Analysis of PAPR in OFDM with CSS

A Thesis submitted in partial fulfillment
of the requirements for the degree of

MASTER OF TECHNOLOGY
in
ELECTRONICS AND COMMUNICATION ENGINEERING
Specialization: Communication and networks

by

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA
ROURKELA, ODISHA, 769 008, INDIA
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Dedicated to My Loving Parents…

Dept of Electronics and Communication Engineering
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Certificate

This is to certify that the work in the thesis entitled **Analysis of PAPR in OFDM with CSS** by **M Palakonda reddy** is a record of an original research work carried out by him during 2014 - 2015 under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of **Master of Technology** with the specialization of **Communication and networks** in the department of **Electronics and Communication Engineering**, **National Institute of Technology Rourkela**. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

Place: NIT Rourkela
Date: 26th May 2015

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M Palakonda Reddy

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Abstract

The present trends in wireless communication industry are in light of multi-carrier transmission technique for example, Orthogonal Frequency Division Multiplexing (OFDM) which is very encouraging as far as higher data rates and better resistance to frequency selective fading. Wireless communication standards like IEEE 802.11a/g/n/ac, IEEE 802.16e and numerous others utilize one or other variety of OFDM, for example, OFDMA and MIMO-OFDM. However, the immense drawback of the OFDM system is its high Peak to Average Power Ratio (PAPR). Every one of these utilizing the linear power amplier at the transmitter side so its operating point will go to the saturation point because of the high PAPR which prompts in-band distortion and out-of-band radiation. This problem can be avoided by increasing the dynamic range of the power of amplifier that leads to high consumption of power and cost at the base station. To battle the impact of high PAPR, a few PAPR reduction techniques have been contrived throughout the most recent couple of decades. Every one of these techniques need to strike a trade-off among a few parameters, for example, computational complexity, PAPR reduction performance, BER performance and others. Depending upon the requirement, the most proper technique is thus chosen. PTS system has been in presence since 1997 and gives an exceptionally successful PAPR reduction procedure with no restriction on the most extreme number of subcarriers.

However the technique experiences an intense issue of high computational complexity. In this course a novel methodology which offers same PAPR diminishment and significantly reduces the complexity of the system by preserving the basic principle of the standard PTS technique is designed. The various quantities of IFFT blocks has been replaced by a single block to decrease the complexity of the framework. The proposed technique has been simulated and the PAPR reduc-

tion performance of the new technique has been compared with that of original PTS technique. Similarly, the complexities of the two techniques are compared based on the block diagrams.

The proposed technique is applied to the multiple antenna system to reduce its PAPR. This system can increase the diversity to combat the deep fades that occurred due to frequency selective fading. This multiple antenna system has been simulated and the PAPR reduction of each antenna is analysed and compared with the standard PTS technique.

Contents

List of Acronyms

Acronym	**Description**
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CCDF	Complementary Cumulative Distribution Function
CSI	Channel State Information
CSS	Cyclically Shifted Sequences
DAB	Digital Audio Broadcasting
DFT	Discrete Fourier Transform
FDD	Frequency Division Duplexing
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
IBO	Input Back-Off
ICI	Inter-Carrier Interference
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
ISI	Inter Symbol Interference
LS	Least Squares
LTE	Long Term Evolution
MBWA	Mobile Broadband Wireless Access
MCM	Multi-Carrier Modulation

MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MMSE	Minimum Mean Square Estimation
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PAPR	Peak to Average Power Ratio
PTS	Partial Transmit Sequence
QPSK	Quadrature Phase Shift Keying
SER	Symbol Error Rate
SIMO	Single Input Multiple Output
SLM	Selective Mapping
SNR	Signal to Noise Ratio
SVD	Singular Value Decomposition
TDD	Time Division Duplexing
VLSI	Very Large Scale Integration
WiMAX	Worldwide interoperability for Microwave access
WLAN	Wireless Local Area Network
4G	Fourth Generation

Nomenclature

Nomenclature	Description
c_{ki}	i^{th} infromation symbol at k^{th} sub-carrier
s_{ki}	Waveform for k^{th} sub-carrier
N	Number of sub-carriers
f_k	Frequency of k^{th} sub-carrier
T_s	Symbol period
$\pi(t)$	Pulse shaping function
r_m	m^{th} received symbol
$c_k^{'}$	Demodulated k^{th} sample
X_N	Data symbols on N^{th} sub-carrier
Δf	Sub-carrier spacing
L	Oversampling factor
γ_0	SNR in dB
M	Number of sub-blocks in PTS
W	Number of allowed phase factors
b_w	W^{th}allowed phase factor
X_m	m^{th} sub-block
x_m	m^{th} Partial Transmit Sequence
$\hat{x}_{opt}$	Optimum transmitted OFDM symbol
Y_N	Received information on N^{th} sub-carrier
ζ	Number of combinations

H	Channel matrix
n	Noise
R_{yy}	Auto-correlation
R_{xy}	Cross-correlation

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PAPR in OFDM: Introduction

The first generation wireless mobile communication technology evolved in $1970's$ by AT&T Bell Laboratories which uses analog modulation techniques and it doesn't have any security to the data transmitted [1]. Later in the second generation mobile communication came into existence which uses single carrier communication with digital modulation techniques. In this along with voice signals text messages are also transmitted but it doesn't support video so, the next generation of mobile communication evolved which supports broadband capacity and provides high data rate by using large bandwidth.

If the bandwidth of the signal is greater than coherence bandwidth of the channel then frequency selective fading occurs. It results in different frequencies get affected differently and may cause deep nulls at some frequencies that leads to some receiver problems. It imposes an upper limit on the data rate of the broadband communication. To tackle this multi-carrier transmission has been evolved.

Orthogonal frequency division multiplexing (OFDM) is a multi-carrier modulation scheme used for 4^{th} generation ($4G$) wireless communication that offers superior performance and benefits over traditional single-carrier modulation schemes. Chang in 1966 first introduced the concept of OFDM and patented in

1970. Later on, it was not developed because of lack of the electronic circuit to support computational complexity required by the OFDM and broadband application that need OFDM. In 1990, the importance of OFDM was recognised with the arrival of broadband digital form and the development of VLSI CMOS chips[2].

In 1995, OFDM was successfully used in broad range applications in the form of European Digital Audio Broadcasting (DAB) standard. OFDM has the strong ability to overcome frequency selective fading and provides good spectral performance. OFDM for high-speed wireless communications like IEEE 802.11a/g/n (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20 (MBWA) are already using this OFDM technology.

1.1 Introduction to OFDM

The fundamental principle of multi-carrier modulation scheme is dividing the available bandwidth into different subbands and each operating at different subcarrier frequency. The bandwidth of each subband must be less than the coherence bandwidth of the channel to avoid the frequency selective fading, and the data rates can also be increased when compared to single carrier communication system significantly. The frequency-selective wide-band channel can be reduced frequency non-selective narrowband channels as shown in below Figure 1.1.

The frequency non-selective narrow band channel can also reduce the complexity of the equaliser that is needed for each narrow band subchannel. The general implementation of multi-carrier modulation system is shown in below Figure 1.2.

The multi-carrier modulation (MCM) transmitted signal can be expressed mathematically as follows [2]

$$s(t) = \sum_{i=-\infty}^{\infty} \sum_{k=1}^{N} c_{ki} s_k(t - iT_s) \tag{1.1}$$

$$s_k(t) = \pi(t) e^{j2\pi f_k t} \tag{1.2}$$

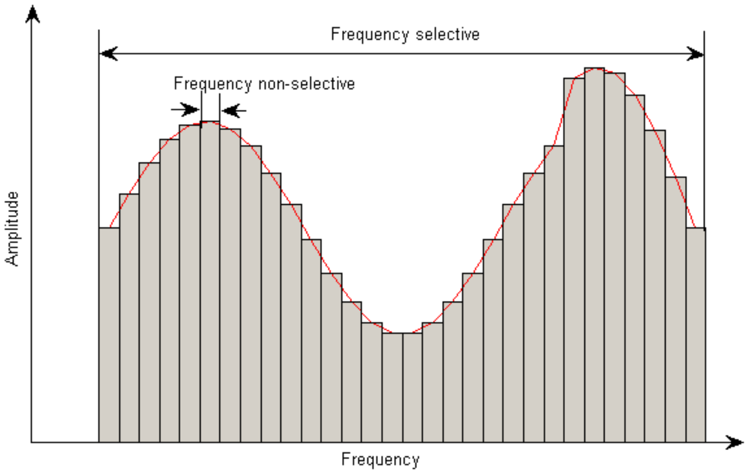

Figure 1.1: Frequency response of multi-channel transmission system

$$\pi(t) = \begin{cases} 1, & 0 < t \leq T_s \\ 0, & t \leq 0, t > T_s \end{cases} \tag{1.3}$$

where

$c_{ki} = i^{th}$ information symbol at k^{th} sub-carrier
$s_{ki} =$ waveform for k^{th} sub-carrier
$N =$ number of sub-carriers
$f_k =$ frequency of k^{th} sub-carrier
$T_s =$ symbol period
$\pi =$ pulse shaping function

At the receiver the information symbol can be detected by using a correlator that is matched to the transmitted sub-carriers. The detected information symbol at the output of the receiver is given as [2]

$$c'_{ki} = \frac{1}{T_s}\int_0^{T_s} r(t - iT_s)s_k^* dt \tag{1.4}$$

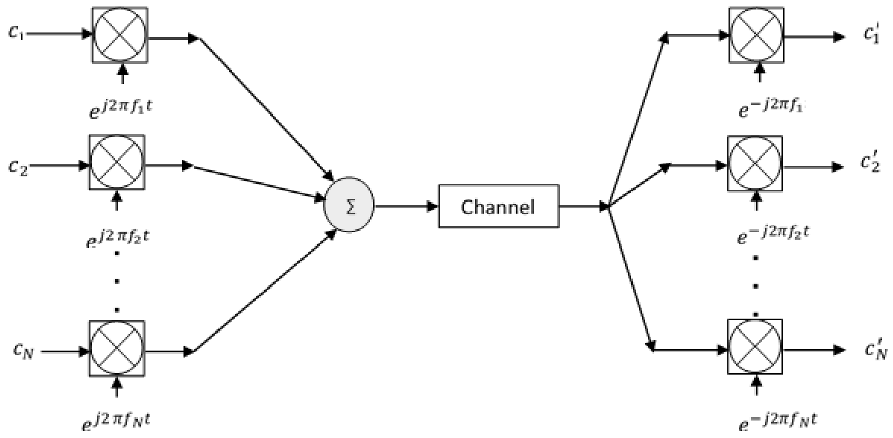

Figure 1.2: Transceiver of multi-carrier system

$$c_{ki}^{'} = \frac{1}{T_s}\int_0^{T_s} r(t - iT_s)e^{-j2\pi f_k t}dt \tag{1.5}$$

where $r(t)$ is the received time domain signal. The correlation among the sub-carriers is given as

$$\delta_{kl} = \frac{1}{T_s}\int_0^{T_s} s_k s_l^* dt \tag{1.6}$$

$$\delta_{kl} = \frac{1}{T_s}\int_0^{T_s} e^{j2\pi f_k t}e^{-j2\pi f_l t}dt \tag{1.7}$$

$$\delta_{kl} = exp(j\pi(f_k - f_l)T_s)\frac{sin\pi(f_k - f_l)T_s}{\pi(f_k - f_l)T_s} \tag{1.8}$$

For orthogonality of two sub-carriers

$$f_k - f_l = m\frac{1}{T_s}$$

where $|m|$=0,1,2,.... then

$$\delta_{kl} = 0$$

That is the carriers are an integral multiple of a fundamental frequency, this type of multi-carrier modulation technique called as Orthogonal Frequency Division Multiplexing (OFDM). Even though the Spectrum of different sub-carriers can be overlapped but, still the information on these sub-carriers can be recovered by using matched filters without any Inter-Carrier Interference (ICI). The orthogonal sub-carriers increases the utilisation of bandwidth without any wastage of bandwidth to separate two sub-carriers like in conventional FDM, and this results in an increase in data rate within the given bandwidth. In spite of this features, OFDM has its advantages and drawbacks [1],[2].

1.1.1 Advantages of OFDM

1. **Increase in spectrum efficiency**

   In OFDM, all the sub-carriers are orthogonal to each other, so there is no need of guard between the sub-carriers to avoid Inter-Carrier Interference (ICI). In this the complete available spectrum is efficiently utilised so, there is an increase in spectrum efficiency. The example of the spectrum of OFDM signal shown in below Figure 1.3.

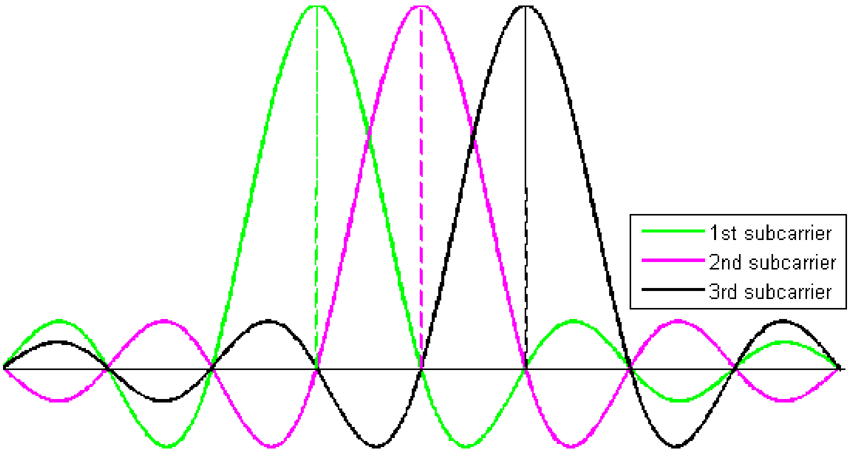

Figure 1.3: Spectrum of OFDM

2. **Robustness against frequency selective fading**

   In OFDM available channel bandwidth is divided into number of narrow-band orthogonal sub-carriers. Each narrow-band sub-carrier is having a bandwidth that is less than the coherence bandwidth of the channel and it is immune to frequency selective fading when compared to the single-carrier communication system.

3. **Resistance to Inter Symbol Interference (ISI)**
   The cyclic prefix is a feature of OFDM used to avoid the Inter-Symbol Interference (ISI) which is caused when signal propagated through the multi-path channel.

4. **Ease of implementation**
   Due to the use of IFFT block at the transmitter side and FFT block at the receiver side it is easy to implement by using Very Large Scale Integration (VLSI) technology. This digital signal processing technology allows to use number of sub-carriers in OFDM.

5. **Ease of channel estimation**
   OFDM can quickly adapt to channel conditions without the need for complex channel equalisation algorithms being employed due narrow-band channel unlike wide-band channel in single carrier system.

1.1.2 Drawbacks of OFDM

Besides these benefits of the OFDM, there are few drawbacks that need to take care of while designing OFDM transmission and reception. The drawbacks of OFDM are discussed below [1],[2]

1. **High PAPR**
   The high PAPR in an OFDM system primarily arises because of the IFFT operation. Here data symbols across sub-carriers are adding up to produce a high peak value signal. As the number of sub-carriers increases the PAPR of the resulting signal increases which causes severe effects that are discussed in section 1.4.3

2. **Sensitivity to phase and frequency offset**
   In OFDM all the sub-carriers are very closely spaced so, this is very sensitive to change in frequency of sub-carriers. The change in frequency results in phase offset error and frequency offset error. A fine tuning of sub-carriers is required to avoid phase and frequency offset errors.

3. **Inter-Carrier Interference (ICI)**
   The orthogonality of the sub-carriers of the OFDM signal sometimes violated when the OFDM signal is transmitted through the real world environment. This causes Inter-Carrier Interference (ICI), and it results in loss of information and increase in Bit Error Rate (BER).

1.2 OFDM Transceiver

The fundamental principle of OFDM is to split the available bandwidth into multiple sub-carriers. As the number of sub-carriers increases, it is more immune to frequency selective fading, and data rates are also increased. However, number of sub-carriers cannot be increased arbitrarily because it increases the complex architecture of the system and symbol durations that make transmission is more sensitive to the time incoherence of the channel.

