PERFORMANCE ANALYSIS OF RADIO RESOURCE ALLOCATION IN MIMO LTE SYSTEMS

by

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A dissertation submitted to the University of Zambia in partial fulfilment of the requirements for the degree of Master of Engineering in Telecommunications Systems

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This dissertation of Tozgani Fainess Mbale has been approved as partial fulfilment of the requirements for the award of Master of Engineering in Telecommunications Systems by the University of Zambia.

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ABSTRACT

This dissertation investigates the effect of spectral efficiency as the number of service antennas and number of users in Multiple-input Multiple-output (MIMO) Long Term Evolution (LTE) network increases. The channel estimators studied namely Zero Forcing (ZF), Minimum Mean Square Error (MMSE) and Maximal Ratio Combining (MRC) all show an increase in spectral efficiency and energy efficiency as the number of service antennas and the number of users increase respectively.

LTE is an evolution upgrade of 3G systems which makes use of MIMO antennas. LTE network delivers large data rates, provides voice, data and video calls at high speeds. MIMO has attracted much attention both in industry and academia due to its high data rate, high-spectrum efficiency and has shown the ability to increase data rate and improve reliability. Working with a 2X2 MIMO antenna or more in LTE can increase wireless channel capacity without the need for additional power or spectrum but also does not always equal better performance of the system in scattering environments. This dissertation focuses on network performance by explaining the behaviour of channel estimators in Multiple Input Multiple Output (MIMO) Long Term Evolution (LTE) systems.

Analytical and simulation results in this dissertation show that the increase in the number of antennas and users improves the spectral efficiency and that MMSE shows superior performance than ZF and MRC under similar conditions. MMSE is 9 bits/Hz/cell more than MR for 65 service antennas and 113 bits/Hz/cell for 37 users.

Despite all the efforts to make this better, there has been a persistent challenge in spectral efficiency and energy efficiency in LTE systems. The results on the other hand show that MMSE performed better than ZF and MRC below 5bits/Hz/cell. At 18bits/Hz/cell ZF has the highest EE to SE ratio of approximately 8.The substantial performance gain by the MMSE is due to effective interference and error reduction, which is consistent with the fundamental property of MMSE. . The substantial performance gain by the MMSE is due to the effective interference and error reduction, which is consistent with the fundamental property of MMSE.

Keywords: MIMO, LTE, Spectral Efficiency, Energy Efficiency, Zero Forcing (ZF), Minimum Mean Square Error (MMSE), Maximal Ratio Combining (MRC)

DEDICATION

This dissertation is dedicated to my beloved family: my husband James Chola Chitundu, our loving daughter Twapalwa Chitundu and my son Lubuto Chitundu of whom my source of confidence, inspiration and encouragement came from and many more children to come. To my late father Maxon Chalo Mbale who encouraged me to finish my master's program before his death because he wanted to see me graduate. My mother Alice Jonah Kilimboyi Mbale to you I say thank you for giving me an opportunity to do what I love best and for ensuring that I had a strong foundation in my education, it's been an amazing journey.

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ABBREVIATIONS AND ACRONYMS

3GPP	Third Generation Project Partnership
1G	1st Generation of wireless telephony
2G	2nd Generation of wireless cellphones
3G	3rd Generation of mobile phone
4G	4th Generation of broadband cellular networks
5G	5th Generation of cellular networks
AP	Access Point
BPSK	Binary Phase Shifting Keying
BS	Base Station
CIR	Channel Impulse Response
CP	Cyclic Prefix
CRRM	Common Radio Resource Management
EE	Energy Efficiency
ENodeB	Evolved Node B
EMMSE	Exponential Minimum Mean Square Error
EPC	Evolved Packet Core
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
HSDPA	High Speed Downlink Packet Access
HSS	Home Subscriber Server
ISI	Inter-Symbol Interference
IP	Internet Protocol
LS	Least Square
LTE	Long Term Evolution
MISO	Multiple Input Single Output
MCS	Modulation and Coding Scheme
MRC	Maximal Ratio Combining
MME	Mobility Management Entity
MISO	Multiple-Input Single-Output
MIMO	Multiple-Input Multiple-Output
MMSE	Minimum Mean Square Error
MU-MIMO	Multi-User Multiple Input Multiple Output

OFDMA	Orthogonal Frequency Division Multiplexing Access
OSIC	Ordered Successive Interference Cancellation
P-GW	Packet Data Network Gateway
PAPR	Peak-Average-Power Ratio
PCRF	Policy and Charging Rules Function
PDP	Power Delay Product
PS	Packet Scheduler
PRB	Physical Resource Block
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QoS	Quality of Service
RAC	Radio Admission Control
RAN	Radio Access Network
RAT	Radio Access Technologies
RB	Resource Block
RLS	Regularized Least Square
RMS	Root Mean Square
RRM	Radio Resource Management
RRU	Radio Resource Unit
SE	Spectral Efficiency
SC- FDMA	Single Carrier Frequency Division Multiple Access
S-GW	Serving Gateway
SMMSE	Simplified Minimum Mean Square Error
SNR	Signal-to-Noise-Ratio
STBC	Space-time Block Coding
SIMO	Single-Input Multiple-Output
SU-MIMO	Single-User Multiple Input Multiple Output
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TMMSE	True Minimum Mean Square Error
UE	User Equipment
UMB	Ultra-Mobile Broadband
V-BLAST	Vertical-Bell Laboratories Layered Space-Time
WiMAX	Worldwide Interoperability for Microwave Access

ZF	Zero Forcing

CHAPTER 1 : INTRODUCTION

1.1 Introduction

This chapter gives the main guidelines of the study. The foundation of this study is laid down in its background information and to further concretise the reader's understanding of the problem statement, aim of the study, objectives, research questions, significance of the study, scope of study, organisation of the dissertation and summary of the chapter.

1.2 Background

Cellular mobile communication systems have been developed over a long period of time. There are already known: First Generation (1G) analogue , Second Generation (2G) digital, Third Generation (3G) broadband, Fourth Generation (4G) known as LTE (Long Term Evolution), or 3.9G standards in some publications and currently under developing and implementing Fifth Generation (5G) [1]. Long-term evolution (LTE) just like electricity has become a necessity and is at the centre of modern society which also is an evolutionary step beyond the 3G in mobile wireless communication[2]. It is mainly characterised by high data rates, minimum delay and the capacity due to scalable bandwidth and its flexibility. Long Term Evolution (LTE), by third-generation project partnership (3GPP) is one of the radio access technologies used for delivering the broadband mobile services. LTE offers many features with flexibilities in terms of deployment options and potential service offerings[3]. 4G LTE is a rapid remote correspondence standard which builds framework's ability and information rates and created by 3GPP. It satisfies the point of accomplishing worldwide broadband portable interchanges[4].

Generally, 4G LTE deployments require two antennas on the mobile side thus LTE cellular handsets and devices inside other equipments provide dual antenna designs and operators assume this capability in their LTE service deployments. The optimization of base station antennas is with the assumption that the device uses at least a 2X2MIMO antenna for LTE [5]. In order to further increase the data transmission rate, multiple-input and multiple-output (MIMO) technology has become an important feature in fourth-generation (4G) wireless communication systems[6]. LTE has a characteristic of all IP based architecture where the mobile devices are communicating based on an IP address. The architecture of LTE is called as Evolved Packet Core which is capable of providing an uplink peak rate of 75 Mbps, a downlink peak rate of 300 Mbps and 20 MHz of bandwidth[7]. LTE aims to deliver high data rates and low latencies that current and future mobile applications will demand [8]. Figure 1.1 shows the network architecture of LTE.

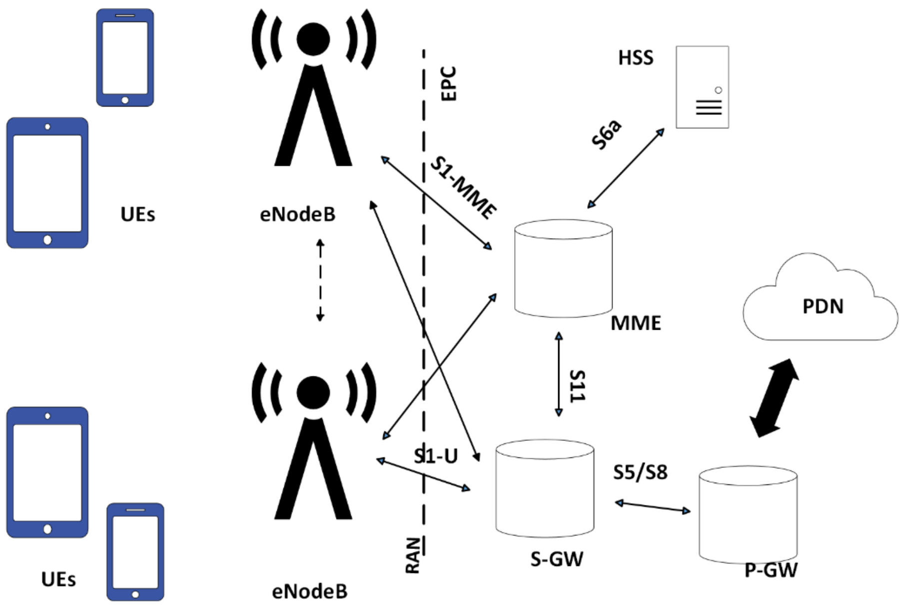

Figure 1. 1 : LTE Network Architecture [9]

The LTE physical layer employs some advanced technologies (Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Input Multiple Output (MIMO)) that are new to cellular applications[10]. MIMO technology can significantly increase channel capacity and spectrum efficiency. With the continuous improvement of transmission speed, with increasing numbers of antennas, numbers of users spectral efficiency and energy efficiency and higher modulation order, the tradeoff between complexity and performance of the MIMO system should be studied[10].

1.3 Problem Statement

In the proposed architecture of LTE, it is obvious that there is no central node managing the resources in a set of eNode B and thus distributed radio resource management must be done which is more difficult and thus a strong centralized component in the (radio resource management) RRM operation is required. This thesis will analyze energy efficiency and spectral efficiency for in MIMO LTE then will consider the three channel estimators Zero Forcing (ZF), Minimum Mean Square Error (MMSE) and Maximal Ratio Combining (MRC).

1.4 Aim of Study

The aim of this study is to analyse how radio resources are allocated in MIMO LTE systems while investigating, examining and creating a relationship between the channel estimators which are Zero Forcing (ZF), Minimum Mean Square Error (MMSE), Maximal Ratio Combining (MRC) with the spectral efficiency, energy efficiency, the service antennas and the number of users.

1.5 Objectives

The objectives of this study were:

1. Investigate Spectral efficiency in MIMO LTE
2. Determine the relationship between Energy efficiency and Spectral efficiency
3. Examine the performance of the three channel estimators ZF, MMSE and MRC in MIMO LTE systems.

1.6 Research Questions

The following research questions were answered in this study to achieve the above objectives:

1. What is the relationship between the spectral efficiency against the number of users and the number of antennas?
2. What is the trade-off between energy efficiency and spectral efficiency?
3. What is the conception of the channel estimators in radio resource allocations?

1.7 Significance of the study

The resource allocation impacts on the applications utilizing the LTE network. Various access methods are used in LTE for radio resource allocation such as OFDMA (Orthogonal Frequency Division Multiple Access) for downlink and uplink uses SC-FDMA (Single Carrier Frequency Division Multiple Access). Radio resource allocation therefore is a significant parameter in a fourth-generation wireless network like LTE.

The findings of this study may have valuable contribution to the telecommunications sector worldwide in that the researcher will understand and be aware of the comparison tradeoff between energy efficiency and spectral efficiency among ZF, MMSE and MRC in MIMO LTE.

