PARTIAL TRANSMIT SEQUENCE BASED LOW COMPLEXITY RECEIVER FOR MULTI-USER STBC MC-CDMA SYSTEM

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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May 2014

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Under the Guidance of
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Dedicated to…,

My parents and my elder brother.

DEPT. OF ELECTRONICS AND COMMUNICATION ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA
ROURKELA – 769008, ODISHA, INDIA

Certificate

This is to certify that the work in the thesis entitled **Partial Transmit Sequence based low complexity receiver for multi-user STBC MC-CDMA system** by S**adananda Behera** is a record of an original research work carried out by him during 2013 - 2014 under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Master of Technology in Electronics and Communication Engineering (Communication and Networks), National Institute of Technology, Rourkela. Neither this thesis nor any part of it, to the best of my knowledge, has been submitted for any degree or diploma elsewhere.

Place: NIT Rourkela
Date: 25th May 2014

Dr. Sarat Kumar Patra
Professor

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ROURKELA – 769008, ODISHA, INDIA

Declaration

I certify that

a) The work contained in the thesis is original and has been done by myself under the general supervision of my supervisor.

b) The work has not been submitted to any other Institute for any degree or diploma.

c) I have followed the guidelines provided by the Institute in writing the thesis.

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Sadananda Behera

25th May 2014

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potential and without whom I would have never been able to achieve whatsoever I could have till date.

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ABSTRACT

Space Time Block Code Multi Carrier Code Division Multiple Access (STBC MC-CDMA) is a promising technology for 4G wireless communication systems. STBC is a special form of Multiple Input Multiple Output (MIMO) originally employed for 2 transmit antennas (N_t) and 1 receive antenna (N_r) by Alamouti under flat fading conditions. So application of STBC to frequency selective channel is challenging and has attracted attention of many researchers. Hence, STBC is integrated with multicarrier techniques such as Orthogonal Frequency Division Multiplexing (OFDM) and Multi Carrier Code Division Multiple Access (MC-CDMA), which convert frequency selective channel to several flat fading channels thereby eliminating ISI and in turn need of equalization. Like all other multicarrier techniques STBC MC-CDMA also suffers from high Peak-to-Average Power (PAPR) problem. To combat the problem of high PAPR, many techniques have been proposed, among which Partial Transmit Sequence (PTS) is considered to be the best PAPR reduction scheme but at a cost of high computational complexity. This dissertation mainly focusses on implementation of PTS technique to STBC MC-CDMA scheme for downlink scenario. Also, a low complexity receiver is designed for the above scheme where the equalization is carried out in time domain basis. Also the proposed STBC MC-CDMA with PTS scheme is compared with Single Input Single Output (SISO) MC-CDMA with PTS scheme in terms of Complementary Cumulative Distribution Function (CCDF) and Bit Error Rate (BER) performance. The simulation results verify that STBC MC-CDMA outperforms SISO MC-CDMA under fading conditions. Also as the no of users increase, CCDF performance improves and BER performance degrades.

CONTENTS

NOMENCLATURE

X : Data symbol vector

x_i : Time domain sample of i^{th} index

X_K : Frequency domain sample of k^{th} index

σ_x^2 : Variance of data vector X

$F(z)$: Cumulative Distribution Function

z : Preset threshold

d^K : Data symbol for K^{th} user

C : Spreading matrix

$c^{(k)}$: Chips of the spreading code

S/P : Serial to Parallel Converter

P/S : Parallel to Serial Converter

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

$\boldsymbol{x}_m$: m^{th} PTS

$b^{(m)}$: Phase factor for the m^{th} PTS

X_1 : Data transmitted from 1^{st} antenna at first time interval

X_2 : Data transmitted from 2^{nd} antenna at first time interval

X_1^* : Data transmitted from 2^{nd} antenna at second time interval

$-X_2^*$: Data transmitted from 1^{st} antenna at second time interval

H : MIMO channel matrix

h : Rayleigh channel fading coefficients

I_F : IFFT matrix

$\hat{X}$: Estimated data symbol

$(\,.\,)^H$: Hermitian operation

$(\,.\,)^T$: Transpose operation

$\hat{a}_{opt}$: Optimum phase factor combination for minimum PAPR for 1st interval and 1st antenna

$\hat{b}_{opt}$: Optimum phase factor combination for minimum PAPR for 2nd interval and 1st antenna

ABBREVIATIONS

ACI : Adjacent Channel Interference

ADC : Analog to Digital Converter

AWGN : Additive White Gaussian Noise

BER : Bit Error Rate

BPSK : Binary Phase Shift Keying

CCDF : Complementary Cumulative Distribution Function

CDF : Cumulative Distribution Function

CDMA : Code Division Multiple Access

CP : Cyclic Prefix

FFT : Fast Fourier Transform

IBO : Input Back-off

IFFT : Inverse Fast Fourier Transform

IM : Inter Modulation

ISI : Inter Symbol Interference

MC-CDMA : Multi Carrier Code Division Multiple Access

MIMO : Multiple Input Multiple Output

OFDM : Orthogonal Frequency Division Multiplexing

PAPR : Peak-to-Average Power Ratio

PTS : Partial Transmit Sequence

SF : Spreading Factor

SISO : Single Input Single Output

SLM : Selective mapping

SNR : Signal-to-Noise Ratio

STBC : Space Time Block Code

W-H : Walsh-Hadamard

ZF : Zero Forcing

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1

AN INTRODUCTION TO MULTICARRIER AND MULTIPLE INPUT MULTIPLE OUTPUT TECHNIQUES

This section deals with the overview of multicarrier techniques and multiple input multiple output schemes.

1.1 Multi carrier techniques

Single carrier systems suffer from heavy Inter Symbol Interference (ISI). ISI occurs when the signal bandwidth is less than the coherence bandwidth or equivalently when the delay spread is greater than the symbol duration. To combat the problem of ISI multicarrier techniques have been proposed. Multicarrier techniques divide the whole bandwidth into large no of narrow band orthogonal subcarriers [1, 2]. Thus the signal bandwidth becomes very less compared to the coherence bandwidth ensuring no ISI in time domain and flat fading in frequency domain. Multicarrier systems such as Orthogonal Frequency Division Multiplexing (OFDM) and Multi Carrier Code Division Multiple Access (MC-CDMA) are considered to be the promising technologies for 4G wireless communication systems [1, 2]. Fig. 1-1 explains the spectrum of multicarrier and single carrier systems. In single carrier system the information symbols are loaded onto one subcarrier whereas in multicarrier system the information symbols are loaded onto multiple no of subcarriers.

Recently, Code Division Multiple Access (CDMA) which is the basis of all 3G wireless communication system is a spread spectrum technique and has gained a lot of attention to support multimedia services in mobile radio communication. On the other hand, OFDM which is a multicarrier technique is considered to be the basis of all 4G wireless communication systems.

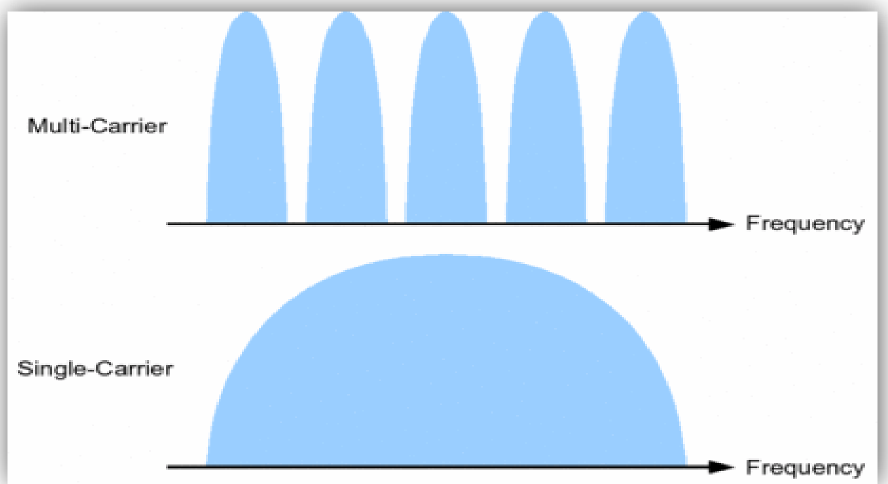

Fig. 1-1 Conventional spectrum of multicarrier and single carrier systems

In 1993, three types of combinations of CDMA to OFDM were proposed [3], such as

- Multi-carrier (MC-) CDMA
- Multi-carrier (MC-) DS-CDMA
- Multi-tone (MT-) CDMA

A brief overview on the above mentioned multicarrier techniques is given below.

1.1.1 MC-CDMA

MC-CDMA spreads the data symbol in frequency direction. The same chip will be transmitted on different subcarriers thus increasing the frequency diversity. MC-CDMA is preferred to be used in downlink. Since downlink is synchronous we don't have to pay attention to the autocorrelation properties of the spreading code. Simple Walsh-Hadamard (W-H) code can be used for spreading which has very good orthogonality property.

1.1.2 MC-DS-CDMA

MC-DS-CDMA spreads the data symbol in time direction after spreading thus increasing the time diversity. MC-DS-CDMA is used in uplink scenario. In uplink Pseudo Noise (PN) code is used since uplink transmission is asynchronous.

1.1.3 MT-CDMA

MT-CDMA scheme is used for longer spreading codes. With longer spreading codes the multiple access interference (MAI) can be minimized in a great manner. MT-CDMA outperforms MC-DS-CDMA but it suffers from inter symbol interference (ISI).

In this dissertation our main focus will be the signal processing aspects associated with MC-CDMA.

1.2 MIMO

The basic parameters that describe the quality of wireless link include Speed, Range and Reliability. There is always a trade-off to achieve all three qualities. But an attractive candidate in this regard is multiple input multiple output (MIMO) [4] system which can boost all of the above compared to single antenna system. MIMO exploits multipath rather than mitigate it.

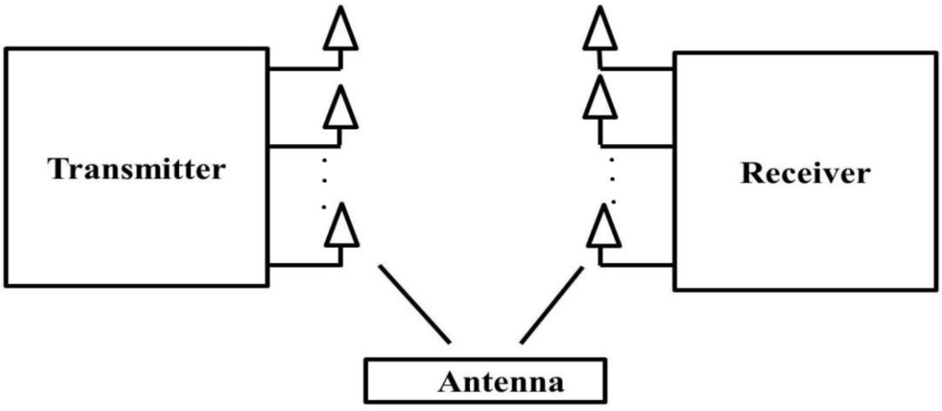

Fig. 1-2 Basic block diagram of MIMO system

Space Time Block Code (STBC) [5] is a special form of MIMO and originally employed for 2 transmit and 1 receive antenna by Alamouti under flat fading conditions. Application of this scheme to frequency selective channel is challenging and has attracted attention of many researchers. Hence, MIMO integrated with multi-carrier techniques such as Orthogonal Frequency Division Multiplexing (OFDM) and Multi-carrier Code Division Multiple Access (MC-CDMA) convert frequency selective channel to several flat fading channels there by eliminating ISI [1, 2].

The serious drawback associated with multicarrier techniques is high Peak-to-Average Power Ratio (PAPR). This high PAPR acts as a bottleneck for multicarrier techniques and limits its applications. So PAPR must be reduced at any cost. This thesis is based on implementation of different PAPR reduction techniques with STBC MC-CDMA scheme.

1.3 Motivation

The growing demand for high speed and reliable communication system has led to the integration of multicarrier techniques and multiple input multiple output (MIMO) techniques. Space Time Block Code (STBC) which is a special form of MIMO is originally developed for flat fading channels only. So application of this to the frequency selective channel is an area of concern. On the other hand, multicarrier techniques such as OFDM and MC-CDMA when integrated with STBC can overcome this problem. The multicarrier techniques convert frequency selective channel to several flat fading channels and then the STBC can be implemented with the flat fading channels. So the MC-CDMA integrated with STBC i.e. (STBC MC-CDMA) can achieve high speed internet connectivity, crystal clear voice conversation, online gaming etc. But the problem associated with all multicarrier techniques is high Peak-to-Average Ratio (PAPR) which is also a drawback for STBC MC-CDMA. PAPR affects efficiency of power amplifiers, increased cost of transceivers. So for this, PAPR must be reduced. Many techniques have been proposed, out of which Partial Transmit Sequence (PTS) has been the best for its PAPR reduction capability. To design a complete low complexity communication system with reduced PAPR and improve Bit Error Rate (BER) performance system has been the motivation of this dissertation.

