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Fuculty of Electrical and Computer Engineering

A thesis submitted in partial fulfillment of the requirements for masters degree in Communication Engineering

PAPR Reduction for MIMO-OFDM System using Integrated Modified PTS Technique.

By

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August, 2019

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Declaration

This thesis is my original work and has not been presented for a Degree in any other Universities.

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Abstract

The progression in age and its growing demands, there has been rapid development in the field of communication system. The combined multiple input multiple output (MIMO) and orthogonal frequency division multiplexing (OFDM) called (MIMO-OFDM) systems. It has been receiving a great attention, for achieving high speed, high quality of service (QOS) and robustness to frequency selective fading channels by changing it in to parallel flat fading channels. It also increases range and reliability of wireless communications system.

Beside those advantages high peak to average power ratio (PAPR) is a major drawback of multicarrier transmission system. It leads power amplifier at transmitter enters into saturation region instead of being in linear region. It also increase the complexity in the analog to digital (ADC) and digital to analog conversion(DAC). Partial Transmit Sequence (PTS) algorithm is used to provide low PAPR and mitigates the out of band radiation in MIMO-OFDM system. However, the use of conventional PTS (C-PTS) technique requires excessive searching in order to find optimal phase sequence out of all permissible combinations, leading to sharp increment in computational complexity.

The integrated modified PTS scheme based on single inverse fast Fourier transform (IFFT) in contrast to the C-PTS require reduced IFFT blocks and iterations. These characteristics considerably decrease processing time and less computation following in decreased complexity. This thesis used a local searching algorithm to optimize the set of phase factors that decrease the searching complexity. The performance of MIMO-OFDM system based on integrated modified PTS scheme using Quadrature Phase Shift Keying Modulation (QPSK) has been evaluated with different factor.

There is a significant improvement in PAPR reduction for the integrated modified PTS that can be quantified as 5.5 dB. when 64 sub carriers, 4 sub-blocks, 4 phase, 4 oversampling factor and 0.6 roll-off factor for 10^2 complimentary cumulative distribution function (CCDF) value variables have been used and it can further increase as number sub blocks increase. In comparison with the C-PTS the integrated modified PTS give better trade off PAPR reduction and computational complexity reduced by 6%. The bit error rate (BER) is evaluated and analyzed with the theoretical value

key words: ***MIMO, OFDM,PAPR, PTS .***

Dedication

To my family.

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Tesfaye Shiferaw

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Abbreviations

ACE	Active Constellation Extension
ACI	Adjacent Channel Interference
ADC	Analog-to-Digital Converter
AM/AM	relationship between the amplitude of output and input signal
BER	bit error rate
BPS	bit per second
BW	bandwidth
CBC	Complement Block Coding
CCDF	Complementary cumulative distribution function
CDF	Cumulative distribution function
CF	Crest Factor
CP	Cyclic Prefix
DIF	differential item functioning
DAC	Digital-to-Analog Converter
DFT	Discrete Fourier Transform
DVB	Digital Video Broadcasting
FFT	Fast Fourier Transform
HPA	High power Amplifier
IBO	Input Back Off
ICI	Inter Carrier Interference
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
I.I.d	independent and identically distributed
ISI	Inter Symbol Interference
MCM	Multicarrier Modulation
MIMO	Multiple Input Multiple Output
MIMO-OFDM	Combination Of MIMO and Orthogonal Frequency Division Multiplexing
OBO	Output Back Off

OFDM	Orthogonal Frequency Division Multiplexing
OOB	Out Of Band radiation
P/S	Parallel to Serial Conversion
PAPR	Peak to Average power Ratio
PTS	Partial Transmit Sequences
QAM	Quadrature Amplitude Modulation
QOS	Quality Of Services
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RMS	Root-Mean-Square
S/P	Serial to Parallel conversion
SC	Single-Carrier
SC-FDMA	Single Carrier Frequency Division Multiple Access
SI	Side Information
SISO	Single Input Single Output
SISO-OFDM	Combination of SISO and Orthogonal Frequency Division Multiplexing
SLM	Selective Mapping
SM	Spatial Multiplexing
SNR	Signal-to-Noise Ratio
SQNR	Signal-to-Quantization Noise Ratio
SSPA	Solid State Power Amplifier
STBC	Space Time Block Coding
TI	Tone Injection
TR	Tone Reservation
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Local and Metropolitan Area Networks
ZMCSCG	Zero Mean Circularly Symmetrical Complex Gaussian

Chapter 1

Introduction

Wireless communication is the need of the present and future generation. Day by day we observe that the bandwidth demand is increasing by limits. However, in the real world scenario, there is a limitation on bandwidth spectrum. Therefore, high spectrum efficiency and the ability to overcome the channel fading in the multi-path channel environment is important for the wireless communication system to transmit high speed data with increased reliability.

Though the task of providing high QOS in wireless environments poses several challenges but it is imperative to meet the ever growing demand for high-speed, spectrally efficient and reliable communication wireless channels. The high data rate requirements of future wireless communication can be achieved by increasing spectral efficiency since the available radio frequency (RF) spectrum bandwidth (BW) is limited in practical systems. The use of multiple antennas at both the transmitter and receiver, which is usually referred to as MIMO communication, offers improved capacity, optimized spectral bandwidth, a high data rate transmission and significant potential for improved reliability compared to single antenna systems without additional transmission time or BW [1–3]. As discussed in the above wireless system need a technique that provides best spectral coverage, more reliable transmission and higher data rate.

In wireless communication systems, OFDM is an efficient modulation technique intended for wireless transmission of data such as audios and videos over radio waves. During transmission they might overlap with each other without any interference to achieve high bandwidth efficiency and receiver can easily demodulate them. By using multiplexing and modulation techniques to achieve higher data rates over wireless channels, OFDM decreases BER performance and ISI, the use of multiple antennas at both transmitter and receiver ends of the wireless network provides better performance. QPSK is used in this thesis in the BER evaluation because of its improved spectral efficiency requirements and needs only half the bandwidth needed for a BPSK scheme therefore QPSK is effective in terms of bandwidth. In order to obtain greater data rates over wireless networks, the use of multiple antennas at both transmitter and receiver ends of the wireless network providing enhanced efficiency. OFDM technology is the best to overcome the difficulty of multipath propagation.

The demand of high speed wireless communication has led to the development of combination of MIMO and OFDM called MIMO-OFDM system. This system is an attractive solution towards achieving high speed, high spectral efficiency, high QOS, and has become the most promising broadband wireless system [1, 2],[4]. This solution could prevent the need of additional bandwidth which is unpractical and expensive.

MIMO system can be implemented in few different ways either to obtain diversity gain or capacity gain. MIMO technique does not need any additional transmission power and bandwidth. Therefore, using MIMO-OFDM system over fading channels is promising approach to increase spectral efficiency of wireless communication system [5, 6].

The growing demand for high speed and high quality of data made MIMO-OFDM, a reliable technology which combines both space time block coding (STBC) and OFDM. MIMO-OFDM with a (STBC) is deployed for transmit diversity and secure means of data propagation even when the user is not stationary [7],[8]. In this system the drawback is high PAPR [1–3]. This is because power amplifier at transmitter enters into saturation region instead of being in linear region. Which, causes distortion to the transmitted signal further results in increased BER at the receiver. And also for battery powered devices, transmitting waveform with low dynamic range is very essential.

1.1 Advantages and Disadvantages of OFDM

The Main Advantage of OFDM

- It can overcome a lot of transmission losses like narrowband interference, high frequency attenuation, multipath fading etc and have high spectral efficiency.
- OFDM is an efficient way to deal with multipath for, a given delay spread, the implementation complexity is significantly lower than that of a single-carrier system with an equalizer.
- In relatively slow time-varying channels, it is possible to enhance capacity signifi-

cantly by adapting the data rate per single carrier (SC) according to the signal-to-noise ratio (SNR) of that particular SC.

- OFDM is robust against narrowband interference because such interference affects only a small percentage of the SCs.
- OFDM makes single-frequency networks possible, which is especially attractive for broadcasting applications.

The Main Disadvantage of OFDM

- OFDM is more sensitive to frequency offset and phase noise.
- OFDM has a relatively large PAPR, which tends to reduce the power efficiency of the radio frequency (RF) amplifier.

In order to use the OFDM technique in practice, these drawbacks need to be restrained or compensated. This study is concerned with implementing techniques for reducing PAPR and addressing the relevant implementation issues.

Reducing PAPR is considered to be very important in order to preserve the advantages of MIMO-OFDM in practical systems [9–11]. To decrease the PAPR a number of techniques have been proposed these are PTS, selective mapping (SLM), Clipping and filtering, coding, tone reservation (TR) and tone injection (TI)[12–16]. All of these methods have a different cost to decrease PAPR. PAPR reduction techniques that are proposed for Single Input Single Output OFDM (SISO-OFDM) system can be applied at each transmitting antenna distinctly in MIMO-OFDM system [3]. Though some methods of PAPR reduction have been summarized, and is important to give a comprehensive review of PAPR reductions in terms of transmission power, data rate loss, implementation complexity and BER performance, etc.

Based on the literature survey, for high throughput OFDM-MIMO System in wireless local area network (WLAN) environment, BER value should be as low as possible and data rate should be as high as possible. The most challenging issues are handling interference from different sources to achieving maximum communications reliability and increase system performance. As a result, some modifications are needed to PAPR reduction techniques to enhance system performance. The modified form of PTS technique

preferred for PAPR reduction but, the computational complexity of Modified PTS technique increase exponentially when subblock increase. It was suggested to challenge the problem of elevated computational complexity [5].
In this work to over come this problem modified PTS technique adopts a neighborhood search algorithm to determine the optimum set of phase rotation factor by assuming a threshold PAPR. Pulse shaping is an effective PAPR reduction method and depends on the correct choice of time-limited waveforms for each subcarrier [18]. In this thesis work implementing integrated modified Partial Transmit Sequence techniques to reduce the PAPR for various subblocks, subcarrier and over sampling factor. The system performance is evaluated using BER, CCDF and PAPR.

1.2 Motivation

In modern communication systems multicarrier OFDM is desirable because of several advantages associated with it, such as tolerance to inter-symbol interference, good spectral efficiency, the best performance of frequency selective fading in a multipath environment, robustness to channel impairments etc. There is a need to address powerful techniques at the transmitter and receiver simultaneously to mitigate the harmful effects of nonlinearity. At the transmitter, there is a need to use the efficient modulation technique such as multicarrier OFDM system with effective PAPR reduction techniques and utilization of effective power amplifier linearization techniques.

High PAPR has become a critical problem that needs to be solved in an OFDM system. The envelope of the OFDM is not constant. Occasionally, a large signal peak can occur when many subcarriers are added in phase. OFDM signals with high PAPR when transmitted through a nonlinear device, such as a high power amplifier (HPA), can suffer intermodulation distortion and out-of-band emission (spectral regrowth). The first effect degrades the BER performance of the system while the latter effect causes interference to other users and thus decreases the cellular capacity of the system. Developing an algorithm to reduce PAPR has become a popular field since the last two decay. Many institutions and universities make this problem the focus of their research.

However, the evaluation criteria for a PAPR reduction algorithm are not limited to PAPR reduction performance. There are many factors that must be considered. Many of the authors did not consider the PAPR reduction and complexity reduction that is one of the main criteria for PAPR reduction at the same time. The major problem of PAPR reduction along with complexity reduction motivated the author to carry out the research work. In this work, focus is made on PAPR reduction as well as complexity reduction. Some PAPR reduction techniques can effectively reduce PAPR but they are too complex to be realized, this confines the use of them in practice. A technique can be simple and easy to implement however, its PAPR reduction performance may not be as good as that of other techniques. Hence, both PAPR reduction performance and computational complexity need to be considered and a trade-off between them need to be made.

1.3 Statement of The Problem

High PAPR is the major drawback of MIMO-OFDM, which results in lower power efficiency that impede in implementing of this system. Most wireless systems for achieving the maximum output power efficiency employ the HPA in the transmitter to obtain sufficient transmission power. The HPA operates at or near the saturation region which introduces inter-modulation between the different sub carriers and additional interference into the systems due to high PAPR of OFDM signals. This additional interference leads to an increase in BER of the MIMO-OFDM system. In order to lessen the signal distortion and keep a low BER, it requires a linear work in its linear amplifier region with a large dynamic range. However, this linear amplifier has poor efficiency and is so expensive. Power efficiency is very necessary in wireless communication as it provides adequate area coverage, saves power consumption and allows small size terminals etc. It is therefore important to aim at a power efficient operation of the non-linear HPA with low back-off values and try to provide possible solutions to the interference problem brought about. Hence, a better solution is try to prevent the occurrence of such interference by reducing the PAPR of the transmitted signal with some manipulations of the OFDM signal itself. For battery powered devices transmitting wave forms with low dynamic range is very essential in order to save power.

The drawback of a large dynamic range imposes pressure on the design of the IFFT/FFT pair. The HPA must be designed to handle irregularly occurring large peaks. when the HPA enters the saturation region, it creates inband distortion, increased BER, out of band distortion, etc. These leads to ACI, in band distortion and out of band radiation. To overcome these problems the HPA should be designed to operate in large linear region. However, this is impractical as the components will be operating inefficiently and the cost becomes prohibitively high. This is especially apparent in the HPA where much of the cost and 50% of the size of a transmitter lies [19],[20].

1.4 Objectives of The Research

1.4.1 General Objective

The general objective of this thesis is to enhance the performance of MIMO-OFDM with combined modified PAPR reduction technique with consideration to balance between the performance and complexity.

1.4.2 Specific Objectives

- To evaluate the PAPR reduction performance of single IFFT based integrated modified PTS.
- To analyze the single IFFT based integrated modified PTS method and show the PAPR reduction performance and computational complexity.
- To analyze the performance of a STBC MIMO-OFDM system with single IFFT based integrated modified PTS algorithm.
- To evaluate BER of STBC MIMO-OFDM with single IFFT based integrated modified PTS in the wireless communication system.

1.5 Methodology

Firstly different publications are reviewed concerning MIMO-OFDM system performance and research done in the area. The serial input data that optimized by STBC first passes the serial to the transmitter's parallel converter. The parallel signal is then mapped to generate data blocks using QPSK modulation. It is further divided into subblocks by using pseudo-random and interleaving PTS partition (PR-IL-PTS) method . The V subblocks are divided into two equal parts in the PR-IL-PTS method, where the subblocks of the first part takes the PR-PTS scheme, and the second part applies the IL-PTS scheme. The subblocks have equal size of N which contains N/V non-zero values in each sub-blocks sequences to create a set of candidates that optimized by local searching algorithm finally, the candidate with the lowest PAPR is chosen for transmission. PAPR reduction performance using Single IFFT based combined modified PTS scheme is analyzed using different performance metrics by employing matlab simulation.

1.6 Scope the Study

The scopes of this thesis includes techniques which are based on scrambling i.e.combined PTS and C-PTS.

The scope and limitations of this work includes the following.

- In PTS technique, the data block is partitioned into non-overlapping sub-blocks and each sub-block is rotated with a statistically independent rotation factor. The rotation factor, which generates the time domain data with the lowest PAPR amplitude, is also transmitted to the receiver as side information.
- The PAPR of the original MIMO-OFDM signal is used as a reference for each comparison.
- The CCDF is employed for comparison the PAPR values with different parameters such as number of sub block, number of sucarrier and over sampling factor.
- For each process, 1000 samples of the OFDM signal are compared.

1.7 Significance of the research

This thesis provides benefits to wireless system in the form of more reliable data with higher speeds as well as a reduced burden of complexity. The ability of OFDM system to change the frequency selective channel to flat fading channel is represented that simplifying the equalization at the receiver. This system is designed to achieve high data rate without raising the channel bandwidth and simultaneously improving the capacity range as well as reliability in the wireless communication system. The main research direction is how to decrease the computational complexity of the PTS scheme while keeping a comparatively effective PAPR reduction performance. The reduction in the number of IFFT blocks is from V to unity that further reduce complexity. The PAPR reduction can significantly save the power, in which the net power saving is directly proportional to the desired average output power. Multi carrier systems such as MIMO-OFDM are now commonly implemented for better transmission of multi carrier waves due to low power consumption than single carrier waves.

1.8 Organization of The Thesis

The organization of this thesis is as follows:
In chapter 2, some basics on MIMO, OFDM and MIMO-OFDM systems are provided and a brief overview of essential techniques is provided in OFDM systems. Chapter 3 introduces the high PAPR problem in MIMO-OFDM systems, which includes PAPR's generation, definition, and distribution of probability. Some common PAPR reduction techniques, including clipping and filtering, interleaving, pulse shaping, SLM, and PTS, are then presented. These methods of PAPR reduction are discussed according to the applicable criteria. Using a set of phase factor optimization, integrated modified PTS schemes with effective PAPR reduction performance and low computational complexity are presented and introduced in chapter 4 of the thesis. In Chapter 5, the results of the simulation are presented and the discussion in the form of graphical representations is compared to that of MIMO-OFDM transmission without any PAPR reduction technique. The conclusion of this thesis and recommendations for the future work are given are given in Chapter 6.

Chapter 2

Technical Background of MIMO-OFDM Systems

This section presents an introduction to (OFDM),the concept of MIMO systems and introduces the theoretical foundations for the research work. This is by introducing the modulation of multicarrier and compare and contrast it with the modulation of a single carrier. Then, describe the modulation and the demodulation process of OFDM systems.

2.1 MIMO Systems

MIMO signaling is a revolutionary development that was founded in Bell Laboratories by Jack Winters in 1984 [2]. A MIMO enables multiple antennas at the transmitter and receiver to support a variety of signal paths to transfer more data in less time. It significantly increases the bandwidth efficiency of the systems. MIMO communications techniques does not require any extra transmission power and bandwidth. It typically assume a frequency-flat fading radio channel environment, that is the coherence bandwidth of the channel is larger than the bandwidth of the signal.

However, MIMO communications will be mainly used in wideband systems that experience frequency-selective fading, and, thus introduce inter symbole interference (ISI) [21, 22]. Several different antenna configurations are used in defining space-time systems. Depending on the number of antennas at transmitter/receivers and coding/decoding schemes used, MIMO techniques are classified into several modes such as SISO, SIMO, MISO and MIMO.

2.1.1 Basic Structure of MIMO System

As it can been seen from Figure 2.1 there exist several communication transmission models.

1. SISO system: It uses only one antenna at both the transmitter and receiver side. It is less complicated than MIMO because of the single transmitter and receiver antenna, but it reduces data speed. SISO systems are susceptible to multi-path effect issues.

2. Single input and multiple output system (SIMO): It uses a single transmitting antenna and multiple receiving antennas [23].

3. Multiple input and single output system (MISO): A MISO system employs multiple transmitting antennas and one receiving antenna, it is also termed as transmit diversity. Transmit diversity techniques are used to reduce the effect of multipath fading and interference [24].

4. MIMO system: MIMO system employs multiple antennas both for transmission and reception. Multiple transmitting and receiving antennas will achieve antenna diversity without reducing the spectral efficiency. By increasing the number of transmit and receive antennas it is possible to linearly increase the throughput of the channel with every pair of antennas added to the system.

In MIMO system, a number of antennas are placed at the transmitting and receiving ends, their distances are separated far enough distance between different base station antennas and mobile station antennas can be separated by half carrier wavelength. The idea is to realize spatial multiplexing and data pipes by developing space dimensions which are created by multi-transmitting and receiving antennas. The block diagram in the Figure 2.1 illustrates the antenna configuration is space-time systems.