The problem of the intricate design of the system was handled by Weinstein and Ebert with the implementation of OFDM modulation by Inverse Discrete Fourier Transform (IDFT) and demodulation by Discrete Fourier Transform (DFT) [2]. To illustrate this consider one OFDM symbol with N different sub-carriers and assume that $s(t)$ is sampled at every time interval T_s/N. The M^{th} sample $s(t)$ is obtained by [2]

$$s_m = \sum_{k=1}^{N} c_k e^{j2\pi f_k \frac{m-1}{N} T_s} \tag{1.9}$$

using the condition for orthogonality $f_k - f_l = m\frac{1}{T_s}$ and $f_k = \frac{k-1}{T_s}$, it can be written as

$$s_m = \sum_{k=1}^{N} c_k e^{j2\pi f_k \frac{(m-1)(k-1)}{N}} \tag{1.10}$$

At the transmitter end this can be written as

$$S_m = IDFTc_k, \qquad m = 1, 2, N \tag{1.11}$$

Similarly at the receiver end if $r(t)$ is the received signal which is sampled at every time interval of T_s/N then the received information symbol can be written as

$$c_k^{'} = DFT r_m, \qquad k = 1, 2, N \tag{1.12}$$

Where r_m is the received sampled signal. The implementation OFDM transmission and reception by using IDFT on the transmission side and DFT at the receiver side need to perform N^2 complex multiplications. The complexity of the system further increases exponentially with the increase in number of sub-carriers. This problem of complexity has been addressed with the use of fast Fourier transforms for OFDM transmission and reception. IFFT block is used on the transmission side of the OFDM signal and FFT block is used at the receiver side of OFDM signal. Now it is possible to increase the number of sub-carriers with relatively less increase in computational complexity of the system.

1.2.1 OFDM transmitter

The incoming serial data is the information that need to be transmitted through the channel using OFDM system. The serial in converted into N different parallel data streams by using serial to parallel converter. These symbols can be modulated by using different modulation techniques and given to the IFFT block as an input. IFFT block gives the digital time domain signal for the given input, and this parallel data is converted into serial data by using parallel to serial converter. The cyclic prefix is introduced between two OFDM symbols to cancel the effect of ISI due to channel dispersion. Now this digital time signal is converted into real time waveform with the use of digital to analog converters. The available baseband signal is up converted to RF passband signal with the use of mixer or modulators. The OFDM transmitter is shown in below Figure 1.4.

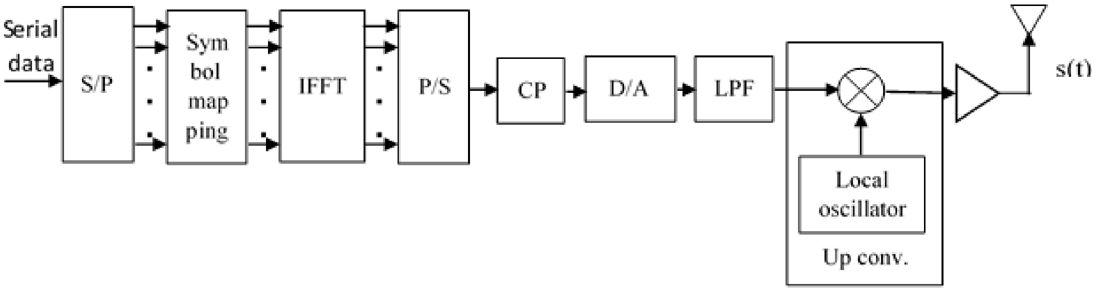

Figure 1.4: OFDM transmitter using IFFT

1.2.2 OFDM receiver

At the receiver end, the received OFDM signal is down converted using the demodulator and sampled with analog-to-digital converters to obtain the digital time domain signal. The digital time domain signal is demodulated by using FFT, and the data that is transmitted can be extracted by using symbol demapper. The OFDM receiver is shown in below Figure 1.5.

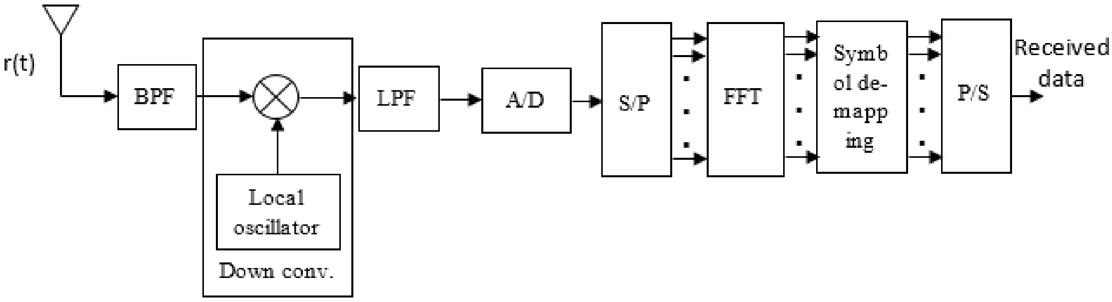

Figure 1.5: OFDM receiver using FFT

1.3 Applications of OFDM

With the arrival of broadband applications that require high data rate, OFDM became famous, and it is using widely in the wireless communications industry. In 1995, the first commercial OFDM was successfully used in broad range applications in the form of European Digital Audio Broadcasting (DAB) standard. The European Digital Video Broadcasting (DVB) came into existence which uses OFDM technology for the immediate development of DAB standard. IEEE 802.16a standard, which is the protocol for WLAN (Wi-Fi) came into existence using OFDM technology. Followed by this IEEE 802.11g WLAN also using OFDM. Nowadays the most popularly used protocol IEEE 802.11n using OFDM as the principle technology operating in 2.4 and 5 GHz band [1],[2],[3].

IEEE 802.16 is the standard for WiMAX using MIMO technology coupled with OFDM technology. Similarly, IEEE 802.15.3a is a standard for wireless Personal Area Network using OFDM technology in the ultra-wideband spectrum.

The 4^{th} generation mobile standard that is popularly using OFDM technology in Long-Term Evolution (LTE). The 3GPP standards were using OFDMA along with the MIMO technology. OFDMA differs from OFDM only in multiplexing of signals. In OFDMA, users can get access in a multiplexed manner.So, the current wireless system extensively using OFDM technology.

1.4 Peak to average power ratio in OFDM

OFDM is basically a multi-carrier modulation technique. The multi-carrier signal is the summation of large number of independent orthogonal sub-carriers. Hence, the envelope of the multi-carrier signal varies considerably. The variation in the envelope of the signal can be measured in the form ratio of peak value to the average value of the signal, and it is called as peak-to-average power ratio (PAPR) of the signal [4]. PAPR is the one of the major limitation of the signal.

1.4.1 Introduction to PAPR

PAPR (Peak-to-Average Power Ratio) is an important feature to evaluate the system performances. In an OFDM system with N sub-carriers, the data symbols transmitted on N different sub-carriers is given by [4]

$$X = [X_0, X_1, ..., X_{N-1}] \tag{1.13}$$

The complex baseband representation of analog OFDM signal is given by

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=o}^{N-1} X_n e^{j2\pi n \Delta f t}, \quad 0 \leq t < NT \tag{1.14}$$

where $j = \sqrt{-1}$, Δf is spacing between sub-carriers. For this transmitted signal its PAPR is given as

$$PAPR = \frac{\max\limits_{0 \leq t \leq NT} |x(t))|^2}{\frac{1}{NT}\int_0^{NT} |x(t))|^2 \, dt} \tag{1.15}$$

The above equation gives the PAPR of the analog signal. Let us consider the OFDM signal which is padded with $(L-1)N$ zeros to obtain the time domain signal precisely by using the Nyquist criteria. The L times oversampled data can be represented as

$$X = [x_0, x_1, x_2, ..x_{NL-1}]^T \tag{1.16}$$

These NL-1 samples of OFDM signal can be obtained from the inverse discrete Fourier transform (IDFT) is given by

$$x_k = x(\frac{k.T}{L}) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi k \frac{\Delta f n T}{L}}, \quad k = 0, 1, ...NL-1 \tag{1.17}$$

now, the PAPR of this L times oversampled signal is given by

$$PAPR = \frac{\max\limits_{0 \leq k \leq NL-1} |x_k|^2}{E[|x_k|^2]} \tag{1.18}$$

Where E[.] represents the expectation of the given signal.

1.4.2 Analysis of PAPR

The performance analysis of PAPR reduction techniques can be done by using complementary cumulative distribution function (CCDF) [5]. CCDF denotes the probability that PAPR of OFDM symbol exceeds the given threshold.

The cumulative distribution function of amplitude sampled signal is given by [4]

$$F(z) = 1 - exp(\gamma_0) \tag{1.19}$$

Now the CCDF of OFDM signal is given by

$$\begin{aligned} pr(PAPR > \gamma_0) &= 1 - pr(PAPR \leq \gamma_0) \\ &= 1 - F(\gamma_0)^N \\ &= 1 - (1 - e^{\gamma_0})^N \end{aligned} \tag{1.20}$$

The example of CCDF curve is shown below Figure 1.6.

1.4.3 Problems due to PAPR

The high PAPR in an OFDM system primarily arises because of the summation of large number of sub-carriers. Here data symbols across sub-carriers are adding up to produce a high peak value signal. In OFDM when the deviation of peak

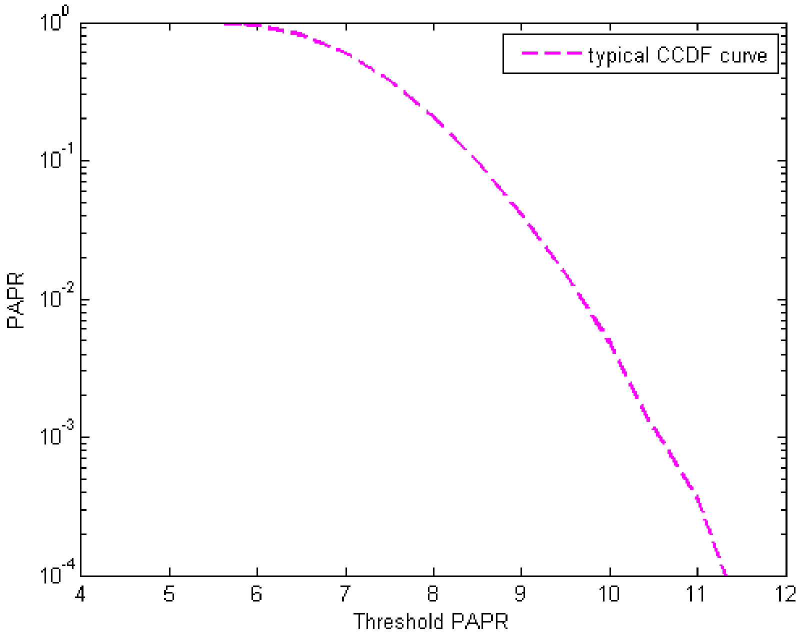

Figure 1.6: OFDM receiver using FFT

value from its average value is very high, the signal level moves outside the linear range of the power amplifier. When the signal moves to outside the linear range of the power amplifier, it leads to saturation of power amplifier [4]. To avoid this, it needs to use high input back-off (IBO) [6], which causes high power requirement. When the amplifier goes into saturation, it causes

- Inter-carrier interference
- Out-of-band radiation

These two effects can degrade the performance of the system by increasing the Bit Error Rate (BER) at the receiver.

1.4.4 Eliminating effects of PAPR

There are different ways to reduce the effect of high PAPR on power amplifier, these are discussed along with their limitations as below

- The linear dynamic range of power amplifier can be increased to reduce the problem of PAPR but power amplifiers with large dynamic range increases the cost of the system and also the range of the signal to be transmitted is decreased [4].

- To decrease the PAPR it need to increase the average power of the signal but it crosses the power limitation imposed by telecom regulatory authority and also it requires more power [4].
- To avoid this high PAPR problem it needs to reduce the PAPR of the signal before the signal is transmitted. There number of techniques to reduce PAPR of the signal to an acceptable level but they add some extra computational complexity to the system.

1.5 PAPR reduction techniques

To overcome the problem of in multi-carrier communication, many techniques have been proposed. The primary objective of each technique is to reduce the peak-to-average power ratio of the signal to before it is transmitted. The different methods have been listed below [4], [7]

- ◇ Amplitude clipping and filtering
- ◇ Coding
- ◇ Partial transmit sequence technique
- ◇ Selective mapping technique
- ◇ Interleaving
- ◇ Tone reservation
- ◇ Tone injection
- ◇ Active constellation extension technique
- ◇ Clustered OFDM
- ◇ Two-dimensional pilot symbol assisted modulation

1.5.1 Criteria for selection of techniques

There are different parameters that need to be considered before selecting the technique to reduce the PAPR of the OFDM signal. Any of these techniques may not satisfy all the parameters that are listed [4], but there is a need of trade-off between these parameters to select the method. Different factors are listed below

1. **PAPR reduction capability**
   It is the capability of the technique to reduce PAPR of the OFDM signal when it is applied. The one which reduces more PAPR that is considered as the best technique and this can be analysed by using CCDF curves.

2. **Power of the OFDM signal**
   The technique should not increase the power of the transmitted signal. If the power of the signal increases it should be within the range of permissible limit.

3. **Bit Error Rate (BER)**
   If the technique causes distortion of the signal when it is applied then at the receiver errors in the received bits increases. So, the technique which doesnt causes distortion of the signal that need to be selected.

4. **Data rate**
   These techniques require extra side information that need to be transmitted to the receiver to recover the information in the received signal. This extra side information reduces the data rate. So while selecting the technique it need to consider amount of side information it is going to add.

5. **Complexity of the technique**
   Complexity is related to the hardware implementation of the technique. At the cost of computational complexity, the techniques may satisfy all the other constraints but the complexity increases the time to process the signal, the power required and the cost of the system also. So computational complexity needs to reduce to speed up the system performance.

PAPR reduction technique	decrease in data rate	power increase	distortion	complexity
Amplitude clipping and filtering	No	No	Yes	Low
coding	Yes	No	No	Medium
PTS	Yes	No	No	Very high
SLM	Yes	No	No	high
Interleaving	Yes	No	No	Medium
TR	Yes	Yes	No	Medium
TI	No	Yes	No	Medium
ACE	No	Yes	No	Medium

Table 1.1: Comparision of different PAPR reduction techniques.

The table 1.1 lists the performance of different techniques based on above criterias mentioned [4].

Among all these techniques, PTS performs better to reduce PAPR, and also it satisfies all the criterias without degrading the signal but it causes high computational complexity [8]. The performance of PTS technique is going to increase with the increase in the computational complexity of the method.

1.6 Literature survey

Orthogonal Frequency Division Multiplexing is also one form of multi-carrier modulation technique that suffers from the problem of PAPR. The various PAPR reduction techniques along with their various advantages and disadvantages discussed in an overview of PAPR reduction techniques in multicarrier communication [4],[**?**]. In PAPR reduction based on modified PTS with interleaving [9] discusses the PTS technique that is more advantageous in terms of PAPR reduction with higher complexity in terms of its implementation. In novel sub-block partitioning scheme [10] discusses the various sub-block partitioning techniques used in the PTS technique.

In performance based channel estimation [**?**], it gives the brief introduction into the MIMO technology and the channel estimation in MIMO. In efficient MIMO channel estimation with optimal training sequences [11] it is given that the pilot symbols that are transmitted to estimate the channel at the receiver. It also explains the different channel estimation techniques that are used to estimate the channel. In pilot aided channel estimation [12] it is given that the arrangement of pilot that is different pilot structures are explained. In co-operative and alternative scheme for PAPR reduction in MIMO-OFDM [13] it is given that the application of PTS technique to the MIMO-OFDM to reduce the PAPR of the signal.

1.7 Motivation

The appearance of 4th generation wireless communication innovation has been conceivable because of the OFDM innovation. The current communication system needs speed, and high data transfer, which is exceptionally all around gave by OFDM. However, implementation of OFDM has the real concern of high PAPR like any multi-carrier signal. In the last few decades, researchers are trying to reduce the PAPR value of an OFDM signal by using different techniques without reducing the data rates or unwanted distortions of the signal. Some of the techniques are of having good PAPR reduction capability, but they offer very high computational complexity while some methods introduce distortion into the signal with the low complexity. Hence, there is a need of trade-off among different factors while choosing the method to reduce PAPR.

The PTS method has been among those methods which shows an exceptional PAPR decrease but yet it has a high computational complexity nature and also loss of data rates. So the researchers are of having great interest on this technique to reduce PAPR but it need to overcome the effects of high computational complexity and loss in data rate. Care need to be taken while improving the disadvantages of this technique to keep its advantages. Motivation came from such research works for the improvement of this technology. In this method computational complexity mainly arises due to the implementation of number of IFFTs and the new technology has been designed based on this concept.

MIMO technology provides more data rate along with the diversity of the signal. Motivation derived from this to implement the new technique to the MIMO technology so that it can provide very high data rates along with the improvements in the drawback of the existing method.