1.4 Objective

The objective of this work is to study different multicarrier techniques such as OFDM and MC-CDMA and STBC codes. Then integration of both the techniques to enhance the speed, range and reliability of the wireless communication link is studied. The main disadvantage associated with the multicarrier techniques is Peak-to-Average Power Ratio (PAPR). To reduce the high PAPR many techniques have been proposed of which Partial Transmit Sequence (PTS) is implemented in this dissertation. The main objective of this dissertation can be summarized as follows:

- Apply PTS technique to STBC MC-CDMA for PAPR reduction.
- Also the focus is on designing a low complexity receiver for the above scheme where both the encoders and decoders are in time domain. So the equalization is carried out in time domain basis which is relatively easier than frequency domain equalization.
- Using transmit diversity the Bit Error Rate (BER) performance is improved. So the primary objective in this whole dissertation is to design a low complexity complete communication system.

1.5 Thesis Organization

This thesis is organised into five chapters. The current chapter describes recent trends in STBC MC-CDMA and the implementation aspects associated with this such as high PAPR.

Chapter 2: Chapter 2 describes introduction to multicarrier techniques such as MC-CDMA and its signal processing aspects.

Chapter 3: Space Time Block Code is explained in Chapter 3. This chapter also deals with integration of STBC with MC-CDMA. The transceiver model of the STBC MC-CDMA is also described.

Chapter 4: This chapter concentrates on the drawbacks of the multicarrier techniques such as PAPR. Also different PAPR techniques have been compared in this chapter.

Chapter 5: Chapter 5 discusses Partial Transmit sequence (PTS) technique for PAPR reduction in single input single output (SISO) system. Also it focuses on the implementation of low complexity PTS technique to STBC MC-CDMA system and designing an efficient receiver for the above scheme.

Chapter 6: This chapter presents the concluding remarks and future scopes of this work.

2

AN INTRODUCTION TO MULTICARRIER TECHNIQUES: MC-CDMA

Since MC-CDMA is a combination of CDMA and OFDM it takes advantage of both the schemes and inevitably has the same drawbacks [2]. OFDM converts frequency selective channel to several flat fading channels thus eliminating ISI and CDMA spreads the data by using orthogonal codes and reduces self-interference. MC-CDMA spreads the data with a particular spreading code in frequency direction thus increasing frequency diversity whereas MC-DS-CDMA spreads the data in time direction and MT-CDMA uses very high spreading factor [3]. This dissertation mainly focusses on signal processing aspects of downlink multiuser MC-CDMA. Since the downlink (from Base Transceiver Station (BTS) to Mobile Station (MS)) is considered to be synchronous, orthogonal codes can be used for spreading since they reduce multiple access interference. Walsh-Hadamard (W-H) code [2] is used for spreading since they are easy to generate and they have very good orthogonality property.

2.1 MC-CDMA Transceiver

It has already been mentioned that MC-CDMA is a combination of OFDM and CDMA. So the transmitter and receiver block diagram of MC-CDMA will contain the transmitter and receiver of OFDM and CDMA individually. MC-CDMA transmitter and receiver block diagrams are given below.

2.1.1 MC-CDMA Transmitter

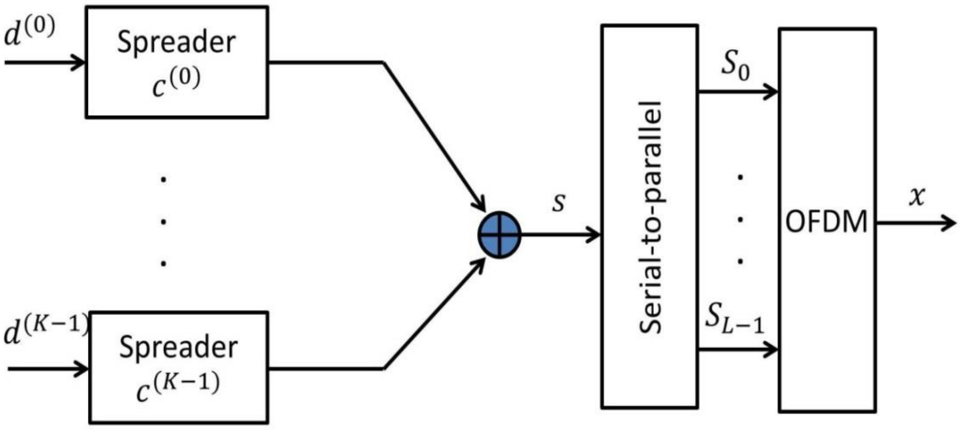

Fig. 2-1MC-CDMA downlink transmitter

From the above figure we can write that

$$s = \sum_{k=0}^{K-1} s^{(k)} = \left(S_{0,}\, S_1, \dots\, S_{L-1}\right)^T \tag{2.1}$$

Equivalently, for downlink we can write

$$s = Cd \tag{2.2}$$

$$C = (c^0, c^1, \dots, c^{K-1}) \tag{2.3}$$

where K= no of active users

c^K = chips of the spreading code

C = spreading matrix

$d = (d^0, d^1, \dots, d^{K-1})^T$ is complex baseband signal of K users

All the user data are spreaded by W-H code and are summed up to produce CDMA signal. Hence, *s* in above figure is essentially CDMA signal. After this OFDM modulation operation is carried out and transmitted through channel.

2.1.2 MC-CDMA Receiver

In the receiver section, first inverse OFDM operation is carried out on the received signal r followed by simple equalization. Then the user data are despreaded by using the same spreading code that was used for spreading at the transmitter side to get back the user information bits.

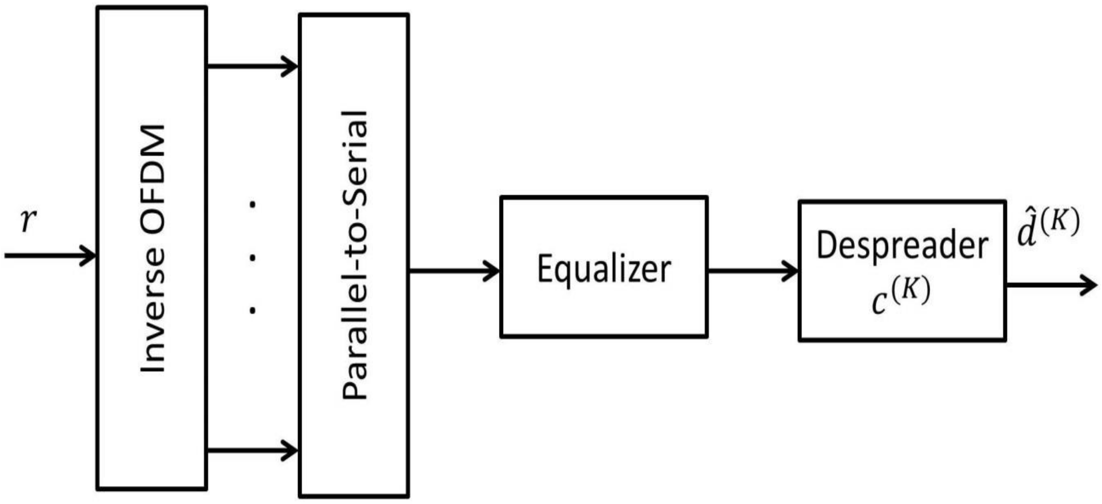

Fig. 2-2 MC-CDMA downlink receiver

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2.2 Insight to MC-CDMA

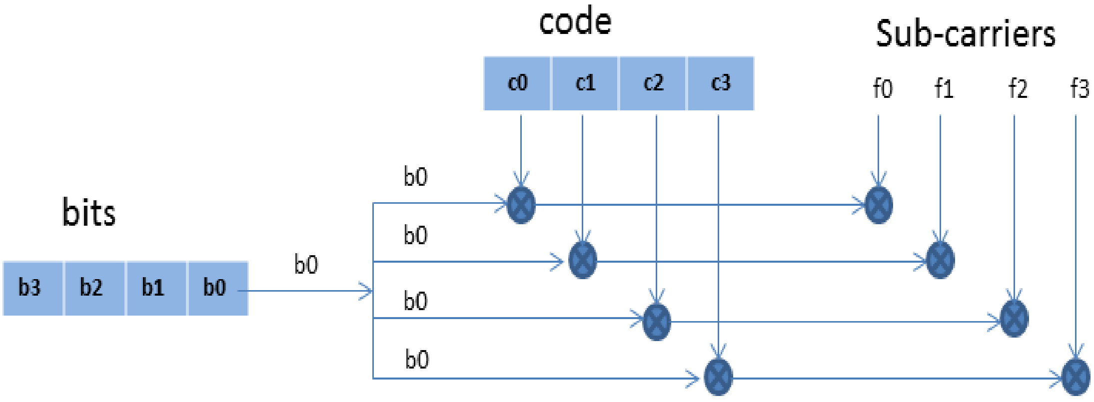


Fig. 2-3 MC-CDMA for a single user for one bit transmission at a time

Here, we can observe that all the bits of a single user are spreaded by a spreading code and transmitted on different sub-carriers. One thing to notice here is that no of sub-carriers have to be taken equal to the spreading factor (SF).

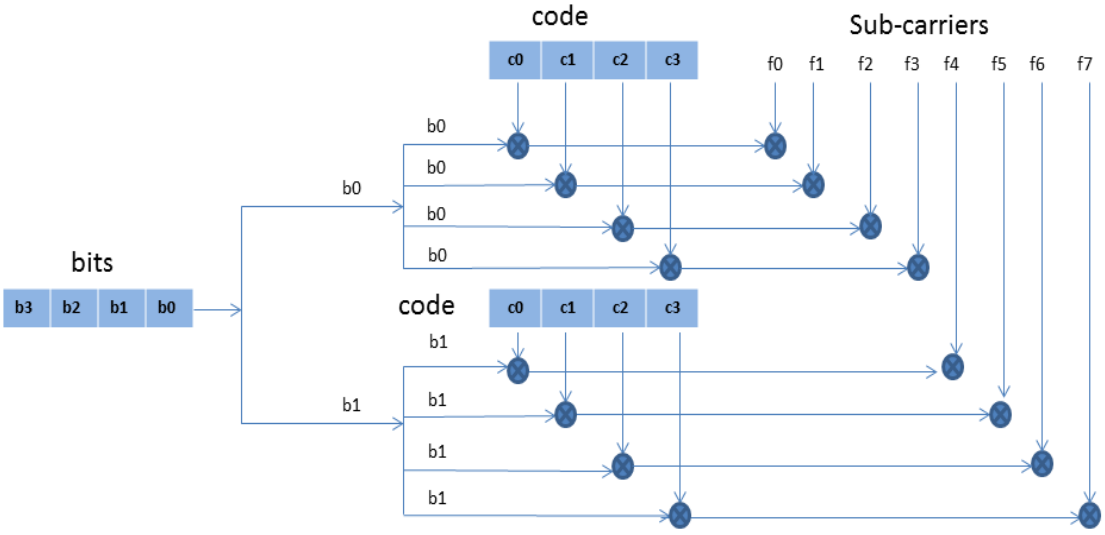


Fig. 2-4 MC-CDMA for a single user for two bit transmission at a time

The disadvantage of previous scheme is that we have to take no of sub-carriers equal to the spreading factor which is not practically feasible for large no of sub-carriers. In this scheme, two bits are transmitted at a time keeping SF same and no of sub-carriers has been doubled. So this system provides a flexible system design such that number of sub-carriers need not be taken equal to the SF [2, 3].

2.3 Results and Discussion

Fig. 2-5 represents the BER plot for 2, 4 and 8 users for AWGN channel. Here, the processing gain (PG) is taken equal to the no of subcarriers (N) i.e. 8. From the graph it is clear that as the no of users increase the BER performance degrades because the no users contribute more interference and maintaining orthogonality between them becomes a difficult task. All simulations are carried out for BPSK modulation and BER graphs are plotted using Monte-Carlo simulation.