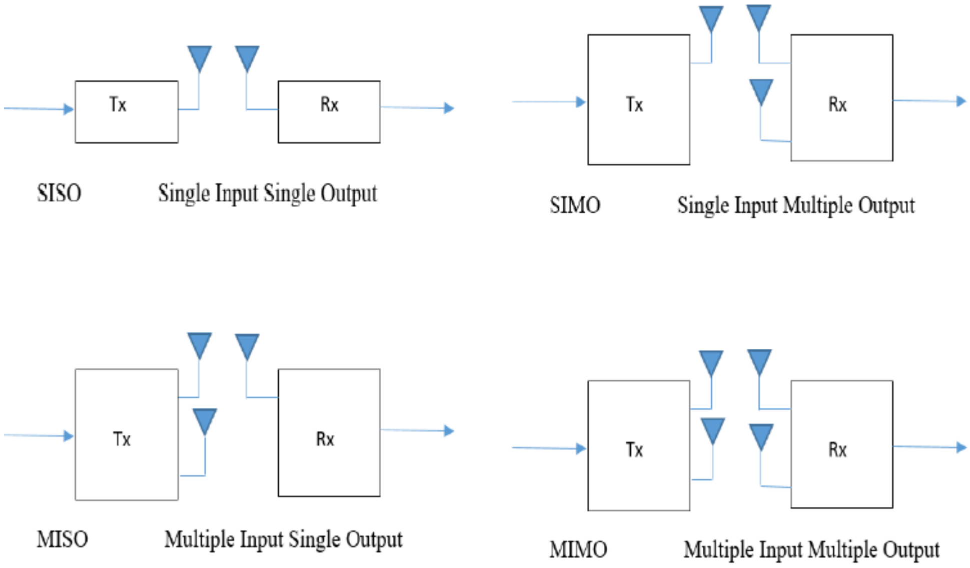


Figure 2.1: Different antenna configurations in space-time systems.

2.1.2 MIMO System Model

In wireless communication system, the main challenge is to combat multipath fading. That occurs due to the arrival of the transmitted signal through different paths. Which arrives at the receiver through different angles, with different time delays and frequency shifts. Because of this, the signal power at the receiver fluctuate giving rise to fading apart from fading, constraints such as low power and limited bandwidth make the communication system designer's mission of increasing data rate and reliability more challenging. MIMO technology is one of the most significant solutions for this capacity issue [15].

For a MIMO system with N_t transmit and $N_r$receive antennas, as shown in Figure 2.2, a narrowband time-invariant wireless channel can be represented by $N_r \times N_t$ deterministic matrix $H \in C^{N_t \times N_r}$. Consider a transmitted symbol vector $X \in C^{N_t \times 1}$, which is

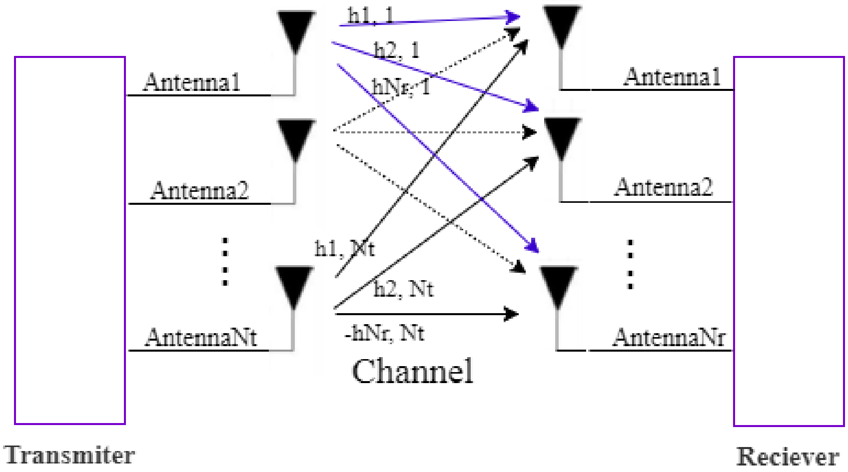


Figure 2.2: Block diagram of MIMO system

composed of N_t independent input symbols can be $x_1, x_2, x_3, ..., x_{Nt}$. Then, the received signal $Y \in C^{N_t \times 1}$, rewritten in a matrix form as follows:

$$Y = \sqrt{\frac{E_X}{N_t}} HX + n \tag{2.1}$$

where X, Y transmit and receive signal and n $=(n_1, n_2, n_3, ..., x_{Nr})^T \in C^{N_r \times 1}$ is a noise vector, which is assumed to be zero-mean circular symmetric complex Gaussian (ZM-CSCG). Note that the noise vector n is referred to as circular symmetric when $e^{j\theta}$ has the same distribution as n for any θ. The autocorrelation of transmitted signal vector is defined as

$$R_{XX} = E\{XX^H\}. \tag{2.2}$$

Note that $Tr(R_{XX}) = N_t$ when the transmission power for each transmit antenna is assumed to be 1.

2.1.3 MIMO System Capacity

The capacity of the MIMO system is defined as the maximum possible transmission rate such that the probability of error is arbitrarily small. We assume that the channel knowledge is unknown at the transmitter and known only at the receiver. The capacity of MIMO channel is defined as

$$C = \max_{f(x)} I(X : Y) \tag{2.3}$$

Where f(x) is the probability distribution of the vector x and $I(X : Y)$ is the mutual information between vectors X and Y. Thus can write

$$I(X : Y) = H(Y) - H(Y/X) \tag{2.4}$$

Where, H(Y) is the differential entropy of the vector Y, while $H(Y|X)$ is the conditional differential entropy of the vector Y, given the knowledge of the vector X. By using the statistical independence of the two random vectors n and X in equation (1.1), we can show the following relationship: $(Y|X) = H(n)$. Therefore,using this relationship, we can express equation(2.4) can be re written as

$$I(X : Y) = H(Y) - H(n) \tag{2.5}$$

From equation (2.5), given that H(n) is a constant, we can see that the mutual information is maximized when H(Y) is maximized. Using equation (1.1), the auto-correlation matrix of Y is given as

$$\begin{aligned}
&R_{YY} = EYY^H = E\{\left(\sqrt{\frac{E_X}{N_t}}HX + n\right)\left(\sqrt{\frac{E_X}{N_t}}X^H H^H + n^H\right)\} \\
&E\{\left(\frac{E_X}{N_t}HXX^H H^H + nn^H\right)\} \\
&\frac{E_X}{N_t}E\{(HXX^H H^H + nn^H)\} \\
&\frac{E_X}{N_t}HE\{(\{XX^H\}H^H + E\{nn^H\})\} \\
&\frac{E_X}{N_t}HR_{XX}\}H^H + I_{Nr}N_0
\end{aligned} \tag{2.6}$$

where E_X is the energy of the transmitted signals, and N_0 is the power spectral density of the additive noise n_i^{Nr},i=1. It has been proven that the differential entropy H(Y) is maximized when Y is Zero Mean Circularly Symmetric Complex Gaussian (ZMCSCG), that implies X must also be a ZMCSCG vector. Then, the mutual information of Y and n is respectively given as [17]

$$\begin{aligned} H(Y) &= \log_2\{\det(\pi^{R_{YY}})\} \\ H(n) &= \log_2\{\det(\pi e N_0 I_{Nr})\} \end{aligned} \tag{2.7}$$

Therefore, I(X:Y) in equation (2.6) can be reduced to

$$I(X:Y) = \log_2 \det(I_{Nr} + \frac{E_X}{N_0 N_t} H R_{XX} H^H) bps/Hz \tag{2.8}$$

And from equation (2.5), the capacity of deterministic MIMO channel is given by

$$C = \max_{T_r(R_{XX}=N_t)} \log_2 \det(I_{Nr} + \frac{E_X}{N_0 N_t} H R_{XX} H^H) bps/Hz \tag{2.9}$$

The capacity C in equation (2.9) is called the error-free spectral efficiency and can be sustained reliability over the MIMO link.

2.2 The Development of OFDM and It's Application

The idea of OFDM techniques was first suggested by R. W. Chang in mid of 60s i.e 1965 [23] and it was patented in 1970 [25], which was used in high-frequency military communication systems. OFDM is a broadly used modulation and multiplexing technology, that become the basis of many telecommunications fields that working in the standard of today's 4G wireless network. It is a multicarrier transmission method where a single high rate data-stream is divided into multiple low rate data-streams and is modulated using subcarriers which are orthogonal to each other so that they can be distinguished in the frequency domain at the receiver [26].

OFDM play an important role for high-speed data transmission due to its advantages in dealing with the multipath propagation problem, protection to frequency selective fading and, transmit high speed data with higher spectral efficiency in many current applications. Such, as digital video broadcasting (DVB) and wireless local area networks (WLANs) [27].

There are two issues regarding the OFDM transmission ISI and Inter Carrier Interference (ICI). As the symbols travel one by one to the other end of the channel, the channel will introduce delay spread in time domain which results into OFDM symbol getting spread out and hence it will interfere with consecutive OFDM symbols which is referred as ISI. The ISI can be eliminated by addition of guard interval between neighboring OFDM symbols. However each OFDM symbol still suffers from ICI when only guard interval is added. ICI is the result of delays in the multipath propagation environment and the frequency offset at the receiver. In order to eliminate ICI, some part at the end of the useful symbol period, which is called cyclic prefix (CP), is appended at the start.

Synchronization is a key issue in the design of a robust OFDM receiver. Time and frequency synchronization are paramount, respectively, to identify the start of the OFDM symbol and to align the modulators and the demodulators local oscillator frequencies. If any of these synchronization tasks is not performed with sufficient accuracy, then the orthogonality of the sub-carriers is (partly) lost. That is, ISI and ICI are introduced.

The orthogonal nature of OFDM sub-carriers that overlapped with each other, also lead to large amount of bandwidth being saved and improved spectral efficiency without ICI compared to other multiplexing techniques such as frequency-division multiplexing (FDM) and time-division multiplexing (TDM). Figure 2.3 shows the difference between the conventional non overlapping multicarrier technique(FDM) and the overlapping MCM technique(OFDM). By using the overlapping MCM technique, we save almost 50% of bandwidth [28]. To realize this technique, however, we need to reduce cross talk between sub-carriers, which means that we want orthogonality between the different modulated carriers.

Wideband channels are sensitive to frequency selective fading which require complex equalizers in the receiver to recover the original signal. OFDM overcomes this problem by dividing the wideband channel into a series of narrowband channels which each experience flat fading. Therefore only 1 tap equalizers are required in the receiver,that reducing complexity greatly.

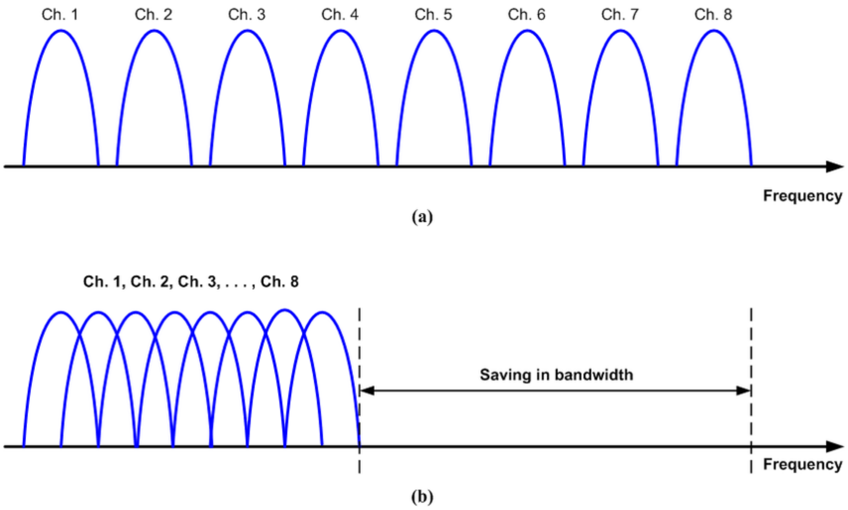


Figure 2.3: Concept of the OFDM signal: (a) conventional multicarrier technique, and (b) orthogonal MCM technique [28]

Fading Channels

Rayleigh fading model is a statistical model for the effect of a propagation environment on a radio signal. In order words, it a rational model when there are many objects in the environment that scatter the transmitted signal to arrival at the receiver antenna. Basically, when large number of paths, applying central limit theorem, each path can be modeled as circularly symmetric complex gaussian random variable with time as the variable. It uses the rayleigh distribution to complement it methods laving zero mean and phase evenly distributed between 0 and 2π radians. The majority of work to date on this area has assumed flat sub channels composing the MIMO channel.

Rayleigh Flat Fading

Flat fading channels can be approximated by rayleigh distribution if there is no line of sight. The received signal can be simplified as

$$r(t) = s(t) * h(t) + n(t)$$

where, h(t) is the random channel matrix having rayleigh distribution and n(t) is the additive white gaussian noise. The transmitted signal bandwidth in flat fading channels is much lower than the coherent bandwidth of the channel. Flat fading happens when the signal's symbol period is more than the channel's root mean square (rms) delay spread [29].

Rayleigh Frequency Selective Fading

Frequency-selective fading can be viewed in the frequency domain, although in the time domain, it is called multipath delay spread. The simplest measure of multipath is the overall time span of path delays from the first pulse to arrive at the receiver to the last pulse to arrive at the receiver. In the case of frequency selective channel, the transmitted bandwidth is larger than the coherence bandwidth of the channel. Because of the short symbol duration compared to the multi-path delay spread, multi-delayed copies of the transmit signal are significantly overlapped with the subsequent symbol, resulting in ISI. When viewed in the frequency domain, a channel is referred to as frequency-selective if $f_0 < 1/Ts = BW$, where the symbol rate, 1/Ts is nominally taken to be equal to the signal BW. Flat fading degradation occurs whenever $f_0 > BW$. Here, all of the signal's spectral components will be affected by the channel in a similar manner (e.g., fading or no fading). For wideband signal, the signal bandwidth, BW_s, may be significantly higher than the coherence bandwidth. Consequently, two frequency components separated by a frequency of the coherence bandwidth or beyond may behave significantly different. Hence, wideband channels are typically frequency-selective fading channel [29]. It is necessary to see single carrier transmission that use a wideband channel and multicarrier use narrowband sub-channels with it's effect. Single carrier systems can increase their data rate by shortening the symbol time, there by increasing the occupied bandwidth.

2.2.1 Single Carrier and Multicarrier (Modulation)

In order to support a higher data rate, the single-carrier transmission system requires wider bandwidth. For symbol rate the minimum required bandwidth is the Nyquist bandwidth. However, as the symbol rate increases, the signal bandwidth becomes larger. When the signal bandwidth becomes larger than the coherence bandwidth of the wireless channel, the link suffers from multi-path fading, which introduces ISI. To deal with the ISI in single carrier system an expensive adaptive equalizer needs to be employed. As a result, a high data rate over a single carrier system may not be a practical solution due to the complexity of the equalizer in the receiver [19]. The basic principle of multicarrier modulation (MCM) is transmitting data by splitting a high-rate data stream into several number of lower-rate streams components. And, sending each of these components over separate carrier signals [30]. The individual carriers have narrow bandwidth but, the composite signal can have broad bandwidth MCM is being used increasing as a modulation format for high data rate transmissions.

MCM signal can be processed in a receiver without the enhancement of noise or interference and the long symbol time used in MCM produces a much greater immunity to impulsive noise and multipath distortion [31]. In a single carrier system, single fade or interferer can cause the entire link to fail, but in a multicarrier system, only a small percentage of the subcarriers may get affected. Due to the problem of single carrier modulation as stated previously, multiple carrier systems are used to support high data rate. All MCM methods are built on the idea of channel partitioning, that, divide a wideband, spectrally designed transmission channel into a set of parallel narrowband sub channels. The channel partitioning can be recognized for both the continuous and discrete (time case). In this work emphasis is given on the discrete time case since it is a more applied technique [13]. OFDM avoids the use of high speed equalization techniques and it is the most common format.

2.2.2 The Basic Principle of OFDM

OFDM is multiplexing techniques where a number of independent message signal are at the same time transmitted over a single channel. It is a practical application of both amplitude and phase modulation scheme. OFDM divides the frequency-selective channel into a set of parallel frequency-flat fading channels and applies a guard interval in the OFDM symbol, called CP. The IFFT at the transmitter and a fast fourier transform (FFT) at the receiver, used to make it simple and attractive for practical use. In 1980s, CP is inserted into OFDM signals to assure the orthogonality among subcarriers, which dramatically decreased the ISI caused by a multi-path channel [9]. The basic OFDM transceiver system is shown in Figure 2.4.

Mostly the input data to be transmitted is converted from serial to parallel form first. Each parallel block contains as many samples as the total number of subcarriers. Then the IFFT of the block is computed to change time domain to frequency domain before adding the CP. After CP addition the result is converted to serial form and delivered

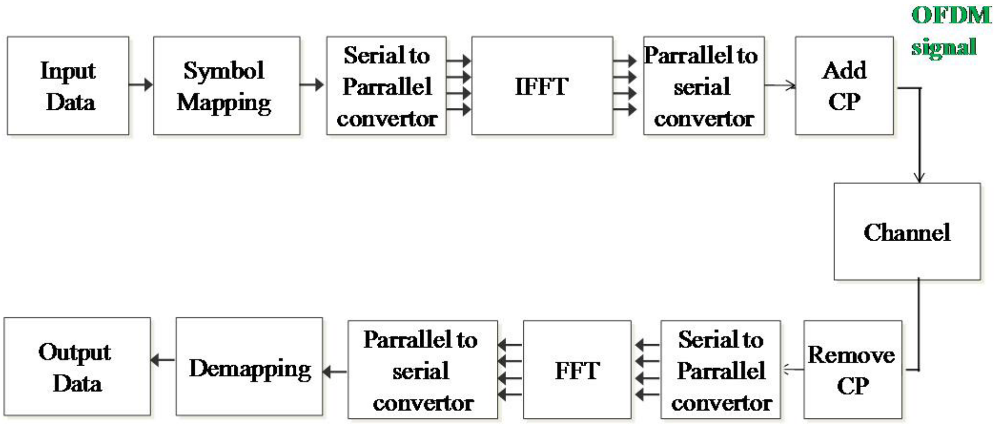


Figure 2.4: OFDM Block Diagram

to the channel for transmission. On the receiver side the operations employed on the transmitter are performed in reverse order. That is after serial to parallel conversion, the CP is removed, to change frequency to time domain FFT is computed to get the symbol estimates which are then converted to serial form.

In an OFDM system with N subcarriers, suppose that the complex symbol X_n is the signal point from the QPSK or quadrature amplitude modulation (QAM) signal constellation that is modulated on the n^{th} subcarrier. The transmitted OFDM signal can be expressed as follows [32]:

$$X(t) = \sum_{n=0}^{N-1} X_n e^{j2\pi f_n t}, 0 \le t \le T \tag{2.10}$$

where $f_n = \frac{n}{T}$ and $T = NT_s$ is the OFDM symbol interval and T_s is the data symbol period and f_n is the sub-carrier frequency spacing. In practice, the subcarriers may have different phases and amplitudes because of different complex symbols; however, the subcarriers are mutually orthogonal over the symbol interval T if the subcarrier spacing is a multiple of $\frac{1}{T}$, as

$$\frac{1}{T}\int_0^T e^{(j2\pi f_n t)} e^{(-j2\pi f_m t)} dt = \begin{cases} 0 & \text{for} \quad n \neq m \\ 1 & \text{for} \quad n = m \end{cases} \tag{2.11}$$

where $|f_n - f_m| = \frac{n}{T}$, 0...N-1

In order to recover the original data symbols, at the receiving terminal, the received signal is fed to a bank of N correlators whose outputs are sampled at the end of each symbol interval t = T. Since the subcarriers are orthogonal, the correlator outputs can be simply obtained as follows:

$$\begin{aligned}
\tilde{X_k} &= \frac{1}{T}\int_0^T X(t)e^{(-j2\pi f_k t)}dt \\
&= \frac{1}{T}\int_0^T \sum_{n=0}^{N-1} X_n e^{j2\pi f_n t} e^{(-j2\pi f_k t)}dt \\
&= \sum_{n=0}^{N-1} X_n[\frac{1}{T}\int_0^T X_n e^{j2\pi f_n t} e^{(-j2\pi f_k t)}dt] \\
&= X_k
\end{aligned} \tag{2.12}$$

For k = 0,..., N - 1.

