARCH METHODOLOGY

The research methodology considered for design and development of the proposed system is purely analytical in nature. Fig.1.6 shows the schematic diagram that is adopted for the proposed study. Owing to easier in understandability, the brief discussion of research methodology is carried out in stage wise, where each stage represents one of the main blocks in Fig.1.6 that corresponds to achieving research objectives discussed in prior section.

The *first stage* of the proposed study is focused on reviewing the existing literatures, where the investigation was carried out on last 10 years of research contribution towards minimizing the problems pertaining to PAPR in OFDM-MIMO. Exploration of the research gap is another essential contribution in this stage of research.

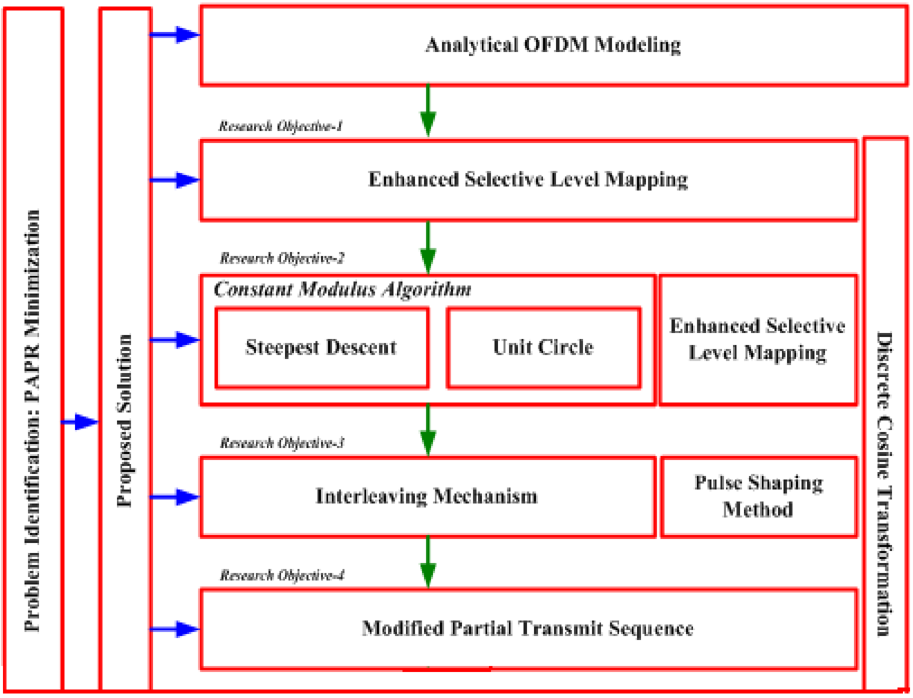


**Fig. 1.6 Schema of Research Methodology Adopted for Proposed System**

The *second stage* of the proposed study is focused on implementing the concept of Selective Level Mapping along with principles of discrete cosine transformation. First the conventional Selective Level Mapping is implemented to observe the behavior of the model and then it is subjected to modification by adding a feature of decision making algorithm before applying on inverse Fast Fourier Transform. The study uses linear block codes to perform the investigation. This *second stage* of the research work, where enhance Selective Level Mapping is dominant principle is further extended to *third stage* of the study that implements the concept of Constant Modulus Algorithm. The algorithm is implemented for both steepest descent approach as well as unit circle approach.

The *fourth stage* of the study is the enhanced version of its prior *third stage* and it focuses on implementing a novel interleaving technique over enhanced Selective Level mapping. This part of the study models the interleaving process. The outcome of the study was assessed with respect to complementary cumulative distribution function with a modulation scheme of QAM (Quadrature Amplitude

Modulation). The *fifth stage* of study investigates about Partial Transmit Sequence over wireless communication system. The communication and multiplexing framework was assessed over its implication towards using the novel scheme of Partial Transmit Sequence. The similar model is extended for its next research phase too. The *sixth stage* of the study is jointly investigates the implications of interleaving mechanism, pulse shaping mechanism, as well as modified Partial Transmit Sequence in order to check its effectiveness in addressing the problems being identified in the research. It could be noticed that the proposed research work emphasizes on core problem of PAPR reduction in OFDM, where the solutions highlighted in Fig.1.6 corresponds to the accomplishment of the research objected. It could also be seen that discrete cosine transformation is also one of the dominant and associated component block for all the research stages discussed briefly in this section. The simulated outcome of the study was assessed for its PAPR reduction on multiple performance parameters considering the case study of both OFDM as well as OFDM with MIMO. The outcomes are also studied with respect to different sub carriers using multiple transformation schemes like inverse Fast Fourier Transform as well as Inverse Discrete Cosine Transform.

## 1.6 THESIS ORGANIZATION

The proposed thesis is organized as follows:

- **Chapter 1- Introduction:** This is the introductory chapter of the proposed study that discuses about the background of the study, problem identification, research aim and objective, and research methodology.
- **Chapter 2- Review of Literature:** This chapter discusses about the existing techniques of minimizing PAPR in both OFDM as well as OFDM-MIMO. The chapter also discusses about the research gap.
- **Chapter 3- Selective Level Mapping:** This chapter introduces a novel framework for enhanced selective level mapping developed

over discrete cosine transformations in order to minimize PAPR. The chapter will discuss the research methodology used to design the framework, algorithm description, and result analysis.

- **Chapter 4- Constant Modulus Algorithm:** This chapter presents a novel framework using Constant Modulus Algorithm for reducing PAPR. The chapter also discusses methodology adopted; algorithm designed, and accomplished results of the framework.

- **Chapter-5: Interleaving and pulse shaping Technique:** This chapter presents a unique modeling technique using a simple interleaving principle along with modified Selective Level Mapping. The framework is discussed using its adopted methodology, algorithm implementation, and result analysis.

- **Chapter 6- Modified Partial Transmit Sequence:** This chapter introduces a Partial Transmit Sequence that is designed along with discrete cosine transform approach. The chapter also discusses its methods adopted, algorithm used, and results accomplished

- **Chapter 7- Conclusion**: This chapter summarizes the entire thesis by elaborating the core findings of the thesis, significant contribution of the thesis, scope and limitation, and future work direction.

# CHAPTER 2

# REVIEW OF LITERATURE

## 2.1 INTRODUCTION

The prior chapter has discussed about the significance of the wireless networking system particularly emphasizing on Orthogonal Frequency Division Multiplexing and its associated problems. The prime problem identification of the proposed study is to address the unsolved issues of Peak-Average-to-Power Ratio or commonly known as PAPR along with the highlights of the research goals and methodology. This chapter discusses about the contributions being made by the significant literatures from numerous researchers for addressing the unsolved issues of PAPR. The chapter will discuss about the techniques used in mitigating PAPR problems in OFDM-based networks, OFDM-MIMO based networks, other forms networks, and also the most frequently used techniques of Selective Level Mapping and Partial Transmit Sequence. The chapter finally concludes by the discussion of the research gap explored from the existing literatures.

## 2.2 STUDIES FOCUSING ON OFDM

There are various studies that have focused on enhancing the performance of the communication system over conventional OFDM system. However, majority of the problems found to address in the research papers published during the year 2002-2015 are associated with conventional OFDM system pertaining to the problem of the PAPR issue. Interestingly, such attempts have made a better pathway for other categories of research works towards further advanced versions of OFDM-based networks in future. This section discusses about the research contribution pertaining to PAPR reduction in OFDM.

Foomooljareona and Fernando [23] have presented a solution towards PAPR problems using two different algorithms. The algorithm make use of the lookup table for choosing the sequences of the input as well as it also scales an envelope of an input pertaining to the subcarriers prior to an inverse operation of Fast Fourier Transform (FFT). The outcome of the study was evaluated with respect to Complementary Cumulative Distribution Function (CCDF) and also compared with some of the existing techniques to show reduced Bit Error Rate (BER) and PAPR. Wen et al. [24] have designed a very unique mechanism of minimizing PAPR in OFDM by using signal mapping scheme. The technique uses a selection criteria based on presence of signals with minimal PAPR value. The author has performed the numerical analysis considering both Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) scheme. The outcome of the study was found to show better descending trend of its PAPR values.

Deng and Lin [25] have presented a study where conventional clipping mechanism is upgraded to incorporate recursive function as well as filtering for accomplishing better PAPR reduction. The idea is to restrict the distortions for all the OFDM signals in order to achieve minimal error rate as well as PAPR. The outcome of the study was found to posse's better reduction of BER, PSD (Power Spectral Density), as well as PAPR when subjected to QAM (Quadrature Amplitude Modulation). Boonsrimuang et al. [26] have introduced a technique using replicated version of the sub-carriers in order to minimize the PAPR in OFDM signal. The technique performs optimization of sub-carriers by altering its prior phase coefficient over signal in time-domain. The technique also introduced an algorithm that switches between time and frequency domain. The outcome of the study show good PAPR reduction capability over Carrier to Noise Ratio (CNR).

Zhang et al. [27] have carried out a study of PAPR minimization over communication channel with multiple carriers. The authors have developed the carriers based on wavelets modulation technique in order to minimize PAPR. The technique performs modulation of the signal which is then subjected to serial-to-parallel converter followed by multicarrier modulation. The processed signal is then subjected to parallel-to-serial converter which then meets its thresholding scheme for energy. The outcome of the study was found to posses better Mean Square Error (MSE), Signal-to-Noise Ratio (SNR) and PAPR over different forms of discrete wavelet transforms. Jiang et al. [28] have introduced a technique of PAPR minimization over OFDM using a sear-based technique. The technique introduced by the author is highly equivalent to combinatorial optimization. The simulation outcome of the study has used Monte Carlo mechanism and is evaluated with respect to CCDR, PAPR, and cost

Zolghadrasli and Ghamat [29][30] have discussed about the significance of the PAPR reduction over OFDM system. With an aid of Monte Carlo simulation model, the authors have performed simulation study using BPSK modulation over Gaussian Noise and fading path. The outcome of the study was evaluated to find better PAPR reduction over QAM in contrast to BPSK modulation. Jiang [31] have presented a very simple technique for reducing an adverse effect of PAPR in OFDM. The author has initially spoken about the significance of PAPR over wireless networking system followed by the discussion of a unique non-linear companding mechanism. With an aid of a simulation study, the author has carried out modulation using QPSK over FFT and IFFT with a size of 256. The outcome of the simulated study was tested with respect to compander input power of 3 dBm over CCDF and BER to justify the effectiveness of the presented technique.

Hong et al. [32] have presented a method that is independent of performing multiple inverse operations in FFT for reducing the ongoing PAPR problems over OFDM. The technique basically uses single operation of FFT and prevents using multiple inverse operation of FFT and replaces using multiple all pass filters. The study outcome was found to posses better capability of addressing PAPR using simulation-based model of 16 QAM. Malode and Patil [33] have introduced a study that is based on using probability theory over linear blocks of codes in OFDM. The technique is designed to select the minimal value of PAPR over various test signals as well as various modulation types too in wireless medium. The study also implements usage of extended Hamming codes for error correction in OFDM channel.

Mukunthan and Dananjayan [34] have used conventional signal scrambling technique as a mechanism for minimizing PAPR in OFDM. Apart from this, the authors have also deployed turbo codes and Golay codes over enhanced radix FFT operation. With an aid of QPSK-based modulation, the simulated outcome of the study was found to posses steep declinations of CCDF over PAPR for Golay sequence as compared to turbo codes. Baig and Jeoti [35] have adopted a turbo coding approach for an objective of accomplishing minimal PAPR over OFDM. The basic idea of this technique is to subject the constellation symbols for precoding operation using a definitive precoder (e.g. Zadoff-Chu matrix Transform), which is done after serial-to-parallel conversion operation for modulation technique (QPSK) in OFDM. The study outcome shows better PAPR reduction performance at a rate of clip $10^{-3}$.

Mohammady et al. [36] have investigated the trends of PAPR minimization using probability-based techniques as well as using signal scrambling mechanism. Bhad et al. [37] have presented a study that emphasized the unsolved problem of PAPR in OFDM. The mechanism adopted by the author is quite simple and effective where clip as well as filter is deployed for minimizing the PAPR values in OFDM-based networks. Gao et al. [38] have carried out a study where the authors have implemented a unique optimization technique for the purpose of minimizing higher computational complexity that leads to increased PAPR problems in OFDM. The authors have used a signal scrambling technique with a aid of simple mathematical modelling along with swarm-based intelligence for enhancing the outcome. The author have performed modulation using QAM and used Monte-Carlo based simulation to see that PAPR value is reduced.

Hernandez et al. [39] have implemented a study that focus on the power problems in OFDM. The authors have introduced a technique where the prediction is introduced over power amplifier with an aid of adaptive-based algorithm design in OFDM (e.g. Least Mean Square, Variable Step Size, etc). The simulation work is carried out with an aid of simple mathematical modelling where the Least Mean Square algorithm has played a significant role. The outcome of the study was evaluated with respect to the output power spectral density with respect to frequency

Shukla et al. [40] have used unique technique of minimizing PAPR with an aid of companding transform of non-linear type. The study is more focused over single carrier based networks and it performs selection of the transform attributes for accomplishing a better and desired tradeoff between error performance and PAPR minimization. Kaur et al. [41] have studied the mechanism of data propagation over OFDM channel with an aid of soliton carriers. The approach of the study was quite simple using conventional modulation scheme. Lee et al. [42] have introduced a technique that uses evolutionary technique as a medium to minimize the PAPR. The author have adopted the principle of tone injection for the purpose of enhancing the mean transmit power for increasing the constellation size that can significant minimize the PAPR value. The outcome of the study was evaluated with respect to PAPR to find increasing fitness ratio of it using evolutionary technique. Hence, it can be seen that there are good number of work being carried out on the perspective of minimizing PAPR in OFDM. Table 2.1 summarizes the contributions in this section.

**Table 2.1 Techniques of PAPR Reduction in OFDM**

| Authors | Technique | Performance Parameter | Advantage | Limitation |
|---|---|---|---|---|
| Foomooljareona [23] | Lookup table, envelop scaling | PAPR, CCDF, BER, | Very simple design | Computational complexity not considered |
| Wen et al. [24] | Signal Mapping | PAPR | Better control of PAPR reduction | Outcomes not benchmarked |
| Deng [25] | Iterative Clipping | BER, PAPR, PSD | Better convergence | Give complexity to both transmitter and receiver side |
| Boonsrimuang et al. [26] | Switching between time and frequency | BER, PAPR, CNR | Better fine tuning of phase coefficient | Doesn't lower much complexity |
| Zhang et al. [27] | Wavelet-based modulation | MSE, PAPR, SNR | Simple design approach | Shift sensitive nature |
| Jiang et al. [28] | Simulated annealing | CCDR, PAPR, cost | Faster processing | Not applicable for complex search mechanism |

| Authors | Technique | Performance Parameter | Advantage | Limitation |
|---|---|---|---|---|
| Zolghadrasli [29][30] | Hadamard matrix, selective scrambling | CCDF, PAPR | Considers noise and interference | Scalability of outcome is missing. |
| Jiang [31] | Non-linear companding | CCDF, BER, SNR | Better performance of BER | Associated with complexity over the receiver. |
| Hong et al. [32] | All pass filter | BER, noise, PAPR | Lower computational complexity | Not applicable for complex networks of OFDM |
| Malode [33] | Probability Theory | PAPR | Better PAPR achievement | Study more inclined towards modulation and less on signal enhancement |
| Mukunthan [34] | Signal Scrambling | CCDF, PAPR | Performance gain, low complexity | No benchmarked outcomes. |
| Baig and Jeoti [35] | Turbo coding approach | CCDF, PAPR | Better PAPR reduction | No benchmarked outcomes |
| Mohammady et al. [36] | Signal scrambling, probability | PAPR | Lower computational complexity | No applicable for reconfigurable network of OFDM |
| Bhad et al. [37] | Filtering, clipping | CCDF | -N/A- | No extensive analysis to prove its robustness and scalability |
| Gao et al. [38] | Signal Scrambling, Swarm optimization | PAPR | Reduced PAPR | Less evidence to prove effective toward lower complexity |
| Hernandez et al. [39] | Adding pre-distortion, Least Mean Square | Power spectral density | Good speed of adaption | No benchmarked outcomes |
| Shukla et al. [40] | Non-linear companding | BER, SNR, CCDF, PAPR | Enhanced BER performance | Doesn’t solve signal attenuation due to companding process |
| Lee et al. [42] | Tone injection, evolutionary technique | PAPR | Less overhead | Complexity computation not enough to support future networks. |

## 2.3 STUDIES FOCUSING ON OFDM-MIMO

Integrating MIMO techniques over OFDM system renders a drastic gain in the data rates of the communication system compared to the legacy networks. It has been observed that by considering multiple number of receive and transmit antenna, a MIMO system is designed. This design is characterized by enhanced factor of reduced number of receive and transmit antenna as compared to single input and output approach in presence of fading channels. Therefore, this design principle of MIMO significant shares the traffic load by increasing the data rates and is also expected to minimize the PAPR problems. Hence, this section will discuss about the existing research work towards techniques of PAPR reduction over OFDM-MIMO.

Rihawi and Louet [43] has considered a problem of PAPR that could possibly occur when multiple signals transmits from multiple antenna in OFDM-MIMO. Hence, the author mainly investigates about the impact of fading channel as well as Gaussian over the PAPR explicitly at the receiver side. The analysis was carried out for both Single and multiple input-output channels with respect to PAPR. The authors evaluated the simulated outcomes for both Rayleigh fading and Additive White Gaussian Noise. Bassem et al. [44] have adopted the mechanism of turbo coding for the purpose of addressing the problems of PAPR in OFDM-MIMO. The technique mainly integrates the usage of turbo coding with permutation of sub-band over inverse operation of FFT. The simulation model is developed where turbo coding is deployed for enabling each antenna for multiple candidate data blocks that significantly increases the data rate. The outcome of the simulation study was assessed using PAPR for conventional turbo coding with proposed system.

Fischer and Hoch [45] have developed a technique for enhancing the existing turbo coding practices, where the outcomes show good PAPR reduction in OFDM-MIMO. Gao et al. [46] have introduced a unique concept of space time block code for the purpose of minimizing the PAPR. The investigation proved that there is a similar characteristics between conjugate symbols between two different antennas. This phenomenon greatly assists to minimize the computational complexity in the network in this work. The outcome of the study shows good PAPR reduction performance.

Rihawi and Louet [47] have presented a study that implements Single Output Context (SOCP) that is performed before carrying out the space time coding scheme. The presented technique enhances the BER performance over WiMAX standard of OFDM-MIMO principle. The technique was evaluated using simulation-based study using Alamouti space time code considering dual antenna for transmitting signals. The outcome of the study shows better PAPR reduction performance evaluated over power spectral density. Gao et al. [48] have presented a technique that uses statistical technique for enhancing the performance of OFDM-MIMO. By adopting ICA (Independent Component Analysis), the authors have presented a compensation scheme of semi-blind approach for addressing spectral overhead. With an aid of channel state information, the technique has attempted to bridge the compensation owing to the I/Q imbalance. The simulated outcome of the study shows better convergence behavior of BER and SNR. Malathi and Vanathi [49] have introduced a very simple technique for minimizing PAPR value in OFDM-MIMO. The authors have used multiple techniques e.g. Partial Transmit Sequence, Selective Mapping, Interleaving, and Tone Reservation for the purpose of reducing PAPR. Manasseh et al. [50] have discussed about a tone reservation technique for minimizing PAPR. It has also used pilot tones over OFDM-MIMO to significantly control PAPR.

Otero and Hernandez [51] have investigated problems pertaining to PAPR reduction for multi carrier signals. The study was emphasized on space frequency block coding specifically on downlink transmission. The authors have developed a unique system model as well as remodeled the PAPR properties for evolving up with the design of the clipping signals. The outcome of the study shows better PAPR performance. Yen and Minn [52] have developed a model for MIMO with OFDMA for the purpose of minimizing complexity associated with PAPR problems. The study also uses phase-rotation techniques, multiple symbol selective mapping principle for the purpose of extended optimization over phase vectors. The simulation outcome of the study was evaluated with respect to PAPR to show better minimization trends of the curves.

Dewangan et al. [53] have emphasized on reviewing the existing technique of PAPR minimization for OFDM with LTE-based networks. The authors have reviewed the existing techniques of clipping, windowing, interleaving, coding, selective mapping, companding, active constellation extension, partial transmit sequence, tone reservation etc. However, the study didn't discuss about possible research gap or any forms of limitations in the existing system. Khademi et al. [54] have presented a technique based on precoding procedures for the purpose of reducing PAPR values in OFDM-MIMO. The technique emphasized on using Eigen beam forming in MIMO, which is one of the regular charecteristics of LTE networks. The technique performs an effective compensation of the equalization and is free from inverting any forms of weights. The entire study uses sequential quadratic programming as the base of optimization process in OFDM-MIMO that has significant potential to minimize the PAPR values. The simulation study was carried out on WiMAX environment to see PAPR is reduced to large extent.

Srinivasarao et al. [55] has implemented sub-optimal approach considering the case study of 4G network. The author identifies the problem of bandwidth efficiency as well as channel with multipath fading. The solution presented is more focused on ensuring reliable transmission using signal scrambling process as well as with probability theory along with phase rotation scheme. The study outcome shows better minimization of PAPR accomplishment. Suban et al. [56] has performed an extensive simulation study for investigating the extent to which PAPR could be reduced in OFDM-MIMO. The authors use QAM for ensuring bandwidth efficiency considering the case study of 4G network. The simulated outcomes were studied for multiple versions of modulations with respect to probability of error and SNR.

Manasseh et al. [57] have developed a technique for minimizing PAPR considering the case study of cognitive radio networks where the core network runs on the principle of OFDM-MIMO. The author uses the mechanism of amplitude clipping technique along with convex optimization policies focusing on single use associated with multiple antennas for transmission. Karande et al. [58] have adopted a turbo coding mechanism for addressing the problem of PAPR in OFDM-MIMO. Considering presence of fading channel, the authors have performed simulation over 1024 sub carriers with 100 MHz clock frequency while considering convolution codes as error correcting codes. The study outcome shows improvement in PAPR distribution evaluated using SNR and BER. Karimi et al. [59] have presented an approach of processing using temporal and spatial factor for minimizing PAPR in OFDM-MIMO. The base idea is to segregate the block of OFDM into certain number of sub-blocks for further analysis at every level of transmit antenna. The study outcome shows better PAPR minimization compared to existing approaches. Shin and Seo et al. [60] have presented a scheme of addressing the problem of PAPR in OFDM-MIMO. The scheme enhances the traditional technique of OFDM-MIMO with cluster-based codebook index feedback. The Monte Carlo based simulation was carried out using QPSK modulation for ETSI channel model. The study outcome was assessed to find better declining trends of BER and PAPR trends.

Tiwari et al. [61] have introduced a technique of turbo coding practices for addressing the problem of in-band distortion owing to spread spectrum of frequency. The simulation is carried out using QPSK modulation over 512 subcarriers to find the presented technique posses better improvement of PAPR reduction over existing techniques. Pachori and Mishra [62] have presented a combinatorial technique along with active gradient projects and space time block coding in OFDM-MIMO. Uniquely, this is the only still till date, where the authors have not only focused on achieving reduction in PAPR but also enhances the data rate of the OFDM-MIMO systems. The study provides a good balance between PAPR and complexity minimization considering the case study of WiMAX standards. Therefore, it can be observed that although OFDM-MIMO is the advanced version of conventional OFDM, it still is shrouded with problems of PAPR. In factor the problem of PAPR in OFDM-MIMO is quite higher and needs more complex solution to minimize it. Table 2.2 summarizes the research contribution.

**Table 2.2 Techniques of PAPR Reduction in OFDM-MIMO**

| Authors | Technique | Performance Parameter | Advantage | Limitation |
|---|---|---|---|---|
| Rihawi [43] | Fading and noise impact | PAPR | PAPR reduces | Doesn't support spatial diversity to large extent |
| Bassem et al. [44] | Turbo coding | PAPR, CCDF | Decreases amount of power | Outcome doesn't support scalability |
| Fischer [45] | Turbo coding | PAPR, CCDF | Decreases amount of power | Outcome doesn't support scalability |
| Gao et al. [46] | Turbo coding, space time block code | PAPR | Better control over computational complexity | Outcomes not benchmarked |
| Rihawi [47] | SOCP | PAPR | Reduces PAPR | More focused on WiMAX. |
| Gao et al. [48] | ICA | BER, SNR | Better compensation technique | Doesn't support spatial diversity to large extent |
| Malathi and Vanathi [49] | PT S, SLM, Interleaving, and Tone reservation | PAPR | Simple design approach | No significant improvement in PAPR |
| Manasseh et al. [50] | Tone Reservation, Pilot Tones | PAPR | No loss of spectrum | Highly dependent on pilot symbols |
| Otero and Hernandez [51] | User reservation | PAPR | Uses spreading codes | Complexity not fully resolved |
| Yen and Minn [52] | phase-rotation techniques, multiple symbol selective mapping | PAPR | No signaling overhead | Complexity computation not enough to support future networks |
| Dewangan et al. [53] | Reviewing existing system | -N/A- | Good Theoretical review | No discussion of limitation or research gap |
| Khademi et al. [54] | sequential quadratic programming | PAPR | Robust optimization Theory | Complexity computation not enough to support future networks |

| Authors | Technique | Performance Parameter | Advantage | Limitation |
|---|---|---|---|---|
| Srinivasarao et al. [55] | signal scrambling, probability theory, phase rotation scheme | PAPR | Minimized PAPR | Iterative algorithm not tested for its computational complexity. |
| Suban et al. [56] | Extensive analysis, turbo coding | PAPR | Good comprehensive evaluation | No significant reduction in complexity |
| Manasseh et al. [57] | Adaptive Amplitude Clipping, convex optimization | PAPR | Better optimization scheme for enhancing the power spectral density | Posses some level of computational complexity |
| Karande et al. [58] | Turbo coding | BER, SNR | Improved BER values accomplished | No significant reduction in complexity, Complexity computation not enough to support future networks |
| Karimi et al. [59] | Temporal & Spatial Processing | PAPR | Performance improvement observed | -N/A- |
| Shin and Seo et al. [60] | Cluster-based codebook index feedback | BER, PAPR | Better BER and PAPR performance | Complexity computation not enough to support future networks |
| Tiwari et al. [61] | Turbo coding | PAPR | Good comparative outcomes | Complexity computation not enough to support future networks, |
| Pachori and Mishra [62] | Combinatorial approach | Probability, PAPR | Less Complex | Outcomes are less reliable owing to usage of probability in constellation approach. |

## 2.4 STUDIES FOCUSING ON DIFFERENT NETWORKS

With the advancement of the networking technologies and evolution of new communication standards, there are various research attempts of conglomerating two or more communication techniques to evolve a new one. Such forms of networking system are called as reconfigurable network. The benefit of reconfigurable network is its potential advantage of retaining both legacy features of merging technologies as well as evolution of new characteristics. Apart from PAPR issues, such forms of networking system which uses OFDM or OFDM-MIMO principles with its legacy networking protocols, it encounters the biggest challenge of protocol conversion and streamlined communication performance. However, this section will only discuss some of the significant literatures when PAPR reduction was addressed in the form of reconfigurable network.