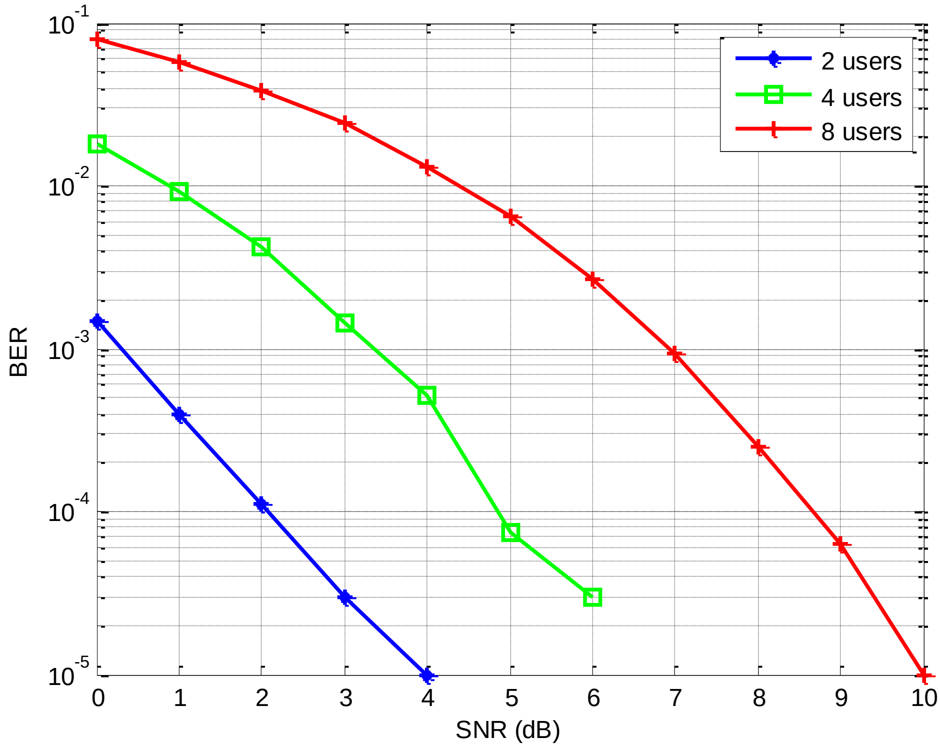


Fig. 2-5 BER plot for MC-CDMA (PG=8, N=8) for AWGN channel

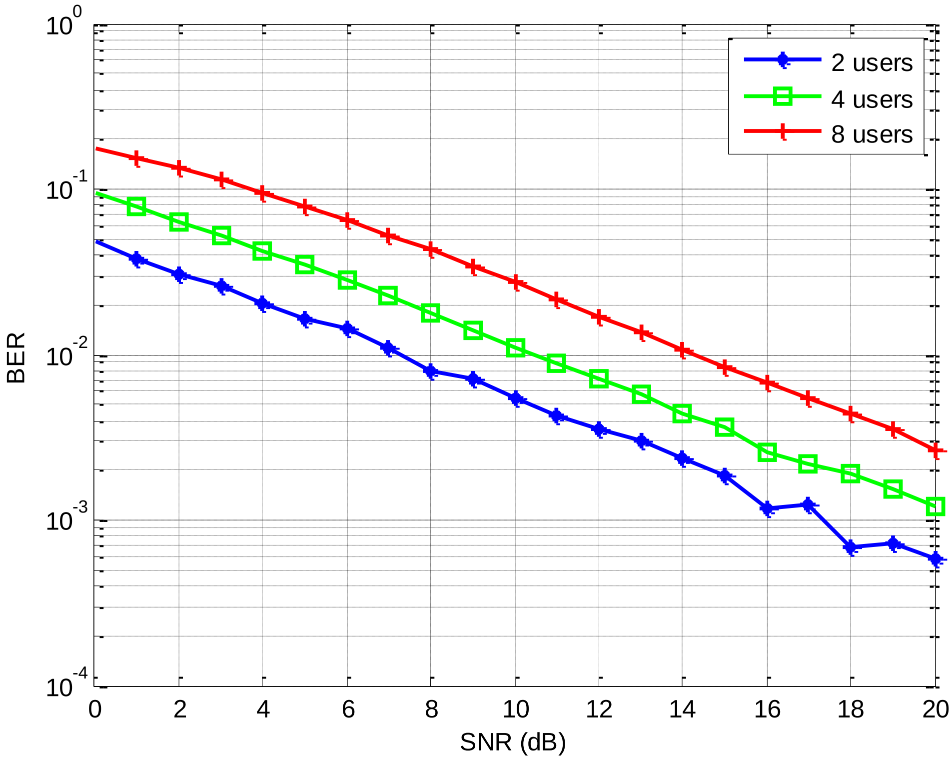


Fig. 2-6 BER plot for MC-CDMA (PG=8, N=8) for Rayleigh channel

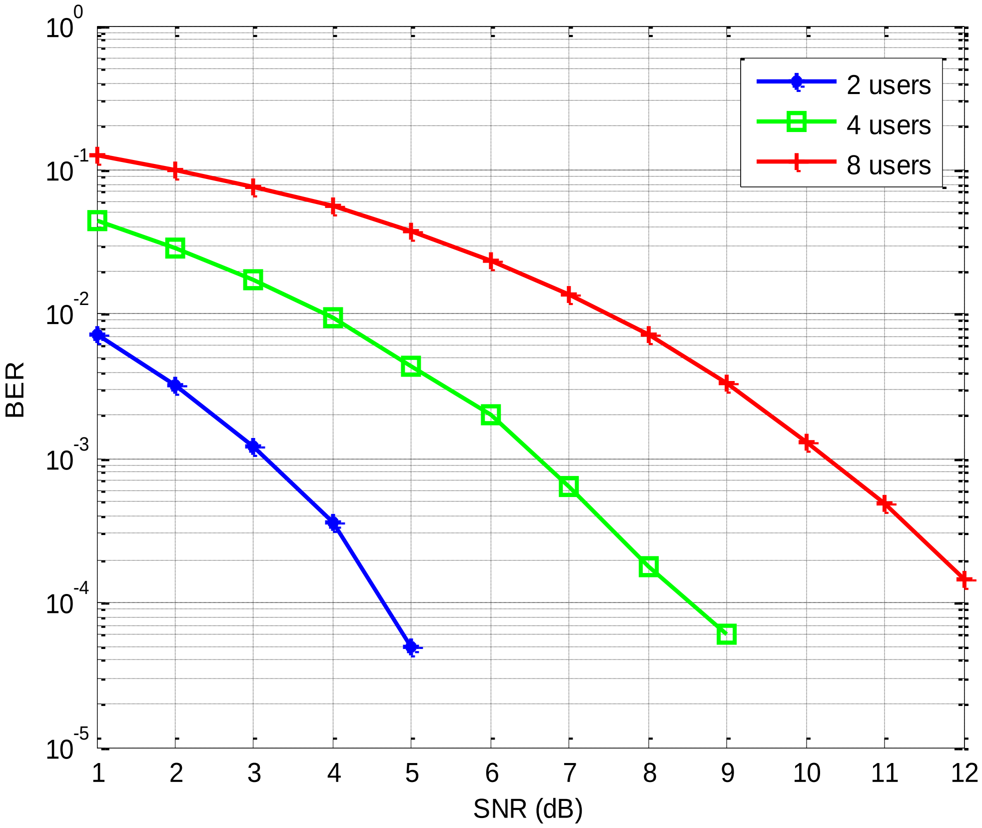


Fig. 2-7 BER plot for MC-CDMA using zero forcing equalization

Fig. 2-6 shows the BER plot for multiple users for Rayleigh channel. Here, the channel is considered to be flat fading channel. From both the figures we can conclude that as the no of users increase the BER performance degrades.

Fig. 2-7 presents the BER plot for MC-CDMA using zero forcing equalization.

2.4 Advantages of MC-CDMA

- ***High spectral efficiency***: Since MC-CDMA is a superposition of large no of overlapping sub-carriers, it provides high spectral efficiency.
- ***Robustness to channel fading***: MC-CDMA converts frequency selective channel to flat fading channels thus eliminating Inter Symbol Interference (ISI).
- ***Flexible system design***: Since no of sub-carriers need not be taken equal to the SF, MC-CDMA offers a flexible system design.

- ***Easy Equalization***: Since ISI is eliminated, equalization is almost not required.
- ***High frequency diversity***: Since MC-CDMA spreads the signal in frequency direction it achieves high frequency diversity.
- ***Fading resistance***: Since it has high frequency diversity it is resistant to fading.

2.5 Disadvantages of MC-CDMA

- ***High PAPR***: Since it is a combination of large no of independent sub-carriers it exhibits a very high PAPR.
- ***Synchronous transmission***: Maintaining synchronization is a difficult task in MC-CDMA as the no of users increase.

2.6 Applications of MC-CDMA

MC-CDMA has a wide variety of applications in wireless communications. MC-CDMA is used in multimedia services of 4G wireless communication system in air interface for downlink scenario. It is a suitable modulation technique for indoor environments with small delay spread and small Doppler spread. MC-CDMA transmission with a low complexity iterative receiver is proposed for the PLC (power line communication) channel.

3

SPACE TIME BLOCK CODES: A SPECIAL FORM OF MIMO

Multiple Input Multiple Output (MIMO) [4] systems can be termed as the extension of smart antennas. Smart antennas have multiple antennas at the transmitter or at the receivers but not at the both. MIMO has multiple antennas at the transmitter and receiver. This doesn’t mean that we have multiple transmitters and receivers. It simply means that we have one transmitter and one receiver which are mounted with multiple antennas.

3.1 Functions of MIMO

MIMO can have different functions depending on its applications. MIMO can be employed for diversity gain by transmitting same information on different antennas or can be employed for capacity gain by transmitting information in parallel stream at the same size.

3.1.1 Diversity

Diversity is a modulation technique which ensures that there is at least more than one transmission path from the transmitter to the receiver. As there are multiple antennas, MIMO system can be employed for diversity gain. MIMO transmits the same information signal on different antennas thus increasing the reliability of the communication link since it is less probable that all the paths will be affected by same amount.

3.1.2 Spatial Multiplexing (SM)

Also MIMO can increase the data rate by transmitting several information streams in parallel at same transmit power. This is known as spatial multiplexing which is otherwise known as multiplexing parallel information streams in space. In SM spectrum utilization remains same. So data rate is very high. MIMO effectively takes advantage of multipath for multiplying transfer rates.

3.1.3 Beamforming

Beamforming also known as spatial filtering is used for directional signal transmission. In Beamforming, the average SNR is increased by focusing the energy in particular direction. Beamforming can be used both at the transmitter and at the receiver to improve spatial selectivity.

3.2 Space Time Block Code (STBC)

STBC is a special form of MIMO and is originally employed for 2 transmit antennas and 1 receiving antenna by Alamouti [5, 6]. Later it was generalized for any no of antennas. It achieves a diversity order of 2 without Channel State Information (CSI) at the transmitter and without bandwidth expansion.

3.2.1 STBC Encoding Scheme

The STBC encoding scheme is depicted in the following figure where there are 2 transmit antennas and 1 receive antenna and the channel coefficients are Rayleigh flat fading coefficients.

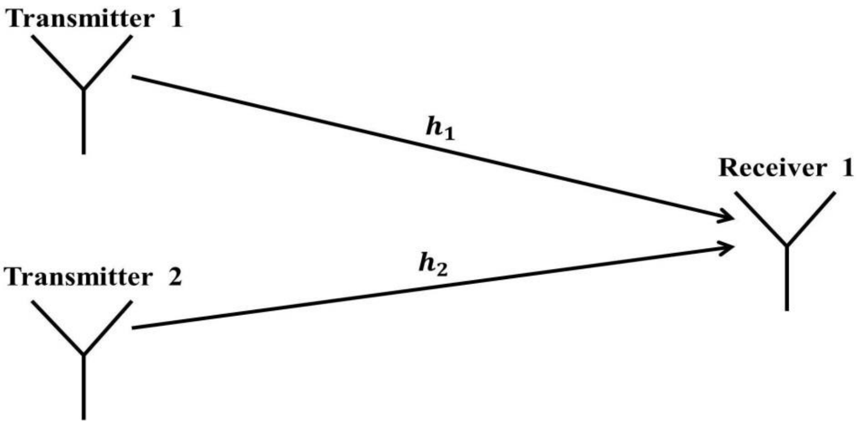


Fig. 3-1 STBC scheme for 2 transmit and 1 receive antenna

In the first symbol time interval, X_1 is transmitted from antenna 1 and X_2 is transmitted from antenna 2 simultaneously, while in second symbol time interval antenna 1 transmits $-X_2^*$ and antenna 2 transmitsX_1^*. The coding rate of this scheme is one since in two symbol periods only two signals are transmitted, meaning that no bandwidth expansion takes place [2]. Due to the orthogonality of the space-time block codes, the symbols can be separated at the receiver by a simple linear combining scheme. At the receiver we can mathematically model the received signal as follows:

Received signal at 1st time slot:

$$y(1) = [h_1 \quad h_2]\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + n(1) \tag{3.1}$$

Received signal at 2nd time slot:

$$y(2) = [h_1 \quad h_2]\begin{bmatrix} -X_2^* \\ X_1^* \end{bmatrix} + n(2) \tag{3.2}$$

where h_1 and h_2 are flat fading channel coefficients and $n(1)$ and $n(2)$ are noise components which is generally Additive White Gaussian Noise (AWGN). In this dissertation, the channel is assumed to be constant over the two time slots. The following table summarizes the STBC encoding scheme.

