ENHANCED METHOD TO REDUCE PAPR IN MIMO-OFDM SYSTEM USING STBC-DPC/THP

A Project report submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF ENGINEERING IN ELECTRONICS ANDCOMMUNICATIONENGINEERING

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

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CERTIFICATE

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CONTENTS

ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is a spectrally proficient multicarrier modulation technique over multipath fading channel for high speed data transmission. On the other hand, MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth. MIMO-OFDM is a powerful combination because it can achieve very high spectral efficiency even when the transmitter does not possess channel state information (CSI). This MIMO-OFDM system suffers from high Peak-to- average power ratio (PAPR) and high Bit Error Rate (BER). In this project , the STBC-DPC system with the modulus operation i.e., Tomlinson-Harashima precoding (THP) scheme, is introduced to retain low peak-to-average power ratio (PAPR) in MIMO-OFDM system. Finally , with the Simulation results we can conclude that the STBC-DPC/THP system with water filling Algorithm can provide excellent bit error rate (BER) performance and STBC-DPC system with THP precoding technique can limit the DPC signal and attain low PAPR.

LIST OF FIGURES

LIST OF ABBREVIATIONS

MIMO	Multiple Input Multiple Output
STBC	Space Time Block Codes
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak to Average Power Ratio
ISI	Inter Symbol Interference
DPC	Dirty Paper Coding
THP	Tomlinson-Harashima Precoding
WFA	Water Filling Algorithm
IFFT	Inverse Fast Fourier Transform
ICI	Inter Carrier Interference
FDM	Frequency Division Multiplexing
TDM	Time Division Multiplexing
WDM	Wavelength Division Multiplexing
SNR	Signal to Noise Ratio
DS	Delay Spread
BER	Bit Error Rate
ICI	Inter Channel Interference

CHAPTER 1

Introduction

1.1 INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission scheme that has become the technology of choice for next generation wireless and Wire line digital communication systems because of its high speed data rates, high spectral efficiency, high quality service and robustness against narrow band interference and frequency selective fading However, among others, Interference is still one of the major drawbacks in the transmitted OFDM signal. Therefore, to reduce the interference of the OFDM signal, the Interference cancellation techniques are used and thus improving the OFDM signal quality.

Orthogonal frequency division multiplexing (OFDM) has been attracting substantial attention due to its excellent performance under severe channel condition. The rapidly growing application of OFDM includes Wi-MAX, DVB/DAB and 4G wireless systems.

The concepts of multiple-input multiple-output (MIMO) have been under development for many years for both wired and wireless systems. For high data rate wideband wireless communications, Orthogonal Frequency Division Multiplexing (OFDM) can be used with Multiple-Input and Multiple-Output (MIMO) technology to achieve superior performance. In conventional MIMO-OFDM systems, subcarrier based space processing was employed to achieve optimal performance. However, it requires multiple discrete Fourier transform/inverse DFT (DFT/IDFT) blocks, each corresponding to one receive/transmit antenna. Even though DFT/IDFT can be efficiently implemented using fast Fourier transform/inverse FFT (FFT/IFFT), its complexity is still a major concern for OFDM implementation. In addition, the use of multiple antennas requires the baseband signal processing components to handle multiple input signals, thus inducing considerable complexity for the decoder and the channel estimator at the receiver.

The MIMO STBC transceiver structure with two transmitter antennas and one receiver antennas is studied. First, to reduce the complexity at receiver, the STBC-DPC precoding technique is done to achieve the low complexity benefit for mobile station. Besides, to improve the performance of the STBC-DPC system, the channel on/off assignment using water filling algorithm is used. It is obvious to enhance the system performance.

Finally, it is well known that the precoding technique will conduct high PAPR problem. The STBC-DPC system with the modulus operation to limit the transmit signal level, i.e., Tomlinson-Harashima precoding (THP) scheme is introduced to constrain high peak power and retain low peak-to-average power ratio (PAPR).

1.2 PROBLEM DEFINITION

The main problem in the OFDM system is the Peak to Average Power Ratio(PAPR). It happens when the symbols from the IFFT block is transmitted over the parallel to serial converter ,then there would be a cumulation of these signals at the output of parallel to serial converter which results in high peak values comparatively to then the average value of the signal .

If these signal peaks are not taken into consideration and sent to the high power amplifier, the high power amplifier (HPA) which has to be operated in linear region tend to operate in non-linear region which results in high PAPR and leads to inter carrier interference and loss of orthogonality among subcarriers.

To eliminate this problem , Tomlinson-Harashima precoding (THP) scheme was introduced to STBC-DPC system to constrain the high peak powers in the OFDM system.

1.3 ORGANIZATION OF DOCUMENT

The documentation of the project is organized in seven chapters including Introduction and Conclusion .

CHAPTER 2	This chapter explains the basic concepts of Multiplexing , Interference and Radio Propagation.
CHAPTER 3	This chapter explains the concepts and mathematical expression of OFDM system , its Generation , Advantages and the concept of PAPR.
CHAPTER 4	This chapter explains about the concept of MIMO , its types ,functions of MIMO and MIMO-OFDM system.
CHAPTER 5	This chapter explains about Space Time Block Code's and Alamouti's STBC.
CHAPTER 6	This chapter explain Dirty Paper Coding and Tomlinson-Harashima precoding.
CHAPTER 7	This chapter provides simulation results.

CHAPTER 2

Basic Concepts

OFDM is currently being used in several new radio broadcast systems including the proposal for high definition digital television (HDTV) and digital audio broadcasting (DAB). However, little research has been done into the use of OFDM as a transmission method for mobile telecommunications systems. In CDMA, all users transmit in the same broad frequency band using specialized codes as a basis of channelization. Both the base station and the mobile station know these codes, which are used to modulate the data sent. OFDM/ allows many users to transmit in an allocated band, by subdividing the available bandwidth into many narrow bandwidth carriers. Each user is allocated several carriers in which to transmit their data.

2.1 MULTIPLEXING

In telecommunications and computer networks, multiplexing (sometimes contracted to mixing) is a method by which multiple analog or digital signals are combined into one signal over a shared medium. The aim is to share a scarce resource. For example, in telecommunications, several telephone calls may be carried using one wire. Multiplexing originated in telegraphy in the 1870s, and is now widely applied in communications. In telephony, George Owen Squier is credited with the development of telephone carrier multiplexing in 1910.

The multiplexed signal is transmitted over a communication channel such as a cable. The multiplexing divides the capacity of the communication channel into several logical channels, one for each message signal or data stream to be transferred. A reverse process, known as demultiplexing, extracts the original channels on the receiver end.

A device that performs the multiplexing is called a multiplexer (MUX), and a device that performs the reverse process is called a demultiplexer (DEMUX or DMX).Inverse multiplexing (IMUX) has the opposite aim as multiplexing, namely to break one data stream into several streams, transfer them simultaneously over several communication channels, and recreate the original data stream.

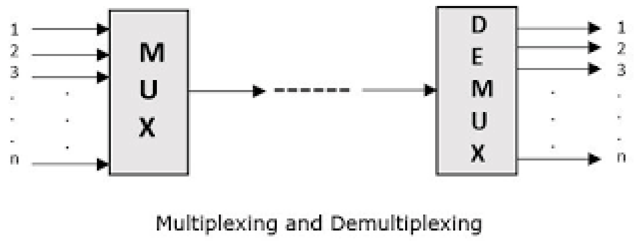


Fig 2.1: Multiplexing and Demultiplexing

The transmission is generated in such a way that the carriers used are orthogonal to one another, thus allowing them to be packed together much closer than standard frequency division multiplexing (FDM). This leads to OFDM/COFDM providing a high spectral efficiency.

Orthogonal Frequency Division Multiplexing is a scheme used in the area of high-data-rate mobile wireless communications such as cellular phones, satellite communications and digital audio broadcasting. This technique is mainly utilized to combat inter-symbol interference and inter carrier interference.

2.2 MULTIPLEXING TECHNIQUES

Multiplexing techniques are mainly used in communication, and these are classified into three types. The 3 types of multiplexing techniques include the following.

1) Frequency Division Multiplexing (FDM)

2) Wavelength Division Multiplexing (WDM)

3) Time Division Multiplexing (TDM)

2.2.1 FREQUENCY DIVISION MULTIPLEXING (FDM)

The FDM is used in telephone companies in the 20th century in long-distance connections for multiplexing number of voice signals using a system like a coaxial cable. For small distances, low-cost cables were utilized for different systems such as bell systems, K-and N-carrier, however, they don’t let huge bandwidths. This is analog multiplexing used to unite analog signals. This type of multiplexing is useful when the link’s bandwidth is better than the United bandwidth of the transmitted signals.

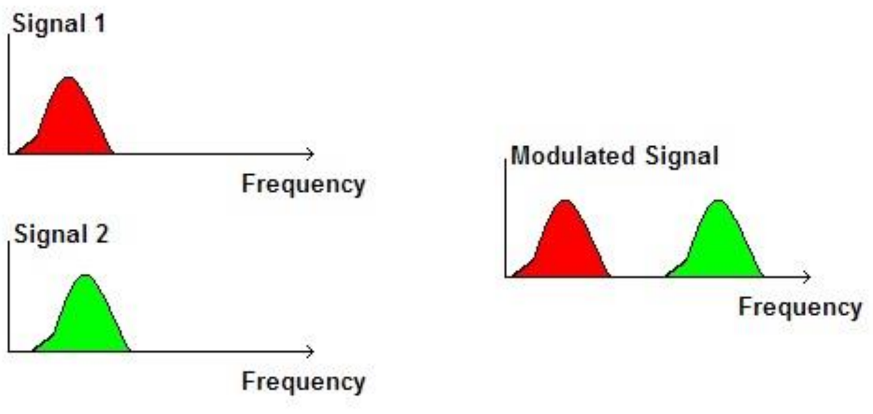


Fig 2.2: Frequency Division Multiplexing

In FDM, signals are produced by transmitting various device modulated carrier frequencies, and then these are united into a solo signal which can be moved by the connection. To hold the adapted signal, the carrier frequencies are divided by sufficient bandwidth, & these ranges of bandwidths are the channels through the different traveling signals. These can be divided by bandwidth which is not used. The best examples of the FDM comprise signal transmission in TV and radio.

2.2.2 WAVELENGTH DIVISION MULTIPLEXING (WDM)

In fiber communications, the Wavelength Division multiplexing (WDM) is an analog technique, in which many data streams of different wavelengths are transmitted in the light spectrum. If the wavelength increases, the frequency of the signal decreases. A prism, which can turn different wavelengths into a single line, can be used at the output of MUX and input of DEMUX.