1.8 Scope of the study

Mobile communication has drastically integrated from 1G to 4G LTE and spilling over to 5G now. From this integration, we have seen an addition of NXN MIMO to the evolution of communication therefore this research has been limited to 2X2 MIMO LTE systems though certain concepts may also apply to 3G as well. Spectral efficiency, Energy efficiency and channel estimators are the main focus of this research. The dissertation will only consider MIMO which creates a relationship between spectral efficiency and energy efficiency.

1.9 Organisation of the Dissertation

This dissertation has five chapters which are organised as follows:

Chapter 1 lays some groundwork on information on background information pertaining to the study. It includes problem statement, aim of study, objectives, research questions, significance of study, scope of study, organisation of the dissertation and chapter summary.

Chapter 2 reviews relevant Literature related to the study which looks at radio resource allocation, performance metrics and the channel estimator's architectural design.

Chapter 3 will cover the research methodology used in this study by systematically solving the research problem and outlining the methods and materials used to conduct the simulation and design.

Chapter 4 presents the performance metrics and compares the results in difference scenarios by giving suggestions of the best parameter to use.

Finally, Chapter 5 draws the conclusion and the recommendations which are based on the major findings of the research.

1.10 Summary

This chapter focussed on background information on MIMO LTE systems as it endeavours to explain the progression trend of mobile communication mostly between the user equipment and the eNodeB. The problem statement aims of study, objectives, research questions, significance of the study, scope of study and organisation of the dissertation has also been presented.

The next chapter reviews the literature relevant to this study to establish what other scholars have written around radio resource allocation.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This chapter focuses on literature review and related works pertaining to this study. Firstly, an introduction to MIMO and LTE systems as the core of 4G mobile network communication bordering on radio resource management between the user equipment (UE) and the eNodeB and how channel estimators are being used as parameters to analyze the performance.

2.2 MIMO Systems

MIMO is an acronym which means Multiple Input Multiple Output. The primary objective of implementing a MIMO system is to improve the system capacity[11] therefore this technology has been treated as an emerging technology to meet the demand for higher data rate and better cell coverage even without increasing average transmit power or frequency bandwidth[12]. To transmit and receive wireless signals on the same frequency, MIMO is used [13].The achievement of maximum data rates in part is through multi antenna or MIMO techniques in the LTE and LTE-Advanced standards there the MIMO receiver separates the combined signals and resolves each of the resource element[14]. The correlation between transmit and receive antenna is an important aspect of the MIMO channel [15].

The use of MIMO has greatly improved the link quality and capacity through the use of multiple antennas at the transmitter and receiver along with advanced digital signal processing [16]. This technology exploits the use of multiple signals transmitted into the wireless medium to improve the wireless channel performance[17]. The LTE system design standards introduced in both uplink and downlink transmission and MIMO is a major element of it. 2X2 MIMO is supported in 3GPP release 8[18] ultra-mobile broadband (UMB), high speed downlink packet access (HSDPA) and IEEE 802.16e (WiMAX). In wireless communication, the downlink and uplink can both make use of the MIMO communication system. For instance, the mobile user being equipped with a single antenna and the base station (BS) equipped with a multiple antenna. It is conventionally referred to as Single Input Multiple Output (SIMO)[19]. MIMO communication, where a multi-antenna base station (BS) or access point (AP) transmits one or many data streams to one or multiple user equipments simultaneously, is a key technology to provide high throughput in broadband wireless communication systems[20]. Consider a 2x 2 MIMO channel in figure 2.1

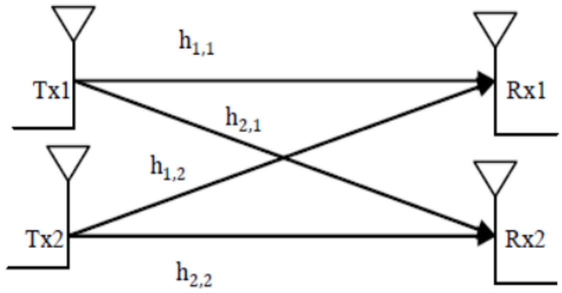

Figure 2. 1 : MIMO 2X2 System Graphical Representation [21]

the received signal on the first and second receive antenna is given by [22]equation 2.1 and 2.2

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = \left[h_{1,1}, h_{1,2}\right]\left[\begin{smallmatrix} x_1 \\ x_2 \end{smallmatrix}\right] + n_1 \tag{2.1}$$

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = \left[h_{2,1}, h_{2,2}\right]\left[\begin{smallmatrix} x_1 \\ x_2 \end{smallmatrix}\right] + n_2 \tag{2.2}$$

The equation can be represented in matrix notation as follows:

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{pmatrix}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix} \tag{2.3}$$

Equivalent to

$$Y=HX+N \tag{2.4}$$

Where,

Y = Received Symbol Matrix.

H = Channel matrix

X = Transmitted symbol Matrix

N = Noise Matrix

The transmitting antenna and the channel are combined with noise to emit a signal at the receiver's antenna as shown in equation 2.1 and equation 2.2. Equation 2.3 shows a combination of the two received signals in equation 2.1 and equation 2.2 to formulate the equation matrix which is shown in equation 2.4.

MIMO has quite a number of configurations. For example, in this study, a 2×2 MIMO configuration is what is reviewed with 2 antennas to transmit signals (from base station) and

2 antennas to receive signals (mobile terminal)[23]. In order to correctly recover the transmitted data, MIMO system solves systems of linear equations as shown in the equation 2.3[14] therefore the achieve good LTE performance, both the antennas in MIMO must have the same efficiency, high isolation between the two antennas and a low correlation coefficient [5]. The key components in MIMO which are spatial multiplexing, transmit diversity, and beam forming support future broadband data service over wireless links by providing higher peak rate at a better system efficiency, which are essential for supporting [12].

2.2.1 Types of MIMO Configurations

There are several types of MIMO antennas, but this study outlines the following;

1. Single-Input Multiple-Output (SIMO): A simple scenario of this is an uplink transmission whereby a multi- antenna base station (eNodeB) communicates with a single antenna User Equipment (UE)[24].
2. Multiple-Input Single-Output (MISO): multipoint-to-point channel where multiple users or transmitters from different geographical locations access the same source with very little or no coordination[19].
3. Single-User MIMO (SU-MIMO): the emitters and sensors are respectively collocated on one transmitter and one receiver which is coordinated at both ends[19].
4. Multi-User MIMO (MU-MIMO): Multi-user MIMO technique allows the eNodeB to transmit or receive a signal to or from multiple users on the same time-frequency grid[25].

2.3 Using MIMO systems

There are many benefits that arise from using MIMO systems and effectively doubling the data throughput is one of them[5]. It also makes transmission more robust, lowers the bit error rate, increases the coverage area and improves position estimation. By improving the wireless system capacity, range, reliability [26] and offering something new compared to the traditional antenna array systems[27], MIMO exploits space dimension. MIMO takes advantage of the operation of multipath as it increases range and throughput[26] and it provides higher capacity over traditional scheme[28].

MIMO exhibits more advantages but its complexity of meeting the ever increasing and challenging demand of data transmission disadvantages it[19]. Smart antennas and multiple-input multiple-output (MIMO) techniques are attracting the attention of the telecommunications industry, given the advantages that can be drawn from diversity and spatial multiplexing[29]. MIMO as part of the LTE physical layer has highly imperative requirements on coverage, capacity, data rates and integration thus necessitates the incorporation of transmission schemes like transmit diversity, spatial multiplexing and beam forming[24].

To achieve this diverse set of objectives and benefits, LTE adopted various MIMO technologies[12] in wireless networks which are array gain, multiplexing gain and spatial diversity[30].

2.3.1 Array Gain

Array gain or Precoding (also referred to as Beam forming) is a MIMO technique that focuses on phase (time) and/or gain (amplitude) shifts (known as coding). Here a signal is transmitted from each of the transmitter antennae. It maximizes the signal strength and quality at the receiving end[31]. The use of multiple antennas show an average increase in the SNR at the receiver due to the coherent combining effect of the transmitted signals. The availability of array again is through multiple antenna processing at the transmitter or the receiver or both[32]. Multiplexing gain and the array gain achieve a huge throughput and energy efficiency [33]. Figure 2.2 shows an example of MIMO beam forming with four transmitter antennas represented by $\omega_1, \omega_2, \omega_3$ and ω_4 and the receiving antenna represented by R_x.

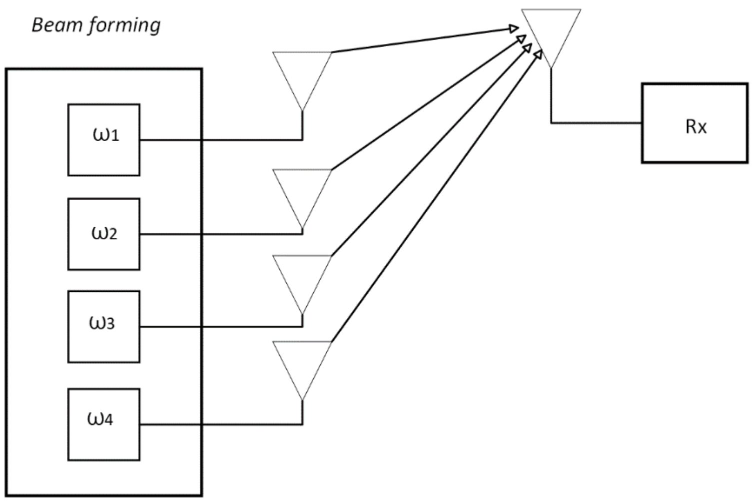

Figure 2. 2 : MIMO beaming forming [15]

2.3.2 Multiplexing Gain

Multiplexing gain transmits multiple independent data streams which therefore lead to linear increase in throughput[30]as shown in figure 2.3. Multiple data streams that are conveyed to independent users enable the attainment of high spectral efficiency and multiplexing gains in MIMO [20]. Diversity gain and BER performance tends to suffer when a full multiplexing gain requires an independent usage of the antennas or each data pipe[34]. Therefore it has been proved that MIMO channels offer a linear increase in the capacity (or transmission rate) for the same bandwidth and with no additional power usage[32].

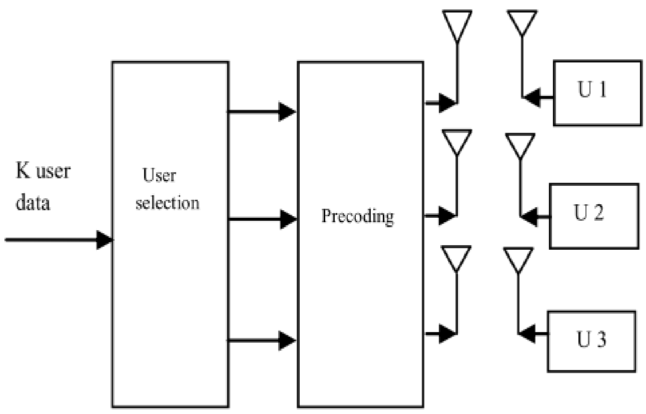

Figure 2. 3 : Multiplexing gain in MIMO[30]

2.3.3 Spatial Diversity

Spatial modulation technique for MIMO system was introduced by dividing the incoming data into [35] multiple sub streams and sending each sub stream on a different antenna[36] as shown in figure 2.4. The streams are transmitted simultaneously and parallel on the same frequency band through different antenna ports[37]. Spatial components are also a contributor of the wireless channel by providing higher spectrum efficiency[28].

Spatial modulation is categorised into two classes namely open and closed loop spatial multiplexing[38]. Open loop spatial multiplexing is a type of multiplexing that involves a user moving in a vehicle at high speeds along an expressway in a multipath rich environment with clear line of sight to the base station and provide better throughput and spectral efficiency[7] while close loop is used for a pedestrian user who definitely has low mobility having and is based on capacity, SNR, condition number for mode adaptation[39]. With increased channel rate and the use of multiple antennas which refers to MIMO, increasing spatial diversity gain increases quality of service without increasing the transmitted power of antennas[30].

