People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research

University M'Hamed BOUGARA – Boumerdes

Institute of Electrical and Electronic Engineering
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Final Year Project Report Presented in Partial Fulfilment of the Requirements for the Degree of

MASTER

In **Electrical and Electronic Engineering**
Option: **Telecommunications**

Title:

Comparative Study of Unencoded MIMO Systems.

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Registration Number:………/2016

Dedications

I dedicate this work to the persons who will be happy for me by achieving this work, the persons who love me and I love them, the persons who will smile by reading my dedications, the persons who merit more than this.

To My Mother, my Father, My Brother, My Sisters, My Grandmothers, and in the memory of My Grandfathers.

To My friends.

To those who will use this work and benefit from it, To IGEE students and stuff.

I dedicate this work to myself.

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Abstract

The need of reliable and high capacity wireless communication has increased nowadays and to satisfy this need and overcome problems inherent to mobile systems, researchers have proposed the use of Multiple Input Multiple Output (MIMO) methods and they implement it in some nowadays-existing standards. In this Simulink based project we study different SISO systems modulated with (4-FSK, QPSK and DQPSK) and MIMO systems with 4-FSK modulation with and without OFDM. The study shows that the increase in the dimensionality of the system (from 2x2 to 3x3) gives better BER performance and it is enhanced with the use of OFDM technique. MIMO is the initial basis of the 5th generation communication standard that is based on "Massive MIMO". The use of MIMO systems opens the horizon to more reliable communication.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER III: Simulation results

CHAPTER I: Background of MIMO system and OFDM technique

CHAPTER II: Fading & Modulation

CHAPTER III: Simulation results

LIST OF ABRIVIATION

AWGN	Additive-White Gaussian Noise
ASK	Amplitude shift keying
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CSI	channel state information
DFT	Discrete Fourier Transform
DQPSK	Deferential QPSK
DB-GSCMs	Double Bounce Geometry-based Stochastic Channel Models
FDM	Frequency Division Multiplexing
FSK	Frequency Shift Keying
GSCMs	Geometry-based Stochastic Channel Models
ICI	Intercarrier interference
IEEE	Instituted of Electrical and Electronic Engineers
IFFT	Inverse Fast Fourier Transform
ISI	Intersymbole interference
LOS	Line of Sight Component
LTE	Long Term Evolution
MBWA	Mobile broadband wireless access
MIMO	Multiple-input Multiple-output
MISO	Multiple-input Single-output
NRZ	Non-Return to zero
OFDM	Orthogonal Frequency Division Multiplexing
QPSK	Quadrature Phase Shift Keying
RMS	Root Mean Square
SB-GSCMs	Single Bounce Geometry-based Stochastic Channel Models
SIMO	Single -input Multiple -output
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
WMAN	Wireless metropolitan area networks

Introduction

Telecommunication systems have made important advances the last decades, especially in the fields of antennas and antenna arrays. Also, Multi-Input Multi-Output (MIMO) systems gained a considerable part of research and benefits from the advancement in antenna in its implementation.

The MIMO is used in wireless communication by dividing the bandwidth into sub channels and send data streams through these channels using different antennas. MIMO has proven that it is able to enhance the reliability and the capacity of the system. MIMO is usually used with orthogonal frequency division multiplexing (OFDM) modulation, this technique is a good tool in optimizing the use of the bandwidth and it is computationally efficient by applying FFT/IFFT algorithms in its computation. An important problem in wireless communication is the fading phenomenon that causes the signal to change its phase, frequency or add a lag time. This is due mostly to multipath propagation.

In this project, we will study the MIMO system with different settings. Starting by a simple Single-Input Single-output (SISO) system with three modulation schemes (4-FSK, QPSK and DQPSK) with three channel models (Rayleigh Fading, Rician Fading and Additive White Gaussian noise AWGN); then, we will study a 2x2 and 3x3 MIMO system with FSK modulation scheme with and without OFDM. The study aims to compare the Bit Error Rate BER performance of the different systems. We consider only unencoded systems. We used Simulink (MATLAB) to simulate and to create the test systems. We will give more consideration to the practical and physical sides over the mathematical one because MIMO topic is of high mathematical complexity nature that will be studied in later works. The aim of the project is to introduce basic MIMO systems.

Basic MIMO systems are worth studying because they are the first step to Massive MIMO which is the basis of the 5^{th} generation communication system.

Chapter I:

Background of MIMO and OFDM Technique.

1.1 Introduction

Due to the extensive theory the subject of MIMO communication has, it is important to resume some of the crucial points to be able to introduce this subject and work on such a system. In this chapter, we will discuss the importance of MIMO and some theory involved in this topic also we will cover some points in OFDM a well-known technique usually used with MIMO. MIMO get a great importance so why it is used?

1.2 Why use MIMO systems?

MIMO systems are used to overcome some disabilities in simple SISO systems. It is mainly used in wireless communication and in wired one either optical or copper communication. In wireless communication, SISO suffers from the multipath propagation phenomena that made the system less reliable [2]. In MIMO systems multi-antennas at different spatial coordination are used in either the transmitter or the receiver to send or receive signals at different positions to save the maximum of information from being lost.

1.3 MIMO in wireless networks and standards

Due to its performance-enhancing capabilities, MIMO technology was applied in many wireless networks and standards. For MIMO cellular network, the users are separated in spatial dimension in addition to (time, frequency and code) division to ameliorate the reuse of time and frequency resources. In ad hoc networks, MIMO is used for sectorization or diversity and to increase the system capacity. Also MIMO technology is now the core of many widely used wireless standards such as: IEEE 802.16 for wireless metropolitan area networks (WMAN), IEEE 802.20 for mobile broadband wireless access (MBWA) and IEEE 802.11n for Wireless Local Area Network (WLAN) that can exceeds a rate of 200 Mbps for 2X2 MIMO configuration and 40Mhz channels. Also WiMAX, HSPA+ and Long Term Evolution (LTE) standards employs MIMO techniques. [1]

1.4 Importance of MIMO techniques

MIMO took a considerable part in research last decade because of its benefits, here are some of them:

- Higher capacity (bits/s/Hz) (Spectrum is expensive; number of base stations limited).[2]
- Better transmission quality (BER, outage).
- Increased coverage.
- Improved user position estimation. [3]

Several different diversity modes are available and provide the previous advantages:

- **Time diversity:** It uses different timeslots and channel coding to transmit a message at different times. [3]
- **Frequency diversity:** It uses different frequencies. It may be in the form of using different channels, or technologies such as spread spectrum / OFDM.
- **Space diversity:** It is the basis for MIMO. It uses antennas located in different positions to take advantage of the different radio paths that exist in a nature. [4]
- **Spatial diversity:** It refers to transmit and receive diversity. These two methodologies are used to provide improvements in the SNR and the reliability of the system with respect to the various forms of fading.
- **Spatial multiplexing**: It increases the capacity with no additional bandwidth consumption obtained through the use of multiple antennas at both sides of a wireless radio link to transmit different information at each channel.
- **Array gain:** It is the power gain obtained when using spatial diversity with respect to SISO power case.