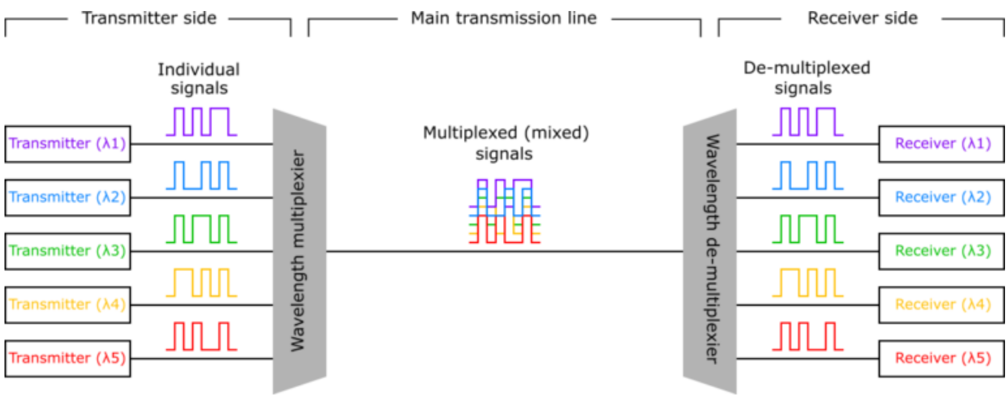


Fig 2.3: Wavelength Division Multiplexing

The main intention of WDM is to utilize the high data rate capacity of the FOC (fiber optic cable). The high data rate of this FOC cable is superior to the data rate of the metallic transmission cable. Theoretically, the WDM is similar to the FDM, apart from the data transmission through the FOC in which the multiplexing & de-multiplexing occupies optical signals.

2.2.3 TIME DIVISION MULTIPLEXING (TDM)

The Time division multiplexing (or) TDM is one kind of method for transmitting a signal over a channel of particular communication with separating the time edge into slots. Like single slot is used for each message signal.

TDM is mainly useful for analog and digital signals, in which several channels with low speed are multiplexed into high-speed channels used for transmission. Depending on the time, every low-speed channel will be assigned to an exact position, wherever it works in the mode of synchronized. Both the ends of MUX and DEMUX are synchronized timely & at the same time switch toward the next channel.

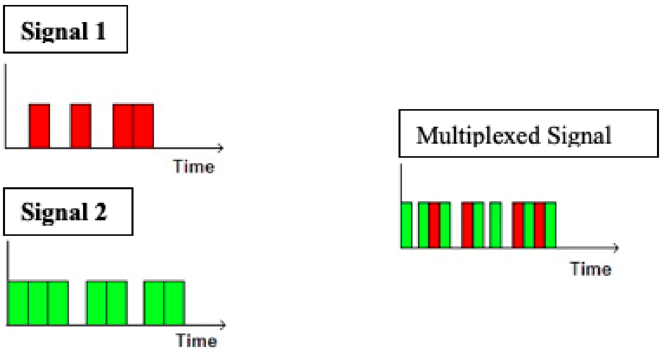


Fig 2.4: Time Division Multiplexing

2.3 APPLICATIONS OF MULTIPLEXING

The applications of multiplexing include the following.

1) Analog Broadcasting
2) Digital Broadcasting
3) Telephony

4) Video Processing

2.4 INTRODUCTION TO INTERFERENCE

In electronic communications, especially in telecommunications ,an interference is that which modifies a signal in a disruptive manner, as it travels along a channel between its source and receiver. The term is often used to refer to the addition of unwanted signals to a useful signal.

Interference is a fundamental nature of wireless communication systems, in which multiple transmissions often take place simultaneously over a common communication medium. In recent years, there has been a rapidly growing interest in developing reliable and spectrally efficient wireless communication systems. One primary challenge in such a development is how to deal with the interference, which may substantially limit the reliability and the throughput of a wireless communication system. In most existing wireless communication systems, interference is dealt with by coordinating users to orthogonalize their transmissions in time or frequency or by increasing the transmission power and treating each other's interference as noise.

The following types of interference can be identified in different wireless systems.

1) Inter-symbol Interference (ISI)
2) Inter channel interference (ICI)

2.4.1 INTER SYMBOL INTERFERENCE

Inter symbol interference (ISI), is a form of distortion of a signal in which one symbol interferes with subsequent symbols. This is an unwanted phenomenon as the previous symbols have similar effect as noise, thus making the communication less reliable. The spreading of the pulse beyond its allotted time interval causes it to interfere with neighbouring pulses. ISI is usually caused by multipath propagation or the inherent linear or non-linear frequency response of a communication channel causing successive symbols to "blur" together.

One of the causes of Inter Symbol Interference is multipath propagation in which a wireless signal from a transmitter reaches the receiver via multiple paths. The causes of this include reflection (for instance, the signal may bounce off buildings), refraction (such as through the foliage of a tree) and atmospheric effects such as atmospheric ducting and ionospheric reflection. Since the various paths can be of different lengths, this results in the different versions of the signal arriving at the receiver at different times. These delays mean that part or all of a given symbol will be spread into the subsequent symbols, thereby interfering with the correct detection of those symbols. Another cause of inter symbol interference is the transmission of a signal through a bandlimited channel, i.e., one where the frequency response is zero above a certain frequency (the cut off frequency). Passing a signal through such a channel results in the removal of frequency components above this cut off frequency. In addition, components of the frequency below the cut off frequency may also be attenuated by the channel.

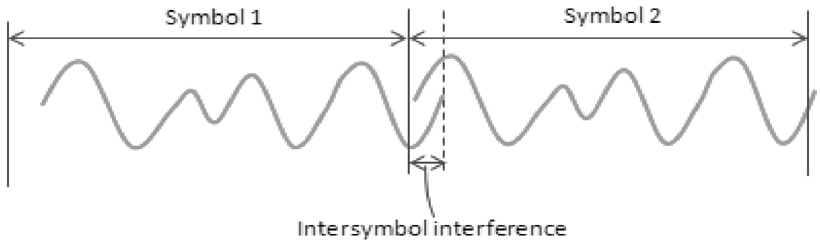


Fig 2.5:Inter Symbol Interference

2.4.2 INTER CARRIER INTERFERENCE

Inter carrier Interference (ICI) is an impairment well known to degrade performance of Orthogonal Frequency Division Multiplexing (OFDM) transmissions. It arises from carrier frequency offsets (CFOs), from the Doppler spread due to channel time-variation. In high mobility environment carrier frequency offset introduced in OFDM systems due to Doppler Effect, or frequency differences between local oscillators at the transmitter and receiver. With this frequency offset, the orthogonality among all OFDM subcarriers is lost and inter carrier interference is generated. So inter carrier interference is the major setback in OFDM and it needs to be taken into account when designing the systems.

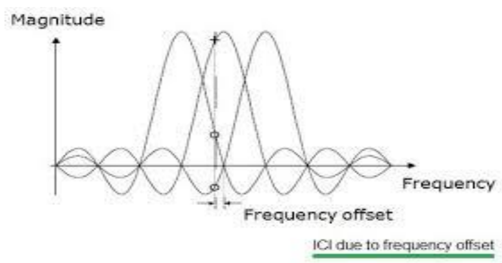


Fig 2.6: Inter Carrier Interference

2.5 RADIO PROPOGATION

Radio propagation is the behaviour of radio waves as they travel, or are propagated, from one point to another, or into various parts of the atmosphere. As a form of electromagnetic radiation, like light waves, radio waves are affected by the phenomenaof reflection, refraction, diffraction, absorption, polarization,
and scattering. However in a real channel, the signal is modified during transmission in the channel. The received signal consists of a combination of attenuated, reflected, refracted, and diffracted replicas of the transmitted signal. On top of all this, the channel adds noise to the signal and can cause a shift in the carrier frequency if the transmitter or receiver is moving (Doppler Effect). Understanding of these effects on the signal is important because the performance of a radio system is dependent on the radio channel characteristics.

2.5.1 MULTIPATH FADING

Multipath fading affects most forms of radio communications links in one form or another. It can affect signals on frequencies from the LF portion of the spectrum and below right up into the microwave portion of the spectrum.
Multipath fading occurs in any environment where there is multipath propagation and the paths change for some reason. This will change not only their relative strengths but also their phases, as the path lengths will change.

Multipath fading may also cause distortion to the radio signal. As the various paths that can be taken by the signals vary in length, the signal transmitted at a particular instance will arrive at the receiver over a spread of times. This can cause problems with phase distortion and inter-symbol interference when data transmissions are made. As a result, it may be necessary to incorporate features within the radio communications system that enables the effects of these problems to be minimised.

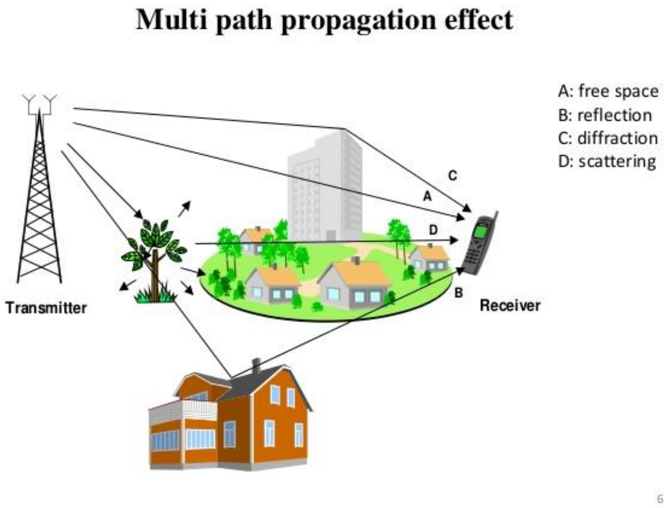


Fig 2.7: Multipath Propagation

2.5.2 DELAY SPREAD

In telecommunication, the delay spread is a measure of the multipath richness of a communications channel. In general, it can be interpreted as the difference between the time of arrival of the earliest significant multipath component (typically the line-of-sight component) and the time of arrival of the last multipath components. The delay spread is mostly used in the characterization of wireless channels, but it also applies to any other multipath channel (e.g. multipath in optical fibers).

Delay spread can be quantified through different metrics, although the most common one is the root mean square (rms) delay spread. Denoting the power delay profile of the channel by $A_C(T)$, the mean delay of the channel is

$$\overline{\tau} = \frac{\int_0^\infty \tau A_c(\tau) d\tau}{\int_0^\infty A_c(\tau) d\tau} \tag{2.1}$$

and the rms delay spread is given by

$$\tau_{\text{rms}} = \sqrt{\frac{\int_0^\infty (\tau - \overline{\tau})^2 A_c(\tau) d\tau}{\int_0^\infty A_c(\tau) d\tau}} \tag{2.2}$$

The importance of delay spread is how it affects the Inter Symbol Interference (ISI). If the symbol duration is long enough compared to the delay spread (typically 10 times as big would be good enough), one can expect an equivalent ISI-free channel.