1.8 Goal of the work

The fundamental goal of this work is to modify a current PAPR reducing method known as PTS Technique such that the computational complexity of this method is decreased. High computational complexity needs more time, hardware and power to operate that equipment. By reducing the complexity of the process but then conveying the performance equivalent to or better than the current system, the power, hardware requirement and expense can be improved. To understand the goal, the following investigation and examinations were undertaken

- Study and analyse the existing PTS method to understand the primary reasons for getting more computational complexity.
- Develop a new method that can decrease the computational complexity by using the principle of PTS method and to simulate it to check the PAPR reduction performance of this newly designed method.
- To integrate this new technique to the MIMO technology to get the advantages offered by MIMO like very high data rate and diversity of the system.

1.9 Thesis organisation

The thesis has been composed into five chapters. The present part gives the prologue to the OFDM innovation and examines the significance of peak-to-average power ratio. Besides this it discusses the different PAPR reduction techniques and compares them based on different parameters. The motivation and objective of the work have been discussed in the following sections. The last section discusses the organisation of the thesis.

Chapter 2:

It describes the standard Partial Transmit Sequence technique along with its merits and demerits. It also discusses the results of PTS technique.

Chapter 3:

This chapter describes the Cyclically Shifted Sequences technique and its receiver. The results of the CSS technique have been compared with the standard PTS and with the normal OFDM signal without using any PAPR reduction technique. The BER performance of the CSS technique is compared with the PTS and normal OFDM signal BER performance.

Chapter 4:

This chapter describes the application of PTS and CSS techniques to MIMO-OFDM. It also describes the use of Singular Value Decomposition to the MIMO technology.

Chapter 5:

The fifth chapter discusses the conclusion of the complete work and its future scope for further research.

2

Partial Transmit Sequence Technique for PAPR reduction

The negative marks of high PAPR caused in OFDM framework is, for the most part, tended to by various PAPR decrease methods that lessen the PAPR worth to a particular edge such that the censorious impacts are disposed of [4]. Some of the methods have moderate PAPR reduction ability however, have lower computational complexity while some have great PAPR diminishment capacity at the expense of high computational complexity. Partial Transmit Sequence strategy conforms to the second sort of methods with high computational complexity and great PAPR diminishment performance. The current PTS method has been depicted in the part supported by numerical mathematical statements and block diagrams.

2.1 Partial Transmit Sequence Technique

PTS technique is one of the best technique among all the available techniques to reduce PAPR of the multi-carrier signal. The algorithm for the PTS technique is shown below.

2.1.1 Algorithm for PTS

The algorithm for PTS method is described below in different steps [14]. Figure 2.1 illustrates the algorithm in the form of a block diagram [4].

- The available serial data from the data source is converted to parallel data as needed in typical OFDM transmission that is depicted in Chapter 1.
- The possible parallel block of information is then partitioned into smaller sub-blocks that are having the same length as that of the first parallel block of data. For example if there are N sub-carriers then the length of parallel block of data is N and the length of each sub-block also need to be N. Here sub-carriers are divided among the sub-blocks such that each sub-block contain some of the sub-carriers has non-zero value and remaining sub-carriers have zero values. Also, it is to be noticed that one sub-carrier doesnt contain a non-zero value in more than one sub-block such that the sum of all the sub-blocks gives the original parallel block of data.
- All the sub-blocks of information is passed at a time through the IFFT blocks, and it performs Inverse fast Fourier transform on each sub-block. The output of these IFFT blocks is termed as Partial Transmit Sequences.
- These Partial Transmit Sequences then rotated with particular set phase factors that are pre-defined. The set pre-defined phase factors are selected from a set of allowed phase values that are characterized before. All the phase rotated PTSs add up to produce a single block of data which is called as candidate signal.
- The above step is repeated on the different set of phase factors. This process is repeated until all the possible combinations of phase factors are completed. This generates a large number of different candidate signals.
- Now PAPR of these candidate signals are calculated. All the candidate signals are compared based on these PAPR values and to select the candidate signal that is having least PAPR value as the required OFDM symbol to be transmitted.

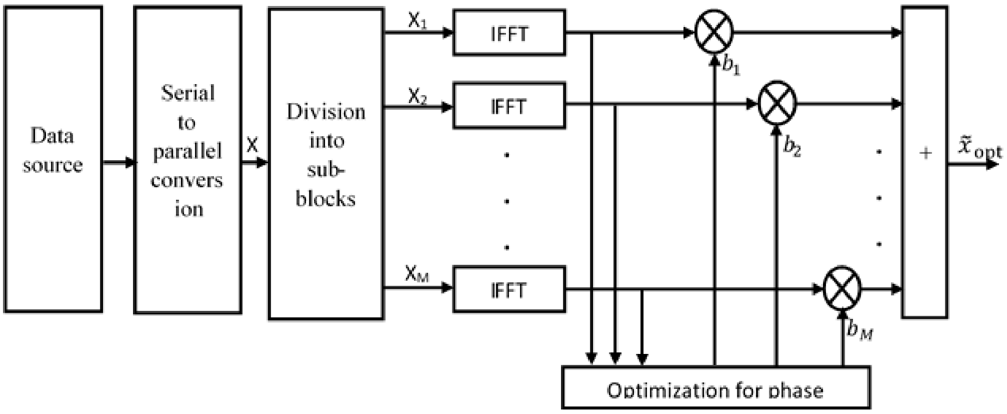

Figure 2.1: Block diagram of PTS technique

2.1.2 Sub-block partitioning

There is no precise plan to partition the approaching parallel block of information into sub-blocks [10]. However to make the methodology advantageous and streamlined three sorts of sub-block division have been proposed. These sub-carrier division plans allot equivalent number of non-zero sub-carriers to every sub-block. It has been demonstrated scientifically by Mller and Huber in their paper that, the more arbitrary the dispersion of sub-carriers is, the lesser the connection that exists among the sub-blocks and thus the better is the PAPR decrease performance [15].

Adjacent Sub-block Partition

If there are a total of N sub-carriers and are going to divide into M sub-blocks, then the first N/M sub-carriers are allotted to the first sub-block. Likewise, the second sub-block will have non-zero values for the following arrangement of N/M sub-carriers and remaining sub-carriers were allocated with zeros. For this situation, the correlation among the sub-blocks is high. This is illustrated in the following Figure 2.3.

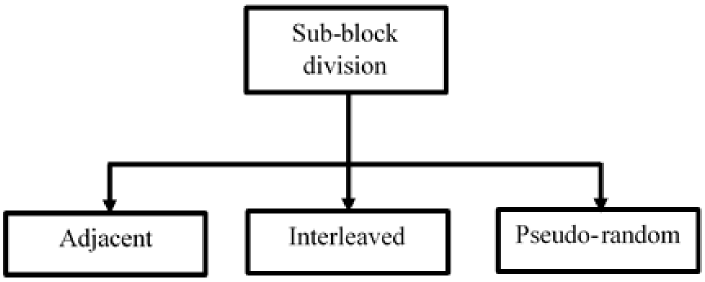

Figure 2.2: subblock partitioning in PTS

Interleaved Sub-block partition

In this partitioning, the sub-carriers with non-zero values are allotted after a fixed interval for each sub-block. If there are M sub-blocks, then every M^{th} sub-carrier of first sub-block is assigned with the non-zero value. Similarly for other sub-blocks also the consequent sub-carriers are allocated with non-zero values and remaining are zeros [9]. This plan is more arbitrary than adjacent type, yet a certain level of relationship exists among the sub-blocks because of its fixed pattern of alignment of sub-carriers. This is illustrated in the following Figure 2.4.

Pseudo-random Sub-block partition

In this partitioning, sub-carriers are allocated randomly to each sub-block due to this it gives least correlation among the sub-blocks. It is termed as pseudo-random because there exists certain measure of pattern in the task of aligning sub-carriers to make the procedure streamlined. This is an ideal method for sub-block partitioning. This is illustrated in the following Figure 2.5.

2.1.3 Mathematical analysis

Let X be the data symbols that need to be transmitted through an OFDM system containing N sub-carriers. The parallel block of information that is obtained after

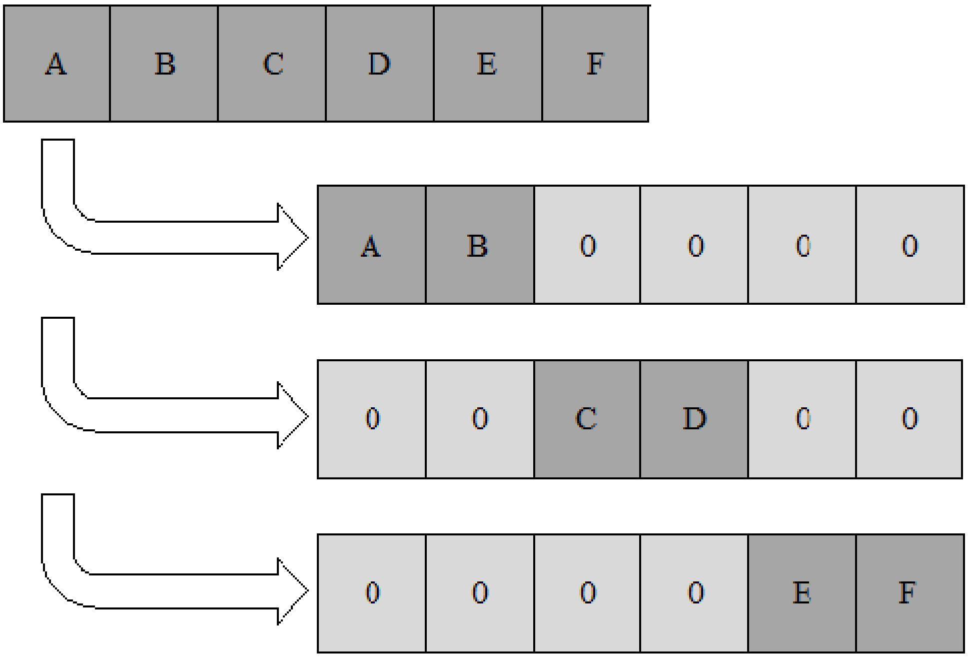

Figure 2.3: Adjacent partitioning

serial to parallel conversion of incoming data is given by [14]

$$X = [X_0, X_1, ., X_{N-1}]$$

In the ordinary PTS technique input data block X is partitioned into M disjoint sub-blocks and each block containing N/M non-zero quantities $X_m = [X_{m,0}, X_{m,1}, ..., X_{m,N1}]$, m=1,2,....M, such that

$$X = \sum_{m=1}^{M} X_m \tag{2.1}$$

Now these sub-blocks are passed through an N-point IFFT to obtain corresponding Partial Transmit Sequences and is given by

$$X_m = IFFT\{X_m\} \tag{2.2}$$

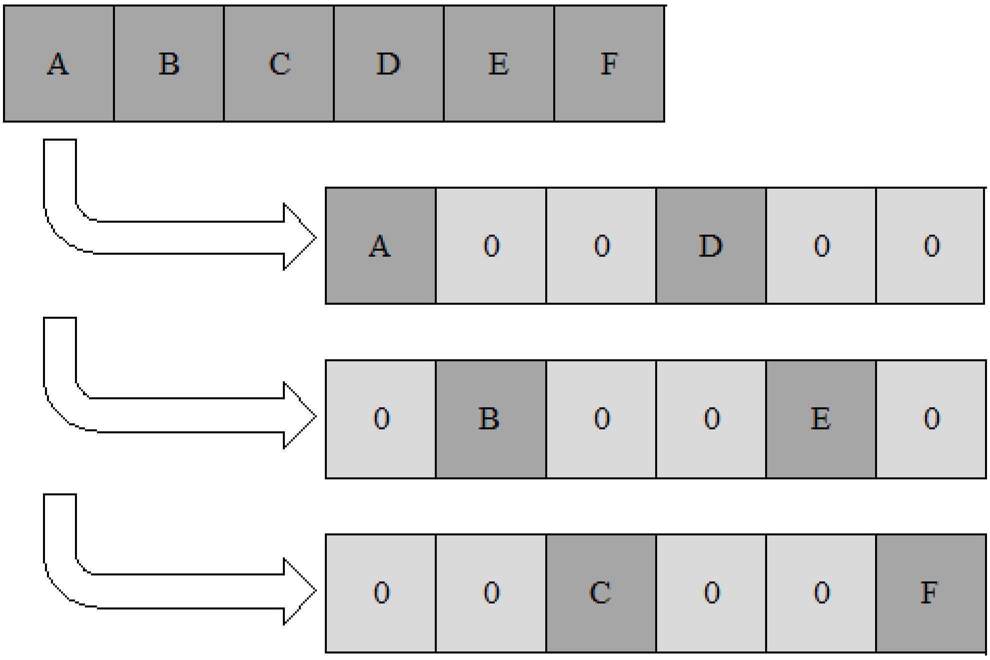

Figure 2.4: Interleaved partitioning

A set of complex phase factors are introduced to rotate these PTSs. The set of allowed phase factors is denoted by [4]

$$b_w = e^{j\phi_w}, \qquad w = 0, 1, ..., W - 1 \tag{2.3}$$

Generally first sub-block is left as it is i.e. $b_1 = 1$ and remaining sub-blocks are rotated without loss of any performance. The OFDM signal obtained after combining all the sub-blocks is given by

$$x^{\zeta} = \sum_{m=1}^{M} b_m^{\zeta} x_m \tag{2.4}$$

Where $\zeta = 1, 2, ...W^{M1}$ are the possible combinations of allowed phase factors.

The optimum transmitted OFDM symbol that is having least PAPR is given

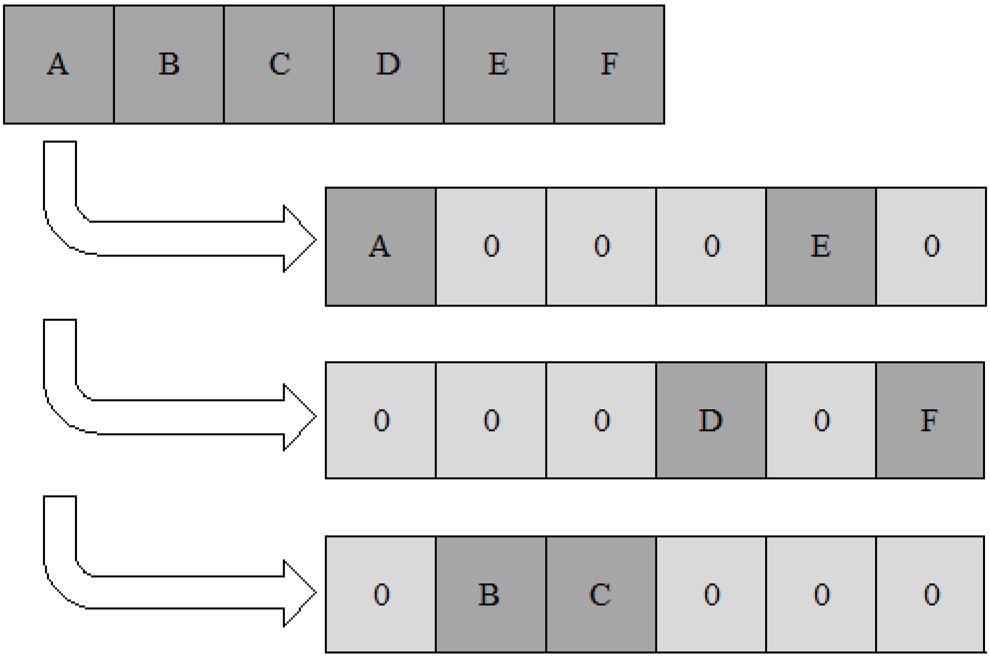

Figure 2.5: Random partitioning

by

$$\tilde{x}_{opt} = \min_{0\leq c\leq \zeta-1} \frac{\max\limits_{0\leq k\leq NL-1} \left|x_k^{\zeta}\right|^2}{E[\left|x_k^{\zeta}\right|]} \tag{2.5}$$

2.2 PTS receiver

At the receiver it needs to decode the transmitted information on the OFDM communication system. The PTS receiver algorithm to decode the information is shown below:

2.2.1 Algorithm for PTS receiver

The algorithm for PTS receiver is shown in different steps. Figure 2.6 illustrates the algorithm in the form of a block diagram.

- The received signal is multiplied with the conjugate of the received phase sequences. At the receiver the number of sub-blocks that is obtained depends on the number of received phase sequences. The received phase sequences indicates the number of sub-blocks at the transmitter side.