  The two main types of array gain when combining signals are average power of combined signals relative to the individual average power and the diversity gain related to the probability level of outage. The diversity gain is dependent on spatial correlation coefficients between antenna signals.[5]

1.5 Chanel model

The basic model of an NxM MIMO channel is given by the formula (1.1) and shown in figure 1.1

$$\boldsymbol{y}(t) = \boldsymbol{H}(t) * \boldsymbol{s}(t) + \boldsymbol{n}(t) \quad \textbf{(1.1)}$$

Where: y(t) is the received, s(t) the transmited , n(t) the noise signal and H(t) is the NxM channel matrix.

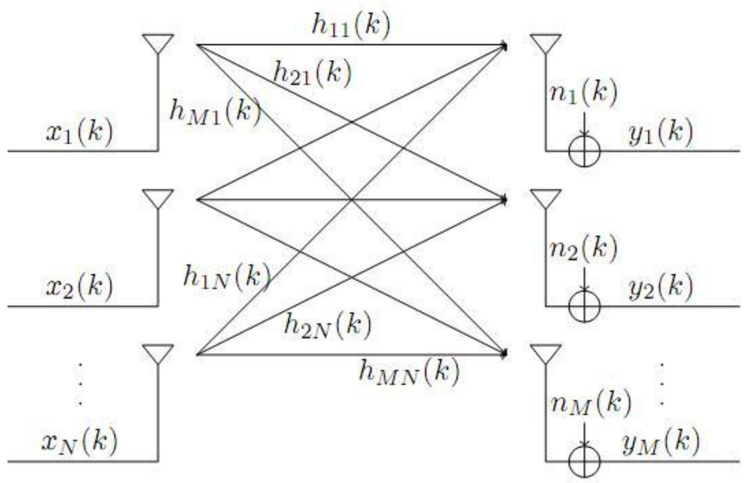

Figure 1.1 MIMO system Basic channel model

1.5.1 MIMO channel propagation models

There are different modeling techniques. to well study a system it is important to have a model that describe its behavior in more realistic manner. MIMO channel modelling has an extensive models, figure 1.2 shows the most important modeling types.

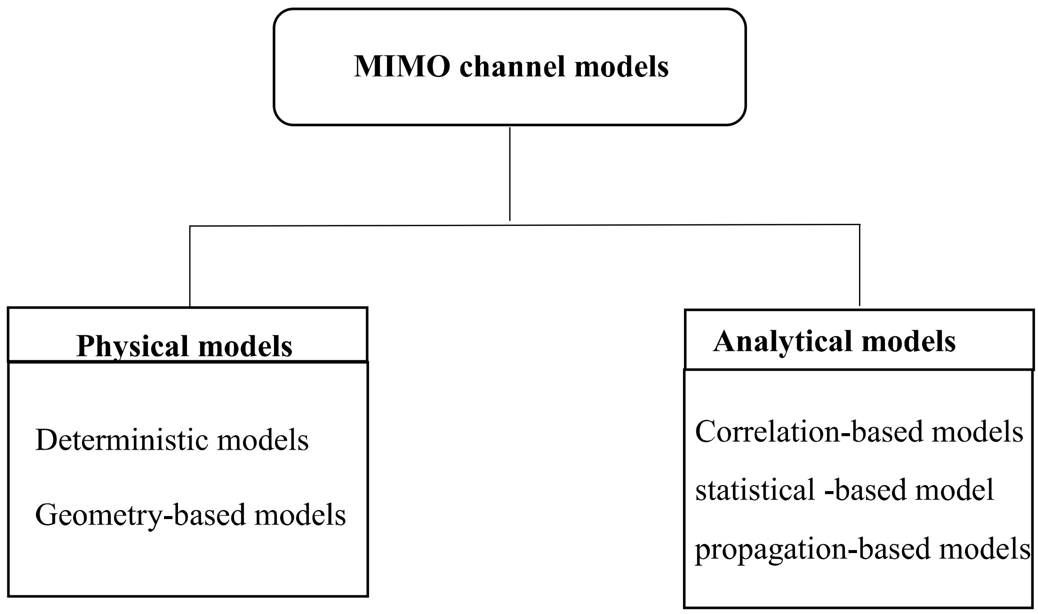

Figure 1.2. MIMO channel propagation models[3]

1.5.1.a Physical models

The MIMO channel model is determined based on the Experimental measurements made for extracting channel propagation parameters including antenna configuration at both the transmitter and the receiver, antenna polarization, scatterers. Physical models include both deterministic models and Geometry-based stochastic channel models (GSCMs). [3]

• Deterministic models define a channel model according to the prediction of the propagation signal.

• Geometry-based Stochastic Channel Models (GSCMs) have an immediate relation with the physical characteristics of the propagation channel. These models suppose that clusters of scatterers are distributed around the transmitter and the receiver. The scatterer's locations are defined according to a random fashion that follows a particular probability distribution. Scatterers result in discrete channel paths and can involve statistical characterizations of several propagation parameters such as delay spread, angular spread and spatial correlation and cross polarization discrimination. We distinguish two possible schemes, which are the Double Bounce Geometry-based Stochastic Channel Models (DB-GSCMs) and the Single Bounce Geometry-based Stochastic Channel Models (SB-GSCMs). That is when a single bounce of scatterers is placed around the transmit antennas or receive antennas.[6]

1.5.1.b Analytical models

The second class of MIMO channel models includes analytical models, which are based on the statistical properties obtained through measurement. Analytical channel models can be classified into correlation-based models (such as i.i.d model, Kronecker model, and Keyhole model), statistical -based models (such as Saleh-Valenzuela model and Zwick model) and propagation-based models (such as Müller model and Finite scatterer model).[3][4]

In our study, we will use the channel model provided by MATLAB Simulink which mainly depends on the "Kronecker model".

1.6 Capacity of MIMO channel

MIMO is used either to increase the transmission data rate via spatial multiplexing, or to improve the system reliability and coverage, via transceiver diversity. When spatial multiplexing is used, MIMO offers capacity gain with respect to SISO, where the SISO channel capacity is given by the standard Shannon formula expressed in bit/s/Hz.

$$C_{siso} = \log_2(1 + SNR.|h|^2) \quad (1.2)$$

Where : - SNR is the signal to noise ratio at the receive antenna

- $|h|^2$ is the normalized channel power characteristic.