2.5.3 RAYLEIGH FADING

Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices.

Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called a communication channel) will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables.

Rayleigh fading is viewed as a reasonable model for tropospheric and ionospheric signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. If there is a dominant line of sight, Rician fading may be more applicable.

2.5.4 ATTENUATION

Attenuation is the "drop in the signal power when transmitting from one point to another. It can be caused by the transmission path length, obstructions in the signal path, and multipath effects". Figure shows some of the radio propagation effects that cause attenuation. Any objects, which obstruct the line of sight signal from the transmitter to the receiver, can cause attenuation.

Shadowing of the signal can occur whenever there is an obstruction between the transmitter and receiver. It is generally caused by buildings and hills, and is the most important environmental attenuation factor. Shadowing is most severe in heavily built up areas, due to the shadowing from buildings. However, hills can cause a large problem due to the large shadow they produce.

CHAPTER 3

Orthogonal Frequency Division Multiplexing

3.1 INTRODUCTION TO OFDM

The OFDM technology was first conceived in the 1960s and 1970s during research into minimizing ISI, due to multipath. The expression digital communications in its basic form is the mapping of digital information into a waveform called a carrier signal, which is a transmitted electromagnetic pulse or wave at a steady base frequency of alternation on which information can be imposed by increasing signal strength, varying the base frequency, varying the wave phase, or other means. In this instance, Orthogonality is an implication of a definite and fixed relationship between all carriers in the collection. Multiplexing is the process of sending multiple signals or streams of information on a carrier at the same time in the form of a single, complex signal and then recovering the separate signals at the receiving end.

OFDM has been adopted in the Wi-Fi arena where the standards like 802.11a, 802.11n, 802.11ac and more. It has also been chosen for the cellular telecommunications standard LTE / LTE-A, and in addition to this it has been adopted by other standards such as WiMAX and many more. Orthogonal frequency division multiplexing has also been adopted for a number of broadcast standards from DAB Digital Radio to the Digital Video Broadcast standards, DVB. It has also been adopted for other broadcast systems as well including Digital Radio Mondiale used for the long medium and short wave bands.

Modulation is the addition of information to an electronic or optical signal carrier. Modulation can be applied to direct current (mainly by turning it on and off), to alternating current, and to optical signals. One can think of blanket waving as a form of modulation used in smoke signal transmission (the carrier being a steady stream of smoke). In telecommunications in general, a channel is a separate path through which signals can flow. In optical fiber transmission using dense wavelength-division multiplexing, a channel is a separate wavelength of light within a combined, multiplexed light stream. This project focuses on the telecommunications definition of a channel.

3.2 DEFINITION OF OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission technique, which divides the available spectrum into many carriers, each one being modulated by a low rate data stream. OFDM is similar to FDMA in that the multiple user access is achieved by subdividing the available bandwidth into multiple channels that are then allocated to users. However, OFDM uses the spectrum much more efficiently by spacing the channels much closer together. This is achieved by making all the carriers orthogonal to one another, preventing interference between the closely spaced carriers.

OFDM is a special form of MCM and the OFDM time domain waveforms are chosen such that mutual Orthogonality is ensured even though sub-carrier spectra may over-lap. With respect to OFDM, it can be stated that Orthogonality is an implication of a definite and fixed relationship between all carriers in the collection. It means that each carrier is positioned such that it occurs at the zero energy frequency point of all other carriers. The sinc function, exhibits this property and it is used as a carrier in an OFDM system.

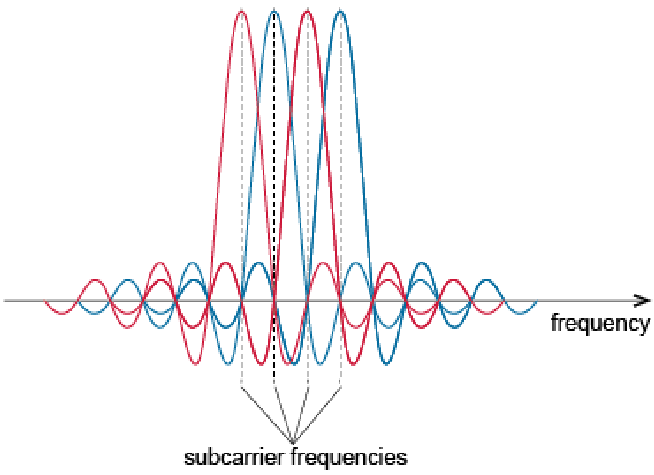


Fig 3.1: OFDM subcarriers in Frequency domain

3.3 ORTHOGONALITY PRINCIPLE

In geometry, orthogonal means, "involving right angles" (from Greek ortho, meaning right, and gon meaning angled). The term has been extended to general use, meaning the characteristic of being independent (relative to something else). It also can mean non- redundant, non-overlapping, or irrelevant. Orthogonality is defined for both real and complex valued functions. The functions $\varphi_m(t)$ and $\varphi_n(t)$ are said to be orthogonal with respect to each other over the interval $a < t < b$ if they satisfy the condition:

$$\int_a^b \varphi_m(t)\,\varphi_n^*(t)\,dt = 0 \quad \text{Where } n \neq m \tag{3.1}$$

To generate OFDM successfully the relationship between all the carriers must be carefully controlled to maintain the Orthogonality of the carriers. For this reason, OFDM is generated by firstly choosing the spectrum required, based on the input data, and modulation scheme used. Each carrier to be produced is assigned some data to transmit. The required amplitude and phase of the carrier is then calculated based on the modulation scheme. The required spectrum is then converted back to its time domain signal using an Inverse Fourier Transform. In most applications, an Inverse Fast Fourier Transform (IFFT) is used. The IFFT performs the transformation very efficiently, and provides a simple way of ensuring the carrier signals produced are orthogonal.

The IFFT performs the reverse process, transforming a spectrum (amplitude and phase of each component) into a time domain signal. An IFFT converts a number of complex data points, of length, which is a power of 2, into the time domain signal of the same number of points. The orthogonal carriers required for the OFDM signal can be easily generated by setting the amplitude and phase of each bin, then performing the IFFT. Since each bin of an IFFT corresponds to the amplitude and phase of a set of orthogonal sinusoids, the reverse process guarantees that the carriers generated are orthogonal.

3.4 OFDM GENERATION

The OFDM system splits the high speed data stream into a number of parallel low data rate streams and these low rates data streams are transmitted simultaneously over a number of orthogonal subcarriers.

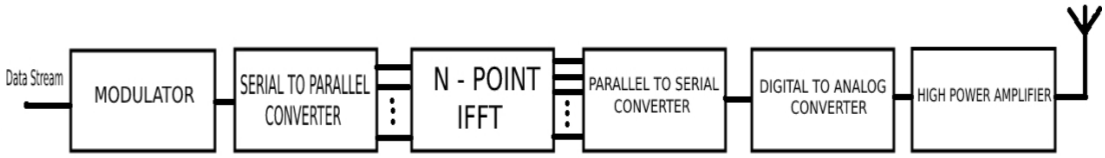


Fig 3.2: OFDM Block Diagram

3.4.1 SERIAL TO PARALLEL CONVERSION

The symbols obtained from the modulation are converted to a set of parallel symbols, to load them onto the various sub carriers for the IFFT operation this is also known as a serial to parallel conversion or a DE MUX or a de multiplexing operation. The size of the DE MUX is totally dependent on the size of the IFFT block.

3.4.2 MODULATION OF DATA

The data to be transmitted on each carrier is then differential encoded with previous symbols. Since differential encoding requires an initial phase reference an extra symbol is added at the start for this purpose. The data on each symbol is then mapped to a phase angle based on the modulation method. The use of modulation method produces a constant amplitude signal and was chosen for its simplicity and to reduce problems with amplitude fluctuations due to fading.

3.4.3 INVERSE FAST FOURIER TRANSFORM

After the required spectrum is worked out, an inverse Fast Fourier transform is used to find the corresponding time waveform (IFFT – Convert frequency domain signal to time domain signal). In Conventional multicarrier modulated system , each subcarrier has to be allocated with a dedicated oscillator and a modulator to generate a output.

If N subcarriers are allocated over a bandwidth B with a fundamental frequency f_0= B/N then the net transmitted signal x(t) is given as

$$x(t) = \sum_{k=0}^{N-1} X(k) e^{j2\Pi k f_0 t} \tag{3.2}$$

Since the signal is a band limited signal ,we can replace the conventional system with a N – point IFFT as the k^{th} transmitted signal x(k) is given as

$$x(k) = \frac{1}{N}\sum_{i=0}^{N-1} X(i) e^{\frac{j2\Pi ki}{N}} \tag{3.3}$$

3.4.4 PARALLEL TO SERIAL CONVERTION

The symbols obtained from the IFFT block are converted to serial symbols to load them onto Digital to Analog Convertor .This is also known as a parallel to serial conversion or a MUX or a multiplexing operation. The size of the MUX is totally dependent on the size of the IFFT block.

3.5 PEAK TO AVERAGE POWER RATIO (PAPR)

The PAPR is the relation between the maximum power of a sample in a given OFDM transmit symbol divided by the average power of that OFDM symbol. In simple terms, PAPR is the ratio of peak power to the average power of a signal. It is expressed in the units of dB.

$$PAPR\{s(t)\} = \frac{max([s(t)]^2)}{Expected([s(t)]^2)} \tag{3.4}$$

PAPR occurs when in a multicarrier system the different sub-carriers are out of phase with each other. At each instant they are different with respect to each other at different phase values. When all the points achieve the maximum value simultaneously; this will cause the output envelope to suddenly shoot up which causes a ‘peak’ in the output envelope. It also occurs when the signals from the IFFT block is transmitted over the parallel to serial converter ,then there would be a cumulation of these signals at the output of parallel to serial converter which might result in high peak values comparatively then the average value of the signal . If these signals are not taken into consideration and sent to the high power amplifier, the high power amplifier which has to be operated in linear region tends to operate in non-linear region which results in high PAPR and leads to inter carrier interference and loss of orthogonality among subcarriers.

Mathematically , the average power of the transmission signal x(k) is equal to A^2/N and the peak power at a sample is A^2. The peak to average power ratio (PAPR) is N for a OFDM system. Therefore, there is a significant increase in the PAPR over the system as the number of sub-carriers value increases i.e. N.