Note that the subcarriers of an OFDM signal can be mutually orthogonal over the symbol interval T, if the frequency separation of the adjacent subcarriers is 1/T [14].

2.2.3 Orthogonality in OFDM

The orthogonality of the subcarriers has the spectrum of each carrier is a null at the center frequency of each of the other carriers as shown in Figure 2.5 the system Due to number of cycles over a symbol period that results in no interference between the carriers. The N equally spaced subcarriers will be orthogonal if the frequency separation between subcarriers is $\Delta f = \frac{1}{NT_s}$, where T_s symbol duration, and N-point IFFT is performed.

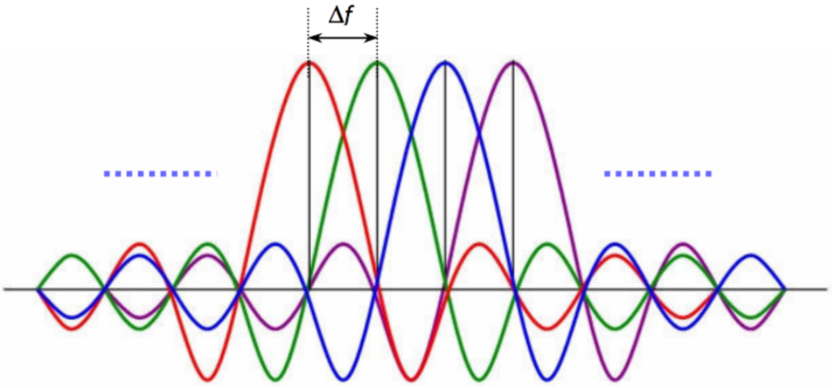


Figure 2.5: OFDM Subcarriers

2.2.4 IFFT/FFT in OFDM System

The FFT and its inverse transform IFFT processors are a key component in OFDM based wireless broadband communication systems. Hence, it is important to develop a low-power and high-performance FFT/IFFT processor to meet the requirement of low cost and real time in such communication systems. The achievement of OFDM is based on its digital implementation which can be easily implemented using the FFT algorithm, that developed by Cooley and Tukey in 1965 which is the efficient computational means for the discrete fourier transform (DFT) [10]. Both FFT and IFFT are helpful for reducing the size of physical components in OFDM transceivers. The FFT algorithm is also appropriate for ensuring that in the OFDM transceiver the orthogonality is maintained and any interference is avoided. The OFDM signal in the transmitted OFDM signal can be produced by the inverse discrete Fourier transform (IDFT) [33]. Sampling the signal x(t) with sample rate L=N yields the following Samples

$$X(k) = X(\frac{kT}{N}) = \sum_{n=0}^{N-1} X_n e^{(j\frac{2\pi}{N}nk)}, k = 0...N-1, \tag{2.13}$$

The above equation is essentially the IDFT of the original symbols X_n. Hence, at the receiving terminal, in order to recover the original symbols X_n, the receiver performs the DFT on the received samples $X(k)$, as

$$X_n = \sum_{k=0}^{N-1} X(k) e^{(-j\frac{2\pi}{N}nk)}, n = 0...N-1, \tag{2.14}$$

In practice, IDFT/DFT can be replaced by IFFT/FFT because of DFT requires long and complicated computations to run it. The IFFT can decrease the computational complexity. According to the differential item functioning (DIF) decomposition algorithm that is mentioned a K-point IDFT needs K^2 complex multiplications while the radix-2 IFFT needs only (K^2) $log2K$ complex multiplications, that make radix-2 IFFT efficient method due to decreased computational complexity.

In OFDM available bandwidth is fully used additionally, OFDM is easy to be combined with other techniques, such as MIMO, space time coding (STC), adaptive resource allocation, adaptive coding, which can further improve the reliability of communication systems [5]. In this way, the interference, including ISI and ICI, can be further eliminated and the system performance can be improved.

CHANNEL ESTIMATION OF OFDM

A channel estimation plays a crucial role in a coherent communication model. This is especially true for MIMO system because MIMO can be produced through the use of multiple antennas system. Two primary issues need to be solved in order to design channel estimators. The first issue is designing pilots because in most cases the wireless channel is a fading channel, pilots need to be transmitted periodically to track changes in channels. The second issue is how to design channel estimators with high accuracy and low complexity.

EQUALIZATION

In order to correct the effect of fading for the receiver equalization measuring the channel response and using this information to correct the received signal is performed in the receiver. Several techniques have been suggested, the more common pilot tones are used at the receiver by certain subcarriers with a known amplitude and phase [34, 35]. The method of equalization depends on the modulation scheme and the characteristics of the channel. Typically, equalization algorithms are used as tapped delay lines. Signals experiencing selective frequency fading like single carrier systems require complex equalization (i.e. more taps) where the complexity is directly proportional to the signal bandwidth. But, the OFDM Signals which experience frequency flat fading only require a 1 tap equalizer. This reduction in equalization complexity is a driving force for the use of OFDM.

2.3 MIMO-OFDM Systems

Increasing spectral efficiency can achieve the elevated data rate requirements of future wireless communication as the available RF spectrum bandwidth (BW) is limited in practical applications. The use of multiple antennas at both the transmitter and receiver, which is usually referred to as MIMO communication, offers improved capacity and significant potential for improved reliability compared to single antenna systems without additional transmission time or BW [36–38]. A MIMO system of N_t transmit and N_r receive antennas for a total of N_tN_r links can be applied to performance improvements compared to single antenna systems [36]. The performance improvements achieved by the use of MIMO-OFDM communication include array gain, diversity gain, interference reduction and spatial multiplexing (SM) gain [36].

A major wireless channel challenge is the co-relation between channels. A systematic matrix method used for the MIMO-OFDM scheme to fix this issue. This technique is used to generate orthogonal behavior between the channels so that there is no correlation between the channels [7]. MIMO-OFDM communications system typically assume a frequency-flat fading radio channel environment, i.e., the bandwidth of the signal lower than coherence bandwidth of the channel. However, MIMO communications will be mainly used in wideband systems that experience frequency-selective fading, and, thus,introduce ISI. This may cause significant performance degradation to the MIMO communications schemes if suitable techniques such as equalization are not applied for mitigating ISI. Another possibility is to apply a multicarrier transmission scheme such as OFDM to transform frequency-selective MIMO channel into parallel flat MIMO channel which is used in this document [14], [21, 22],[39–41]. Multicarrier modulation is currently used in many modern wireless systems. During the period 1997 to 2005 many OFDM based systems were introduced, such as terrestrial digital video broadcasting, wireless LAN IEEE 802.11a, broadband wireless MAN IEEE 802.16a/d, and OFDM-based mobile cellular networks [43].

However, MIMO-OFDM has been identified as a promising approach for high spectral be long enough to accommodate the delay spread of the channel. Thus, OFDM does not require any additional equalization techniques for mitigation of ISI. OFDM can be implemented with efficiency wideband systems and has been included in many upcoming wireless standards.

2.4 Literature review

A MIMO-OFDM simulation model based on STBC that built and analyzed transmission performance under different channels. The simulation results indicate that the STBC-based MIMO-OFDM system outperforms other BER with out MIMO-OFDM systems [44].

presented a mechanism to demonstrate the similarity of OFDM to COFDM. The proposed model used the BER parameter to analyze MIMO's performance over the AWGN channel. Result simulation shows that the BER values of the MIMO-OFDM network need to be improved [45].

The interleaving technique fulfills the worst PAPR reduction performance, but it has the lowest computational complexity compared to the other partitioning schemes. The computational complexity of the interleaved PTS scheme is lower than that of the psedo random PTS, adjacent PTS schemes in the frequency domain, since the interleaved PTS scheme requires a smaller number of IFFT stages to transform its subcarriers [46].

The performances of the Combination of SM and STBC forms hybrid MIMO models with different modulations such as QPSK and QAM with multiple antennas are measured with respect to BER [47]. STBC for two transmitting antennas and two receiving antennas for analyzing MIMO-OFDM performance using simulation software. Performance for MIMO-OFDM is improved one due to use of STBC. Result for QAM scheme shows better result. BER performance is better for PSK in comparison with QAM for less data rate but for high data rate QAM is best but with increase in SNR [44]. All the above discussed papers improve the performance of the system with the cost of increasing complexity therefore the cost of system complexity must be considered to be lower for PAPR reduction technique.

Inference from the existing work both in-band and out-of-band interference to signals are caused by the nonlinear effects. Therefore, a backup approximately equal to the PAPR is required by the power amplifiers for distortion-less transmission. This subsequently decreases the efficiency for amplifiers. PAPR minimization has been focused in different schemes and algorithms by employing several techniques.
Some of the methods have a moderate PAPR reduction capability but are less complex, while some have a very good PAPR reduction capability at a very high complexity cost. The Partial Transmit Sequence method is consistent with the second type of methods with high computational complexity and good PAPR reduction performance. In the PTS, the exhaustive search complexity of optimal phase factors exponentially increases with increasing the number of sub-blocks and phase rotation factors. To mitigate the search complexity, several different suboptimal PTS methods have been investigated in the previous studies that present a novel approach based on particle swarm optimization (PSO) to overcome the computational complexity of the PAPR reduction problem in the PTS technique but, with loss of of PAPR performance [49, 50]. In [51] Sub-optimal solutions for modified PTS circular shifting in MIMO-OFDM are needed to reduce the computational complexity and/or SI. Two sub-optimal solutions are proposed, with slight loss of

PAPR reduction performance.

For the inherent defect of conventional PTS algorithm, complex computing, a very effective iterative method is introduced to determine sub-optimal weighting factor for each sub-block instead of conducting an ergodic searching so as to reduce the calculation complexity significantly. This sub-optimal algorithm gives a better approach to the real conditions in engineering practice by providing a compromise between the PAPR reduction performance and computational complexity but with lose of PAPR. The sub-optimal PTS technique can be implemented in the working platform of MATLAB and the results analyzed to demonstrate the performance of the proposed PAPR reduction in MIMO-OFDM using modified PTS scheme. In sub optimized PTS algorithms, the complexity of PAPR reduction will be greatly reduced along with the utilization of PTS scheme efforts.

In [48] the PAPR performance of modified PTS can be improved by using the interleaved sub block partition scheme. However increase of the number of sub-block offered better performance but increased the complexity. The integrated interleaved sub-block partitioning method, modified PTS and pulse shaping method are simple to implement and reduce the transmitter complexity but, this paper has gap on complexity analysis and evaluation of BER. Combined interleaving technique uses the multiple transmit antennas for achieving better PAPR performance. Hence, the introduced scheme becomes more efficient for high data-rate MIMO-OFDM system. The main objective of this research is to offer low complexity schemes to reduce the PAPR in MIMO-OFDM based systems of practical use by solving the drawbacks that currently exist in the literature works. Investigation of an efficient PAPR reduction schemes for MIMO-OFDM system is considered as one of the problem areas explored hence, it is intended to use an integrated interleaved sub-block partitioning modified PTS method for PAPR reduction in MIMO-OFDM system. The integrated modified PTS scheme is based on phase-factor optimization Moreover, in the PTS scheme, the corresponding phase factor of each signal can be obtained by using exhaustive searching. for the introduced integrated modified PTS scheme exhaustive search for the optimum phase factors has been performed based on a local searching algorithm to optimize the set of phase factors that decrease the searching complexity. This work used a local searching algorithm to optimize the set of phase factors that decrease the searching complexity.

Chapter 3

Peak to Average Power Ratio (PAPR)

The instantaneous output signal of an OFDM system often has large fluctuations compared to traditional single-carrier systems due to the sum of many narrowband signals in the time domain. This system requires devices, such as power amplifiers, ADC and DAC, must have large linear dynamic ranges. If this is not satisfied, a series of undesirable interference is encountered when the peak signal goes into the non-linear region of devices at the transmitter, such as high out of band radiation and inter modulation distortion. PAPR reduction techniques are the very important for OFDM systems [45].

3.1 Criteria of PAPR Reduction in MIMO-OFDM Systems

Every method used to reduce the PAPR has some drawbacks and merits. There are many factors that should be considered before a specific PAPR reduction technique is chosen. There is always a trade-off between PAPR reduction and some other factors like bandwidth, computational complexity, average power etc. The criteria of the PAPR reduction is to find the approach that it can reduce PAPR largely and at the same time it can keep the good performance in terms of the following factors as possible.

1. High potential to limit the PAPR: It is a key factor to be consider in the selection of technique to reduce the PAPR with few harmful side effects like in-band distortion and out of band radiation.

2. Low average power: even though it can reduce PAPR through the average power of the original signals increase, it requires a larger linear operation region in HPA and which led in the deterioration of BER performance.

3. Low implementation complexity: Commonly, complexity techniques viewing better ability of PAPR reduction. Both time and hardware requisites for the PAPR reduction must be minimal.

4. No bandwidth expansion: The bandwidth is an infrequent resource in systems. The bandwidth expansion has directly resulted in the data code rate loss due to side information (like the complementary bits in complement block coding (CBC) and phase factors in PTS. Additionally, when the side information is received in error unless some methods of protection such as channel coding employed. For that reason, when channel coding is utilized, the loss in data rate is increased further due to side information. Therefore, the loss in bandwidth due to side information must be avoided or at least be preserved minimal.

5. No BER performance degradation: The goal of the PAPR reduction is to achieve the best system performance, including BER than that of the original OFDM system. Therefore, all the methods, which have an increase in BER at the receiver, must be paid more attention in practice. Furthermore, if the side information is received in error at the receiver, which may also result in entire incorrect data frame and thus the BER performance is reduced.

6. Without the additional power required: The design of a wireless system should always take into account the efficiency of power. If an operation of the PAPR reduction technique which require more additional power, it deteriorates the BER performance when the transmitted signals are normalized back to the original power signal.

7. No spectral spillage: Any PAPR reduction techniques cannot eliminate OFDM attractive technical features like immunity to the multipath fading. Therefore, the spectral spillage must be avoided in the PAPR reduction.

8. Good Spectral Efficiency: If a technique destroys the inter channel interference (ICI) or immunity to multipath fading or some other advantage related to spectrum would be considered as a good PAPR reduction technique.

9. Other factors: It also should be focused greater concentration on the effect of the nonlinear devices utilized in signal processing loop in the transmitter like DACs, mixers and HPAs since the PAPR reduction basically avoid nonlinear distortion as a consequence of these memories-less devices introducing into the communication channels. At the same time, the cost of these nonlinear devices is also the important factor to design the PAPR reduction scheme.

3.2 The PAPR Problem

In general, even linear amplifier or DAC and ADC introduce a nonlinear distortion on their outputs due to their saturation characteristics caused by the input being much larger than its normal value. Figure 3.1 below illustrates the characteristic of a HPA, which is a typical relationship between the amplitude of output signal and the amplitude of input signal (AM/AM) response for HPA. A high peak signal generates out-of-band energy and in-band distortion. These degradations may affect system performance. To avoid such nonlinear effects, a waveform with high peak power must be transmitted in the linear region of the HPA by decreasing the average power of the input signal [11]. This is called (input) back off (IBO) and results in a proportional output back off (OBO). The input back off can be written as

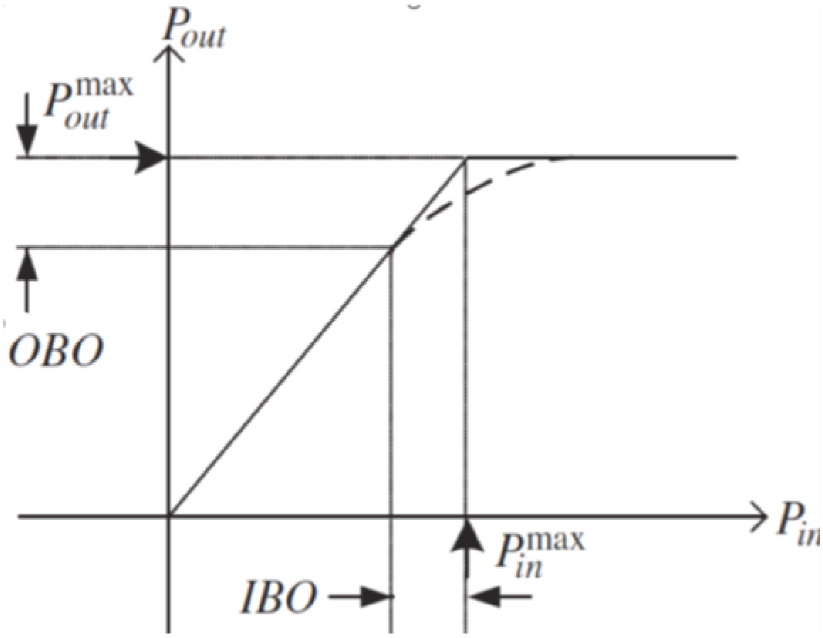


Figure 3.1: Input-output characteristic of a HPA [19]

$$IBO = 10log_{10}\frac{P_{insat}}{P_{in}} \tag{3.1}$$

Where P_{insat} is the saturation power, above which is the nonlinear region, and P_{in} is the average input power. The amount of back off is usually greater than or equal to the PAPR of the signal.

3.2.1 Nonlinear Characteristics of HPA and ADC

The HPA's nonlinear feature is very subject to the variability in signal amplitudes. To overcome the low power efficiency of the HPA needs not only big back-off and wide dynamic range DAC but also extremely effective HPA, which is very essential in wireless communication because it gives appropriate area coverage, saves power consumption and enables small terminals etc. and linear converters. These requirements lead in expensive hardware and complicated systems. Therefore, it has become essential to employ efficient PAPR reduction methods to reduce the complexity of complex hardware design [52, 53].

Most radio systems employ the HPA in the transmitter to obtain sufficient transmission power and maximum output power efficiency. Moreover, the nonlinear characteristic of the HPA is very sensitive to the variation in signal amplitudes. However, the variation of OFDM signal amplitudes is very wide with high PAPR.

Large PAPR also demands the DAC with enough dynamic range to accommodate the large peaks of the OFDM signals. Although, a high precision DAC supports high PAPR with a reasonable amount of quantization noise, but it might be very expensive for a given sampling rate of the system. Whereas, a low-precision DAC would be cheaper, but its quantization noise will be significant, and as a result it reduces the SNR when the dynamic range of DAC is increased to support high PAPR. Furthermore, OFDM signals show gaussian distribution for large number of subcarriers, which means the peak signal quite rarely occur and uniform quantization by the ADCs is not desirable. If clipped, it will introduce in band distortion and out-of-band radiation (adjacent channel interference) into the communication systems. Therefore, the best solution is to reduce the PAPR before OFDM signals are transmitted into nonlinear HPA and DAC.

3.2.2 Power Saving

Because of the larger dynamic range, a linear HPA at the transmitter will have low power efficiency. The PAPR reduction can significantly save the power, in which the net power saving is directly proportional to the desired average output power [54]. The power amplifier efficiency described as the proportion of RF output to DC input power is provided by, $\eta = P_{out}/P_{in}$, where P_{in} is the amount of power consumed by the amplifier, while

P_{out} is the average output power. For example Class A power amplifier has a maximum efficacy of 50% and an efficacy of 50% is η=0.5/OBO [12]. PAPR input signal efficiency can be described in the equation $\eta(\%) = 0.5/PAPR_x$.

After PAPR reduction, the power consumed by the DC input amplifier is less. The decrease in power consumption is the difference between DC input power without reduction of PAPR and DC input power with reduction of PAPR. Accordingly, the amplifier's effectiveness will improve as DC input power decreases owing to PAPR reduction. The DC input power is reduced by a factor (P_{PAPR}/P) where P_{PAPR} and P are the PAPR of MIMO-OFDM signal with and without PAPR decrease, respectively. The The increase in power amplifier efficacy owing to modified PTS method combined with interleaving and pulse shaping is realized as an increase in reliable SNR [55]. The efficient SNR affecting the OFDM system's BER is proportional to $(P_{out}/PAPR/N_0)$.