The capacity of both MISO and SIMO channels are given by equations (1.3) and (1.4), respectively.

$$C_{miso} = \log_2(1 + \frac{SNR}{N_t}\sum_{i=1}^{N_t}|h|^2) \quad (1.3)$$

$$C_{simo} = \log_2(1 + SNR\sum_{i=1}^{N_t}|h|^2) \quad (1.4)$$

The capacity of an $N_t \times N_r$ single user MIMO system, when no channel state information (CSI) is available at the transmitter, with N_t transmit antennas and N_r receive antenna, in terms of bits/s/Hz is given by equation (1.5)

$$C_{mimo} = \log_2\left[\det(I_{N_r} + \frac{SNR}{N_t}.HH^H)\right] \quad (1.5)$$

Where H is the MIMO channel matrix.

The MIMO channel capacity can also be written in the form of the sum of N_t channels in terms of the HH^H eigenvalues λ_i as follows:

$$C_{mimo} = \sum_{i=1}^{i=N_t}\log_2\left(1 + \frac{SNR}{N_t}.\lambda_i\right) \quad (1.6)$$

To achieve these capacities MIMO uses some technologies one of them is the OFDM.[5]

1.7 Orthogonal Frequency Division Multiplexing

Orthogonal Frequency Division Multiplexing (OFDM) is a new digital modulation technique who consists of transmitting a data stream on several carriers instead of using only one carrier.

OFDM is mainly used on wideband transmissions. It is well suited for transmissions in frequency selective channels. Such a situation is met for example in multipath environments.

1.7.2.a Orthogonality in time domain

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 others over the interval $a < t < b$ if they satisfy the condition of Equation **(1.7)**:

$$\int_a^b \boldsymbol{\varphi_n}(t)\, \boldsymbol{\varphi_m^*}(t)dt = 0 \qquad \textbf{(1.7)}$$

Where n is never equal to m.

As an example, equation **(1.8)** shows a set of orthogonal sinusoids, which represent the subcarriers for an unmodulated real OFDM signal:

$$f(x) = \begin{cases} \sin(2\pi k f_0 t) & 0 < t < T \; k = 1,2,\ldots M \\ 0 & , \text{ otherwise} \end{cases} \qquad \textbf{(1.8)}$$

Where f_0 is the carrier spacing, M is the number of carriers, T is the symbol period. Since the highest frequency component is Mf_0, the transmission bandwidth is also then Mf_0. These subcarriers are orthogonal to each other because when we multiply the waveforms of any two subcarriers and integrate over the symbol period the result is zero. Multiplying the two sine waves together is the same as mixing these subcarriers. This results in sum and difference frequency components, which will always be integer subcarrier frequencies, as the frequency of the two mixing subcarriers has integer number of cycles. Since the system is linear, we can integrate the result by taking the integral of each frequency component separately then combining the results by adding the two sub-integrals. The two frequency components after the mixing have an integer number of cycles over the period and so the sub-integral of each component will be zero, as the integral of a sinusoid over an entire period is zero. Both the sub integrals are zeros and so the resulting addition of the two will also be zero, thus we have established that the frequency components are orthogonal to each other.[7]

1.7.2.b Orthogonality in frequency domain

Another way to view the orthogonality property of OFDM signals is to look at its spectrum. In the frequency domain, each OFDM subcarrier has a sinc (*sin(x)/x*) frequency response, as shown in Figure 1-4 decays slowly away from the center. Each carrier has a peak at the center frequency and nulls evenly spaced with a frequency gap equal to the carrier spacing. The orthogonal nature of the transmission is a result of the peak of each subcarrier corresponding to the nulls of all other subcarriers. [8] When this signal is detected using a Discrete Fourier Transform (DFT) the spectrum is not continuous, but has discrete samples. The sampled spectrums are shown as ‘o’ in the complexity. A practical design choice for the symbol time is to be at least five times the guard time, which leads to a reasonable SNR loss. [3]

1.8.3 Number of Sub-carriers

After setting the symbol duration, the number of sub-carriers required can be found by first calculating the sub-carrier spacing which is just the inverse of the symbol time. The number of sub-carriers is the available bandwidth divided by the sub-carrier spacing. [7]

1.8.4 Modulation and Coding Choices

The first step is determining the number of bits carried by an OFDM symbol. Then, by assuming that each channel is almost AWGN, a suitable combination of modulation and coding techniques can be chosen to fit the input data rate into the OFDM symbols and, at the same time, satisfying the bit-error rate requirements.

1.9 Advantages of OFDM

OFDM technique enhance the system by providing the following benefits:

- A very efficient use of the spectrum by allowing carrier overlapping.
- More resistive to frequency selective fading by dividing the channel into narrow band flat fading channel.[8]
- Reduces ISI and ICI with the use of guard interval via cyclic prefix.
- Channel equalization.
- Computationally efficient by the use of FFT and IFFT algorithms[7]
- Recover symbols lost caused by frequency selectivity by employing adequate channel coding and interleaving techniques.

1.10 Conclusion:

From this chapter we can conclude that MIMO system can provide an improvement in the communication system by either enhancing the capacity compered to SISO and/or increasing its reliability through minimizing the BER. OFDM it is a convenient technique that can be used with MIMO due to its use of multicarrier to transmit data. These techniques combined with an appropriate modulation scheme can be used to protect information from multipath propagation phenomena and fading.

Chapter II:

Fading and Modulation.

2.1 Introduction

An important problem in telecommunication system that MIMO can reduce its effects is the multipath fading. It is useful to understand this phenomena, its causes and how it effects the propagated signal and to mention the different modulation schemes that can be used in combination with OFDM.

2.2 Causes of Fading

Fading is caused by different physical phenomenon that occur to the wave during its propagation and make some changes in the signal mainly the time delay, phase shift and frequency shift, these changes are caused by the following effects:

2.2.1 Doppler Shift

When a mobile is moving at a constant velocity v along a path, $\boldsymbol{vs}$ is the velocity of the source, f' is the observed frequency and f is the emitted frequency. All these terms will ±be related by the following equation:

$$\boldsymbol{f'} = (\boldsymbol{v}/(\boldsymbol{v} \pm \mathrm{vs}))\boldsymbol{f} \qquad \textbf{\textit{(2.1)}}$$

From the above equation, that the detected frequency increases for objects moving towards the observer and decreases when the source moves away. This phenomena is known as the Doppler Effect.[9]

2.2.2 Reflection

It occur when a propagating electromagnetic wave imposes on object having a large dimensions compared to wavelength of the propagating wave. Actually, we know that if the plane wave is incident on a perfect dielectric, part of the energy is transmitted and part of the energy is reflected back into the medium. If the medium is a perfect conductor, all the energy is reflected back. Reflections occur from the surface of the earth and from buildings and walls. In practice, not only metallic materials cause reflections, but dielectrics also cause this phenomenon.[10]

2.2.3 Diffraction

The sharp irregularities (edges) of a surface between transmitter and receiver and obstructs the radio path then diffraction will occurred. The bending waves around the obstacle, even when a Line of Sight does not exist between transmitter and receiver the secondary waves will be spread over the space. Diffraction looks like a reflection at high frequencies depends on the amplitude, phase and polarization of the incident wave and geometry of the object at the point of diffraction.