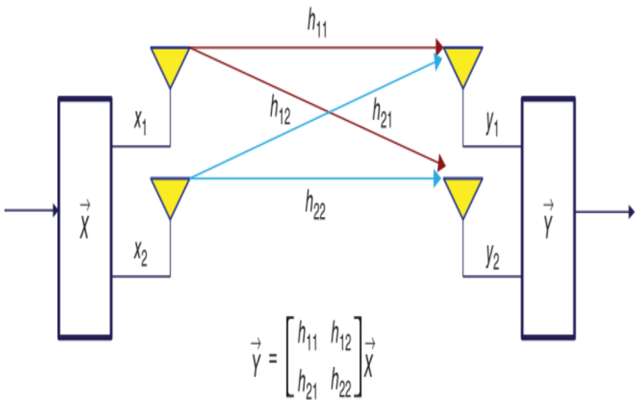

Figure 2. 4 : MIMO spatial multiplexing [15]

2.4 LTE systems

Long Term Evolution(LTE) is a term that defines a novel air interface by the 3rd Generation Partnership Project (3GPP)[40]and it doesn't need new spectrum therefore it utilizes existing 2G and 3G spectrum and new spectrum[41]. It was developed to achieve downlink (DL) peak data rate of 300 Mbps and uplink (UL) peak data rate of 150 Mbps for data transmission by combining multiple input and multiple output (MIMO)[42]. LTE supports both frequency-division duplex (FDD) and time-division duplex (TDD)[43]. LTE has higher spectral efficiency as compared to 3G networks [44] thus necessitating this study. The LTE solution provides spectrum flexibility with scalable transmission bandwidth between 1.4 MHz and 20 MHz depending on the available spectrum for flexible radio planning [45].

LTE makes use of two duplexing methods namely Time Division Duplex (TDD) and Frequency Division Duplex (FDD). FDD mode operates on different carrier frequencies having the downlink path (DL), from the eNode B to UE, and the uplink path (UL), from the UE to eNode B. The downlink and the uplink in TDD mode paths operate on the same carrier frequency but in different time slots[46]. The LTE air interface supports both FDD and TDD modes, with different frame structure[47].

2.4.1 Frequency Division Duplex (FDD)

Half-duplex frequency division duplex (FDD) allows the sharing of hardware between uplink and downlink one at a time since the uplink and downlink are never used simultaneously [47]. Frequency Division Duplex (FDD) is also sometimes known as type 1 which is considered in the LTE transmission frame. The length of the Type 1(Fig 2.5) LTE frame is 10 ms which is divided into 20 individual 0.5 ms slots, each two slots make a 1 ms LTE sub-frame. Each 0.5 ms time slot represents the LTE RB which consists of 84 resource elements (7 OFDM symbols by 12 subcarriers) [48].

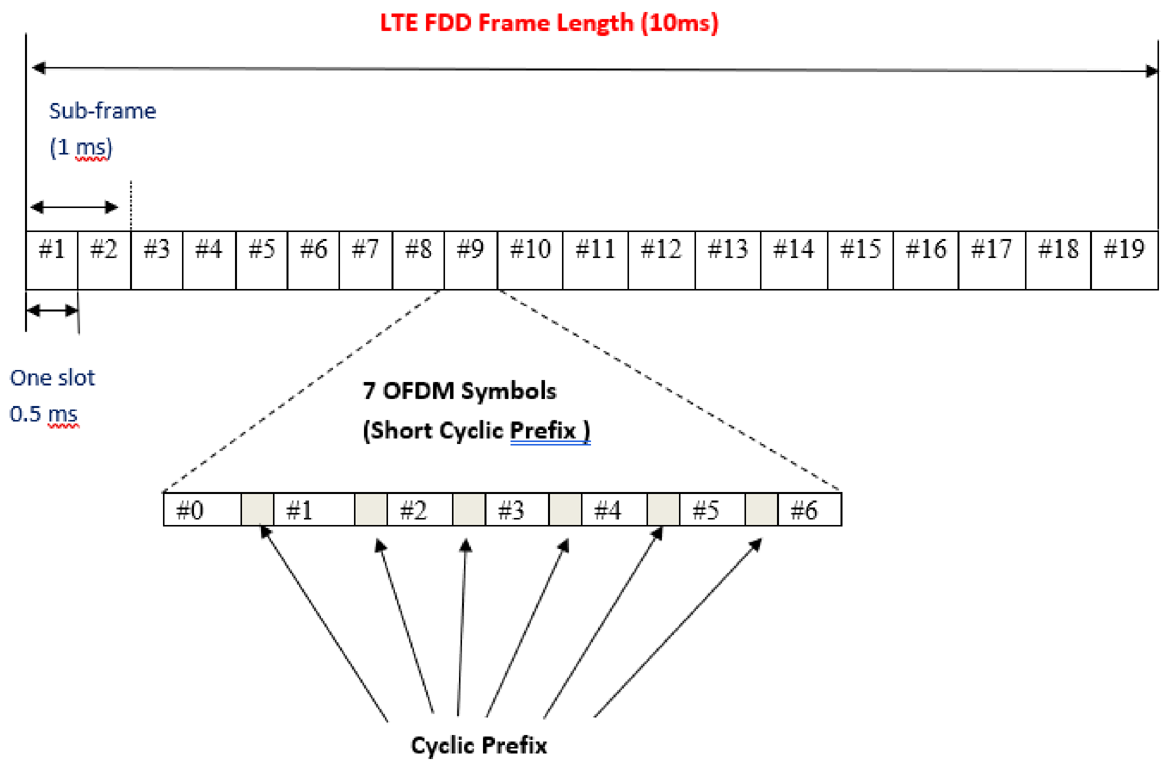

Figure 2. 5 : LTE FDD Frame structure[46]

2.4.2 Time Division Duplex (TDD)

Time Division Duplex (TDD) requires a single unpaired frequency band. Therefore, the uplink and downlink share the same frequency, being time multiplexed[47]. The type 2 structure (Fig. 2.6) is applied to Time Division Duplex (TDD) mode maintaining only full duplex operation. Type 1 lasts 10 ms equivalent to 10 sub- frames (each 1 ms long) or 20 slots (each 0.5 ms long) [49].

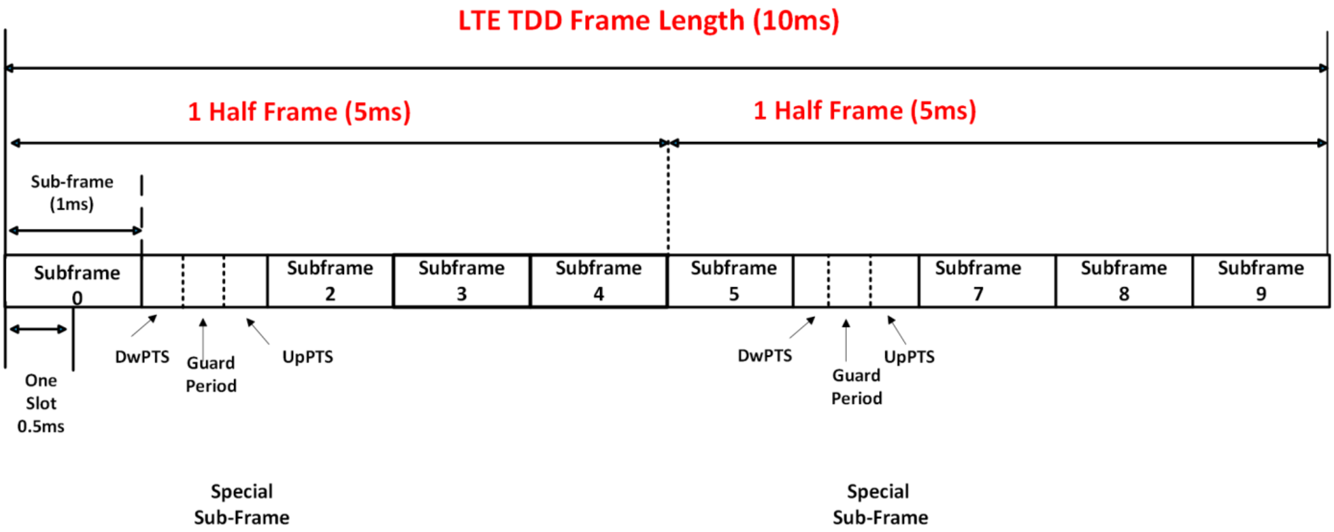

Figure 2. 6 : LTE TDD Frame structure[46]

2.5 LTE Multiple Access Technologies

LTE has two multiple access techniques used in the uplink and downlink which are Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier Frequency Division Multiple Access (SC-FDMA)

The LTE downlink uses orthogonal frequency division multiple access (OFDMA), which is also applied in wireless LAN and other systems and uplink uses the uplink uses single-carrier (SC) FDMA [50].

2.5.1 Orthogonal Frequency Division Multiple Access (OFDMA)

OFDMA is a multi-user multiple access combination of OFDM and multiple access schemes; Time division multiple access (TDMA) and Frequency division multiple access (FDMA OFDMA allocates subsets of subcarriers to individual users. Data is simultaneously transmitted by numerous users by modulating a limited set of orthogonal subcarriers[51].

Orthogonal Frequency Division Multiple Access (OFDMA) has very robust characteristics against frequency selective channels and is used in the downlink of the LTE system[7]. It has a distinguished nature that makes use of OFDM and is attributed to the scheduling and assigning of resources [2]. An Orthogonal Frequency Division Multiple Access (OFDMA) schemes' main advantage is to reduce power consumption and interference[55]. Adjusting the frequency and multiuser diversity improves and achieves high spectrum efficiency [52]. Over the years, it has been used by the eNode B to serve multiple users according to the LTE.

In an OFDMA system a different subset of sub-carriers is assigned to each user in a cell[53]. In[54], authors focused on the conventional SE-based or EE-based on radio resource allocation in multi-cell OFDMA networks. The inclusion of OFDMA in the LTE system has several benefits which include the robust multipath suppression, ability to combat intersymbol interference (ISI), flexibility in accommodating many users with widely varying data rates, high throughput[55], more frequency efficient and dynamically mapping traffic to frequencies based on their instantaneous throughput[56].

It is widely considered as the multiple access technology for state-of-the-art and future wireless communication due to high-spectral efficiency and more flexibility in radio resource allocation[57]. A Physical Resource Block (PRB) is the smallest element of resource allocation assigned by the base station scheduler. It consists of 12 consecutive subcarriers for one slot (0.5msec) in duration. One resource block is equivalent to one of the subcarriers for duration of one slot and is the main unit that schedules transmissions over the air interface[3].

Figure 2.7 shows a block diagram of the OFDMA system, were $x[n]$ is the transmitting signal, $w[n]$ is the added noise and $y[n]$ is the signal received. When information is sent, it passes through a convertor S/P that converts a serial signal to parallel signal. It is then subjected to an inverse fast Fourier transform (IFFT) to convert the frequency-domain subcarriers into time-domain signals. A cyclic prefix is then added during transmission then later the information passes through the P/S block that converts the parallel signal to serial signal[58].