3.3 Quantifing the PAPR

To design and develop an effective PAPR reduction technique, it is very important to accurately identify the distribution of PAPR in MIMO-OFDM systems. The distribution of PAPR plays an important role in the design of the whole MIMO-OFDM system. The distribution of PAPR can be used in determining the proper output back-off of the HPA to minimize the total degradation. It can be used directly to calculate the BER and to estimate the achievable information rates [10].

Suppose that the input data streams in the transmitted OFDM signal is statistically independent and identically distributed (i.i.d.), i.e. the real and imaginary part are uncorrelated and orthogonal. As mentioned previously, the MIMO-OFDM system transmit data over n parallel-frequency channels, the resulting waveform is the superposition of n narrowband signals. These n narrow bands are the result of n Point IFFT operations involving the sum of n complex numbers. According to the central limit theorem, the output can be accurately modelled as complex gaussian random variables with zero mean and variance $\delta^2 = \frac{\varepsilon_x}{2}$. The amplitude of the output signal can be expressed as

$$X(n) = \sqrt{(\Re\{X[n]\})^2 + (\Im\{X[n]\})^2} \tag{3.2}$$

Which is rayleigh distributed with parameter δ^2. The output power can be expressed as

$$X[n] = (\Re\{X[n]\})^2 + (\Im\{X[n]\})^2 \tag{3.3}$$

Which is exponentially distributed with mean $2\delta^2$. The PAPR of the transmitted OFDM signal can be defined as

$$PAPR = \frac{\max|X[n]|^2}{E[|X[n]|^2]}, 0 \leq n \leq N-1 \tag{3.4}$$

The PAPR of [x(n)] at (dB)

$$= \log_{10}\frac{\max|X[n]|^2}{E[|X[n]|^2]} \tag{3.5}$$

Where $E[]$ denotes the expectation operator represents, the transmitted OFDM signals which are obtained by taking IFFT operation on modulated input symbols. The PAPR of pass band OFDM signal is approximately twice that of base band PAPR [56].

For a continuous time baseband OFDM signal, the PAPR of any signal is defined as the proportion of the maximum instantaneous power of the signal and its average power. If X (t) is a transmitted baseband OFDM signal, then PAPR is defined as:

$$PAPR[(X(t))]_{0\leq t\leq T_s} = \max\frac{[|X[t]^2]}{\rho_{av}} \tag{3.6}$$

Where, ρ_{av} is the average power of X (t) and can be computed in frequency domain because IFFT is a unitary transformation T_s is useful duration of an OFDM symbol [56]. The above power characteristics can also be described in terms of their magnitudes (not power) by defining the crest factor (CF), which is defined as the ratio between maximum amplitude of OFDM signal X(t) and root-mean-square (RMS) of the waveform. The CF is defined as:

$$CF = \frac{\max|X[t]|^2}{E[|X[t]|^2]} = \sqrt{PAPR} \tag{3.7}$$

In most cases, the peak value of signal X(t) is equals to a maximum value of its envelope $|X(t)|$ However, it can be seen from Figure 3.2 that the appearance of peak amplitude is very rare, thus it does not make sense to use max $|X(t)|$ to represent the peak value in real application. Therefore, the PAPR performance of OFDM signals is commonly measured by certain characterization constants which relate to probability [57].

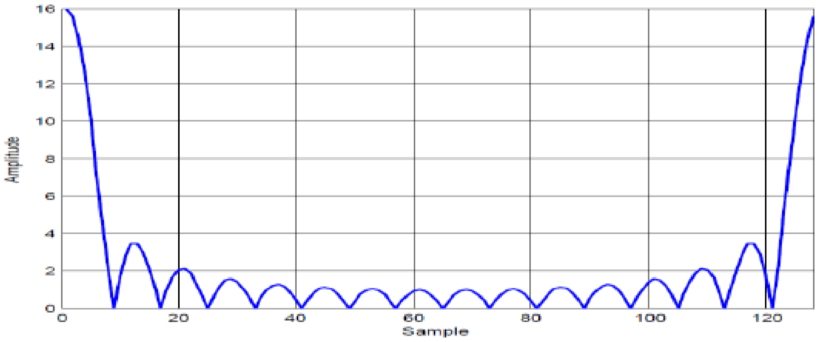


Figure 3.2: High PAPR when sub-carriers are modulated by same symbols [57]

3.4 Probability Distribution Function of PAPR

The statistical description of the PAPR is the most commonly used due to the occurrence of the maximum PAPR. Cumulative distribution function (CDF) shows how much time signal remain below any given level where as a CDF curve shows how much time the signal remains at or above a given power level. The percentage of time the signal spends at or above each power level defines the probability for that particular power level. A CDF curve is a plot of relative power levels. The PAPR of passband OFDM signal is approximately twice that of baseband PAPR. The CCDF can be expressed as

$$CCDF = 1 - CDF \tag{3.8}$$

The output signal has an exponential distribution, thus the CDF of the amplitude of a signal sample is given by

$$CDF = 1 - e^{-Z} \tag{3.9}$$

And, The CCDF denotes the probability that the PAPR of the OFDM signal exceeding the threshold value, or without any PAPR reduction technique notable, for conventional (single antenna) OFDM, the CCDF of the OFDM signals is expressed as [5], [6], [57].

$$CCDF = P(PAPR > Z) = 1 - (1 - e^{-Z})^N \tag{3.10}$$

where the Z is the threshold value.

Since the MIMO-OFDM systems are based on OFDM, they also suffer from the high PAPR issue. According to the central limit theorem, the time domain signal samples are mutually independent and uncorrelated and it is not accurate for a small number of sub carriers. To catch some peaks of the signal that do not appear in the PAPR calculation, oversampling is employed in the discrete baseband signal by inserting (L-1)* N zeros to the OFDM signal. Therefore, the CCDF of the continuous OFDM signal is given as [57]

$$CCDF = P(PAPR > Z) = 1 - (1 - e^{-Z})^{LN} \tag{3.11}$$

where L is the oversampling factor and N number of subcarrier.

In MIMO-OFDM systems, the probability that the PAPR of a randomly generated OFDM symbol over all N_t transmit antennas exceed Z is given by

$$CCDF = \text{P(PAPR>Z)} = 1 - (1 - e^{-Z})^{N_t LN} \tag{3.12}$$

Since the MIMO-OFDM systems are based on OFDM, they also suffer from the high PAPR issue. This work, use the CCDF as a metric to assess the performance of the technique used for PAPR reduction.

3.5 PAPR Definition in MIMO-OFDM

In MIMO-OFDM system the analysis of the PAPR performance is similar to the OFDM system with single antenna. The PAPR of the entire system is defined as the maximum of the PAPRs among all the transmit antennas [58].

$$PAPR_{MIMO-OFDM} = \ \text{max}_{1 \leq i \leq N_t} PAPR_{N_t} \tag{3.13}$$

where $PAPR_i$ denotes the PAPR at the i^{th} transmit antenna and N_t is the number of the transmitter antenna in the system.

3.6 Factors That Influence PAPR Performance

The parameters that effect on PAPR performance and effluent directly to reduce the PAPR can be divided into three:

- Modulation schemes.
- Number of sub-carriers.
- Sampling rate factor.

The three parameters above are closely related to PAPR performance and it is important to study the effect of those parameters with the original OFDM signals.

3.6.1 Number of Sub Carriers (N)

The working principle of OFDM system depends on dividing the frequency into subcarriers, each user can occupy one channel. Therefore, increasing sub-carriers lead to increasing the information that is transmitted, thus the numbers of users are also increasing. The numbers of sub-carriers play an important role for PAPR performance due to the varying information carriers. Different numbers of sub-carriers result in different PAPR performances. The simulation result will show the influencing number of subcarriers on PAPR performance.

3.6.2 Modulation Scheme

The input sequences in OFDM system should modulate by one type of the modulation scheme before converting from frequency domain to time domain through using IFFT to generate OFDM samples. There are several types of modulation schemes used for modulating the transmitted signal. Common types of modulation schemes such as binary phase shift keying (BPSK), QPSK, 4-QAM, 16-QAM and 64-QAM among several types of modulation schemes are used to evaluate the PAPR performance. High data bandwidth efficiency (in terms of b/s/Hz) this can be achieved by utilizing higher order modulations based, for instance, on QAM. When using a higher-order modulation such as QAM type, the PAPR of the summed OFDM signal is increased by the PAPR of the QAM constellation utilized. Nevertheless, the probability of these higher peaks happening is accordingly less. The performance of these PAPR reduction methods remains almost unchanged for various modulation scheme (QPSK, BPSK and 16 QAM) on OFDM signal [42]. As seen from the simulation in Figure 3.3 the performance of OFDM based system in QPSK and 16-QAM remain unchanged.

3.6.3 Oversampling Rate Factor (L)

In the real implementation, continuous-time OFDM signal cannot be described precisely due to the insufficient N points sampling. Some of the signal peaks may be missed and

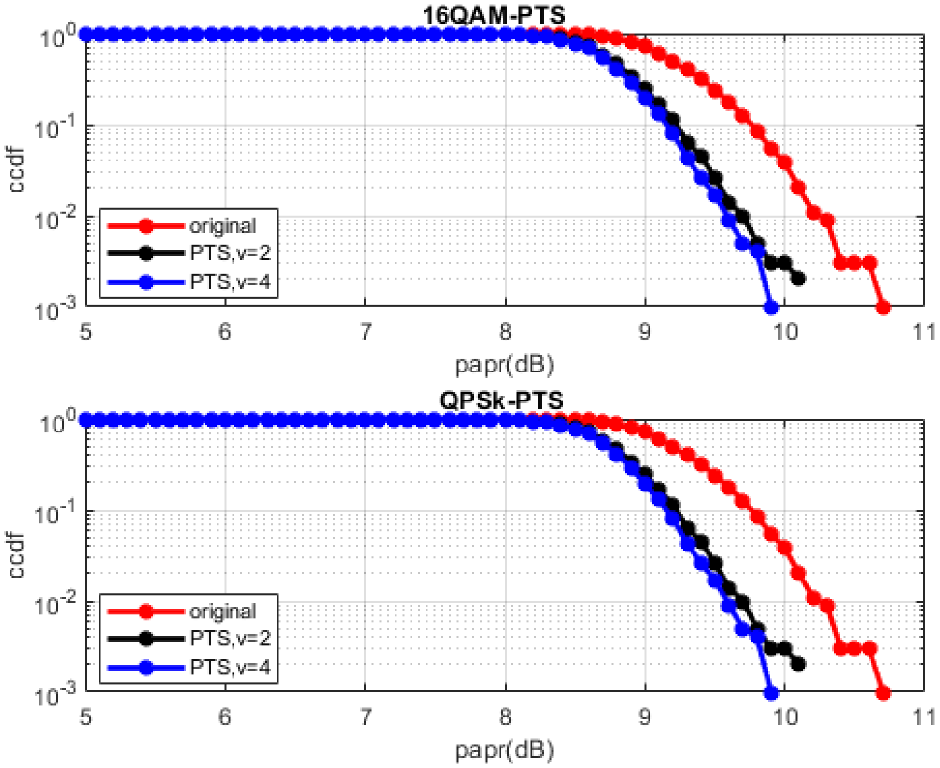


Figure 3.3: Types of modulation schemes on PAPR performance

PAPR reduction performance is unduly accurate. In order to get more precise value of PAPR, the oversampling scheme is commonly employed by inserting L*N points to IFFT of the original data with the $(L-1)*N$ zero-padding before the OFDM modulation that ensures to catch the peaks of the signal and PAPR performance be more accurate. [59] has shown that the effective PAPR results can be obtained at L=4. The OFDM signal x(n) can be written as :

$$X(\frac{n}{L}) = \frac{1}{\sqrt{LN}} \sum_{k=0}^{N-1} X_k e^{\frac{j2\pi nk}{NL}}, 0 \leq n \leq LN-1. \tag{3.14}$$

Where L represents an oversampling factor, so that, using suitable oversampling factor L is an influence to PAPR performance.

3.7 PAPR Reduction Techniques

The main aim of PAPR reduction technique is to reduce the fluctuations in the envelope of the signal which are to be transmitted by the power amplifier. Numerous techniques have been proposed and optimized in the literature to reduce the PAPR of OFDM sig-

nals. These techniques are usually classified into three main categories: signal distortion techniques, probabilistic techniques and coding techniques.
This section, will briefly review the principles of these PAPR reduction techniques. At the same time, it mainly focus on the important optimization among these techniques and point out the advantages and disadvantages of them.

At present, there are many PAPR reduction techniques of OFDM. The first is distortion technique, such as clipping, companding and so on. These techniques are simple and, able to reduce PAPR in great level, but result in signal distortion, which leads to worse BER performance. The major difference between clipping, and companding is that companding transforms enlarge the small signals while compressing the large signals in order to remove interference from noise, whereas clipping method does not change the small signals.

The second is coding technique is an efficient method to reduce the PAPR for a small number of subcarriers, but it is inefficient transmission rate significantly for a large number of subcarriers. It causes no distortion and creates no out-of-band radiation, but it suffers from bandwidth efficiency as the code rate is reduced. It also suffers from complexity to find the best codes and to store large lookup tables for encoding and decoding, especially for a large number of subcarriers [60].

The third kind is probabilistic (scrambling) technique or the redundancy technique which is including SLM and the PTS [61, 62]. Due to the high PAPR appears randomly, these techniques focus on lower probability of high peaks of OFDM signals. The principle of these techniques is that different scrambling sequences are weighted to original OFDM signals to optimize phase sequences. Then, one combination between OFDM signal and phase sequence that has minimum PAPR is selected to be transmitted. The probability of high peaks occurrence will be reduced through this way and then PAPR is reduced. This paper is mainly focus on PTS technique to reduce PAPR which give better performance as compare to SLM. The overall comparison of different PAPR reduction techniques are illustrate in the given table 3.1 below[67, 68].

Table 3.1: Shows the comparison of different PAPR reduction techniques.

PAPR reduction technique	complexity	power increase	distortion	data rate loss
Amplitude clipping & filtering	Low	No	Yes	No
SLM	High	No	No	yes
Interleaving	Low	No	No	Yes
Coding	High	No	No	Yes
PTS	Very high	No	No	Yes
The integrated modified PTS	Low	No	No	Yes

3.7.1 Clipping and Filtering

Clipping and filtering is a powerful PAPR reduction technique. In this technique, the OFDM signal is deliberately clipped before amplification at a specific threshold value. However, clipping creates band distortion and out of band noise due to which the rate of bit error and spectral efficiency are reduced [13]. The clipping and filtering block diagram is shown below in Figure 3.4.

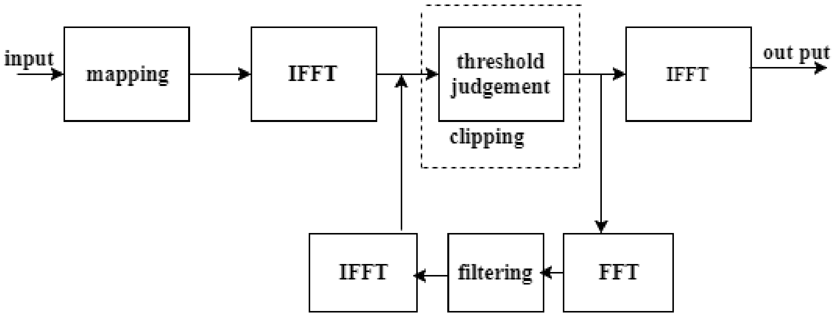


Figure 3.4: Clipping and Filtering block diagram

The processing steps in Figure 3.4. are as follows, initially the peak is detected and is clipped. Again it is transferred to frequency domain and Out-of-band signal is set to zero. Finally using IFFT it is converted to time domain signal, and is transmitted as output.

3.7.2 Selective Mapping Method(SLM)

The entire data stream is divided into different blocks of N symbols, in specific SLM method. Each block is multiplied by different phase factors to generate modified blocks before the modified block is given. Each modified block is given to the IFFT block giving OFDM as output [63]. Figure 3.5 shows the block diagram of SLM.

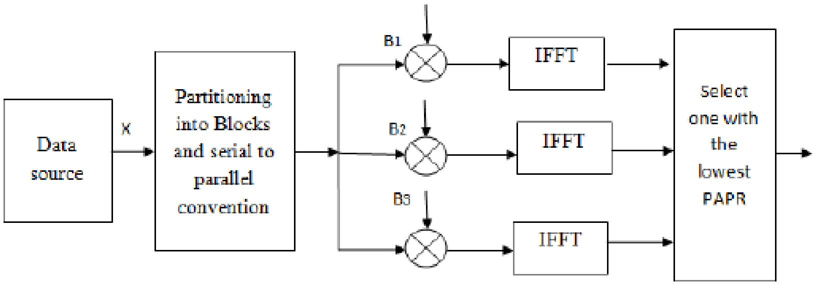


Figure 3.5: Block diagram of SLM technique

In SLM one OFDM signal is selected from several signals containing the same information data . SLM is very flexible scheme and it effectively reduce the PAPR . To improve its performance modified block must be increased. It includes several IFFT stages and complex optimization procedure which increase the complexity and computational burden.

3.7.3 Partial Transmit Sequence (PTS)

PTS is one of the powerful PAPR reduction technique used to reduce PAPR in MIMO-OFDM system which is implemented in this paper. The aim of this technique is subdividing the original OFDM symbol data into sub-data which is transmitted through multiple non-overlapping sub-blocks and rotated with a statistically independent rotation factor. Which are differed by the phase rotation factor until choosing the optimum value which has low PAPR for transmission is selected. There are three sub block partition schemes as showen in Figure 3.6 that are pseudo-random, adjacent and interleaved. Pseudo random sub block partition scheme gives the good result compared to other two methods. But in terms of hardware complexity the pseudo random is very complex compared to others whereas the interleaved partition has the worst PAPR reduction performance and is very less hardware complexity compared to others scheme[63],[64].

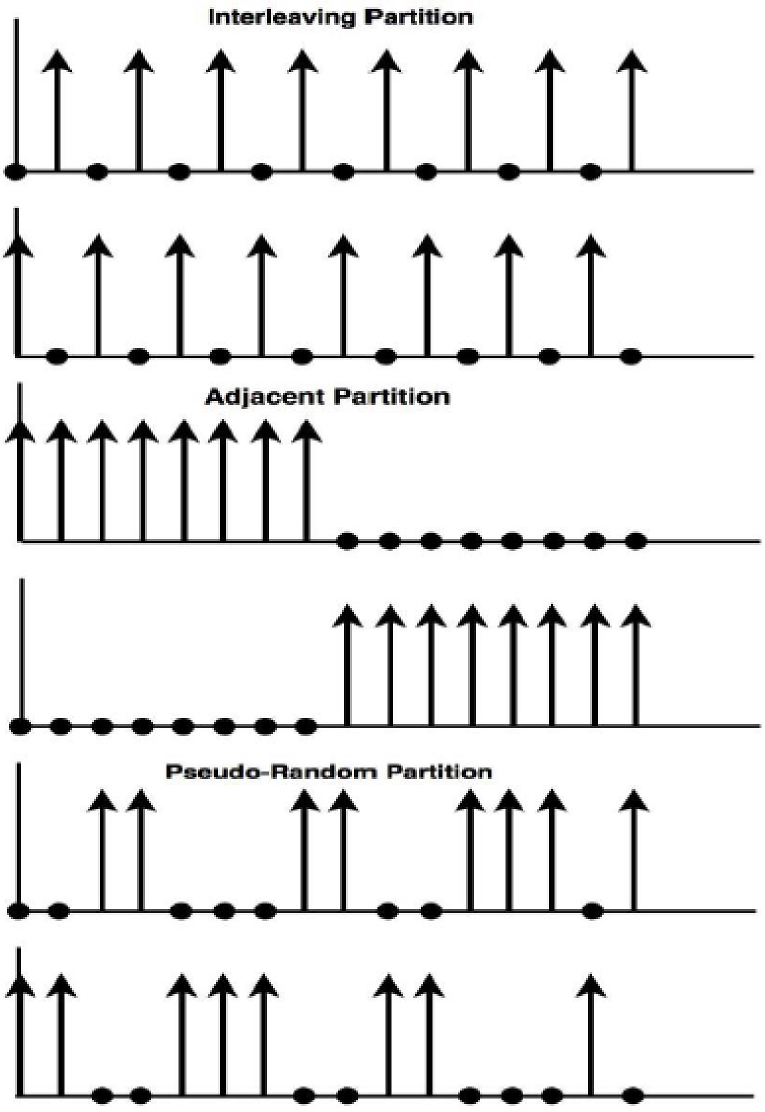


Figure 3.6: Subblock partitioning technique

Similar to SLM, the major drawback of PTS is also the computational complexity (search complexity for optimal phase factor and, multiple IFFT blocks) and low data rate (required side information). In the original PTS technique the IFFT blocks itself has a complexity of N*log2N where, N is the number of sub-carriers. Several techniques have been proposed in the literature to reduce the search complexity and overhead (by reducing/avoiding the usage of side information). The complexity of PTS is less than SLM [63],[64].