3.6 ADVANTAGES OF OFDM

- Robustness against frequency selective fading and time dispersion.
- Low computational complexity implementation (FFT).
- Makes efficient use of the spectrum by allowing overlap.
- By dividing the channel into narrowband flat fading sub channels, OFDM is more resistant to frequency selective fading than single carrier systems are.
- Eliminates ISI through use of a cyclic prefix.
- Using adequate channel coding and interleaving one can recover symbols lost due to the frequency selectivity of the channel.
- Channel equalization becomes simpler than by using adaptive equalization techniques with single carrier systems.
- OFDM is computationally efficient by using FFT techniques to implement the modulation and demodulation functions. Also, for multiple communication channels, as is the case in digital audio broadcasting (DAB) systems, partial FFT algorithms can be used in order to implement program selection and decimation.
- In conjunction with differential modulation there is no need to implement a channel estimator.
- Is less sensitive to sample timing offsets than single carrier systems are.

- Provides good protection against cochannel interference and impulsive parasitic noise.
- Preservation of Orthogonality in severe multipath.
- Used for highest speed applications.
- Supports dynamic packet access.
- Support for TX and RX diversity.

3.7 DRAWBACKS OF OFDM

- High Peak to Average Power.
- Sensitivity to frequency offset.
- Sensitivity to nonlinear amplification.

CHAPTER 4

MIMO – OFDM System

4.1 INTRODUCTION

MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth, though extra transmit power is needed since multiple transmit antennas are employed instead of only one as in SISO systems. It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading). Because of these properties, MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (WIFI), 4G, 3GPP Long Term Evolution, WiMAX.

4.2 TYPES OF MIMO

4.2.1 SINGLE-INPUT SINGLE-OUTPUT SYSTEM (SISO)

SISO is an acronym for Single Input and Single Output system. In control engineering it usually refers to a simple single variable control system with one input and one output. In radio it is the use of only one antenna both in the transmitter and receiver.

SISO systems are typically less complex than multiple-input multiple-output (MIMO) systems. Usually, it is also easier to make order of magnitude or trending predictions "on the fly" or "back of the envelope".

MIMO systems have too many interactions for most of us to trace through them quickly, thoroughly, and effectively in our heads. Often SISO controllers will be PI, PID, or lead-lag.

Fig 4.1: Single Input Single Output (SISO)

4.2.2 SINGLE INPUT MULTIPLE OUTPUT (SIMO)

In a **Single Input Multiple Output (SIMO)** system, there is one antenna at the transmitter side and multiple antennas (each with an RF chain respectively) at the receiver side. In a **switched diversity** or **selection diversity** implementation, the receiver chooses the best antenna to receive a stronger signal from the transmitter.

Fig 4.2: Single Input Multiple Output (SIMO)

4.2.3 MULTIPLE INPUT SINGLE OUTPUT (MISO)

The Multiple Input Single Output (MISO) system is the other way round, with multiple antennas (each with an RF chain respectively) at the transmitter and a single antenna at the receiver.

A technique known as Alamouti Space Time Coding (STC) is employed at the transmitter with 2 antennas, allowing the transmitter to transmit signals both in time and space. This means data is transmitted by the 2 antennas at 2 different times consecutively.

Fig 4.3: Multiple Input Single Output (MISO)

4.2.4 MULTIPLE INPUT MULTIPLE OUTPUT (MIMO)

Multiple Input Multiple Output (MIMO) system is commonly used in today's wireless technology, including 802.11n WIFI, WiMAX, LTE, etc. Multiple antennas (and therefore multiple RF chains) are put at both the transmitter and the receiver.

Fig 4.4: Multiple Input Multiple Output (MIMO)

A MIMO system with same amount of antennas at both the transmitter and the receiver in a point-to-point (PTP) link is able to multiply the system throughput linearly with every additional antenna.

For example, a 2x2 MIMO will double up the throughput. In radio, multiple-input and multiple-output, or MIMO (commonly pronounced my-moh or me-moh), is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology.

4.3 FUNCTIONS OF MIMO

MIMO can be sub-divided into three main categories, precoding, spatial multiplexing or SM, and diversity coding.

4.3.1 PRECODING

Precoding is a generalization of beam forming to support multi-stream (or multi-layer) transmission in multi-antenna wireless communications. In conventional single-stream beam forming, the same signal is emitted from each of the transmit antennas with appropriate weighting (phase and gain) such that the signal power is maximized at the receiver output. When the receiver has multiple antennas, single-stream beam forming cannot simultaneously maximize the signal level at all of the receive antennas. In order to maximize the throughput in multiple receive antenna systems, multi-stream transmission is generally required.

In point-to-point systems, precoding means that multiple data streams are emitted from the transmit antennas with independent and appropriate weightings such that the link throughput is maximized at the receiver output. In multi-user MIMO, the data streams are intended for different users (known as SDMA) and some measure of the total throughput (e.g., the sum performance or max-min fairness) is maximized.

In point-to-point systems, some of the benefits of precoding can be realized without requiring channel state information at the transmitter, while such information is essential to handle the inter-user interference in multi-user systems.

4.3.2 SPATIAL MULTIPLEXING

In spatial multiplexing, each spatial channel carries independent information, thereby increasing the data rate of the system. This can be compared to Orthogonal Frequency Division Multiplexing (OFDM) technique, where, different frequency subchannels carry different parts of the modulated data.

But in spatial multiplexing, if the scattering by the environment is rich enough, several independent subchannels are created in the same allocated bandwidth. Thus the multiplexing gain comes at no additional cost on bandwidth or power.

The multiplexing gain is also referred as degrees of freedom with reference to signal space constellation. The number of degrees of freedom in a multiple antenna configuration is equal to $\mathbf{min(N_T,N_R)}$, where $\mathbf{N_T}$ is the number of transmit antennas and $\mathbf{N_R}$ is the number of receive antennas. The degrees of freedom in a MIMO configuration governs the overall capacity of the system.

In the spatial multiplexing technique, each bit of the data stream (independent information) is multiplexed on three different spatial channels thereby increasing the data rate.

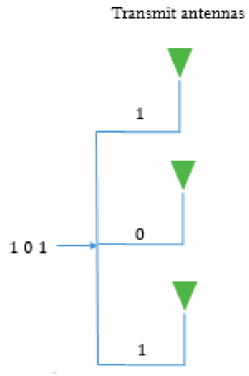
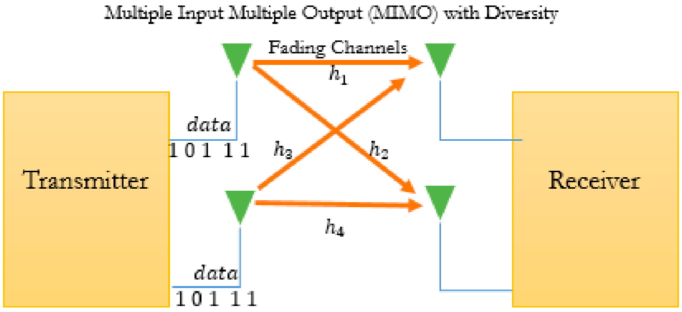


Fig 4.5: Spatial Multiplexing

4.3.3 DIVERSITY CODING

In diversity techniques, same information is sent across independent fading channels to combat fading. When multiple copies of the same data are sent across independently fading channels, the amount of fade suffered by each copy of the data will be different. This guarantees that at-least one of the copy will suffer less fading compared to rest of the copies. Thus, the chance of properly receiving the transmitted data increases. In effect, this improves the reliability of the entire system. This also reduces the co-channel interference significantly. This technique is referred as inducing a “spatial diversity” in the communication system.

The following figure illustrates a 2 x 2 MIMO system with number of diversity paths equal to 2 x 2 = 4.



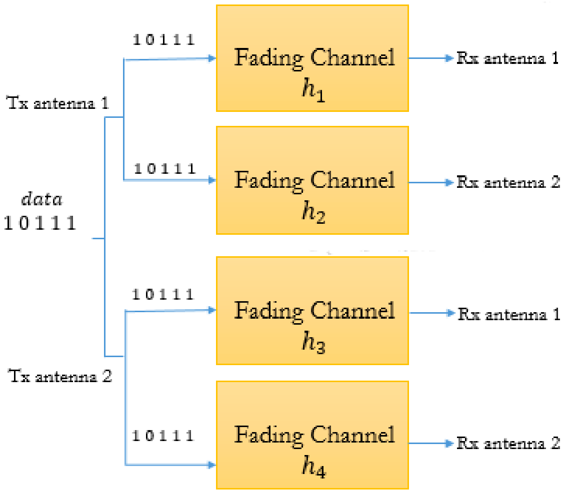


Fig 4.6: MIMO system with Diversity Coding

4.4 MIMO-OFDM SYSTEM

Multiple-input, multiple-output orthogonal frequency-division multiplexing (MIMO-OFDM) is the dominant air interface for 4G and 5G broadband wireless communications. However, due to spectral limitations, it is often impractical or sometimes very expensive to increase bandwidth. In this case, using multiple transmit and receive antennas for spectrally efficient transmission is an alternative solution. Multiple transmit antennas can be used either to obtain transmit diversity, or to form multiple-input multiple-output (MIMO) channels. It combines multiple-input, multiple-output (MIMO) technology, which multiplies capacity by transmitting different signals over multiple antennas, and orthogonal frequency-division multiplexing (OFDM), which divides a radio channel into a large number of closely spaced subchannels to provide more reliable communications at high speeds.

MIMO-OFDM is a particularly powerful combination because MIMO does not attempt to mitigate multipath propagation and OFDM avoids the need for signal equalization. MIMO-OFDM can achieve very high spectral efficiency even when the transmitter does not possess channel state information (CSI). When the transmitter does possess CSI (which can be obtained through the use of training sequences), it is possible to approach the theoretical channel capacity.

4.5 ADVANTAGES OF MIMO-OFDM SYSTEM

- MIMO-OFDM is a particularly powerful combination because **MIMO** does not attempt to mitigate multipath propagation and **OFDM** avoids the need for signal equalization.
- MIMO-OFDM can achieve very high spectral efficiency even when the transmitter does not possess channel state information (CSI).
- Systems with MIMO offers high QoS (Quality of Service) with increased spectral efficiency and data rates.
- MIMO based system is widely adopted in latest wireless standards viz. WLAN (802.11n, 802.11ac etc.), WiMAX (IEEE 802.16e), LTE, LTE-Advanced etc.

4.6 DISADVANTAGES OF MIMO-OFDM SYSTEM

However, high peak-to-average power ratio (PAPR) of the transmitted signal is a major drawback of the OFDM scheme. Since MIMO-OFDM system is based on OFDM, it also has the same issue .

This high PAPR is sensitive to nonlinear distortion, which is caused by the high power amplifier (HPA).