- All the sub-blocks of information is passed at a time through the FFT blocks, and it performs fast Fourier transform on each sub-block.
- All the sub-blocks are combined to get the one parallel block of information. The combination of these sub-blocks depends on the partition technique used at the transmitter side. The parallel block of information obtained contains the N data symbols.
- Now baseband demodulation is performed on these parallel block of information. It performs demodulation on each sub-carrier and gives the original transmitted information on the OFDM system.
- The available parallel block of information is converted into serial data by using parallel to serial converter. This gives the required serial data.

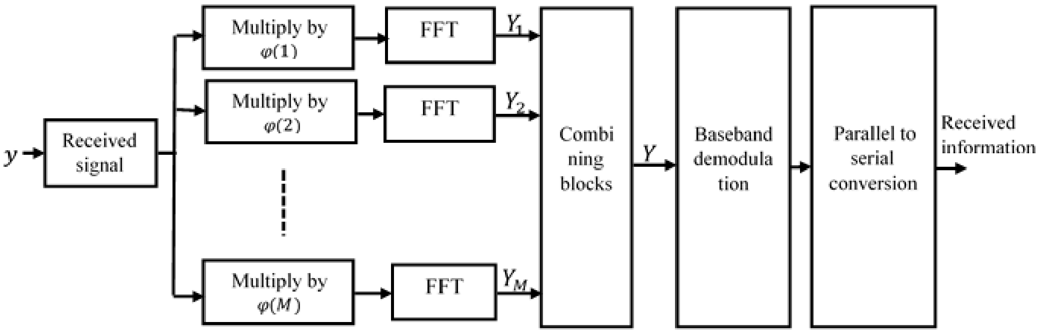

Figure 2.6: Block diagram of PTS Receiver

2.2.2 Mathematical analysis

Let Y be the received signal that is obtained through an OFDM system containing N sub-carriers. Let b be the set of phase sequences that are received as the side information and they are given by

$$b = [b_1, b_2, ., b_M] \tag{2.6}$$

From the received signal different sub-blocks are obtained by using the received phase sequences. Here the received signal is multiplied with the conjugate of the received phase sequences to obtain sub-blocks. The conjugate of the phase sequences is given by

$$\phi(m) = conj(b_m), \qquad m = 1, 2, ..., M \tag{2.7}$$

The sub-blocks obtained after multiplication with the conjugate of the phase sequences is given by

$$y_m = \phi(m) * y, \qquad m = 1, 2, ..., M \tag{2.8}$$

Now these sub-blocks of information are passed through an N-point FFT blocks. The output these FFT sub-block is given by

$$Y_m = FFT(y_m), \qquad m = 1, 2, ..., M \tag{2.9}$$

Now these sub-blocks are combined to get one parallel block of information containing N sub-carriers. For adjacent sub-block partitioning the combination of these sub-blocks is given by

$$Y = \sum_{m=1}^{M} Y_m(\frac{N}{M}(m-1) + 1 : \frac{N}{M}m), \qquad m = 1, 2, ..., M \tag{2.10}$$

The received parallel block of information is given by

$$Y = [Y_0, Y_1, ..., Y_{N-1}]$$

The parallel block of information is passed through the parallel to serial converter and the corresponding serial data is given by

$$Y = [Y_0, Y_1, ..., Y_{N-1}]^T \tag{2.11}$$

2.3 Merits and Demerits

PTS technique is also of having some merits and demerits like any of the other techniques. These are explained in the following sub-sections [4],[**?**].

2.3.1 Merits of PTS technique

1. **Distortion less technique**
   PTS technique doesnt introduce any distortion during the processing of the OFDM signal. Hence, the bit error rate performance of the system is not get affected.

2. **Works with arbitrary number of sub-carriers**
   PTS technique is not depending on the number of sub-carriers used in the system. As the number of sub-carriers increases, the data rate of the system also increases, so it is possible to use the PTS technique with arbitrary number of sub-carriers.

3. **Works with any modulation**
   This technique doesnt impose any restriction on the modulation that is used for different sub-carriers. So it is possible to use any higher order modulation techniques including BPSK and QPSK also.

4. **PAPR reduction performance**
   It is the best technique to reduce the PAPR of the signal when compared to all other methods. This is the main advantage of the technique compared to other advantages offered by this technique.

5. **Flexibility**
   The PTS technique provides many independent parameters like number of sub-carriers, type of modulation, the number of sub-blocks and the allowed number of phase factors. So it is possible to implement as per our requirement and modify as per our need.

2.3.2 Demerits of PTS technique

Even though it is having so many advantages there are some drawbacks that need to be considered. The drawbacks are listed below

1. **Increase in computational complexity**
   The significant drawback of the system is the high computational complexity of the technique. The complexity of the technology acquired due to

the use of number of IFFT blocks and need to perform number of iterations needed to get different candidates of the signal. The PAPR reduction performance of the technique mainly depends on the number of candidate signals, so it needs to perform number of iterations.

2. **Loss in data rate**
   At the receiver, the information of the phases that are applied on PTSs needed to decode the information. The information about phase sequences needs to be transmitted along with the OFDM symbol as the side information [16]. This side information decreases the data rate of the system. This drawback can be minimized by using more number of sub-carriers with less number of sub-blocks and allowed phase sequences.

2.4 Simulation Results

The PTS algorithm for decreasing the PAPR of the OFDM signal has been simulated in MATLAB R2013a on a CPU. Simulations performed for both adjacent and interleaved sub-block partitioning with four (M=4) sub-blocks using QPSK modulation, and the phase factors were chosen from $\{\pm 1, \pm j\}$. CCDF curves plotted by taking the PAPR threshold for reference on X-axis and probability that PAPR of our signal exceeds the threshold PAPR on the Y-axis. The different parameters considered are tabulated in table 2.1 for Figure 2.7. The values mentioned in Table 2.1 have been used to get the CCDF of PTS technique and compared it with the CCDF of original OFDM signal without using any PAPR reduction technique.

Parameter	Value
Number of sub-carriers	128
Number of sub-blocks	4
Number of allowed phase factors	4
Type of partitioning	Adjacent

Table 2.1: Different parameters for simulating Figure 2.7

For a probability of10^{-4}, it has been observed that PAPR=7.5 dB by using PTS technique but without using any method for standard OFDM signal

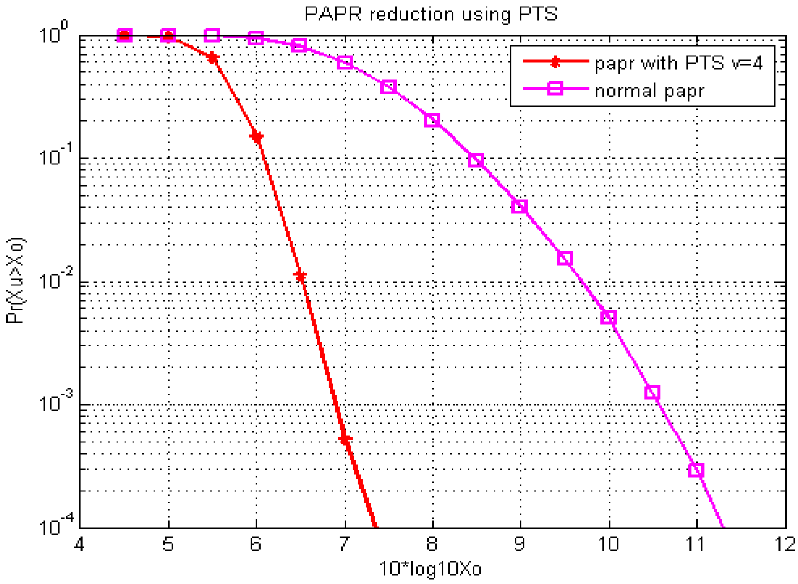

Figure 2.7: CCDF of PAPR for N=128, M=4, OFDM with PTS and OFDM without PTS

PAPR=11.5 dB that is very high when compared to the use of PTS. So, by using PTS there is an improvement of around 4 dB. It is expected that as the number of sub-blocks increases the number of candidate signals also increases. As the number of candidate signals increases the PAPR of the OFDM signal decreases. The same thing observed from the Figure 2.8. The CCDF curve shifting close to the origin as the number of sub-blocks increases.

It is known that as the number of subcarriers increases the PAPR of the signal is also increases. The same thing can be observed even by using PTS technique as shown in fig. 2.9. Here we are using different subcarriers, i.e., N=64, 128,256, as the number of subcarriers increases the CCDF curve is shifting to the right side, that shows that the PAPR of our signal is going to increase.

Figure 2.10 shows the CCDF curve for different sub-block partitioning techniques. In this it is observed that the PAPR of the OFDM signal with interleaved partitioning is more when compared to the adjacent partitioning. Both the partitioning techniques provides same number of candidate signals. In interleaved partitioning different candidate signals having same PAPR value but in case of adjacent partitioning the candidate signals have different PAPR values. So the

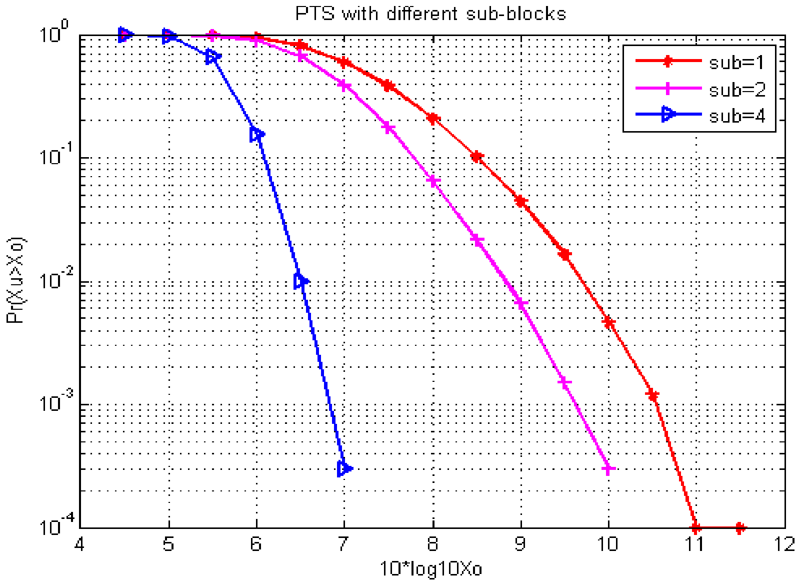

Figure 2.8: CCDF of PAPR for N=128, OFDM with PTS, OFDM without PTS by using different sub-blocks

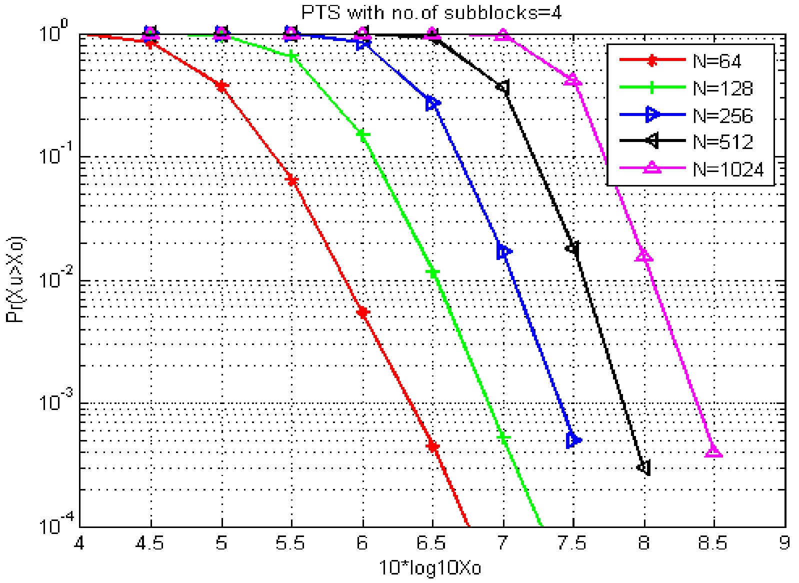

Figure 2.9: CCDF of PAPR for M=4, OFDM with PTS by using different number of sub-carriers

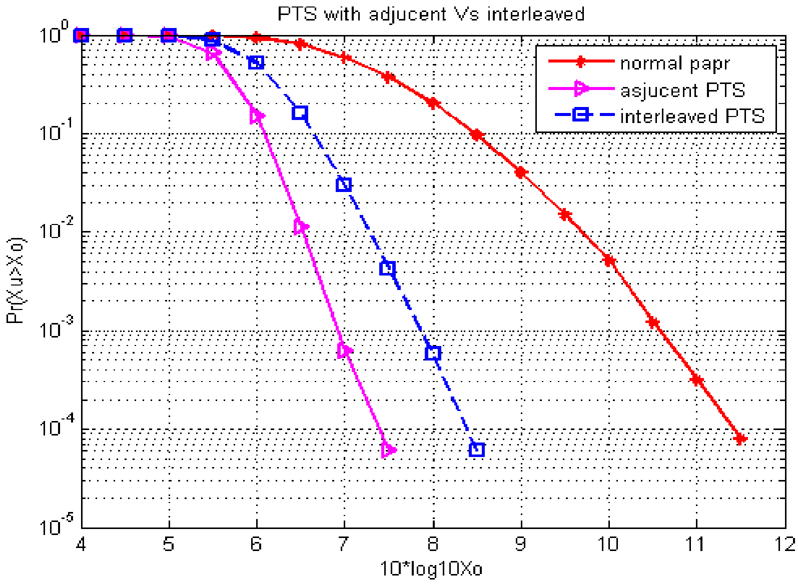

Figure 2.10: CCDF of PAPR for N=128, M=4, OFDM with PTS, OFDM without PTS by using different sub-block partitioning techniques.

resultant signal PAPR decreases in adjacent partitioning.

2.5 BER Performance

The performance of this PTS technique can be measured by simulating the PTS transmitter and receiver in the presence of the channel. One of the way to do this is by using Monte Carlo simulation.

The performance of any technique can be analyzed by using Monte Carlo simulation. In this, the system is made to operate for a repeated number of times. To operate for number of times, a large amount of data need to be collected. The simulation steps are discussed below

1. OFDM symbol is generated at the transmitter side by using Cyclically Shifted Sequences as the PAPR reduction technique.

2. The generated OFDM symbols are transmitted through the AWGN channel. When the signal is passes through the channel Additive White Gaussian Noise is added to the signal.

3. At the receiver side from the received signal data is decoded by using appropriate receiver design.
4. Received data is compared with the transmitted data to know the number of bits that are received as error due to channel conditions.
5. This process is repeated for large number of OFDM symbols.
6. Steps 1-6 are repeated for different SNR values starting from 0 dB to 20 dB and each time the Bit Error Rate (BER) is calculated.
7. Finally plot is obtained for SNR

The SER Vs SNR graph for PTS technique is shown in figure 2.11

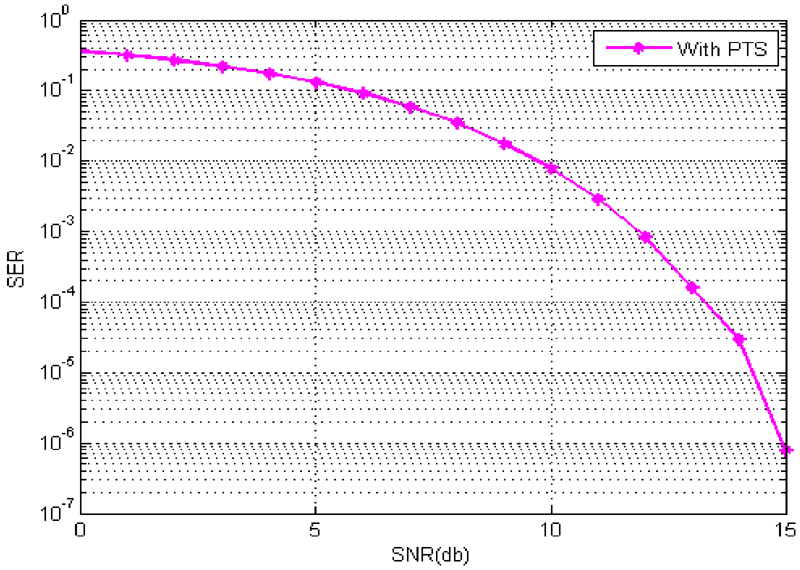

Figure 2.11: SER Vs SNR graph for 10^4 OFDM symbols transmitted

The comparison of performance of the performance of the PTS technique can be analyzed by comparing with the normal OFDM signal without using any technique.

The BER performance of PTS compared with the normal OFDM signal without using any PAPR reduction technique. From Figure 2.12 it is observed that both the techniques have same SER performance.