The block diagram for PTS technique implementation is shown in Figure 3.7 below. The data sequence X in frequency domain is sub-divided into V sub-sequence which were transmitted in disjoint sub-blocks without overlapping. That having equal size of N which contains $\frac{N}{V}$ non-zero values in each sub-blocks sequences to create a set of candidates finally, the candidate with the lowest PAPR is chosen for transmission [64]. With the assumption that the sub-blocks have equal size without having any gap between them. The input data block in X is divided in to V disjoint sub-blocks, which are represented by the vectors X^v,v=0,1...,V-1 the input data block X can be written in terms of X^v as

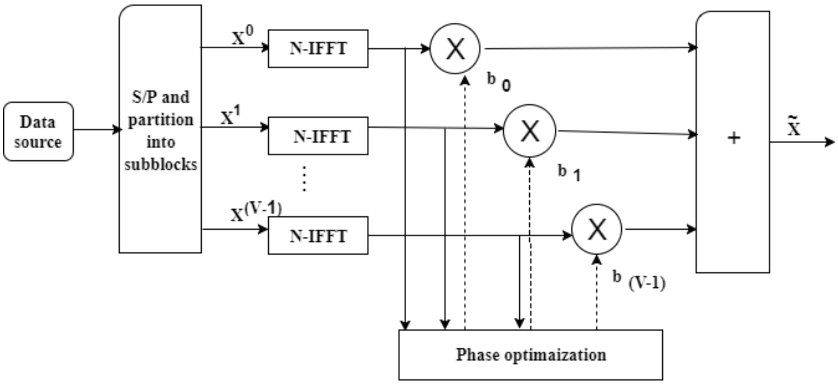


Figure 3.7: Block diagram of PTS technique for PAPR Reduction

$$X = \sum_{v=0}^{V} X^v for, v = 0, 1, ..., V - 1 \tag{3.15}$$

Where $X^v = X_0^v, = X_1^v ..., X_{N-1}^v$ with $X_k^v = X^k$ or 0 After that, the sub-blocks X^v are transformed into V, time-domain PTS by taking the IFFT of length N. These partial transit sequences can be written as: $X^v = X_0^v, X_1^v ..., X_{N-1}^v$ with $X_k^v) = X^k$ for, v = 0,1,...,V-1. These partial sequences X^v are then independently rotated by phase factors written as

$$X^v = X_0^v, X_1^v ..., X_{N-1}^v = IFFT[X^v] for, v = 0, 1, , V - 1 \tag{3.16}$$

The partial sequence X^v are then independently rotated by phase factor $b_v = e^{j\theta v}$. for, v =1,2, ...V the rotated the partial sequence then optimally combined to obtain the OFDM signal with lowest PAPR. The time domain signal after combine is given

$$\tilde{X} = \sum_{v=0}^{V-1} b_v X^v \tag{3.17}$$

The object of PTS is finding the lowest PAPR of all the phase factor combination, and get the best phase factors so that

$$\{b_1, b_2 ... b_V\} = \arg\min\{\ \max\{|\tilde{X}|^2\}\}$$

There are two main issues of any PTS scheme: to reduce the computational complexity for searching the optimal phase factors and to reduce the overhead by minimizing the side information. Without loss of generality, b_1 can be set to "1". Suppose that there are W phase angles to be allowed,thus W_v can has the possibility of W different values. Therefore there are W^{V-1} alternative representations for an OFDM symbol. We should compute W^{V-1} times of PAPR, and the computational complexity increases exponentially with the number of the sub-blocks.
The search complexity increases exponentially with the number of sub-blocks V to reduce the search complexity and overhead (by reducing/avoiding the usage of side information) [65]. These methods achieve significant reduction in search complexity with marginal PAPR performance degradation. The useful comparison between PTS and SLM techniques has shown that the PTS outperforms SLM in terms of PAPR reduction at the cost of increase side [66].

3.7.4 Interleaving

The interleaving technique is extremely similar to SLM technique. In this method, a set of interleavers, devices that permute or reorder symbols in a specific way, instead of phase sequences $X = [X_0, X_1, , X_{N-1}]^T$is used to reduce the PAPR. So original data block becomes many different permuted blocks by the use of these interleavers. Then the IDFT operation is performed on each one of these different permutations separately to generate multiple OFDM signals. The one with the smallest PAPR is chosen for transmission. To recover the original data block correctly, the receiver only need to know which interleaver is used at the transmitter, thus, the number of required side information bits is 2 log k, where k represents the number of interleavers. So the amount of PAPR reduction and the degree of complexity in this method depend on k and the design of the interleavers.

Chapter 4

The Introduced System Model

4.1 System Model

In OFDM systems, the transmitted signal is the sum of orthogonal sub-carriers that are modulated by complex data symbols. For MIMO-OFDM system with N sub-carriers, the complex baseband signal can be written as

$$X_{N_t}(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi f_N t}, 0 \leq t \leq nT \tag{4.1}$$

Where N_t transmit antenna that uses N subcarriers. In OFDM modulation, a block of n data symbols (one OFDM symbol), X_n where n = 0, 1...n-1 is the complex data symbol at n^{th} sub-carrier will be transmitted in parallel. Then each symbol modulates a different subcarrier from a set f_N where N = 0, 1... N-1. The N subcarriers are orthogonal, i.e. $f_N = N\Delta f$ where $\Delta f = \frac{1}{nT}$, T is the duration of the OFDM symbol. The above power characteristics can also be described in terms of their magnitudes (not power) by defining the crest factor as given in equation 3.7. In equation 4.1 the real and imaginary components evaluate the expectation and variance of them and then after applying central limit theorem for large N, the probability distribution of X_n will follow the gaussian distribution with probability density function (PDF) is given by [43]
$Pr\{X(t)\} = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{[X(t)]^2}{2\sigma^2}}$, where, standard deviation σ, σ^2 is the variability of X(t).

4.1.1 MIMO Space Time Block Code

The technique of space-time coding is fundamentally a two-dimensional method of processing space and time. While multiple antennas are used for transmission and reception to enhance the capacity and data rate of wireless communication systems in the space-domain. In the time domain, at different time slots, different signals can be transmitted simultaneously using the same antenna. There is a correlation between time and space between signals that are transmitted by different antennas so that the receiver antennas can perform reception of diversity. Space-time coding is therefore designed primarily for higher coding gain without the use of more bandwidth that efficiently enhances wireless system capacity [3]. The block diagram of MIMO space time block code is given in Figure 4.1 MIMO-STBC structure concatenated with OFDM is modeled in this document, then the capability of the OFDM scheme to alter the frequency selective channel to flat fading channel is portrayed [21, 22].

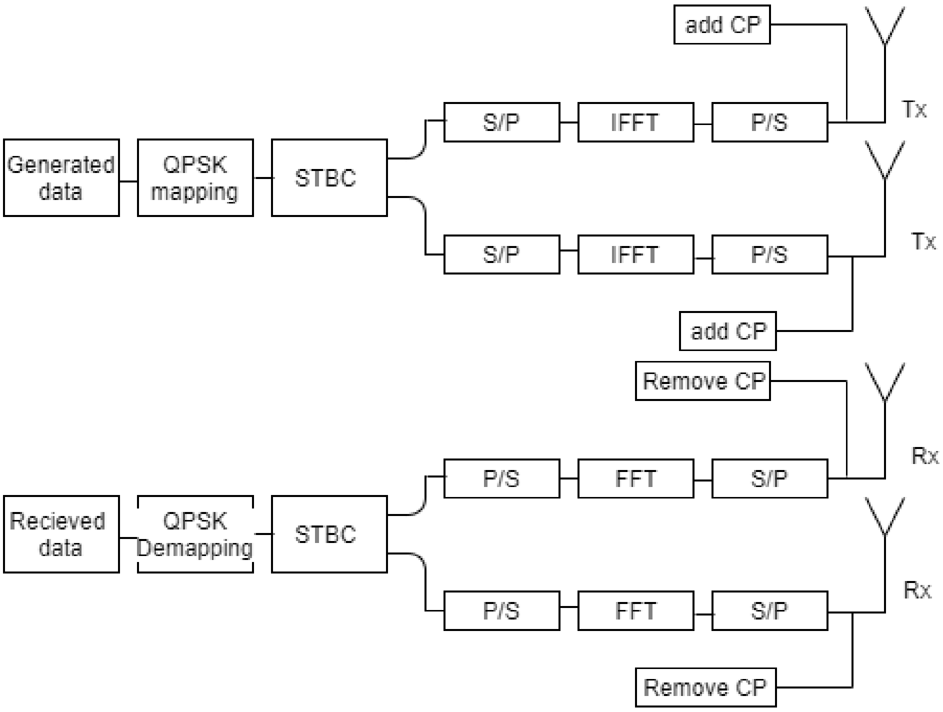


Figure 4.1: Structure of STBC MIMO-OFDM [3]

A manuscript work presented by Alamouti suggested a technique for maintaining orthogonal behavior, known as STBC [7]. This thesis evaluates the performance of a multitude of OFDM modulation systems with QPSK in fading channels.

Two antennas are used in this system for transmitting and one antenna for receiving which have the diversity gain of twice the SISO scheme. In Alamouti STBC, two different symbols are simultaneously transmitted from the two antennas during any symbol period. In this method, two symbols X_1 and X_2 are transmitted. During the first time period, the first symbol in the sequence, X_1 is transmitted from antenna 1 while the second symbol, X_2 is simultaneously transmitted from antenna 2. During the next symbol time the signal $-X_2^*$ is transmitted from the antenna 1 and the signal X_1^* is transmitted from antenna 2 [7]. In the Alamouti encoder, two consecutive symbols X_1 and X_2 are encoded with the following space-time code word matrix:

$$X = \begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix} \tag{4.2}$$

Transmission of the Alamouti encoded signal is done from the two transmitter antennas over two symbol periods.

The same process is repeated to transmit next two symbols, and so on. Four symbols X_1, X_2, X_3 and X_4 will take four consecutive time slots in Figure 4.2 below. Two symbols are encoded as a block.

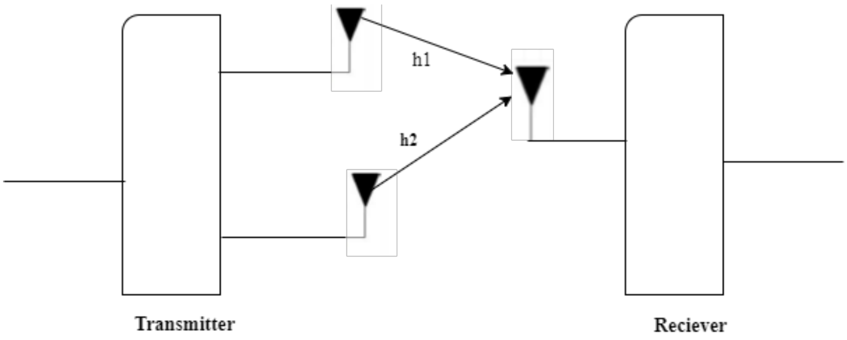


Figure 4.2: Two Transmitter-one Receiver Scheme

Steps of transmission for Almouti STBC

- In the first time slot, send X_1 and X_2 from the first and second antenna.
- In second time slot send $-X_2^*$ and X_1^* from the first and second antenna.
- In the third time slot send X_3 and X_4 from the first and second antenna.
- In fourth time slot send $-X_4^*$ and X_3^* from the first and second antenna.

The received signals Y_1 and Y_2 are composed of signals from antenna 1 and 2, in addition with additive noise.

$$\begin{aligned} Y_1 &= h_1X_1 + h_2X_2 + n_1 \\ Y_2 &= -h_1X_2^* + h_2X_1^* + n_2 \end{aligned} \tag{4.3}$$

Where n_1 and n_2 represents additive noise at time t and t + T_s, respectively and h_1 , h_2 represent channel gain. We assume memory less and flat channel, it is also assumed that the receiver has complete channel state information (CSI), therefore the receiver can determine and calculate h_1 and h_2. By taking the complex conjugation of the second received signal, we have the following matrix vector equation:

$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} = H \begin{bmatrix} X_1 \\ X_2^* \end{bmatrix} \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \tag{4.4}$$

and the value of H (channel matrix) is given by,

$$H = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \tag{4.5}$$

The design of channel matrix H is very important and it is made orthogonal, which can be verified by the relation
$HH^H = I$
Where HH, $(.)^H$ is hermitian matrix and hermitian transpose respectively and I is the identity matrix. In Alamouti scheme two symbols are transmitted in two time intervals, thus rate is equal to one. In Alamouti scheme two symbols are transmitted in two time intervals, thus rate is equal to one. Thus the channel matrix is so composed that it can be interpreted as two antennas (space diversity) by two time intervals (time diversity), preserving the orthogonality of H matrix and this is known as space time block code.

4.1.2 Modified PTS Technique Integrated With Interleaving and Pulse Shaping

Consider the OFDM system shown in Figure 4.3 with N orthogonal subcarriers. Each symbol in the data block will modulate one of N subcarriers. The symbols in the block is given by, $X[k] = [X_n(0), X_n(1)X_n(N-1)]^T, 0 \le k \le N-1$. Each element of the vector

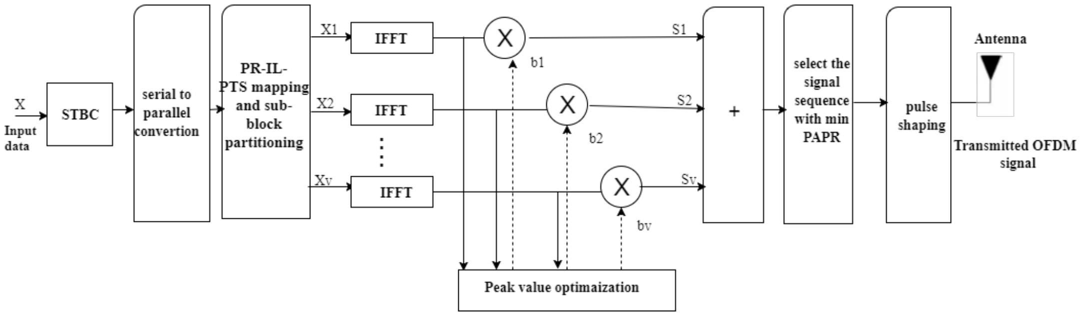


Figure 4.3: The block diagram of combined modified PTS

$X_n[k]$ is an independently modulated data symbol. The OFDM signal is the superimposition of modulated subcarriers using IFFT operation.

In PTS technique, computational complexity increase exponentially as the number of subblocks increases. In this thesis a neighborhood search algorithm based local searching is defined in modified PTS technique as a function of the current PAPR and the threshold PAPR value ($PAPR_o$) is used to find the optimum set of phase factors. A new phase factor set is learned in the default region and PAPR is calculated. If the new PAPR is less than the threshold value ($PAPR_o$) will be substituted with the new value. For finite number of searches, the process of finding the optimum set of phase factors to yield less PAPR is repeated. If the PAPR is not below the threshold value, the present values of PAPR and the set of phase factor are taken as the optimal solution. PAPR reduction performance is enhanced at decreased computational complexity with modified PTS method. This method is combined with interleaving and pulse shaping for better decrease of PAPR. Technique of interleaving attempts to break the high correlation between the data symbols of the block that provide reduction of PAPR performance. The long correlation patterns present in the N symbols of a data block is reduced by using (K-1) interleavers, where K is the interleaving factor [48]. The interleaving method will reorder the N data symbols in the X_n input data block. Pulse shaping is a flexible method for decrease PAPR and is based on the correct choice of time-limited waveforms of the different subcarriers [18]. Pulse shaping also introduces controlled inter-channel interference. In frequency selective fading channels, optimum detectors with successful results can be designed without any loss in bandwidth performance. The pulse shaping of the separate subcarriers with the same form will only improve the peak amplitude of the transmitted signal without altering the correlation characteristics between the separate samples of the same block. The new set of pulse shapes shows that each subcarrier pulse has a distinct shape all obtained from the same pulse through cyclic shifts. This will decrease the PAPR of the transmitted MIMO-OFDM signal as the peak of the distinct pulse shapes never occurs at the same moment. Raised cosine pulse is a commonly used pulse shape used in wireless communication and is regarded to analyze the MIMO-OFDM system's PAPR performance.

4.1.3 Pulse Shaping

In modern wireless communication, pulse shaping plays a vital role in spectral shaping to decrease spectral bandwidth. For low cost, reliable, power and spectrally efficient mobile radio communication systems, pulse shaping is a spectral processing technique by which fractional out of band power is lowered. It is evident that in addition to reducing ISI, the pulse shaping filter also reduces adjacent channel interference. The transmitted signal must be limited to a certain bandwidth in many applications for data transmission. Therefore, the infinite bandwidth associated with a rectangular pulse is not acceptable. The raised cosine filter gets its name from the shape of its frequency response, rather than its impulse (or time domain) response [18]. A commonly used pulse shaping filter satisfying the Nyquist criterion while having a faster decay is called the raised cosine filters having the following equation,

$$g(t) = \left(\frac{sin(\pi t/T)}{\pi t/T}\right)\left(\frac{cos(\pi\alpha t/T)}{1-(2\alpha t/T)^2}\right), t = -\propto to \propto$$

where α is the excess bandwidth parameter and takes values from 0 to 1.

With α =0, the raised cosine filter reduces to the classical Nyquist filter with zero excess bandwidth outside.

With α =1 it is called 100 % excess bandwidth and does not occupy frequencies outside .

The frequency response of the raised cosine filter is given by,

$$G(f) = \begin{cases} T, & \text{for} \quad |f| \leq \frac{1-\alpha}{2T} \\ Tcos^2\left[\frac{\pi T}{2\alpha}(|f| - \frac{1-\alpha}{2T})\right], & \text{for} \quad \frac{1-\alpha}{2T} < |f| \leq \frac{1+\alpha}{2T} \\ 0, & \text{for} \quad \frac{1+\alpha}{2T} < |f| \end{cases}$$

The frequency response of the raised cosine filter in the time domain and frequency domain representations for different values of α is given in Figure 4.4 the simulation result shown that frequency domain outperform the time domain.