Bulakci et al. [63] have investigated the problems pertaining to complexity minimization as well as PAPR minimization over optical network using OFDM principles. The authors have applied discrete cosine transform as a medium of precoding for enhancing the performance. The simulated study outcome shows better performance of Optical Signal-to-Noise Ratio (OSNR). Forozesh et al. [64] have presented a work for investigating the possible factors responsible for upgrading the communication performance of optical network supporting OFDM principle. The outcome of the study shows that usage of dispersion map heavily influences the value of PAPR as well as OSNR.

Innan et al. [65] have investigated about the problems pertaining to OFDM based network and presented a solution to address the problem of noise compensation. The study has introduced a technique for mitigating the issues based on non-linearities and its compensation techniques on optical network that is based on OFDM. The outcome of the study shows moderate gain in OSNR and better gain in BER.

Giacoumidis et al. [66] have presented a study focusing on the minimization of PAPR reduction in passive optical network supported by OFDM.

The study uses bit loading algorithm as well as distortion technique of non-linear type for enhancing performance of the networks. With a support of simple clipping mechanism, the study outcome shows better PAPR reduction using 16-QAM modulation.

Khademi et al. [67] have presented a study for minimizing PAPR values exclusively for WiMAX system enabled with OFDM method. The technique uses beamforming principle on the transmitting antenna that carries both data as well as pilot. The authors have also applies sequential quadratic programming for the computation of phase shift and the presented technique is considered as better alternative as compared to existing way of minimizing PAPR. Mishra et al. [68] have applied a technique of phase sequence for investigation its possible influence on PAPR minimization over OFDM. The study uses turbo coding mechanism over QAM based networks supported by OFDM. The significant contribution of the study was to testify the possible impact of various sequence schemes e.g. Chu, Hadanard, Hilbert, Riemann, Circulant, Newman etc on PAPR.

Mugala et al. [69] have investigated about the problems of the crest factor to be possibly minimized over WiMAX network support by OFDM system. The authors have presented a novel PAPR reduction scheme by integrating the concept of tone reservation and turbo coding mechanism. The simulated outcome shows better control over the complexity. Yen and Chong [70] have presented a study directing towards both OFDM and OFDMA for the purpose of PAPR minimization using enhanced turbo coding. The simulation outcomes over LTE networks shows lowered signaling overhead and minimal complexity. Chen et al. [71] have discussed about an approach of using asymmetrical clipping as well as filtering mechanism as a medium of controlling the PAPR values in optical network supported by OFDM system. The base idea of the study is to alter the signal with positive and real baseband corresponding to certain threshold to zero value followed by implication of filtering and clipping procedure. The simulated outcome of the study shows better control over BER and PAPR is reduced to good extent.

Pervez and Hossain [72] have mechanism a design by conglomerating windowing system as well as Hadamard transformation scheme as a medium to minimize the PAPR values in OFDM system. The presented techniques with support of BPSK modulation are found capable fo minimizing noise, BER, and PAPR. Wang et al. [73] have developed a system that can minimize the PAPR for optical network working on OFDM principle. The author used the technique of companding and make of enhanced hyperbolic tangent transform that is found with the capability of scaling up smaller signals as well as scaling down larger signals.

Baig et al. [74] have developed a PAPR reduction scheme that uses the case study of 4G system where OFDMA is used. The authors have used precoding scheme that is based on discrete sine transform along with arbitrary interleaving operation over uplink transmission. The simulated outcome of the study is tested over multiple variants of modulation scheme (e.g. QPSK, 16QAM, 64QAM, 128QAM, 256 QAM etc) to find better PAPR reduction capability. Gawande and Ladhake [75] have applied the scheme of filtering and clipping for reducing the values of PAPR on OFDM system. Although, the authors have presented the technique to be efficient but it is already known that such scheme significantly give rise to heavy distortions of the signals.

Tsokanos et al. [76] have presented a study that adopts the technique of PAPR reduction focusing on the case study of the passive optical network supported by OFDMA principle. The author incorporates multiple techniques for minimizing interference as well as PAPR e.g. clipping, bit loading, thermal detuning, etc. The outcomes of the study show better control of errors over increasing channel spacing. Joseph and Kumar [77] have considered the case study of futuristic communication system and have discussed the problems of PAPR in it.  The authors have presented a unique architecture for software defined radio endowed with OFDM system. The study uses FPGA (Field Programmable Gate Array) with multiple modulation techniques e.g. BPSK, QPSK, and QAM to implement companding transform and band pass filter. The study outcomes show better PAPR reduction and efficient BER performance.

Rindhe et al. [78] have developed a technique for addressing the problem of PAPR. The study performs comparative evaluation of various frequently existing techniques for PAPR minimization and found that amplitude clipping is the most suitable approach for minimizing the PAPR in OFDM based optical network. The outcome of the study shows better PAPR reduction capability. Vujicic et al. [79] have designed and developed a scheme for controlling the power dissipation on multiple carrier channels. The study took the case study of optical network powered by OFDM. Haque and Mowla [80] have used filtering as well as amplitude clipping for mitigating the problems of PAPR reduction in LTE based OFDM system. The authors have used elliptical filtering mechanism with infinite impulse response focusing on the downlink system. The outcome of the study shows better BER performance and can significantly minimize PAPR

Juliao et al. [81] have considered the case study of 5G network in order to evaluate its effectiveness with respect to spectrum aggregation. The technique implements microwave on software defined radio that has potential supportability of 5G networks. The author have performed experimental design using FPGA Virtex tool for evaluating the spectrum to find reduced PAPR. Zhang et al. [82] have presented a very interesting technique which makes its very different from any techniques of PAPR reduction till date in optical network based OFDM. The authors have used cryptography for minimizing the PAPR of passive optical network with 16QAM modulation. The study outcome shows better BER performance and minimized PAPR accomplishment. Therefore, it can be seen that there are various studies that have focused on minimizing PAPR values on different types of networks that uses OFDM principle. Table 2.3 summarizes the contribution of PAPR reduction in different networks.

**Table 2.3 Techniques of PAPR Reduction in other networks**

| Authors | Technique | Performance Parameter | Advantage | Limitation |
|---|---|---|---|---|
| Bulakci et al. [63] | Precoding using Discrete Cosine Transform | OSNR | Complexity reduction | Outcome specific to control scenario |
| Forozesh et al. [64] | Dispersion mapping | OSNR | Improves communication performance | No benchmarking, not applicable for high data rate OFDM networks |
| Innan et al. [65] | Pilot Tone | OSNR | Better BER performance | No benchmarking outcomes |
| Giacoumidis et al. [66] | Bit loading, non- | PAPR | Better BER performance | No benchmarking outcomes |
| Khademi et al. [67] | Precoding, sequential quadratic programming | PAPR, power, operation, number of blocks | Applicable to both OFDM and OFDMA, significantly minimize PAPR | No benchmarking outcomes |
| Mishra et al. [68] | Turbo coding | CCDF | Comprehensive comparison analysis of sequences | Outcomes not shown standardized to existing or futuristic applications |
| Mugala et al. [69] | Turbo coding, tone reservation | PAPR | Significant control over complexity. | No benchmarking outcomes |
| Yen and Chong [70] | Turbo Coding | PAPR | Reduced Signal Overhead | No benchmarking outcomes, |
| Chen et al. [71] | Filtering, asymmetric clipping | PSD, BER, Noise | BER is reduced | No benchmarking outcomes, |
| Pervez and Hossain [72] | Windowing, Hadamard transform | PAPR | Efficient comparative outcomes | Narrowed scope of outcomes, applicability of outcomes not discussed |

| Authors | Technique | Performance Parameter | Advantage | Limitation |
|---|---|---|---|---|
| Wang et al. [73] | Companding Approach | Optical power, PAPR | Better BER performance | No benchmarking outcomes |
| Baig et al. [74] | Precoding with Discrete Sine Transform | PAPR | Better PAPR reduction | No discussion of algorithm complexity, applicable only on uplink transmission |
| Gawande and Ladhake [75] | Clipping, filtering | Power Spectral Density, PAPR | Better PAPR reduction | No outcomes, Narrowed scope of outcomes. |
| Tsokanos et al. [76] | clipping, bit loading, thermal detuning | PAPR | PAPR reduced, better BER performance | No benchmarking outcomes, Narrowed scope of outcomes, |
| Joseph and Kumar [77] | companding transform and band pass filter | PAPR, power Spectral density | PAPR reduced, better BER performance | No benchmarking outcomes, Narrowed scope of outcomes, |
| Rindhe et al. [78] | Amplitude clipping | PAPR, BER | -N/A- | No benchmarking outcomes, Narrowed scope of outcomes, |
| Vujicic et al. [79] | Semi conductor optical amplifiers | BER | Optimized spectral efficiency | No benchmarking outcomes, Narrowed scope of outcomes, |
| Haque and Mowla [80] | Elliptical filtering, clipping | BER | PAPR reduced, better BER performance | No benchmarking outcomes |
| Juliao et al. [81] | Experimental Approach | PAPR | PAPR reduced | No benchmarking outcomes |
| Zhang et al. [82] | cryptography | BER, PAPR | PAPR reduced, better BER performance | Complexity not reduced |

## 2.5 STUDIES USING PARTIAL TRANSMIT SEQUENCE

Among all the technique for PAPR reduction, Partial Transmit Sequence (PTS) is one of the frequently used techniques in OFDM. The technique allows the data symbols to be partitioned into certain number of sub blocks of disjoint types. The sequences are also subjected to rotation using a phase factor to generate an OFDM signal in time domain. This sections details about some of the significant research contribution using time domain techniques in OFDM for PAPR reduction.

Alavi et al. [83] have presented a technique using PTSon OFDM system for minimizing the PAPR value. The study uses sphere decoding mechanism where the elite weight attribute is computed using exhaustive search technique over each sub blocks. The technique essentially optimizes the OFDM signal in order to minimize the PAPR. Yang et al. [84] have presented a technique using PTSalong with a predefined threshold factor in order to address the problem of computational complexity in OFDM. The technique mainly thrives to establish a relationship between the transmitted bit vector as well as weighing factors for minimizing PAPR value in OFDM. The outcome of the study was assessed using ROC (Receiver Operating Curve), ASN (Average Search Number), and PAPR to see better PAPR reduction.

Lim et al. [85] have presented a scheme of PAPR reduction where the inverse function of FFT in segregated into two parts. According to the scheme, the input sequences is subjected to transformation scheme using the specific number of the stages of inverse FFT that results in certain sequence of signal, which is again subjected to partition. The final signals are added which allows the system to select only the signal with lowest PAPR. The study outcome is shown to minimize the computational complexity to a great extent. Ghassemi et al. [86] have developed a technique for addressing the problem of complexity and PAPR reduction in OFDM system. The authors have enhanced the conventional PTS by adding more decomposition of it to generate sub blocking. There are various levels of transforms that are applied to each sub blocks. The study outcomes are found to show enhanced PAPR on multiple variants of Partial Transmit Sequence.

Ghassemi et al. [87] have jointly used PTS along with error correction for minimizing PAPR. The authors developed the OFDM signal using the autocorrelation function, which is then followed up by sub-blocking features. The authors have also used error correction that significantly reduces the extents of errors. The study outcome shows PAPR is reduced using radix FFT technique. Wu et al. [88] have considered the problem of partitioning during the interleaving process in PTSby developing a unique conjugate scheme of it. The sub-blocks are subjected to conjugate operation, which are then optimized for enhancing the PAPR minimization in OFDM signals. Yang et al. [89] have designed and developed a new OFDM signal which lacks the side information. The study uses cyclic shifting mechanism for generating the candidates. The study also allows the successful recovery of the original signal. The study is also found to accomplish better BER performance in presence of standard noise and fading effect. Gao et al. [90] have presented a technique called as Harmony Research algorithm for the purpose of minimizing PAPR in OFDM. The technique is more or less a replica of genetic algorithm, where the simulation study is carried out using QAM modulation with only 256 carriers. The simulation outcome shows better PAPR reduction. Hou et al. [91] have presented a scheme of minimizing the computational complexity using correlational factor among the candidate signals that is generated due to Partial Transmit Sequence. The study outcome shows better PAPR reduction for 256 sub carrier using QPSK modulation.

Lain et al. [92] have used genetic algorithm for optimizing the PAPR reduction with an aid of Partial Transmit Sequence. The evolutionary-based optimization scheme is more based on real valued logic. The simulation was carried out using 64 subcarriers, where the study outcomes show better PAPR minimization.

Pradabpet and Dejhan [93] have evolved up with a novel technique of minimizing PAPR by integrating PTS with a unique power minimization technique in OFDM. The technique allows the sequence to be rearranged for the purpose of minimization of PAPR. Simulation results for 64 subcarriers shows better enhancement of the PAPR, BER, and effective power spectral density.

Mouhib and Oquour [94] have adopted the swarm intelligence based optimization along with PTSfor solving the problem of PAPR in OFDM-MIMO. The simulated outcome shows better minimization of computational complexity along with PAPR reduction.

Taspinar et al. [95] have adopted bee colony optimization for the purpose of PAPR reduction in OFDM. The technique also makes use of the arbitrary search technique. Modulated using QAM over 256 subcarriers, the simulation outcome shows better minimization of PAPR compared to conventional techniques of Partial Transmit Sequence. Cuteanu and Isar [96] have implemented a joint technique of PTS along with Clipping for minimizing the PAPR of the OFDM. The prime principle of the presented technique deals with the linear transformation. With an aid of QAM modulation, the proposed study was simulated to show it has better power spectral density with an effective BER performance.

Duanmu and Chen [97] have used both SLM with PTS for addressing PAPR minimization problems. It extracts the advantageous features of both to ensure better signal performance. The technique also classifies the signal into dual parts where the first part of the signal is subjected to Selective Level Mapping and second part is subjected to PTS. The outcome shows better BER performance. Ye et al. [98] have enhanced the conventional Partial Transmit Scheme by adding the principle of offset QAM scheme. The base idea is to classify the overlapped signals into multiple segments which are then multiplied with discrete factors of phase rotation.

Zahra et al. [99] have developed a technique that is almost equivalent to the work carried out by Duanmu and Chen [97]. The simulation study was carried out with 64 subcarriers considering QPSK modulation scheme. Zhi et al. [100] have used evolutionary technique over the PTSfor minimizing PAPR. The simulated outcomes show better improvement in contrast to existing techniques. The technique has better capability to recover data without any dependency of side information. Dong et al. [101] have implemented ant colony optimization for enhancing the PAPR minimization. The study also enhances the PTS. In order to overcome the dependency of the legacy algorithm, the technique uses the unused subcarriers for forwarding the side information. The simulated outcome of the study shows better minimization of PAPR.

Guo et al. [102] have developed a dual stage recursive algorithm for Partial Transmit Sequence. The simulation study was carried out using QPSK on 128 subcarriers by applying pseudo random partitioning. However, the technique fails to achieve better PAPR. Hence, it can be seen that the frequently used PTSis also associated with degradation of PAPR. Although, there are various techniques that has been presented till date, but all the technique are found with certain advantages and limitations. Table 2.4 summarizes the work being carried out in this regards.

**Table 2.4 Techniques of PAPR Reduction using Time-domain techniques**

| Authors | Technique | Performance Parameter | Advantage | Limitation |
|---|---|---|---|---|
| Alavi et al. [83] | Sphere decoding | PAPR | Better benchmarked outcomes, 50% complexity minimized | Iterative process leads to computational complexity that is not testified |
| Yang et al. [84] | Predefined thresholding | ROC, ASN, PAPR | Minimized computational complexity | Outcomes not benchmarked |
| Lim et al. [85] | Enhanced partial transmit sequence | BER, Power Spectral Density | Minimize complexity by 48%, supports high data rate | Outcome doesn't supports scalability |
| Ghassemi et al. [86] | Enhanced Partial Transmit Sequence | PAPR | Mitigates complexity and PAPR | Occurrences of lower complex values are less |
| Ghassemi et al. [87] | Error correction | PAPR | Minimizes complexity | Less Effective benchmarking |
| Yang et al. [89] | Cyclic shifting | BER, PAPR | Complexity reduced | Highly dependent on channel information |
| Gao et al. [90] | Harmonic Research Algorithm | PAPR | PAPR is reduced | Less focus on complexity mitigation due to harmonic algorithm |
| Hou et al. [91] | Correlation among the signals | PAPR | Reduces complexity | Convergence behaviour of optimization not addressed |
| Lain et al. [92] | Genetic Algorithm | PAPR | Minimizes PAPR | The time consumption to exploring global maxima is not |

| Authors | Technique | Performance Parameter | Advantage | Limitation |
|---|---|---|---|---|
| | | | | ensured, hence not scalable |
| Pradabpet and Dejhan [93] | Partial Transmit Sequence, | BER, PAPR | Reduces BER | Convergence behaviour of algorithm is not discussed |
| Mouhib and Oquour [94] | Swarm intelligence | PAPR, BER | Complexity and PAPR is reduced | Outcomes not benchmarked |
| Taspinar et al. [95] | Bee Colony Optimization | BER, PAPR | Good PAPR reduction | BER could be further improved |
| Cuteanu and Isar [96] | Clipping, partial transmit sequence | PAPR, BER | Complexity and PAPR is reduced | Outcomes not benchmarked |
| Duanmu and Chen [97] | Partial Transmit Sequence, Selective Level Mapping | PAPR, BER | Better BER performance | Convergence behaviour of algorithm is not discussed |
| Ye et al. [98] | Enhanced Partial Transmit Sequence | BER, PAPR | Complexity, BER, and PAPR is reduced | Complexity could be further reduced |
| Zahra et al. [99] | Partial Transmit Sequence, Selective Level Mapping | PAPR, BER | Better BER performance | Convergence behaviour of algorithm is not discussed |
| Zhi et al. [100] | Genetic Algorithm | BER, | Good data recovery | Less effective benchmarking |
| Dong et al. [101] | Ant Colony Optimization | PAPR, BER | Resists loss of throughput | Convergence behaviour of algorithm is not discussed |
| Guo et al. [102] | Enhanced PTS | PAPR, BER | Complexity reduces | Convergence behaviour of algorithm is not discussed |

## 2.6 STUDIES USING SELECTIVE LEVEL MATCHING

Selective Level Mapping is another frequently used technique for enhancing the performance of OFDM system pertaining to PAPR reduction. Basically, it is a form of turbo coding system that considering the multiplication of input symbol sequence with predefined sequence in order to generate an alternative sequence of input symbol. The mechanism of Selective Level Mapping considers the sensitivity of the OFDM signal with respect to the phase shift over frequency domain. Till date, there has been various research works to state that adoption of Selective Level Mapping significantly reduce the PAPR in OFDM. This section will present brief discussion about some significant research work till date on OFDM using Selective Level Mapping.

Cheng et al. [103] have presented a work that enhanced the conventional Selective Level Mapping by adding the chaotic factor in it. The authors have come up with a new factor for evaluating the influence of multiple sequence of phase completely based on the empirical correlation on all the signals of OFDM. The simulation was performed on 64 subcarriers with 16 QAM to find the presented technique reduces the PAPR. Heo et al. [104] have developed a technique of minimizing PAPR over OFDM by enhancing the existing techniques of Selective Level Mapping. The presented technique has attempted to generate increasing number of alternative signals of OFDM sequences followed by transmission of subcarriers with minimum PAPR. Using 2058 subcarriers and 16 QAM modulation, the outcome of the study shows better effect on PAPR minimization. Chandwani et al. [105] have used Riemann sequence along with the thresholding mechanism of the power amplifier for optimizing the computational complexity associated with Selective Level Mapping Technique in OFDM. The simulation study is carried over 64 subcarriers using 64 QAM to find the present technique has positive effect on complexity control.

Jeon et al. [106] have used a bit based approach in OFDM for minimizing the PAPR values. The study has used bitwise and partial inversion of bit over conventional Selective Level Mapping in order to achieve its desired outcome using QAM modulation. The simulated outcome shows an effective gain in shaping and PAPR minimization. Wang et al. [107] have presented a technique that jointly implements Selective Level Mapping with discrete cosine transform in order to minimize the PAPR values of the OFDM. The simulation model is developed considering a channel with additive white Gaussian noise over 64 subcarriers and QPSK modulation. The study outcome shows better PAPR control. Abdullah et al. [108] have presented a study that performs comparative analysis of the existing techniques for minimizing PAPR in OFDM. However, the study was only theoretical and gave sound information about theory of multiple techniques e.g. block coding, interleaving, clipping and filtering, selective level mapping, tone reservation, PTSetc. Dubey et al. [109] have enhanced the existing Selective Level Mapping that directly affects in minimizing the PAPR values in OFDM. The technique permits the segmentation of a complex signal into imaginary as well as real segments. It then selects the value with reduced PAPR.

Meng et al. [110] have investigated on Ultra Wide Band based OFDM signal for minimizing PAPR problems. The technique attempts to make the system independent from side information for lowering the PAPR. Dhungana et al. [111] have investigated the joint impact of PTSwith selective level mapping for minimizing the PAPR values in OFDM. The study uses symbol scrambling technique with multiple sequences. The simulation was carried out on 128 subcarriers and QPSK modulation to find good declination of PAPR values in OFDM.

Goyoro et al. [112] have presented a study using Riemann Sequence along with discrete cosine transform for minimizing the PAPR values in OFDM. The system uses Riemann matrix for extracting the phase sequences used in selective mapping technique. Simulated using 256 subcarriers and BPSK modulation, the study outcomes shows better PAPR achievement. Hasan et al. [113] have presented a very unique precoding technique for enhancing the operation of Selective Level Mapping. The study have implemented Vandermonde –like matrix for minimizing the correlation of the input sequences for accomplishing better minimization of PAPR values in OFDM.

Hussain [114] have presented a technique of reducing PAPR using Selective Level Mapping in the transmitter design of OFDM. The study uses a technique called as partial selective level mapping that divides the inverse FFT block into micro blocks that further implements legacy selective level mapping. The simulation is carried out using 32 subcarriers using QPSK modulation to find better

PAPR minimization. Mahdi et al. [115] have investigated the problem of PAPR in OFDM and thereby presents a solution based on joint operation of selective level mapping and clipping.  By this technique, the system is able to overcome the problem of dependency of side information and degraded performance of bit error.

Adegbite et al. [116] have presented a unique study of integrating Shapiro Rudin sequence with Selective Level Mapping in OFDM system. The simulation is carried out over 256 subcarriers using QAM modulation for the purpose of enhancing the PAPR values of the OFDM system. Haris and Jose [117] have developed a scheme based on clipping process and selective level mapping in OFDM system for the purpose of PAPR minimization. The study uses clipping technique using mapping data that has cyclic shift for producing series of data block mapping with source information. The simulation is carried out by 64 subcarriers in presence of additive white Gaussian noise and QPSK modulation.

Pyla et al. [118] have developed a mechanism for enhancing the PAPR performance over OFDM system using Selective Level Mapping. The study uses the approach of distortionless policy for minimizing the PAPR values along with usage of turbo codes and forward error correction mechanism. The outcome of the study was tested for peak power values in presence of multiple modulation schemes (BPSK, QPSK, 8PSK, and 16QAM). Regi and Haris [119] have presented a scheme of selective level mapping that orients the phase angle of the input data after being subjected to inverse FFT operation. The study also uses Hadamard code as well as clipping for minimizing PAPR in OFDM.

Sonna and Suma [120] have designed and developed a technique that jointly implements companding operation with selective level mapping in OFDM for minimizing the PAPR. The simulation study was carried out using 128 subcarriers using BPSK modulation and was evaluated over multiple sequences. Adegbite et al. [121] have presented a technique that performs cancellation of side information without any need of transmission of side information in SLM. This charecteristics has significant effect on PAPR reduction in OFDM system. Mhatre and Khot [122] have performs a simple simulation study considering 64-256 subcarriers for minimizing PAPR in OFDM.  The author have used 64-1024 subcarriers to study the performance of Selective mapping. The study outcome shows PAPR is indirectly proportional to phase sequence and directionly proportioanal to number of subcarriers. Table 2.5 summarizes the research contribution in this regards.