2.2.4 Scattering

The wave travels through the medium consists of smaller dimension objects compared to the wavelength and having larger volumes of obstacles per unit volume, then scattering will occurred. Due to rough surfaces, small objects and irregularities in the channel-scattered waves are produced.[11]

Since there are different causes of fading there are several types of fading discussed in the next section.

2.3 Types of Fading

According to the effect of multipath, there are two types of fading [12]

a) Large Scale Fading, In this type of fading, the received signal power varies gradually due to signal attenuation determined by the geometry of the path profile.
b) Small Scale Fading If the signal moves over a distance in the order of wavelength, in small scale fading leads to rapid fluctuation of the phase and amplitude of the signal.

In our study we are interested in small scale fading, the following subsection discuss it.

2.3.1 Types of small scale fading

There are many models that describe the phenomenon of small-scale fading. Out of these models, Rayleigh fading, Rician fading and Nakagami fading models are most widely used.

a) **Rayleigh fading model:**

   The Rayleigh fading is primarily caused by multipath propagation. It is a statistical model for the effect of a propagation environment on a radio signal. It is a reasonable model for troposphere and ionospheres‟ 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 line of sight between the transmitter and receiver, which is more probable in real situations.[9]

b) **Ricean fading model:**

   The Rican fading model is similar to the Rayleigh fading model, except that in Ricean fading, a strong dominant component is present. This dominant component is a stationary (non-fading) signal and is commonly known as the LOS (Line of Sight Component). [9]

c) **Additive White Gaussian Noise Model**

The simplest radio environment in which a wireless communications system or a local positioning system will have to operate is the Additive-White Gaussian Noise (AWGN) environment. Additive white Gaussian noise (AWGN) is the commonly used to transmit signal while signals travel from the channel and simulate background noise of channel [11]. The mathematical expression in received signal that passed through the AWGN channel is:

$$r(t) = s(t) + n(t) \tag{2.2}$$

where s(t) is transmitted signal and n(t) is background noise

2.4 Signal to Noise Ratio (SNR)

SNR is the ratio of the received signal strength over the noise strength in the frequency range of the operation. It is an important parameter of the physical layer. Noise strength, in general, can include the noise in the environment and other unwanted signals (interference). BER is inversely related to SNR, that is high BER causes low SNR. High BER causes an increase in information loss, increase in delay and decreases throughput. The exact relation between the SNR and the BER is not easy to determine in the multi-channel environment. Signal to noise ratio (SNR) is an indicator commonly used to evaluate the quality of a communication link, measured in decibels, and represented by Eq. (2.3). [12]

$$\mathbf{SNR = 10 \log_{10}(Signal\ Power\ /\ Noise\ Power)\ dB.} \tag{2.3}$$

2.5 Bit Error Rate (BER):

The BER or quality of the digital link is calculated from the number of bits received in error divided by the number of bits transmitted.

BER= (Bits in Error) / (Total bits received) **(2.4)**

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. The BER is the number of bit errors divided by the total number of transferred bits during a particular time interval. BER is a unit less performance measure, often expressed as a percentage. [13]

2.6 MODULATION AND DEMODULATION TECHNIQUES

To transmit an information from a source the information, streams need to be modulated in a transmittable signal with a specific carrier. At the receiver the inverse is done to recover the data from this signal, this operation is referred to as demodulation. Techniques of the modulation usually put the information in either the amplitude, the phase or frequency of the signal. It is helpful to mention some of the techniques that will be used in this study.

2.6.1 Binary Phase Shift Keying (BPSK)

(a) BPSK Modulation

In BPSK modulation, the phase of the RF carrier is shifted 180 degree in accordance with a digital bit stream. A "one" causes a phase transition, and a "zero" does not produce a transition. In BPSK modulator, phase of carrier is varied represent binary 1 or 0. Both peak amplitude remains constant as phase changes. For example, if we start a phase of o degree to represent binary "1", then we can change the phase to 180 degree to send binary "0".figure shows below the generation of BPSK with clock signal .pattern or baseband data, 1bit encoded. Normal sine wave or carrier is transmitted for logic 1.As shown in the waveform.

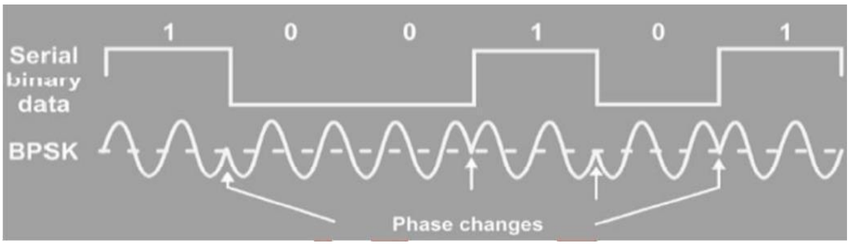

Figure 2.1: phase change of frequency with binary signal

(b) BPSK demodulation

The incoming modulated BPSK signal is multiplied with carrier signal generated from the carrier generator. The output of the multiplier contents high frequency and low frequency components. The integrator blocks integrate multiplier output. With help of comparator, received signal is compared with different threshold.

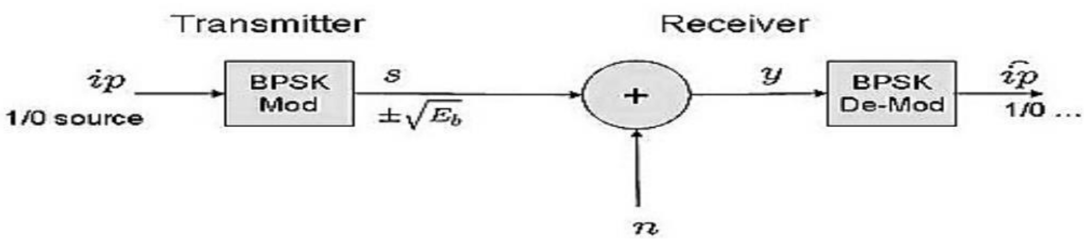

Figure 2.2: BPSK modulation and demodulation

2.6.2 Quadrature Phase Shift Keying (QPSK)

a) QPSK modulation

The binary bit stream or massage signal passes through line coding such as bipolar NRZ. The output signal of the NRZ encoder is multiplied with cosine and sine representing two term real and imaginary. The phase changes according to the order of successive bits defining the symbol. This scheme is shown in figure 2.3.