CHAPTER 5

Space Time Block Codes

5.1 INTRODUCTION

Most work on wireless communications had focused on having an antenna array at only one end of the wireless link usually at the receiver. An alternative approach to utilizing multiple antennas relies on having multiple transmit antennas and only optionally multiple receive antennas. Space–time codes (STCs) achieve significant error rate improvements over single-antenna systems. Their original scheme was based on trellis codes but the simpler block codes were utilised to develop space–time block-codes (STBC).

STC involves the transmission of multiple redundant copies of data to compensate for fading and thermal noise in the hope that some of them may arrive at the receiver in a better state than others. In the case of STBC in particular, the data stream to be transmitted is encoded in blocks, which are distributed among spaced antennas and across time. While it is necessary to have multiple transmit antennas, it is not necessary to have multiple receive antennas, although to do so improves performance.

5.2 SPACE–TIME CODE (STC)

A space–time code (STC) is a method employed to improve the reliability of data transmission in wireless communication systems using multiple transmit antennas. STCs rely on transmitting multiple, redundant copies of a data stream to the receiver in the hope that at least some of them may survive the physical path between transmission and reception in a good enough state to allow reliable decoding.
Space time codes may be split into two main types:

- Space–time trellis codes (STTCs) distribute a trellis code over multiple antennas and multiple time-slots and provide both coding gain and diversity gain. But complexity high.
- Space–time block codes (STBCs) act on a block of data at once (similarly to block codes) and provide only diversity gain, but are much less complex in implementation terms than STTCs.

STC may be further subdivided according to whether the receiver knows the channel impairments. In coherent STC, the receiver knows the channel impairments through training or some other form of estimation. These codes have been studied more widely because they are less complex than their non-coherent counterparts. In noncoherent STC the receiver does not know the channel impairments but knows the statistics of the channel. In differential space–time codes neither the channel nor the statistics of the channel are available.

In MIMO communication systems, array gain means a power gain of transmitted signals that is achieved by using multiple-antennas at transmitter and/or receiver, with respect to SISO case. It can be simply called *power gain*. In a broadside array, the array gain is almost exactly proportional to the length of the array. This is the almost always the case provided that the elements of the antenna are not spaced to a point at which large radiation side lobs form in other directions and that the array length exceeds one or two wavelengths. The power gain of a broadside array is nearly independent of the number of broadside elements as long as both of these conditions are met.

5.2.1 SPACE–TIME BLOCK CODING

It is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. The fact that the transmitted signal must traverse a potentially difficult environment with scattering, reflection, refraction and so on and may then be further corrupted by thermal noise in the receiver means that some of the received copies of the data will be 'better' than others. This redundancy results in a higher chance of being able to use one or more of the received copies to correctly decode the received signal. In fact, space–time coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible.

An STBC is usually represented by a matrix. Each row represents a time slot and each column represents one antenna's transmissions over time.

$$\text{time-slots}\downarrow \overset{\text{transmit antennas}}{\longrightarrow} \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n_T} \\ s_{21} & s_{22} & \cdots & s_{2n_T} \\ \vdots & \vdots & & \vdots \\ s_{T1} & s_{T2} & \cdots & s_{Tn_T} \end{bmatrix} \tag{5.1}$$

Here, s_{ij} is the modulated symbol to be transmitted in time slot $i$from antenna j. There are to be **T** time slots and $\mathbf{n_T}$ antennas as well as $\mathbf{n_R}$ receive antennas. This block is usually considered to be of 'length' **L** . The code rate of an STBC measures how many symbols per time slot it transmits on average over the course of one block. If a block encodes **K** symbols, the code-rate is

$$r = \frac{k}{T} \tag{5.2}$$

Only one standard STBC can achieve full-rate (rate 1) — Alamouti’s code.

5.3 ALAMOUTI’S CODE

Alamouti invented the simplest of all the STBCs in 1998,although he did not coin the term “space–time block code” himself. It was designed for a two-transmit antenna system and has the coding matrix

$$C_2 = \begin{bmatrix} c_1 & c_2 \\ -c_2^* & c_1^* \end{bmatrix} \tag{5.3}$$

where * denotes complex conjugate.

It is readily apparent that this is a rate-1 code. It takes two time-slots to transmit two symbols. Using the optimal decoding scheme discussed below, the bit-error rate (BER) of this STBC is equivalent to $2n_R$-branch maximal ratio combining (MRC). This is a result of the perfect orthogonality between the symbols after receive processing — there are two copies of each symbol transmitted and n_R copies received.

This is a very special STBC. It is the only orthogonal STBC that achieves rate-1. That is to say that it is the only STBC that can achieve its full diversity gain without needing to sacrifice its data rate. Strictly, this is only true for complex modulation symbols. Since almost all constellation diagrams rely on complex numbers however, this property usually gives Alamouti's code a significant advantage over the higher-order STBCs even though they achieve a better error-rate performance.

The significance of Alamouti's proposal in 1998 is that it was the first demonstration of a method of encoding which enables full diversity with *linear* processing at the receiver. Earlier proposals for transmit diversity required processing schemes which scaled *exponentially* with the number of transmit antennas. Furthermore, it was the first open-loop transmit diversity technique which had this capability. Subsequent generalizations of Alamouti's concept have led to a tremendous impact on the wireless communications industry.

5.4 ALAMOUTI STBC

A Simple Transmit Diversity Technique for Wireless Communication, offers a simple method for achieving spatial diversity with two transmit antennas. The scheme is as follows:

1. Consider that we have a transmission sequence, for example $\{x_1, x_2, x_3, \ldots, x_n\}$
2. In normal transmission, we will be sending x_1 in the first time slot, x_2 in the second time slot, x_3 and so on.
3. However, Alamouti suggested that we group the symbols into groups of two. In the first time slot, send x_1 and x_2 from the first and second antenna. In second time slot send $-x_2^*$ and x_1^* from the first and second antenna. In the third time slot send x_3 and x_4 from the first and second antenna.In fourth time slot, send $-x_4^*$ and x_3^* from the first and second antenna and so on.
4. Notice that though we are grouping two symbols, we still need two time slots to send two symbols. Hence, there is no change in the data rate.

5. This forms the simple explanation of the transmission scheme with Alamouti Space Time Block coding.

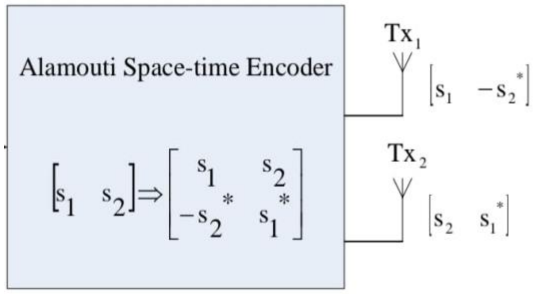


Fig 5.1: Alamouti Space-Time Encoder

CHAPTER 6

STBC and DPC Technique

6.1 INTRODUCTION

The MIMO STBC transceiver structure with two transmitter antennas and one receiver antennas is studied. First, to reduce the complexity at receiver, the STBC-DPC precoding technique is done to achieve the low complexity benefit for mobile station. Besides, to improve the performance of the STBC-DPC system, the channel on/off assignment using water filling algorithm is used. It is obvious to enhance the system performance.

Finally, it is well known that the precoding technique will conduct high PAPR problem. The STBC-DPC system with the modulus operation to limit the transmit signal level, i.e., Tomlinson-Harashima precoding (THP) scheme is proposed to constrain high peak power and retain low peak-to-average power ratio (PAPR) performance.

6.2 DIRTY PAPER CODING

In telecommunications, dirty paper coding (DPC) is a technique for efficient transmission of digital data through a channel subjected to some interference known to the transmitter. The technique consists of precoding the data in order to cancel the effect caused by the interference. Precoding means that multiple data streams are emitted from the transmit antennas with independent and appropriate weightings such that the link throughput is maximized at the receiver output.

Instances of dirty paper coding include Costa precoding. Suboptimal approximations of dirty paper coding include Tomlinson-Harashima precoding and the vector perturbation technique of Hochwald et al. DPC and DPC-like techniques requires knowledge of the interference state in a non-causal manner, such as channel state information of all users and other user data. Hence, the design of a DPC-based system should include a procedure to feed side information to the transmitters.

Recently, there has been interest in DPC as a possible solution to optimize the efficiency of wireless networks, in particular multiuser MIMO networks and into an interference aware coding technique for dynamic wireless networks. Recently, DPC has also been used for “informed digital watermarking”. In wireless communications, channel state information (CSI) refers to known channel properties of a communication link. This information describes how a signal propagates from the transmitter to the receiver and represents the combined effect of, for example, scattering, fading, and power decay with distance. The CSI makes it possible to adapt transmissions to current channel conditions, which is crucial for achieving reliable communication with high data rates in multiantenna systems.

Dirty-paper coding achieves the channel capacity, without power penalty and without requiring the receiver to gain knowledge of the interference state. Dirty paper coding is a coding technique that pre-cancels known interference without power penalty. Only the transmitter needs to know this interference, but full channel state information is required everywhere to achieve the weighted sum capacity. The joint STBC-DPC precoding technique can be used to acquire the spatial diversity and multiplexing gain.

6.3 STBC AND DPC SIGNAL MODEL

In this section, we will introduce the STBC and DPC systems. Then the drawback and benefit of the two systems will be investigated. First, for Alamouti's STBC system , 2-transmit antennas and 1-receiver antenna are used to achieve transmit diversity. That is, in time slot 1, antenna-1 and antenna-2 transmit signal $x1$ and $x2$ and time slot 2 transmit signal $-x2^*$ and $-x1^*$, respectively. The received signal is given by

$$[y_1 \quad y_2] = [h_1 \quad h_2]\begin{bmatrix} x_1 & x_2^* \\ x_2 & -x_1^* \end{bmatrix} + [n_1 \quad n_2] \qquad (6.1)$$

The transmitted signal can be detected by

$$[\hat{x}_1 \quad \hat{x}_2]^{\mathrm{T}} = H^H [y_1 \quad y_2^*]^{\mathrm{T}} = (H^H H)[x_1 \quad x_2]^{\mathrm{T}} + [\tilde{n}_1 \quad \tilde{n}_2] \qquad (6.2)$$

Where $\mathrm{H} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}$ with $\mathrm{H^H H} = \mathrm{diag}\{|\,\mathrm{h}_1\,|^2 + |\,\mathrm{h}_2\,|^2, |\,\mathrm{h}_1\,|^2 + |\,\mathrm{h}_2\,|^2\}$ (6.3)

As shown in above equation, we can find that the diagonal term of **($\mathbf{H^H H}$)** matrix has the transmit diversity. Next, the dirty paper coding system uses the concept of precoding. It involves two characteristics, i.e., interference free and lower receiver complexity. The system structure is shown as follow.