Table 3-1 STBC Encoding scheme

space ⟶

time ↓

	Antenna 1	Antenna 2
time t	X_1	X_2
time t+T	$-X_2^*$	X_1^*

3.2.2 STBC Decoding Scheme

For detection of signals, simple zero forcing (ZF) equalizer can be used. Now, the received signal vectors from () and () can be stacked as

$$\begin{bmatrix} y(1) \\ y(2)^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} n(1) \\ n(2)^* \end{bmatrix} \tag{3.3}$$

For detection of signals we can define,

Let $H = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}$ and $\bar{Y} = \begin{bmatrix} y(1) \\ y(2)^* \end{bmatrix}$

We can define pseudo inverse as

$$W = (H^H H)^{-1} H^H \tag{3.4}$$

Then the term,

$$(H^H H) = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}$$

$$= \begin{bmatrix} |h_1|^2 + |h_2|^2 & 0 \\ 0 & |h_1|^2 + |h_2|^2 \end{bmatrix} \tag{3.5}$$

Since the channel coefficients are orthogonal to each other we can have $h_1^* h_2 = h_2^* h_1 = 0$ and $(H^H H)$ is a diagonal matrix, the inverse of this can be written directly as

$$(H^H H)^{-1} = \begin{bmatrix} \dfrac{1}{|h_1|^2 + |h_2|^2} & 0 \\ 0 & \dfrac{1}{|h_1|^2 + |h_2|^2} \end{bmatrix} \tag{3.6}$$

To estimate the transmitted symbols we can employ

$$\hat{X} = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = W\bar{Y} = (H^H H)^{-1} H^H \begin{bmatrix} y(1) \\ y(2)^* \end{bmatrix} \quad (3.7)$$

From (3.3),

$$\hat{X} = (H^H H)^{-1} H^H \left(H \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} n(1) \\ n(2)^* \end{bmatrix} \right) \quad (3.8)$$

$$\Rightarrow \hat{X} = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + (H^H H)^{-1} H^H \begin{bmatrix} n(1) \\ n(2)^* \end{bmatrix} \quad (3.9)$$

The 2nd term in above relationship is essentially noise.

3.2.3 Results and Discussion

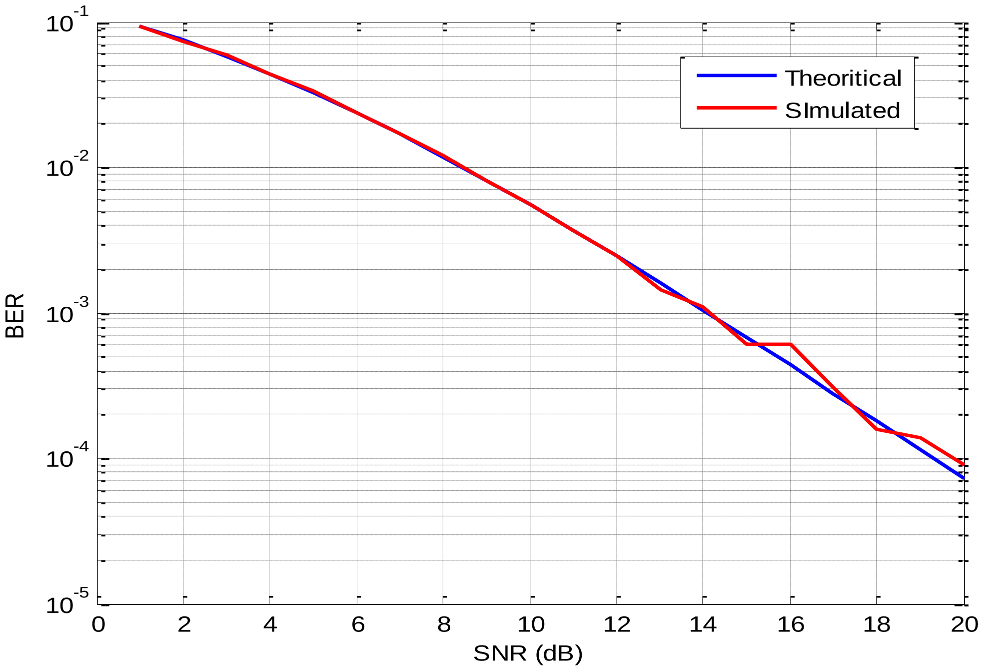


Fig. 3-2 BER plot for STBC scheme

Fig. 3-2 represents the BER plot for STBC scheme employing 2 transmitting antennas and 1 receiving antenna for BPSK modulation. The channel here is considered to be Rayleigh flat fading and is assumed to be constant over the two time slots. From the figure we can conclude that the simulated BER plot approaches the theoretical plot.

3.3 STBC MC-CDMA: An integration of STBC and MC-CDMA

The STBC schemes are originally employed for flat fading channels. So application of this scheme to frequency selective channels is challenging and has attracted attention of many researchers. Multi-carrier techniques such as OFDM and MC-CDMA which convert frequency selective channel to several flat fading channels are integrated with STBC to produce STBC OFDM [7] and STBC MC-CDMA [10] respectively. This dissertation mainly focusses on STBC MC-CDMA and its signal processing aspects. In STBC MC-CDMA first CDMA operation is carried out and then OFDM operation is carried out.

3.4 STBC MC-CDMA Transceiver

STBC MC-CDMA transmitter and receiver block diagram for multiuser system is given below for 2 transmit antenna and 1 receive antenna. The channel is Rayleigh flat fading channel.

3.4.1 STBC MC-CDMA Transmitter

The baseband signal processing is presented at Fig. 3-3. The information bits of different users are digitally modulated and then spreaded using orthogonal Walsh-Hadamard (W-H) codes. All the spreaded signals are summed up to produce the CDMA signal and then passed through STBC encoder. The STBC encoding is done as described in above section 3.2.1. Each of these STBC encoded outputs are passed through individual OFDM modulators. In OFDM modulator part first the symbols are passed through the IFFT block to convert frequency domain samples to time domain samples. After the IFFT operation the samples must be separated from each other to ensure no inter symbol interference (ISI). For that guard band or cyclic prefix (CP) can be used. After that the signals are transmitted through channel.

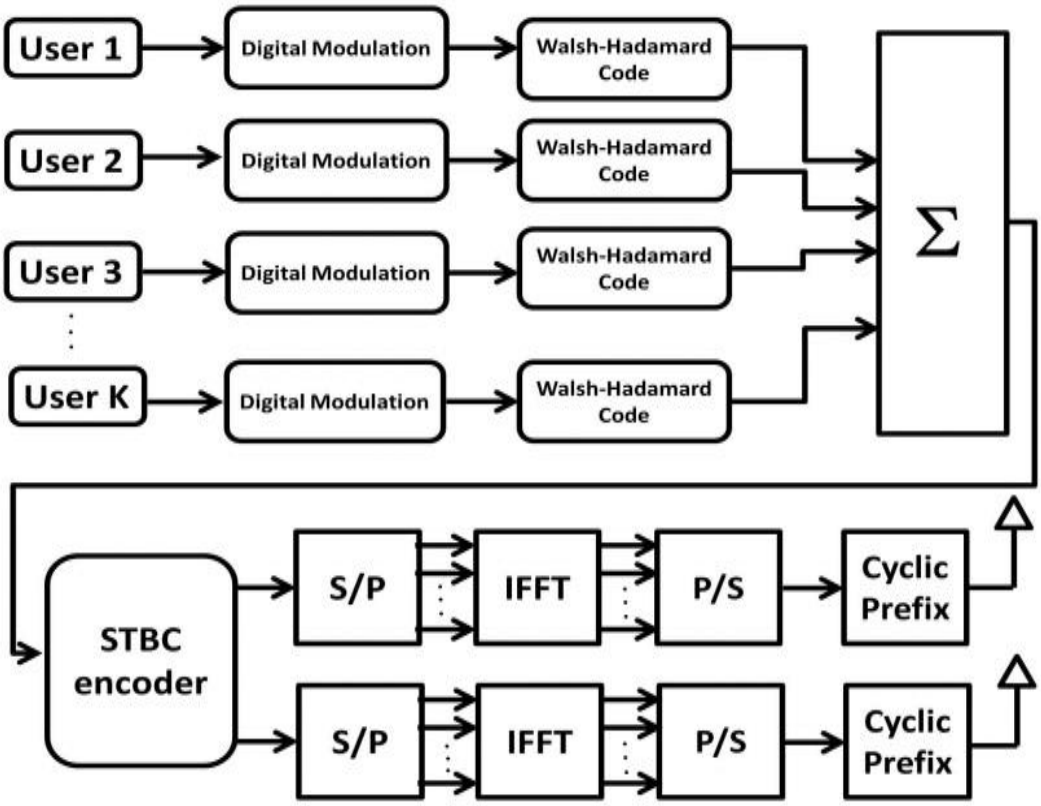


Fig. 3-3 Transmitter block diagram of STBC MC-CDMA system

At the receiver first the CP is removed and then the channel equalization is carried out in time domain as shown in Fig. 3-4. In the conventional STBC MC-CDMA [8] equalization is implemented in frequency domain which increases the complexity by processing the channel coefficients which are already present in time domain into frequency domain. For detection of signal, simple ZF equalizer can be used which is described in 3.2.2.

After the channel effects are nullified the data are sent to the FFT block and the signals are despreaded by using the same W-H code assigned to the specified user at the transmitter side. Then the digital demodulation is carried out to retrieve all the user information bits. Here the receiver must have the knowledge about the channel coefficients and the Walsh-Hadamard code used for spreading at the transmitter accurately for correct detection of the transmitted signals from different users. In the simulation, we have compared the STBC MC-CDMA with STBC OFDM.

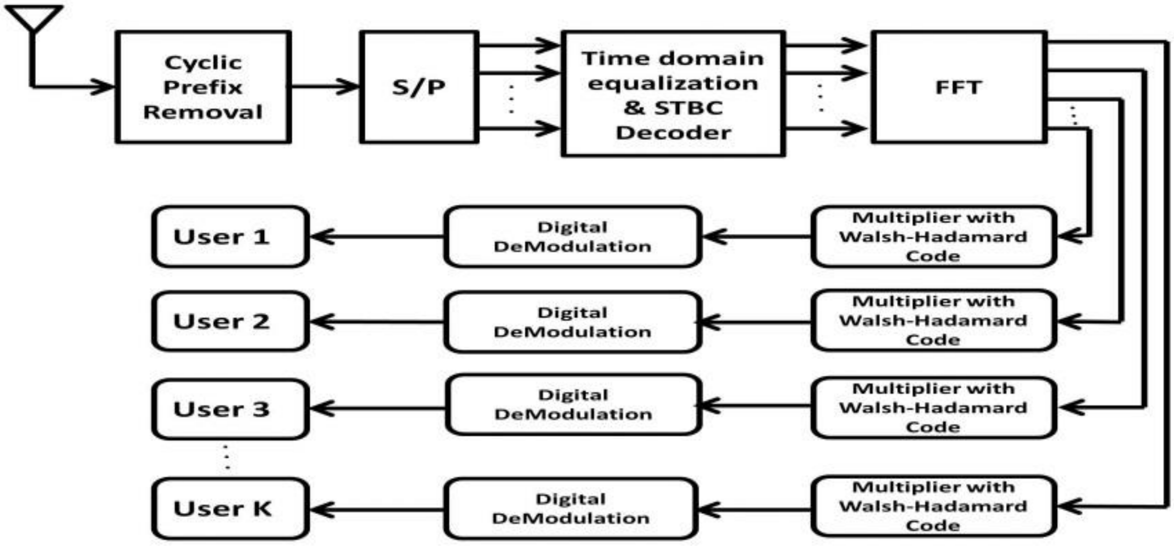


Fig. 3-4 Receiver block diagram of STBC MC-CDMA system

3.5 Results and discussion

Fig. 3-5 and Fig. 3-6 present that the STBC MC-CDMA performs better than STBC OFDM under AWGN and Rayleigh channel. For BER of 10^{-3}, STBC MC-CDMA achieves a SNR gain of around 6 dB in AWGN and Rayleigh fading channel. In Fig. 3-7, it is observed that as the no of users increase the BER performance degrades.