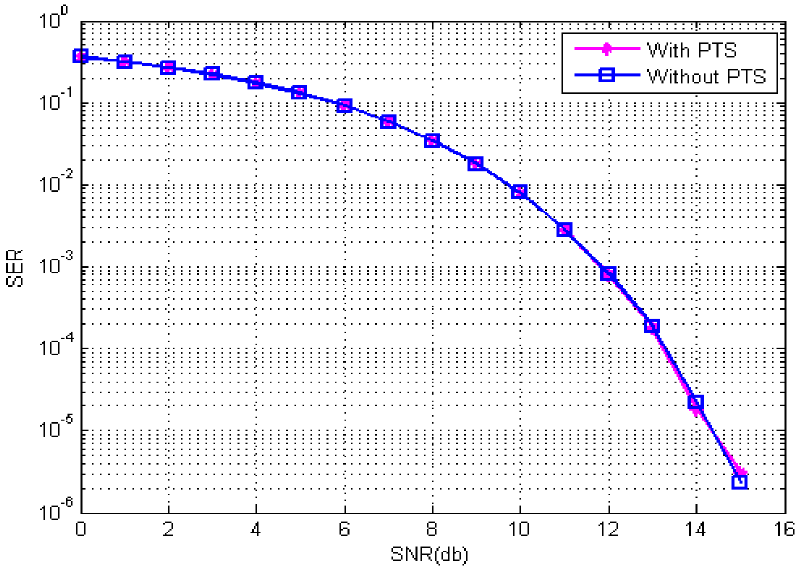

Figure 2.12: Comparison of SER Vs SNR graph for 10^4 OFDM symbols transmitted

3

Cyclically Shifted Sequences Technique for PAPR Reduction

This part explains in details, the novel method for usage of Cyclically Shifted Sequences Technique, which overcomes the significant drawback of unique PTS system. The way to deal with the configuration of the new strategy has been discussed. The distinction of the new approach with the methods examined in Chapter 2 has likewise been discussed in this chapter. The novel method utilizes the cyclically shifting of an available block of the data sequence and hence it is referred to as Cyclically Shifting Sequences technique. The algorithm for the method has been talked about supported by numerical mathematical statements. A block diagram has been exhibited which represents the algorithm and to understand it more conveniently.

This chapter is organised as the first two sections describes the traansmitter part of CSS technique with the block diagram and an algorithm to explaing each the operation of each sub-block. The mathimatical analysis of the algorithm also described in the same sections. the next couple of sections discusses the receiver of the CSS technique supported by some mathematical statements. Later on in this chapter the remaining sections expalins the simulation results that are exhibited in terms of graphical representations. An examination of these results regarding PAPR reduction performance has been done, and these results are compared with the results of original PTS technique and also with the OFDM transmission without any PAPR reduction techniques. The computational complexity of the new algorithm has been investigated and compared to justify the advantage of new method to reduce the complexity of the existing PTS.

3.1 Cyclically Shifted Sequences: Design Approach

The partial transmit sequences are generated by utilizing the multiple IFFT blocks for each sub-block in the original PTS technique. The IFFT blocks have a computational complexity of $N * log_2^N$ where N is the number of sub-carriers that are using in OFDM system. The complexity of the system increases with the increase in the number of IFFT blocks and number of sub-carriers needed for transmission.

The new design approach mainly concentrated on number of IFFT blocks used. The quantity of IFFT blocks has been reduced to unity in the proposed procedure. The algorithm has therefore been changed to perform the whole process utilizing one and only IFFT block. It also performs parallel processing like the original PTS technique. The phase factors are selected based on the different combinations of allowed phase sequences. The selection of phase sequences also same as the original PTS technique. It utilizes the concept of cyclically shifting the available data sequences. As a result, it eliminates the utilization of multiple IFFT blocks.

On the other hand, it has been confirmed numerically that the proposed method keeps the fundamental standard of unique PTS strategy in place. There is no loss of data rate because it is also using N-point IFFT. The proposed method generates an OFDM symbol that is having lower PAPR value, and it is mathematically similar to that produced by the original PTS technique.

3.2 CSS Transmitter

The algorithm for CSS transmitter along with the mathematical analysis of the algorithm is discussed in the following subsections. The block diagram is also shown below that supports the algorithm of CSS transmitter.

3.2.1 Algorithm of CSS Transmitter

The fundamental principle of PTS technique is to divide the available parallel block of information into different sub-blocks and to apply IFFT operation on each sub-block. The output of these IFFT sub-blocks are rotated by a set of phase sequences and added up such that PAPR value of this particular OFDM symbol is reduced. This can be repeated W^{M-1} times using the different combination of phase sequences and to select the candidate signal that is having less PAPR as the required OFDM symbol to be transmitted.

This technique is modified to utilize only one IFFT block, and the corresponding algorithm is discussed below. Figure 3.1 illustrates the block diagram for the proposed algorithm.

- The available serial data from the data source is converted to parallel data as needed in typical OFDM transmission that is depicted in Chapter 1.
- The parallel block of information is modulated on different sub-carriers using baseband modulation techniques like BPSK, QPSK or any higher order modulation techniques.
- The possible parallel block of information is then passed through the N-point IFFT block, and it performs Inverse fast Fourier transform on the input data.
- Now this data is copied into V sub-blocks and perform circularly right shift operation on each sub-blocks. The first sub-block is circularly right shifted N/V samples with respect to actual block that is the output of IFFT block. The second block is shifted again shifted $2N/V$ samples. Similarly, all the sub-blocks are circularly right shifted.

- These circularly right shifted sequences then rotated with particular set phase factors that are pre-defined. The set pre-defined phase factors are selected from a set of allowed phase values that are characterized before. All the phase rotated sequences add up to produce a single block of data which is called as candidate signal.
- The above step is repeated on the different set of phase factors. This process is repeated until all the possible combinations of phase factors are completed. This generates a large number of different candidate signals.
- Now PAPR of these candidate signals are calculated. All the candidate signals are compared based on these PAPR values and to select the candidate signal that is having least PAPR value as the required OFDM symbol to be transmitted.

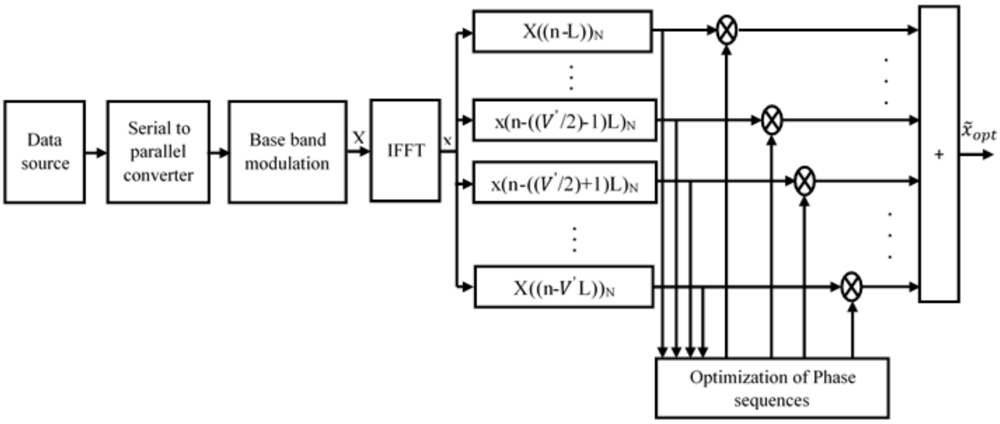

Figure 3.1: CSS transmitter using single IFFT

Thus, the new approach uses only one N-point IFFT block, and it performs the process in parallel manner. The optimum phase factors are selected based on the PAPR value of the candidate signal.

3.2.2 Mathematical analysis

Let X be the data symbols that need to be transmitted through an OFDM system containing N sub-carriers. The parallel block of information that is obtained after serial to parallel conversion of incoming data is given by

$$X = [X_0, X_1, ., X_{N-1}] \tag{3.1}$$

Now this parallel block of information is passed through the IFFT block that performs inverse fast Fourier transform operation. The output of IFFT block is given by

$$x = IFFT\{X\} \tag{3.2}$$

A set of complex phase factors are introduced to rotate these sub-blocks. The set of allowed phase factors is denoted by

$$b_w = e^{j\phi_w}, \qquad w = 0, 1, ..., W-1 \tag{3.3}$$

Here new type of set of phase sequences are proposed that are given below

$$D = [b_1, b_2, ...b_M, b_M, ..., b_2, b_1] \tag{3.4}$$

Where the length of new phase sequences (D) is given by Length of $D = V^{'} = 2M$. The sub-blocks are rotated by using a set of new phase sequences. The OFDM signal obtained after combining all the sub-blocks is given by

$$x^{\zeta} = \sum_{\substack{i=0 \\ i=\frac{V^{'}}{2}}}^{V^{'}-1} q_i^{\zeta} \left\{ x((n - iV^{'}))_N \right\} \; ; \quad \zeta = 1, 2, ..., W^{M-1} \tag{3.5}$$

Where

$$q_i^{\zeta} = IFFT\left\{D^{\zeta}\right\}$$

$$D^{\zeta} = [b_1^{\zeta}, b_2^{\zeta}, ..., b_M^{\zeta}, b_M^{\zeta}, , ..., b_2^{\zeta}, b_1^{\zeta}] \tag{3.6}$$

Here $i = \frac{V^{'}}{2}$ is not included while obtaining the OFDM symbol because $q_i^{\zeta} = 0$. So it needs to multiply new phase sequences to the only $V-1$ sub-blocks.

The optimum transmitted OFDM symbol that is having least PAPR is given by

$$\tilde{x}_{opt} = \min_{0 \leq c \leq \zeta - 1} \frac{\max\limits_{0 \leq k \leq NL-1} \left| x_k^{\zeta} \right|^2}{E[\left| x_k^{\zeta} \right|]} \tag{3.7}$$

3.3 CSS Receiver

The receiver is designed for receiving the information that is transmitted through the OFDM communication system that uses CSS technique to reduce the PAPR of the OFDM signal. The CSS receiver has been depicted supported by mathematical statements and block diagrams.

3.3.1 Algorithm of CSS receiver

The essential principle of the design of the receiver is to balance the changes that were joined in the transmitter side while decreasing the PAPR of the OFDM signal. Based on the transmitter design approach the receiver for the Cyclically Shifted Sequences is designed.

The algorithm for the CSS receiver is as shown below. Figure 3.2 represents the block diagram that illustrates the algorithm of the CSS receiver.

- The received signal is circularly left shifted by N/V samples with respect to the original received signal. The second sub-block is obtained by circularly left shifting N/V with respect to the first sub-block. Similarly, this process is repeated until V sub-blocks are formed.
- Now these sub-blocks are multiplied by the conjugate of the received phase sequences. At the receiver, the number of sub-blocks that is obtained depends on the number of received phase sequences.
- All the V sub-blocks are combined to get the one parallel block of information. The parallel block of information obtained contains the N data symbols.
- Now baseband demodulation is performed on these parallel block of information. It performs demodulation on each sub-carrier and gives the original transmitted information on the OFDM system.

- The available parallel block of information is converted into serial data by using parallel to serial converter. This gives the required serial data.

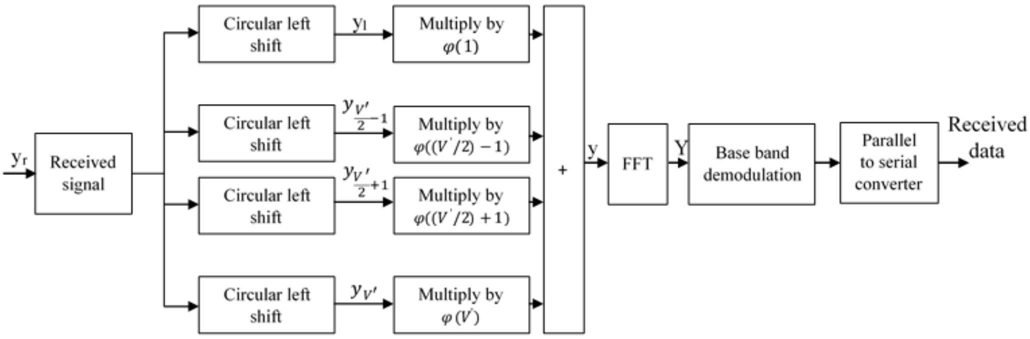

Figure 3.2: CSS transmitter using single IFFT

3.3.2 Mathematical analysis

Let y_r be the received signal that is obtained through an OFDM system containing N sub-carriers. Now the received signal is circularly left shifted by N/V samples with respect to the previous sub-blocks. The sub-blocks can be expressed as

$$y_i = y_r((n + i\frac{N}{V'}))_N, \qquad i = 1, 2, ..., V' \tag{3.8}$$

At the receiver, the number of sub-blocks that is obtained depends on the number of received phase sequences. Now these sub-blocks are multiplied by the conjugate of the received phase sequences. The resultant sub-blocks are combined to get the one parallel block of information. The obtained parallel block can be represented as

$$y = \sum_{i=1}^{V'} y_i \phi(i), \qquad i = 1, 2, ..., V' \tag{3.9}$$

where

$$\begin{aligned} \phi &= conj(D) \\ D &= IFFT[b_1, b_2, ..., b_{M-1}, b_{M-1}, ..., b_2, b_1] \\ b &= [b_1, b_2, ..., b_{M-1}] \end{aligned}$$

Here, b is the received phase sequences along with the OFDM symbol in the form of side information. The parallel block of information is now given to the N-point FFT block that performs fast Fourier transform operation on the given data. The output of the FFT block is given by

$$Y = FFT\left\{y\right\} \tag{3.10}$$

The parallel block of information is passed through the parallel to serial converter and the corresponding serial data is given by

$$Y = [Y_0, Y_1, ..., Y_{N-1}]^T \tag{3.11}$$

3.4 Analysis of CSS

The CSS technique can be analysed by comparing the different features of both PTS and CSS technique. Table 3.1 shows the different features of the techniques and their comparison.

Features	PTS	CSS
Computation at Tx.	M N-point IFFTs and generating W^{M-1} phases	N-point IFFT,L-point IFFT, generating, W^{M-1} phases
Number of multiplications	MN($\frac{1}{2}log_2^N + W^{M-1}$)	$\frac{N}{2}log_2^N+$ $\frac{L}{2}log_2^L+$ $(V^{'}-1)NW^{M-1}$
Side information	(M-1)log_2^W	$(M-1)log_2^W$
Distortion	No	No
Power increase	No	No
Data rate	Decreases	Decreases

Table 3.1: Different features of PTS and CSS.

The computational complexity is the main difference between both original PTS and proposed CSS technique. In original PTS, there is a need for an IFFT block for each sub-block. so for M sub-blocks it requires M N-point IFFTs. Each IFFT needs $\frac{N}{2}log_2^N$ complex multiplications. The number of multiplications increases with the increase in the number of sub-carriers and also with the increase in the number of sub-blocks.

This drawback can be eliminated by using the CSS technique. At the transmitter side, this method needs only one N-point IFFT and one M-point IFFT. It requires only $\frac{N}{2}log_2^N$ complex multiplications for IFFT operation and $\frac{M}{2}log_2^M$ complex multiplications for computing phase sequences. Even if the number of sub-carriers increases the number of multiplications needed not increases sharply like original PTS technique. So the complexity of the system is decreased when compared to the basic PTS technique. The same thing can be observed in the following table 3.2

Features	PTS	CSS
Computation at Tx.	4 128-point IFFTs and generating 64 phases	128-point IFFT, 4-point IFFT, generating 63 phases
Number of multiplications	34560	17288
Side information	6	6

Table 3.2: numerical example for M=4, W=4, N=128

The proposed CSS technique preserves the fundamental principle of PTS technique that can be observed by seeing the other features of the technique like the loss in data rate, side information required, distortion and power increase. In both the cases, the side information that needs to send to decode the transmitted information at the receiver is same.

The CSS technique doesnt introduce any distortion into the signal because it is only rotating the phase of the signal without affecting its amplitude. It is reducing the PAPR to a great extent without any additional increase in the power of the signal. So there is no need of additional power requirement.

Side information needs to be transmitted to the receiver to retrieve the information at the receiver. The side information bits needs to send in place of the data symbols of the OFDM communication system. This can decrease the data rate of the system.