The transmitted signal in MIMO-OFDM system is the sum of orthogonal subcarriers that are modulated by complex data symbols. Figure 4.5 illustrates a simplified block diagram of the STBC MIMO-OFDM scheme with Nt=2 transmitting antennas. Partitioning of data is performed in two branches each branches, provided that the same subcarrier grouping and these partitions are further transmitted into the corresponding IFFT blocks the process of selecting different set of phase value is repeated and during each repetition,

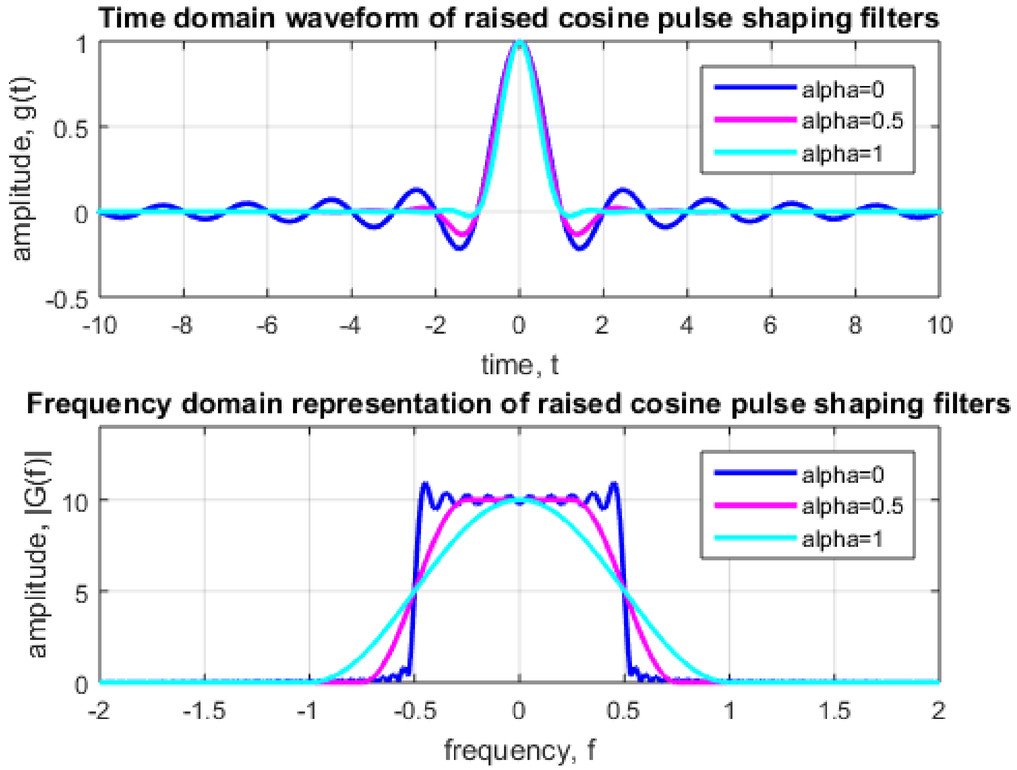


Figure 4.4: Time and frequency domain waveform of raised cosine pulse shaping filters respectively

PAPR of the block is computed and the set of phase rotation values which gives minimum PAPR is selected and are simultaneously sent from antennas T_{X1} and T_{X2} respectively [48].

The code word to be transmitted is divided into several subblocks, V, of N/V length. Mathematically, expressed by

$$s = \sum_{v=1}^{V} X_k^{(v)}, v = 1, 2, ...V \tag{4.6}$$

The one rule is obeyed by segmentation methods is that the length of segmented subsequence is N, each sub-carrier appear in one subsequence, and the location of subsequence without subcarrier sets zero. Random segmentation realization is complex. First, it is essential to generate a vector with a length of N. The vector contains N different random integers. This vector is used to get the value from the signal sequence and to divided the signal into V sub-sequences. Because interleave segmentation is easily realized and computational complexity is low and the better PAPR reduction performance of random segmentation the hybrid pseudo-random and interleaving PTS partition (PR-

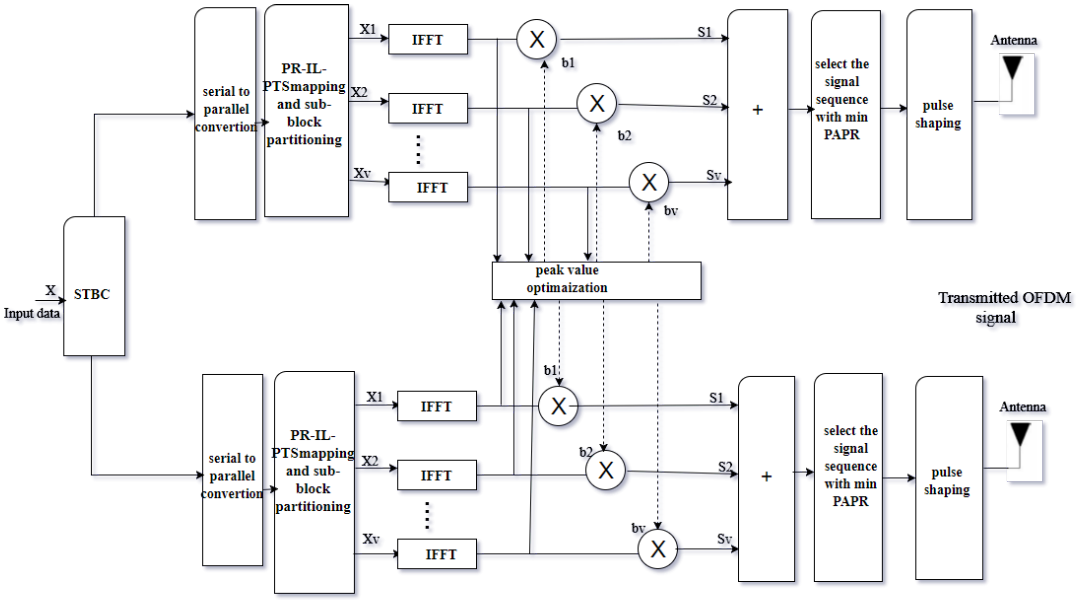


Figure 4.5: Block diagram of combined PTS with STBC MIMO-OFDM system

IL-PTS) method is introduced in the document to improve the performance of PAPR. For the PTS technique, the sub-block partition is directly related to the correlation property. After evaluating the auto-correlation function of these three different sub-block partition technique, we know that for pseudo random sub-block partition, can derive as [69]

$$|R_{ij}(\tau)| = \frac{1}{N}|\sum_{v=1}^{V} b_i^v b_j^{v^*}|.|\sum_{k\in\phi v} \exp(j\frac{2\pi k\tau}{N})| \tag{4.7}$$

Where ϕv = {P random independent subcarriers}, $1 \leq v \leq V$ and define P= N/ V presents the number of subcarriers in each subblock.

If $\tau \neq 0$, when V is small, since the allocation of sub-carriers is random in any sub-block,the value of equation. (4.7) is approximates to 0. This can rewrite as

$$|R_{ij}(\tau)| \approx \begin{cases} 0 & \text{for} \quad \tau \neq 0 \\ \frac{1}{V}.|\sum_{v=1}^{V} b_{ij}^v b_{ij}^{v^*}| & \text{for} \quad \tau = 0 \end{cases} \tag{4.8}$$

From the formula, we notice that the strongest correlation value exists only at τ=0, while at other time shift points, the auto-correlation values are very small. The pseudo random sub-block partition system therefore has a unique merit on this point. For Interleaved Subblock Partition correlation function define as $|R_{ij}(\tau)$ [69]

$$R_{ij}(\tau) = \frac{1}{N}\sum_{v=1}^{V} b_i^v b_j^{v^*} \sum_{k\in\phi v} \exp(j\frac{2\pi k\tau}{N}) \tag{4.9}$$

Where $\phi v = \{(v-1), V+(v-1), ., (P-1)V+(v-1)\}, 1 < v < V$

There only 2V points are nonzero. Because it is symmetrical around m = O, so analyzing 0 < m < V part is enough. Especially

$$|R_{ij}(0)| = \frac{1}{V}.|\sum_{v=1}^{V} b_\iota^v b_\iota^{v^*}|$$

$$\max_{0\leq\tau<N} R_{ij}(\tau) = \frac{1}{V} \max_{0\leq m<V} |\sum_{v=1}^{V} b_\iota^v b_\iota^{v^*} \exp(j\frac{2\pi mv}{V})| \tag{4.10}$$

The aim is to optimally combine the V clusters in the frequency domain that is given by

$$\tilde{s} = \sum_{m=0}^{V} b_m S_m \tag{4.11}$$

where, b_m, m=l, 2,. .., V are weighting factors and are assumed to be perfect rotations. In other words, the time domain is given by

$$s = \sum_{m=0}^{V} b_m S_m \tag{4.12}$$

where, s_m consist of a set of subblocks with equal size and b_m is the phase rotation factor, which are required to inform the receiver as the side information. The set of weighting factor for V subblocks are optimised in the time domain so as to achieve the better PAPR performance. PTS generates a signal with a low PAPR through the addition of appropriately phase rotated signal parts. All subcarriers positions in $X_k^{(v)}$ which are occupied in another subblock are set to zero. Each of the blocks, v, has an IFFT performed on it,

$$x_n^{(v)} = IFFTX_k^{(v)} \tag{4.13}$$

The output of each block except for first block which is kept constant, is phase rotated by the rotation factor given by

$$e^{j\theta(v)} \in [0, 2\pi] \tag{4.14}$$

Here, the phase value considered in each block is given by $\wp^{(v)} = \frac{2\pi i}{W}$, i=1,2,...W-1 where, W is the number of predetermined discrete phase.

The blocks are then added together to produce alternate transmit signals containing the same information as given by

$$\tilde{x_n} = \sum_{v=1}^{V} x_n^{(v)}\ e^{j\theta(v)} \tag{4.15}$$

The objective is to and the optimum phase factor that can achieve minimum PAPR value of the OFDM signal. Therefore, the optimum phase factor can be obtained as

$$\{\phi^2, \phi^3....\phi^v\} = \arg \min_{1\leq w\leq W} \left(\max_{0\leq n\leq NL-1} | \sum_{v=1}^{V} x_n^v e^{j\theta(v)} | \right) \tag{4.16}$$

The set of weighting rotation parameters is selected to minimize the PAPR. The computational complexity of the PTS technique relies on the amount of required phase rotation factors. The phase rotation factors can be chosen from an infinite number of phase $\phi^v \epsilon (0, 2\pi)$. But discovering the best weighting factors is definitely a complicated issue. These phase factors combination correctly maintains the orthogonality between the different modulated carriers to improve the capacity of PAPR reduction performance for the PTS technique. However, the performance improvement of the PTS PAPR reduction scheme is accomplished at the cost of issues with high complexity and challenging parameter setting. Modified PTS therefore use the potential of MIMO transmission to reduce PAPR. In MIMO communication, data rate or order of diversity can be enhanced by exploiting the spatial dimension [70]. In the same spirit, PAPR decrease can be enhanced by collectively handling the parallel transmission signals.

4.1.4 Interleaved MIMO-OFDM

Highly correlated OFDM signal data frames have high PAPRs, which could be decreased if long correlation patterns are broken down. In this mechanism, a set of fixed permutations (interleaving) is used to break these patterns of correlation [70, 71]. K-1 interleavers are used at the transmitter in this approach. These interleavers generate permuted input data frames of K-1. For transmission, the minimum PAPR frame of all K frames is chosen. The identity of the corresponding interleaver is also sent as side information to the receiver. If all K, PAPR computations are performed simultaneously and the smallest PAPR sequence is selected in one step, the transmitter processing delay is significantly reduced. Therefore, it can also be used with high-speed data transmission. Interleaved MIMO-OFDM can also be used to track the spectrum. Since subcarriers of one subblock are similarly spaced, their frequency locations can be determined by capturing one subcarrier with knowledge of system parameter. Users can monitor radio activity on one subblock by detecting only one or two subblock subcarriers instead of all subcarriers across the entire frequency band. Interleaving can be used to combat the effects of noise bursts and fading in error correction systems. The peaks in the related OFDM signal can be compressed by interleaving a data frame.

The N subcarriers are partitioned into V groups with each group having Θ adjacent subcarriers for Interleaved MIMO-OFDM. Then the k^{th} subcarrier of each group is assigned to the k^{th} user.

$$x^k(n) = \sum_{m=0}^{V-1} X_m^k e^j(\frac{2\pi}{N})(m\Theta + k)n \tag{4.17}$$

in which k=0,1,. . . Θ -1 is the index of users. let $m = N(q + n)$ where $0 \leq q \leq \Theta - 1$ and $0 \leq n \leq N - 1$ as showen in "appendix B" $\tilde{x_m}$ is given by

$$\tilde{x_m} = \frac{1}{\Theta} x_n \tag{4.18}$$

Here an N-sample interleaved OFDM block is generated by repeating ι for Θ times [71]. The resulting time symbols $\tilde{x_m}$ are just a repeat of the initial input symbols x_n in the time domain [72]. Hence, an interleaved MIMO-OFDM system with N subcarriers can be scaled from an OFDM system.

4.1.5 Computational Complexity Analysis

The introduced method was intended with the goal of reducing the computational complexity that is a significant drawback of the original PTS method. If the number of subcarriers is $N = 2^n$ and the oversampling factor is $L = 2^d$, the number of complex multiplication n_{mul} and the complex addition n_{add} of the conventional PTS scheme is given by $2^{n+d-1}(n+d)V$ and $2^{n+d}(n+d)V$ respectivly where V is the number of subblocks [73]. To emphasize the fact that the introduced method has a significantly decreased computational complexity compared to the original PTS, it is essential to evaluate both methods to see operations that significantly contribute to the complexity of computation. The major operations in both the techniques that contribute to computational complexity are as listed below:

- Phase rotation of arrays of size $[N \times 1]$
- PAPR calculation of partially formed OFDM symbol of size $[N \times 1]$
- Comparison of PAPR values to obtain the minimum
- N-point IFFT

- Vector addition of arrays of size $[N \times 1]$

Simple mathematical calculations have been done for both C-PTS and integrated modified PTS techniques to find out the number of times these operations have to be performed below .Where, W and V are weighting factor and subblock respectively [74].

Table 4.1: Comparison of computational complexity C-PTS with Integrated modified PTS for V=4, W=4, N=64

Process	C-PTS	Integrated modified PTS
N-point IFFT	VW^{V-1}= 256	V = 4
N-point vector addition	VW^{V-1} =256	W(V-1) = 12
Phase factor multiplication	$V(W^{V-1}-1)$ =252	W(V-1)=12
PAPR calculation	W^{V-1} =64	W(V-1) = 12
PAPR value comparison	$W^{V-1}-1$ =63	W(V-1) =12

Table 4.2: Comparison of computational complexity C-PTS with Integrated modified PTS for V=8, W=4, N=64

Process	C-PTS	Integrated modified PTS
N-point IFFT	VW^{V-1}= 131072	V = 8
N-point vector addition	VW^{V-1} = 131072	W(V-1) = 28
Phase factor multiplication	$V(W^{V-1}-1)$ =131064	W(V-1)=28
PAPR calculation	W^{V-1} =16384	W(V-1) = 28
PAPR value comparison	$W^{V-1}-1$ =16383	W(V-1) =28

For a given value in table 4.1 and 4.2 the complexity of the introduced integrated modified PTS is reduce computational complexity of the original PTS by 6% and 3% for V=4 and V=8 respectively.

Computational Complexity Reduction Ratio (CCRR)

An important computational complexity related parameter is the computational complexity reduction ratio defined as

$$CCRR = (1 - \frac{\text{comp of integrated modified PTS}}{\text{comp of conventional PTS}}) \times 100\%. \tag{4.19}$$

It reduces the percentage of complexity by using the introduced PTS scheme as compared to the C-PTS scheme. It is possible to estimate the performance of a system using CCRR from Table 4.1 CCRR is 94.16%. Higher CCRR percentage specifies good performance of the integrated modified PTS scheme relative to conventional system performance. As stated in table 4.1, the search complexity is decreased from W^{V-1} to W(V-1), which means that exponential searches are changed to linear searches.

4.1.6 Bit Error Rate

BER is used to measure the difference among original transmitted signal and received signal at the receiving end.

BER(t)=abs(X(t) - Y(t)) Where, X(t) is the originally generated signal at transmitter and Y(t) is the received signal at the receiver end at time (t). In brief, the BER is the vector of unit time bit error and the Bit Error Ratio (BER) is

$$BER = \frac{\text{number of error}}{\text{total number of bite transmitted}} \tag{4.20}$$

A situation where the transmission speed and average is good at a particular time but the SNR is high then BER becomes very low. The SNR in decibel (dB) is commonly referred to as the SNR.

$$SNR = 10\text{log}\frac{\text{signal power}}{\text{noise power}} \tag{4.21}$$

It is an indicator used to assess a communication link's quality. It implies that when the SNR is greater, a communication connection is in good condition.

BER Performance Analysis of 2×1 Alamouti Scheme

To derive MIMO Alamouti's overall 2×1 system. For Almouti with two transmit antenna and n receive antenna, the channel matrix norm is:

$$\zeta = |h_{ij}|^2 = \Sigma_{j=i}^{2}\Sigma_{i=1}^{i}(|h_{ij}|^2) \tag{4.22}$$

Where $h1j$ and $h2j$ (j=1) are the first transmit antenna's impulse response with the receivers and the second antenna's impulse response with the receivers respectively [75]. Then, to obtain the average bit or symbol error rate we must average the conditional probability over the channel state. The average bit or symbol error rate is

$$P_{C2\times}n = Q(\sqrt{|h_{in}|^2\rho_s}) \tag{4.23}$$

where the Q function is the gaussian defined for random variable and ρ_s is the bit energy is given by $(|h_{n1}|^2)^2E_s$. For a rayleigh fading channel, the square norms of complex gaussian random variables with variance 1/2 in each dimension are each of the terms in this summation. Therefore, each of these terms is chi-square distributed with parameter 1 (i.e., exponential) two degrees of freedom. The sum of N independent and identically distributed exponential random variables, if all the channel gains are assumed to be central chi-square distributed with 4N degrees of freedom [75]. Therefore, the probability density function of β is given by: $P(\beta) = \frac{\beta^{2n-1}}{(2n-1)!}e^{-\beta}$
Because the conditional probability is a random variable, to obtain the average bit or symbol error rate, we need to average it over the channel statistics.

Chapter 5

Result and Discussion

The transmission power and channel bandwidth define the two primary resources of a communication scheme. The bandwidth of the channel is dependent on the bit rate (signaling rate). The carrier signal is the most prominent parameter of digital communication. However, after it has been modulated, the carrier signal is transmitted over a channel along with the baseband signal. It means that the signaling rate is decreased when two or more bits are combined as a symbol, thus decreasing the frequency of the carrier. Bit grouping in symbols also decreases the bandwidth of the transmission channels.