**Table 2.5 Techniques of PAPR Reduction using Frequency-Domain approach**

| Authors | Technique | Performance Parameter | Advantage | Limitation |
|---|---|---|---|---|
| Cheng et al. [103] | Chaotic theory | PAPR | Reduces PAPR | Narrowed Scope of results over futuristic applications |
| Heo et al. [104] | Enhanced Selective Level Mapping | PAPR | Effective control on computational complexity | Narrowed Scope of results over futuristic applications |
| Chandwani et al. [105] | Riemann Sequence | PAPR | Effective control on computational complexity | Narrowed Scope of results over futuristic application, outcomes not benchmarked |
| Jeon et al. [106] | Partial bit inversion | PAPR | Effective benchmarked outcomes, low complexity | Convergence behaviour of an algorithm over multiple modulation not studied |
| Wang et al. [107] | Joint operation of Selective Level Mapping and Discrete Cosine Transform | PAPR | Controlled PAPR to 1.2 dB | Narrowed scope of outcome, extensive simulation result is missing |
| Dubey et al. [109] | Enhanced selective level mapping, signal separation to real and imaginary parts | PAPR | Good mathematical modelling | PAPR could be further reduced, complexity is not reduced optimally |
| Meng et al. [110] | Enhanced Selective Level Mapping | PAPR | Independent from side information | Narrowed scope of outcome, couldn’t minimize the complexity |
| Dhungana et al. [111] | Joint operation of PTS and selective level mapping | PAPR | Minimized PAPR | Outcomes not benchmarked |

| Authors | Technique | Performance Parameter | Advantage | Limitation |
|---|---|---|---|---|
| Goyoro et al. [112] | Joint operation of Selective Level Mapping, Riemann Sequence, and Discrete Cosine Transform | PAPR | Reduce PAPR to 4.7dB | Less effective benchmarking |
| Hasan et al. [113] | Vandermonde – like matrix | BER, PAPR | Good benchmarked outcomes | Should have tested with multiple modulation schemes too |
| Hussain [114] | Partial selective level mapping | PAPR | PAPR reduced to 3 dB | Less Effective benchmarking, narrow scope of result |
| Mahdi et al. [115] | Clipping, Channel state information | PAPR, BER, SNR | PAPR and BER minimization | Convergence behaviour of an algorithm not studied |
| Adegbite et al. [116] | Shapiro Rudin Sequence | PAPR | Enhances the energy efficiency of the processor | The convergence behaviour as well as correlation behaviour is not studied |
| Haris and Jose [117] | Clipping, Selective Level Mapping | PAPR, BER | Reduced PAPR | Data correlation of the complexity is not studied |
| Pyla et al. [118] | Selective Level Mapping | PAPR | Minimize PAPR | Time complexity not studied for presented digital modulations |
| Regi and Haris [119] | Hadamard Sequence, clipping, SLM | BER, PAPR | Minimize PAPR to 3.9 dB | Extensive simulated Outcomes missing |
| Sonna and Suma [120] | Companding and Selective Level Mapping | PAPR | Good PAPR reduction | Convergence behaviour of an algorithm for multiple modulation not studied |
| Adegbite et al. [121] | Selective level mapping | BER, PAPR | Good PAPR reduction | Convergence multiple modulation not studied |

## 2.7 RESEARCH GAP

From the prior section it can be seen that there are various techniques for minimizing the PAPR in OFDM systems till date. This chapter has studied precisely 100 standard research documents published till date addressing the problems of PAPR. All the studies that have been implemented till date have obvious advantages and some new evolution of the potential theory. At the same time, it is also associated with some major pitfalls. This section will brief about the core research gap explored after reviewing the existing solutions towards minimizing PAPR.

- **Lack of Potential Benchmarking**: It has been observed that 95% of the existing studies are not subjected to an effective benchmarking, which leads to uncertainty about the future adoption of such techniques. Lack of benchmarking also gives vagueness on the claimed contribution of the presented studies.

- **Smaller Scope of Implementation**: There is no doubt that there are massive range of research publications towards addressing the problems of PAPR. There are also some set of research that attempts to hybridize the existing techniques to further optimize PAPR reduction. However, extent of hybridization is found to be limited by joint operation of not more than 3 techniques at same time. Although, there are better possibility to evolve up with optimized results by adding more techniques but it was not found in existing literatures.

- **Inefficient evaluation of Algorithm behaviour**: Till date, it is quite obvious that 97% of the international journals in PAPR minimization uses digital modulation schemes as well as it is more of computational model. Although, it is known fairly by all researchers that an effectiveness of a computational model can be only judged by its time and space complexity, but there is no single study where such standards were owned to prove effectiveness or show standard outcomes.

- **Fluctuations in Simulation Modelling**: Majority of the research papers published till date have higher variance or non-uniformity of considering simulation parameters e.g. number of subcarriers, modulation techniques, etc. In such conditions, it is not possible to compare the outcomes of one research work with others when the simulation parameters differ.

- **Less Emphasis on Reconfigurable Networks**: Majority of the existing networks and communication principles are migrating towards reconfigurable network, which is associated with many complex issues. The standards e.g. 4G, 5G, IoT (Internet-of-Technology) should be more emphasized by evolving up with higher scale of design in OFDM principle. At present, extent of novelty in PAPR reduction methods are extremely less in numbers.

## 2.8 SUMMARY

This chapter has presented an elaborated discussion of 100 standard research publications to review the existing techniques of PAPR reduction in OFDM. The outcome of the review shows that there are various research contributions in this regards but still there is an open research gap, which should be addressed. The next chapter discusses about one of the proposed preliminary models for building such research gap discussed in this chapter.

# CHAPTER 3

# PAPR REDUCTION TECHNIQUES IN OFDM SYSTEMS USING DCT AND IDCT

## 3.1 INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) has gained much popularity in the field of wireless communication because of its ability to transfer the data at higher rates, high bandwidth efficiency and its robustness to multipath fading. But, OFDM signal has high Peak to Average Power Ratio (PAPR). So, many techniques were proposed to reduce it. In this chapter, modified SLM technique based on discrete cosine transform [30] is proposed to reduce the PAPR of the transmitted signal. The PAPR reduction performance of the proposed technique is compared with that of IFFT based modified SLM technique and IDCT based modified SLM technique. A discretecosine transform (DCT) based modified Selective Level Mapping (SLM) technique is used to reduce the PAPR of the OFDM signal. In this technique, instead of using Inverse Fast Fourier transform (IFFT), inverse discrete cosine transform (IDCT) is used with modified SLM to reduce the PAPR. The performance of PAPR reduction of the proposed technique is compared with IFFT based modified SLM technique. Modified SLM technique with DCT improves the PAPR reduction of OFDM signal.

## 3.2 PAPR IN OFDM AND MIMO –OFDM SYSTEM

The PAPR of transmitted OFDM signal is defined as the ratio between the maximum instantaneous power and the average power, and it is expressed as,

$$PAPR = \frac{\max|x(t)|^2}{E\left[|x(t)|\right]^2} \tag{3.1}$$

where $x$ (t) denotes an OFDM signals after IFFT, and E [.] denotes expectation. Let us denote the data block of length N as a vector Y= [$Y_{0,}$ $Y_{1,}$ $Y_{2\ldots}$ $Y_{N-1}$] $^T$ where N is equal to the number of subcarriers and $(.)^T$ denotes transpose. The duration of a data symbol in Y modulates one of a set of subcarriers, {FN=0, 1… N-1}.The N subcarriers are chosen to be orthogonal, that is $f_{m=}m\Delta f$, where $\Delta f$=1/NT and NT is the duration of an OFDM data block .The complex envelope of the transmitted OFDM signal is given by

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=1}^{N-1} Y_k e^{j2\pi k\Delta ft} \tag{3.2}$$

where $Y_k$is the data symbol carried by the $k^{th}$ subcarrier.

According to the limit central theorem, when N is large, both real and imaginary part of $x$ (t) is Gaussian distributed. The Cumulative Distributed Function (CDF) of the signal is

$$F(z) = 1 - e\text{-}z \tag{3.3}$$

If there are N subcarriers in an OFDM system, and all the sampling values are complete independent, the CDF of the system is given by the equation:

$$P\left(PAPR > PAPR_0\right) = 1 - \left(1 - e^{PAPR_0}\right)^N \tag{3.4}$$

So in case of no over sampling, the Complementary Cumulative Distribution Function (CCDF), this is usually used as an important parameter to describe the PAPR of an OFDM signal which is written as follows

$$P\left(PAPR > PAPR_0\right) = 1 - \left(1 - e^{PAPR_0}\right)^N \tag{3.5}$$

where $PAPR_0$ is the clipping level. This equation is read as the probability that the PAPR of a symbol block exceeds some clip level $PAPR_0$.

$$p\left(PAPR_{MIMO-OFDM} > PAPR_0\right) = 1 - \left(1 - e^{PAPR_0}\right)^{M_t N} \tag{3.6}$$

Since in MIMO-OFDM, $M_t$ N is the time domain samples are considered compared to in OFDM system.SLM is one of the probabilistic techniques adopted to reduce the PAPR of the OFDM signal. Hence it can achieve PAPR reduction without distorting the signal and will not cause any loss of data.

## 3.3 SELECTIVE LEVEL MAPPING SCHEME

As shown in Fig. 3.1, In SLM technique the input data is partitioned into Y data block of length N .Then the OFDM data block is multiplied element by element with phase sequence $E^{(u)}=[e_{u,0},e_{u,1},\ldots e_{u,N-1}]^T$ where u=1,2,…………U , U phase rotated OFDM data block $Y^u$ is obtained.

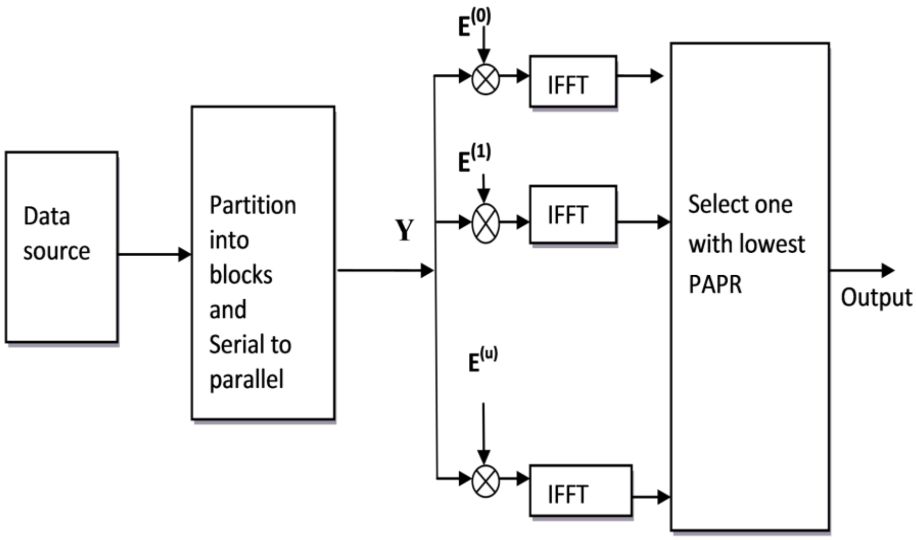


**Fig. 3.1 Selective Level Mapping Scheme**

All phase rotated OFDM data blocks represent the same information as the unmodified OFDM data block provided that the phase sequence is known.

$$Y(t) = \frac{1}{\sqrt{N}} Y_k e_m k e^{j2\pi k \Delta f t} \tag{3.7}$$

Among the phase rotated OFDM data blocks one with the lowest PAPR is selected and transmitted. The information about the selected phase sequence should be transmitted to the receiver as side information. At the receiver, reverse operation should be performed to recover the unmodified OFDM data block. In ordinary SLM technique, there is no restriction on the construction of phase sequence s. However, we set a structural limitation on the phase sequence for modified SLM.

## 3.4 DCT TRANSFORM

The peak value of the auto correlation is the average power of input sequence. DCT conceptually extends the original N-point data sequence to 2N-point sequence by doing mirror –extension of the N-point data sequence. Since the both end of data is always continuous in the DCT, the lower order of components will be dominated in the transform domain signal after converted by DCT. The DCT is a Fourier-like transform, which was first proposed by Ahmed et al. [17] [20]. The idea to use the DCT transform is to reduce the autocorrelation of the input sequence to reduce the peak to average power problem and the transmitted signal does not require any side information at the receiver. In the section, we briefly review DCT transform. The 1D discrete cosine transform (1D DCT) A[k] of a sequence a[n] of length N is defined as:

$$A[k] = a[k] \sum_{n=0}^{N-1} a[n] \cos\left[\frac{\pi(2n+1)k}{2N}\right] \tag{3.8}$$

For k = 0, 1 . . . N- 1, the inverse DCT is defined as

$$a[n] = \sum_{n=0}^{N-1} a[k] A[k] \cos\left[\frac{\pi(2n+1)k}{2N}\right] \tag{3.9}$$

n= 0, 1… N-1 where a[k] is defined as:

$$a[k] = \begin{cases} \sqrt{1/N} & for \quad k=0 \\ \sqrt{2/N} & for \; k=1,2,............N-1 \end{cases} \tag{3.10}$$

The basis sequences of the 1D DCT are real, discrete-time sinusoids defined by:

$$C_N\left[n,k\right] = \cos\frac{\pi(2n+1)k}{2N} \tag{3.11}$$

The DCT basis consists of the following N real sequences.

$$C_N\left[n,0\right], C_N\left[n,1\right], ............C_n\left[n,N-1\right] \tag{3.12}$$

The equation (3.8) is expressed in matrix

$$A = C_N a \tag{3.13}$$

where A and an are both the vector with Nx1 and $C_N$ is a DCT transform matrix with N x N.

The row (or column) of the DCT matrix $C_N$ are orthogonal matrix vectors. Then we can use this property of the DCT matrix and reduce the peak power of OFDM signals.DCT can reduce the autocorrelation between the each component of OFDM signal this is the root cause to reduce PAPR.

### 3.4.1 DCT with Modified Selective Level Mapping

DCT along with Selective Level Mapping become an efficient PAPR reduction technique by integrating SLM and DCT matrix transform. PAPR is reduced by modifying the OFDM signal without any distortion, but still the complexity of SLM is high. For every OFDM frame, SLM technique requires ‘n’ IFFT operation and this operation makes the system complicated. So as to prevail over system complexity of SLM, modified SLM is proposed. The modified SLM reduces IFFT block and also the PAPR. This technique comprises of an IFFT block at the transmitter end and the decision of selecting data with lowest PAPR is accomplished using a decision algorithm before IFFT. The algorithm for modified SLM is given as follows,

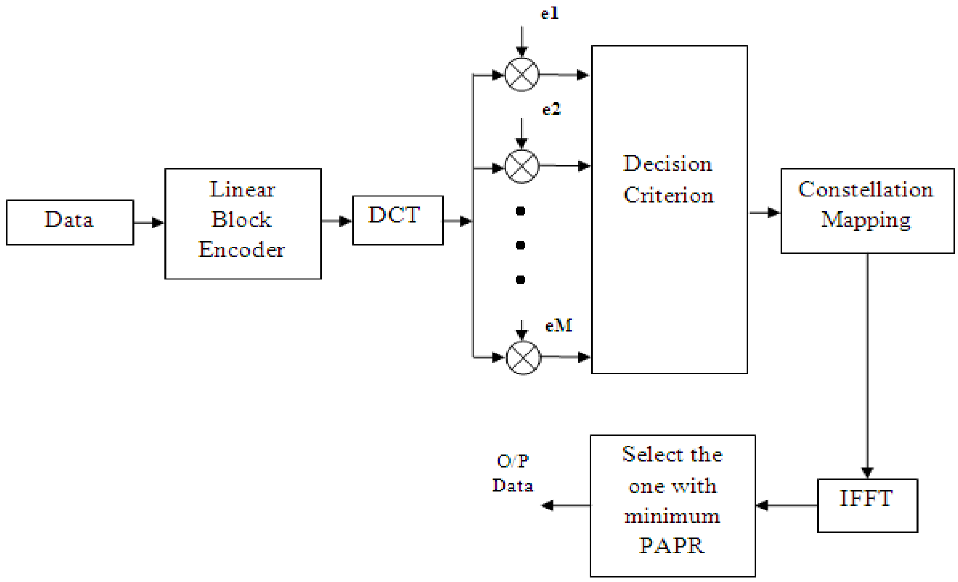


**Fig. 3.2 Modified SLM with IFFT**

**Algorithm**

---

I. *Let $X_1$, $X_{2}$,..., $X_n$ be the Binary information blocks.*

II. *Assume W as the encoding code word.*

III. *Every block is encoded into w using Hamming encoder.*

IV. *A control bit is appended to w and extended hamming code of 8-bits is calculated.*

V. *The error table and coset leader is computed.*

VI. *Vectors w+e1, w+e2, ..., w+e16 are constructed for (every code word)*

VII. *Calculate* $A = X^2 + Y^2 + Z^2$.

VIII. *Code word that has minimumA is chosen and transformed into OFDM signal through constellation mapping and IFFT.*

---

The block diagram of DCT with modified SLM using IFFT is shown in Fig. 3.2 and the corresponding output signal is described by assume, $s = [s_0, \quad s_1 \quad \cdots \quad s_{n-1}]^T$ as a discrete time OFDM signal vector. Then, the IFFT of vector s takes the form as,

$$s = QS \tag{3.14}$$

where, $Q$ symbolizes the IFFT matrix and it can be represented as, [13]

$$Q = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 1 & e^{j2\pi/n} & \cdots & e^{j2\pi(n-1)/n} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & e^{j2\pi(n-1)/n} & \cdots & e^{j2\pi(n-1)(n-1)/n} \end{bmatrix} \tag{3.15}$$

Thus, as column matrix IFFT matrix $Q$ can be expressed as,

$$Q = [Q_0 \quad Q_1 \quad \cdots \quad Q_{n-1}] \tag{3.16}$$

In this proposed system, DCT with modified selective level mapping technique is considered to reduce the PAPR in OFDM system. The sequence of process is given below.

*i.* At the transmitter end, the source data is forwarded to the linear block encoder

*ii.* To the outcome of encoder DCT is applied and the transformed data are processed by modifying SLM unit

*iii.* The modified algorithm illustrated in algorithm-1 is invoked

*iv.* The information with low PAPR is selected and output is generated

### 3.4.2 Modified SLM with Inverse DCT for OFDM

OFDM system is employed considering orthogonal basis of the complex exponential function set. But, OFDM can also be implemented using a single set of

Co sinusoidal function as an orthogonal basis. This Co sinusoidal function is integrated along with a DCT, and hence this scheme is termed as DCT-OFDM and the output signal are given as,

$$x(n) = \sqrt{\frac{2}{n}} \sum_{i=0}^{n-1} ds_i D_i \cos\left(\frac{i\pi n}{T_s}\right) \tag{3.17}$$

In equation (18) $ds_0, \; ds_1, \; \cdots \; ds_{n-1}$ represent the independent data symbols that are attained as of a modulation constellation. $T_s$ symbolize the sampling interval. $D_i$ takes the value as,

$$D_i = \begin{cases} 1/2 & i=0 \\ 1 & i=1,2.....n-1 \end{cases} \tag{3.18}$$

The system that uses modified SLM with Inverse Discrete Cosine Transform (IDCT) is pictured in Fig. 3.3.

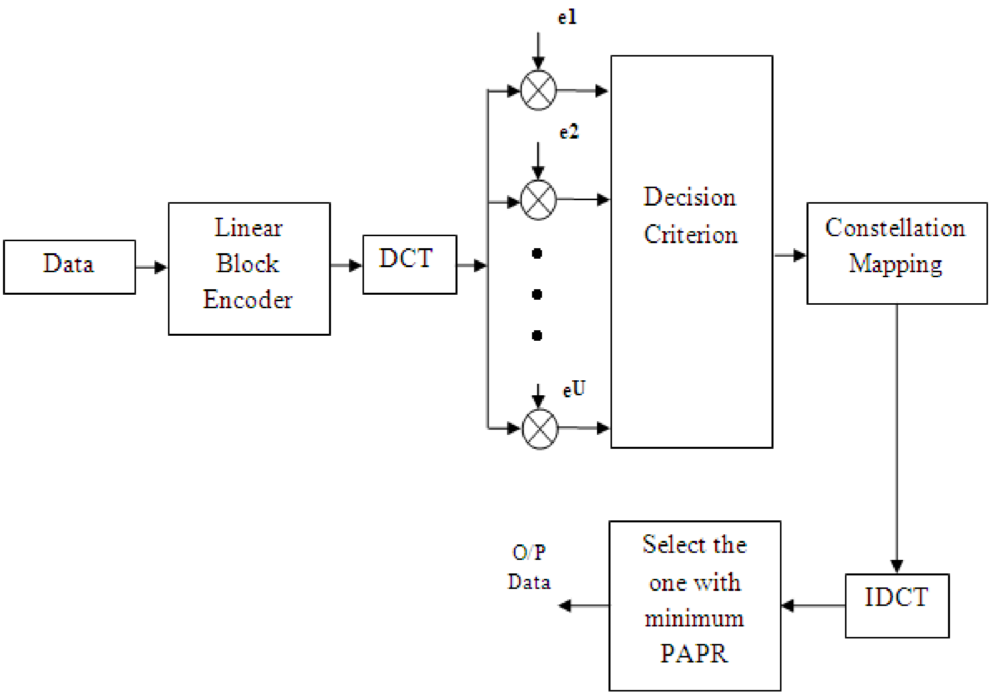


**Fig. 3.3 Modified SLM with IDCT**

In this work, the data stream is transformed by DCT. It can linearly transform data into the frequency domain, where the data can be represented by a set of coefficients. The advantage of DCT is that the energy of the original data may be concentrated in only a few low frequency components of DCT depending on the correlation in the data. and then the transformed data are processed by the SLM unit where each data block is multiplied by *C* different number of phase sequence vectors. If the data passed by DCT matrix before IDCT, the autocorrelation coefficient of IDCT input sequence is reduced with low complexity and no side information is required because the matrices can be generated to recover the original data at the receiver and the data is transmitted with lowest PAPR.

## 3.5 SIMULATION RESULTS AND DISCUSSION

The analysis of the modified SLM with DCT, IFFT and IDCT has been carried out using MATLAB software. The entire simulation parameters considered for this analysis is summarized in Table 3.1.

**Table 3.1 Simulation parameters for modified SLM with DCT, IFFT and IDCT**

| Simulation parameter | Type/value |
|---|---|
| Number of subcarriers (N) | 64,128,256,512,1024 |
| Modulation Scheme | QAM |
| Phase weighting factor(e) | 16,64 |
| Coding technique | Linear block coding |

In the OFDM System under consideration, modified SLM technique is applied to the encoded information in the sub blocks, which is modulated by QAM modulation. The performance evaluation is done in terms of CCDF.

### 3.5.1 Different Subcarriers using IFFT for OFDM System

Fig. 3.4 shows the comparison of PAPR reduction performance for DCT based modified SLM with different subcarriers 64,128,256,512 and 1024 in OFDM system. it is evident that the PAPR values of are obtained for different subcarriers of size 4.5dB, 5.2dB, 5.4dB,5.6db and 6.1dB respectively at CCDF of $10^{-3}$ .the simulation result shows that with increase in the number of subcarriers ,the PAPR reduction performance is degraded.

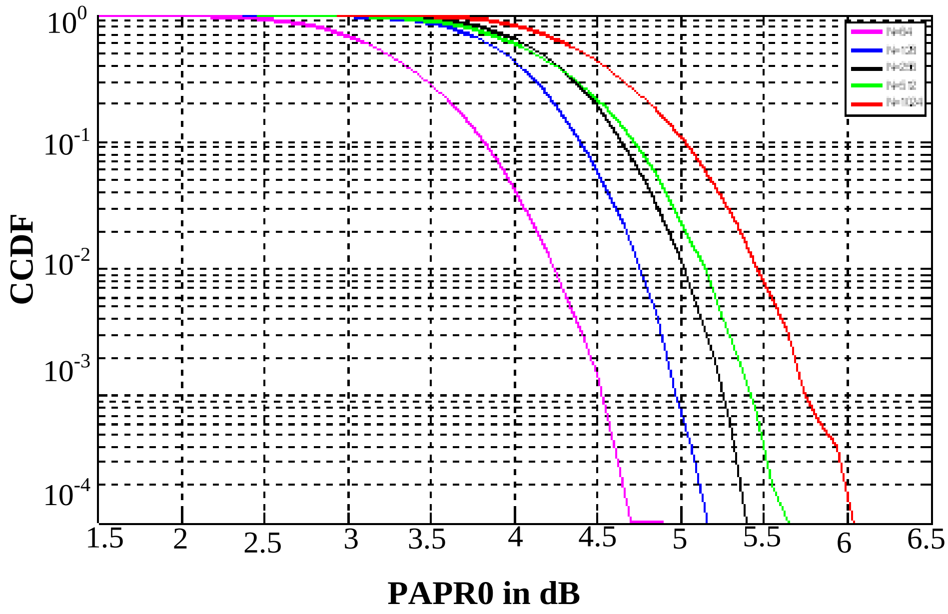


**Fig. 3.4 Different Subcarriers using IFFT for OFDM System**

### 3.5.2 Different Subcarriers using IDCT for OFDM System

In order to obtain high data rate, large number of subcarriers are needed which in turn increases the PAPR and computational complexity. To overcome this limitation, the size of the subcarriers can be varied with subcarrier size. The performance of DCT based modified SLM technique in OFDM system for different number of subcarriers is analyzed with IDCT. It is illustrated in 64,128,256, 512 and 1024 Figure 3.5. From this figure, it is found that the PAPR values for the various subcarriers 64, 128,256,512 and 1024 are 4.5 dB, 5.1 dB, 5.3 dB, 5.6dB and 5.8 dB respectively at CCDF of $10^{-3}$. It shows that the performance of PAPR reduction is increased when the number of subcarriers is increased.

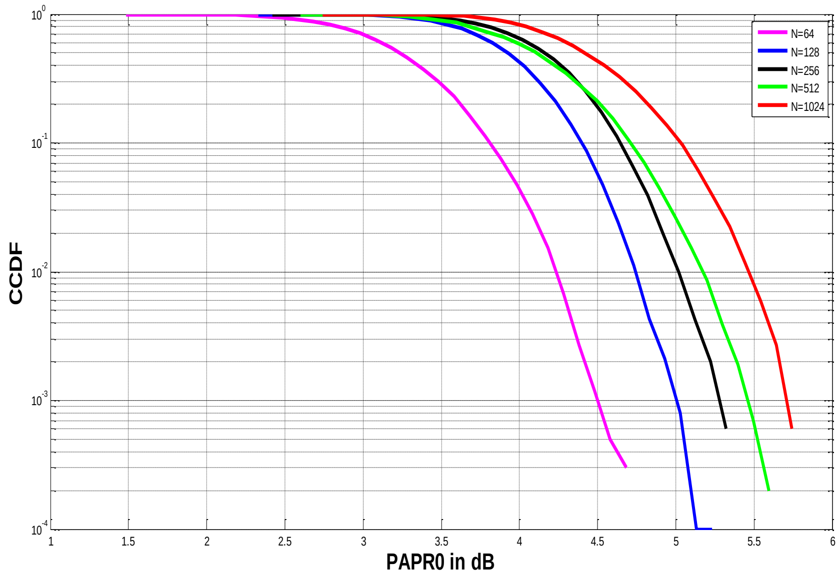


**Fig. 3.5 Different Subcarriers using IDCT for OFDM System**

### 3.5.3 Different Subcarriers using IDCT for MIMO-OFDM System

Fig. 3.7 displays the PAPR reduction performance of modified PTS with interleaving technique for different subcarriers of size 64, 128, 256, 512 and 1024 keeping IDCT in MIMO-OFDM with $M_t$ = 2. It can be observed that the PAPR values of 4.6 dB, 5.2 dB, 5.4 dB, 5.6 dB and 6.1 dB are obtained for different subcarriers of size 64, 128, 256, 512 and 1024 respectively at CCDF of $10^{-3}$.