3.5 Simulation Results

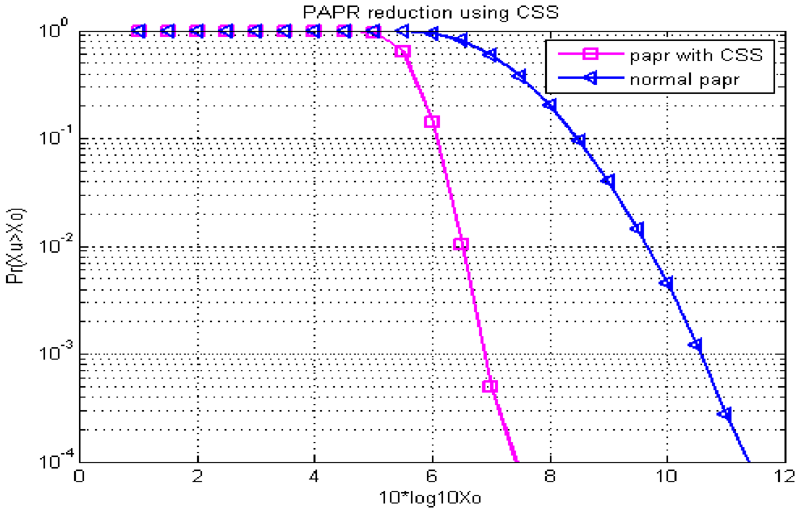

Figure 3.3: CCDF of PAPR for N=128, W=4, OFDM with CSS and OFDM without CSS

The CSS algorithm for decreasing the PAPR of the OFDM signal has been simulated in MATLAB R2013a on a CPU. Simulations performed with eight ($v = 8$) sub-blocks using QPSK modulation, and the phase factors were chosen from $\{\pm 1, \pm j\}$. CCDF curves plotted by taking the PAPR threshold for reference on X-axis and probability that PAPR of our signal exceeds the threshold PAPR on the Y-axis.

The CCDF curves for CSS techniques are drawn by using N=128 sub-carriers and it is compared with the CCDF of original OFDM signal without using any PAPR reduction technique. From Figure 3.3, for a probability of 10^{-4}, it has been observed that PAPR=7.5 dB by using CSS technique but without using any method for standard OFDM signal PAPR=11.5 dB that is very high when compared to the use of PTS. So, by using PTS there is an improvement of around 4 dB.

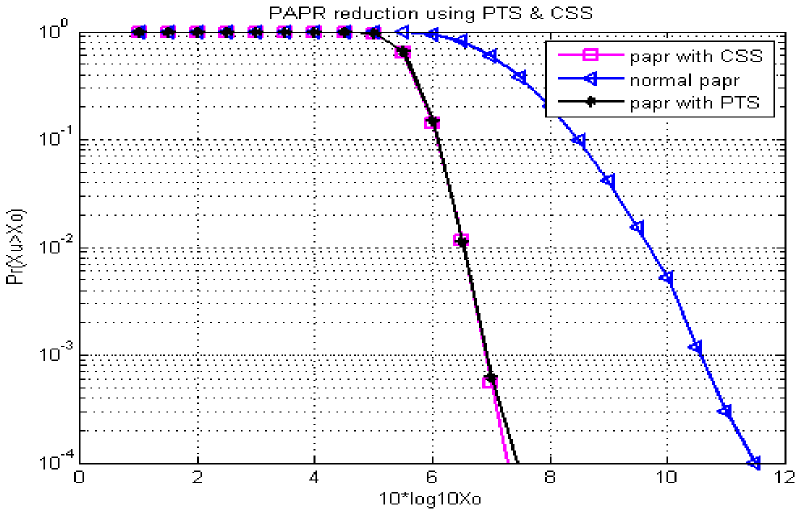

Figure 3.4: CCDF of PAPR for N=128, W=4, OFDM with CSS, PTS and OFDM without CSS

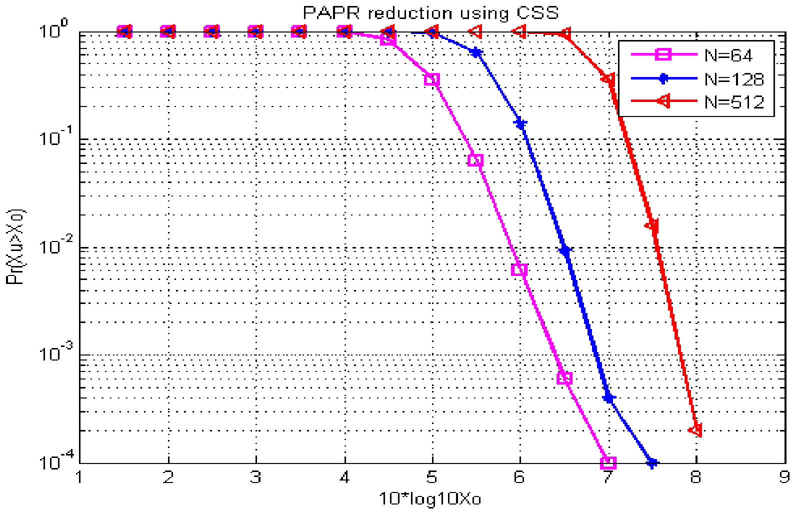

Figure 3.5: CCDF of PAPR for OFDM with CSS by using different number of sub-carriers

The CCDF curves of CSS technique compared with the PTS technique to analyse the performance of the technique. From Figure 3.4 it is observed that both the techniques have same performance in terms of PAPR reduction.

As it is known that PAPR of the multi-carrier signal increases with the increase in number of sub-carriers. From Figure 3.5 the same thing is observed for different number of sub-carriers.

3.6 BER Performance

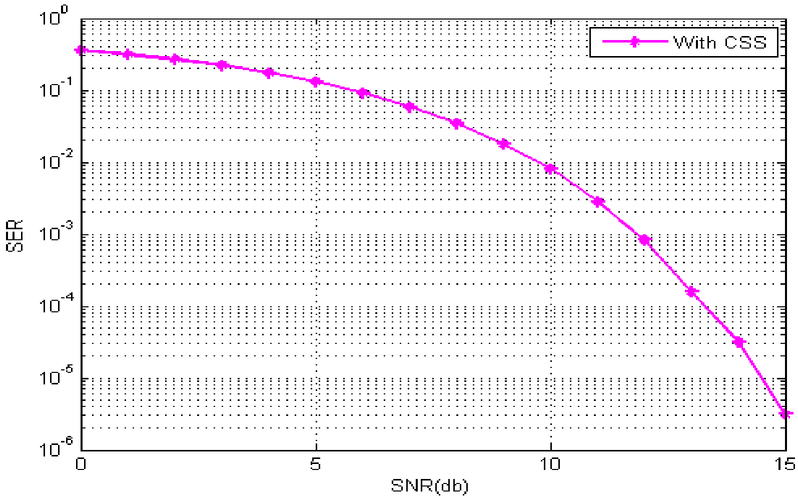

Figure 3.6: SER Vs SNR graph for 10^4 OFDM symbols transmitted

The performance of this CSS technique can be measured by simulating the CSS transmitter and receiver in the presence of the channel. One of the way to do this is by using Monte Carlo simulation. The performance can be measured by using the Symbol Error Rate (SER).

The SER Vs SNR graph for PTS technique is shown in figure 3.6 in the presence of the AWGN channel.

The SER performance of the CSS technique is compared with the PTS technique and it is shown in Figure 3.7. From this it is observed that both the techniques are having same SER performance.

Figure 3.8 shows comparison of the SER performance of the CSS technique with OFDM signal without any technique. It shows that the CSS doesnt cause any distortion.

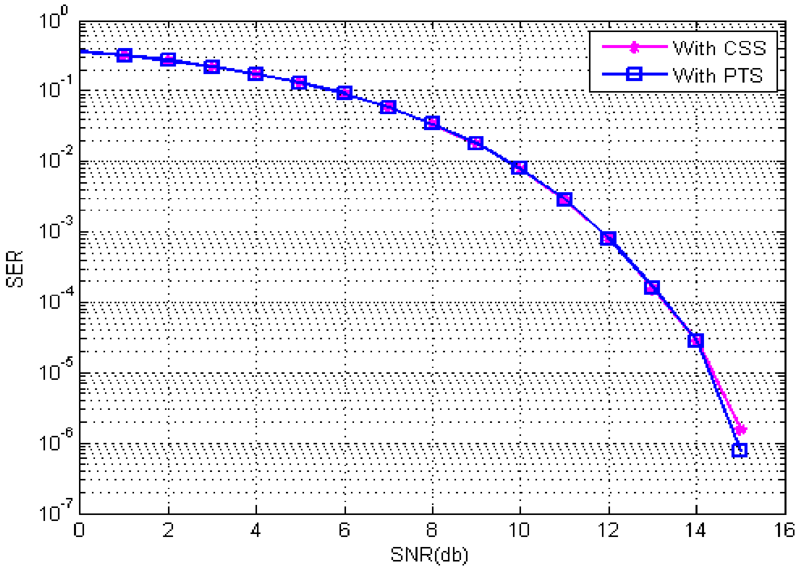

Figure 3.7: Comparison of SER Vs SNR graph for both PTS and CSS

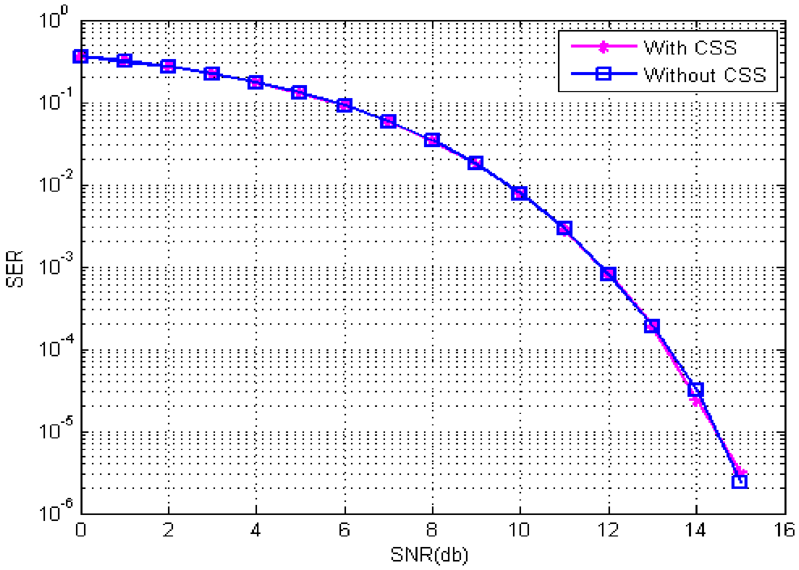

Figure 3.8: Comparison of SER Vs SNR graph for both CSS and without CSS

4

Application to MIMO-OFDM

In wireless communication, deep fade occurs because the signals from different paths add up randomly in amplitude and phase. This causes at sometimes it is constructive, and sometimes it is destructive. This destructive interference causes deep fade in wireless communication system. When the system is in deep fade, the probability of bit error rate is very high. This causes the performance of the wireless communication system is very weak. The fundamental technique to improve the performance of wireless communication is “diversity”.

If at the receiver side multiple antennas and at the transmitter side single antenna used, then it is called as receiver diversity or Single Input Multiple Output (SIMO) system. If at the transmitter side multiple antennas and at the receiver side single antenna is used then it is called as transmitter diversity or Multiple Input Single Output (MISO) system [17]. These two type of systems increases the diversity of the system. But if we use multiple antennas on both the sides that is at the transmitter and receiver sides then it is called as Multiple Input Multiple Output (MIMO) system [18], [19].

4.1 MIMO system model

MIMO communication systems use multiple antennas both at the transmitter and receiver. There are multiple antennas in MIMO system so that it can be employed for "Diversity gain" MIMO can increase the data rate by transmitting several information streams in parallel with the same power [?]. It gives spatial multiplexing because it is multiplexing information in space.

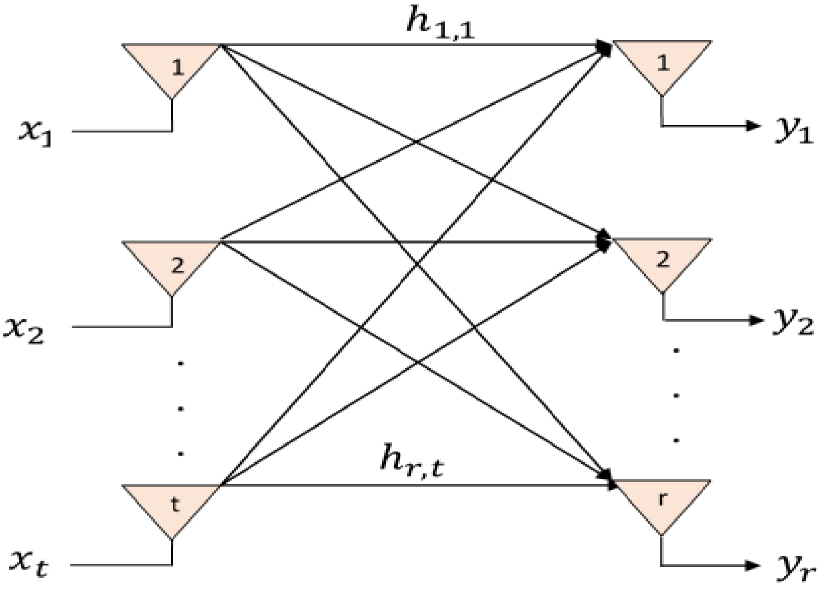

Figure 4.1: MIMO system model

Here it is considered a frequency selective MIMO wireless system with N_t transmit and N_r receive antennas. The data symbols that are transmitted are arranged in the vector

$$x = [x_1, x_2, ..., x_t]^T \tag{4.1}$$

The received signal can be expressed as

$$y = [y_1, y_2, ..., y_r]^T \tag{4.2}$$

Now the received signal vector can be written as

$$\bar{y} = H\bar{x} + n \tag{4.3}$$

Where

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1t} \\ h_{21} & h_{22} & \cdots & h_{2t} \\ \vdots & \vdots & \ddots & \vdots \\ h_{r1} & h_{r2} & \cdots & h_{rt} \end{bmatrix}$$

$$H - \text{r}\times\text{t matrix}$$

$$y - \text{r}\times 1 \text{ matrix}$$

$$x - \text{t}\times 1 \text{ matrix}$$

Where H is the channel matrix contains different channel coefficients. an MIMO system with N_t transmit antennas and N_r receive antennas utilizes a channel with N_tN_r separate paths, and the gains for these paths are described using an $N_t \times N_r$ matrix H. the capacity that is maximum throughput of an MIMO channel dependent on the characteristics of its transmission matrix H, in particular, its singular values. MIMO systems operate by transmitting multiple signals in the same frequency band at the same time over multiple transmit antennas.

4.2 SVD for MIMO

At the receiver, we are going to get interference from all the transmit antennas along with the noise from the channel. SVD Converts the MIMO channel into a parallel channel and at the receiver it Improves the communication quality. The singular value decomposition of MIMO channel can be expressed as the [20]

$$H = U\Sigma V^H \tag{4.4}$$

Where U and V are two unitary matrices.
The columns of U matrix are orthonormal that is

$$\|u_i\|^2 = 1, \quad u_i^H u_j = 0 \;\; if \;\; i \neq j$$

Similarly the rows of matrix V are orthonormal that is

$$\|v_i\|^2 = 1, \quad v_i^H v_j = 0 \;\; if \;\; i \neq j$$

And V is a unitary matrix

$$V^H V = V V^H = I$$

Σ is a diagonal matrix contains singular values which are real and non-negative.

$$\sigma_1, \sigma_2, ..., \sigma_t \geq 0$$

$$\sigma_1 \geq \sigma_2 \geq ...... \geq \sigma_t \geq 0$$

4.2.1 Multi-stream MIMO

Here we are going to apply SVD for MIMO to convert MIMO channel into a parallel channel [20]. Now to decode the information at the receiver it needs to perform precoding at the transmitter end. This can be shown in the below figure. Without using precoding and SVD the received signal can be given as

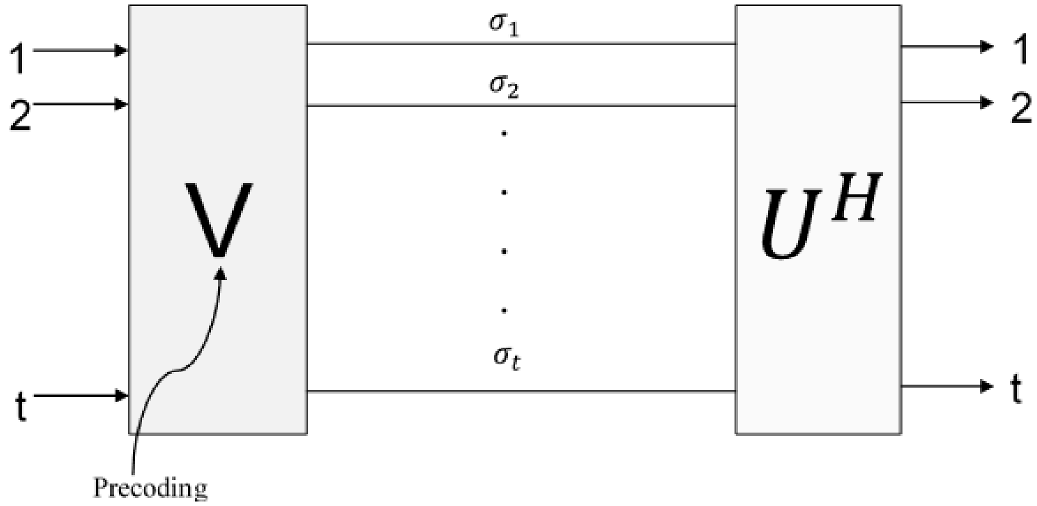

Figure 4.2: Multi-stream MIMO

$$\bar{y} = H\bar{x} + n$$

Now after using precoding at the transmitter and the SVD for the channel the received signal can be expressed as the [20]

$$\bar{y} = \Sigma\bar{x} + n \tag{4.5}$$

Where Σ is a diagonal matrix contains t singular values. So it is expressed as t parallel streams. By using SVD it is possible to transmit t parallel information streams in the same frequency at the same time. So it is called as "Spatial multiplexing".