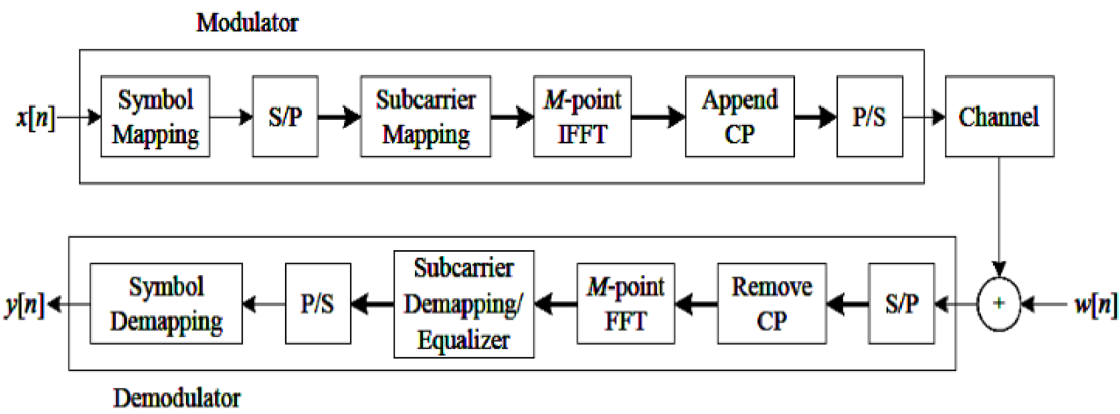

Figure 2. 7 : OFDMA technique block diagram for LTE

2.5.2 Single Carrier Frequency Division Multiple Access (SC-FDMA)

Single-Carrier Frequency Division Multiple Access (SC-FDMA) is used in the uplink access scheme because of its low Peak-to-Average Power Ratio (PAPR) properties and in order to show its' benefits in using PAPR, SC-FDMA requires Resource Blocks (RBs) to be allocated for each user in a contiguous manner [59].The noise degrades the SC-FDMA performance as it spreads over all the subcarriers and generates an effect called noise enhancement thus requires the use of a more complex equalization method which is based on a minimum mean square error (MMSE) [60].The challenge SC-FDMA system has is the channel estimation in fast time-varying channels[61]. Figure 2.8 shows a block diagram of a SC-FDMA[58].

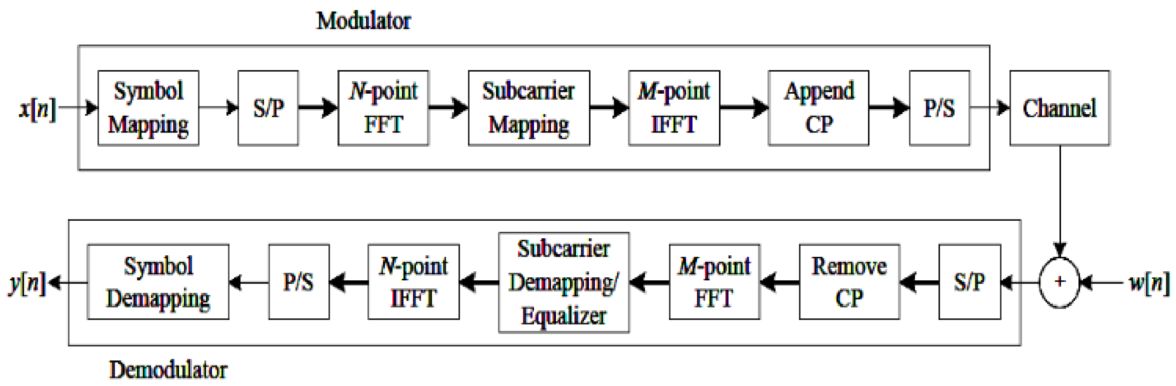

Figure 2. 8 : SC-FDMA technique block diagram for LTE

2.6 LTE Architecture

LTE network architecture can be simply divided into two sub networks: Radio Access Network for LTE and Core Network for LTE [62] as shown in Figure 2.9

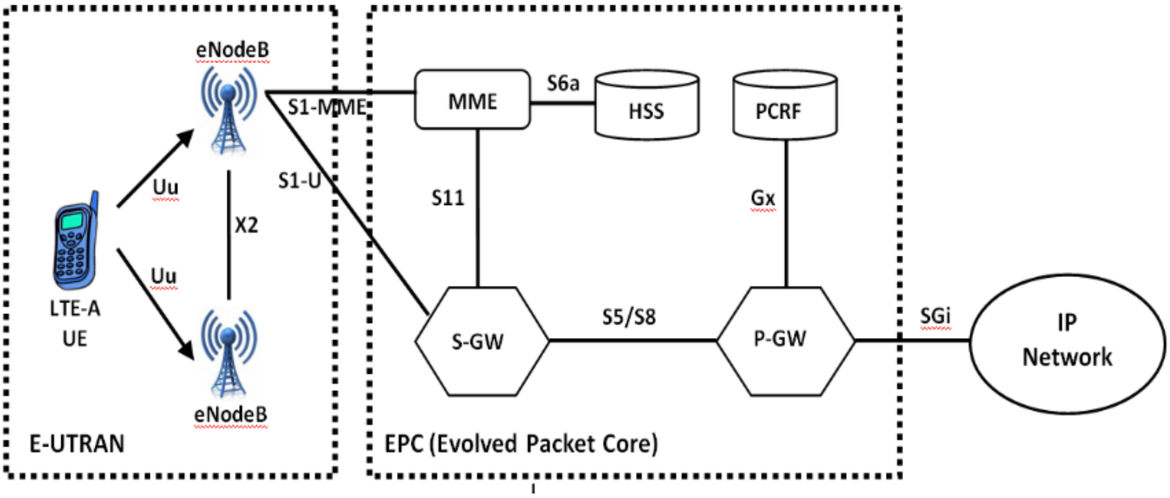

Figure 2. 9 : Diagram of LTE Architecture[62]

2.6.1 Radio Access Network

The radio access network in most cases can also be referred to as the E-UTRAN (Evolved Universal Terrestrial Radio Access Network) which comprises of the subscribers and the core network [13].It is responsible for all radio-related functions, which can be summarized briefly as:

1. Radio resource management (RRM) – The purpose of this is dynamically allocation of resources to UEs in both uplink and downlink and cover all functions related to the radio bearers [63].
2. Header Compression – compresses the IP packet headers that could otherwise represent a significant overhead, especially for small packets such as VoIP [63].
3. Security – for security purposes all data sent ought to be encrypted.
4. To determine handover decisions, following information might be included: – Radio link quality connections in an LTE cell, UE capability, call type, QoS requirements, and policy related aspects[64].
5. Measurement reports are prepared and contain information on the neighbouring eNode Bs. The serving eNode B provides the list of eNode B as requested by the UE[64].

2.6.2 Core Network

The core network (called EPC in SAE) is responsible for the overall control of the UE and establishment of the bearers[63].

1. Mobility Management Entity (MME) –Responsible for the connection between a user and packet network, mobility control such as location registration and handover and terminal authentication in cooperation with home subscriber server (HSS)[65].
2. Serving Gateway (S-GW)- connects the LTE RAN to the EPC. It functions as a mobility anchor when UEs move from one eNode B to another and also handles user data tunnels between the eNode B and the Packet Data Network Gateway (PDN-GW) and it acts as the gateway router to the internet[66].
3. Packet Data Network (PDN) Gateway (P-GW)-it supports Policy enforcement features, Packet filtering (for example, deep packet inspection for application type detection) and Charging support (for example, per-URL charging[67].

2.7 Radio Resource Allocation

2.7.1 Introduction

Resource allocation is particularly challenging in wireless communication systems mainly due to the wireless medium variability and channel randomness, nevertheless, high spectral efficiency and multiplexing gains can be attained in MIMO systems since multiple data streams can be conveyed to independent users[18]. Resource management is also an important aspect to wireless communication as it also confronts huge challenges[68]. A radio network has a basic unit called resource block (RB) and it consists of 12 subcarriers and a bandwidth of 180 kHz. In the time domain, 0.5 ms is used for an RB therefore for a system with the bandwidth of 10 MHz, the number of total RBs is 50 according to the specifications in [69]. The joint or separate performance of radio resource allocation includes resource blocks (RBs) and power allocation [25]. Radio resource management and allocation schemes are the key operational techniques that allow a wireless access network operator to optimize utilization of the available spectrum that suits its needs[70] and having an assignment problem where the objective is to obtain both the optimal allocation of RBs and the optimal transmission power for each UE[71]. Frequency, time and space are LTE's 3-dimensions in radio resources[72].

2.7.2 Radio Resource Management

Radio Resource Unit (RRU) is a set of basic physical transmission parameters necessary to support a signal waveform transporting end user information corresponding to a reference service. Physical transmission parameters depend on the multiple access technique which is used. In Frequency Division Multiple Access, a radio resource unit (RRU) is equivalent to a certain bandwidth within a given carrier frequency. In TDMA (Time Division Multiple Access), a radio resource unit(RRU) is equivalent to a pair of a carrier frequency and a time slot RRM functions are in charge of allocating and managing the provisioned RRUs[73].

The Radio Resource Management (RRM) plays a crucial role in LTE networks by managing the limited radio resources in such a way that the radio transmission is as efficient as possible thus the role of RRM focuses on two major aspects which are Radio Admission Controller (RAC) and Packet Scheduler (PS) [71]. RRM entity aims at allocating efficiently the limited radio resources among users and therefore the adequate frequency bandwidth is determined and allocated to a cell[25]. It has to be performed in such a way that the interference within the system is minimized [74]. The base station (BS) also plays a role in deciding which users should share the same time and frequency resource within a cell[75]. They are responsible for basic RAN functionalities, such as radio resource allocation, admission control and handover management, and can communicate with each other via the X2 interface[76].

Radio Resource Management exhibits challenges of allocation decisions that are concerned with waveforms(“channels”), access ports (or base stations) and, finally, with the transmitter powers[77]. It has determined the timing, ordering and the amount of the resources to be allocated to each user in a wireless multiuser environment[48]. Resource management is an important part in the design and optimization of network performance in wireless communication system and the power of the base station saves total power consumption [20]. Operators sharing a RAN cause radio resource issues therefore there is a great need for radio resource control between multiple operators. QOS is a crucial aspect as RRM needs enhancement among users belonging to more than one operator sharing the same radio resource[57].

2.8 Performance Evaluation

To be able to meet the challenges of spectral and energy deficiencies, a technology that can provide higher spectral efficiency, at the same time as being energy efficient, is needed[78]. The two important system performance indicators for a general OFDMA network that should be used to guide system designs are Energy Efficiency (EE) and Spectral Efficiency (SE) [79]. Furthermore, studies in [80] show that channel state information estimation has great potential in improving the system spectrum efficiency and energy efficiency[80].

Adjustments to system designs could be to further develop the MIMO technology by using any of the three channels which are Zero Forcing (ZF), Maximum Ratio Combining (MRC) or Minimum Mean Square Error (MMSE)[81]. To fully evaluate the effectiveness of the transmission, the energy-efficiency (EE) concept has been put forward as a complementary performance metric to spectral efficiency (SE) in 5G cellular networks to resolve the escalation of overall energy requirement [82]. Finally reducing the consumption of energy in communication equipment improves the spectral efficiency of wireless networks[83].

2.8.1 Spectral Efficiency (SE)

The spectral efficiency (SE) in wireless communication is the rate at which information can be transmitted over a given bandwidth (in bps/Hz) [84]. Spectral efficiency is improved in many ways by efficiently applying a transmitting scheme like beam forming, subcarrier allocation[85], channel coding techniques, bandwidth modulation techniques, massive multiple access techniques, and or combining all the three techniques ; channel coding, bandwidth modulation and multiple access techniques [86].

As spectral efficiency measures the average realized data rate within a system, it also characterizes the system performance of the transmission capacity[80][87].The two multiple access technologies (Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier Frequency Division Multiple Access (SC-FDMA)) considered in this study reduce the mobile channel impairments, increase data rate and improves spectral efficiency through subcarrier allocation. The subcarrier allocation is performed to a given number of users forming a subset of total users in the system with K users and N subcarriers[85]. This ideally can easily double the spectral efficiency by doubling the number of base station antennas (M) or by doubling the number of active users(K) per cell[88] which enables the system to attain a higher spectral efficiency [89]. It gradually increases due to continuous upgrade of device capabilities and base station transmit antenna number[90].

2.8.2 Energy Efficiency (EE)

Energy efficiency (EE) is becoming increasingly important and should be considered in resource allocation[91]. It is measured by the number of bits transmitted per joule of energy consumed[55].