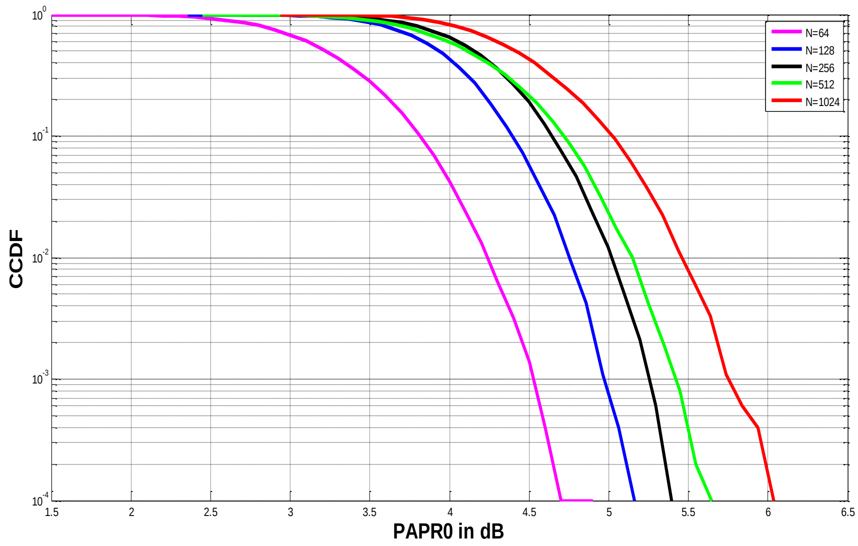


**Fig. 3.6 Different Subcarriers using IDCT for MIMO-OFDM System**

### 3.5.4 Different Subcarriers using IDCT for MIMO-OFDM System

Fig. 3.7 displays the PAPR reduction performance of the modified PTS with an interleaving technique for different subcarriers of size 64, 128, 256, 512 and 1024 keeping IFFT in MIMO-OFDM with $M_t = 2$. It can be observed that the PAPR values of 4.7 dB, 5.2 dB, 5.4 dB, 5.6 dB and 5.8 dB are obtained for different subcarriers of size 64, 128, 256, 512 and 1024 respectively at CCDF of $10^{-3.}$

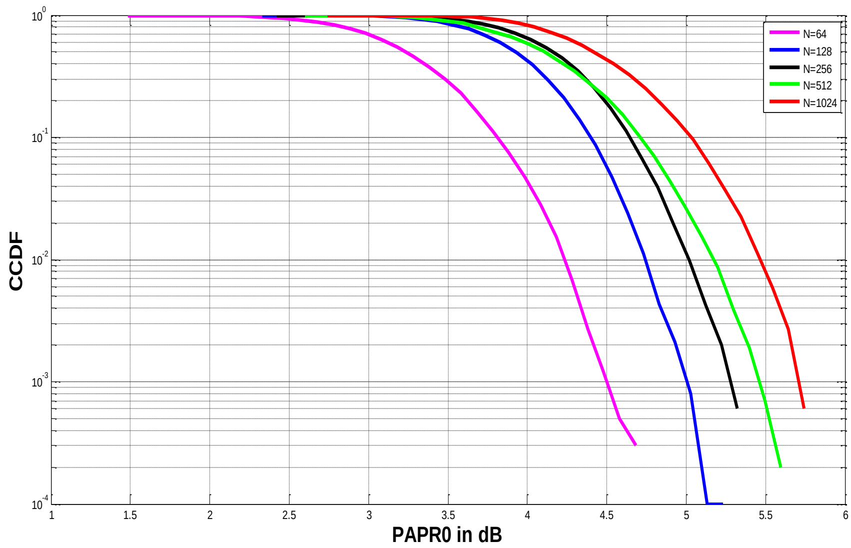


**Fig. 3.7 Different subcarriers using IFFT for MIMO-OFDM System**

## 3.6 SUMMARY

In this paper, PAPR analysis in DCT based OFDM is performed. Discrete Cosine Transform (DCT) based modified Selective Level Mapping (SLM) as an effective technique to reduce Peak to Average Power Ratio (PAPR) in OFDM. Modified SLM with Inverse Fast Fourier transform (IFFT) provides high PAPR .In order to reduce PAPR further modified SLM with Inverse Discrete Cosine Transform (IDCT) PAPR analysis is made using two techniques. Modified SLM technique with DCT improves the performance of OFDM signal with respect to PAPR and reduces autocorrelation coefficient .it uses only real data hence it reduces computational complexity. It provides efficient frequency spectrum utilization .OFDM proves invaluable demand for next generation communication system.

# CHAPTER 4

# MODIFIED SLM WITH CONSTANT MODULUS ALGORITHM IN OFDM AND MIMO-OFDM SYSTEMS

## 4.1 INTRODUCTION

The high PAPR of multicarrier signals is one of the major obstacles in implementing an OFDM system. The occurrence of large peaks in the signal seriously hampers the efficiency of a power amplifier. Hence, linear and consequently efficient amplifiers are required for the amplification of these signals to avoid distortion. The previous chapter dealt about the modified SLM combined with DCT technique to improve PAPR reduction performance in OFDM and MIMO-OFDM systems. Another way to improve the PAPR reduction performance is the use of Constant Modulus algorithm(CMA). CMA is an adaptive filtering technique that adjusts the filter coefficient in order to minimize the envelop variation for phase modulated signals. The time domain signals from many subcarriers are linearly combined using pre-coding weights, transparent to the receiver. And the pre-coding weights are designed to minimize the modulus variation of the resulting signal leading to reduction in PAPR. It uses two optimization algorithms to reduce PAPR. In Steepest Decent CMA the time domain signals from resource blocks consisting of several subcarriers are linearly combined using precoding weight, transparent to receiver, as shown in Fig. 4.1. In Unit Circle CMA the precoding weights can be designed to minimize the modulus variation of resulting signals leading to reduction in PAPR [123,124]. These techniques are compatible with different beam forming modes in single antenna and MIMO systems. The basic idea of using DCT transform in OFDM and MIMO OFDM is to reduce the autocorrelation of the input sequence to reduce PAPR. it reduces peak by spreading the signal using DCT matrix [125-132].

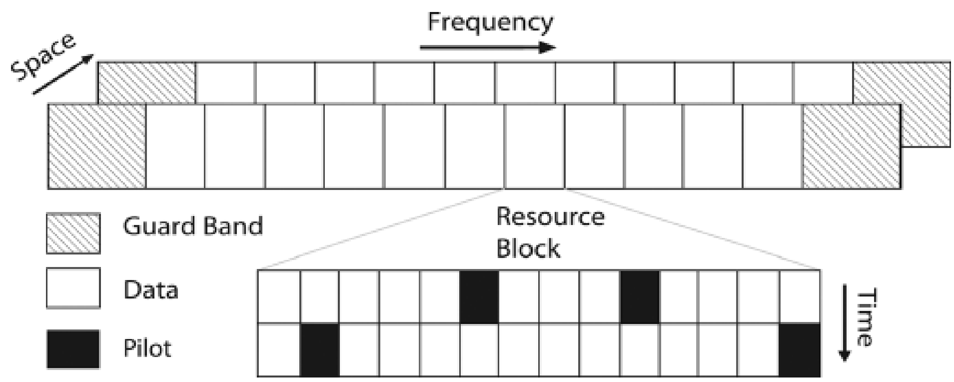


**Fig. 4.1 OFDM block for a MIMO-OFDM Downlink**

## 4.2 MODIFIED SLM AND IDCT SCHEME

Generally, the OFDM system is employed by considering orthogonal basis of complex exponential function set. However, OFDM can also be implemented by using a single set of co-sinusoidal function as an orthogonal basis. This co-sinusoidal function is integrated along with a DCT. The sequences normally used in any sort of transform from one domain to the other are referred to as the basis sequences. These are complex periodic sequences in case of Discrete Fourier transform. Thus, it is important to find out if there exist some real valued basis sequences that results in a real valued transform sequence. This has ended up in finding up of a lot of other transforms, which are all orthogonal transforms, such as Hadamard Transform, Hartley Transform etc. But there is another transform which is quite closely related to the DFT, which is called the DCT. DCT expresses a sequence of finitely many data points in terms of a sum of cosine functions oscillating at different frequencies. DCTs are important to numerous applications in science and engineering, from lossy compression of images where small high frequency components can be discarded. The most common variant of discrete cosine transform is the type II DCT, which is often called simply "the DCT" and its inverse, the type III DCT, is correspondingly often called simply "The inverse DCT" or "the IDCT". The use of cosine rather than sine functions is critical in these applications: for compression, it turns out that cosine functions are much more efficient as fewer functions are needed to approximate a typical signal. In particular, a DCT is a Fourier related transform similar to the discrete Fourier transform (DFT), but using only real numbers.

## 4.3 MIMO MODEL

The spatial data in frequency domain is given by,

$$V = Z^I A \qquad (4.1)$$

where I is the channel matrix and $Z = \left[Z^{(1)I,} \ldots, Z^{(C)I}\right]^I$, $A = \in \lambda^{CC_t \times D}$ is a block-diagonal matrix along with guard intervals. $C_t$ rows of this matrix represent the D symbols to be transmitted from $C_t$.

The time-domain model is obtained by taking IDCT of V by using,

$$W = VF^I = Z^I AF^I \qquad (4.2)$$

where $F^I \in \lambda^{D \times D}$ represents the IDCT matrix,

$W \in \lambda^{C_t \times D}$ includes the resulting transmit OFDM sequences for each of the $C_t$ antennas. Thus, beam formed OFDM block is given by the equation (4.3).

$$W = Z^I G \qquad (4.3)$$

where $G = AF^I$ = time domain data matrix.

The total energy in A is given by,

$$E_A = \|A\|_F^2 = \|\mathrm{vec}(A)\|^2 = \beta K_t \qquad (4.4)$$

where $K_t = KC_t$, vec (A) is a column vector whose elements are the columns of matrix A, $K_t$= total number of sub-carriers, sent from all $C_t$ antennas and $\beta$ = average transmit power per sample including zero power guard band.

## 4.4 PRE CODING MATRIX

PAPR is used to measure the distortion caused by probable high peaks of the OFDM signal in MIMO-ODFM block. It is defined as,

$$PAPR(W) = \frac{\beta K_t \| vec(W) \|_\infty^2}{\| vec(W) \|_2^2} \tag{4.5}$$

The reduced value of PAPR is attained for a constant modulus signal, for which the infinity norm is equal to the average power of the sequence. It is required to design a pre-coding matrix to transform OFDM symbols to constant modulus signal with lower PAPR. The resultant MIMO-OFDM matrix is,

$$\psi = \mathrm{Z}^{\mathrm{I}} \delta \mathrm{A} \mathrm{F}^{\mathrm{I}} \tag{4.6}$$

If $\tau$ = vecdiag ( $\delta$ ),then PAPR can be reduced by properly designing $\delta$ as follows , $\delta$ it is a diagonal precoding matrix.

$$\min_{\tau} \|\mathrm{vec}\ (\psi)\|_\infty^2 \text{ such that } \|\mathrm{vec}\ (\psi)\|_2^2 = \mathrm{E} \tag{4.7}$$

where E = $\beta$ $K_t$ = fixed total transmit power.

The pre-coding matrix reduces the dynamic range of OFDM block. It preserves the beam forming property and remains transparent to the receiver. It does not have any impact on bit error rate.

## 4.5 PROPOSED CONSTANT MODULUS APPROACH WITH MODIFIED SLM

The estimated $\Psi$ is a transmit matrix optimized and rewritten as by using Kronecker properties as follows from equation (4.6)

$$\psi = vec(\psi) = (\overline{G} \circ Z)^I vecdiag(\delta) =: Y\tau \tag{4.8}$$

where $Y \in \lambda^{K_t \times CC_t}$ , $AF^I = G \in \lambda^{CC_t \times K}$ , $\bar{G}$ denotes complex conjugate of G, ∘ iskhatri-Rao product column wise Kronecker product. vecdiag (A) generates column vector whose elements are main diagonal of Amatrix.

The optimization solution is,

$$\min_{\tau} \|\text{vec}(Y\tau)\|_{\infty}^{2} \text{ such that } \|\text{vec}(Y\tau)\|_{2}^{2} = \beta K_t \quad (4.9)$$

The relevant cost function is given using following equation (4.10)

$$O(\tau) = \| Y\tau \square (\bar{Y\tau}) - \beta 1_{K_t} \|_2^2 = \sum_{n=1}^{K_t} (\tau^I y_n y_n^I \tau - \beta)^2 \quad (4.10)$$

where $y_n^I$ (n = 1, 2…$K_t$) = n[th]row of Y matrix, $1_{K_t}$ is a column vector with all elements in the entries equal to 1 and dimension $K_t$, = Schur-hadamard product. Using steepest descent CMA technique, $\tau$ is updated until it converges.

$$\hat{\psi}^i = Y\tau^i \quad (4.11)$$

$$\text{er}^i = (er^i = (\hat{\psi}^i \square t\hat{\psi}^i) - \beta 1_{K_t} \quad (4.12)$$

$$\hat{\psi}_e = \hat{\psi}_e \square er^i \quad (4.13)$$

$$\varnothing \tau^{i+1} = \tau^i - \varepsilon \nabla s(\tau^i) = \tau^i - \varepsilon Y^T \hat{\psi}_e \quad (4.14)$$

where $\varepsilon$ is the step size, $\hat{\psi}_e$ is the update error and $\nabla$s( $\tau$ ) is the gradient vector . In order to limit the solution within unit circle, a normalization step has been added to each iteration after (14)

$$\tau^{i+1} = \tau^{i+1} | \tau^{i+1} | \quad (4.15)$$

where $\varnothing$ point-wise division and |.| is the absolute value of each entry of the vector argument.

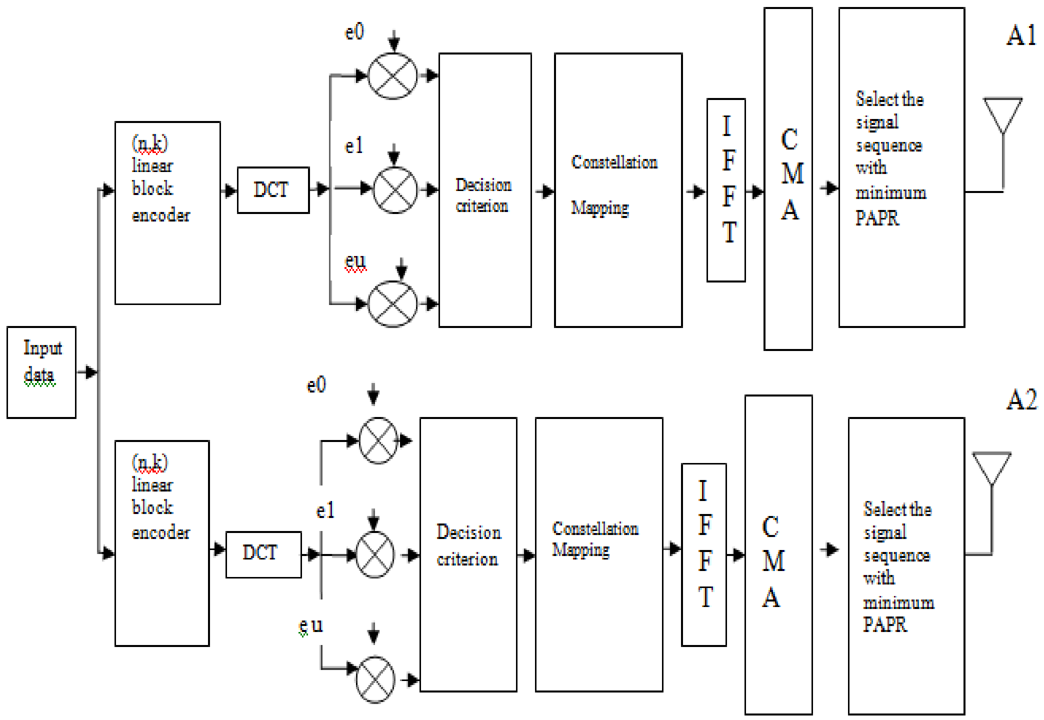


**Fig. 4.2 Block Diagram of MIMO-OFDM using Modified SLM IFFT with CMA Technique for the Reduction of PAPR**

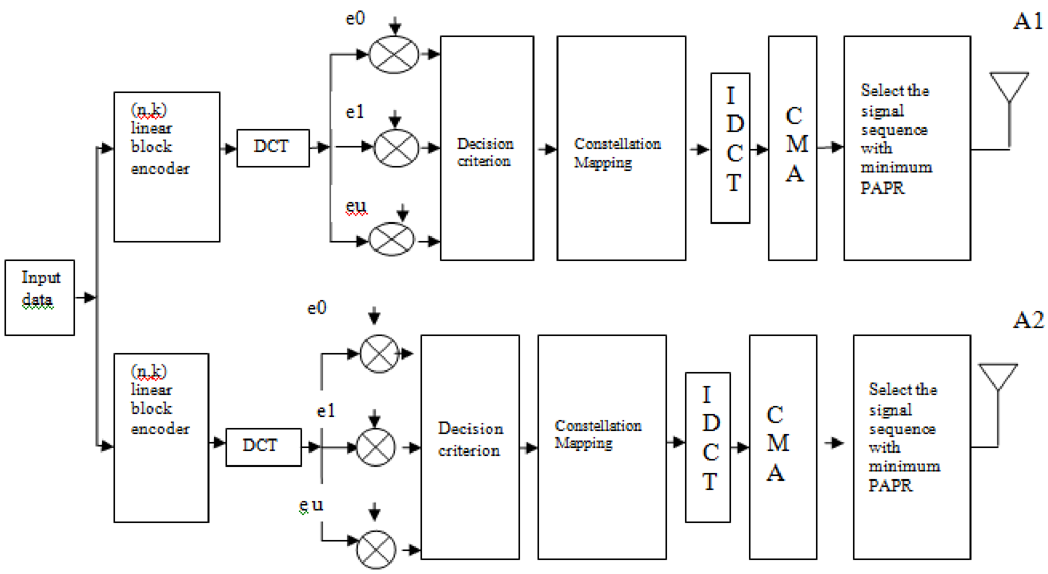


**Fig. 4.3 Block Diagram for MIMO OFDM using Modified SLM IDCT with CMA Technique for the Reduction of PAPR**

The algorithm for Fig. 4.2 and Fig. 4.3 using modified SLM with SD-CMA and UC-CMA is given as follows,

**Algorithm**

---

i. *$X_1$, $X_2$,..., $X_n$ are Binary information blocks.*

ii. *Encoding code word is w.*

iii. *Every block is encoded into w using Hamming encoder.*

iv. *A control bit is appended to w and extended hamming code of 8-bits is calculated.*

v. *The error table and coset leader is computed.*

vi. *Vectors w+e1, w+e2, ..., w+e16 are constructed for (every code word) Code word that has minimum value is chosen and transformed into MIMO-OFDM signal through constellation mapping and IDCT.*

vii. *Constant modulus approach is applied with Steepest descent and unit circle method using IFFT and IDCT.*

viii. *The signal sequence with minimum value is obtained.*

---

**A. Steepest Descent CMA**

The method of steepest descent is an iterative procedure that has been used to find exterma of nonlinear functions. The basic idea of this method is as follows:

1. Initialize the steepest descent algorithm

2. ithm with an initial estimate Ψ0 of optimum weight vector.

3. Evaluate the gradient of $s(\tau)$ at the current estimate, $\psi_n$ of the optimum weight vector.

4. Update the estimate at time $\tau$ by adding a correction that is formed by taking a step size $\varepsilon$ in the negative gradient direction.

5. Go back to (2) and repeat the process.

**B. Unit Circle CMA**

In order to restrict the solution to be on the unit circle, a normalized step is added to each iteration. The other method for updating algorithm is called unit circle CMA. It projects the solution of CMA to a unit circle at each iteration.

## 4.6 SIMULATION RESULTS

The analysis of PAPR reduction performance for modified SLM combined with CMA has been carried out using MATLAB 2012a. The simulation parameters considered for this analysis are summarized in Table 4.1.

**Table 4.1 Simulation Parameters used for analysis of Modified SLM with CMA**

| Parameters | Values |
|---|---|
| Number of transmit antenna | 1,2,4 |
| Modulation scheme | QAM |
| Scaling Factor | 1,0.5,0.25,0.125,0.0625 |
| Number of Subcarriers | 64, 128, 256, 512, 1024 |

### 4.6.1 PAPR Performance of Modified SLM with SD-CMA for Different Subcarriers using OFDM

Fig. 4.4 shows that the performance of the modified SLM technique with Steepest descent algorithm - CMA and IFFT method for OFDM system with different number of subcarriers. From this figure it is noted that the values of PAPR for 64, 128, 256, 512, and 1024 subcarriers are 5.4dB, 6.9dB, 6.9dB, 7dB and 7.2 dB respectively at CCDF of $10^{-2}$.

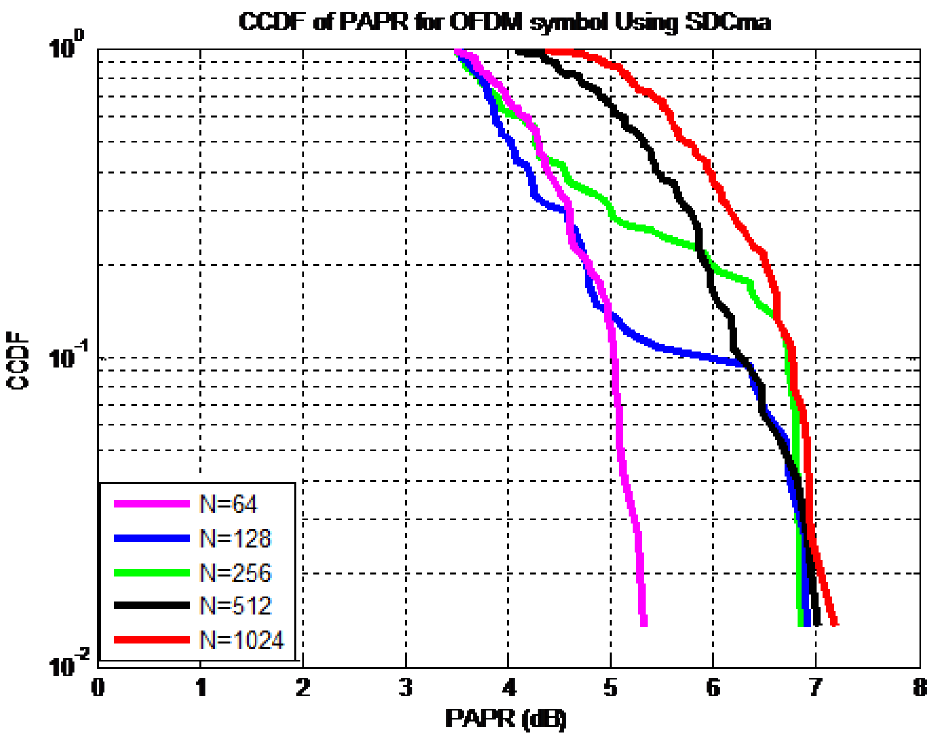


**Fig. 4.4 PAPR Performance of Modified SLM with SD-CMA for Different Subcarriers using OFDM**

### 4.6.2 PAPR Performance of Modified SLM with SD-CMA for Different Subcarriers using IFFT

Fig. 4.5 shows that the performance of the modified SLM technique with Steepest descent algorithm - CMA and IFFT method for OFDM system with different number of subcarriers. From this figure it is noted that the values of PAPR for 64, 128, 256, 512, and 1024 subcarriers are2.2dB, 2.6dB, 3.8dB, 4dB and 4.1dB respectively at CCDF of $10^{-2}$.

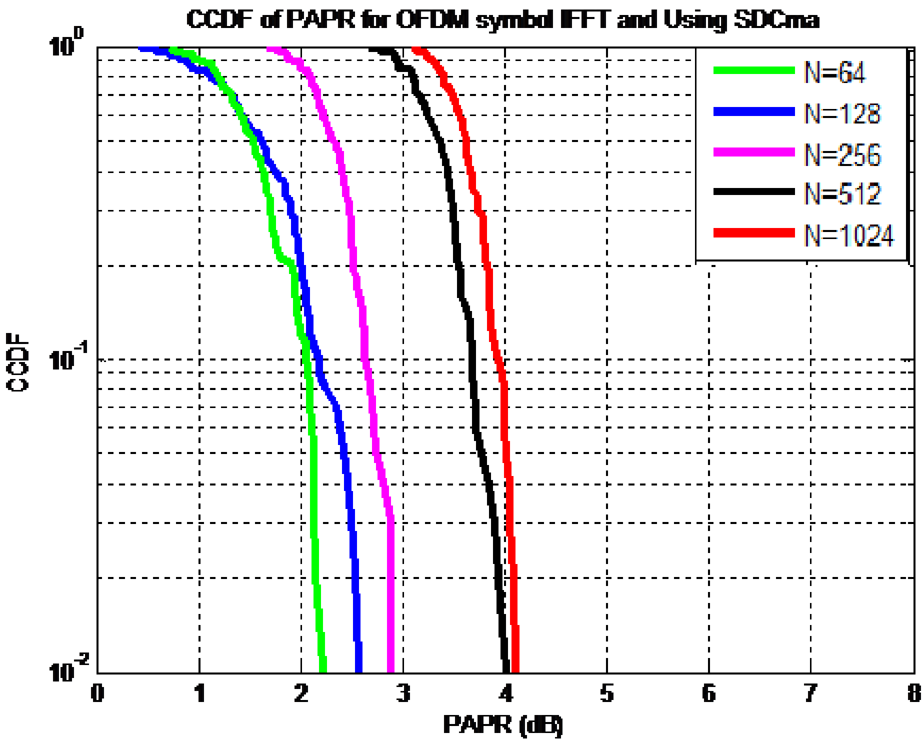


**Fig.4.5 PAPR Performance of Modified SLM with SD-CMA for Different Subcarriers using IFFT**

### 4.6.3 PAPR Performance of Modified SLM with SD-CMA for Different Subcarriers using IDCT

Fig.4.6 shows that the performance of the modified SLM technique with Steepest descent algorithm–CMA and IDCTmethod for OFDM system with different number of subcarriers. From this figure it is noted that the values of PAPR for 64, 128, 256, 512, and 1024 subcarriersare 1.5 dB, 1.7dB, 2.2 dB, 2.5 dB and 3.1dB respectively at CCDF of $10^{-2}$.