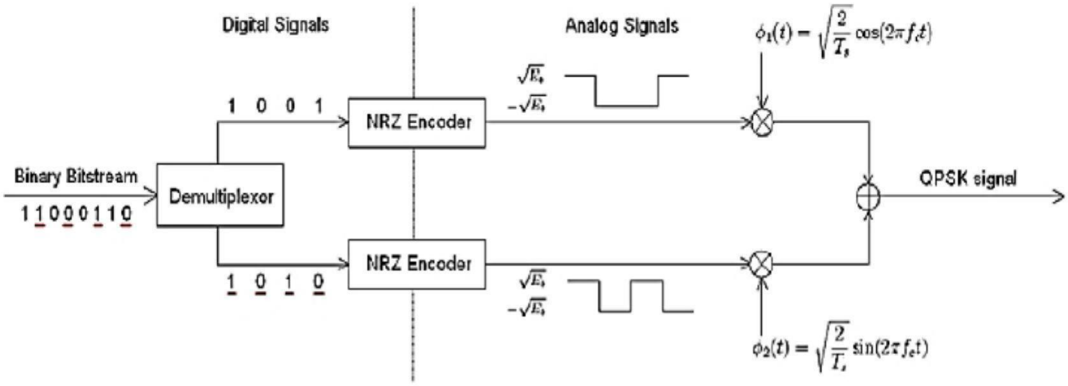

Figure 2.3: QPSK modulation

(b) QPSK demodulation

To get our original bit stream, the modulated signal passes through a matched filter tuned at the two orthonormal signals (cosine and sine) or an integrate and dump receiver. Then the depending on the sign of the magnitude of this signal the bis are decided. '0' if the magnitude is negative and '1' if it is positive. As shown in figure 2.4.

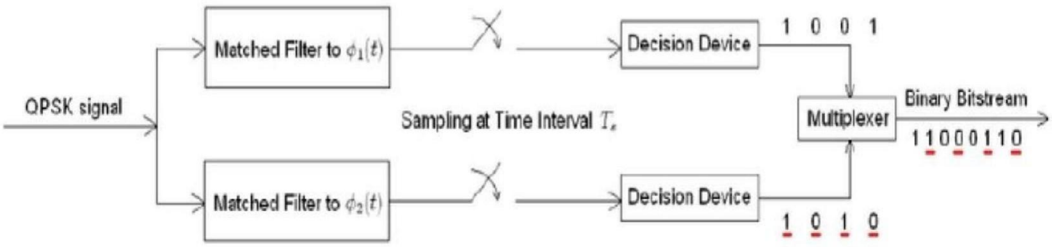

Figure 2.4: QPSK demodulation

2.6.3 Amplitude shift keying (ASK)

a) ASK modulator

In ASK modulators, level of amplitude are used to represent bits .We can think of carrier signal as an ON or OFF Switch. In modulated signal logic 0 is represented by the absence of carrier, thus giving OFF/ON keying operation and hence the name given mathematically equation of ASK.

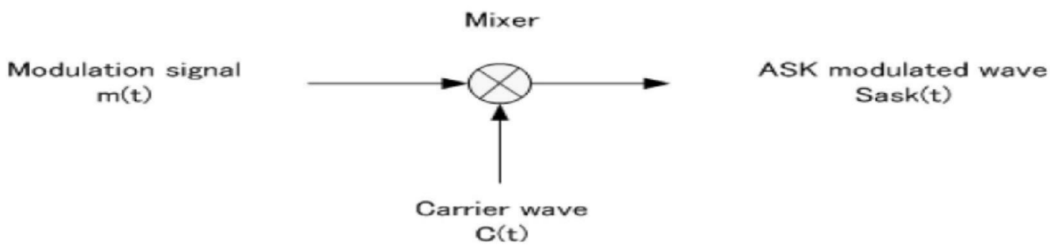

Figure 2.5: ASK modulation

b) ASK Demodulators

At receiver side ASK modulated signal is multiplied by the carrier signal in which is generated from the carrier generator. The output of the multiplier consists of high and low frequency components this output of integrated and passed by Comparator block. Comparator blocks recover digital data by comparing threshold values with the integrated signal.

 ASK waveform act as ON/OFF. Pulse shaping can be employed to remove spectral spreading.

 ASK poor performance, as it is heavily affected by noise, fading and interference.

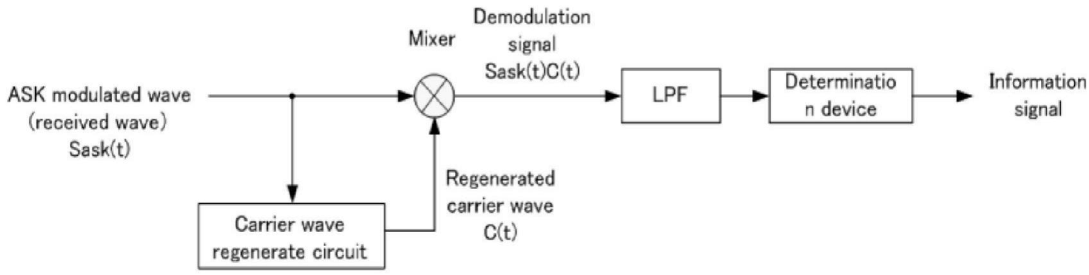

Figure 2.6: block diagram of ASK demodulation

2.6.4 Frequency Shift Keying (FSK)

a) FSK Modulator

In frequency shift keying, the frequency of carrier's shifted according to the binary symbol. The phase of carrier is unaffected. That is we have to different frequency signals according to binary symbols. Each symbol is modulated with carrier at different frequencies. A BFSK system is shown in figure 2.7.

b) FSK Demodulator

It has been proven that an optimum FSK receiver is no more than a band pass filter. To recover the sent signal, the received signal is multiplied by each carrier signal and integrated then the decision is made in preference of the maximum one. [14]

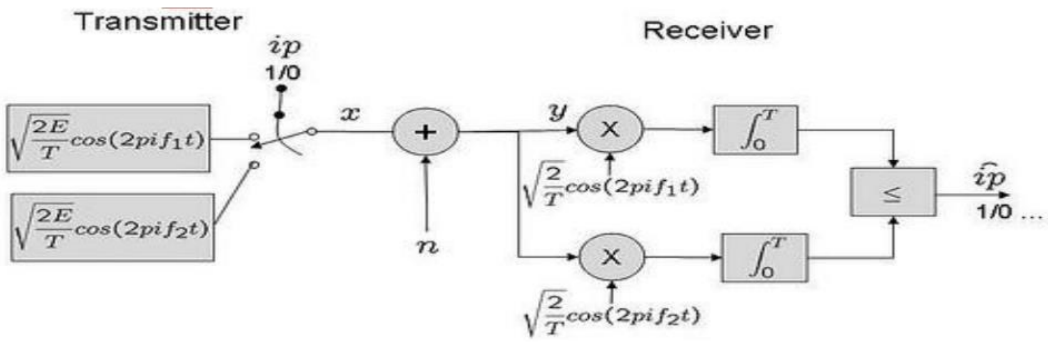

Figure 2.7: Block Diagram of FSK

2.7 Conclusion:

This chapter gives an overview of some important points that should be known before working on or simulate some telecommunication systems. We have seen the fading effects and causes and the influence of noise on the error occurrence and some modulation schemes. This background permit the start of simulating some proposed systems.

Chapter III:

Simulation and Results.