Table 5.1: Simulation Parameters

Parameter	Symbol	Value/type
Channel type	-	Flat - fading
pulse shaping	$P_m(t)$	Raised cosine filter
Subblock partitioning scheme	-	Interleaving
Number of sub carriers	N	64, 128, 256, 512, 1024
Over sampling factor	L	2, 4, 8, 16
Number of sub blocks	V	2, 4, 8, 16
Ro11 off factor	α	0.6
Number of antennas	N_t, N_r	2, 1
Modulation scheme	QPSK	QPSK
Phase weighting factor	b	1, -1, j, -j

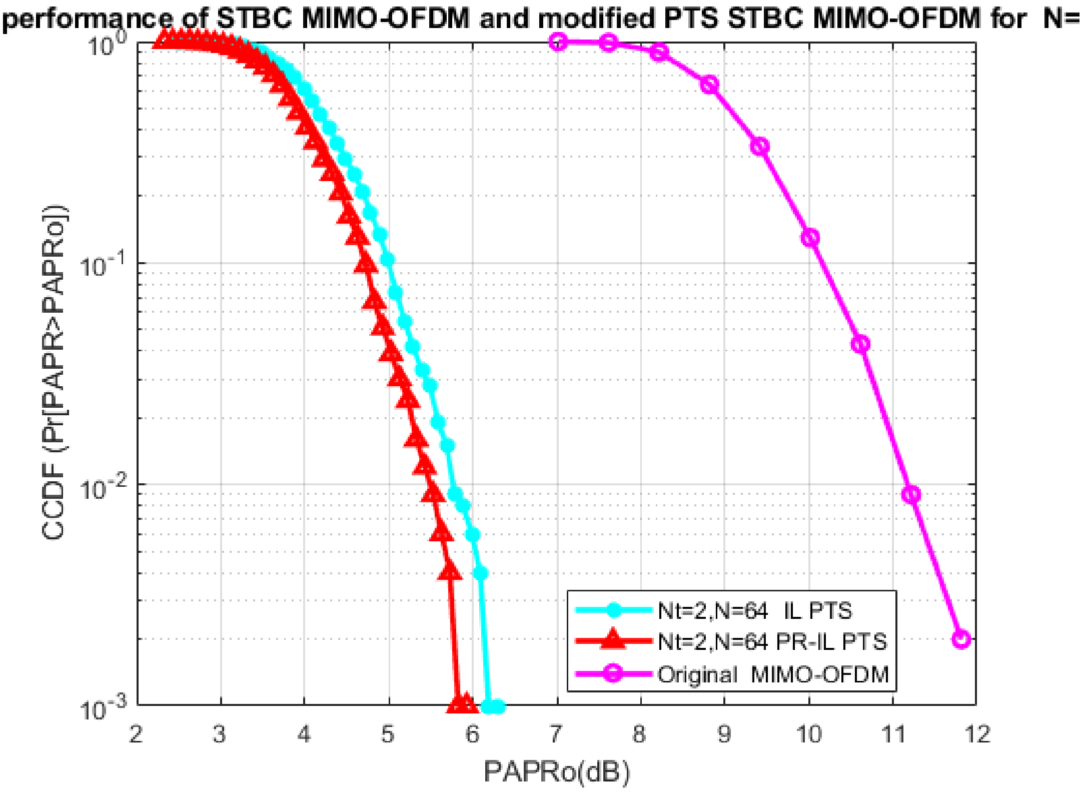


Figure 5.1: comparirition of proposed PTS MIMO-OFDM and MIMO-OFDM

The above simulation in Fig 5.1 shows the CCDFs of PAPR performance of the combined modified PTS method in STBC MIMO-OFDM system with subblocks V=4 for a random data of block size 1000 with N=64 subcarriers, oversampling factor L=4 and roll-off factor α=0.6. The X-axis represents the PAPR thresholds and the Y-axis acts as the CCDF probability (PAPR probability above the PAPR threshold). It can be seen from the simulation that series improvement that is 5.5 dB when PR-IL-PTS is applied than applying IL-PTS that is 5.2 as shown in the simulation for STBC MIMO-OFDM system with combined modified PTS compared to original STBC MIMO-OFDM when CCDF= 10^{-2} .

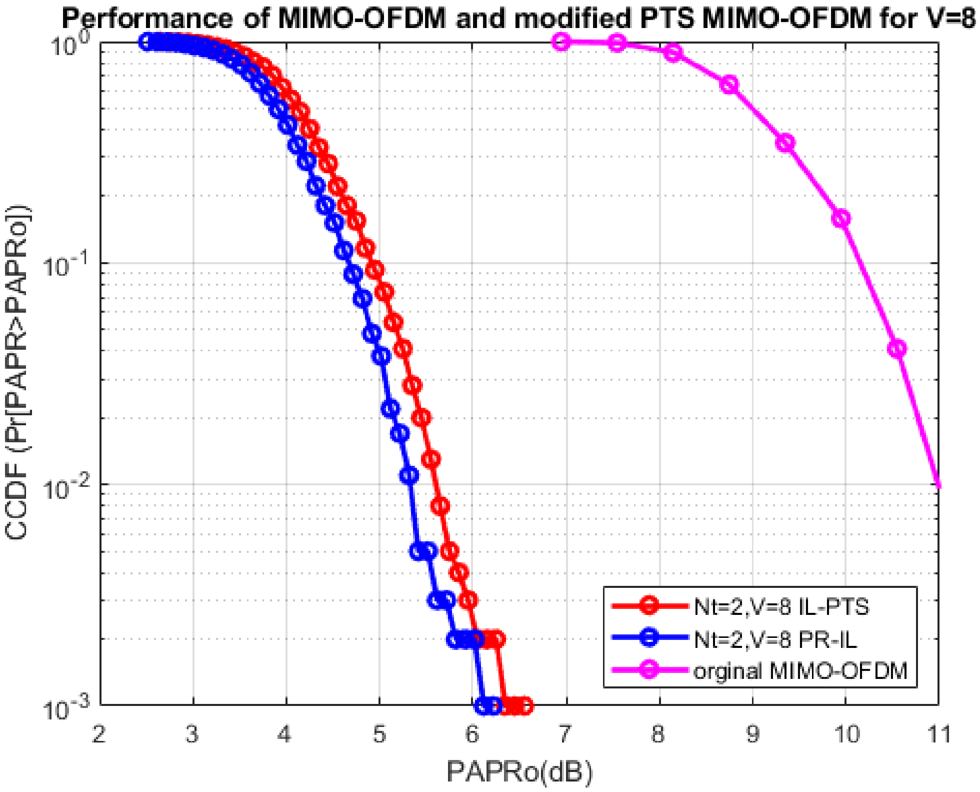
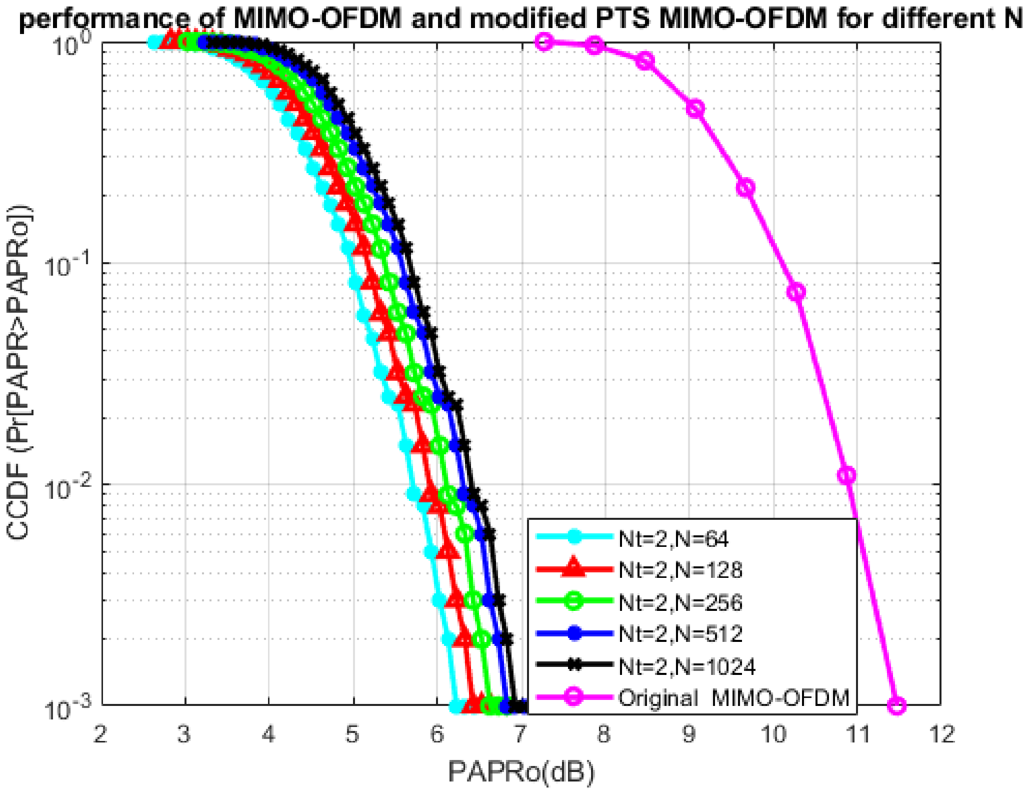


Figure 5.2: comparirition of proposed PR-IL PTS MIMO-OFDM,IL PTS MIMO-OFDM and MIMO-OFDM

The above simulation in Fig 5.2 shows the CCDFs of PAPR performance of the combined modified PTS method in STBC MIMO-OFDM system with subblocks V=8 for N=64 subcarriers, oversampling factor L=4 and roll-off factor α=0.6. It can be seen from the simulation that series improvement that is 5.4 dB (IL-PTS) and 5.8 dB (PR-IL-PTS) therefore PR-IL-PTS further improve system performance with low complexity for original STBC MIMO-OFDM and STBC MIMO-OFDM system with combined modified PTS when CCDF= 10^{-2} .



sub.png

Figure 5.3: MIMO-OFDM system for different number of subcarriers

The simulation result in Figure 5.3 demonstrates that distribution of PAPR with different subcarrier numbers for N=64, 128, 256, 512 and 1024 the values of PAPR. The modulation technique is QPSK, with 1000 samples being taken as the sampling factor (L=4). We observe that the performance of the integrated modified PTS method in the MIMO-OFDM system for various number of subcarriers that the PAPR values rise as a subcarrier increase for a specified CCDF value. This implies that growing numbers of sub-carriers increase the PAPR value due to an increase in sub-carriers leading to an increase in data on those carriers, thus increasing the PAPR value and computational complexity reduction ratio. The number of sub-carriers is therefore a very significant parameter affecting the value of PAPR.

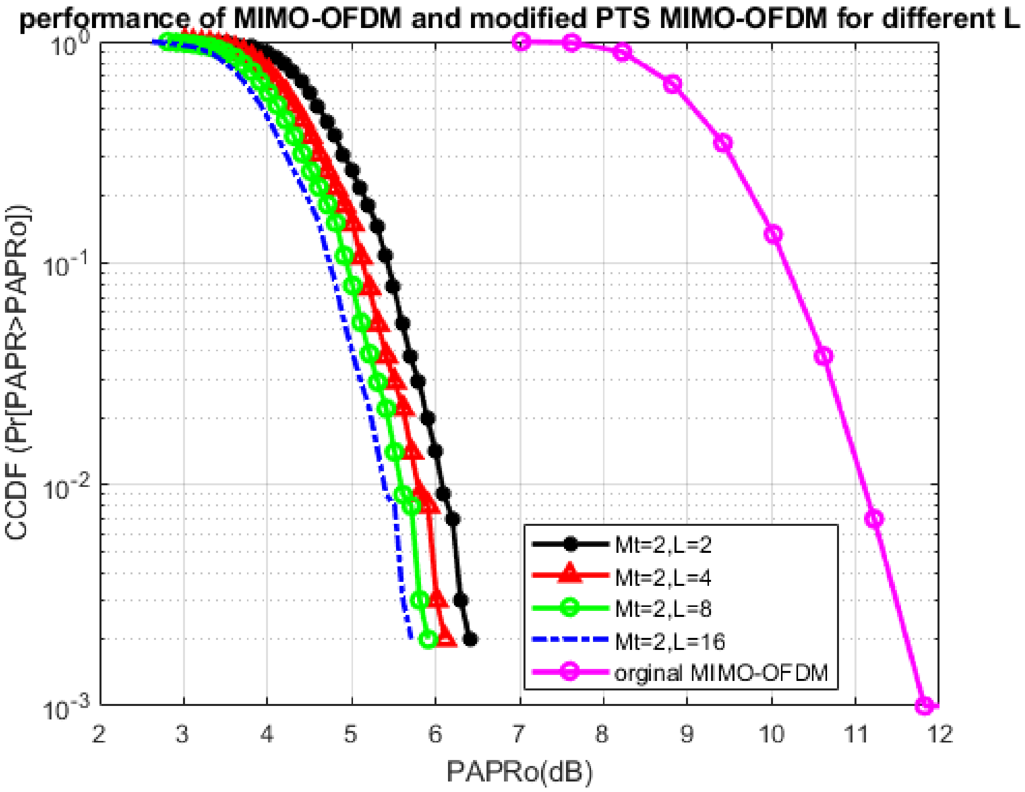


Figure 5.4: MIMO-OFDM system for different oversampling factor

Figure 5.4 illustrates the complementary cumulative distribution function of the PAPR in the MIMO-OFDM signal for the case of N=64 subcarriers, V=4 subblocks and for different oversampling factor (L) increased from 2 to 4, 8, and 16. If L is raised, enhanced performance can be obtained. This occurs at an increasing level of complexity. Increasing L beyond 4 seems to bring negligible improvement in performance but, an increasing level of complexity.

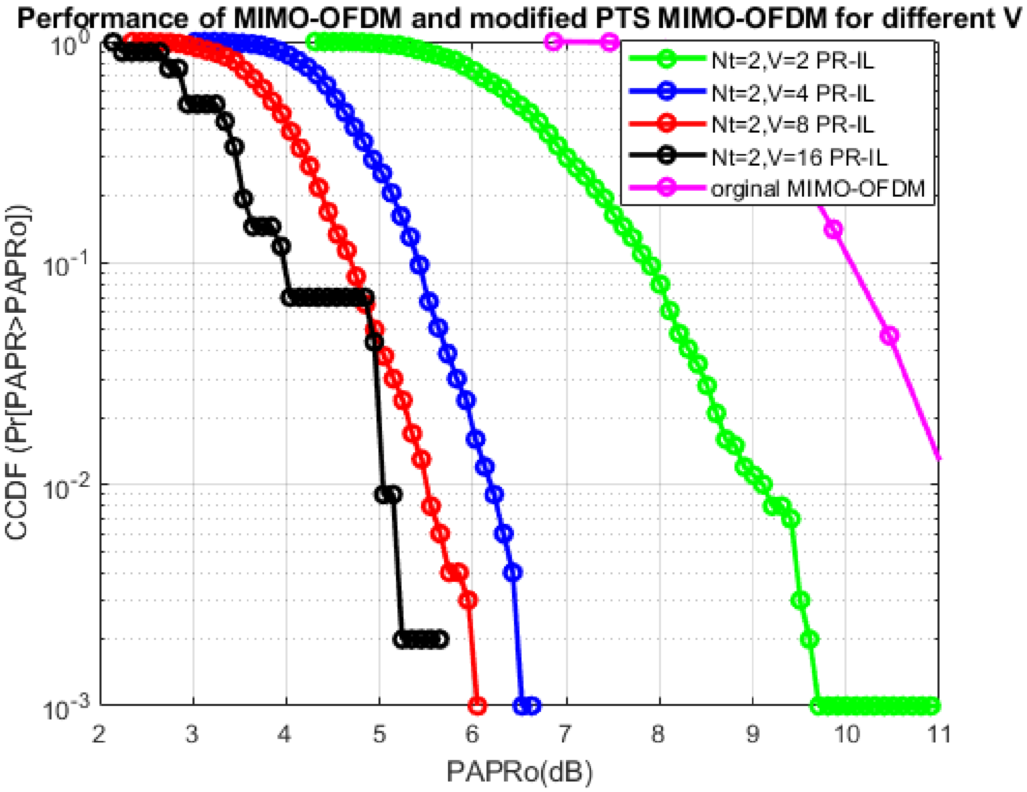


Figure 5.5: MIMO-OFDM system for different number of subblocks

Figure 5.5 shows the CCDFs of PAPR performance for the integrated modified PTS method in MIMO-OFDM system with different number of subblocks (V) = 2, 4, 8, and 16 the PAPR is reduced to 9.4dB and 5.2dB respectively for 2 and 16 subblock value given in this simulation when CCDF=10^{-2} for a random data of block size 1000 with N=64 subcarriers, oversampling factor L=4 and roll off factor $\alpha = 0.\ 6$. It can be seen that as the subblock size is increased the PAPR value is decrease at a given CCDF value. which resulting in PAPR performance improvement as the number of sub blocks increases.

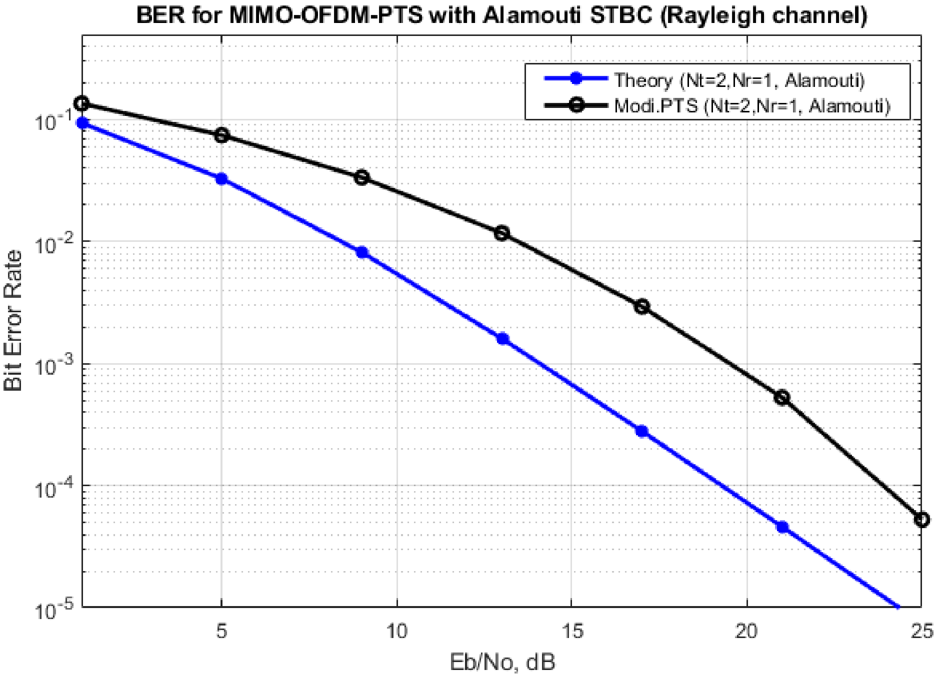


Figure 5.6: performance of BER

BER is a parameter which gives an excellent indication of the performance of a data link. Knowledge of the BER also enables other features of the link such as the power and bandwidth. For QPSK, the value of BER in theoretical and simulation is not alike. As shown in Figure 5.5 the value of simulation BER is larger than that of theoretical value but, it approach to theoretical value.

Chapter 6

Conclusion and Recommendation

6.1 Conclusion

MIMO-OFDM systems is used to improve the performance of wireless communication system especially for internet and multimedia services. In this paper STBC concatenated with MIMO-OFDM system for diversity and secure means of data propagation even the user is not stationary.

PAPR is one of the major drawbacks of the MIMO-OFDM system in practical application because it operates in the nonlinear region so that the system encounters many restrictions in the practical application. The signal scrambling methods are used in optimizing the statistical characteristics of PAPR in MIMO-OFDM system. In MIMO-OFDM transmission some methods avoid the use of any extra IFFTs but instead is based on a proper selection of the different subcarriers and sub-blocks. It is important to give a comprehensive review to the parameters that influence on reducing PAPR value which is discussed in this paper. In this work, focus is made on PAPR reduction as well as complexity reduction. Some PAPR reduction techniques can effectively reduce PAPR but they are too complex to be realized, this confines the use of them in practice.

The comparison of different PAPR reduction techniques are given. Comparison was also made between the complexity of the C-PTS and the introduced method and the calculation showed that complexity is decreased . This thesis formulate a technique that would use the principle of PTS and reduce PAPR effectively and yet can be efficiently deployed in real time systems. The method was simulated and the results were obtained using the introduced MIMO-OFDM system and MIMO-OFDM system without any PAPR reduction technique in the form of CCDF graphs.

By interleaved subblock partitioning method combined with modified PTS and pulse shaping method is simple to implement and reduces the transmitter complexity can be optimized. It is possible to conclude that the factor stated in the document influenced the PAPR performance as shown in simulation but,increasing L beyond 4 brings negligible improvement in performance but, it increase level of complexity. For more number of transmit antennas C-PTS and modified PTS suffer from PAPR problem in MIMO-OFDM system but, the integrated modified PTS technique utilizes the multiple transmit antennas, to achieve better PAPR performance. As the number of subcarriers increases the computational complexity reduction ratio increases. Therefore, the integrated modified PTS scheme becomes more efficient for high data rate MIMO-OFDM system. We conclude from the simulation that series improvement for original MIMO-OFDM and MIMO-OFDM system with combined modified PTS that is 5.5 dB improvement when CCDF$= 10^{-2}$.

In this paper, the approach to finding the optimum phase factor in the introduced PTS has been changed to accommodate only single IFFT block in the scheme that is effective in reducing the original PTS method's computational complexity by 6% and also produced better PAPR reduction performance. The best tradeoff between PAPR reduction capability and transmission power, data rate loss, implementation complexity, and BER performance should be provided to an effective PAPR reduction technique. The BER performance of MIMO-OFDM system with integrated modified PTS has been compared with that of the theoretical value. Finally the integrated modified PTS is a better approach to the real conditions in engineering practice by providing a compromise between the PAPR reduction performance and computational complexity.