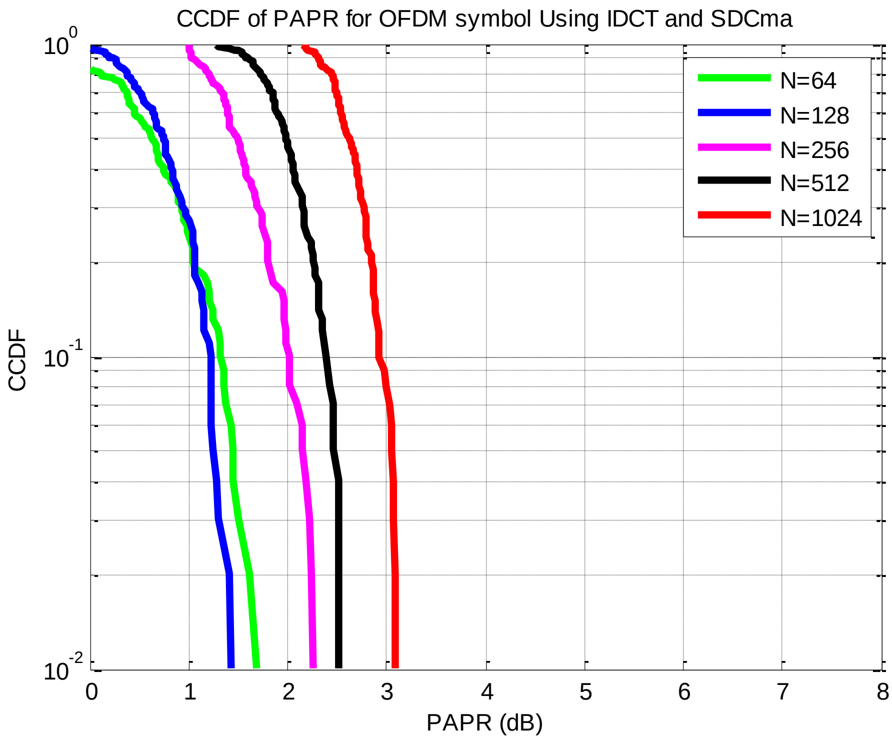


**Fig. 4.6 PAPR Performance of Modified SLM with SD-CMA for Different Subcarriers using IDCT**

### 4.6.4 PAPR Performance of Modified SLM with UC-CMA for Different Subcarriers using OFDM

Fig4.7 shows that the performance of the modified SLM technique with unit circle–CMA and IFFT method for OFDM system with different number of subcarriers. From this figure it is noted that the values of PAPR for64, 128, 256, 512, and 1024 subcarriers becomes 5.1 dB, 6.7dB, 6.8 dB, 6.9 dB and 6.9 dB respectively at CCDF of $10^{-2}$.

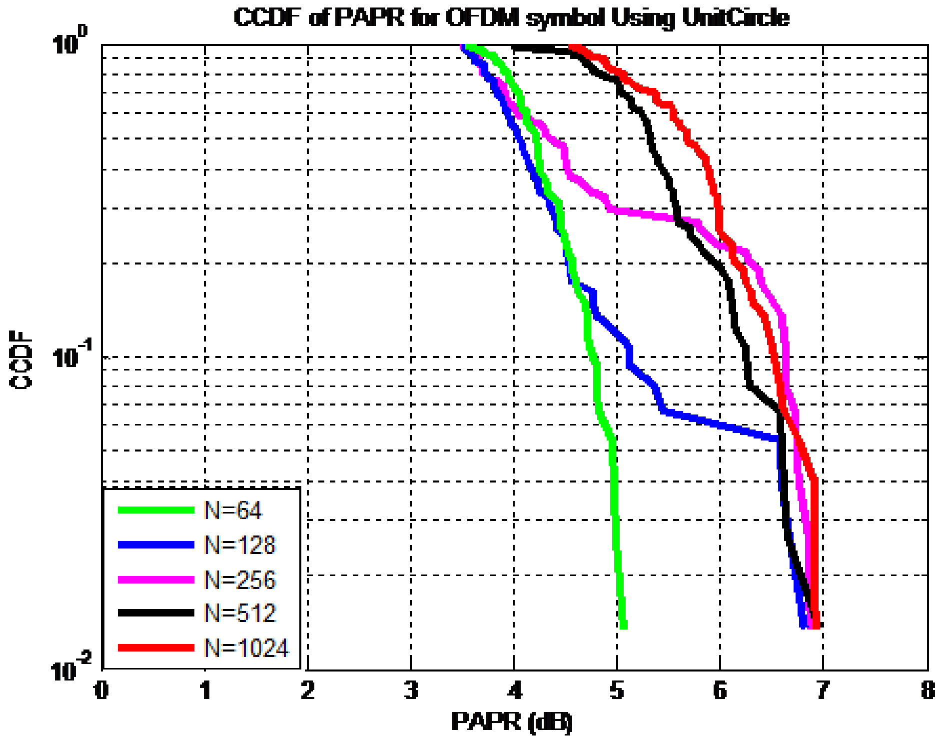


**Fig. 4.7 PAPR Performance of Modified SLM with UC-CMA for Different Subcarriers using OFDM**

### 4.6.5 PAPR Performance of Modified SLM with UC-CMA for Different Subcarriers using IFFT

Fig. 4.8 shows that the performance of the modified SLM technique with unit circle–CMA and IFFT method for OFDM system with different number of subcarriers. From this figure it is noted that the values of PAPR for64, 128, 256, 512, and 1024 subcarriers becomes 3 dB, 3.1dB, 3.5 dB, 4.3 dB and 4.5 dB respectively at CCDF of $10^{-2}$.

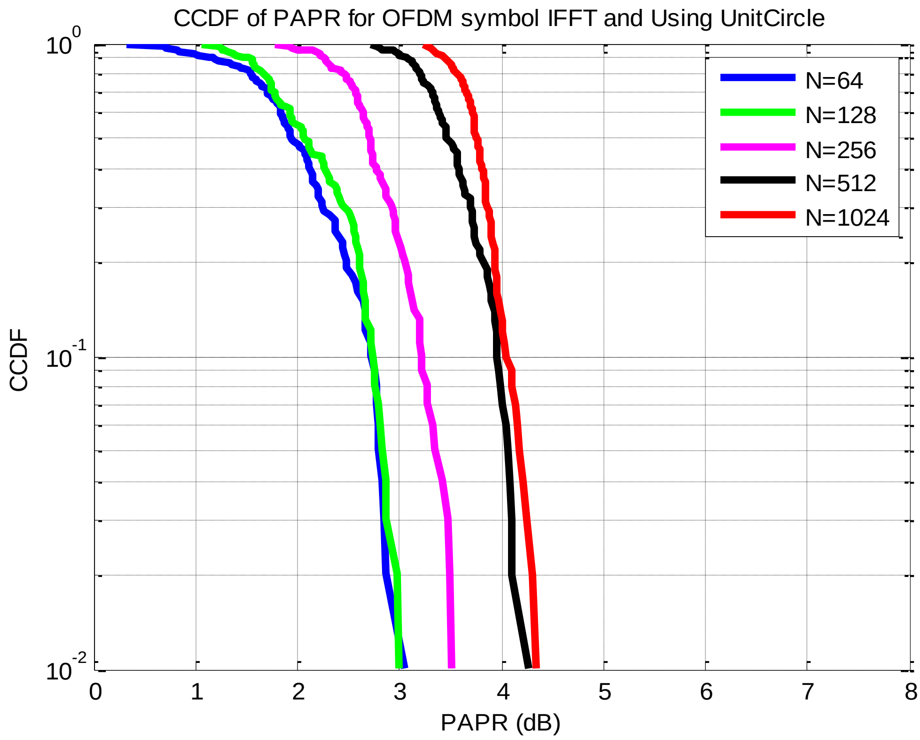


**Fig. 4.8 PAPR Performance of Modified SLM with UC-CMA for Different Subcarriers using IFFT**

#### 4.6.6 PAPR Performance of Modified SLM with UC-CMA for Different Subcarriers using IDCT

Fig. 4.9 shows that the performance of the modified SLM technique with unit circle–CMA method for OFDM system with different number of subcarriers using DCT with IDCT. From this figure it is noted that the values of PAPR for64, 128, 256, 512, and 1024 subcarriers becomes 2.2dB, 2.5dB, 2.8 dB, 2.8 dB and 3.4 dB respectively at CCDF of $10^{-2}$.

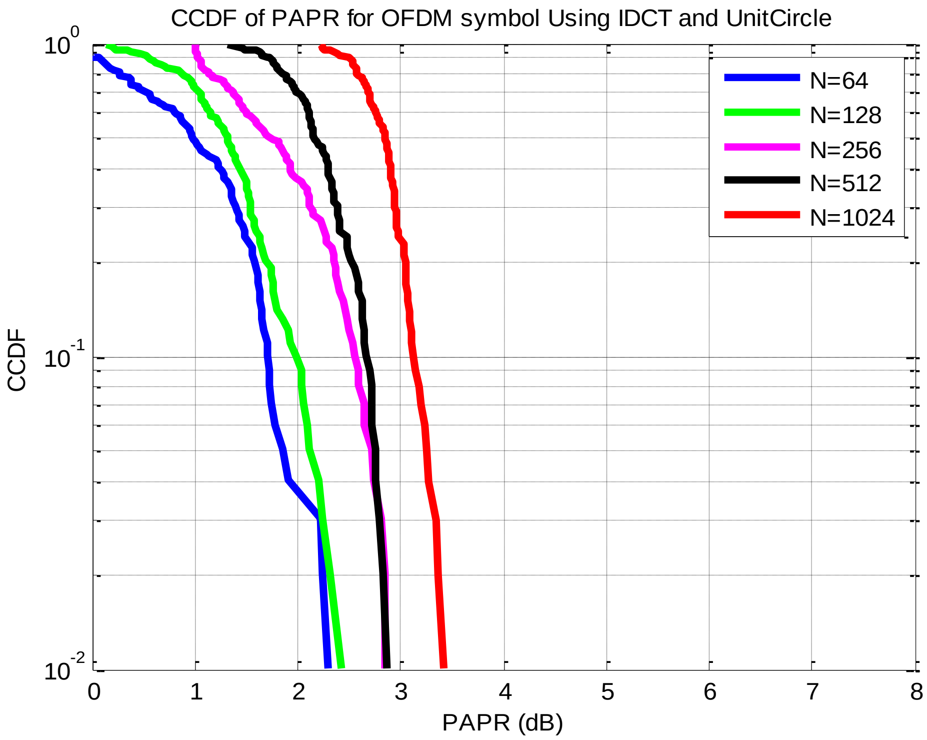


**Fig. 4.9 PAPR Performance of Modified SLM with UC-CMA for Different Subcarriers using IDCT**

### 4.6.7 PAPR Performance of Modified SLM with SD-CMA and UC-CMA for Different Subcarriers using MIMO-OFDM for Various Antennas 1,2,3 and 4

Fig. 4.10 shows that the performance of the modified SLM technique with steepest descent and unit circle – CMA for IFFT and IDCT method for MIMO-OFDM system with different number of antennas. From this figure it is noted that the values of PAPR for 64, 128, 256, 512, and 1024 subcarriers are comparatively reduced as the number of subcarriers are increased PAPR increases but it comparatively less than 40% when compared to other distortion methods.

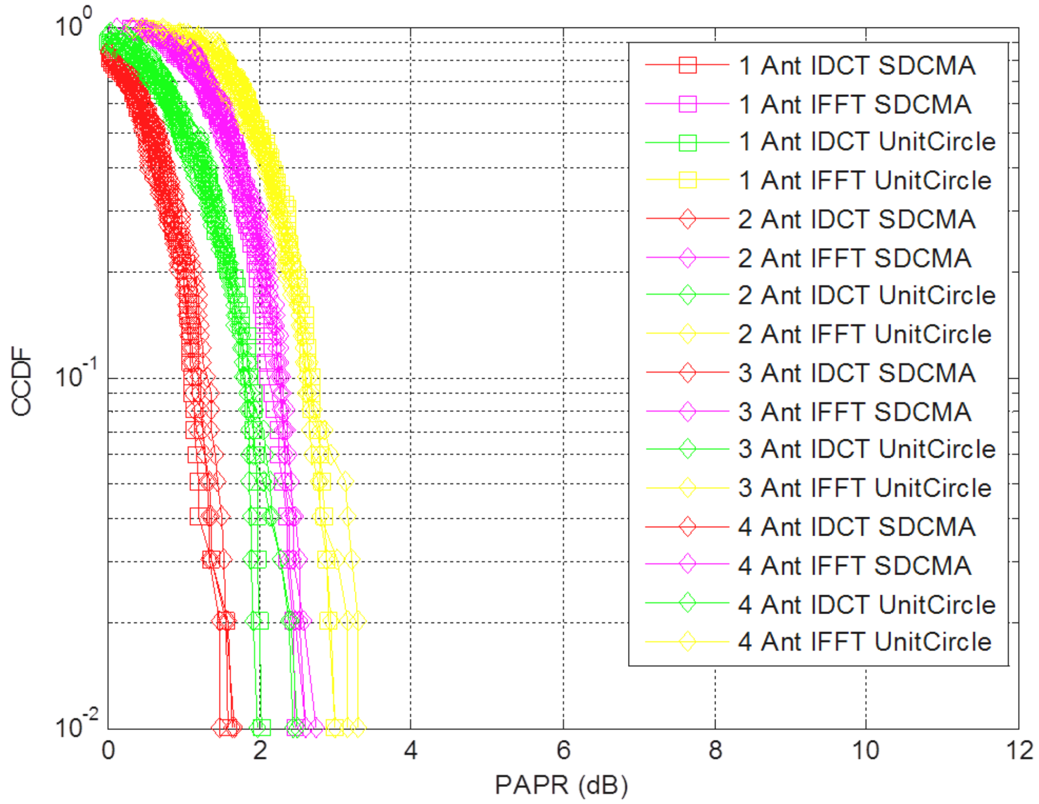


**Fig. 4.10 PAPR Performance of Modified SLM with SD and UC-CMA for Different Subcarriers**

## 4.7 SUMMARY

Modified SLM based CMA uses two methods. In the first method steepest descent algorithm is used to reduce PAPR in OFDM and MIMO-OFDM. In the second method unit circle is used. Here the pre-coding weights is modified to decrease the modulus variations of the resulting signal that leads to reduction in the PAPR for the OFDM and MIMO-OFDM. The above two methods use DCT and IDCT Matrix instead of IFFT which is normally used OFDM and MIMO-OFDM for reducing PAPR. DCT with IDCT reduces PAPR when compared with DCT with IFFT. It has been shown that the PAPR performance can be improved by using modified SLM combined with CMA based on steepest decent and unit circle method. The proposed system becomes more suitable for high data rate OFDM and MIMO –OFDM system and it reduces the computational complexity.

# CHAPTER 5

# MODIFIED SLM WITH INTERLEAVING TECHNIQUE FOR OFDM AND MIMO-OFDM SYSTEMS

## 5.1 INTRODUCTION

MIMO-OFDM is a most enthralling technology, which has been recently proposed in wireless communication. It provides high data rate services and offer better system performances. It improves data throughput and delivers highest capacity as well. However, MIMO-OFDM suffers with the disadvantage of high PAPR for the large number of subcarriers, which can affect the system output. Therefore, to overcome the problem of high PAPR in OFDM systems, an effective technique called Modified SLM is used along with IDCT matrix combined with interleaving and pulse shaping to reduce the PAPR ratio on both transmitter and receiver sides. By simulation results, it is seen that the proposed technique reduces PAPR.

## 5.2 MODIFIED SLM USING DCT WITH INTERLEAVING AND PULSE SHAPING METHOD FOR OFDM SYSTEM

In interleaving, a set of fixed permutations is used to break the highly correlated frames of OFDM to reduce PAPR [133]. In this technique, the transmitter uses K-1 interleaves which produce K-1 permuted frames of the input data. The minimum PAPR frame among all the K frames is selected for transmission. The identity of the corresponding interleave is also sent to the receiver as additional information. If all the K, PAPR computations are done simultaneously and lowest PAPR sequence is selected in one step, the processing delay at the transmitter is significantly reduced. Therefore, it can also be used with high speed data transmissions. The long correlation patterns explained in above concept can be broken down and reduces PAPR further. An arrangement of settled changes i.e. interleaving is utilized to separate these examples and serves to lessen the PAPR. In this, a methodology of P-1 interleaves is utilized for transmitter and produces P-1 permuted edges of the information. For transmission, the least PAPR frames are selected having K frames and even transmitted at the receiver end. On the off chance that every one of the counts are done at the same time, the lower PAPR succession is chosen instantly and the deferral at the transmitter is altogether decreased.

Pulse shaping is the method indicating changing of transmitted pulses. The main purpose of pulse shaping technique is to provide better suitable transmitted signal for the communication of data. Inter symbol interference is caused due to transmission of high modulated signal. When signal bandwidth is increased by the channel bandwidth, it starts introducing distortion into the signals. The pulse shaping filters are used at the transmitter where it determines the

Signal's spectrum. A group of time waveforms that reduces the PAPR of OFDM signals was proposed in [134, 135]. However, the reduction obtained was not considerable. Consider a time waveform with constant energy equals to energy signal (Es=1) and uncorrelated symbols within each OFDM block, the maximum PAPR is obtained as follows:

$$PAPR \leq PAPR_{\max} = \frac{1}{N} \max \left[ \sum_{n=0}^{N-1} \left| P_m(t) \right| \right]^2, 0 \leq t \leq T \tag{5.1}$$

where $P_m(t)$ is a pulse shape used at each subcarrier. With large number of subcarriers, the maximum of the PAPR occurs with very low probability.

The cross-correlation function of the OFDM signal is obtained as,

$$R_s(t_1, t_2) = \sum_{n=0}^{N-1} \sum_{m=0}^{N-1} SS^*_{m,k} p_n(t_1) p^*_m(t_2) e^{i\omega_c(nt_1 - mt_2)} \tag{5.2}$$

where $\omega_c$ is the carrier frequency of the system and the cross-correlation coefficient is zero for all samples separated by multiples of T.

A possible solution to reduce the PAPR of the OFDM signals is then to create some correlation between the different OFDM samples of the same block. The new set of pulse shape indicates that each subcarrier pulse of the OFDM scheme has a different shape and all these pulse shapes are derived from the same pulse. This will also reduce the PAPR of the OFDM transmitted signal since the peak amplitude of the different pulse shapes will never occur at the same time instant unless time waveform is a rectangular pulse.

The impulse response of a raised cosine filter is

$$r(t) = \text{sinc}(\pi \frac{t}{T}) \left[ \cos(\frac{\pi \alpha t}{T}) / 1 - \frac{4\alpha^2 t^2}{T^2} \right] \quad (5.3)$$

where $\alpha$ is the roll-off factor which ranges between 0 and 1. Lower values of $\alpha$ introduce more pulse shaping and more suppression of out-of-band signal components. Pulse shapes are very flexible and can control the correlation between the OFDM block samples without destroying the orthogonality property between the subcarriers of the OFDM modulated signal.

Interleaving is the information reordering which is to be transmitted in a manner that progressive bytes of information are scattered over a bigger arrangement of data to diminish the upshot of burst lapses as shown in Fig. 5.3. The utilization of interleaving, all things considered, builds the capacity of blunder assurance codes for amended burst lapses.

MIMO-OFDM interleaving operation is very feasible for spectrum monitoring. The frequency location of every subcarriers of one subblock can be controlled by catching one subcarrier with framework parameters. For interleaved $\text{MIMO} - \text{OFDM}$, the N subcarrier gets parceled into V groups. At that point $k^{th}$ subcarrier of every gathering is relegated to $k^{th}$ user.

$$x^{(k)}(n) = \sum_{m=0}^{V-1} X_m^{(k)} e^{j\left(\frac{2\pi}{N}\right)(mQ+k)n} \tag{5.4}$$

where k=0, 1 ….Q-1 is the file of users and N is the aggregate number of subcarriers.

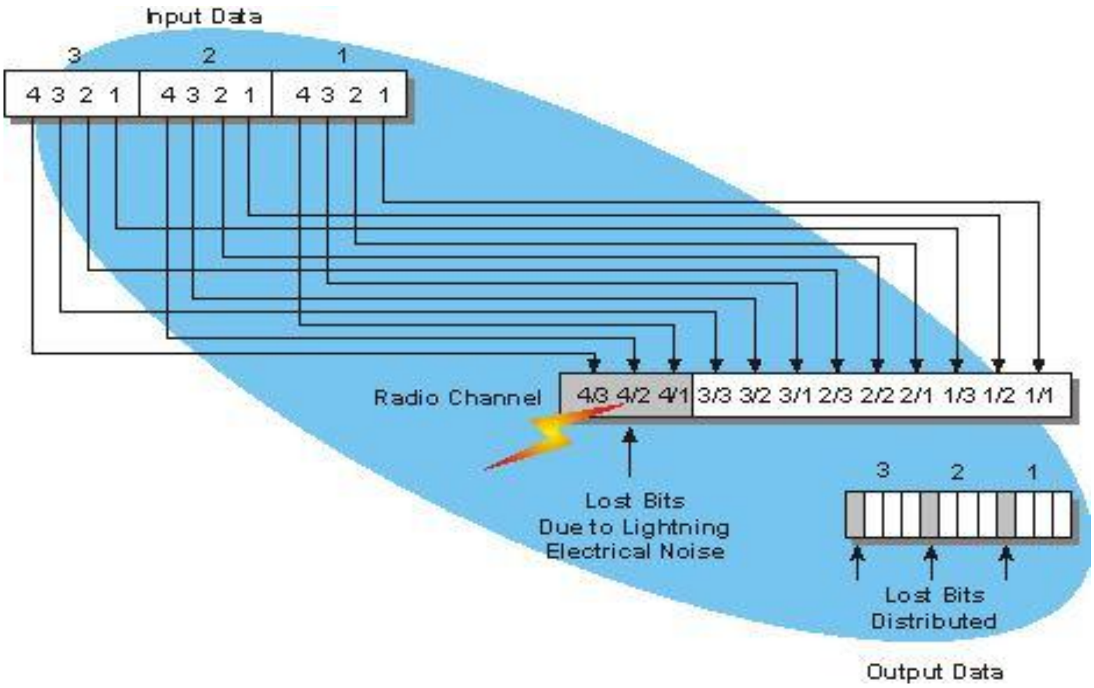


**Fig. 5.1 Interleaving Operation**

An interleaved MIMO-OFDM framework with N subcarriers is scaled from OFDM framework. Fig. 5.2 shows the system model for modified SLM with interleaving and pulse shaping method for PAPR reduction in OFDM system. The baseband operation at transmitter includes mapping the information data bit stream to symbols according to a QAM modulation scheme. The serial data bit streams are converted into parallel data bit stream using serial to parallel converter. Then these data streams are real-valued time domain sequences sets are constructed that correspond to the IDCT of the phase sequences sets, then used to directly generate the real valued baseband OFDM signals is more deteriorative than of complex-valued baseband OFDM signals.

## 5.3 MODIFIED SLM USING DCT WITH INTERLEAVING AND PULSE SHAPING METHOD FOR MIMO-OFDM SYSTEM

Fig. 5.3 illustrates the block diagram of modified SLM with DCT for PAPR reductions in MIMO-OFDM with multiple transmit antennas. The input data is applied to the space-time encoders where it is divided into two streams, resulting encoded data is converted into serial to parallel format, and then it passes through the IFFT and IDCT block. Again the same superimposed on constellation mapping and interleaving process has been followed by pulse shaping (with two transmit antennas) to produce the minimum PAPR. The CCDF of the PAPR in MIMO-OFDM system is calculated by using equation (5.2).