4.2.2 Drawbacks

1. **Need of H at the transmitter**
   In multi-stream MIMO, precoding is required at the transmitter side. For precoding, channel information is required at the transmitter side. It is difficult to estimate the channel information at the transmitter side if the channel is time-varying.

2. **Decrease in throughput**
   The channel information that is estimated at the receiver side needs to send back to the transmitter. This can decrease the data rate of the system and it intern causes the decrease in throughput.

4.3 Precoding

In multi-stream MIMO at the transmitter it is considered to have perfect channel knowledge (CSI), which is obtained by means of a feedback channel in Frequency Division Duplexing (FDD) or, in the case of using Time Division Duplexing (TDD) by assuming reciprocity. The CSI at the receiver is needed for both FDD and TDD that can be obtained by using the channel estimation Techniques [11].

4.3.1 Channel estimation Techniques

There are two types of channel estimation techniques commonly used [21], those are Least Squares (LS) and Minimum Mean Square Estimation (MMSE).

1. **Least squares (LS)**
   The least square channel estimation is given by [22]
   $$\hat{h}_{r,LS} = \left[X^H X\right]^{-1} X^H y_r \tag{4.6}$$
   For non-white Gaussian noise the channel estimation by using this least squares is given by
   $$\hat{h}_{r,LS} = \left[X^H R_{nn}^{-1} X\right]^{-1} X^H R_{nn}^{-1} y_r \tag{4.7}$$
   Where $(.)^{-1}$ and $(.)^H$ denotes the inverse and Hermitian respectively.

2. **Minimum Mean Square Estimation (MMSE)**
   The Minimum Mean Square Estimation (MMSE) channel estimation is given by [11]
   $$\hat{h} = R_{yy}^{-1} R_{yx} \tag{4.8}$$
   Where R_{yy},R_{yx} denotes the auto-correlation and cross- correlation respectively.

Here X is the pilot symbols that is known data need to be transmitted to estimate the channel. Here the optimal pilot symbols can be designed by using Perfect Root-of-Unity Sequences (PRUS). The perfect root-of-unity sequences $X(k)$ of length N can be designed by using Frank-Zadoff-Chu-sequences [11]

$$X(k) = \begin{cases} e^{j\pi \frac{Mk^2}{N}} & forNeven \\ e^{j\pi \frac{Mk(k+1)}{N}} & forNodd \end{cases}, \quad k = 0, 1, ..., N-1 \tag{4.9}$$

Where M is a natural number greater than zero ($M > 0$) and coprime to N. Now after precoding the different streams can be transmitted with different antennas.

4.3.2 Pilot structures

Depending on the arrangement of pilots, three different types of pilot structures considered [12],[23]

1. **Block type**
   The block type pilot arrangement is shown in Figure 4.3 below [12] In this,

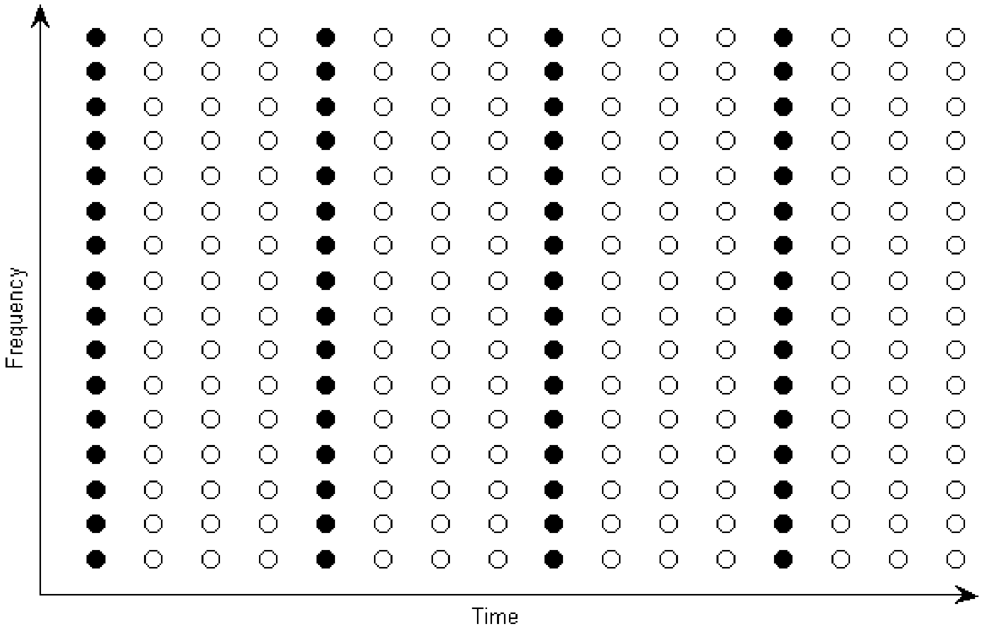

Figure 4.3: Block-type pilot arrangement

pilot symbols are placed on all sub-carriers and at one instant of time as shown in Figure 4.3. These pilot OFDM symbols need to be transmitted periodically. The pilot symbol period need to satisfy the following condition

$$S_t \leq \frac{1}{f_{Doppler}} \tag{4.10}$$

Pilot symbols are placed on all sub-carriers so it is suitable for estimating frequency-selective channels.

2. **Comb type**
The comb type pilot arrangement is shown in Figure 4.4 below [12] In this, pilot symbols are placed at every instant of time on some sub-carriers. The pilot symbols needs to be placed periodically in frequency as shown in Figure 4.4. The pilot symbol period need to satisfy the following condition

$$S_f \leq \frac{1}{\sigma_{max}} \tag{4.11}$$

This arrangement is suitable for fast-fading channels, but not for frequency-selective channels.

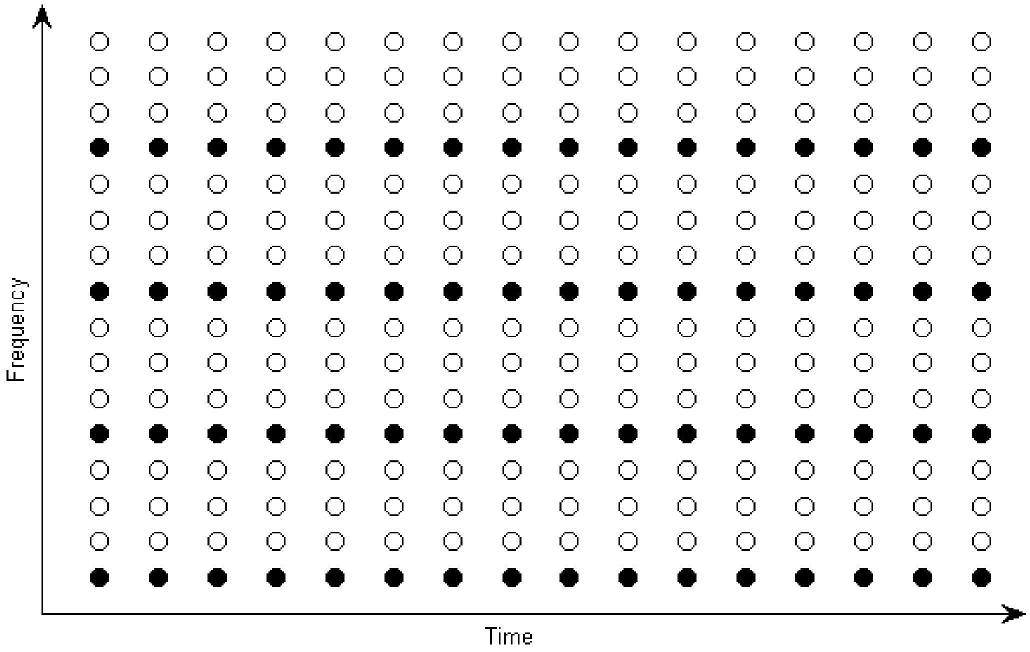

Figure 4.4: Comb-type pilot arrangementt

3. **Lattice type**
   In this pilots are inserted along both time and frequency axes. To track the both time-varying and frequency-selective channels characteristics pilot symbols need to satisfy both the conditions in equation (4.10), equation (4.11).

4.4 PTS for MIMO-OFDM

The block diagram for MIMO-OFDM along with PTS technique is shown in Figure 4.5 [24]

Here in MIMO-OFDM at the transmitter side it uses N_t transmit antennas [13]. At every instant of time we are transmitting $N_s(N_s \leq N_t)$ data streams and each antenna is going to operate with the same set of subcarriers. The PAPR reduction technique is applied individually to each antenna. To increase the capacity of the system Precoding used at the transmitter, for this Channel State Information (CSI) is required at the transmitter [25].

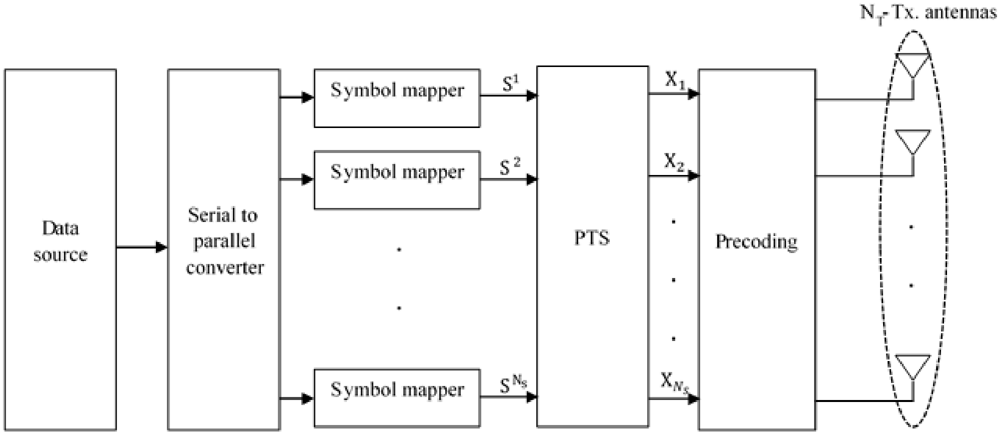

Figure 4.5: MIMO-OFDM with PTS technique

4.5 CSS for MIMO-OFDM

The block diagram for MIMO-OFDM along with CSS technique is shown in Figure 4.6

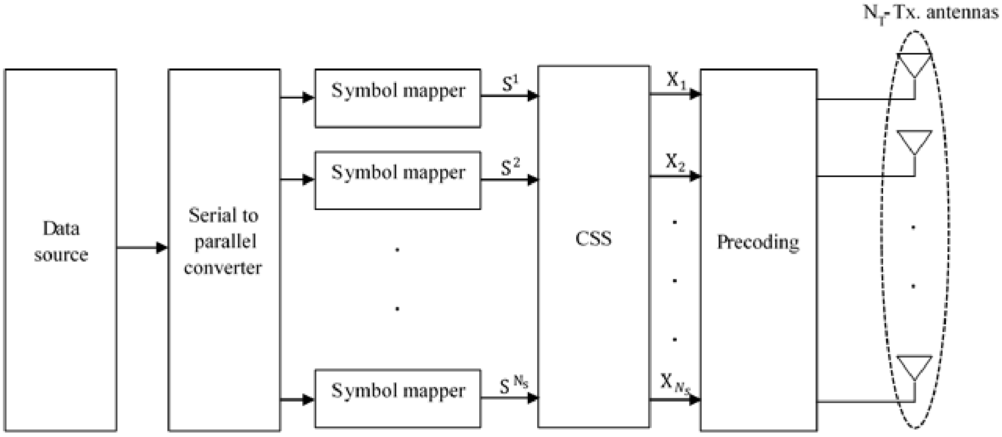

Figure 4.6: MIMO-OFDM with CSS technique

Now here in place of PTS technique we are going to use CSS technique as a PAPR reduction technique. The CSS technique is very useful especially in place of MIMO. In MIMO at each and every antenna it needs to PAPR reduction so, the CSS technique can perform it with very less computational complexity.

4.6 Simulation Results

Simulations performed for adjacent sub-block partitioning which can provide better performance when compared to interleaved and random sub-block partitioning with four (M=4) sub-blocks using QPSK modulation and the phase factors were chosen from $\{\pm 1, \pm j\}$. CCDF curves plotted by taking the PAPR threshold for reference on X-axis and probability that PAPR of our signal exceeds the threshold PAPR on the Y-axis.

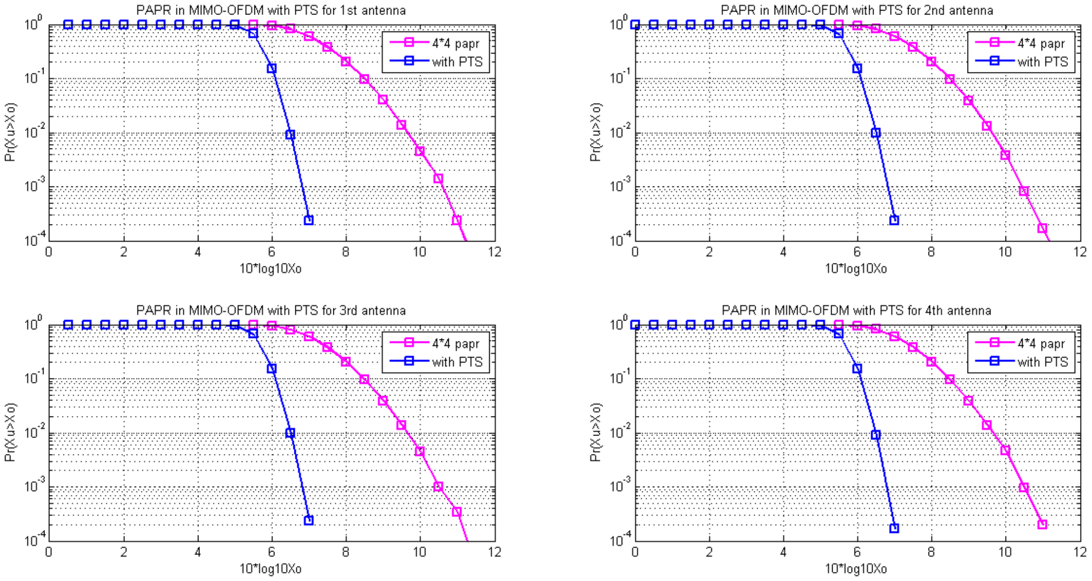

Figure 4.7: Simulation results for PTS

From Figure 4.7 it can be observed that here we taken transmit antennas $N_t = 4$ and each antenna provided with $N = 128$ sub-carriers. For a probability of 10^{-3} it has been observed that the $PAPR = 6.5dB$ by using PTS technique but without using any method for standard OFDM signal we are getting $PAPR = 10.5dB$. This is very high when compared to the use of PTS. So, by using PTS, there is an improvement of around $4dB$.

From Figure 4.7 it is also observed that different CCDF curves for different antennas. This is because of providing different data to different antennas and on this we are applying PAPR reduction technique. Fig.4.7 also shows that for all the four antennas we are getting almost same CCDF curves. This is because all the antennas have same number of sub-carriers and carrying with the random data.