Wireless communications devices consume much more energy due to the huge exploitation of mobile communication systems in 3G systems and 4G systems[83]. An increase in the number of antennas assists in directing the radiated energy towards much smaller-regions, this improves the throughput and EE[92]. In reducing the consumption of energy in communication equipment, the energy efficiency of wireless networks greatly improves[83].Increasing the number of antenna does not always improve the energy efficiency [80] this is why this study has focused on a 2X2MIMO system. So, optimization of Radio Resource Allocation in Energy Efficient OFDMA Systems is necessary to support the need of high data rate as well as energy efficiency. The base station (BS) can decide which users should share the same time and frequency resource within a cell[75]. A number of new transmission techniques can be exploited for energy efficiency transmission of the data over the air, such as MIMO (multiple input multiple output), adaptive antennas, coordinated multipoint transmission mechanisms, and advanced retransmission techniques[93].These enable energy efficiency by increasing the power efficiency of the transceivers in the base stations.

When Modulation and Coding Scheme (MCS) with a higher order is used in a wireless network, the transmission time is reduced by a factor of $\log_2 M$. This in turn reduces the energy consumption at the transmitter as well as the receiver[48]. It was also observed that Quality of Service (QoS) plays an important role in wireless networks to minimize energy consumption [83].

2.9 Channel Estimators

During motion at vehicular speed, the wireless channel changes over time and this usually caused by the transmitter and/or receiver or both. Channel estimation is therefore important in mobile wireless networks[94]. It ends up to be a crucial aspect, whose effectiveness deeply influences the equalization procedure and determines the receiver performance[95]. It was noted that an advanced channel estimator is required at the receiver side in order to perform an efficient channel equalization[95]. Through this, we can estimate the transmission coefficient of the channel and at last restore the original transmission signal[96] thus the channel estimator estimates the channel impulse response for each burst separately from the well-known transmitted bits and corresponding received samples[97]. The number of the receive antennas is independent of the resource, time and frequency but proportional to the number of transmit antennas required for channel estimation in a MIMO system[98].

Most wireless communication systems are equipped with an equalizer which gives average performance, good results under expected circumstances and have high data rate transmission capacity thus making use of these techniques which have proved to be very important [99].Figure 2.10 shows a block diagram of channel estimation where the signal passes through the channel encoder then to the modulator. QAM or QPSK are modulation schemes used by binary data streams mapped into sequence of complex numbers[100].During transmission, a multipath channel contains some inter symbol interference (ISI) in the received signal. The noise is inevitable meaning every wireless channel has noise added to it. The signal detector shown in figure 2.10 needs to know the channel impulse response (CIR) characteristics to ensure successful equalization (removal of ISI)[101].The signal will then undergo channel estimation before demodulation takes places at the receiver end.

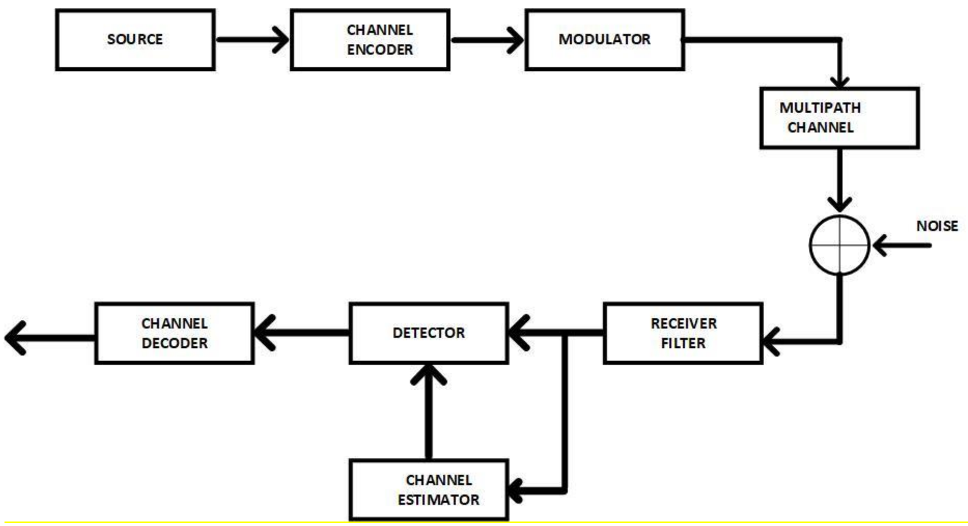

Figure 2. 10 : Block diagram of channel estimation[94]

2.9.1 Zero Forcing (ZF)

Zero Forcing (ZF) is easy to implement as it is a low complexity detection algorithm compared[102] to MMSE and MRC. To restore the signal before the channel, Zero-Forcing will apply the inverse of the channel to the received signal [22].The benefit of this algorithm is that it is used to minimize the interference[21] by bringing down the Inter symbol Interference (ISI) to zero in a noise free case. This will therefore be useful when ISI is significantly compared to noise[103].To meet this constraint, the Zero Forcing (ZF) detector has a formula which is formulated from equation (2.4) and is given by[22],

$$W = \left(H^H H\right)^{-1} H^H \tag{2.5}$$

Where, W - Equalization Matrix and H - Channel Matrix

A general M x N matrix known as the Pseudo inverse is considered in a 2X2 MIMO.

2.9.2 Minimum Mean Square Error (MMSE)

In telecommunications, a Minimum Mean Square Error (MMSE) estimator is a type of channel estimator which follows an estimation method. It minimizes the mean square error for the fitted values of various dependent variables. Because of its ability to overcome drawbacks of noise enhancement of ZF,MMSE is a good option to use in wireless communication[17]. It does not usually eliminate ISI completely but minimizes the total power of the noise and ISI components in the output. The Minimum Mean Square Error (MMSE) approach tries to find a coefficient W which minimizes the criterion[22].Equation 2.6 shows W - Equalization Matrix, H - Channel Matrix and n - Channel noise and y - Received signal.

$$E\left\{\left[W_{y\text{-}x}\right]\left[W_{y\text{-}x}\right]^H\right\} \tag{2.6}$$

To solve for x, we need to find a matrix W which satisfies $WH = I$. The Minimum Mean Square Error (MMSE) detector for meeting this constraint is shown in equation 2.7.

$$W = \left(H^H H + N_0 I\right)^{-1} H^H \tag{2.7}$$

2.9.3 Maximal Ratio Combining (MRC)

Maximal-Ratio Combining combines signals in a diverse way from each channel and are added together. The gain of each channel is made proportional to the Root Mean Square (RMS) value of the signal and inversely proportional to the mean square noise level in that channel[104]. It restores the original shape of the signal after receiving the signal and each received signal is multiplied by a weight factor [105]. It also gives an average SNR output which is the same as summing the average SNRs of the several branches if it is assumed that all the branches have equal average SNR[19].

The signal received on the i^{th} antenna in [105] is where

$$y = [y_1 y_2 ... y_N]^T \tag{2.8}$$

$$h = [h_1 h_2 ... h_N]^T \tag{2.9}$$

$$n = [n_1 n_2 ... n_N]^T \tag{2.10}$$

Equalized symbol is

$$x = \frac{h^H y}{h^H h} = \frac{h^H x}{h^H h} + \frac{h^H n}{h^H h} = x + \frac{h^H n}{h^H h} \tag{2.11}$$

Where,

$h^H n = \sum_{i=1}^{N} \left| h_i^2 \right|$ represents the sum of channel powers across all the receive antennas.

Equation 2.8 shows the received symbol from all the receive antennas. Equation 2.9 shows the channel on all the receive antenna, equation 2.10 is the noise on all the receive antennas and equation 2.11 is the equalized symbol x which is the transmitted symbol.

The three channel estimators are summarised in figure 2.11 which shows the performance at high SNR to have zero forcing (ZF) and maximal – ratio combiner (MRC) at low SNR[17].

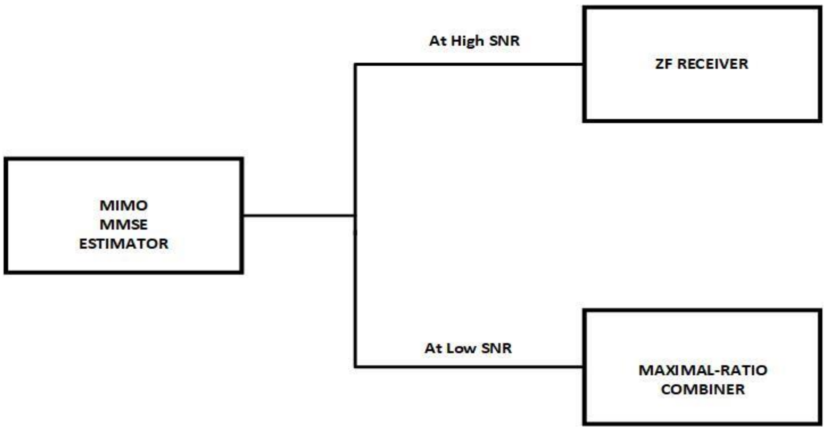

Figure 2. 11 : MIMO Estimator[17]

2.10 Related works

This section focuses on some related works in radio resource allocation and channel estimation in MIMO LTE.

The authors of [3] focussed throughput maximization in downlink and reviewed some resource allocation techniques. They first discussed the general overview of the LTE and its frame structure. Furthermore, they established that resource allocation affects the quality of users at low cost therefore the reviewed research conducted on several resource allocation schemes improved the system's throughput in LTE downlink. They studied and summarized four different resource block (RB) allocations with Modulation and Coding Scheme (MCS) selection schemes which are: Adaptive Block-Level Resource Allocation technique, Modulation and Coding Scheme (MCS) Selection for Throughput Improvement in Downlink LTE Systems, Quality of Service (QoS) Guaranteed RB Allocation Algorithm for LTE systems and Resource Allocation in an LTE cellular Communication System. They concluded by stating that resource allocation scheme with QoS consideration has the highest throughput compared to other schemes.

In [73],the authors focused on the RRM problem in heterogeneous wireless networks where different Radio Access Technologies (RAT) coexist. The framework for developing Common Radio Resource Management (CRRM) strategies including the functional model and a description of the major functionalities was provided. Also, different approaches for the RAT selection procedure have been presented, making use of policy- based strategies and fuzzy-neural methodology.

In [57], the authors proposed a radio resource allocation algorithm for downlink mobile MIMO-OFDMA and this algorithm adaptively allocates power, bandwidth and antennas among mobile users in MIMO-OFDMA system. The proposed algorithm still could be used to improve system capacity even when the practical channel estimation and prediction bias was included. The channel equalization was integrated into a signal model to cancel the inter-antenna and inter-carrier interference. They also proposed a cross-layer design resource allocation for mobile MIMO-OFDMA. They concluded that the proposed algorithm may be one choice when considering next generation wireless communication systems.

The authors in [106] firstly presented the required network architectural enhancements with the introduction of various transmission schemes related to Machine Type Communication Devices (MTCDs). Then, several radio resource allocation schemes for different transmission links were proposed with the aim of minimizing co-channel interference and maximizing network efficiency. The simulation results demonstrated that the proposed schemes could improve the network performance in terms of user utility.