The system is assumed by 2x1 MIMO system, where the transmitted signal can be expressed as

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} \\ 0 & r_{22} \end{bmatrix}^{-1} \begin{bmatrix} r_{11} & 0 \\ 0 & r_{22} \end{bmatrix} \begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \end{bmatrix} \tag{6.4}$$

$$\mathrm{R} = \begin{bmatrix} r_{11} & r_{12} \\ 0 & r_{22} \end{bmatrix} \mathrm{R}_{\mathrm{diag}} = \begin{bmatrix} r_{11} & 0 \\ 0 & r_{22} \end{bmatrix} \tag{6.5}$$

After DPC precoding, the original signal $\tilde{x}_1, \tilde{x}_2$ can be transmitted by x_1 and x_2, the received signal y_1, y_2 can be given by

$$\begin{bmatrix} \mathrm{y}_1 \\ \mathrm{y}_2 \end{bmatrix} = \mathrm{Q}^{\mathrm{H}}\mathrm{H} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{6.6}$$

Next, substituting (6.4)-(6.5) into (6.6), the received signal *y*1, *y*2 can be rewritten by

$$\begin{bmatrix} \mathrm{y}_1 \\ \mathrm{y}_2 \end{bmatrix} = \begin{bmatrix} r_{11} & 0 \\ 0 & r_{22} \end{bmatrix} \begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{6.7}$$

From (4.6), we can see that the received signal *y*1, *y*2 involves a diagonal composite channel matrix. The diagonal matrix can eliminate the interference from multi-streams

6.4 WATER FILLING ALGORITHM (WFA)

In the previous section, we can see the improvement in Bit Error Rate performance by using STBC-DPC system. However, if the composite channel response r_{ii} is degraded, the ML searcher cannot detect the i^{th} symbol $\tilde{x}_i$. In order to overcome the problem, the channel on/off assignment is done by introducing the water filling algorithm. That is, the i^{th} original signal is weighted by the channel pre-assignment factor w_i , i.e.,

$$\tilde{\tilde{x}}_i = w_i \tilde{x} \tag{6.8}$$

where $w_i \in \{0,1\}$ is determined by signal variance, noise variance, and the composite channel response r_{ii} , i.e., water filling algorithm:

$$w_i = \left(\mu - \frac{\sigma_n^2}{|r_{ii}|} \right) > 0 \tag{6.9}$$

With $\mu = \frac{1}{4}\left(\sigma_x^2 + \sum_{i=1}^{4} \frac{\sigma_n^2}{r_{ii}} \right)$ and σ_x^2, σ_n^2 being the signal and noise variance, respectively.

6.5 TOMLINSON-HARASHIMA PRECODING (THP)

It is well known that the precoding technique will induce the high PAPR problem. So, to reduce this problem, Tomlinson-Harashima Precoding Technique is introduced to reduce PAPR. Tomlinson-Harashima Precoding was invented for reducing the peak-to-average power ratio. Due to DPC scheme conducting transmit signal variation, the modulus operation, i.e., THP, is introduced to use for the DPC signal and retain the transmitted signal power. The modulus operation which can be represented as

$$\mathrm{mod}_{\mathrm{A}}(x) = x - 2\mathrm{A}\left[(\mathrm{x} + \mathrm{A} + \mathrm{jA})/2\mathrm{A} \right] \tag{6.10}$$

where x is the DPC signal, A= $\sqrt{\mathrm{M}}$ is the limited signal level, M is M-ary PAM constellations. The TH precoding indeed reduces PAPR. It will be verified in the simulation section.

CHAPTER 7

Results and Conclusion

7.1 SIMULATION RESULTS

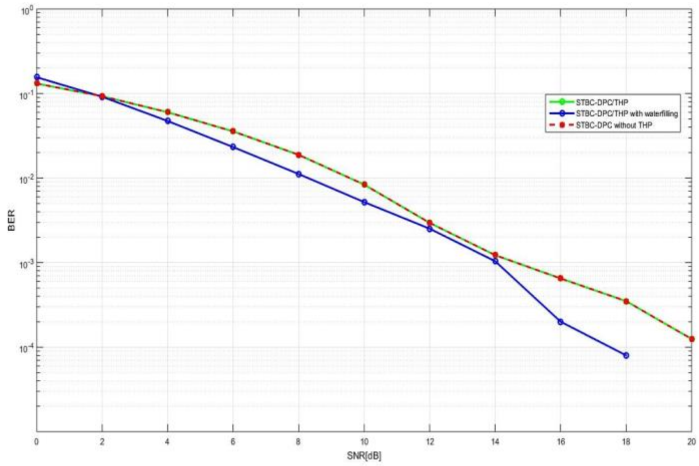


Fig 7.1 : Bit Error Rate Vs Signal to Noise Ratio

This simulation result evaluate the BER performance for the STBC-DPC systems. Figure 17. shows the output BER curves. It is observed that the STBC-DPC/THP with water filling Algorithm can provide better performance than the STBC-DPC/THP and STBC-DPC systems at SNR>24 dB.

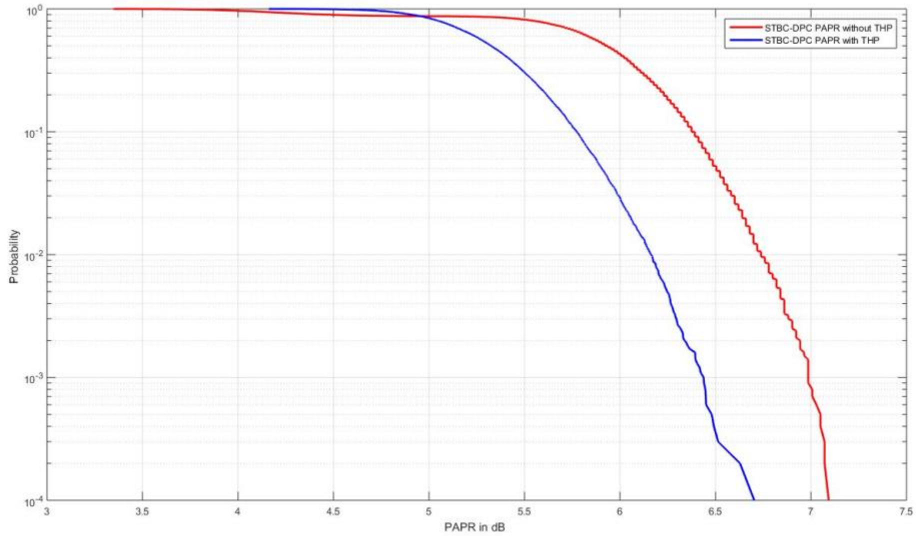


Fig 7.2: PAPR Performance of STBC-DPC system With THP and Without THP

Figure 18 shows the PAPR of STBC-DPC system with THP is demonstrated. It shows that the STBC-DPC with THP system can provide lower PAPR values than without THP system about 1 dB at Probability=10^{-3} . It confirms that the modulus operation of Tomlinson-Harashima Precoding (THP) precoding can limit the DPC signal and attain better PAPR performance.

7.2 CONCLUSION

In the project, we have explained about the MIMO-OFDM system and also about the working of Space time block codes (STBC) and Dirty Paper Coding (DPC). We have understood that STBC-DPC structure not only reduces the complexity, but also improves the Bit Error Rate performance. However, the higher Peak to Average Power Ratio (PAPR) is a drawback about DPC scheme. Finally , the Simulation results conclude that the STBC-DPC/THP system with water filling Algorithm can provide excellent bit error rate (BER) performance and STBC-DPC system with THP precoding technique can limit the DPC signal and attain low PAPR value in the MIMO-OFDM system.

CHAPTER 8

APPENDIX

a) MATLAB Introduction

MATLAB is a high performance language for technical computing .It integrates computation visualization and programming in an easy to use environment. Matlab stands for matrix laboratory. It was written originally to provide easy access to matrix software developed by LINPACK (linear system package) and EISPACK (Eigen system package) projects. MATLAB is therefore built on a foundation of sophisticated matrix software in which the basic element is matrix that does not require pre dimensioning.

Typical uses of MATLAB

1. Math and computation
2. Algorithm development
3. Data acquisition
4. Data analysis, exploration and visualization
5. Scientific and engineering graphics

The main features of MATLAB

1) Advance algorithm for high performance numerical computation, especially in the Field matrix algebra
2) A large collection of predefined mathematical functions and the ability to define one's own functions.
3) Two-and three dimensional graphics for plotting and displaying data
4) A complete online help system
5) Powerful, matrix or vector oriented high level programming language for individual applications.
6) Toolboxes available for solving advanced problems in several application areas

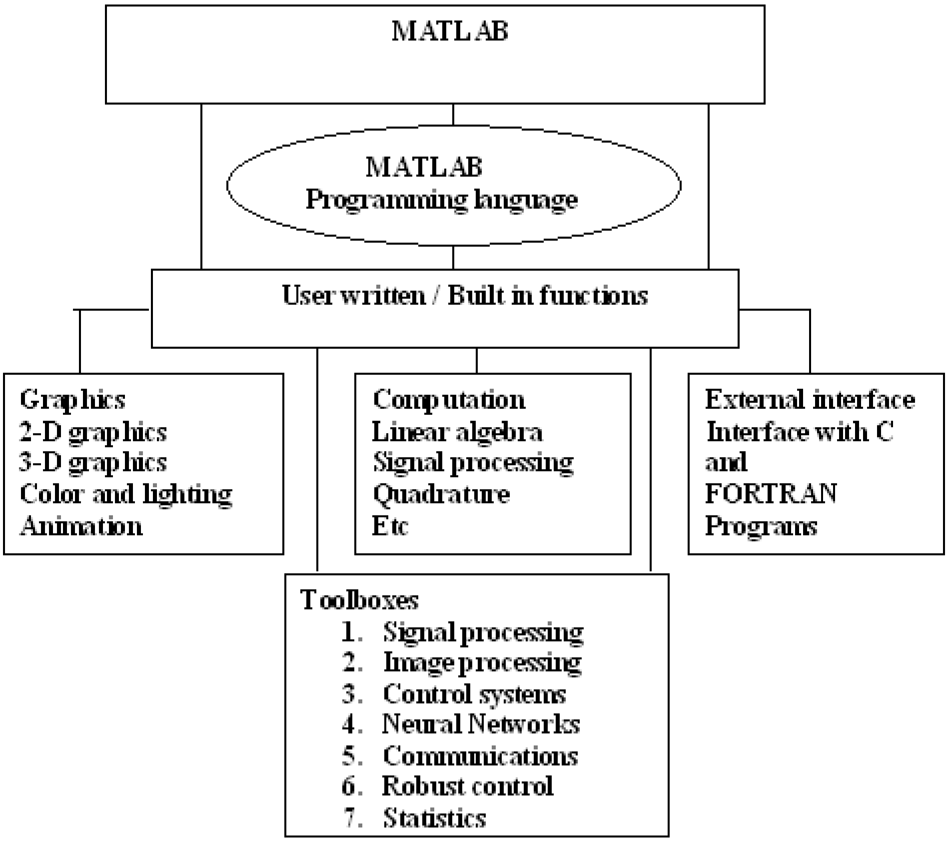


Fig 8.1: Features and capabilities of MATLAB

b) The MATLAB System

The MATLAB system consists of five main parts:

Development Environment:

This is the set of tools and facilities that help you use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, an editor and debugger, and browsers for viewing help, the workspace, files, and the search path.