6.2 Recommendation

- This paper was done MIMO based on OFDM it is recommended for the future work may use filtered-OFDM (OFDM release) and waveform candidate such as universal filter multicarrier (UFMC) and generalized frequency division multiplexing (GFDM).
- This paper was done using space-time coded MIMO-OFDM system the future work may include spatial multiplexing using space-time coded MIMO-OFDM system.
- As this paper was done using reduced complexity PAPR reduction technique for MIMO-OFDM system, multi user massive MIMO-OFDM system is recommended for this scheme.

Bibliography

[1] Abdullah, E. and Hidayat, N.M., 2017, November. SCS-SLM PAPR reduction technique in STBC MIMO-OFDM systems. In 2017 7th IEEE International Conference on Control System, Computing and Engineering (ICCSCE) (pp. 104-109). IEEE.

[2] 1A. Sundaramoorthy and 2Dr. M. C. John Wiselin, MIMO-Future Wireless Communication International Journal of Trend in Research and Development, Volume 3(1), IJTRD Jan-Feb 2016 ISSN: 2394-9333

[3] Sahraoui, L., Messadeg, D. and Doghmane, N., 2013. Analyses and performance of techniques PAPR reduction for STBC MIMO-OFDM system in (4G) wireless communication. arXiv preprint arXiv:1311.3638.

[4] Hassaneen, S.S., Soliman, H.Y. and Elhennawy, A.E., 2013, December. Reducing the peak to average power ratio in MIMO OFDM systems. In 2013 9th (ICENCO) (pp. 128-133). IEEE.

[5] Shilpa A. Talele Aarti G. Ambekar Deepshikha Hinger Novel PTS Technique to PAPR Reduction for STBC MIMO-OFDM using Four Transmitting Antennas International Conference on Computer Technology (ICCT 2015)

[6] TÃűren, M. and Ciflikli, C., 2018. Peak-to-Average-Power-Ratio (PAPR) reduction Methods with wavelet transform in MIMO-OFDM. IETE Journal of Research, 64(3), pp.415-421.

[7] A Mahender, K., Kumar, T. A., and Ramesh, K. S. (2018). Simple Transmit Diversity Techniques for Wireless Communications. Advances in Intelligent Systems and Computing, 329-342.

[8] Mishra, P., Singh, G., Vij, R. and Chandil, G., 2013, February. BER analysis of Alamouti space time block coded 2 × 2 MIMO systems using Rayleigh dent mobile radio channel. In 2013 3rd IEEE International Advance Computing Conference (IACC) (pp. 154-158). IEEE.

[9] Sameer A. Jagtap1, Venkat N. Ghodke2 2015 July Effect of Cyclic Prefix on OFDM Signal International Journal for Research in Applied Science and Engineering Technology (IJRASET) Volume 3 Issue VII, July 2015 IC Value: 13.98 ISSN: 2321-9653

[10] Cortes, A., Velez, I., Turrillas, M. and Sevillano, J.F., 2012. Fast Fourier transform processors: implementing FFT and IFFT cores for OFDM communication systems. Fourier Transform-Signal Processing, pp.953-978.

[11] Sharma, C., Tomar, S.K. and Gupta, A.K., 2011. PAPR reduction in OFDM system using adapting coding technique with pre-distortion method. WSEAS Trans. on Com, (9), pp.255-262.

[12] Moegiharto, Y., Trisnadewi, I., Anisah, I. and Briantoro, H., 2018, October. Power Saving Analysis of Peak to Average Power Ratio Reduction Technique in OFDM System using Hybrid Improved Partial Transmit Sequence and Clipping Filtering Technique. In 2018 International Electronics Symposium on Engineering Technology and Applications (IES-ETA) (pp. 196-201). IEEE.

[13] R. M. Ali, R. K.Rao and V. Parsa, PAPR reduction in OFDM systems using clipping based on symbol statistics, in proceedings of IEEE 30th Canadian Conference on Electrical and Computer Engineering (CCECE), Windsor, Onterio, (2017), pp. 1-5.

[14] J. Hou, X. Zhao, F. Gong, F. Hui and F. Ge, PAPR and PICR Reduction of OFDM Signals With Clipping Noise -Based Tone Injection Scheme, in IEEE Transactions on Vehicular Technology, vol. 66, no. 1, (2017), pp. 222-232.

[15] Odeyemi, K. and Ogunti, E., 2014. Capacity Enhancement for High Data Rate Wireless Communication System. International Journal of Electrical and Computer Engineering, 4(5), p.800.

[16] E. A. A. Hagras, S. A. Fathy and M. S. El-Mahallawy, Genetic algorithm based tone-reservation for PAPR reduction in wavelet-OFDM systems, in proceedings of 33rd National Radio Science Conference (NRSC), (2016), pp. 223-232

[17] Telatar, I. (1999) Capacity of multi-antenna Gaussian channels. European Trans. Tel., 10(6), 585âĂŞ595.

[18] Kang, A.S. and Sharma, V., 2011. Pulse shape filtering in wireless communication-a critical analysis. IJACSA) International Journal of Advanced Computer Science and Applications, 2(3).

[19] Cho, Y.S., Kim, J., Yang, W.Y. and Kang, C.G., 2010. MIMO-OFDM wireless communications with MATLAB. John Wiley & Sons.

[20] Hill, G., 2011. Peak power reduction in orthogonal frequency division multiplexing transmitters (Doctoral dissertation, Victoria University).

[21] Roy, J.S., 2016. Multiple-Antenna Techniques in Wireless Communication-Technical Aspects. IJICTDC, 1(1), pp.24-32.

[22] Wu, J. and Fan, P., 2016. A survey on high mobility wireless communications: Challenges, opportunities and solutions. IEEE Access, 4, pp.450-476.

[23] Suban, A., RagaviBrintha, R., Gayatri, M. and Prabha, R.N., 2012. Comprehensive analysis of MIMO-OFDM with PAPR reduction using PTS. In 2012 IEEE Conference on Electrical, Electronics and Computer science (Vol. 5, pp. 35-44).

[24] Mohana, H.K., Mohankumar, N.M. and Devaraju, J.T., 2014. The Study and Analysis of Effect of Multi-Antenna Techniques on LTE network with Different Bandwidth Configurations in the Downlink. International Journal of Advanced Networking and Applications, 6(3), pp.2314-2318.

[25] Vidya, M., Vijayalakshmi, M. and Ramalingareddy, K., 2015, December. Performance enhancement of efficient partitioning technique for PAPR reduction in MIMO-OFDM system using PTS. In 2015 Conference on (PCCCTSG) (pp. 247-253). IEEE.

[26] Kaur, S. and Bharti, G., 2012. Orthogonal frequency division multiplexing in wireless communication systems: A Review. International Journal of Advanced Research in Computer Engineering & Technology, 1(3).

[27] Idarwazeh, S., 2011. Inverse discrete Fourier transform-discrete Fourier transform techniques for generating and receiving spectrally efficient frequency division multiplexing signals. American Journal of Engineering and Applied Sciences, 4(4), pp.598-606.

[28] S.V.Kiran1, K.L.V. Prasad1, R Anil Kumar1 PAPR Reduction by using Modified SLM-PTS Techniques in OFDM (IJRIAS) | Volume III, Issue I, January 2018 |ISSN 2454-6194

[29] Maharaja, N., Mishra, B.K. and Bansode, R., 2016. Performance Evaluation of Spatial Multiplexing MIMO-OFDM System using MMSE Detection under Frequency Selective Rayleigh Channel. Global Journal of Computer Science and Technology.

[30] Zhang, R., Cai, L. and Pan, J., 2016. Resource Management for Multimedia Services in High Data Rate Wireless Networks. Springer.

[31] Lin, H., B<> com, 2019. Method for transmitting a multi-carrier signal, a receiving method, devices, and associated computer programs. U.S. Patent Application 10/243,774.

[32] S.A. Alkhawaldeh , Wideband Channel Estimation for Full Rate Full Diversity Antenna Selection Wireless Systems 2012.

[33] Nsikan Nkordeh, Francis Idachaba, Ibinabo Bob-Manuel, Oluyinka Oni,Members IAENG Implementing Orthogonal Frequency Division Multiplexing Using IFFT/FFT Proceedings of the World Congress on Engineering 2016 Vol IWCE 2016, June 29 - July 1, 2016, London, U.K

[34] Channel Estimation Techniques Based on Pilot Arrangement in OFDM Systems SINEM COLERI, MUSTAFA ERGEN, ANUJ PURI, AND AHMAD BAHAI Presented By: Belal Essam Eldiwany 31 January 2017

[35] Acar, Y., DoÄ§an, H. and Panayirci, E., 2017. Pilot symbol aided channel estimation for spatial modulation-OFDM systems and its performance analysis with different types of interpolations. Wireless Personal Communications, 94(3), pp.1387-1404

[36] B.I.Bakare1 and Aggokabo Esther2 Performance Evaluation of Channel Capacity of Mimo-Ofdm in Wireless Communication (IOSR-JECE)e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 13, Issue 6, Ver. I (Nov.-Dec. 2018).

[37] Malik, J., Patnaik, A. and Kartikeyan, M.V., 2015, December. Capacity estimation of a comapct pattern diversity MIMO antenna. In 2015 (ICMOCE) (pp. 25-28). IEEE. 871-878.

[38] Jing, Q. and Wu, J., 2017. Performance comparison of space-time block and trellis codes in the MIMO land mobile satellite channels. Radioelectronics and Communications Systems, 60(1), pp.112.

[39] Chang, R.W., 1966. Synthesis of band-limited orthogonal signals for multichannel data transmission. Bell System Technical Journal, 45(10), pp.1775-1796.

[40] Nagaradjane, P., Rajan, Y.A., Muralidharan, P., Karthik, S. and Sarathy, V., 2011, March. Performance of transmitter preprocessing assisted DSTTD over frequency-selective wireless communication channels. In 2011 IEEE Wireless Communications and Networking Conference (pp. 1298-1303). IEEE. Communications and Networking Conference (pp. 1298-1303). IEEE.

[41] Cimini, L., 1985. Analysis and simulation of a digital mobile channel using orthogonal frequency division multiplexing. IEEE transactions on communications, 33(7), pp.665-675.

[42] Munni, T. N., & Hossam-E-Haider, M. (2018). Performance Analysis of Peak to Average Power Ratio (PAPR) Reduction Techniques in OFDM System for Different Modulation Schemes. 2018 4th International Conference on Electrical Engineering and Information & Communication Technology (iCEEiCT).

[43] Grover, A. and Grover, N., 2014. On limits of wireless communications in a fading environment: a general parameterization quantifying performance in fading channel. (IJEEI), 2(3), pp.125-131.

[44] Jagannatham, A.K., Introduction to OFDM and Multicarrier Modulation Advanced 3G and 4G Wireless Mobile Communications (online course). Indian Institute of Technology,Kanpur, India. Retrieved 01/10/2014.

[45] Anshu Jaiswal, Ashish Dubey and Manish Gurjar, Channel Estimation in BPSK-QPSK-PSK 16 and 64 QAM MIMO-OFDM System international journal of current engineering and technology, Vol. 4, pp. 2346-2348, 2014

[46] Jawhar, Y.A., Audah, L., Taher, M.A., Ramli, K.N., Shah, N.S.M., Musa, M. and Ahmed, M.S., 2019. A Review of Partial Transmit Sequence for PAPR Reduction in the OFDM Systems. IEEE Access, 7, pp.18021-18041.

[47] B U Rindhe1 Jyothi Digge2 S K Narayankhedkar2 Enhancement of Quality of Service of MIMO-OFDM International Conference and Workshop on Emerging Trends in Technology 2013, TCET, Mumbai, India

[48] P . Mukunthan and P Dananjayan P APR Reduction based on a Modified PTS with Interleaving and Pulse Shaping method for STBC MIMO-OFDM System 26th -2Sth July 2012.

[49] Vittal, M.V.R. and Naidu, K.R., 2017. A novel reduced complexity optimized PTS technique for PAPR reduction in wireless OFDM systems. Egyptian informatics journal, 18(2), pp.123-131.

[50] Singh, M. and Patra, S.K., 2017. Partial transmit sequence optimization using improved harmony search algorithm for PAPR reduction in OFDM. ETRI Journal, 39(6), pp.782-793.

[51] Hassaneen, S.S., Soliman, H.Y. and Elhennawy, A.E., 2013, December. Reducing the peak to average power ratio in MIMO OFDM systems. In 2013 9th (ICENCO) (pp. 128-133). IEEE.

[52] Hung, H.L. and Huang, Y.F., 2012. Peak-to-average power ratio reduction in orthogonal frequency division multiplexing system using differential evolution-based partial transmit sequences scheme. IET communications, 6(11), pp.1483-1488.

[53] R. D. Kanti, and R.V. Ch. Sekhar Rao 2014. Systematic Comparison of Different PAPR Reduction Methods in OFDM Systems International Journal of Electronics and Communication Engineering, vol. 7, no.1, pp. 21-30,.

[54] Moegiharto, Y., Trisnadewi, I., Anisah, I. and Briantoro, H., 2018, October. Power Saving Analysis of Peak to Average Power Ratio Reduction Technique in OFDM System using Hybrid Improved Partial Transmit Sequence dan Clipping Filtering Technique. In 2018 (IES-ETA) (pp. 196-201). IEEE.

[55] Chen, N., Zhou, G.T. and Swami, A., 2005, July. Bandwidth and power efficiency considerations for optimal training in OFDM. In IEEE/SP 13th Workshop on Statistical Signal Processing, 2005 (pp. 1364-1369). IEEE. pp.1364-1369.

[56] Choudhary, C. and Gupta, V., 2013. A study of performance enhancement schemes for multicarrier transmission. International Journal of Computer Applications, 68(5).

[57] Al-Jawhar, Y.A., Shah, N.S.M., Taher, M.A., Ahmed, M.S. and Ramli, K.N., 2016. An enhanced partial transmit sequence segmentation schemes to reduce the PAPR in OFDM systems. (IJACSA), 7(12), pp.66-75.

[58] Baig, I., Jeoti, V. and Drieberg, M., 2011, September. A ZCMT precoding based STBC MIMO-OFDM system with reduced PAPR. In 2011 National Postgraduate Conference (pp. 1-5). IEEE.

[59] Webb, W. ed., 2007. Wireless communications: The future. John Wiley & Sons.

[60] Kumar, V.B. and Prasad, K.Y., 2014. Reduction of PAPR and BER by Using Golay Sequences for OFDM System. International Journal of Emerging Engineering Research and Technology, 2(7), pp.191-198.

[61] Ike, D.U., John, S.N. and Ndujiuba, C., 2017. Modified Selected Mapping Technique for Peak-to-Average Power Ratio Reduction in Orthogonal Frequency Division Multiplexing Systems. (IJCET), 7, pp.1427-1432.

[62] Joshi, A. and Saini, D.S., 2017. GA-PTS using novel mapping scheme for PAPR reduction of OFDM signals without SI. Wireless Personal Communications, 92(2), pp.639-651.

[63] Singh, K., Dogra, A. and Naryal, G.S., 2012. A New Phase Sequence PAPR Reduction Technique Based On SLM And PTS Techniques. (IJIEASR), ISSN, pp.2319-4413.

[64] Al-Jawhar, Y.A., Ramli, K.N., Ahmed, M.S., abdulkareem Abdulhasan, R., Farhood, H.M. and Alwan, M.H., 2018. A new partitioning scheme for PTS technique to improve the PAPR performance in OFDM systems. International Journal of Engineering and Technology Innovation, 8(3), p.217.

[65] Joo, H.S., Kim, K.H., No, J.S. and Shin, D.J., 2017. New PTS schemes for PAPR reduction of OFDM signals without side information. IEEE Transactions on Broadcasting, 63(3), pp.562-570.

[66] Wu, D.X., 2011, October. Selected mapping and partial transmit sequence schemes to reduce PAPR in OFDM systems. In 2011 International Conference on Image Analysis and Signal Processing (pp. 1-5). IEEE.

[67] Abdullah, M.I., 2011. Comparative study of PAPR reduction techniques in OFDM.

[68] Singh, J., Garg, R. and Aulakh, I.K., 2016. Comparison of PAPR reduction techniques in OFDM based Cognitive Radio. International Journal of Applied Engineering Research, 11(5).

[69] Xia, L., Yue, X., Shaoqian, L., Kayama, H. and Yan, C., 2006, June. Analysis of the performance of partial transmit sequences with different subblock partitions. In 2006 International Conference on Communications, Circuits and Systems (Vol. 2, pp. 875-878). IEEE.

[70] Jae-Hyun Ro, Jong-Kwang Kim, Young-Hwan You and Hyoung-Kyu Song * Linear Approximation Signal Detection Scheme in MIMO-OFDM Systems Received: 29 September 2017; Accepted: 13 December 2017; Published: 1 January 2018

[71] Sarawong, J., Mata, T., Boonsrimuang, P. and Kobayashi, H., 2011, May. Interleaved partitioning PTS with new phase factors for PAPR reduction in OFDM systems. In The 8th Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI) Association of Thailand-Conference 2011 (pp. 361-364). IEEE.

[72] Shukla, A., Sapra, R., Goyal, V. and Shukla, M., 2012, May. Performance analysis of PAPR reduction in helical Interleaved OFDM system. In 2012 International Conference on Communication Systems and Network Technologies (pp. 639-642). IEEE.

[73] Varahram, P., Al-Azzo, W.F. and Ali, B.M., 2010. A low complexity partial transmit sequence scheme by use of dummy signals for PAPR reduction in OFDM systems. IEEE Transactions on Consumer Electronics, 56(4), pp.2416-2420.

[74] Gupta, I. and Patra, S.K., 2012, December. Single IFFT block based reduced complexity Partial Transmit Sequence technique for PAPR reduction in OFDM. In 2012 (CODIS) (pp. 53-56). IEEE.

[75] Christopher Cox John Wiley and Sons, Ltd LTE, LTE-ADVANCED, SAE, VoLTE AND 4G MOBILE COMMUNICATIONS This edition first published 2014

Appendix A

Appendix A

The chi-square distribution results when independent variables of κ are squared and summed up with standard normal distributions. The formula for the chi-square distribution's probability density function is

$f(x) = \frac{e^{\frac{-x}{2}} x^{\frac{\kappa}{2}-1}}{2^{\frac{\kappa}{2}}\Gamma(\frac{\kappa}{2})}$,for x ≥ 0

where κ is the shape parameter and Γ is the gamma function. The formula for the gamma function is

$\Gamma(a) = \int_0^{\propto} t^{a-1}e^{-t}dt$

The chi-square distribution is considered as a "standardized distribution" (i.e., no location or scale parameters) in a testing context.

Appendix B

let $m = N(q+n)$ where $0 \leq q \leq \Theta - 1$ and $0 \leq n \leq N-1$ then

$$\begin{aligned}
\tilde{x_m} = \tilde{x_{Nq+n}} &= \frac{1}{V}\sum_{\iota=0}^{V-1} X_\iota e^{j2\pi\frac{\tilde{m}}{v}\iota} \\
&= \frac{1}{N}\cdot\frac{1}{\Theta}\sum_{k=0}^{N-1} X_k e^{j2\pi\frac{m}{v}k} \\
&= \frac{1}{N}\cdot\frac{1}{\Theta}\sum_{k=0}^{N-1} X_k e^{j2\pi\frac{Nq+n}{N}k} \\
&= \frac{1}{\Theta}\left(\frac{1}{N}\sum_{k=0}^{N-1} X_k e^{j2\pi\frac{n}{N}k}\right) \\
&= \frac{1}{\Theta}x_n
\end{aligned}$$

where ι denotes a normalized discrete time instance, q is the sub-channel index of the k^{th} user and N is the total number of sub carriers.