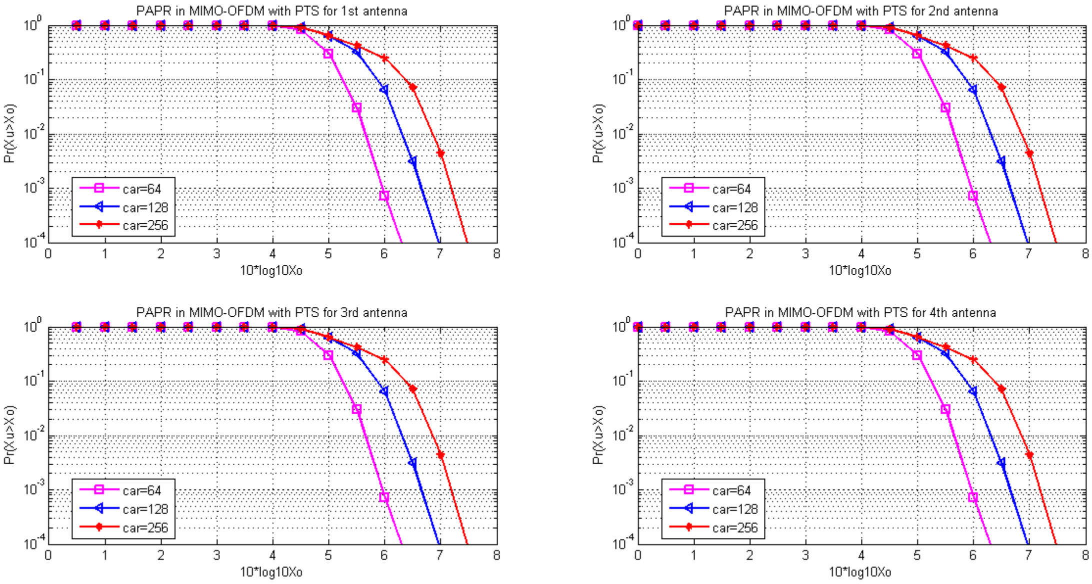

Figure 4.8: Simulation results for PTS with different number of subcarriers.

It is known that as the number of sub-carriers increases the PAPR of the signal is also increases, the same thing can be observed even by using PTS technique in Figure 4.8. Here we are using different number of sub-carriers i.e. $N = 64, 128, 256$, as the number of subcarriers increases the CCDF curve is shifting to the right side, that shows that the PAPR of our signal is going to increase.

Now the performance of CSS technique can be observed along with the PTS technique. In the Figure 4.9, which shows that the CSS technique gives the same performance as PTS technique. But, if we observe the Figure 2.1, Figure 3.1 the CSS technique has more number of IFFT blocks compared to PTS. IFFT blocks needs to perform more number of complex multiplications which increases the complexity of the system along with the time consumption.

Figure 4.10 shows the simulation result for CSS with different sub-carriers $N = 64, 128, 256$, as the number of sub-carriers increases the PAPR is also increasing.

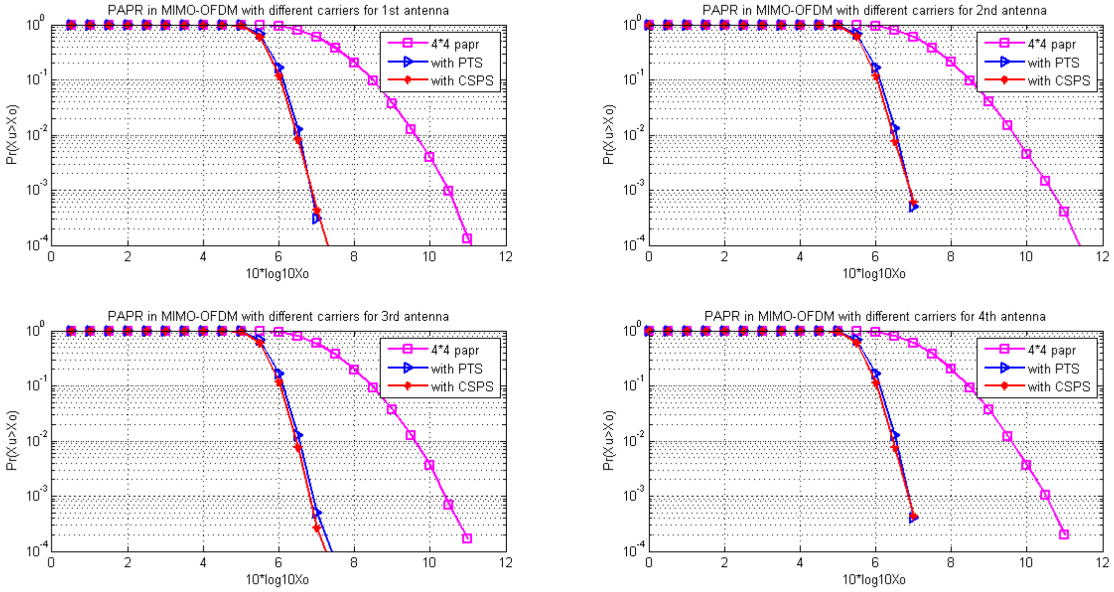

Figure 4.9: Simulation results for CSS and PTS.

For a probability of 10^{-3} the PAPR values for N=128,256 sub-carriers at different antennas are listed in table 4.1

Technique	Antenna-1		Antenna-2		Antenna-3		Antenna-4	
	N=128	N=256	N=128	N=256	N=128	N=256	N=128	N=256
PTS	6.5 dB	7.2 dB	6.5 dB	7.2 dB	6.5 dB	7.2 dB	6.5 dB	7.2 dB
CSS	6.5 dB	7.2 dB	6.5 dB	7.2 dB	6.5 dB	7.2 dB	6.5 dB	7.2 dB

Table 4.1: PAPR analysis at different antennas for a probability of 10^{-3}

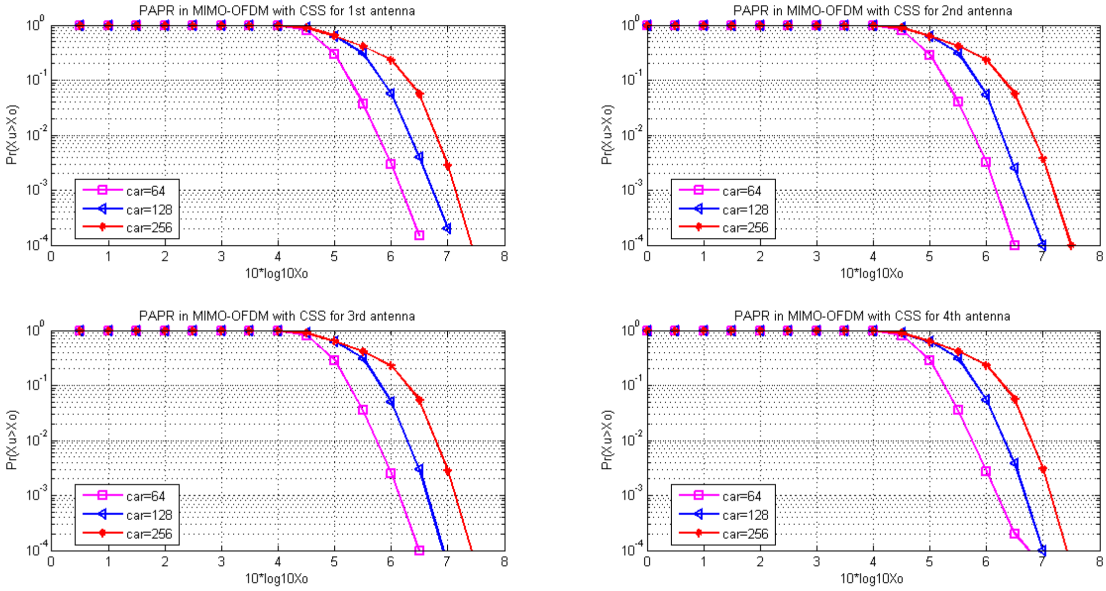

Figure 4.10: Simulation results for CSS with different number of sub-carriers.

5

Conclusion

5.1 Conclusion

The most important technology that is trending in wireless communication is OFDM. There are many standards using OFDM or its variant. Consequently all the frameworks need to face the essential disadvantage of high PAPR brought about in ordinary OFDM. Several techniques have been implemented to reduce the PAPR of the signal to an acceptable limit. PTS is one of the techniques that can perform very good PAPR reduction and with the greater computational complexity. The PTS technique has been simulated and the results are plotted in the form of CCDF curves and these are compared with the standard OFDM signal without any PAPR reduction technique. From the graphs it is envisioned that there is an increment of 4 dB enhancement in PAPR diminishment by using PTS when compared to the PAPR of the OFDM signal without any technique.

In any communication system receiver is required to test the transmitted signal over the channel. The receiver for the PTS technique is designed and it is modelled into a complete communication system by the use of AWGN channel as a signal propagation environment. The Symbol Error Rate (SER) is plotted for different SNR values. The SER vs SNR graph of PTS technique is compared with the original OFDM signal without using any PAPR reduction technique. From this it is observed that both gives the same SER performance.

The Cyclically Shifted Sequences (CSS) technique has been proposed after analysing the PTS technique. This technique utilises only one IFFT block instead of many quantities that are used in PTS technique. This technique is simulated and plotted the CCDF curves to observe its performance. The PAPR reduction of this technique is compared with the PTS technique and also with the standard OFDM signal. From the results is observed that both the techniques gives the same PAPR reduction capability. The complexity of the proposed technique decreases when compared to the PTS technique but it preserves the basic principle of PTS technique. The technique is tested for different number of sub-carriers and from that it is observed that the as number of sub-carriers increases the CCDF curves shifting away from the origin.

The receiver of this CSS technique is designed and the symbol error rate of the system is tested over the AWGN channel. From the results it is observed that both the techniques have same SER performance. This indicates that the new technique doesnt introduce any distortion into the signal.

The CSS technique is applied to the MIMO technology that provides higher data rates along with the diversity of the signal. The Singular Value Decomposition (SVD) is applied to convert the MIMO channel into parallel stream of channels. This reduces the interference of the signal at the receiver. The MIMO-OFDM along with the PAPR reduction techniques are simulated and the corresponding CCDF curves are plotted. The PAPR of the signal at each antenna has been analysed by using one CCDF curve for each antenna. From this it is observed that it gives same performance as SISO communication in terms of PAPR reduction.

5.2 Limitations of work

- The number of candidate signals considered are very large to reduce the Peak-to-average power ration of the OFDM signal.
- The Frequency Division Duplex (FDD) channel is not considered to send back the channel infromation from receiver to the transmitter.
- The Bit Error Rate performance of MIMO-OFDM by using PAPR reduction technique is not done in Rayleigh fading channel.

5.3 Future work

The number of candidates of the signal should be reduced to further reduce the complexity of the system. This can also reduce the time to process the signal. The analysis of avoiding side information that is required to decode the information from the signal at the receiver need to be done.

The spectrum of the signal with and without PAPR reduction techniques need to observed. The effect of frequency offset on the specturum of the signal and also the Bit Error Rate performance due to this frequency offset need to be observed.

Bibliography

[1] H. Liu and G. Li, *"OFDM-based broadband wireless networks: design and optimization"*. John Wiley & Sons, chap 1 ,pp 1-8, 2005.

[2] W. Shieh and I. Djordjevic, *"OFDM for optical communications"*. Academic Press, chap 2 ,pp 31-44, 2009.

[3] H. Schulze and C. Lüders, *"Theory and applications of OFDM and CDMA: Wideband wireless communications"*. John Wiley & Sons, chap 4 ,pp 145-160, 2005.

[4] S. H. Han and J. H. Lee, "An overview of peak-to-average power ratio reduction techniques for multicarrier transmission," *Wireless Communications, IEEE*, vol. 12, no. 2, pp. 56–65, 2005.

[5] V. Sudha and D. Sriram Kumar, "Papr reduction of ofdm system using pts method with different modulation techniques," in *International Conference on Electronics and Communication Systems (ICECS).* pp. 1-5, IEEE, 2014.

[6] J. Shukla, A. Joshi, R. Bansal, and R. Tyagi, "Papr reduction of ofdm systems using pts with genetic algorithm at low computational complexity," in *Recent Advances and Innovations in Engineering (ICRAIE), 2014.* pp. 1-6, IEEE, 2014.

[7] Y. Rahmatallah and S. Mohan, "Peak-to-average power ratio reduction in

ofdm systems: A survey and taxonomy," *Communications Surveys & Tutorials, IEEE*, vol. 15, no. 4, pp. 1567–1592, 2013.

[8] X. Gu, S. Baek, and S. Park, "Papr reduction of ofdm signal using an efficient slm technique," in *The 12th International Conference on Advanced Communication Technology (ICACT)*, vol. 1. pp. 324-328, IEEE, 2010.

[9] P. Mukunthan and P. Dananjayan, "Papr reduction based on a modified pts with interleaving and pulse shaping method for stbc mimo-ofdm system," in *Third International Conference on Computing Communication & Networking Technologies (ICCCNT).* IEEE, July 2012.

[10] S. G. Kang, J. G. Kim, and E. K. Joo, "A novel subblock partition scheme for partial transmit sequence ofdm," *IEEE Transactions on Broadcasting*, vol. 45, no. 3, pp. 333–338, 1999.

[11] O. Weikert and U. Zölzer, "Efficient mimo channel estimation with optimal training sequences," in *Proc. of the Workshop on Commercial MIMO-Components and Systems (CMCS 2007)*, 2007.

[12] C. Yin, J. Li, X. Hou, and G. Yue, "Pilot aided ls channel estimation in mimo-ofdm systems," in *8th International Conference on Signal Processing*, vol. 3. IEEE, 2006.

[13] Y. Li, M. Gao, and Z. Yi, "A cooperative and alternate pts scheme for papr reduction in stbc mimo-ofdm system," in *14th International Conference on Communication Technology (ICCT).* IEEE, 2012.

[14] Y. Xiao, X. Lei, Q. Wen, and S. Li, "A class of low complexity pts techniques for papr reduction in ofdm systems," *Signal Processing Letters, IEEE*, vol. 14, no. 10, pp. 680–683, 2007.

[15] Y. Inoue, H. Tsutsui, and Y. Miyanaga, "Study of papr reduction using coded pts in 8× 8 mimo-ofdm systems," in *International Symposium on Intelligent Signal Processing and Communications Systems (ISPACS).* pp. 363-368, IEEE, 2013.

[16] E. Kalaiselvan, P. Elavarasan, and G. Nagarajan, “Papr reduction of ofdm signals using pseudo random pts without side information,” in *International Conference on Communications and Signal Processing (ICCSP).* pp. 29-33, IEEE, 2013.

[17] G. Priya and B. Senthil, “An efficient scheme for papr reduction in alamouti mimo-ofdm systems,” in *International Conference on Information Communication and Embedded Systems (ICICES).* pp. 1-5, IEEE, 2014.

[18] F. S. AL-Qahtani, “Mimo techniques for higher data rate wireless communications,” Ph.D. dissertation, Faculty of Engineering, RMIT University Melbourne, 2009.

[19] X. Yan, W. Chunli, and W. Qi, “Research of peak-to-average power ratio reduction improved algorithm for mimo-ofdm system,” in *WRI World Congress on Computer Science and Information Engineering*, vol. 1. pp. 171-175, IEEE, 2009.

[20] H. Zamiri-Jafarian and M. Rajabzadeh, “A polynomial matrix svd approach for time domain broadband beamforming in mimo-ofdm systems,” in *Vehicular Technology Conference, VTC Spring.* IEEE, 2008.

[21] M.-J. Vincent Hogue, A. O. Dahmane, S. Moussa, and C. D’Amours, “Rapid prototyping of channel estimation techniques in mimo-ofdm systems,” in *Wireless and Mobile Networking Conference (WMNC), 2013 6th Joint IFIP.* pp. 1-4, IEEE, 2013.

[22] L. Xin, L. Yunting, X. Jun, and L. Guangming, “Least square channel estimation for mimo-ofdm system,” in *Wireless Communications, Networking and Mobile Computing, 5th International Conference on WiCom’09.* IEEE, 2009.

[23] K. P. Bagadi and S. Das, “Mimo-ofdm channel estimation using pilot carries,” *International Journal of computer applications*, vol. 2, no. 3, 2010.

[24] S. S. Hassaneen, H. Y. Soliman, K. A. Elbarbary, and A. E. Elhennawy, “Modified pts with circular shifting for papr reduction in mimo ofdm sys-

tems," in *Japan-Egypt International Conference on Electronics, Communications and Computers (JEC-ECC).* pp. 1-6, IEEE, 2013.

[25] H. Tiwari, R. Roshan, and R. K. Singh, "Papr reduction in mimo-ofdm using combined methodology of selected mapping (slm) and partial transmit sequence (pts)," in *9th International Conference on Industrial and Information Systems (ICIIS).* pp. 1-5, IEEE, 2014.