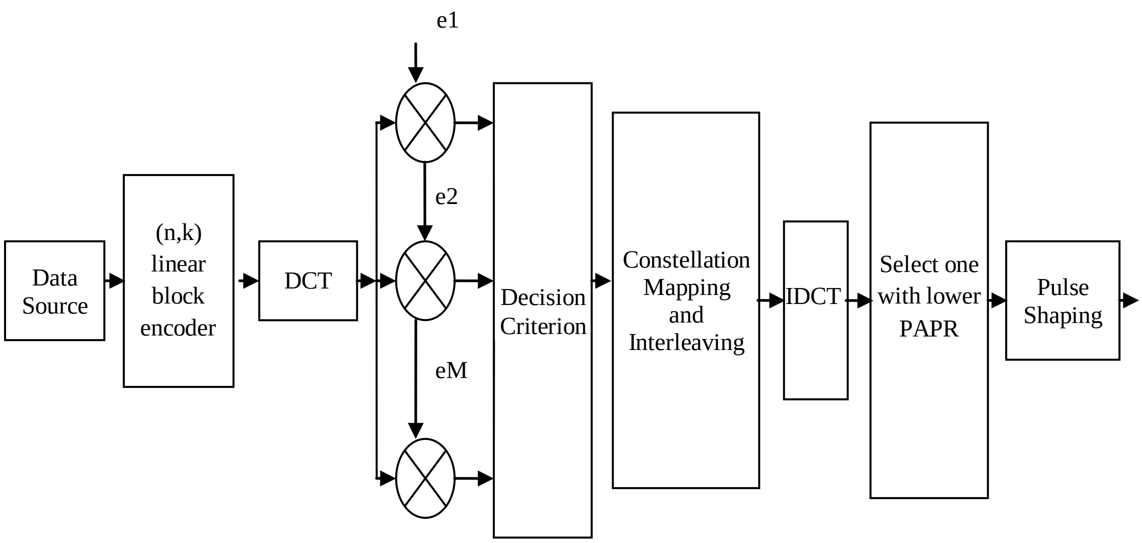


**Fig. 5.2 Block Diagram of DCT based Modified SLM with Interleaving and Pulse Shaping for OFDM**

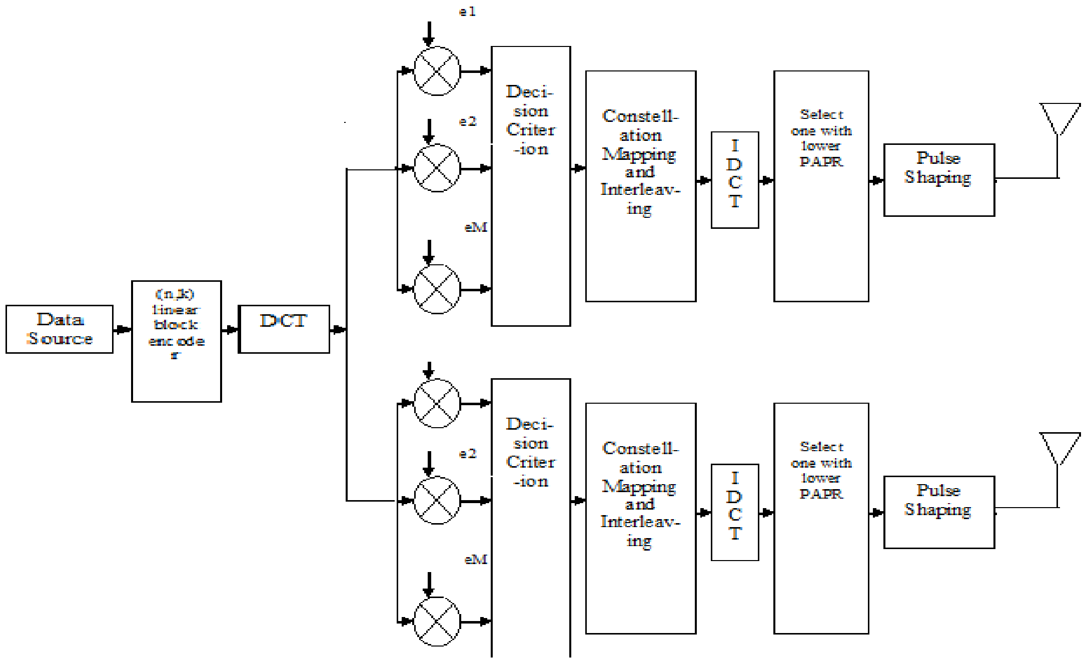


**Fig. 5.3 Block Diagram of DCT based Modified SLM with Interleaving and Pulse Shaping for MIMO OFDM**

## 5.4 RESULTS AND DISCUSSION

The analysis of PAPR reduction using modified SLM with interleaving technique in the OFDM and MIMO-OFDM systems has been carried out using MATLAB. The simulation parameters considered for the analysis is tabulated in Table 5.1. The performance evaluation is done in terms of CCDF of the PAPR, which is the probability that the PAPR of the signal exceeds the threshold $PAPR_0$.

**Table 5.1 Simulation Parameters for Modified SLM with Interleaving Technique**

| Simulation parameters | Type/Values |
|---|---|
| Number of subcarriers (*N*) | 64,128, 256, 512, 1024 |
| Oversampling factor (*L*) | 4 |
| Number of antennas(*Mt*) | 1 and 2 |
| Modulation scheme | QAM |
| Type of pulse shaping | Raised cosine |

### 5.4.1 PAPR Performance of Modified SLM for Different Subcarriers using DCT with IFFT for Interleaving and Pulse Shaping

Fig. 5.4 shows that the PAPR performance of modified SLM with interleaving technique for different subcarriers of size 64, 128, 256, 512 and 1024 in OFDM systems. It is evident that the PAPR values of 3.4 dB, 3.6 dB, 4.1 dB, 4.8 dB and 5.1 dB are obtained for different subcarriers of size 64, 128, 256, 512 and 1024 respectively at CCDF of $10^{-3}$. This simulation result shows that with increase in the number of subcarriers, the PAPR reduction performance is degraded.

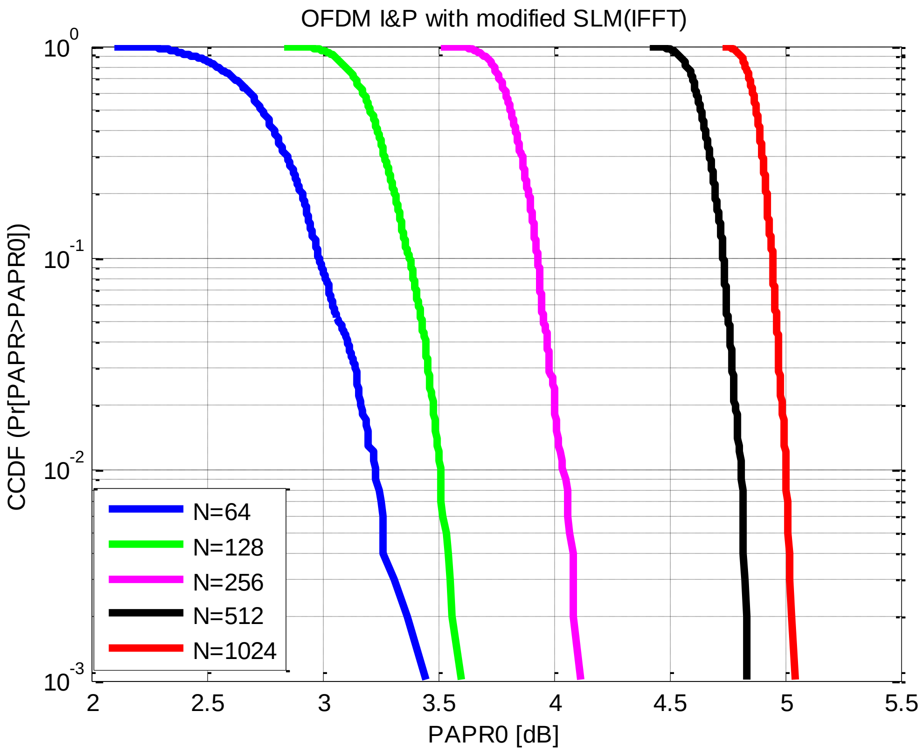


**Fig. 5.4 CCDF of PAPR for Different Subcarriers using IDCT with Interleaving and Pulse Shaping**

### 5.4.2 PAPR Performance of Modified SLM for Different Subcarriers using DCT with IDCT for Interleaving and Pulse Shaping

Fig. 5.5 shows that the PAPR performance of modified SLM with interleaving technique for different subcarriers of size 64, 128, 256, 512 and 1024 in OFDM systems. It is evident that the PAPR values of 2.7 dB, 2.9 dB, 3.1 dB, 3.3 dB and 3.4 dB are obtained for different subcarriers of size 64, 128, 256, 512 and 1024 respectively at CCDF of $10^{-3}$. This simulation result shows that with increase in the number of subcarriers, the PAPR reduction performance is degraded.

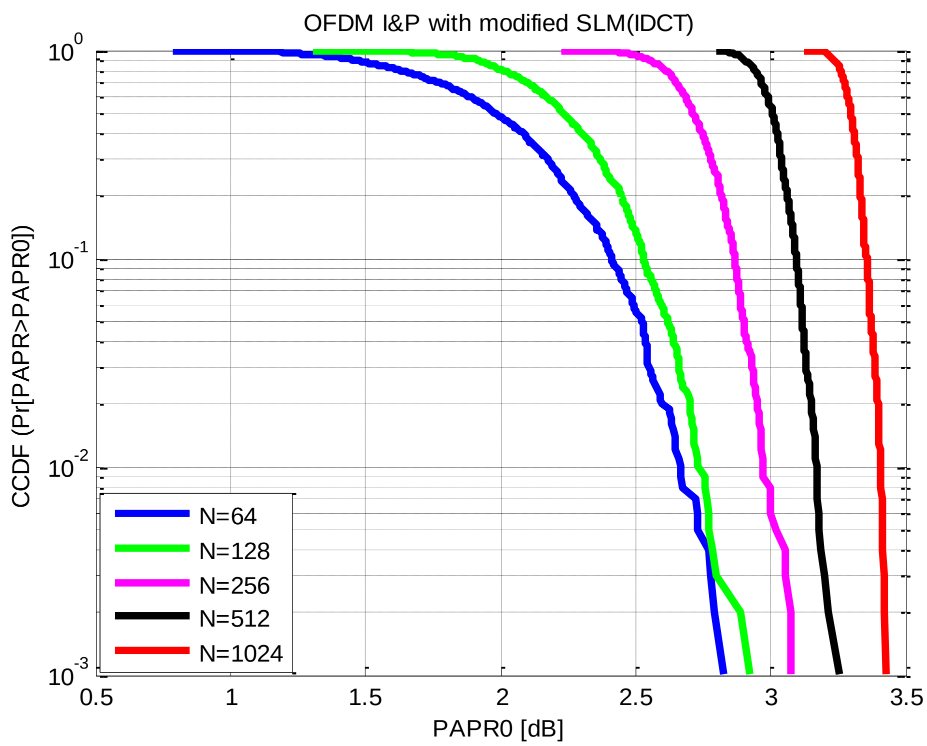


**Fig. 5.5 CCDF of PAPR for Different Subcarriers using IDCT with Interleaving and Pulse Shaping**

### 5.4.3 PAPR Performance for MIMO-OFDM using Different Subcarriers DCT with IFFT

Fig. 5.6 displays the PAPR reduction performance of modified SLM with interleaving technique for different subcarriers of size 64, 128, 256, 512 and 1024 in MIMO-OFDM with $M_t$ = 2. It can be observed that the PAPR values of 3.4 dB, 3.6 dB, 4.1 dB, 4.8 dB and 5 dB are obtained for different subcarriers of size 64, 128, 256, 512 and 1024 respectively at CCDF of $10^{-3.}$ . Thus, it can be concluded that by using modified SLM combined with interleaving and pulse shaping techniques, better PAPR reduction performance is achieved with increase in the number of subcarriers.

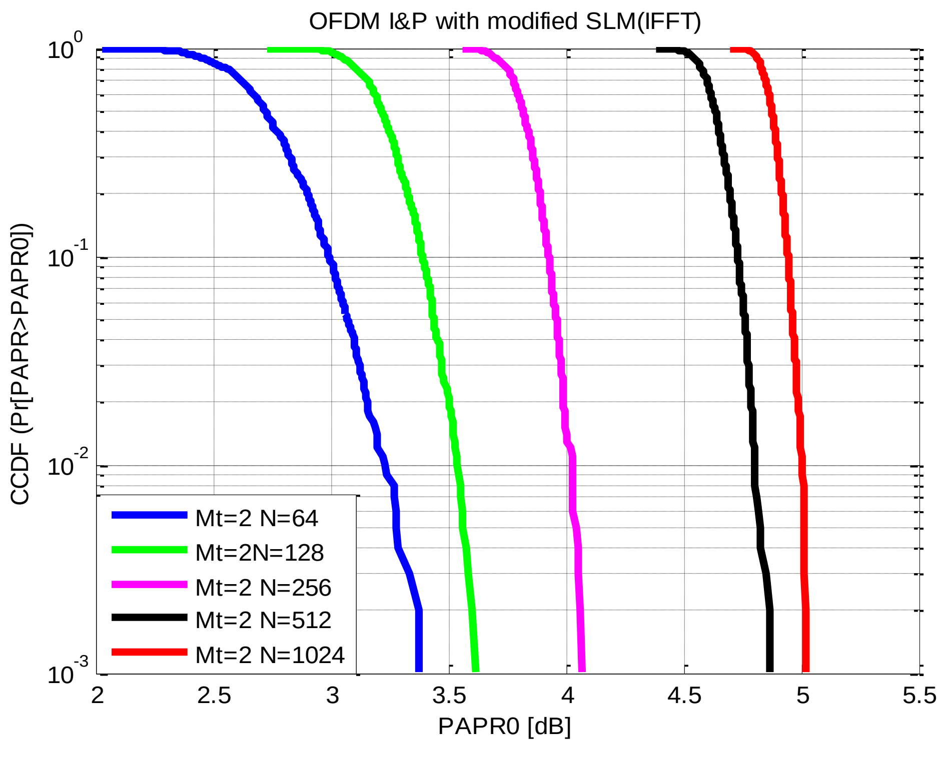


**Fig. 5.6 MIMO –OFDM Different Subcarriers DCT and IFFT**

### 5.4.4 MIMO-OFDM Different Subcarriers DCT with IDCT

Fig. 5.7 displays the PAPR reduction performance of modified SLM with interleaving technique for different subcarriers of size 64, 128, 256, 512 and 1024 in MIMO-OFDM with $M_t$ = 2. It can be observed that the PAPR values of 2.7 dB, 2.9 dB, 3.1 dB, 3.3 dB and 3.4 dB are obtained for different subcarriers of size 64, 128, 256, 512 and 1024 respectively at CCDF of $10^{-3}$ . This method is an effective scheme to achieve a better trade-off between PAPR reduction and computational complexity. The computational complexity reduction ratio increases as the number of subcarriers increases.

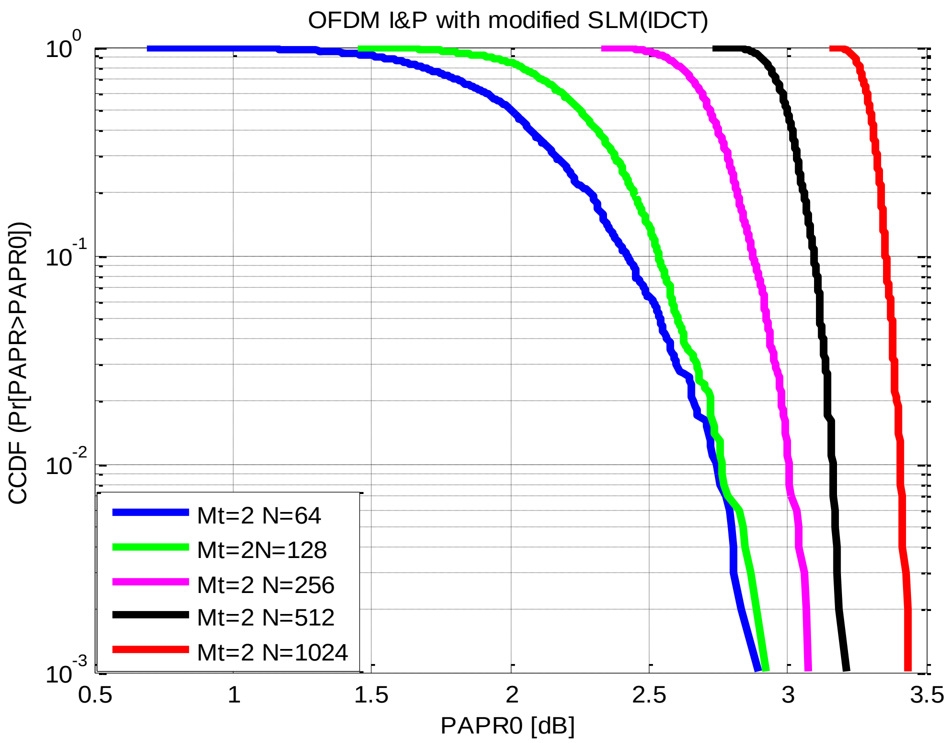


**Fig. 5.7 MIMO –OFDM Different Subcarriers DCT and IDCT**

## 5.5 SUMMARY

The modified SLM with interleaving technique has been analysed in this chapter to solve the high PAPR problem for OFDM and MIMO-OFDM systems. The efficient PAPR reduction performance is achieved by increasing the number of subcarriers for fixed number of IFFT and IDCT block subcarriers. It can be observed that the PAPR performance of OFDM and MIMO-OFDM systems has improved by using interleaving technique. Simulation results prove that the PAPR reduction is around 30% using modified SLM with interleaving technique when compared to modified SLM in OFDM and MIMO-OFDM.

# CHAPTER 6

# PAPR REDUCTION BY PTS TECHNIQUE WITH DCT IN OFDM AND MIMO-OFDM SYSTEM

## 6.1 INTRODUCTION

Among PAPR reduction techniques, signal distortionless technique efficiently reduces PAPR of the OFDM signal. Amidst of two methods of signal distortionless techniques, PTS technique [137] reduces PAPR efficiently and has less hardware complexity. PTS technique, which divides the input sequence into subsequences and after IFFT process, chooses the phase optimized minimum PAPR signal for transmission. Here the hardware complexity is reduced by reducing the usage of number of IFFT blocks. Number of IFFT blocks required is equal to number of phase factors. However, increased number of phase factors reduces the PAPR profitably but in turn increases the hardware complexity of the system. In this technique, modulated data bits are once again scrambled using phase factor after application of IFFT operation [138]. This data scrambling reduces the similarity between data bits, which helps to avoid summing up of in-phase signals. This reduces the PAPR efficiently. In order to reduce the PAPR further still more similarity should be reduced among data bits.

## 6.2 DISCRETE COSINE TRANSFORM

In particular, a Discrete Cosine Transform [139-144] is a Fourier-related transform similar to the discrete Fourier transform , but using only real numbers. DCTs are equivalent to DFTs of roughly twice the length, operating on real data with even symmetry (since the Fourier transform of a real and even function is real and even), where in some variants the input and/or output data are shifted by half a sample. There are eight standard DCT variants, of which four are common. Like any Fourier-related transform, DCTs express a function or a signal in terms of a sum of sinusoids with different frequencies and amplitudes. Like DFT, a DCT operates on a function at a finite number of discrete data points. The obvious distinction between a DCT and a DFT is that the former uses only cosine functions, while the latter uses both cosines and sines (in the form of complex exponentials). However, this visible difference is merely a consequence of a deeper distinction: a DCT implies different boundary conditions than the DFT or other related transforms. The peak value of the auto correlation is the average power of input sequence. DCT conceptually extends the original N-point data sequence to 2N-point sequence by doing mirror – extension of the N-point data sequence. Since the both end of data is always continuous in the DCT, the lower order of components will be dominated in the transform domain signal after converted by DCT. The idea to use the DCT transform is to reduce the autocorrelation of the input sequence to reduce the peak to average power problem and the transmitted signal does not require any side information at the receiver. Among the four dimensional of DCT, only one dimensional DCT has orthogonality property. The one dimensional (1D) DCT A[k] of a sequence a[n] of length N is given by:

$$A[k] = \alpha[k] \sum_{n=0}^{N-1} a[n] cos \frac{\pi(2n+1)k}{2N} \tag{6.1}$$

For k = 0,1 . . . N- 1 , the inverse DCT is defined as,

$$A[k] = \frac{1}{\sqrt{N}} \qquad for\ k = 0; \tag{6.2}$$

$$= \sqrt{\frac{2}{N}} \qquad for\ k = 1,2, \ldots\ldots N-1$$

The basis sequences of the 1D DCT are real, discrete-time sinusoids defined by:

$$C_N[N,K] = cos \frac{\pi(2n+1)k}{2N} \tag{6.3}$$

The DCT basis consists of the following N real sequences,

$$C_N[N,0], C_N[N,1], \dots \dots \dots .. C_N[N, n-1]$$

$$A_N = C_N \alpha \tag{6.4}$$

where A and α are both the vector with Nx1 and $C_N$ is a DCT transform matrix with N x N. The row (or column) of the DCT matrix $C_N$ are orthogonal matrix vectors. Then we can use this property of the DCT matrix and reduce the peak power of OFDM signals. Although the direct application of these formulas would require $O(N^2)$ operations, it is possible to compute the same thing with only $O(N \log N)$ complexity by factorizing the computation similarly to the fast Fourier transform (FFT). One can also compute DCTs via FFTs combined with $O(N)$ pre- and post-processing steps. In general, $O(N \log N)$ methods to compute DCTs are known as Fast Cosine Transform (FCT) algorithms.

The advantages of DCT are the transformation is orthogonal (inverse is transpose and energy is preserved), fast algorithms can be used for computation, and the output for (near) constant matrices generally consists of a large number of (near) zero values. There is one major disadvantage of the DCT is that while the input from preprocessed 8 x 8 blocks is integer-valued, the output values are typically real-valued. Thus we need a quantization step to make some decisions about the values in each DCT block and produce output that is integer-valued.

## 6.3 DCT WITH PTS TECHNIQUE

As discussed in section 6.1, in order to reduce PAPR even after application of PTS technique autocorrelation between data bits have to be reduced still more which will reduce the similarity between the data bits. DCT [143, 141] has main characteristics of reduction of autocorrelation between data sequences. So in the proposed work DCT is applied along with PTS technique. The application of DCT is done before and after PTS technique and simulation result are noted using MATLAB 2010a.

### 6.3.1 DCT Before PTS Technique

The first proposed work is that of using Discrete Cosine Transform before the Partial Transmit Sequence. The application of DCT [141] before PTS reduces the autocorrelation of conventionally digital modulated data bits. Because of this reduction, the similarity among phases of data get reduced . PTS is a data scrambling technique, which uses different combination of phase factor to reduce the autocorrelation between data. This proposed work is simulated which shows reduction in PAPR compared to conventional PTS technique.

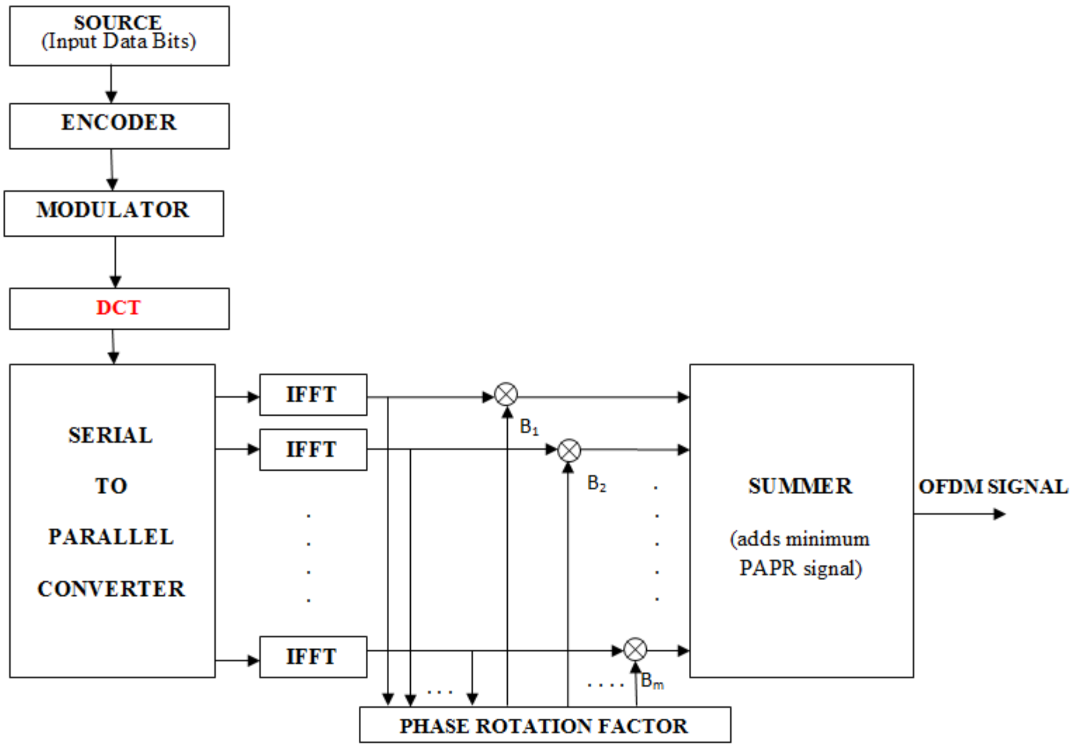


**Fig. 6.1 Block Diagram of DCT before Partial Transmit Sequence**

The mathematical analysis of DCT before PTS is done by first computation of DCT followed by IFFT of divided subsequences. The DCT of modulated data is given by,

$$C_N = \frac{1}{2}[a_0 + -1^k a_0] + \sum_{i=1}^{n-2}\left(a_i \cos\frac{\pi k i}{n-2}\right) \tag{6.5}$$

The IFFT of partially divided DCT data is given by,

$$x(u) = \sum_{j=1}^{m} \sum_{i=1}^{n/m} \left( C_N \, \mathrm{e} \frac{j2\pi ui}{n} \right) \tag{6.6}$$

where

| | |
|---|---|
| a | is the phase modulated data bits |
| N | is the length of data sequence K = 0, 1, ...........N-1 |
| $C_N$ | is the Discrete Cosine Transformed data sequence |
| u | is the number of subcarriers |
| n | is total number of data sequence |
| m | is the total number of phase factor used |

### 6.3.2 DCT after PTS Technique

The second proposed work is using of DCT after PTS technique. The conventionally modulated data bits are converted into parallel streams. The paralleled converted data bits are applied to data scrambling technique PTS technique, which reduces the similarity between data by rotating with 'm' number of phase factors. The signals with minimum PAPR are added using summer and the output is given to DCT block. The DCT reduces the autocorrelation between the summed OFDM signal. The simulation result shows that the DCT after PTS reduces PAPR compared to conventional PAPR. But DCT before PTS shows better performance compared to DCT after PTS. This is because DCT after PTS reduces only autocorrelation between minimum PAPR signals where as in the DCT before PTS reduces the autocorrelation between each of the conventionally digital modulated data bits. The mathematical analysis of DCT after PTS technique is obtained by first computation of IFFT of divided subsequences followed by DCT. The DCT of modulated data is given by,

$$x(u) = \sum_{j=1}^{m} \sum_{i=1}^{\frac{n}{m}} \left( a_N \, e \frac{j2\pi ui}{n} \right) \qquad (6.7)$$

The DCT of orthogonal signal is given by,

$$C_N = \frac{1}{2}[x(0) + -1^k x(1)] + \sum_{i=1}^{u-2} \left( x(u) \cos \frac{\pi ki}{u-2} \right) \qquad (6.8)$$

where

a is the phase modulated data bits

N is the length of data sequence K = 0, 1, ...........N-1

$C_N$ is the Discrete Cosine Transformed data sequence

u is the number of subcarriers

n is total number of data sequence

m is the total number of phase factor used

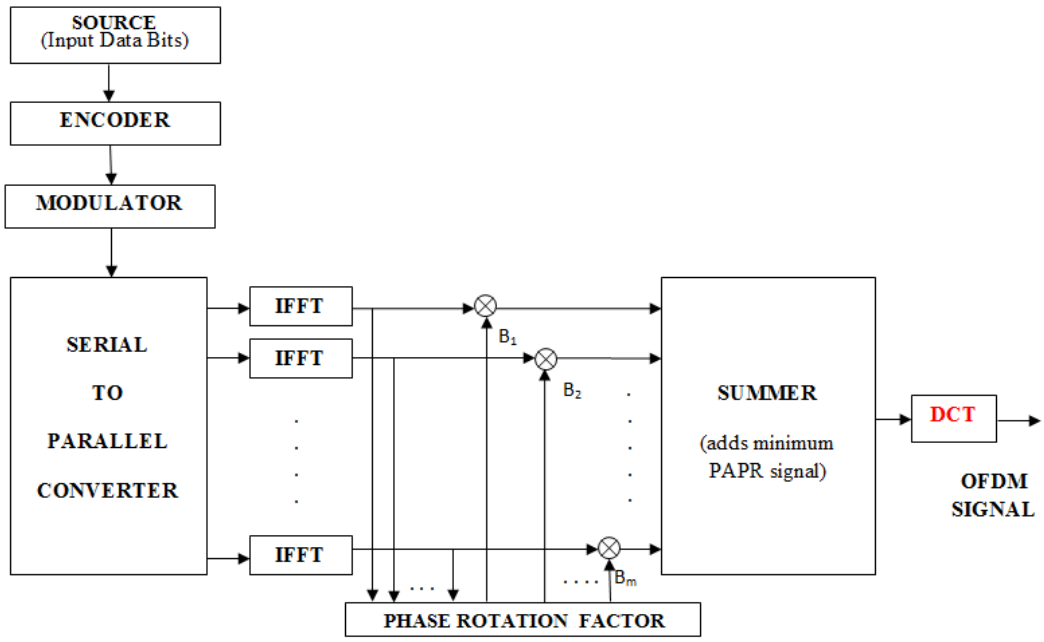


**Fig.6.2 Block Diagram of DCT after Partial Transmit Sequence**

## 6.4 MODIFIED PTS TECHNIQUE

In the modified PTS technique [143], the neighbourhood search is employed as a searching algorithm to find the phase factor, and then set a threshold to reduce the computational complexity and get a suboptimum. The algorithm sets an initial solution $s_0$ and then searches the better solutions at the neighborhood of $s_0$iteratively. If there is such a solution $s'$, $s_0$is replaced as $s'$. A local optimum $s'$ is got when there is not a better solution in its neighborhood. The neighborhood search algorithm has follow features:

a. The algorithm is easy to achieve.

b. The performance is depending on the initial solution and the neighborhood function.

c. Part optimization.