3.1.Introduction

In the previous chapters, we have discussed some important concepts about MIMO systems and the effects of propagation on signals. In this chapter, we will simulate the studied effects using Simulink MATLAB for deferent modulation schemes manly FSK, QPSK and DQPSK. Also, we will investigate OFDM systems through MIMO channels with Rayleigh fading.

3.2.Simulation Procedure

In our work that aims to compare some different modulation schemes in different conditions, we followed a procedure that relies on the models provided by Simulink MATLAB software. We have chosen this software for manly two reasons:

1. Simulink provides a simpler way to obtain the required results.
2. The advance in the models and the computational methods in MATLAB.

We used the predefined blocks provided because our main objective is to study the performance of the systems and not to model the channel nor to build elements of the system.

Our works relies on the following methodology:

1. Set the channel model and other parameters.
2. Set the modulation scheme.
3. Vary the SNR and get the results: BER, BER vs SNR graph and constellation when possible.
4. Differ the parameters of the same system.
5. Change the modulation scheme and edit the system if required.
6. Differ the channel model and redo the same steps.

We did this for 1x1(SISO), 2x2 and 3x3 MIMO Wireless channels we focused on Rayleigh fading and we used AWGN model for SISO and Rician fading for QPSK.

To ensure that the simulated systems are correct each time we do a test step by removing any noise or fading and ensure that the BER=0%. The comparison is done between deferent modulation schemes of the same system and between either the best or the worst results of deferent systems or models. In this study, we used simple systems and we did not simulate standard systems such as LTE or 3GPP where MIMO is applied because this does not contribute to the objective of the study.

We used MATLAB R2016a trial version because it has a predefined OFDM and MIMO channel blocks. In the next section, we will investigate the systems we have simulated and discuss the obtained results.

3.3.Simulation and results

As we mentioned in the previous section, the deferent experiment depends on varying the used techniques. Table 3.1 resumes these experiments.

Number of Antennas N_t x N_r	Channel models	Modulation schemes
SISO 1x1	- AWGN. - Rayleigh Fading. - Rician Fading.	- 4-FSK - QPSK - DQPSK
MIMO 2x2	- Rayleigh Fading.	- 4-FSK - OFDM 4-FSK
MIMO 3x3		

Table 3.1: The studied systems.

From the previous table we can see that we have 9 combinations for SISO and 6 for MIMO because we used 1-symbol and 2-symbols OFDM. We think about changing the parameters (number of paths, Maximum Doppler shift …etc.) in the channel for each system but this will just increase the combinations uselessly. We tried some changes as extra experiments of this project since its aim is to compare MIMO dimensions and modulation schemes these parameters will be fixed through all the experiments.

3.2.1SISO(1x1) system

SISO system is considered as a special case of MIMO where N_t=N_r=1.

3.2.1.a AWGN Channel

Starting by AWGN channel model we built the system shown in figure 3.1 for 4-FSK scheme for other modulation we just change the modulator and the demodulator blocks.

The integer generator is used to generate four different symbols, the integer to bit converter block is used to make the BER measurement possible instead of SER (Symbol Error Rate) also we used Align signals block to ensure that no delay between the sent and received signals. Actually, for the AWGNC no delay is introduced by the used blocks but in later systems the align block will has a great importance. The signal to workshop block is used to be able to exploit the BER results in workspace and to draw the BER vs Eb/No graphs.

For QPSK and DQPSK we just change the modulator/ demodulator blocks for each one. The results we get and the theoretical BER vs. Eb/No are shown in figure 3.2. Each used modulation has a 4-symbol alphabet {0, 1, 2, 3}. The difference between the theoretical and the simulation is due to the change in simulation conditions such as the noise, the number of samples and the separation frequency for FSK etc…

Discussion: From Figure 3.2, it is clear that the theoretical and simulated results are not exactly the same even though they have the same shape. The simulated has greater BER and this is due the fact that the theoretical usually gives just a lower bound of the probability of error. Also we can see that the more effected modulation scheme is the DQPSK that gives the highest BER compared to both QPSK and 4-FSK since the Additive noise effects the amplitude the most and since it is white, its contribution in change of the signal spectrum will be effect less since it add the same amount to all frequencies. And since the information is conserved in the frequency of the signal for the FSK scheme this can justify the lower BER for the 4-FSK. This channel effects the QPSK signal by changing its amplitude so that the symbol can be interpreted as its opposing one. Also the settings of the channel block plays a role in having results differing from theory.

3.2.1.b Rayleigh and Rician channels

The same procedure is done for Rayleigh and Rician fading channels for the three selected modulation schemes. Our interest is in the Rayleigh fading because it is the most probable in real wireless communication situations where the line of sight is usually unavailable only in some rare cases when the user is outside any building and there is no barrier between the user and the base station. Figures 3.4 and 3.5 show examples of the systems used in this experiment, the channel is a cascade of either Rayleigh or Rician Fading channel with AWGN channel because this design is better than adding a source of noise to the output of the fading channel and gives more realistic simulation [10]

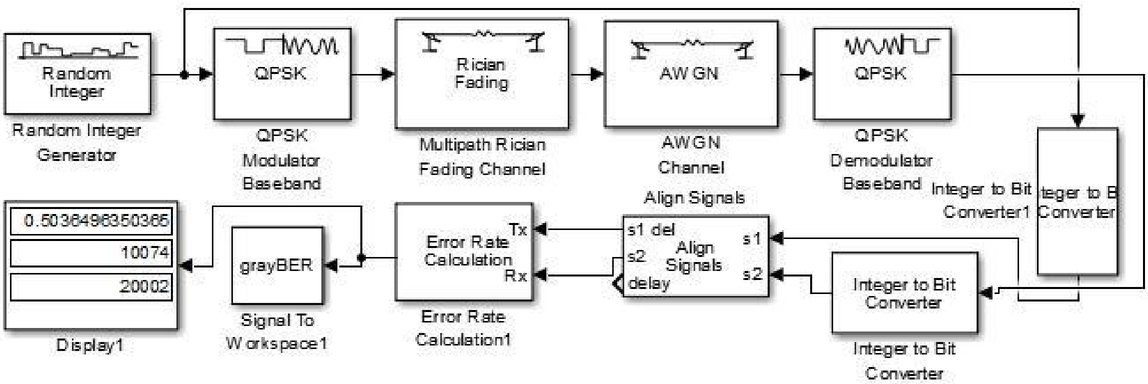

Figure 3.4: Block Diagram of a QPSK system through Rician Fading channel.

As mentioned in chapter 2, fading has effects on three main parameters of the signal either the frequency, the phase or the lag. The change in frequency is caused when there is a mobility in the channel; in our study, we assume low mobility conditions by taking the maximum Doppler shift to be 0.001 Hz and we set three paths with different gains. From this configuration of the

3.2.2 MIMO system

Now, to take advantage of the spatial diversity we increase the number of channels in the used systems and increase the number of transmit and receive antennas and use different systems to measure the BER of these systems and verify whether it is enhanced or not?