The authors in [94] compared channel estimation techniques in MATLAB using modulation techniques which were BPSK and QPSK in a MIMO system as shown in figure 2.12

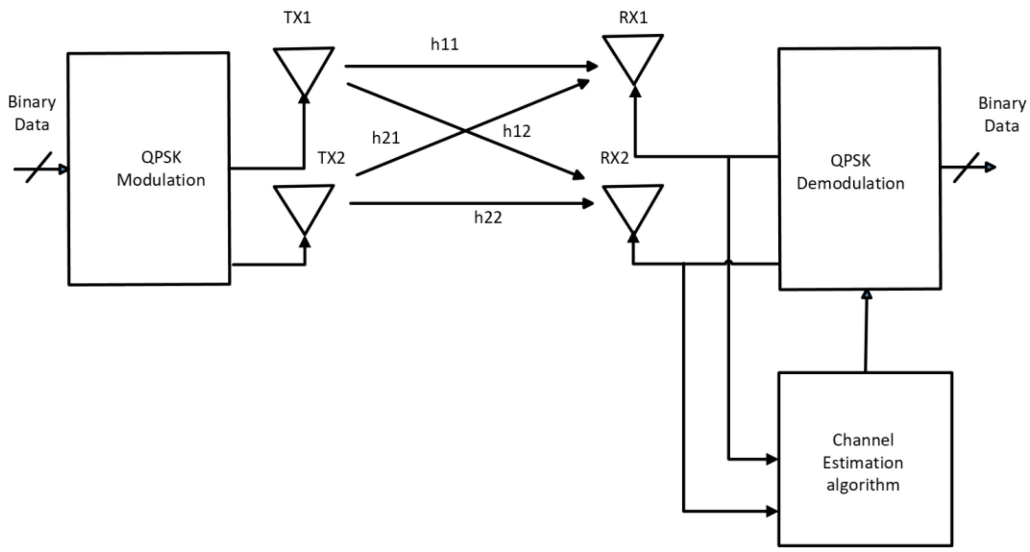

Figure 2. 12 : Block diagram of 2X2 MIMO Project[94]

The Zero forcing (ZF), Minimum Mean Square Error (MMSE) and Alamouti Space–time block coding (STBC) were coded and simulated in MATLAB. Alamouti Space–time block coding (STBC) transmits multiple copies of data streams across a number of antennas and improves the reliability of data. The design of the system from the transmitter to receiver was dependant on type of channel and type of modulation. Under different conditions BPSK and QPSK modulation with 2Tx, 2Rx MIMO Zero forcing, MMSE, Alamouti STBC (Rayleigh channel) Alamouti STBC code gave a better performance as compared to Zero forcing and MMSE channel estimation algorithms.

In [42] the authors considered the LTE downlink system parameters and the LTE channel model. They measured the performance of channel estimators that was done for different channel lengths with estimated Power-Delay Product (PDP) as well as exponential PDP. All the channel estimators namely; Least Square (LS) method, Regularized Least Square (RLS), True Minimum Mean Square Error (TMMSE), Exponential Minimum Mean Square Error (EMMSE) and Simplified Minimum Mean Square Error (SMMSE) were investigated and compared with the mean square error against the signal to noise ratio. Among these, the performance of TMMSE showed a much better result and similar results obtained for 2x2, 4x2 and 4x4 systems under different antenna correlation showed different channel estimator performance for 2x2 is better than 4x2 followed by 4x4 MIMO with MSE difference less than 2 dB.

The authors in [83] designed a system model of downlink OFDMA system which is shown in figure 2.13

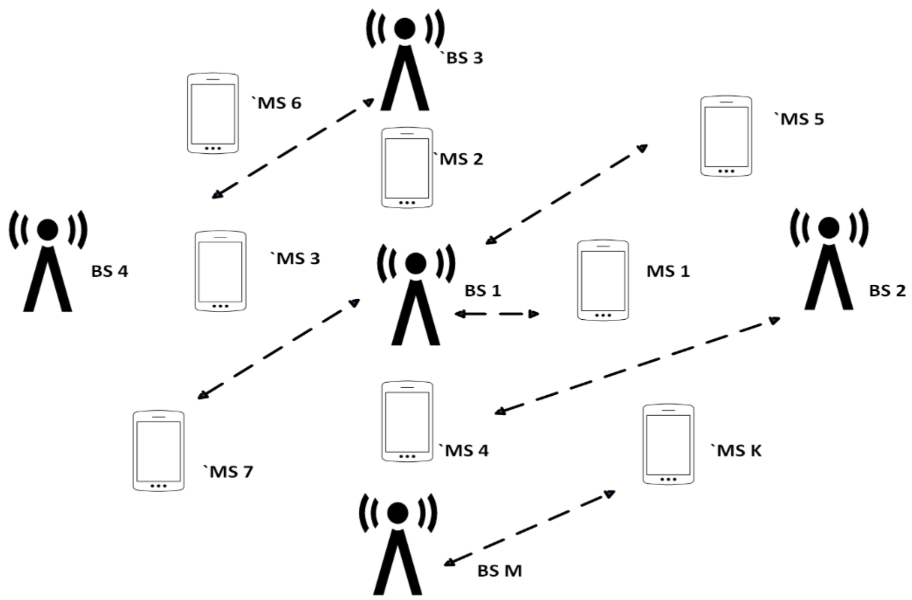

Figure 2. 13 : System model of downlink OFDMA system[83]

They proposed algorithms which included Adaptive sub-carrier allocation algorithm, sub-channel assignment algorithm and Transmit Power allocation algorithm. They reviewed that the main aim of Adaptive sub-carrier allocation algorithm was to reduce transmission power as well as interference from BS to the mobile stations (MS) in nearby cells. The sub-channel assignment algorithm assigns the sub-channels with high channel- to-noise ratio for each user and the transmit power for the allocated subcarriers to maximize the capacity. The proposed optimized algorithm achieved a higher spectral efficiency and energy efficiency compared to existing algorithms.

The authors of this research focused on improving the performance of spectral efficiency and energy efficiency in Massive MIMO systems. To evaluate the system energy consumption, the LTE base station model was studied. The authors analysed the spectral efficiency (SE) with the increased number of antennas and concluded that SE does not always get improved because of the constant transmit power. They also reviewed that energy efficiency (EE) improved when the antenna number was small. [80]

In [107] the authors studied the vertical BLAST (V-BLAST) model as shown in figure 2.14.The transmitter is an ordinary quadrature amplitude modulation (QAM) transmitter with M transmitting antennas and N receiving antennas. V-Blast adopted an Ordered Successive Interference Cancellation (OSIC) detector that detects the data streams iteratively through the ZF or MMSE filter.

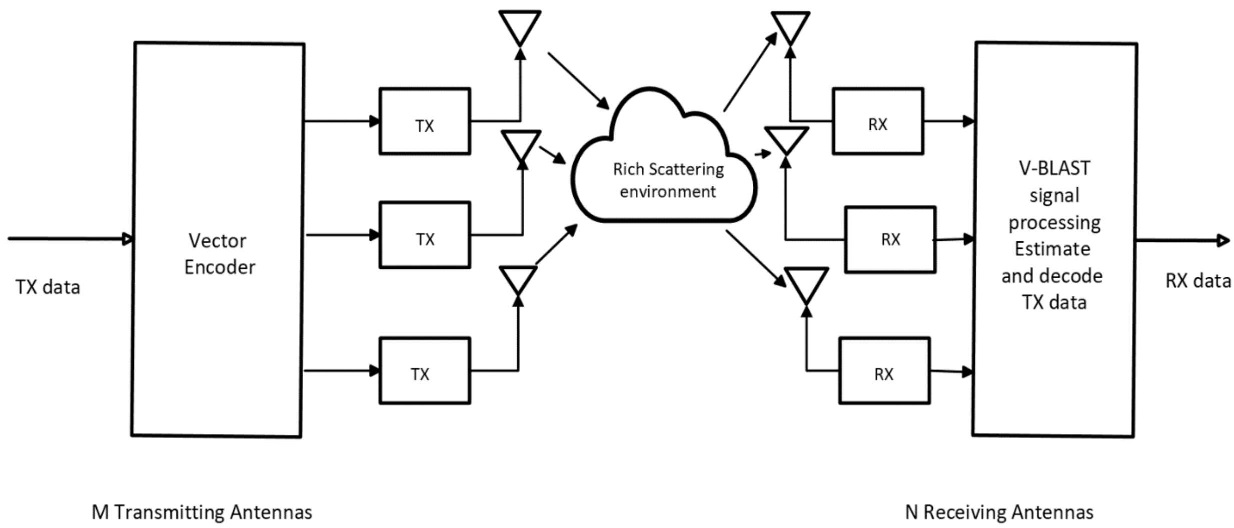

Figure 2. 14 : General V-BLAST model[107]

They concluded that when regularization was introduced in MMSE, it outperformed the ZF at lower constellation data rates whilst at higher constellation data rates, the BER in MMSE and

ZF was similar. The modulation scheme QAM yielded the best results at lower constellation data rates.

In [15],the authors outlined the characteristics of each equalizer: Zero Forcing (ZF),Minimum Mean Square Error (MMSE), Ordered Successive Interference Cancellation (OSIC) and Maximum Likelihood (ML). They calculated the ergodic capacity (upper bound of the capacity on the time-varying channel) according to the Signal to Noise Ratio (SNR) for the different MIMO systems; MIMO, SIMO, MISO and SISO system with application to Rayleigh channel. They concluded that MIMO capacity increased when the number of antennas increased with or without noise making which is the most powerful system compared to the other systems (SIMO, MISO and SISO). The ZF, MMSE, OSIC and ML were compared as well under different conditions and was concluded that ML gave the overall best results.

The authors in [48] proposed a multi objective radio resource function which aimed at maximizing EE at a given data rate. This is depicted in Figure 2.14

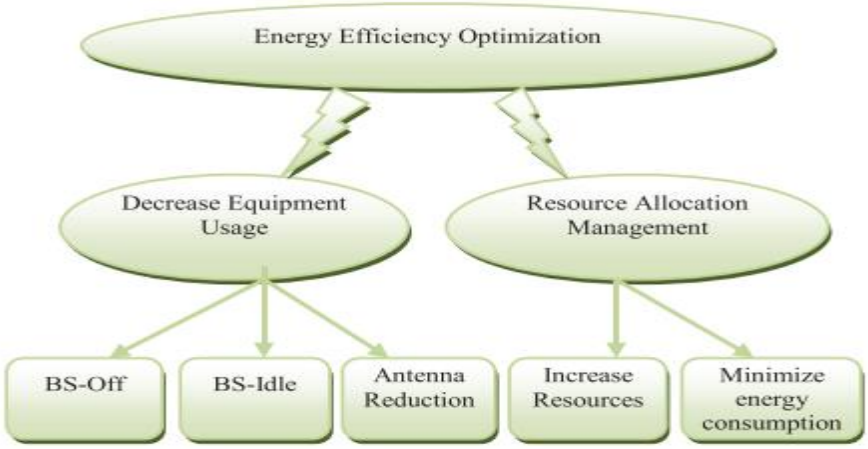

Figure 2. 15 : EE Optimization [48]

The three main parts that consumed energy were the main and auxiliary equipments such as cooling facilities, the core network (hardware equipment and traditional servers), modulation schemes, resource allocation and routing optimization. In the radio resources, the transmission bandwidth and channel bandwidth were compared and analysed. The radio resource allocations were classified into objective functions which were rate adaptive, rate adaptive with fairness and margin adaptive.

CHAPTER 3 : METHODOLOGY

3.1 Introduction

This chapter answers the research questions by presenting the methodology used to carry out this research. The relationship between the spectral efficiency, the number of service antennas, the number of users and energy efficiency are considered using the three-channel estimators: Zero Forcing (ZF), Minimum Mean Square Error (MMSE) and Maximal Ratio Combining (MRC).

3.2 Signal Model

The signal received at the input illustrates the system architecture which comprises of information source, transmitter, channel, and receiver (output).