The MATLAB Mathematical Function Library:

This is a vast collection of computational algorithms ranging from elementary functions, like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix Eigen values, Bessel functions, and fast Fourier transforms.

The MATLAB Language:

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quickly programs, and "programming in the large" to create large and complex application programs.

Graphics:

MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, video processing, animation, and presentation graphics. It also includes low-level functions that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on your MATLAB applications.

The MATLAB Application Program Interface (API):

This is a library that allows you to write C and Fortran programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

Starting MATLAB:

On Windows platforms, start MATLAB by double-clicking the MATLAB shortcut icon on your Windows desktop. On UNIX platforms, start MATLAB by typing mat lab at the operating system prompt. You can customize MATLAB start-up. For example, you can change the directory in which MATLAB starts or automatically execute MATLAB statements in a script file named start-ups

MATLAB Desktop:

When you start MATLAB, the MATLAB desktop appears, containing tools (graphical user interfaces) for managing files, variables, and applications associated with MATLAB.

c) MATLAB Code

Bit Error Rate vs Signal to Noise Ratio:

```
function MAIN_THP();
warning off;
no_iteration=100;  N_packet=100;
order=2;  M=2^order;
mod_obj=modem.qammod('M',M,'SymbolOrder','Gray','InputType','bit');
demod_obj = modem.qamdemod(mod_obj);
N_L=64;
M_L=2;
N_tx=2;   % no of tx antennas
N_rx=1;   % no of rx antennas
no_bits=N_tx*order*no_iteration;
N_tbits_MMSE=no_bits*N_packet;
W_F= DFC_PRECODE(N_L,M_L);
I=eye(N_rx,N_rx);
SNR = [0:2:25];
hhh=waitbar(0.1,'----please wait-----')
for i_SNR=1:length(SNR)
  sigma = sqrt(N_tx*10^(- SNR(i_SNR)/10));
  rand('seed',1); randn('seed',1);
    N_ebits_MMSE=0;
```

```
  for i_packet=1:N_packet
      R=reighley_fading(N_tx,N_rx);
R1=[0.1 0.2 0.05 0.4;0 1 1.2 0.2;0 0 0.8 0.5;0 0 0 0.9];
R=R*R1;
     for i=1:N_L
        cal(i) = norm(R*W_F(:,:,i),'inf');
     end
     [val,Index] = max(cal);
     RW_F = R*W_F(:,:,Index);
     RW_norm = norm(RW_F)^2;
     input_message = randint(no_bits,1);
     [C_tx Scale]=signal_x(no_bits,mod_obj,N_tx,no_iteration,input_message);
R_signalMMSE=MMSE_receive(no_iteration,sigma,N_rx,Index,R,W_F,C_tx,N_tx,S
NR,i_SNR,I);
         ML_MMSE=combiner(RW_F,R_signalMMSE,RW_norm,no_iteration);
           S_hat_MMSE = reshape(ML_MMSE/Scale,N_tx*no_iteration,1);
         s_hat_MMSE = S_hat_MMSE -2*sqrt(M)*floor((S_hat_MMSE
+sqrt(M))/(2*sqrt(M)));
         output_message_MMSE = demodulate(demod_obj,S_hat_MMSE);
         N_ebits_MMSE = N_ebits_MMSE +
sum(output_message_MMSE~=input_message);
  end
```

```
    BER_MMSE(i_SNR) = N_ebits_MMSE/N_tbits_MMSE;
end
figure
semilogy(SNR,BER_MMSE,'-go', 'LineWidth',2);
grid on;
xlabel('SNR[dB]'),
ylabel('BER');
hold on
hhh=waitbar(0.2,'----please wait-----')
pause(0.1)
MAIN_THPwater();
hold on
pause(0.1)
MAIN_wTHP();
pause(0.1)
extendddd();
axis([0 20 0.00001 1]);
legend('STBC-DPC/THP','STBC-DPC/THP with waterfilling','STBC-DPC without
  THP','SFBC-almout');
hhh=waitbar(1,'----process completed-----')
function W_F= DFC_PRECODE(N_L,M);
cloumn_index=[1 2];
```

```
rotation_vector=[1 7 52 56];

kk=0:3;

ll=0:3;

w = exp(j*2*pi/4*kk.'*ll)/sqrt(4);

w_1 = w(:,cloumn_index([1 2]));

theta = diag(exp(j*2*pi/N_L*rotation_vector));

W_F(:,:,1) = w_1 ;

for i=1:N_L-1

   W_F(:,:,i+1) = theta*W_F(:,:,i);

end

function  H=reighley_fading(N_tx,N_rx);

Q=sqrt(2);

H = (randn(N_rx,4)+j*randn(N_rx,4))/Q;

function  [C_tx Scale]=signal_x(no_bits,mod_obj,N_tx,no_iteration,input_message);

     s = modulate(mod_obj,input_message);

      Scale = modnorm(s,'peakpow',1);

      TX_SIGNAL = reshape(Scale*s,N_tx,1,no_iteration);

            X1=TX_SIGNAL(1,1,:);

            X2=TX_SIGNAL(2,1,:);

            C_tx = [X1 -conj(X2); X2 conj(X1)];

function MMSE=mean_error(H_MMSE,N_tx,sigma,SNRdBs,i_SNR,I);

temp_W = H_MMSE'*inv(H_MMSE*H_MMSE'+(N_tx*10^(-
```

```
  SNRdBs(i_SNR)/10)*3/2)*I);
      beta = sqrt(N_tx/trace(temp_W*temp_W'));
      mms = beta*temp_W';
      MMSE=sigma*H_MMSE/mms;
function
  R_signalMMSE=MMSE_receive(no_iteration,sigma,N_rx,Index,H,RW_F,C_tx,N_t
  x,SNR,i_SNR,I);
 for i=1:no_iteration
               H_MMSE = (randn(N_rx,2)+j*randn(N_rx,2))/sqrt(2);
              MMSE=mean_error(H_MMSE,N_tx,sigma,SNR,i_SNR,I);
           R_signalMMSE(:,:,i) = H*RW_F(:,:,Index)*C_tx(:,:,i)+MMSE;
end
function ML=combiner(HW_F,R_signal,HW_norm,no_iteration);
 for i=1:no_iteration
 ML(1,i) = (HW_F(1)'*R_signal(:,1,i)+HW_F(2)*R_signal(:,2,i)')/HW_norm;
  ML(2,i) = (HW_F(2)'*R_signal(:,1,i)-HW_F(1)*R_signal(:,2,i)')/HW_norm;
 end
function MAIN_THPwater();
warning off;
no_iteration=100;  N_packet=100;
order=2;  M=2^order;
mod_obj=modem.qammod('M',M,'SymbolOrder','Gray','InputType','bit');
```

```
demod_obj = modem.qamdemod(mod_obj);
N_L=64;
M_L=2;
N_tx=2;
N_rx=1;
no_bits=N_tx*order*no_iteration;
N_tbits_MMSE=no_bits*N_packet;
W_F= DFC_waterfilling(64,M_L);
I=eye(N_rx,N_rx);
SNR = [0:2:25];
hhh=waitbar(0.4,'----please wait-----')
for i_SNR=1:length(SNR)
   sigma = sqrt(N_tx*10^(- SNR(i_SNR)/10));
   rand('seed',1); randn('seed',1);
    N_ebits_MMSE=0;
   for i_packet=1:N_packet
       R=reighley_fading(N_tx,N_rx);
R1=[0.1 0.2 0.05 0.4;0 1 1.2 0.2;0 0 0.8 0.5;0 0 0 0.9];
R=R*R1;
for i=1:N_L
         cal(i) = norm(R*W_F(:,:,i),'inf');
      end
```

```
    [val,Index] = max(cal);
    RW_F = R*W_F(:,:,Index);
    RW_norm = norm(RW_F)^2;
    input_message = randint(no_bits,1);
    [C_tx Scale]=signal_x(no_bits,mod_obj,N_tx,no_iteration,input_message);
R_signalMMSE=MMSE_receive(no_iteration,sigma,N_rx,Index,R,W_F,C_tx,N_tx,S
NR,i_SNR,I);
        ML_MMSE=combiner(RW_F,R_signalMMSE,RW_norm,no_iteration);
        S_hat_MMSE = reshape(ML_MMSE/Scale,N_tx*no_iteration,1);
        s_hat_MMSE = S_hat_MMSE -2*sqrt(M)*floor((S_hat_MMSE
+sqrt(M))/(2*sqrt(M)));
        output_message_MMSE = demodulate(demod_obj,S_hat_MMSE);
        N_ebits_MMSE = N_ebits_MMSE +
sum(output_message_MMSE~=input_message);
  end
    BER_MMSE(i_SNR) = N_ebits_MMSE/N_tbits_MMSE;
end
semilogy(SNR,BER_MMSE*1.6,'-bo', 'LineWidth',2);
grid on;
xlabel('SNR[dB]'),
ylabel('BER');
hold on
hhh=waitbar(0.6,'----please wait-----')
```

```
function W_F= DFC_waterfilling(N_L,M);
cloumn_index=[1 2];
rotation_vector=[1 7 52 56];
kk=1:4;
ll=0:3;
mu=1;
sigma=0.5;
kk=round(mu-sigma./kk);
w = exp(j*2*pi/4*kk.'*ll)/sqrt(4);
w_1 = w(:,cloumn_index([1 2]));
theta = diag(exp(j*2*pi/N_L*rotation_vector));
W_F(:,:,1) = w_1 ;
for i=1:N_L-1
   W_F(:,:,i+1) = theta*W_F(:,:,i);
end
function MAIN_wTHP();
warning off;
no_iteration=100;  N_packet=100;
order=2;  M=2^order;
mod_obj=modem.qammod('M',M,'SymbolOrder','Gray','InputType','bit');
demod_obj = modem.qamdemod(mod_obj);
```

```
N_L=64;
M_L=2;
N_tx=2;
N_rx=1;
no_bits=N_tx*order*no_iteration;
N_tbits_MMSE=no_bits*N_packet;
W_F= DFC_PRECODE(N_L,M_L);
I=eye(N_rx,N_rx);
SNR = [0:2:25];
hhh=waitbar(0.8,'----please wait-----')
for i_SNR=1:length(SNR)
   sigma = sqrt(N_tx*10^(- SNR(i_SNR)/10));
   rand('seed',1); randn('seed',1);
    N_ebits_MMSE=0;
   for i_packet=1:N_packet
        R=reighley_fading(N_tx,N_rx);
R1=[0.1 0.2 0.05 0.4;0 1 1.2 0.2;0 0 0.8 0.5;0 0 0 0.9];
R=R*R1;
      for i=1:N_L
         cal(i) = norm(R*W_F(:,:,i),'inf');
      end
      [val,Index] = max(cal);
```

```
RW_F = R*W_F(:,:,Index);

RW_norm = norm(RW_F)^2;

input_message = randint(no_bits,1);

[C_tx Scale]=signal_x(no_bits,mod_obj,N_tx,no_iteration,input_message);

R_signalMMSE=MMSE_receive(no_iteration,sigma,N_rx,Index,R,W_F,C_tx,N_tx,S
NR,i_SNR,I);

ML_MMSE=combiner(RW_F,R_signalMMSE,RW_norm,no_iteration);

S_hat_MMSE = reshape(ML_MMSE/Scale,N_tx*no_iteration,1);

s_hat_MMSE = S_hat_MMSE -2*sqrt(M)*floor((S_hat_MMSE
+sqrt(M))/(2*sqrt(M)));

output_message_MMSE = demodulate(demod_obj,S_hat_MMSE);

N_ebits_MMSE = N_ebits_MMSE +
sum(output_message_MMSE~=input_message);

end

BER_MMSE(i_SNR) = N_ebits_MMSE/N_tbits_MMSE;

end

semilogy(SNR,BER_MMSE,'--r*', 'LineWidth',2);

grid on;

xlabel('SNR[dB]'),

ylabel('BER');

function extenddd();

L_frame=130; N_Packets=400; % Number of frames/packet and Number of packets

NT=2; NR=1; b=2;
```

```
SNRdBs=[0:2:18];  sq_NT=sqrt(NT); sq2=sqrt(2);
for i_SNR=1:length(SNRdBs)
   SNRdB=SNRdBs(i_SNR);  sigma=sqrt(0.5/(10^(SNRdB/10)));
   for i_packet=1:N_Packets
      msg_symbol=randint(L_frame*b,NT);
      tx_bits=msg_symbol.';  tmp=[];   tmp1=[];
      for i=1:NT
         [tmp1,sym_tab,P] = modulator(tx_bits(i,:),b); tmp=[tmp; tmp1];
      end
      X=tmp.'; X1=X; X2=[-conj(X(:,2)) conj(X(:,1))];
      for n=1:NT
         Hr(n,:,:)=(randn(L_frame,NT)+j*randn(L_frame,NT))/sq2;
      end
      H=reshape(Hr(n,:,:),L_frame,NT);  Habs(:,n)=sum(abs(H).^2,2);
      R1 = sum(H.*X1,2)/sq_NT + sigma*(randn(L_frame,1)+j*randn(L_frame,1));
      R2 = sum(H.*X2,2)/sq_NT + sigma*(randn(L_frame,1)+j*randn(L_frame,1));
      Z1 = R1.*conj(H(:,1)) + conj(R2).*H(:,2);
      Z2 = R1.*conj(H(:,2)) - conj(R2).*H(:,1);
      for m=1:P
         tmp = (-1+sum(Habs,2))*abs(sym_tab(m))^2;
         d1(:,m) = abs(sum(Z1,2)-sym_tab(m)).^2 + tmp;
         d2(:,m) = abs(sum(Z2,2)-sym_tab(m)).^2 + tmp;
```

```
    end
    [y1,i1]=min(d1,[],2);   S1d=sym_tab(i1).';    clear d1
    [y2,i2]=min(d2,[],2);   S2d=sym_tab(i2).';    clear d2
    Xd = [S1d S2d];   tmp1=X>0;  tmp2=Xd>0;
    noeb_p(i_packet) = sum(sum(tmp1~=tmp2));% for coded
  end % End of FOR loop for i_packet
  BER(i_SNR) = sum(noeb_p)/(N_Packets*L_frame*b*10);
  if i_SNR >6
     BER(i_SNR) = sum(noeb_p)/(N_Packets*L_frame*b*30);
  end
end
semilogy(SNRdBs,BER,'m', 'LineWidth',2),
grid on;  xlabel('SNR[dB]'); ylabel('BER');
function [mod_symbols,sym_table,M] = modulator(bitseq,b)
N_bits = length(bitseq);
if b==1      % BPSK modulation
  sym_table=exp(j*[0 -pi]);  sym_table=sym_table([1 0]+1);
  inp=bitseq;   mod_symbols=sym_table(inp+1);   M=2;
 elseif b==2    % QPSK modulation
  sym_table = exp(j*pi/4*[-3 3 1 -1]); sym_table=sym_table([0 1 3 2]+1);
  inp=reshape(bitseq,b,N_bits/b);
  mod_symbols=sym_table([2 1]*inp+1);   M=4;
```

```
 elseif b==3    % generates 8PSK symbols
   sym_table=exp(j*pi/4*[0:7]); sym_table=sym_table([0 1 3 2 6 7 5 4]+1);
   inp=reshape(bitseq,b,N_bits/b); mod_symbols=sym_table([4 2 1]*inp+1);
   M=8;
 elseif b==4    % 16-QAM modulation
   m=0;  sq10=sqrt(10);
   for k=-3:2:3
      for l=-3:2:3
         m=m+1; sym_table(m) = (k+j*l)/sq10; % power normalization
      end
   end
   sym_table = sym_table([0 1 3 2 4 5 7 6 12 13 15 14 8 9 11 10]+1); % Gray code
mapping pattern for 8-PSK symbols
   inp = reshape(bitseq,b,N_bits/b);
   mod_symbols = sym_table([8 4 2 1]*inp+1);  % maps transmitted bits into 16QAM
symbols
   M=16; %16 constellation points
 else
   error('Unimplemented modulation');
end
```