We will study two systems the first is a simple MIMO and the second is a MIMO OFDM system with 2-FSK modulation scheme. MIMO is mainly used either to increase the capacity by exploiting the spatial multiplexing or increasing the reliability through the time diversity. In our experiments, we will send the same data through the different channels (time diversity) to study the benefits of MIMO in enhancing the BER.

3.2.2.a MIMO system modulated with 4-FSK scheme

To test a simple MIMO system modulated with FSK for four symbols source we have built the system shown in figure 3.9 the system takes the same signal from the 4-FSK modulator and input it to the 2x2 channel at the output of the channel the two received signals are added and averaged then it is demodulated. The use of the integer to bit converter blocks is to measure the Bit Error Rate instead of the Symbol Error Rate (SER). MIMO channel is set to Rayleigh fading with three different delays. The configuration of the system is shown in table 3.1.

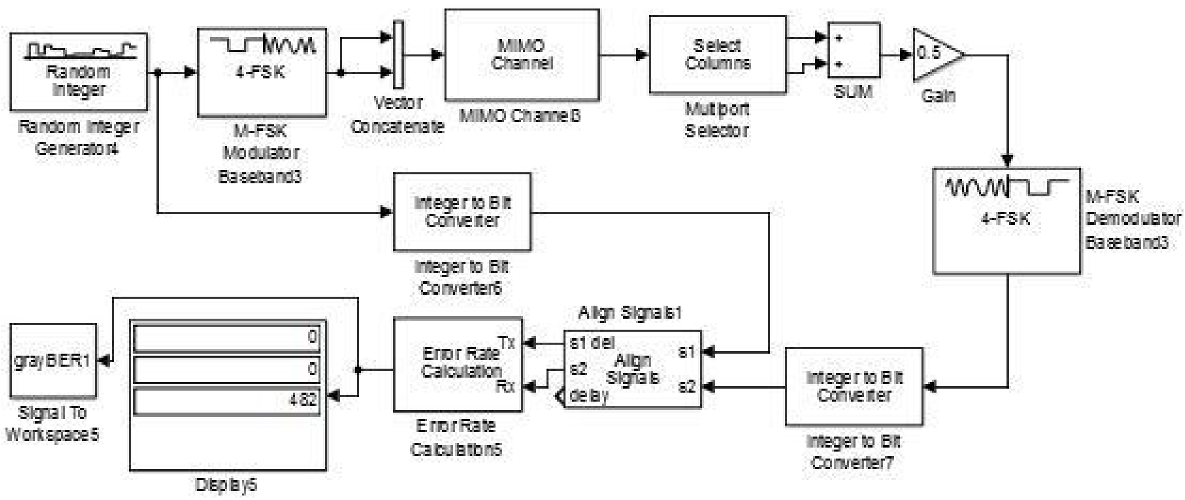

Figure 3.9: simple 2x2 MIMO system.

Type of Fading	Rayleigh
Path Delays (μs)	[0.1 1 1.5]
Path gains (dB)	[-3 -10 -10]
Maximum Doppler shift Hz	0.01
Eb/No (dB)	5

Table 3.2: System configuration.

With the same configuration we built a 3x3 MIMO system that sends the same data in three channels as shown in figure 3.9 also it is easy to edit the design to be 4x4.

In this experiment we are not interested in the study of the system performance by the variation of noise so we fix it and compare the BER of the different systems as the N_T and N_R varies. The results are given in table 3.3

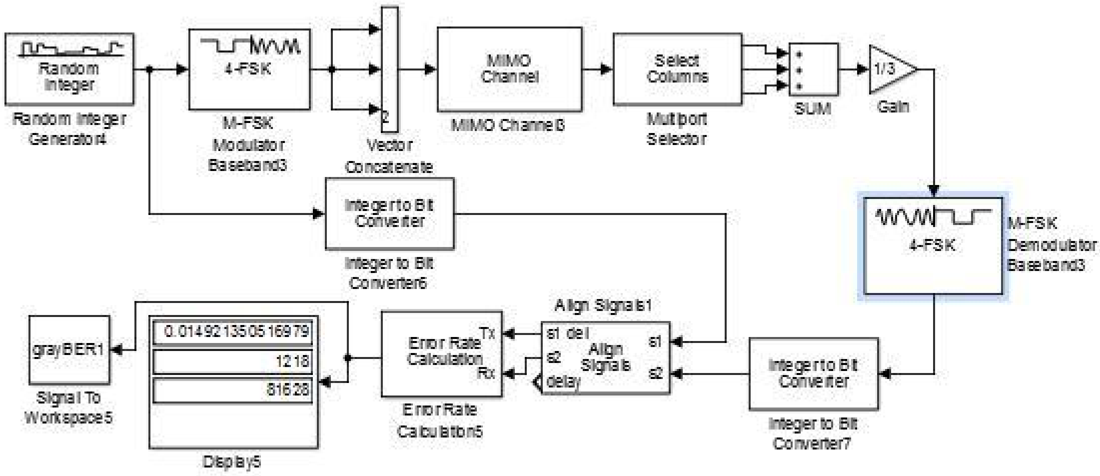

Figure 3.10: simple 3x3 MIMO system.

System	1x1	2x2	3x3	4x4
BER(%)for SNR= 5dB	14.14	11.15	8.29	10.04

Table 3.3: BER of some MIMO systems.

Discussion

From the above table it is clear that a 3x3 is better than a 2x2 and 2x2 is better than 1x1 in terms of the BER analysis. By adding two antenna one at the transmitter and another at the receiver, the error reduced by 3% that is equivalent of adding 1 dB to the SNR in the SISO system or increase the bit energy 25% the original one. The reduction of the error for 3x3 with respect to the 2x2 one is 2.86% is less than the previous one but it is still better and it can be achieved in SISO system by increasing the SNR by 3dB, in other words, by doubling the bit energy. We can see that by using the same power, the BER is reduced by 5.85% just by extending the 1x1 system to 3x3 system. For the 4x4 system, the BER increases 1.75% compared to the 3x3. We can explain this by the fact that increasing in the dimensionality of the MIMO system leads to more complexity and increase the effect of the multipath fading, and the system we used is just a simple one. In theory the complexity of the MIMO system increases when the dimension exceeds 8X8 and enter in another case of MIMO which is MASSIVE MIMO or “large scale MIMO”.

3.2.2.b MIMO system with OFDM modulation

Trying to enhance the previous MIMO system, we employed OFDM technique and measure the BER. Since this technique reduces the effect if ISI and ICI with guard intervals by adding cyclic prefixes. We expect this technique to reduce the BER by eliminating errors caused by ISI and ICI. The block diagram is shown in figure 3.10.

The OFDM block has many crucial settings to edit to get the system work properly. These settings are: the FFT length, number of guard bands, number of OFDM symbols, cyclic prefix length and the number of transmit antennas. OFDM technique can be used in SISO as so in MIMO in our study we focus on its use in MIMO systems.