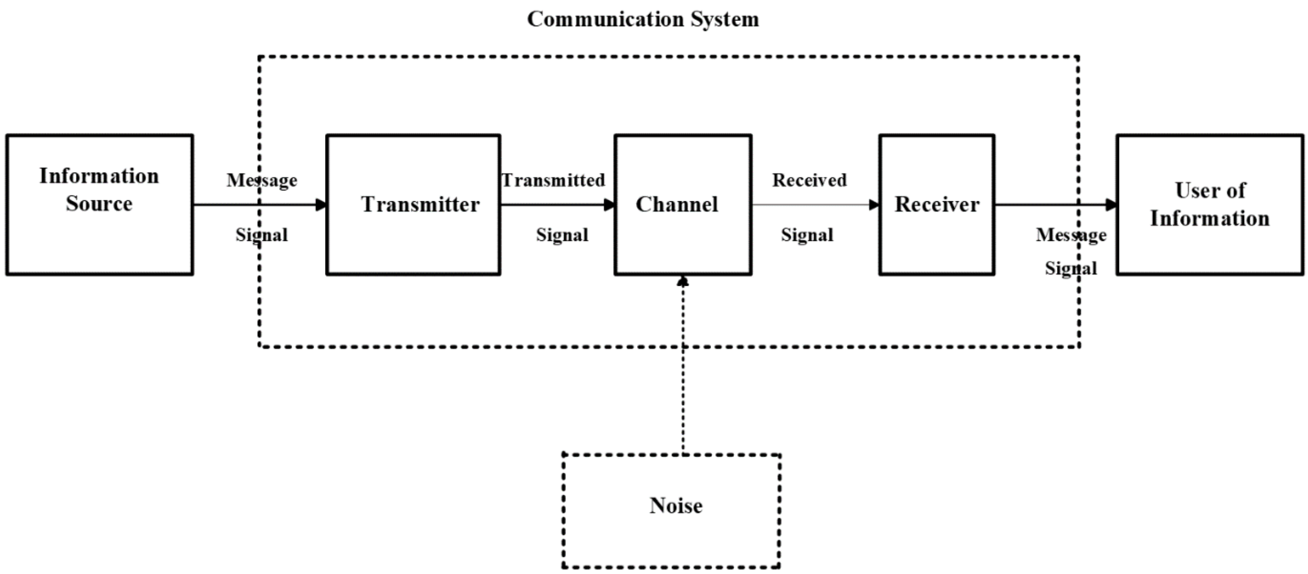

Figure 3. 1 : General Wireless Communication System

Then the relationship between the inputs and the outputs of this linear system can be characterized by:

$$y = Hs + n \quad (3.1)$$

Where $y \in \mathbb{F}^{N_o}$ is the received signal vector, $H \in \mathbb{F}^{N_o \times N_I}$ is the transfer function/channel matrix of the system, and $n \in \mathbb{F}^{N_o}$ represents the additive random noise vector. Depending, on the specific applications considered, F can be either the field of real numbers, $\mathbb{R}$, or the field of complex numbers, $\mathbb{C}$, the linear MIMO detector can also be designed from the perspective of a linear equalizer but this research focussed on real numbers[108].

The signal vector $y_j^{ul} \in \mathbb{C}^N$ at the BS_j at a given time instant reads:

$$y_j^{ul} = \sqrt{\rho_{ul}} \sum_{l=1}^{L} \mathrm{H}_{jl} x_l^{ul} + n_j^{ul} \quad (3.2)$$

Where

$\mathbf{H}_{jl} = [\mathbf{h}_{jl1} \cdots \mathbf{h}_{jlK}] \in \mathbb{C}^{N \times K}$, $\mathbf{h}_{jlk} \in \mathbb{C}^N$, is the channel from UT k in cell l to BS_j

$x_l^{ul} = [x_{l1}^{ul} \cdots x_{l1K}^{ul}]^T \sim \mathcal{CN}(0, \mathbf{I}_N)$,with x_{lk}^{ul} the transmit signal of UT k in cell l ,$n_j^{ul} \sim \mathcal{CN}(0, \mathbf{I}_N)$, is a noise vector and $\rho_{ul} > 0$ denotes the uplink SNR.

In the downlink, the received signal can be expressed as $y_{jm}^{dl} \in \mathbb{C}$ of the mth UT in the jth cell given as;

$$y_{jm}^{dl} = \sqrt{\rho_{ul}} \sum_{l=1}^{L} \mathrm{h}_{ljm}^{\mathrm{H}} s_l + n_{jm}^{dl} \quad (3.3)$$

Here $\boldsymbol{s}_l \in \mathbb{C}^N$ is the transmit vector of BS l , $n_{jm}^{dl} \sim \mathcal{CN}(0,1)$ is receiver noise, and $\rho_{dl} > 0$ denotes the downlink SNR. We assume channel reciprocity, i.e., the downlink channel h_{ljm}^{H} is the Hermitian transpose of the uplink channel [109]. Equations 3.2 and 3.3 show the uplink and downlink expressions.

3.3 System Simulation

This section presents the simulation of the proposed model. The simulation was done in MATLAB R2016a using Monte Carlo methods which is a class of numerical methods that relies on random sampling. It involves the generation of random samples of the input according to the distributions of the inputs, and analysis of a particular set of inputs in the sample. Monte Carlo makes use of random sampling by estimating desired outputs and gets rid of uncertainty in these outputs[110].

The simple design model was used to simulate Monte Carlo in Matlab R2016a.The model was divided into three parts:

1. User Terminal (UT)
2. Channel realizations (Channel estimation calculations)
3. Service Antennas at the Base Station

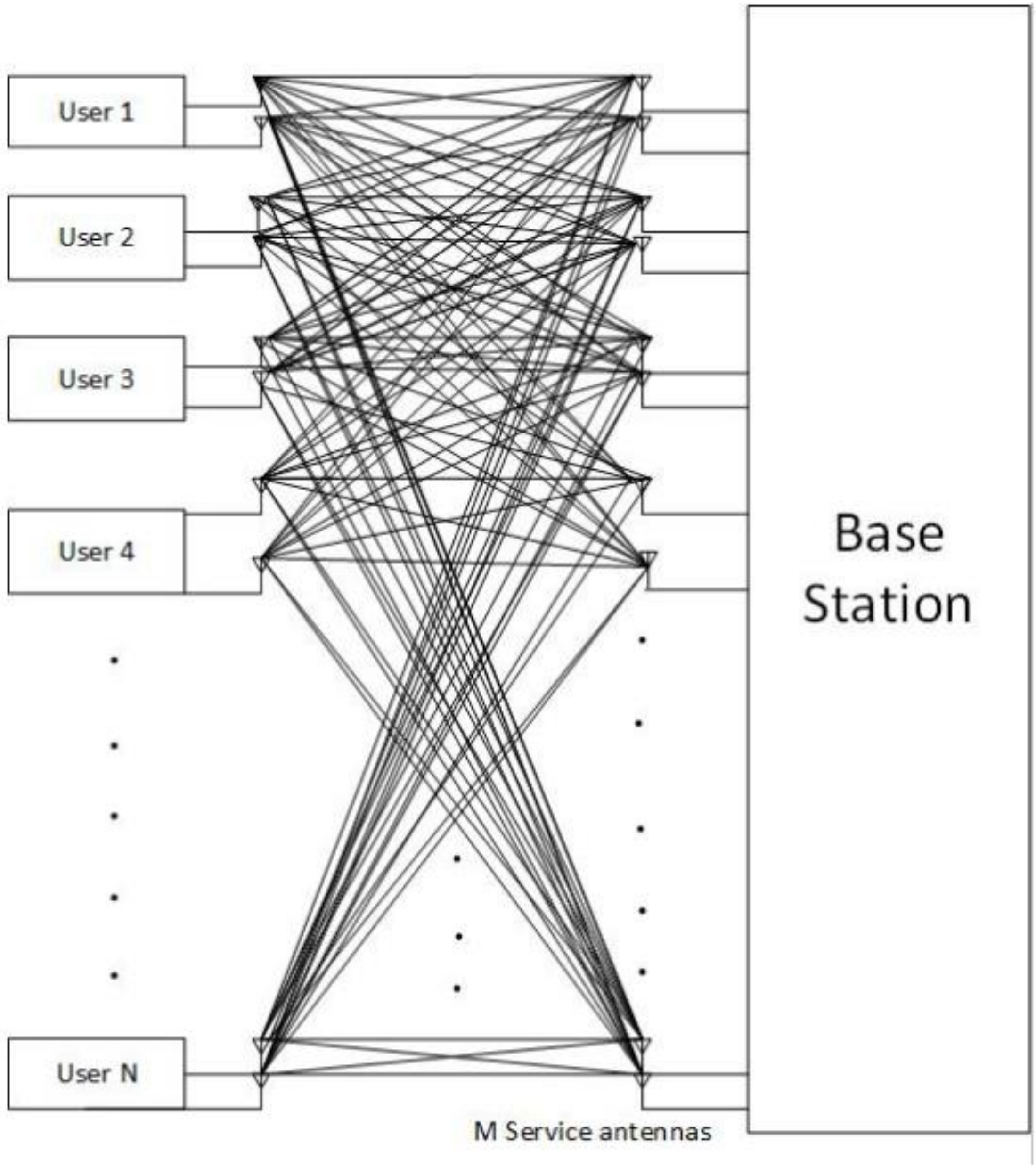

Figure 3. 2 : System Model

In the system simulation, N users each were having 2 antennas transmitting to service antennas of FDD mode mobile users for each carrier having 15000Hz as the bandwidth and the total number of subcarriers adding to 1200 giving a total subcarrier bandwidth of 1.8MHz which was considered to analyse the performance of the system model. The signals transmitted from the user terminal to the service antennas were generated using Monte Carlos. The processing was done by randomly selecting 100 Monte Carlo Realizations.

The channel matrix was a multipath channel which generated Rayleigh fading channel realizations that were used to analyse and investigate the channel behaviour thus determining the propagation parameters on the capacity of the channel. The FFT size is 2040 which is the required FFT size in LTE [111].The power per user was compared on the dB scale as -5dBW. The channel estimation is independent of the number of receive antennas therefore this dissertation analysed the service antennas by the Rayleigh channel realizations. There was equalization (MMSE, ZF and MRC) at the BS with an increased number of antennas. It's important to use Precoding techniques in massive MIMO systems. Table 1 shows the simulation parameters.

Table 1 : Simulation Parameter

Simulation Parameters	**Values**
Number of service antennas (M)	1 - 64
Number of users (N)	1-37
Number of subcarriers OFDMA	1200
Number of antennas per user	2
Coherence block length	100
Power per user	-5dBW
Subcarrier Bandwidth	15000Hz

Figure 3.3 is a flow chart of the proposed system which has 2 antennas per terminal a representation of 2X2 MIMO system. The number of service antennas, users, subcarrier bandwidth, FFT size, power dB etc were defined.