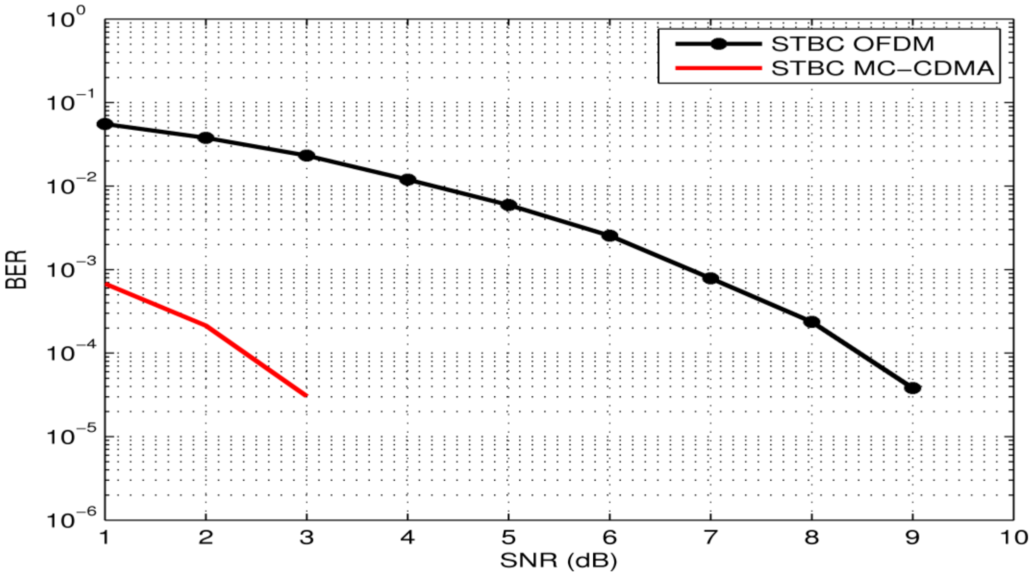


Fig. 3-5 BER performance of STBC OFDM and STBC MC-CDMA under AWGN channel for single user

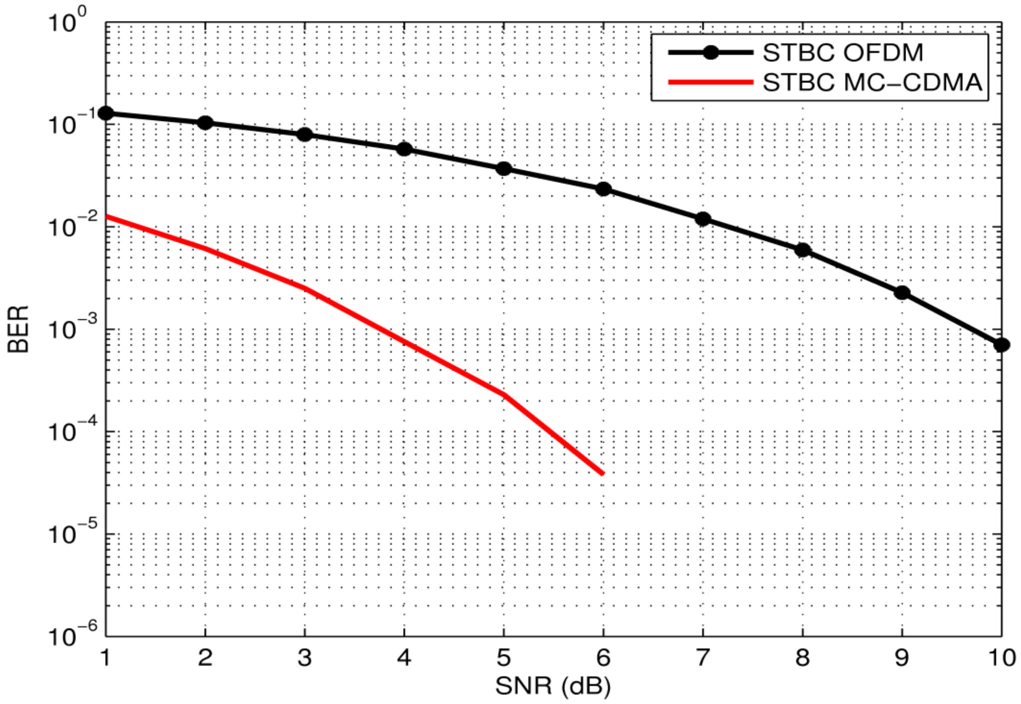


Fig. 3-6 BER performance of STBC OFDM and STBC MC-CDMA under Rayleigh fading channel for single user

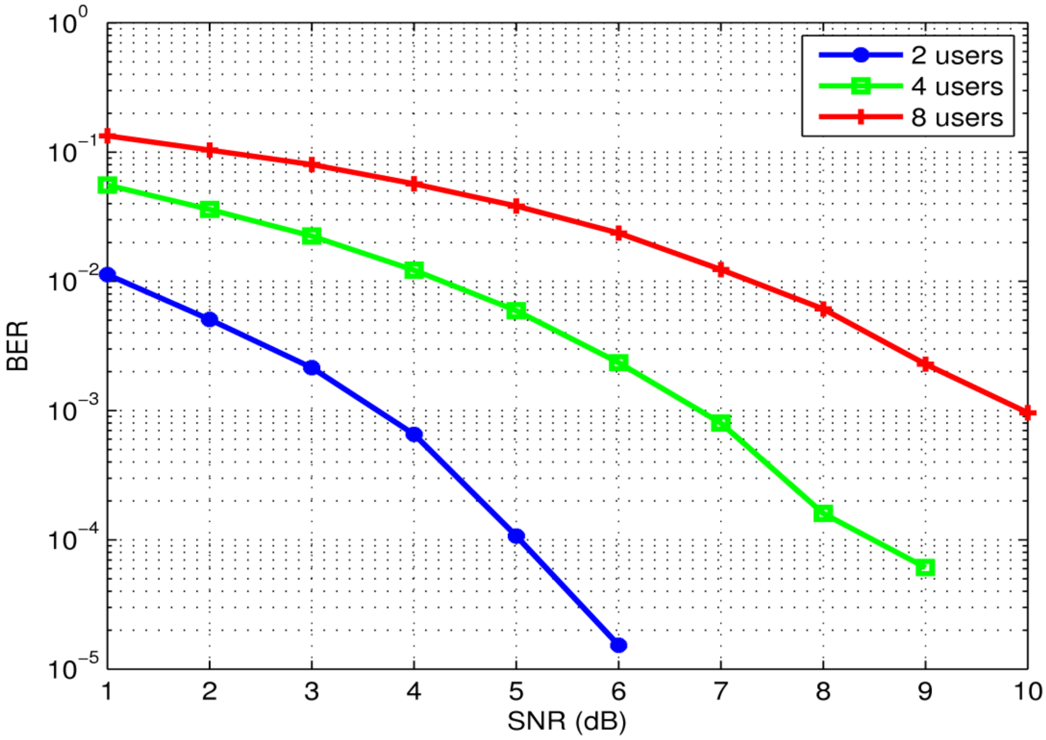


Fig. 3-7 BER performance for 2, 4 and 8 users for SF=4 of STBC MC-CDMA under Rayleigh fading channel

4

PEAK TO AVERAGE POWER RATIO: AN INTRODUCTION

In all multicarrier techniques Inverse Fast Fourier Transform (IFFT) is the main building block for generation of orthogonal subcarriers. Occasionally, all the subcarriers may get added to give a very high transmitted power. This high transmitted power may be significant in deviation from the mean power giving rise to high Peak-to-Average Power Ratio (PAPR) which is given as the ratio of maximum power to average power. This high PAPR may affect the orthogonality of the subcarriers. Once the orthogonality is lost many problems arise. High PAPR has been a bottleneck for multicarrier techniques.

Like all multi-carrier techniques, STBC MC-CDMA suffers from high PAPR. The high PAPR of the transmitted signal which in turn results in high input-back-off (IBO) for the power amplifier, drives the power amplifier to operate in non-linear region generating inter modulation (IM) products. IM causes out-of-band emissions and in-band distortions. Out-of-band emissions, or spectral regrowth, result an increased transmission bandwidth and causes Adjacent Channel Interference (ACI) and in-band distortion causes self-interference and degrades bit error rates performance at the receiver. So it is highly essential to alleviate this problem. To combat the problem of high PAPR, many techniques [5] have been proposed.

4.1 PAPR reduction techniques

There are so many PAPR reduction techniques exist. Some of the important PAPR reduction techniques include

- Clipping and filtering
- Coding
- Interleaving
- Tone injection
- Tone reservation
- Active constellation extension
- Selected mapping (SLM) and
- Partial transmit sequence (PTS)

Among all the techniques, PTS [5, 6] is considered to be the best for PAPR reduction scheme but at a cost of high computational complexity. Other techniques are application specific but PTS and SLM are flexible. It has been seen in many occasions PTS has performed better than SLM. Table 4-1 presents the comparison of all the PAPR reduction techniques. Most of the PAPR reduction techniques reduce PAPR at a cost of Bit Error Rate (BER) degradation, signal constellation distortion, increased complexity etc. So choosing a good PAPR reduction technique is a difficult task.

Table 4-1 PAPR reduction techniques comparison

Technique name	**Power increase**	**Distortion-less**	**Loss in data rate**	**Computational Complexity**
Amplitude clipping & filtering	No	No	No	Low
Coding	No	Yes	Yes	Medium
Partial Transmit Sequence	No	Yes	Yes	Very High
Selected Mapping	No	Yes	Yes	High
Interleaving	No	Yes	Yes	Medium
Tone Reservation	Yes	Yes	Yes	Medium
Tone Injection	Yes	Yes	No	Medium
Active constellation extension	Yes	Yes	No	Medium

4.2 Mathematical model for PAPR calculation

Let X denote data vectors such that $X = [X_{0,} X_1, \dots, X_{N-1}]^T$ where $i = 0,1, \dots, N-1$, N being no of subcarriers. The time domain complex baseband representation of this data block for a multicarrier signal can be represented as

$$x_i = IFFT\{X\} = \frac{1}{\sqrt{N}} \sum_{K=0}^{N-1} X_K e^{j2\pi ki/N} \tag{4.1}$$

Since the multicarrier signal is a combination of large no of independent subcarriers it may exhibit high PAPR. The PAPR of the transmitted signal can be represented by

$$PAPR = \frac{\max_{0 \le i \le N-1} |x_i|^2}{E[[x_i]^2]} = \frac{\max_{0 \le i \le N-1} |x_i|^2}{\sigma_x^2} \tag{4.2}$$

From the central limit theorem, the in-phase and quadrature phase components of the time domain samples resemble Gaussian distribution with mean zero and variance of σ_x^2 for sufficiently large no of subcarriers [6]. The numerator in the above equation represents the maximum power where the denominator is the average power which can also be termed as variance of the time domain samples. In [7], PTS technique is applied to STBC MIMO-OFDM systems. This thesis proposes to apply this technique to STBC MC-CDMA. Also, a low complexity receiver for the above scheme is designed where the equalization is carried out in time domain thus avoiding the need of converting time domain channel coefficients to frequency domain. Time domain equalization is preferred over frequency domain equalization because it is simple to implement and less complex.

4.2.1 Complementary Cumulative Distribution Function: A PAPR parametric

PAPR is characterized using Complementary Cumulative Distribution Function (CCDF). The amplitude of the multicarrier signals follows Rayleigh distribution and power distribution becomes central chi-square distribution [6, 5]. The Cumulative Distribution Function (CDF) of amplitude of a signal sample can be represented as

$$F(z) = 1 - e^{-z} \tag{4.3}$$

where z is pre-set threshold. Then the CCDF can be defined as

$$\text{CCDF}=1-\text{CDF} \tag{4.4}$$

Thus CCDF of the PAPR denotes the probability that the PAPR of a data block exceeds a given threshold. Mathematically,

CCDF: $P(PAPR > z) = 1 - P(PAPR \leq z)$

$= 1 - F(z)^N$

$= 1 - (1 - e^{-z})^N$ where N is no of subcarriers.

4.3 Results and discussion

Fig. 4-1 represents the CCDF plot for SISO PTS scheme in which number of subblocks are taken as 4 and number of subcarriers are 128. In the figure, CCDF plot using PTS technique, theoretical plot and the original CCDF plot without PTS scheme are represented. It can be seen that CCDF performance improves significantly when PTS is used compared to other two graphs and in turn PAPR is reduced.

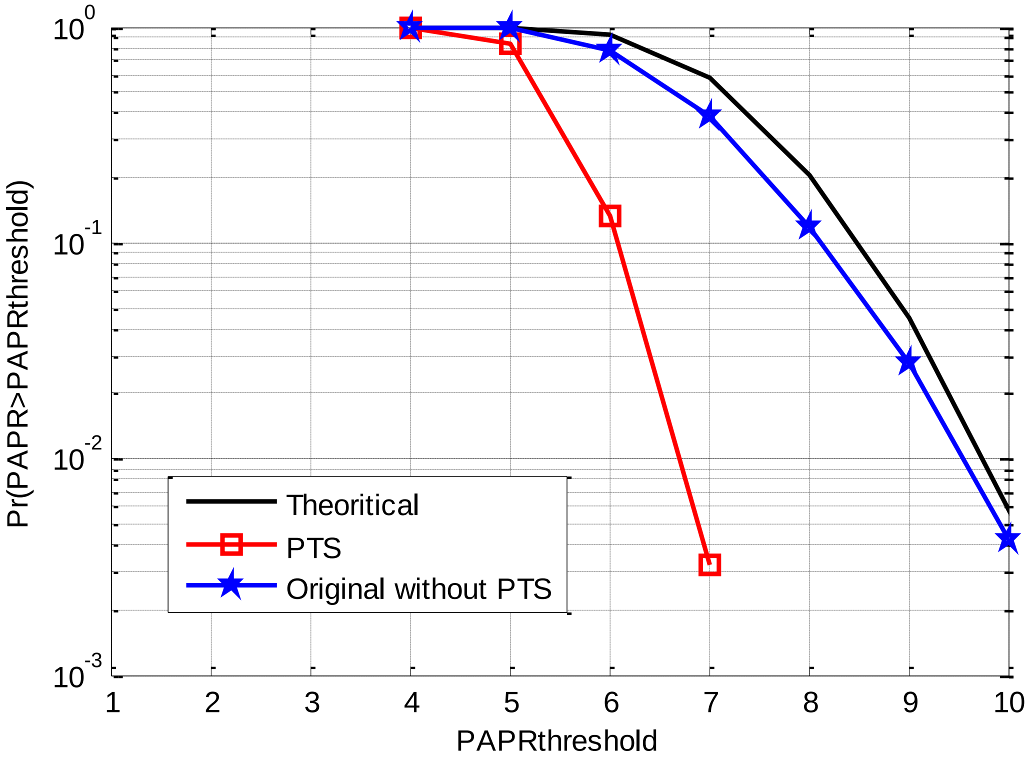


Fig. 4-1 CCDF plot for SISO PTS scheme

5

PARTIAL TRANSMIT SEQUENCE (PTS): PAPR REDUCTION TECHNIQUE FOR SISO AND STBC SYSTEM

Like all multi-carrier techniques, MC-CDMA also suffers from high PAPR problem. To combat this problem many techniques have been proposed of which Partial Transmit Sequence (PTS) is considered to be the best for PAPR reduction.