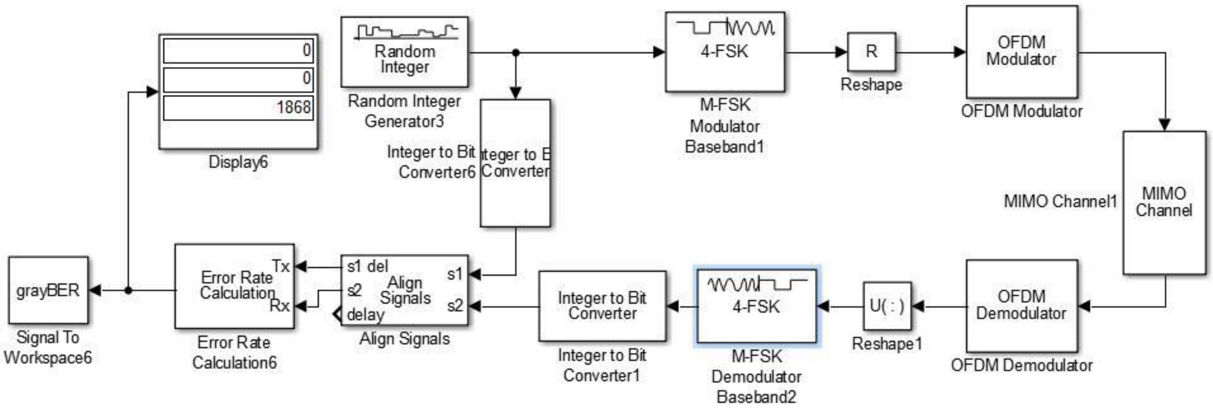

Figure 3.11 Diagram MIMO system with OFDM Modulation

How to set the OFDM parameters?

The OFDM blocks needs accurate setting because of their input and output dimensions. The OFDM modulator must have a 3D input signal and gives 2D output signal and the inverse for the demodulator. That is why the reshape blocks are used in the design.

In our system we didn't use the pilot carriers and we used one cyclic prefix and for the guard interval we used [6; 5] where 6 is the left guard and 5 is the left guard. The FFT length is set to 128 and no DC nulls are inserted. These data restricts the number of samples per symbol in the FSK blocks where the sample per symbol in our case is given by:

$$N_{samples} = \left(N_{FFT} - N_{Glf} \_ N_{GR}\right)\left(N_T * N_{sym}\right) \quad (3.10)$$

$$N_{samples} = (128 - 6 - 5)\left(N_T * N_{sym}\right) = 117\left(N_T * N_{sym}\right) \quad (3.11)$$

Where: N_{FFT}: is the FFT length.

N_{GR}: is the number of Right guard intervals.

N_{Glf}: is the number of left guard intervals.

N_{sym}: is the number of the OFDM symbols.

N_T: is the number of the transmit antenna.

We have ($N_T = N_R$) and we will simulate the system for two N_R and N_T values and for two different numbers of OFDM symbols, this gives four situations as explained in table3.4.

N_T or N_R	Number of OFDM symbols	Number of Samples per symbol	Configuration Name
2	2	468	A
2	3	702	B
3	2	702	C
3	3	1053	D

Table 3.4 Configuration of the simulated OFDM Systems.

The configurations are named just to make the discussion more simpler.

For a fixed Eb/No=5dB the results are shown in table 3.5.

The configuration	A	B	C	D
BER simulate (%)	11.20	10.12	7.98	6.51

Table 3.5 BER results for the simulated systems.

For 265 OFDM symbol with the use of Pilot and encoding the BER for 2x2 system is 1% [15]

Discussion

From table 3.5 we can note that the BER decreases with the increase of MIMO dimensionality. In the same MIMO dimension the BER also increases with increasing the number of OFDM symbols. In 2x2 systems (A and B configurations), the amount by with the BER decreases when adding an OFDM symbol is 1.08% and in 3x3 system this amount is 1.47%. This increase is considerable because no additional power or bandwidth is added just by changing the system parameters. Compared to the results given by [15] the decrease in simulation BER is much smaller. This is due to, mainly two points, the first is the simplicity of the used system since we didn't use the pilots, the second is the use of an unencoded system which is a cornel pillar in MIMO system. The theoretical results given by the reference is not available for the 3x3 system.

Conclusion

From the previous experiments, the spatial diversity is studied using a MIMO channel and an unencoded system that gives its best performance in 3x3 MIMO dimension it can be enhanced using OFDM technique that is convenient in such cases. Also, employing coding may ameliorate the system.

Conclusion

This set of experiments gives us some important information about the telecommunication system analysis and design. The use of Simulink made these experiments easier since it provides useful predefined blocks especially for the channels models since the study doesn't focus on the channel modeling. The reliability of the used systems are confirmed by eliminating the noise and fading and check the probability of error to be zero.

The BER of MIMO system is better than the SISO system with low complexity MIMO. The modulation scheme used in wireless communication depends on the channel state; QPSK is not a good choice when the channel follows a Rayleigh fading although it gives good results is AWGN channels, in new systems, channel state information (CSI) is a parameter used to decide on the system settings such as the modulation scheme and data rates. For MIMO it can be ameliorated by using OFDM technique and for better results is better to add coding in the system and the most studies about MIMO is for encoded MIMO.

Conclusion

In this work, we have simulated SISO systems with three modulation schemes (4-FSK, QPSK and DQPSK) over three channel models (AWGN, Rayleigh and Rician Fading). The results show that over the three channels the 4-FSK is the least affected by the change of channel type. So the 4-FSK scheme was used in the MIMO (2x2 and 3x3) systems in two ways, the first was simple without OFDM, the second used OFDM technique. We have found that the BER decreases with the increase of the MIMO dimension from 2x2 to 3x3 and also when employing OFDM technique. The increase was smaller than the theoretical one. This is due to the simplicity of the system we used and to the non-use of error coding in the system that is a crucial point in MIMO.

Recommendations for future research

Through this research experience with the topic of MIMO systems, we have encountered some points that we found interesting and worth more investigation. We ambition to extend our work to if time allows. MIMO is the basis for future generation communication system (5^{th}G) where it focuses on Massive or Large scale MIMO, so it is helpful to advance our understanding and research projects to contribute in the development of this hot topic and new developing technology. The topic we suggest are:

- MIMO system in Ultra wide Band (UWB) systems.
- Study of the encoded MIMO systems.
- Implementation and design of MIMO system.
- Number of channel optimization for a given Bandwidth.
- Comparative study of the capacity of different MIMO systems.
- Study of Large scale MIMO systems.
- Design and implementation of Massive MIMO systems.
- Synchronization of the MIMO system.
- Study of Multi-user MIMO (Mu-MIMO) systems.

This set of topics contains some topics that are under considerable study at the present time.

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