In practical OFDM, the PAPR should be reduced to a range so that the amplitude of the signal is always at the linear region of amplifier. So a threshold $L$ is set, the phase factor $s$ is searched by neighborhood search algorithm until PAPR is less than $L$In order to apply the neighborhood search algorithm to find the phase factors of PTS, follow modifications should be added:

i. The region of neighborhood $\Delta s$ is set to be the function of $PAPR$ (current PAPR) and L. and $\Delta s = f(\Delta E) = f(PAPR - L)$. So that the region shrinks with the reduction of PAPR.

ii. If there isn't any better solution at the neighborhood of s for 1 $C$ times, $s$ changes randomly in a large region for one time.

iii. Set a maximum of search times $C$ , if the PAPR still not reduces to $L$ at $C$ times, stop to search and take currant optimum solution as final solution.

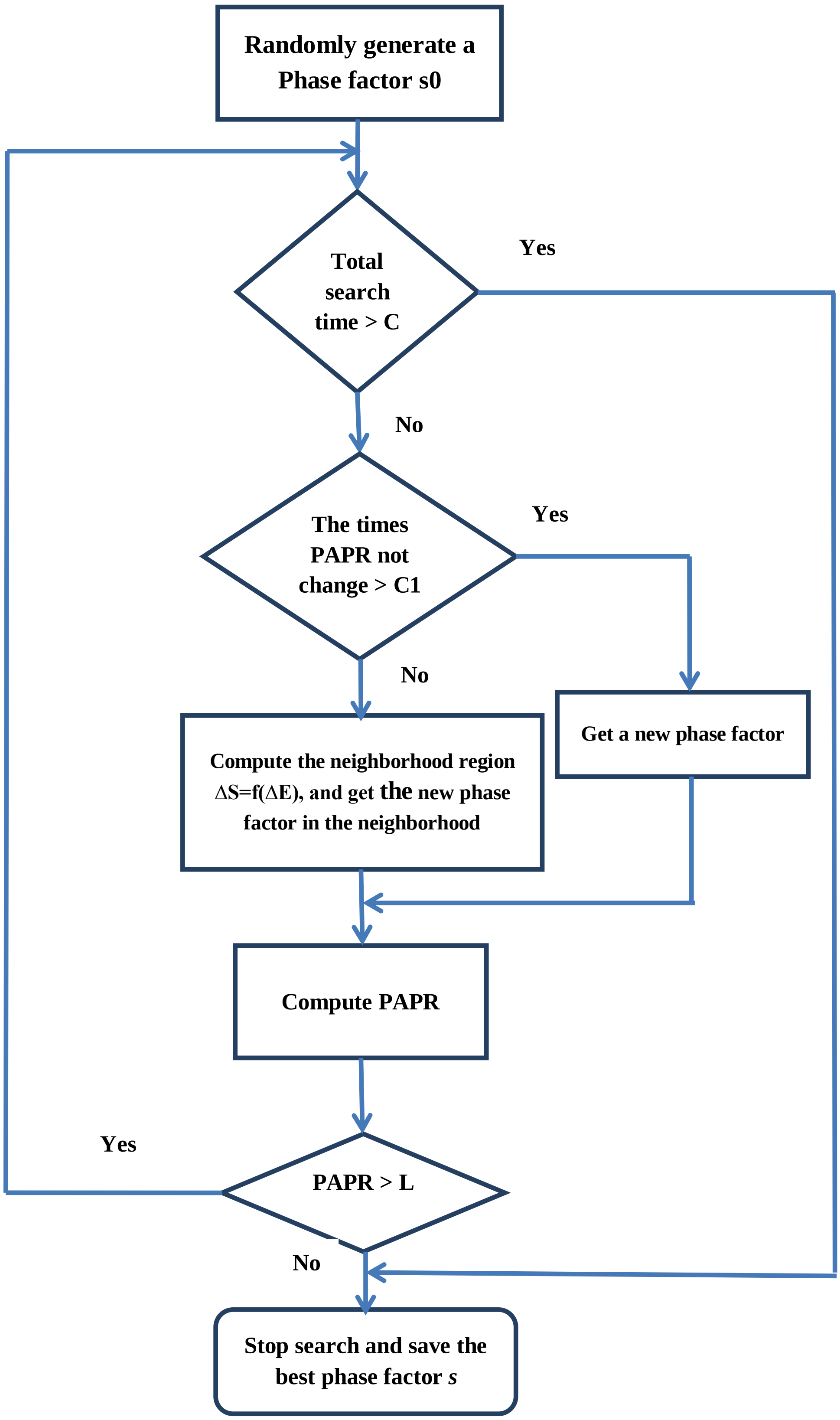


**Fig. 6.3 Flow Chart of Modified PTS Algorithm**

## 6.5 MIMO –OFDM BASED PTS AND MODIFIED PTS

The first proposed work is that of using Discrete Cosine Transform before the Partial Transmit Sequence. The application of DCT before PTS reduces the autocorrelation of conventionally digital modulated data bits. Because of this reduction, the similarity among phases of data get reduced . STBC technique is used to implement MIMO- OFDM system which transmits information in two antennas. PTS is a data scrambling technique which uses different combination of phase factor to reduce the autocorrelation between data is applied individually to different antenna. This proposed work is simulated which shows reduction in PAPR compared to conventional PTS technique.

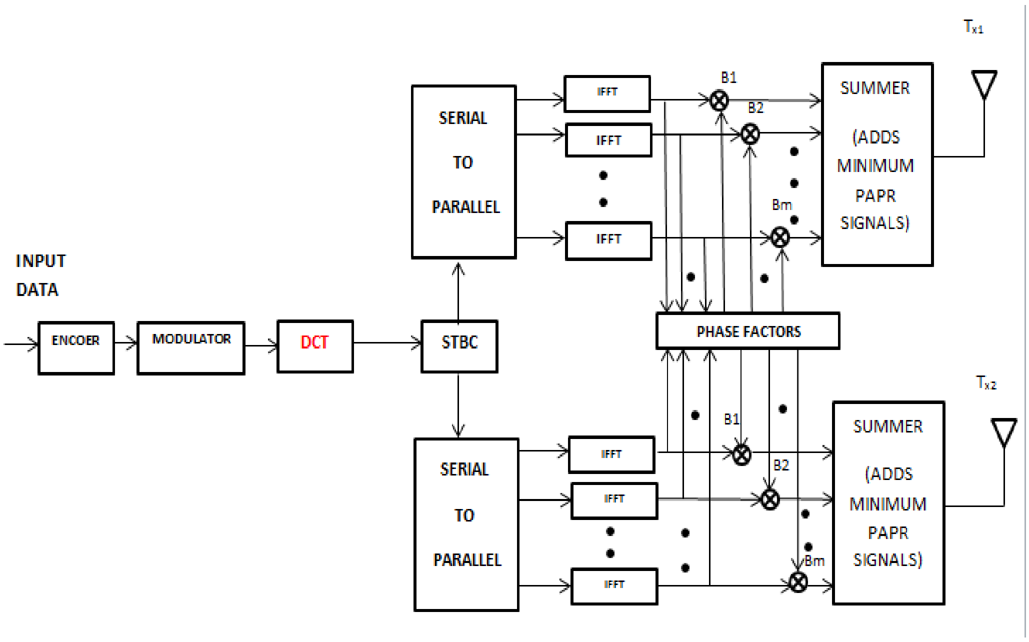


**Fig. 6.4 Block Diagram of MIMO-OFDM with DCT before Partial Transmit Sequence**

The mathematical analysis of DCT before PTS is done by first computation of DCT followed by IFFT of divided subsequences. The DCT of modulated data is given by,

$$X_N = \frac{1}{2}\left[a_0 + -1^K a_0\right] + \sum_{i=1}^{n-2}\left(a_i \cos\frac{\pi K i}{n-2}\right) \tag{6.10}$$

The IFFT of partially divided DCT data is given by,

$$X_u = \sum_{j=1}^{m} \sum_{i=1}^{\frac{n}{m}} \left( x_N e^{\frac{j2\pi ui}{n}} \right)$$

(6.11)

where

a is the phase modulated data bits

N is the length of data sequence K = 0, 1, ...........N-1

$X_N$ is the Discrete Cosine Transformed data sequence

u is the number of subcarriers

n is total number of data sequence

m is the total number of phase factor used

### 6.5.1 MIMO-OFDM for DCT After PTS Technique

The second proposed work is using of DCT after PTS technique. The conventionally modulated data bits are transmitted in two different antennas using STBC scheme. The data bits for two antennas are applied to data scrambling technique PTS technique individually which reduces the similarity between data by rotating with 'm' number of phase factors. The signals with minimum PAPR are added using summer and the output is given to DCT block. The DCT reduces the autocorrelation between the summed OFDM signal. The simulation result shows that the DCT after PTS reduces PAPR compared to conventional PAPR. But DCT before PTS shows better performance compared to DCT after PTS. This is because DCT after PTS reduces only autocorrelation between minimum PAPR signals where as in the DCT before PTS reduces the autocorrelation between each of the conventionally digital modulated data bits.

The DCT of orthogonal signal is given by,

$$X_{N=}\frac{1}{2}[x(0)+-1^{k}x(1)]\sum_{i=1}^{u-2}\left(x(u)\cos\frac{\pi ki}{u-2}\right) \tag{6.12}$$

where

a is the phase modulated data bits

N is the length of data sequence

K = 0, 1, ..........N-1

$X_N$ is the Discrete Cosine Transformed data sequence

u is the number of subcarriers

n is total number of data sequence

m is the total number of phase factor used

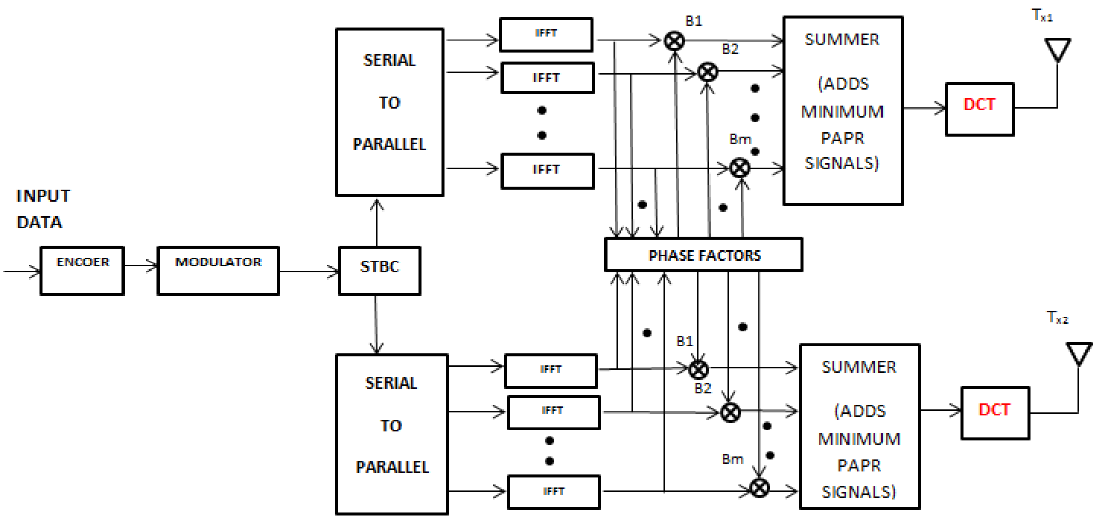


**Fig. 6.5 Block Diagram of MIMO-OFDM with DCT after Partial Transmit Sequence**

## 6.6 SIMULATION RESULTS

The proposed work of DCT before modified PTS technique and DCT after modified PTS technique in OFDM system are simulated using MATLAB software. The parameters used for simulation are discussed in below Table 6.1,

**Table 6.1 Simulation Parameters**

| Parameter | Type/Value |
|---|---|
| Number of subcarrier | 64, 128,256, 512, 1024 |
| Modulation scheme | 4-QAM |
| Number of Phase Rotation Factor | 2, 4, 8, 16 |
| Number of combinations of Phase Factors | 16 |

The OFDM system is designed by using modified PTS technique in order to reduce PAPR. The application of first order DCT which introduces orthogonality is used before and after PTS are simulated. The CCDF curve is plotted to find the number of PAPR of the signals greater than clipping level of power amplifier.

### 6.6.1 PAPR Performance of OFDM System with DCT before Modified PTS Technique with 64 Subcarrier and 4 Phase Factors

The Fig. 6.6 shows comparison among modified PTS, DCT before modified PTS technique and DCT after modified PTS technique. The proposed work DCT before modified PTS efficiently reduces PAPR effectively compared to other proposed and conventional schemes. The proposed work DCT after modified PTS technique also shows reduction in PAPR compared to conventional modified PTS but not efficient as DCT before modified PTS technique. The DCT before modified PTS shows 26.93% PAPR reduction compared to conventional modified PTS. The DCT after modified PTS shows 15.96% PAPR reduction compared to conventional modified PTS technique. Whereas the DCT before modified PTS shows nearly 13.05% PAPR reduction compared to DCT after modified PTS. In DCT before modified PTS technique, the autocorrelation between every modulated data bits are reduced so that PAPR is get reduced. In DCT after modified PTS technique, the autocorrelation between processed OFDM signals are get reduced so that PAPR is reduced.

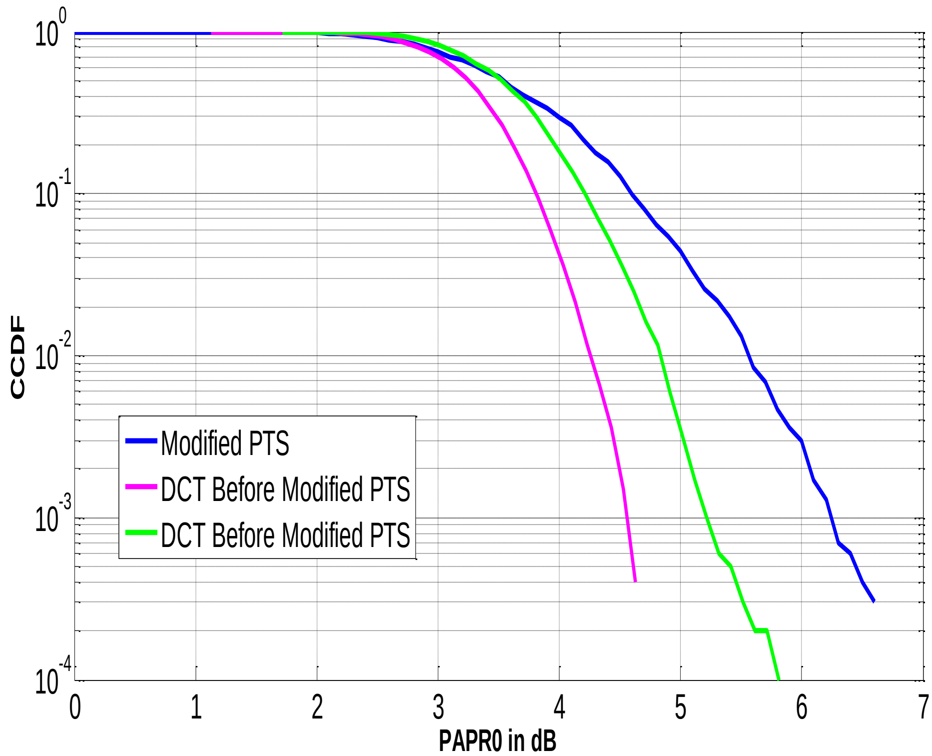


**Fig. 6.6 CCDF Performance of OFDM System with DCT before Modified PTS Technique with 64 Subcarrier and 4 Phase Factors**

### 6.6.2 PAPR Performance of OFDM System with DCT before Modified PTS Technique with 64 Subcarrier and 4 ,8, and 16 Phase Factors

The Figs. 6.7 to 6.10 show the comparison of OFDM system with DCT before modified PTS technique for different subcarriers using different phase factors and 4-QAM scheme. In various subblocks, using 64 subcarriers showing better performance compared to other subcarriers because increase in number of subcarriers leads to more loss of orthogonality which increases the value of PAPR. It is observed that increases in number of subblocks reduces the PAPR but increases the complexity of the system. The table 6.2 shows the PAPR value at CCDF $10^{-3}$ for different number of subcarriers and different number of sub-blocks. Using 64 subcarriers in DCT before modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 19.19%, 25.13% and 45.59% PAPR reduction compared to 2 sub-blocks. Using 128 subcarriers in DCT before modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 15.43%, 20.46% and 31.87% PAPR reduction compared to 2 sub-blocks. Using 256 subcarriers in DCT before modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 12.65%, 15.39% and 28.71% PAPR reduction compared to 2 sub-blocks. Using 512 subcarriers in DCT before modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 8.5%, 9.217% and 23.38% PAPR reduction compared to 2 sub-blocks. Using 1024 subcarriers in DCT before modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 7.16%, 8.09% and 18.01% PAPR reduction compared to 2 sub-blocks. From the percentage analysis of PAPR shows that less number of subcarriers with more number of sub-blocks shows better performance.

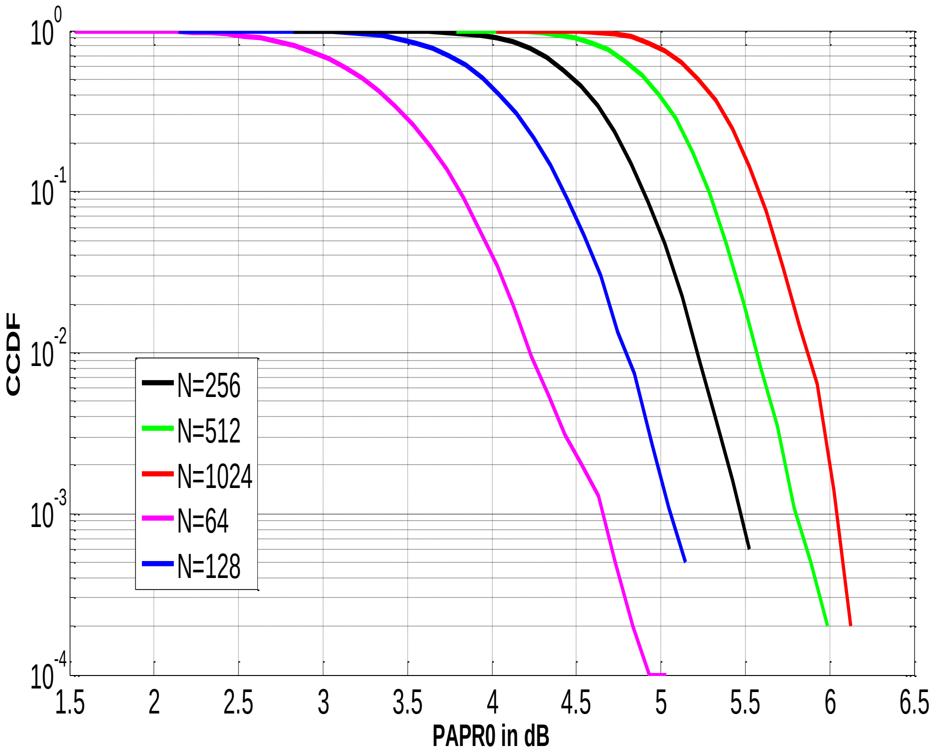


**Fig. 6.7 CCDF Performance of OFDM System with DCT before Modified PTS Technique using 4-QAM Scheme and 2 Phase Factor**

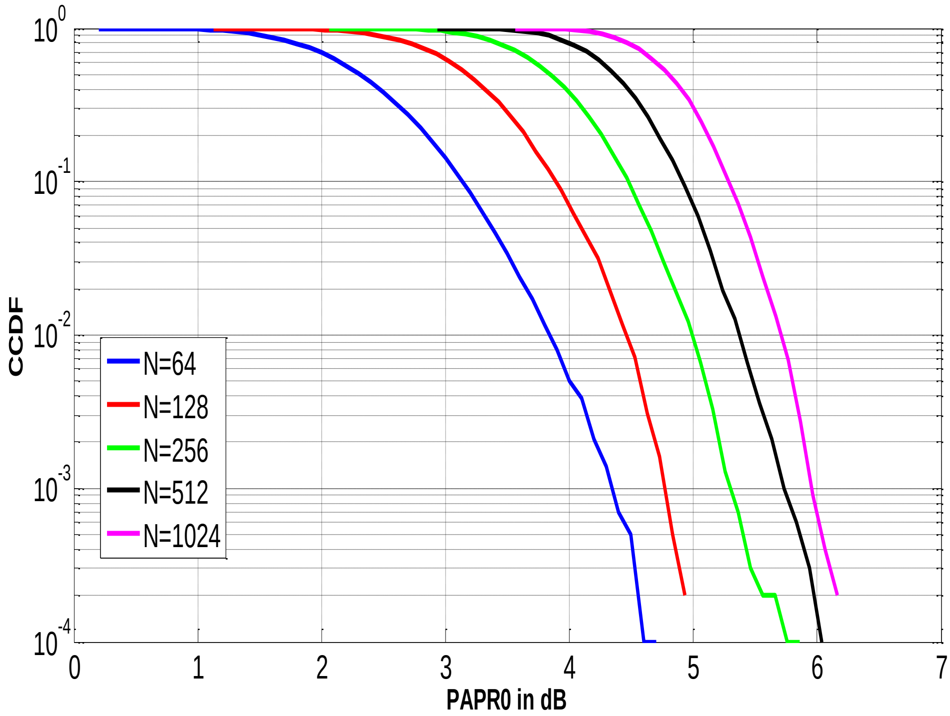


**Fig. 6.8 CCDF Performance of OFDM System by DCT before Modified PTS Technique using 4-QAM Scheme and 4 Phase Factors**

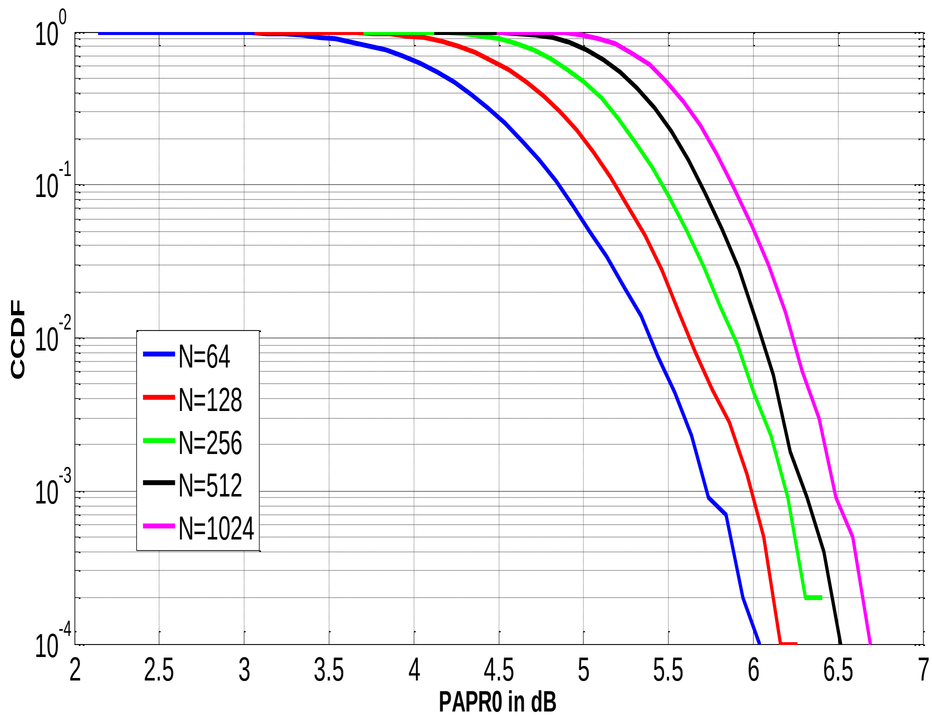


**Fig.6.9 CCDF Performance of OFDM System by DCT before Modified PTS Technique using 4-QAM Scheme and 8 Phase Factors**

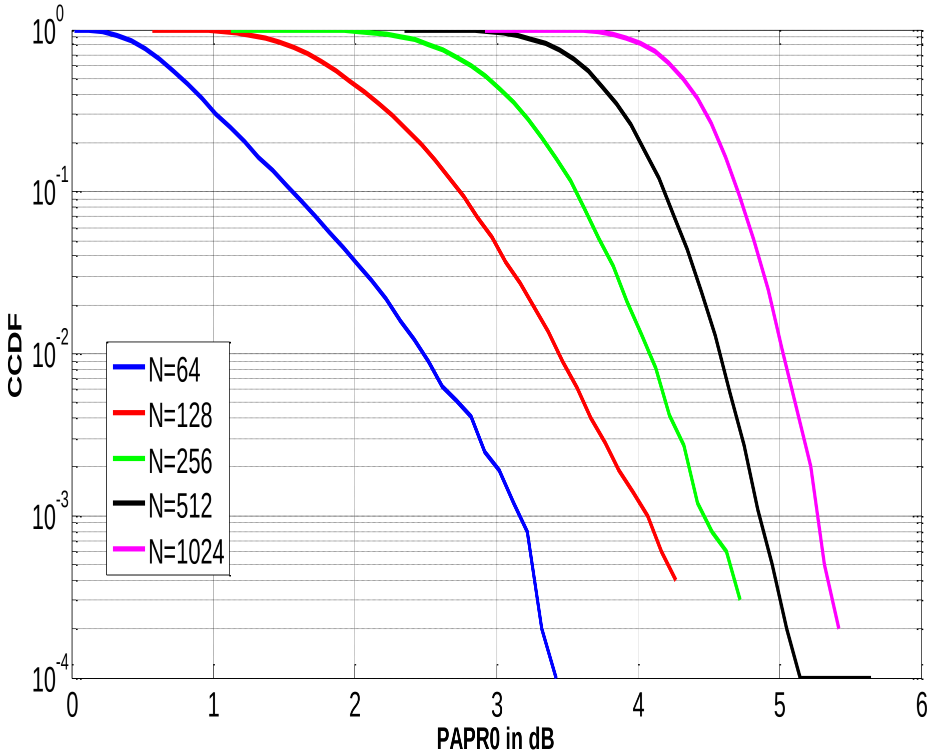


**Fig. 6.10 CCDF Performance of OFDM System with DCT before Modified PTS Technique using 4-QAM Scheme and 16 Phase Factors**