5.1 Partial Transmit Sequence (PTS)

A SISO PTS scheme for transmitter using OFDM [9, 10, 11] is presented in Fig. 5-1. In SISO PTS, the input data block X is divided into disjoint and equal length M subblocks such that the position of subcarriers assigned to one subblock is not assigned to other subblocks. Hence,

$$\sum_{m=1}^{M} X_m = X \tag{5.1}$$

where X_m is the data block. After subblock partitioning, IFFT operation is applied to individual subblocks and then the time domain signals are weighted by phase factors denoted as b chosen from an allowed phase factor combinations as shown in Fig. 4-1. The time domain signal after phase factor multiplication is presented as

$$x = \sum_{m=1}^{M} b_m x_m \tag{5.2}$$

where $b_m = [b_1, b_2, \ldots, b_M]^T$ and $x_m = IFFT\{X_m\}$

The block diagram of conventional PTS is given below:

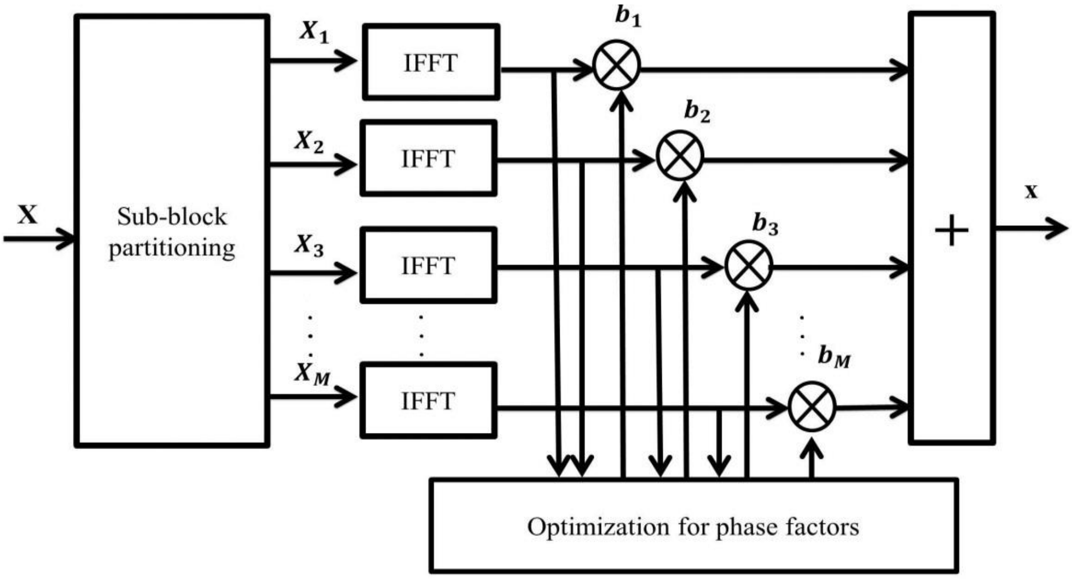


Fig. 5-1 Block diagram of a conventional SISO PTS scheme

The PAPR is calculated according to (4.2) and the signal with minimum PAPR is transmitted. The phase factor combination which provides minimum PAPR is transmitted as the side information (SI) to the receiver to rotate back the subcarriers so as to retrieve the original data transmitted. The phase factors are chosen from a set of allowed phase factors given by

$$P = e^{j2\pi l/W} | l = 0,1, \ldots W-1 \tag{5.3}$$

where W is the set of allowed phase factors. Here, we have assumed that $b_1 = 1$. For example, for $W = 4, P = \{\pm 1, \pm j\}$

The amount of PAPR reduction depends upon different subblock partitioning [12] and no of sub-carriers chosen. There are different subblocks partitioning schemes such as adjacent, interleaved, pseudo random etc.

1. **Adjacent subblock partitioning:**

The example of adjacent subblock partitioning is given below in Fig. 5-2.

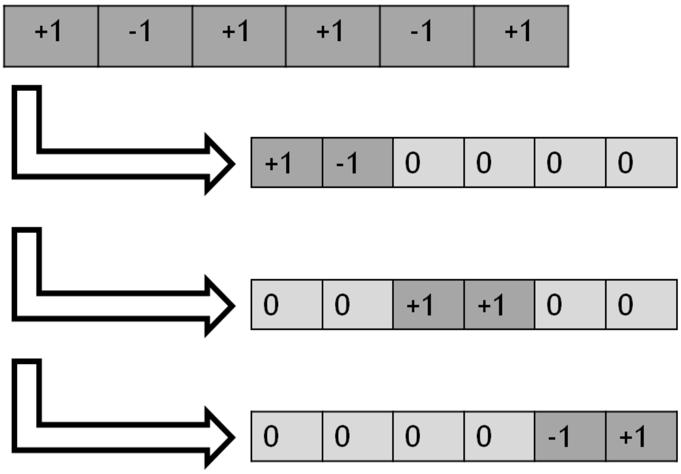


Fig. 5-2 Adjacent subblock partitioning

In adjacent subblock partitioning if the no of data bits N are multiple of no of subblocks M then first N/M data bits are assigned to the 1st subblock and rest are assigned zero. Similarly the 2nd subblock will have non-zero values for next N/M data bits as shown above and rest are zero and so on. The amount of PAPR reduction also depends upon the correlation that exists between the subblocks. Adjacent subblock partitioning has very high correlation.

2. **Interleaved subblock partitioning:**

In interleaved subblock partitioning the subcarriers are assigned in a fixed pattern interleaved by fixed amount of zeroes between two non-zero values. An example of interleaved subblock partitioning is given in Fig. 5-3. Here, the subcarriers are interleaved by two zeroes in all the subblocks. This subblock partitioning still has some correlation between the subblocks since the interleaving is carried out in a fixed manner.

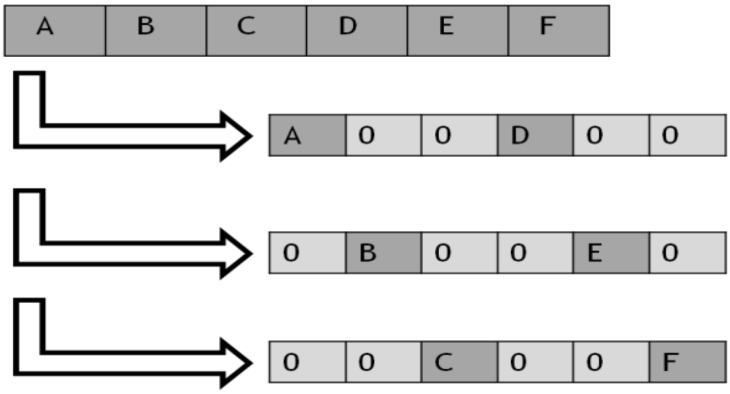


Fig. 5-3 Interleaved subblock partitioning

3. **Pseudo-random subblock partitioning:**

   Pseudo-random subblock partitioning is considered to be the best subblock partitioning since it has better PAPR reduction capabilities than other subblock partitioning schemes described above. The example of pseudo-random subblock partitioning is given in Fig. 5-4 where the no of subcarriers assigned is in a random manner. So there exists no correlation between the subblocks.

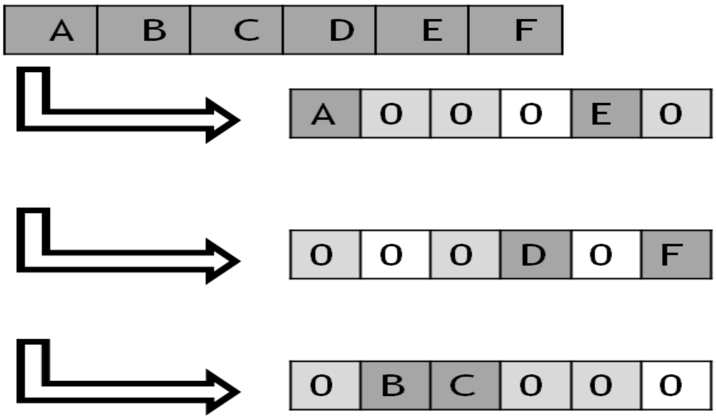


Fig. 5-4 pseudo random subblock partitioning

One thing to remember in the entire subblock partitioning schemes is that, the more the no of subblocks the better it has PAPR reduction capabilities but at the cost of added complexity. Also, when all the subblocks are summed up they will essentially be turned into the original data stream.

5.2 Advantages and Disadvantages of PTS

Like all other PAPR reduction techniques PTS also has a wide set of advantages and has a few serious draw backs.

5.2.1 Advantages of PTS

- ***Distortion less technique***: PTS doesn't distort the signal in its processing. Hence, Bit Error Rate (BER) performance is unaffected.
- ***Compatible with arbitrary subcarriers and type of modulation***: This technique is unrestricted to no of subcarriers being used. Hence, data rate can be increased by increasing the no of subcarriers within the same bandwidth. Also PTS performance is unaffected with type of modulation being carried out for base band modulation.
- ***Flexible system design***: Since it is compatible with arbitrary no of subcarriers and any type of modulation, PTS offers a flexible system design with no restriction on the parameters like no of subblocks and set of allowed phase factors.
- ***PAPR reduction capability***: It has been proved that PTS is considered to be the best PAPR reduction technique.

5.2.2 Disadvantages of PTS

- ***High computational complexity***: Very high computational complexity has turned out to be the bottleneck for implementation of PTS technique in real time systems despite of having very good PAPR reduction capabilities. The main reasons for increased computational complexities include no of IFFT operations for different subblocks which increase with as no of subblocks increase and vigorous searching algorithm to find optimum phase factor from a large set of phase factors.

- ***Loss in data-rates***: The phase factors used at the transmitter side to rotate the subcarriers must be transmitted to the receiver to rotate back the subcarriers. This is known as Side Information (SI) which is transmitted along with the OFDM symbol. SI will reduce the data rate if it is significant.

5.3 Partial Transmit Sequence (PTS): PAPR reduction technique for STBC MC-CDMA system

In previous section we have analyzed STBC MC-CDMA scheme and PTS technique individually. This chapter focusses on application of PTS technique to STBC MC-CDMA system. Also this section emphasizes on designing a low complexity receiver for the above scheme.

5.4 PTS based STBC MC-CDMA Transceiver

PTS technique is applied to multiuser STBC MC-CDMA for downlink wireless communication system for PAPR reduction and also a low complexity receiver is designed for the above scheme. Both the transmitter and receiver schematic are explained below.

5.5 PTS based STBC MC-CDMA Transmitter

Fig. 5-5 represents the transmitter schematic of STBC MC-CDMA system in which the users data are digitally modulated and spreaded using W-H orthogonal codes having Spreading factor (SF) same for all the users for mathematical simplification. Then all the spreaded information bits are summed up to provide the CDMA signal as denoted by X in Fig. 5-5. The CDMA signal is divided into two streams for encoding in STBC format for two transmitting antennas as explained in Chapter 3. Now the PTS technique is applied. The principle is to apply PTS technique to all the transmitting antennas individually.