PAPR Performace:

```
function MAIN_PAPR();

K = 128;%no of subcarriers

Usim = 8;

qpsk_modulation  = [1 -1 j -j];

phase_vector = [1 -1];

total_symbols  = 1e4;

Fs = 5e6;

Fsub = [0:total_symbols-1]*Fs; % Subcarrier spacing.

for nSymbol=1:total_symbols

   Index(1,:)   = randint(1,K,length(qpsk_modulation))+1;

   Index(2:Usim,:) = randint(Usim-1,K,length(phase_vector))+1;

   signal(1,:) = qpsk_modulation(Index(1,:));

   Phase_Rotation = phase_vector(Index(2:Usim,:));

   signal(2:Usim,:) =
repmat(signal(1,:),Usim1,1).*Phase_Rotation*exp(j*2*pi*Fsub(nSymbol)*1/Fs);

    x = 1/sqrt(20)*ifft(signal,[],1);

   Signal_Power = abs(x.^2);

   Peak_Power   = max(Signal_Power,[],2);

   Mean_Power   = mean(Signal_Power,2);

   PAPR_temp = 10*log10(Peak_Power./Mean_Power);

   PAPR_Orignal1(nSymbol) = PAPR_temp(3);
```

```
    PAPR_Orignal2(nSymbol) = PAPR_temp(2);
end
[cdf1, PAPR1] = ecdf(PAPR_Orignal1);
[cdf2, PAPR2] = ecdf(PAPR_Orignal2);
 paprci();
semilogy(PAPR1,1-cdf1,'-r',PAPR2,1-cdf2,'-b','linewidth',2)
xlabel('PAPR0 ');
ylabel('Pr ');
grid on
legend('SFBC CI-OFDM','STBC-DPC PAPR without THP','STBC-DPC PAPR with THP')
function paprci();
ifftn = 128;
zz=1;
symbol_num = 1024;
data_length = ifftn*symbol_num;
j = 0;
data_source = rand(1,data_length);
data_source(find(data_source<0.5)) = -1;
data_source(find(data_source >=0.5)) = 1;
MM=1:.1:10;
data4ifft = reshape(data_source,ifftn,symbol_num);  %S/P
```

```
ccdf1=zeros(1,91);
for i=1:4:symbol_num;
    w1(:,i)=ifft(data4ifft(:,i));
    w1(:,i)=w1(:,i)*ifftn;
    x2=(abs(w1(:,i))).^2;
    m1=mean(x2);
    v1=max(x2);
    papr(i)=10*log10(v1/m1);
    for j=1:91;
        if papr(i)>MM(j);
            ccdf1(j)=ccdf1(j)+1;
        end
    end
    zz=zz+1;
end
ccdf1 = ccdf1./symbol_num;%high
figure
 semilogy([0:0.055:5],ccdf1/0.25,'m');
xlabel('papr(dB)'),ylabel('ccdf')
grid on;
hold on;
```

BIBLIOGRAPHY

[1] M. Costa, "Writing on dirty paper," *IEEE Trans. Info. Theory*, vol. 29, no.3, pp. 439–441, May 1983.

[2] VanNee,R.,deWild,A.,―Reducingthepeak-toaveragepowerratio of OFDM,‖ Vehicular Technology Conference, vol. 3, pp. 2072– 2076, May 1998.

[3] S. Alamouti, "A simple transmit diversity technique for wireless communications,"IEEE J. on Sel. Areas in Comm., vol. 16, pp. 1451-1458, Oct. 1998

[4] A Low-Complexity Precoding Transceiver Design for Double STBC System by Juinn-Horng Deng, Shiang-Chyun Jhan, and Sheng-Yang Huang

[5] S. H. Han and J. H. Lee, ―An overview of peak-to-average power ratio reduction techniques for multicarrier transmission,‖ IEEE Wireless Commun. Mag., vol. 12, pp. 56–65, Apr. 2005.

[6] Y. S. Cho, J. Kim, W. Y. Yang, and C. G. Kang, *MIMO-OFDM Wireless Communications with MATLAB*, Chapter 12 and Chapter 13, John Wiley & Sons (Asia) Pte Ltd, 2010.

[7] MIMO-OFDM Wireless Communications with MATLAB by Yong Soo Cho, Jaekwon Kim, Won Y. Yang, Chung G. Kang , 2010

[8] Reducing the Peak to Average Power Ratio of MIMO-OFDM System by Asim M. Mazin and Garth V. Crosby, International Journal of Computer Networks & Communications (IJCNC) Vol.5, No.3, May 2013.