**Table 6.2 PAPR Reduction by DCT before Modified PTS**

| Number of Subcarriers | PAPR in dB (CCDF at $10^{-3}$) | | | |
|---|---|---|---|---|
| | m=2 | m=4 | m=8 | m=16 |
| 64 | 5.73 | 4.63 | 4.29 | 3.12 |
| 128 | 5.96 | 5.04 | 4.74 | 4.067 |
| 256 | 6.205 | 5.42 | 5.25 | 4.423 |
| 512 | 6.317 | 5.78 | 5.735 | 4.84 |
| 1024 | 6.489 | 6.024 | 5.964 | 5.32 |

### 6.6.3 PAPR Performance of OFDM System by DCT after Modified PTS Technique using 4-QAM Scheme and 2, 4, 8 and 16 Phase Factors

The Figs. 6.11 to 6.14 shows the comparison of OFDM system with DCT after modified PTS technique for different subcarriers using different phase factors and 4-QAM scheme. In various subblocks, using 64 subcarriers showing better performance compared to other subcarriers because increase in number of subcarriers leads to more loss of orthogonality which increases the value of PAPR. It is observed that increases in number of subblocks reduces the PAPR but increases the complexity of the system. The table 6.3 shows the PAPR value at CCDF $10^{-3}$ for different number of subcarriers and different number of sub-blocks. Using 64 subcarriers in DCT after modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 34.26%, 35.52% and 50.69% PAPR reduction compared to 2 sub-blocks. Using 128 subcarriers in DCT after modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 27.47%, 25.70% and 43.27% PAPR reduction compared to 2 sub-blocks. Using 256 subcarriers in DCT after modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 23.37%, 20.02% and 40.82% PAPR reduction compared to 2 sub-blocks. Using 512 subcarriers in DCT after modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 20.96%, 18.7% and 39.13% PAPR reduction compared to 2 sub-blocks. Using 1024 subcarriers in DCT after modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 17.66%, 17.14% and 38.25% PAPR reduction compared to 2 sub-blocks. From the percentage analysis of PAPR shows that less number of subcarriers with more number of sub-blocks shows better performance. The DCT before modified PTS with different sub-blocks and different number of subcarriers in all combinations shows better performance compare in DCT after modified PTS technique.

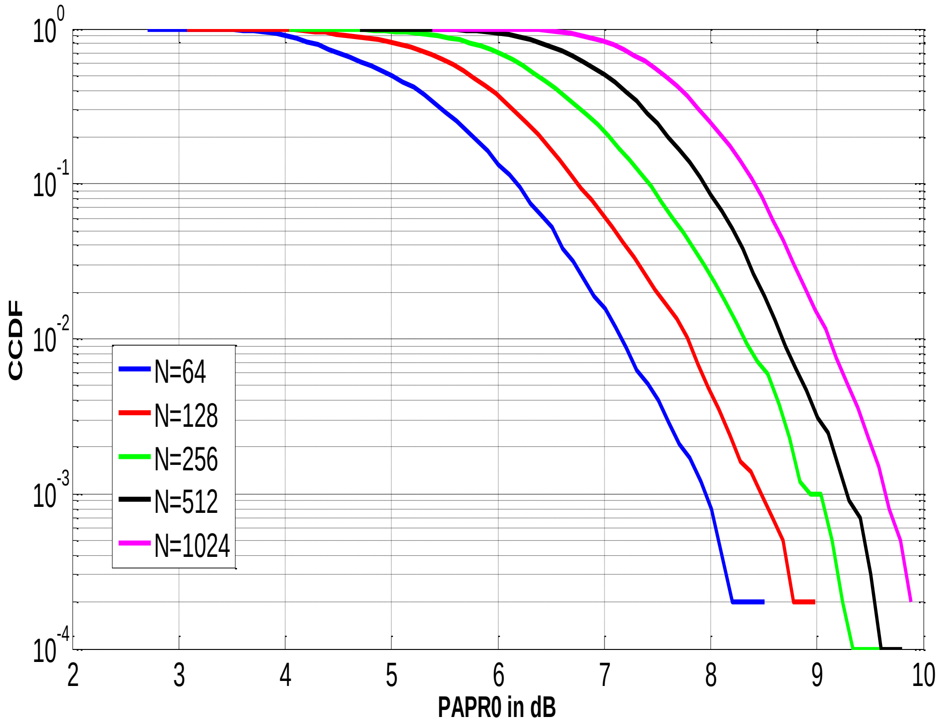


**Fig. 6.11 CCDF Performance of OFDM System by DCT after Modified PTS Technique using 4-QAM Scheme and 2 Phase Factors**

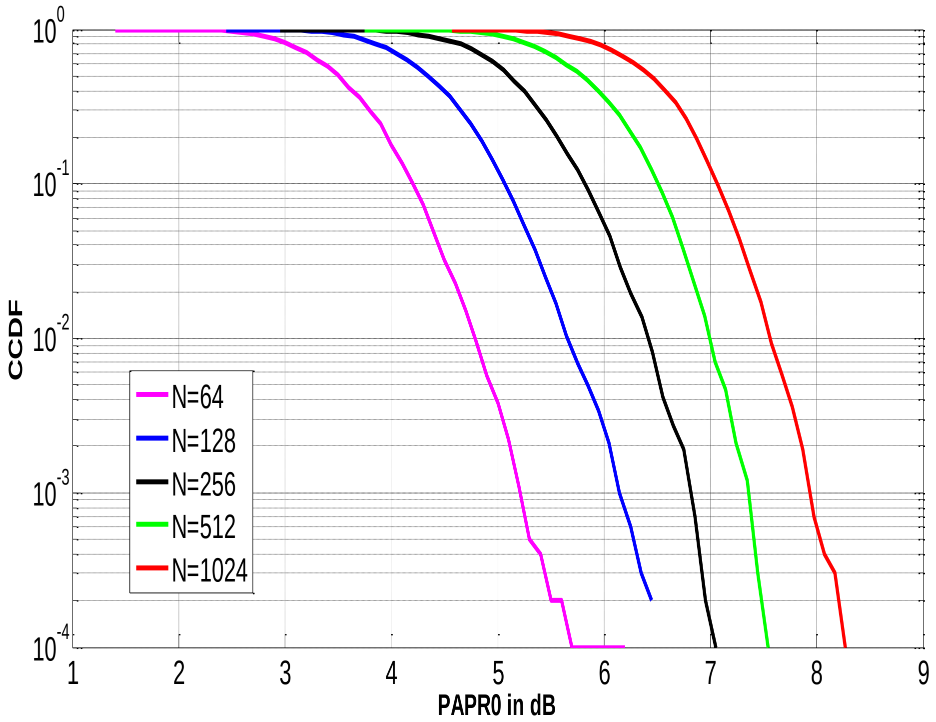


**Fig. 6.12 CCDF Performance of OFDM System by DCT after Modified PTS Technique using 4-QAM Scheme and 4 Phase Factors**

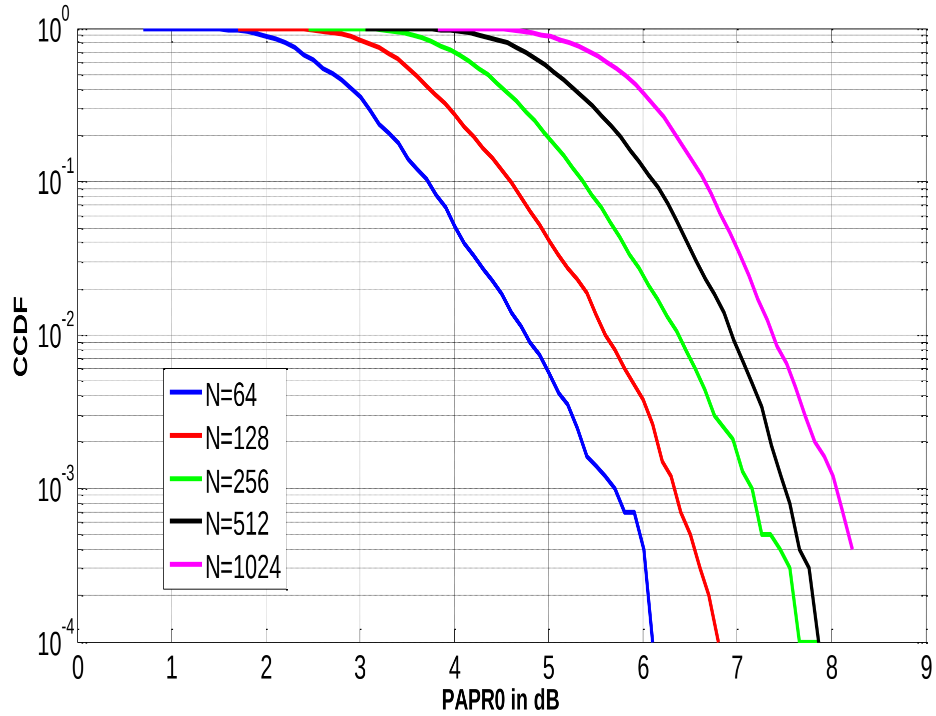


**Fig. 6.13 CCDF Performance of OFDM System by DCT after Modified PTS Technique using 4-QAM Scheme and 8 Phase Factors**

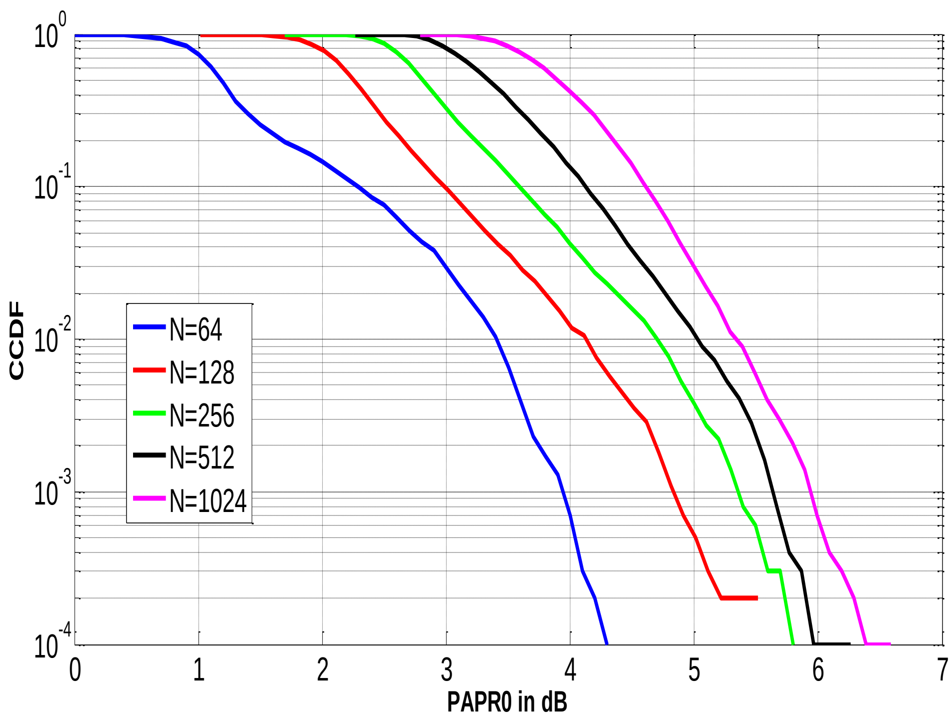


**Fig. 6.14 CCDF Performance of OFDM System by DCT after Modified PTS Technique using 4-QAM Scheme and 16 Phase Factors**

**Table 6.3 PAPR Reduction by DCT after Modified PTS**

| Number of Subcarriers | PAPR in dB (CCDF at $10^{-3}$) | | | |
|---|---|---|---|---|
| | **m=2** | **m=4** | **m=8** | **m=16** |
| **64** | 7.91 | 5.20 | 5.1 | 3.9 |
| **128** | 8.48 | 6.15 | 6.30 | 4.81 |
| **256** | 8.94 | 6.85 | 7.15 | 5.29 |
| **512** | 9.30 | 7.35 | 7.56 | 5.66 |
| **1024** | 9.68 | 7.97 | 8.02 | 5.88 |

## 6.7 SUMMARY

OFDM is an orthogonal modulation and multiplexing scheme which is used mainly to overcome the problem of selective fading effects. In spite of its many advantages it has a main drawback of PAPR problem. Many PAPR reduction techniques are present in which signal distortion less technique reduces PAPR efficiently. PTS is one of those technique which has less hardware complexity comparatively. In the proposed work, characteristics of DCT is utilized in PTS technique to reduce the PAPR further. The proposed work uses DCT before and after PTS in order to reduce PAPR. The modified PTS technique which has less computational complexity compared to conventional PTS is also combined with DCT to reduce PAPR in the same configuration as that with conventional PTS. In the proposed work both in conventional PTS and modified PTS, application of DCT before the technique shows more PAPR reduction compared to application of DCT after the PTS .techniques. In DCT before PTS techniques, the autocorrelation between every modulated data bits are reduced whereas in DCT after PTS techniques, the autocorrelation between processed OFDM signals are reduced. Because of the application of DCT in PTS techniques increases the hardware complexity of the OFDM system.

MIMO-OFDM is an Multiple Input Multiple Output of orthogonal modulation and multiplexing scheme which is used mainly to overcome the problem of selective fading effects and has high capacity. In spite of its many advantages it has a main drawback of PAPR problem. In the proposed work, characteristics of DCT is utilized in PTS technique to reduce the PAPR e modified PTS technique which has less computational complexity compared to conventional PTS is also combined with DCT to reduce PAPR in the same configuration further. The proposed work uses DCT before and after PTS in order to reduce PAPR. In DCT before PTS techniques, the autocorrelation between every modulated data bits are reduced whereas in DCT after PTS techniques, the autocorrelation between processed MIMO-OFDM signals are reduced. Because of the application of DCT in PTS techniques increases the hardware complexity of the MIMO-OFDM system.

# CHAPTER 7

# SUMMARY AND CONCLUSIONS

## 7.1 GENERAL

An attempt has been made in the present work to improve the PAPR reduction performance based on the combination of distortion less methods such as modified SLM,DCT,IDCT,CMA with steepest decent and unit circle method, interleaving and pulse shaping, modified PTS with DCT The summary, salient conclusions and scope for further research work are presented in this chapter.

## 7.2 SUMMARY

Recently wireless communication is facing a lot of challenges and researches for achieving reasonable data rate without sacrificing the bandwidth efficiency. The principle deliberation of OFDM system has been to prevent spectral growth and improve the efficiency of the power amplifier at the transmitter side.

In this work, an attempt has been made to combine modified SLM and PTS with DCT improves the PAPR reduction performance and minimize the computational complexity without degradation in BER performance. This approach has reasonable PAPR reduction and computational complexity increases exponentially with increase in the subcarriers. Moreover, when large numbers of subcarriers are used, there exist high PAPR. So significant improvement is needed for PAPR reduction and this can be achieved using modified SLM and PTS combined with DCT along with CMA, interleaving and pulse shaping. Even though, both these techniques provide acceptable PAPR reduction it invokes unacceptable complexity and affects bandwidth efficiency. Yet there has not been a satisfying solution.

Furthermore, to get an excellent PAPR reduction performance, modified PTS has been combined with DCT. A better trade-off between PAPR reduction and computational complexity are achieved. This system will be suitable to medium and high mobility scenarios. However, modified PTS combined with DCT before and after PTS method has the PTS preceded with DCT provides minimum the PAPR of the OFDM signal without affecting the bandwidth efficiency of the system. All above mentioned techniques have been incorporated to optimize the PAPR reduction in OFDM and MIMO-OFDM system.

## 7.3 CONCLUSIONS

### 7.3.1 PAPR Reduction using Modified SLM Combined with DCT and IDCT Method

The modified SLM technique is combined with DCT and IDCT is used in OFDM to improve the performance of PAPR reduction. Modified SLM technique with DCT improves the performance of OFDM signal with respect to PAPR.As there is an increasing demand for efficient frequency spectrum utilization. OFDM proves invaluable demand to next generation communication system. It has been found from the simulation result that the PAPR values of normal OFDM and modified SLM is 10.8dB and 9.5dB respectively when 256subcarriers are used at CCDF of $10^{-3}$. An improvement in PAPR reduction performance of around 35% is obtained for modified SLM with DCT based technique compared to normal OFDM. When the subcarriers are varied as 64,128, 256, 512 and 1024. The modified SLM with DCT and IDCT technique can achieve the PAPR values of 2.2dB, 2.4dB, 2.7dB, 3dB and 3.3dB respectively at CCDF of $10^{-2}$ thereby providing 35% PAPR reduction performance compared to the modified SLM technique using FFT and IFFT. Similar conclusions are obtained for MIMO-OFDM systems. Even if we increase the number of subcarriers the PAPR is less compared to normal OFDM signals.

### 7.3.2 PAPR Reduction using Modified SLM with DCT and Constant Modulus Algorithm

Recent advances in wireless communication systems have increased the throughput over wireless channels and networks. In 3G, Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system have been proposed for providing high data rate services over wireless channels. However, the MIMO-OFDM system provides high PAPR when compared to single carrier system and it is one of the most detrimental aspects in the OFDM system. The PAPR problem is more important in the uplink since the efficiency of power amplifier is critical due to the limited battery power. The modified SLM technique based Constant Modulus Algorithm (CMA) with IDCT matrix is used to reduce the PAPR. It involves two methods such as steepest decent CMA and unit circle constant modulus algorithm to reduce the PAPR further in MIMO-OFDM. The simulation result shows that there is a significant improvement in PAPR performance of MIMO-OFDM system.

It is observed that modified SLM based CMA with two methods is proposed in first method steepest descent algorithm is used to reduce PAPR in MIMO-OFDM where the time domain signal from the Resource Block is combined linearly using precoding weights which is transparent to the receiver side and in the second method unit circle is used here the precoding weights is modified to decrease the modulus variations of the resulting signal, that leads to reduction in the PAPR for the MIMO-OFDM. The method uses DCT and IDCT instead of IFFT which is normally used MIMO-OFDM for reducing PAPR. it has been shown that the PAPR performance can be improved up to 40% by using modified SLM combined with CMA based on steepest decent and unit circle method. The proposed system becomes more suitable for high data rate MIMO –OFDM system.

### 7.3.3 PAPR Reduction using Modified SLM with Interleaving and Pulse Shaping Method

MIMO-OFDM is Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing scheme. It is used as a resource sharing multiple access method in 4G and 5G technology. The main advantages of MIMO-OFDM are high data rate, high capacity, mitigates multipath fading effects, etc. The major disadvantage of this system is the highest peak to average power ratio which requires costlier HPA and DAC for processing.

Interleaving and raised cosine pulse shaping to the DCT with modified SLM in MIMO-OFDM system is done. Interleaving is applied after modulation technique which scrambles the modulated data bits which helps to reduce the similarity between data bits. The reduction of similarity helps to reduce PAPR of the OFDM signal. Raised cosine pulse shaping is used in DCT with Modified SLM techniques in order to maintain the boundary condition of orthogonal signals. Since the DCT has different boundary condition, raised cosine pulse shaping technique is incorporated with it. The overall results show that better PAPR reduction performance of 40% is obtained on comparing modified SLM with interleaving technique.

### 7.3.4 PAPR Reduction using PTS and Modified PTS Combined with DCT and IDCT Method

The basic idea is to explore the special structure of interleaved OFDM, so as to reduce the complexity for PAPR reduction. Although it takes extra power to transmit the side information and PAPR will be increased, this investigation determines the optimal phase weighting factor such that the overall system complexity is reduced. When the subblocks size is increased to 4, 8, and 16 for 256 subcarriers, the modified PTS with interleaving and pulse shaping method provides PAPR of 4.7dB, 1.8dB and 0.5dB respectively at CCDF of $10^{-3}$. The modified PTS with interleaving and pulse shaping method has 30.3% improvement in PAPR reduction performance compared to modified PTS with superimposed training sequence method. Discrete Cosine Transform technique has the property of signal energy compaction and reduction of autocorrelation.

## 7.4 SCOPE FOR FURTHER WORK

The following potential areas that might be interesting for researchers to pursue and explore in future are mentioned below.

i. Efforts can be made to provide a power control technique based on PAPR reduction using water filling algorithm in the channel estimation approach.

ii. Developing a Channel Dependent Scheduling (CDS) algorithm for the system to monitor the channel quality as a function of frequency for the each terminal and adapt subcarrier assignments to change in the channel frequency response of all the terminals.

It would be necessary to investigate the performance of PAPR reduction using various modulation techniques, where the PAPR problem may not have been considered when optimizing the system parameters

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# LIST OF PUBLICATIONS

**International Journals:**

1. **S.SUJATHA and P.Dananjayan** "PAPR Reduction Techniques In OFDM systems Using DCT And IDCT", ***Journal of Theoretical and Applied Information Technology***, 30 June 2014, Vol. 74. No. 3 – 2014.

2. **S. Sujatha, R.Jayshri and P. Dananjayan**. "DCT Based Partial Transmit Sequence Technique For PAPR Reduction in OFDM Transmission", ***ARPN Journal of Engineering and Applied Science***, vol. 10,No.5 March 2015, ISSN online: 1819-7708.

3. **S.Sujatha and P.Dananjayan** "Modified SLM with DCT for PAPR reduction in OFDM system with different subcarrier Modified SLM with DCT for PAPR reduction in OFDM system with different subcarrier'' ***,International Journal of Applied Engineering Research***, Vol. 10 No.73 (2015) ISSN online: 0973-4572.

4. **S. Sujatha, Raja and P. Dananjayan**. "Modified SLM combined with interleaving and pulseshaping method for PAPR reduction using DCT and IDCT in MIMO-OFDM ", ***International Journal of soft computing and Engineering*** , Vol. 5 issue 6 Jan 2016 ISSN online: 2231-2307

5. **S. Sujatha, R.Jayshri and P. Dananjayan**. (2016) PAPR Reduction for OFDM System using DCT Based Modified PTS Technique. ***International Journal of Communications*, 1**, 36-49

**International Conferences**

6. **S.Sujatha and P.Dananjayan** "Modified SLM with DCT for PAPR red.uction in OFDM system with different subcarrier", ***International Conference "Computational Systems in Engineering and Technology*** (ICCSET 2014).

**7.** **S.Sujatha and P.Dananjayan** "PAPR reduction using Constant Modulus Algorithm and IDCT in MIMO-OFDM Networks", ***Proceedings of Third International Conference on Eco-friendly Computing and Communication Systems***, Mangalore, India, pp.238-241, December 18-21, 2014.

8. **S.Sujatha and P.Dananjayan** "PAPR Reduction by DCT based PTS Techniques with Interleaving in OFDM System ", ***Proceedings of Third International Conference on Eco-friendly Computing and Communication Systems***, Melmaravathur, India, April 3-5 2015.

*9.* **S.Sujatha and P.Dananjayan** "MIMO based Modified SLM Combined with interleaving and Pulse Shaping Method Based on PAPR Reduction using DCT ". ***International Conference on Advanced Communication, Control & Computing Technologies (ICACCCT), Ramanadapuram, India, May 25-27 2016 (Accepted).***

# VITAE

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