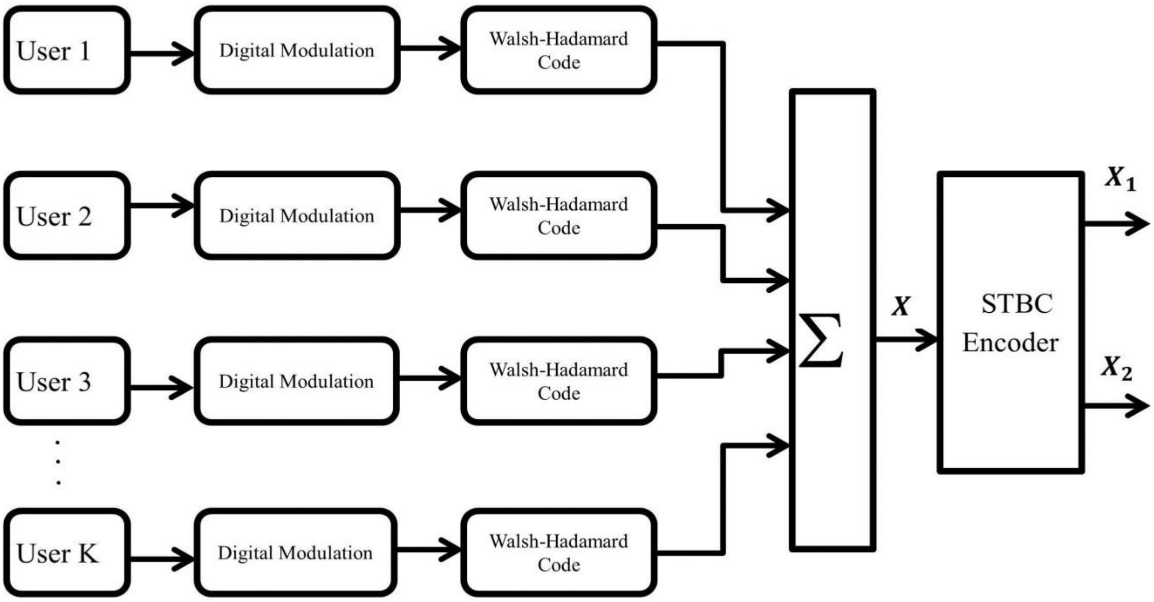


Fig. 5-5 PTS based STBC MC-CDMA transmitter block diagram

In 1st time instant, X_1 is transmitted from transmitting antenna 1 and X_2 is transmitted from transmitting antenna 2 and SISO PTS is applied to individual antennas. Then the PAPR is calculated and the minimum PAPR will be transmitted from both the antennas. Similarly, in 2nd time instant, $-X_2^*$ is transmitted from antenna 1 and X_1^* from transmitting antenna 2. The basic principle will be to apply again PTS technique to these two antennas individually for PAPR reduction which will increase the complexity in a large proportion. But such is not the case. It can be verified that the PAPR characteristics remain same for both the transmitting antennas [10, 12]. So a simple mathematical phase factor conversion will prevent from applying cumbersome PTS technique in the 2nd time interval and thus will reduce the complexity by 50%. This technique is summarized in Fig. 5-6. In this figure, only one transmitting antenna for two time intervals is presented. Application of this technique to 2nd transmitting antenna for both the intervals is straight forward.

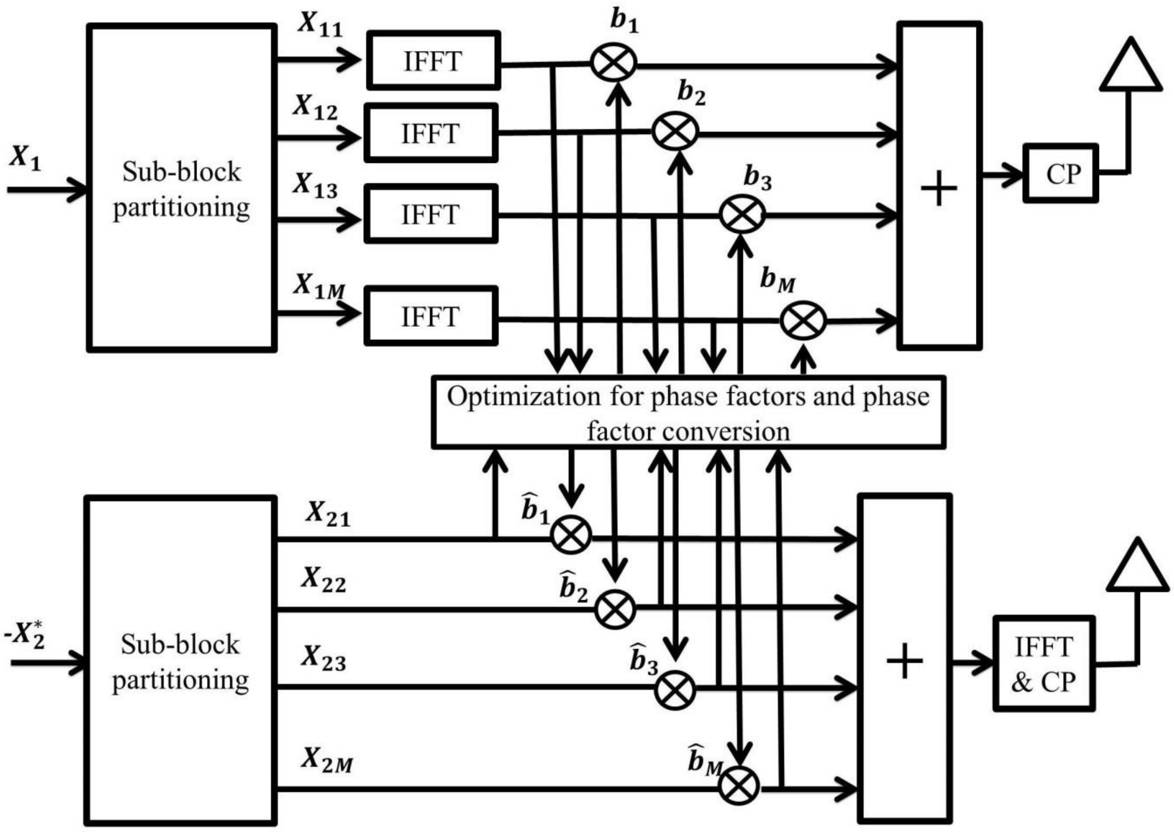


Fig. 5-6 PTS in same transmitting antenna of STBC MC-CDMA

5.6 PTS based STBC MC-CDMA Receiver

After the minimum PAPR candidate signal is searched, it is transmitted after addition of cyclic prefix (CP) through Rayleigh flat fading channel. Optimum value of phase factor combination is found for the minimum PAPR candidate signal and is denoted as

$$\hat{a}_{opt} = [\hat{b}_1, \hat{b}_2, \dots, \hat{b}_M]^T \tag{5.3}$$

This is known as Side Information (SI) which must be transmitted to the receiver side for rotating back the subcarriers. The same procedure is applied for both the transmitting antenna for finding out the SI in 1st time interval. For calculation of PAPR in 2nd time interval, simple phase factor conversion is required for the phase factor combination obtained from the 1st time instant. Thus the optimum phase factor combination for 2nd time interval can be written as

$$\hat{b}_{opt} = \hat{a}^*_{opt} \tag{5.2}$$

Also the simulation results verify that for 2nd time interval (i.e.$-X^*_2, X^*_1$), the antennas produce the same PAPR as is the case for the 1st time interval. So in STBC MC-CDMA employing two transmitting antennas, we need to minimize PAPR for the 1st time interval only.

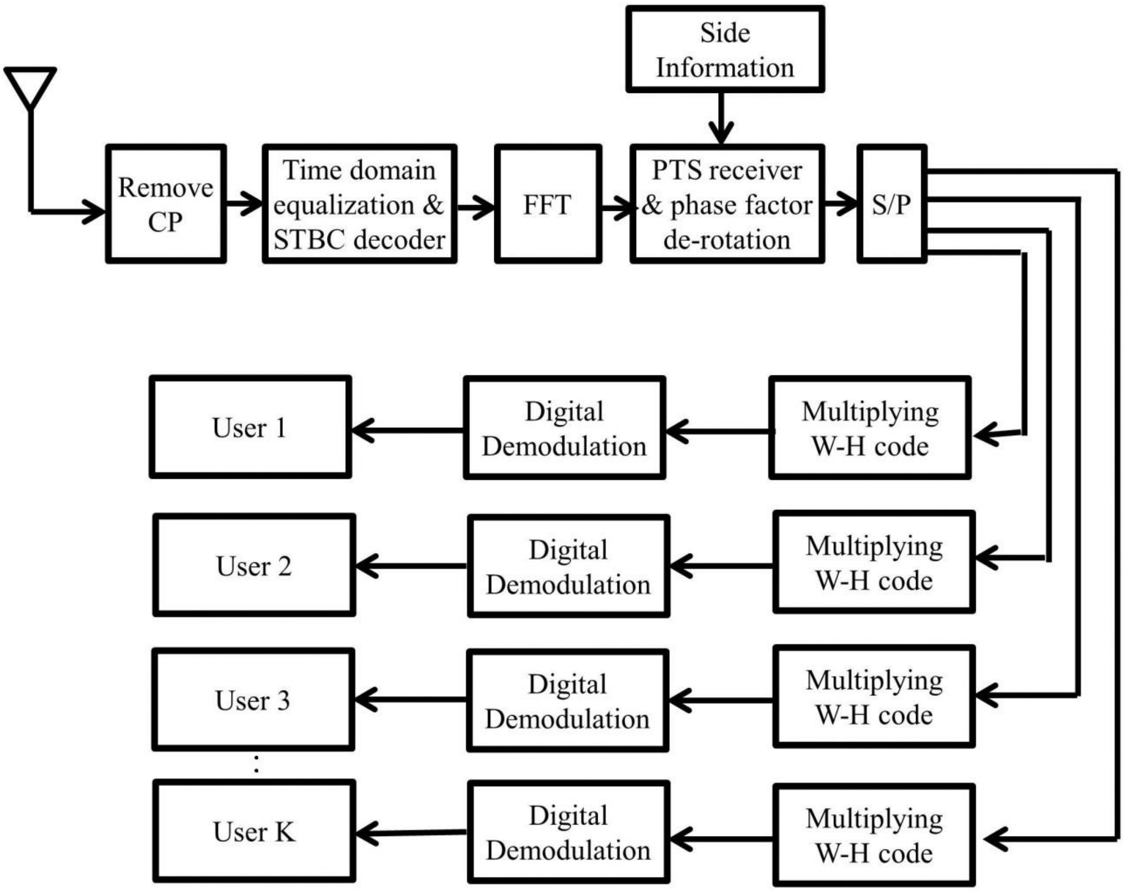


Fig. 5-7 Block diagram of receiver structure for STBC MC-CDMA PTS scheme

The above diagram represents the receiver diagram for PTS based STBC MC-CDMA scheme employing two transmitting antennas and one receive antenna. First the cyclic prefix (CP) is removed from the noisy received signal. Then time domain equalization and STBC decoding scheme is employed as described in Chapter 3. The equalization carried out here is essentially Zero Forcing (ZF) to nullify the channel effects caused at the transmitter. Since the equalization is carried out in time domain basis the signals available after STBC decoding block is also in time domain. Now the signals must pass through the FFT block to reverse the effects due to IFFT block at the transmitter. The PTS receiver operation described in Fig. 5-7 can be mathematically modeled as given below.

Let D denote the original data available such that$D = [D_0, D_1, \dots, D_{N-1}]^T$, N being the no of subcarriers. After partitioning into M subblocks, let it be represented by $Y_{N\times M}$. Then IFFT operation is applied to this individual subblocks given by

$$C_{M\times N} = IFFT\{Y\} = \left(I_{F_{N\times N}} Y_{N\times M}\right)^T \tag{5.4}$$

where I_F is the IFFT matrix. Now if $\hat{a}_{opt} = \left[\hat{b}_1, \hat{b}_2, \dots, \hat{b}_M\right]^T$represents the optimum phase factor then clearly the received signal vector

$$R_{1\times N} = \hat{a}_{opt}^T C \tag{5.5}$$

Now using (5.3), we can further write

$$R_{1\times N} = \hat{a}_{opt}^T (I_F Y)^T \tag{5.6}$$

$$\Rightarrow R_{1\times N} = \hat{a}_{opt}^T Y^T I_F^T \tag{5.7}$$

$$\Rightarrow \hat{a}_{opt}^T Y^T = R I_F^{-T} = R_y \tag{5.8}$$

Hence,

$$\hat{Y} = (\hat{a}_{opt}^T R_y)^T \tag{5.9}$$

After the subcarriers are rotated back the data are multiplied with the same W-H code to despread the signal of all the users. Then digital demodulation is performed to retrieve all the transmitted bits of all the users.

5.7 Results and Discussion

Simulations were performed for adjacent subblock partitioning scheme with 4 subblocks with BPSK modulation and phase factors were chosen from $\{\pm 1, \pm j\}$ with a spreading factor of 8. For BER plot Monte-Carlo simulation was used. CCDF graphs are plotted between preset PAPR threshold and probability that PAPR exceeds this threshold along X-axis and Y-axis respectively.

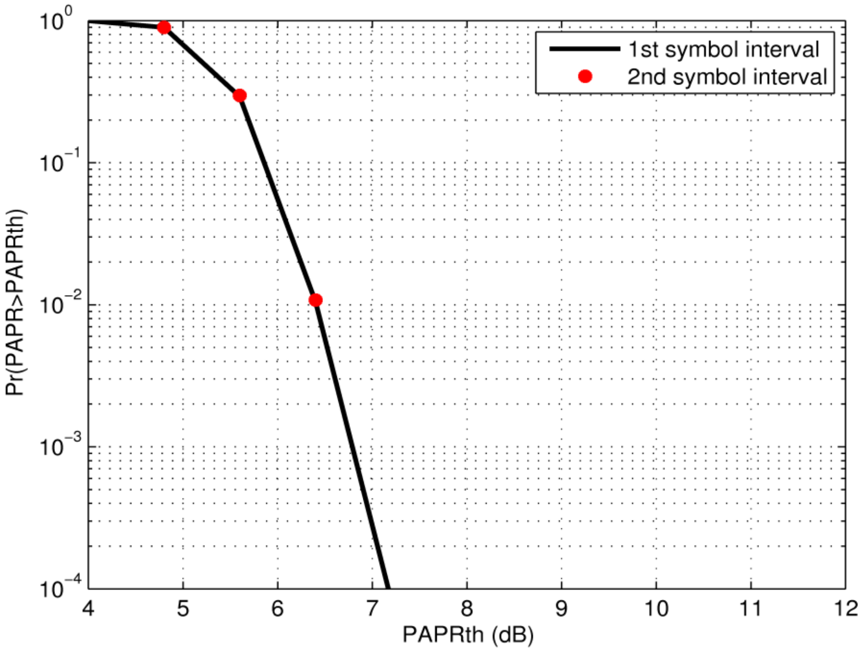


Fig. 5-8 CCDF plot for the same antenna at 1st and 2nd time interval (8 users, SF=8, W=4, M=4, N=128)

From Fig. 5-8, it is clearly seen that PAPR characteristics remain unaltered for the same antenna in 1st and 2nd symbol interval of STBC encoding scheme. So reduction of PAPR is restricted to 1st symbol interval only. CCDF plot for STBC MC-CDMA PTS scheme and SISO MC-CDMA PTS scheme are given in Fig. 5-9. Here, it can be seen that SISO MC-CDMA has marginal better PAPR performance (around 0.3dB) than proposed STBC MC-CDMA but at the cost of severe BER degradation which is presented in Fig. 5-11. The cause of marginal enhancement of PAPR for STBC MC-CDMA scheme than SISO MC-CDMA scheme may due to the fact that in STBC MC-CDMA, two transmitting antennas are used which increases the transmitted power which in turn increases PAPR. The theoretical CCDF plot and the original CCDF without PTS are also plotted in Fig. 5-9 to differentiate the PAPR performance with and without PAPR reduction technique, PTS.

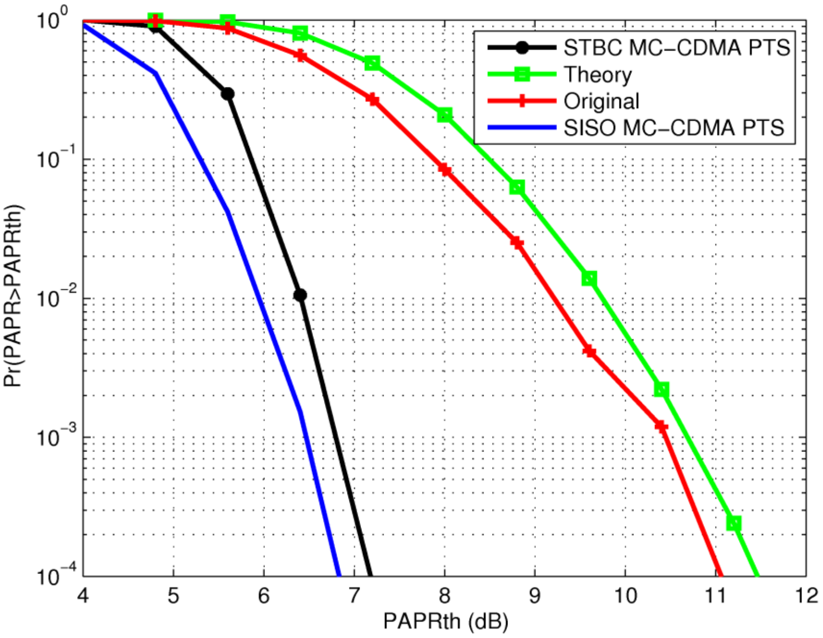


Fig. 5-9 CCDF plot for STBC MC-CDMA PTS and SISO MC-CDMA PTS (SF=8, W=4, M=4, N=128)

It is observed from Fig. 5-10 that as the no of users increase the CCDF performance improves. This is due to the W-H code used for spreading which increases the average value of the users data. As the users increase, the average value increases which in turn decreases PAPR. In Fig. 5-10 CCDF plot for 2, 4 and 8 users have been plotted.

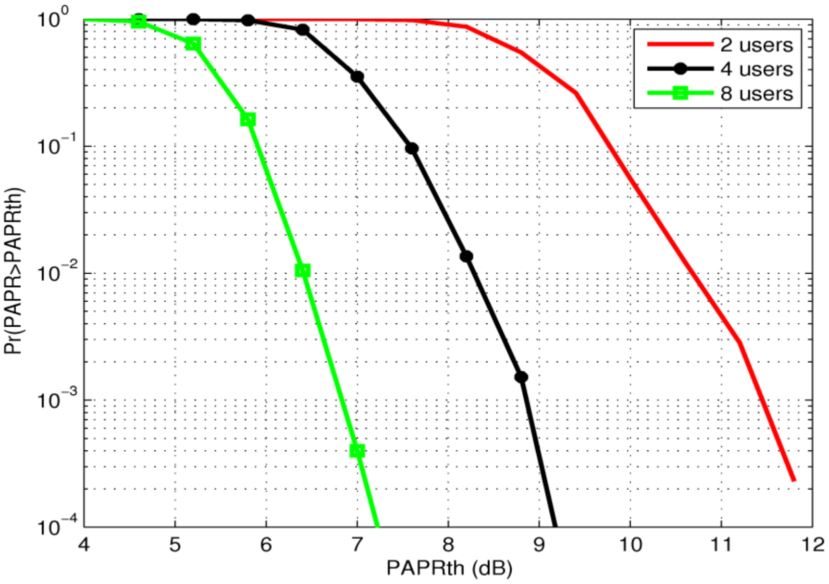


Fig. 5-10 CCDF plot of different users for STBC MC-CDMA (SF=8, W=4, M=4, N=128)

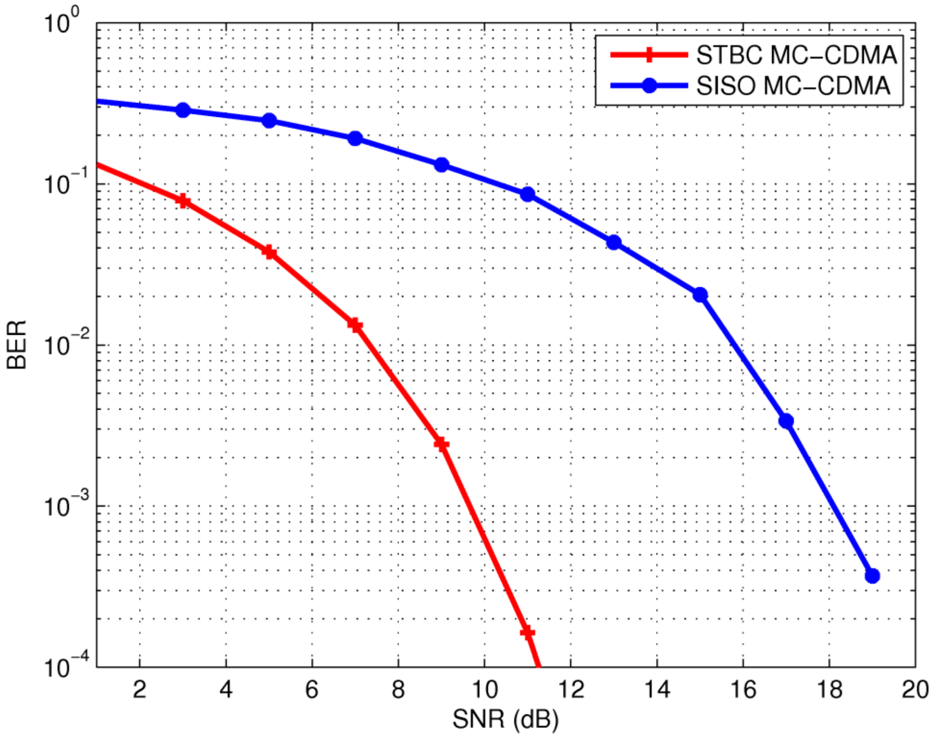


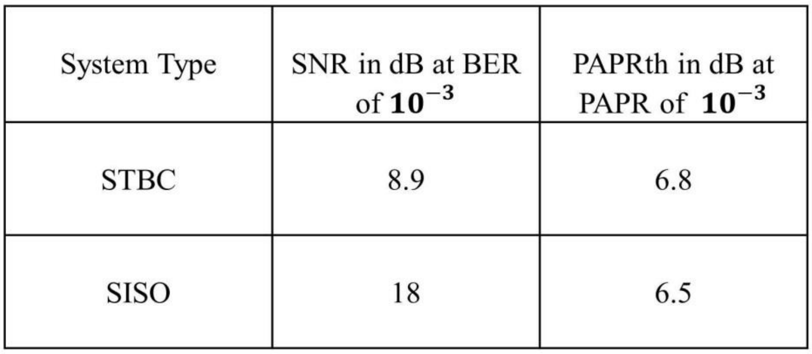
Fig. 5-11 BER plot for STBC MC-CDMA and SISO MC-CDMA

In Fig. 5-11, the BER performance for STBC MC-CDMA and SISO MC-CDMA for 8 users is given which shows that STBC MC-CDMA outperforms SISO MC-CDMA. This is due to the fact that the proposed STBC scheme achieves a diversity order of 2 which improves the BER performance. From the graph, for BER of 10^{-3}, STBC MC-CDMA achieves a SNR gain of around 8dB in comparison to SISO MC-CDMA at a marginal increase in PAPR.

5.8 Complexity analysis of STBC MC-CDMA and SISO MC-CDMA

The complexities associated in both the SISO and STBC schemes are summarized in Table 5-1. STBC scheme employing two transmitting antennas and one receiving antenna performs better than SISO scheme. As the no of antennas are increased on either side of transmitter or receiver, the PAPR will increase but at the same time the diversity order will increase which in turn will improve the BER performance. So there is always a trade-off when going for higher no of antennas to achieve minimum PAPR and better BER performance.

Table 5-1 Complexity analysis associated with STBC MC-CDMA and SISO MC-CDMA in terms of PAPR and BER performance



System Type	SNR in dB at BER of $\mathbf{10^{-3}}$	PAPRth in dB at PAPR of $\mathbf{10^{-3}}$
STBC	8.9	6.8
SISO	18	6.5

6

CONCLUSION

MC-CDMA has been the promising technology for 4G wireless communication system. Since it is a combination of both OFDM and CDMA, it explores the advantages of both the schemes. MIMO integrated with multicarrier techniques can boost the data rate and the reliability of the link. Also by using multi antenna elements MIMO can achieve diversity which in turn will improve BER performance thus improving the reliability at the receiver. So STBC MC-CDMA is a suitable candidate in this regard which can achieve speed, range and reliability simultaneously.

But the problem with multicarrier technique is PAPR which is also the major drawback for STBC MC-CDMA and restricts its application. High PAPR causes intermodulation products, increases the cost of the transmitter, and increases the complexity of the ADC. So PAPR must be reduced at any cost. To reduce PAPR many methods have been proposed. Most of the methods proposed are application specific such as they are only applicable to binary signaling or particular no of subcarriers. But PTS is a flexible technique which is applicable for any modulation scheme or any no of subcarriers. In this dissertation, PTS is applied to STBC MC-CDMA for PAPR reduction. Since STBC employs 2 transmitting antennas, PTS must be applied to both the antennas in both intervals. But implementation of PTS is restricted to 1st symbol time interval only. The optimum phase factors obtained in the 1st symbol interval is directly applied to the 2nd symbol time interval with some simple mathematical calculation. Hence the cumbersome task of applying PTS to 2nd symbol time interval for both the antennas is eliminated. So the complexity is reduced by 50%. Also a low complexity receiver is designed for the above scheme where the receiver is assumed to have knowledge of side information bits transmitted from the transmitter side after obtaining the optimum phased factor. These bits are used for rotation back of the subcarriers at the receiver side to retrieve the transmitted bits. The STBC encoding and decoding scheme are operated in time domain. The proposed STBC MC-CDMA with PTS technique is compared with SISO MC-CDMA with PTS technique in terms of CCDF and BER performance. CCDF plots show that SISO MC-CDMA with PTS scheme performs marginally better than STBC MC-CDMA with PTS scheme at a huge BER degradation. CCDF and BER plots for multiple users have also been plotted and it can be concluded that as the no of users increase the CCDF performance improves and BER performance degrades.

6.1 Future Work

The PTS technique has huge computational complexities when it is required to find the optimum phase factor from a set of large phase factor combinations. The complexity increases exponentially with increase in number of subblocks and number of subcarriers. So the future work can be derived from this drawback of PTS scheme.

Optimization algorithms can be developed for finding out the optimum phase factor which produces the least PAPR. Thus the complexity can be reduced in a huge manner.

Another way to minimize PAPR is to optimize subblock partitioning schemes. Designing of new subblock partitioning schemes can reduce the PAPR in a great deal.

In this dissertation we have assumed that the receiver has the knowledge about channel coefficients. This may not be possible in adverse situations. So receiver side channel estimation is essential for better reception of the signal. Also we have assumed that the side information bits are known at the receiver. This means that additional spectrum is used for transmission of these side information bits. This may lead to data loss if these bits are significant. So the future work will be to estimate the transmitted bits without using side information bits.

DISSEMINATION:

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