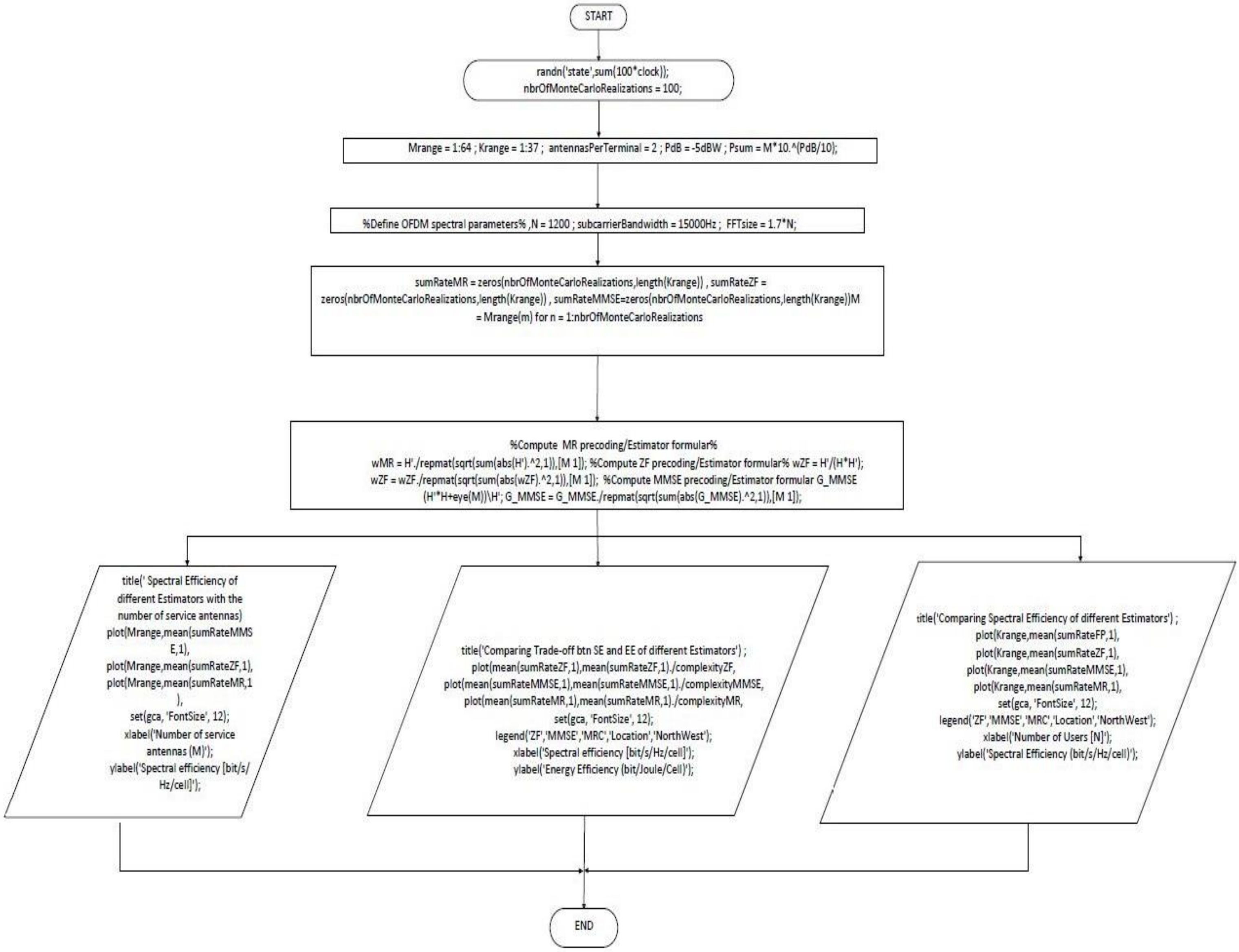

Figure 3. 3 : Flowchart of the simulation

CHAPTER 4 : RESULTS AND DISCUSSION

This chapter presents the results of the study. Section 4.1 shows the simulation results for spectral efficiency against the number of service antennas for ZF, MMSE and MRC. Section 4.2 compares the spectral efficiency against the number of users among ZF.MRC and MMSE and section 4.3 compares the spectral efficiency and energy efficiency against ZF,MMSE and MRC and section 4.4 discusses channel estimators and radio resource.

4.1 Spectral Efficiency and the Number of Service Antennas in a Network

This section presents the results of the spectral efficiency performance against the number of service antennas for ZF, MRC and MMSE.

Figure 4.1 shows a steady exponential increase for the three estimators in spectral efficiency as the number of service antennas increases. Up to ten antennas, MMSE has the highest spectral efficiency of 12bits per Hertz per cell followed by MR and ZF which both had 8bits per Hertz per cell spectral efficiency value. However, at four service antennas, the performance of ZF was at 3bit/s/Hz/cell. Another interesting observation is that beyond twenty service antennas both MMSE and ZF performed better than MR averaging between 24bit/s/Hz/cell to 33bit/s/Hz/cell. The implications of these results are that below ten service antennas ZF performs quite poorly compared the MMSE and MR because at few antennas, ZF is affected greatly by noise and interference. Beyond ten service antennas MMSE and ZF performs better. The convergence seen between MMSE and ZF is because of the channel matrix composition due to the large number of service antennas.

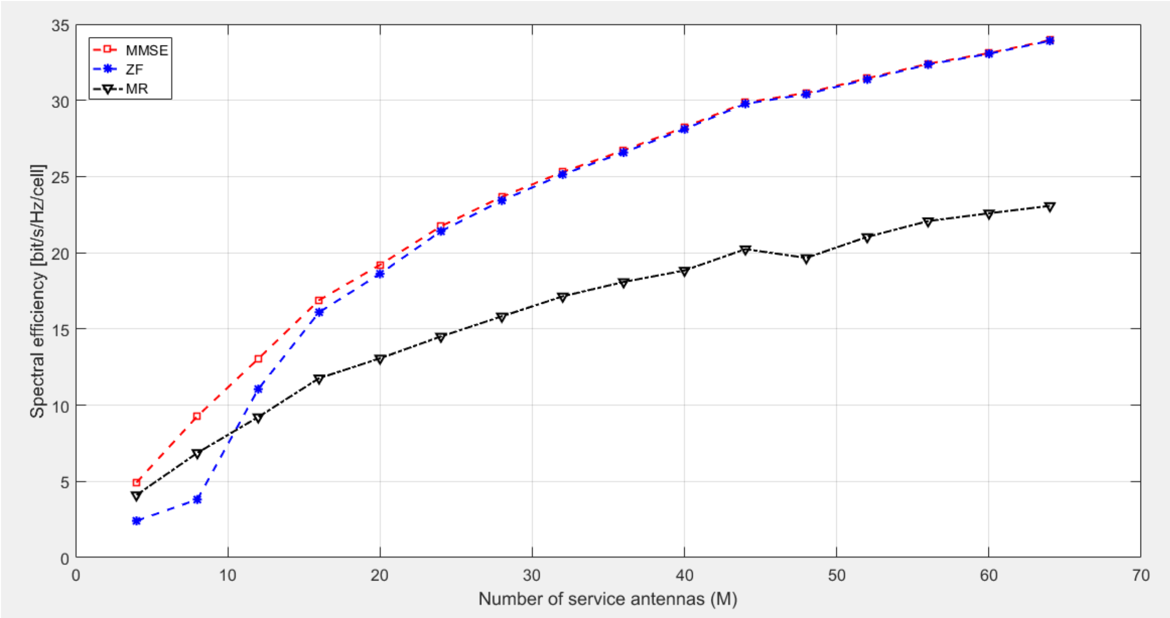

Figure 4. 1 : Spectral efficiency against the number of service antennas for ZF, MMSE and MRC

4.2 Spectral Efficiency and the Number of Users in a Network

Figure 4.2 shows the effect of spectral efficiency as the number of users increase. Results show that irrespective of the number of users, MMSE and ZF increases gradually as compared to MR which had a moderate increase.

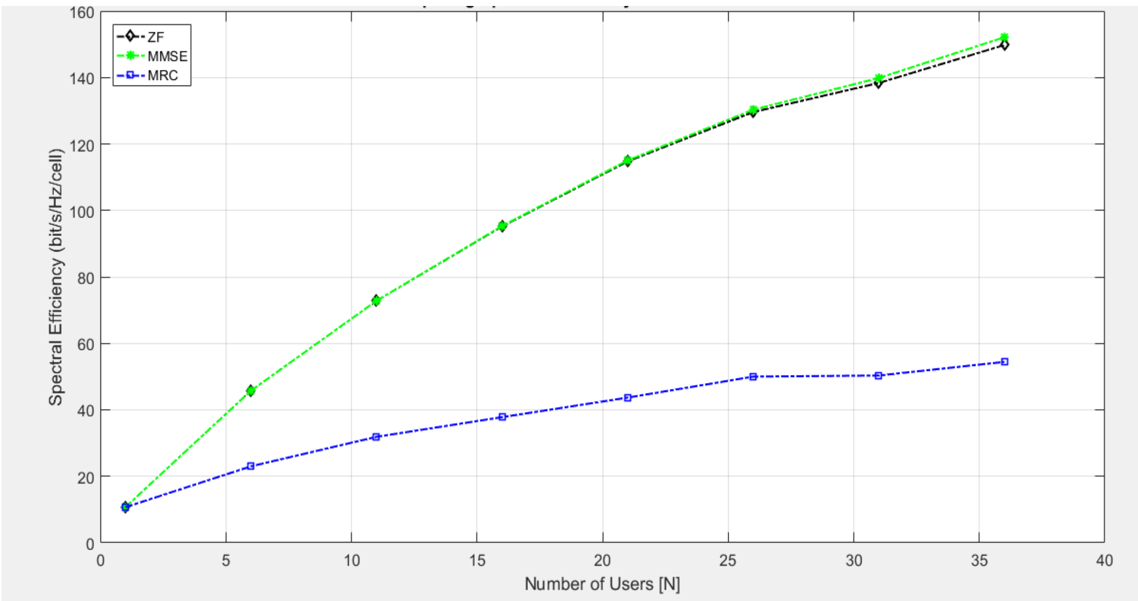

Figure 4. 2 : Spectral efficiency against number of users of ZF, MMSE and MRC

Both MMSE and ZF converged achieving a maximum of close to 150 bit/s/Hz/cell at 37 users. For the same number of users MR only achieved spectral efficiency of 57bit/s/Hz/Cell. This means that MR performance has a marginal increase as the number of users increase but with lower performance when compared with ZF and MMSE because it combines multiple signals with noise and interference that are added together.

4.3 Energy Efficiency and Spectral Efficiency in a Network

Figure 4.3 analysed the energy efficiency against the spectral efficiency. ZF gave a reading at 4bit/s/Hz/cell thereafter maintaining a constant increase in its performance. Energy efficiency (EE) and spectral efficiency (SE) both increase due to capacity gain as the number of service antennas are varied. ZF, MMSE and MRC all peak with maximum capacity making good use of both the SE and EE. MRC shows the least performance with an inconsistent response as it increased, decreased, and later increased as shown in the Figure 4.3. On the other hand, MRC, MMSE and ZF achieved a constant increase from 5bit/s/Hz/cell to 11 bit/s/Hz/cell. The drop in MMSE and MRC shown have less performance because they consume power in stabilizing the network against noise and interference thereby reducing energy efficiency. With the increased number of service antennas, ZF overcomes the effect of both noise and interference there by reducing power consumption of the network.

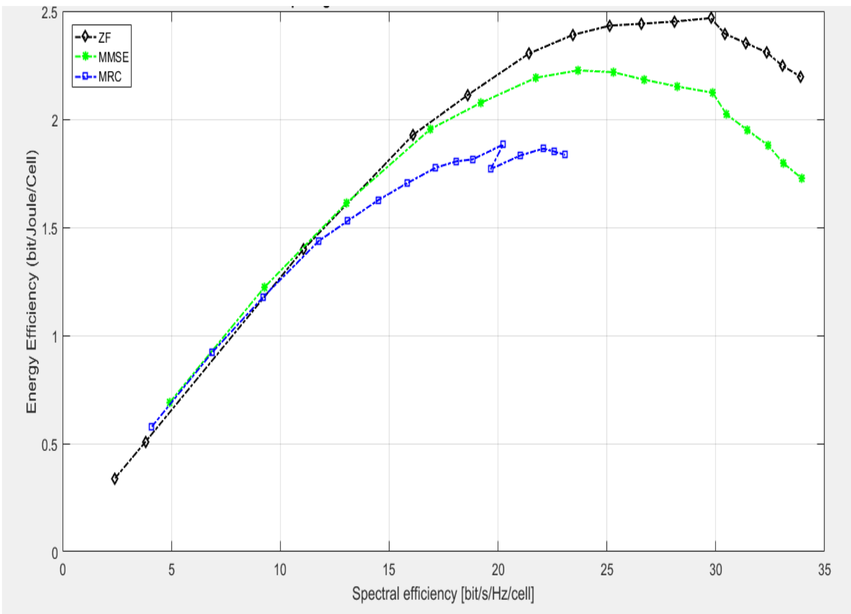

Figure 4. 3 : Energy efficiency against Spectral Efficiency of ZF, MMSE and MRC

4.4 The channel estimators in radio resource performance

This section compares the proposed system model with other system designs. Most studies have focused on comparing QOS, BER, MCS, throughput, SINR and SNR in MIMO systems.
In[15], the authors presented a system model that was frequency selective and non-selective in time. The ergodic system (bits/transmission) was calculated based on the number of antennas according to SNR measured at different values of SNR 60dB and 80 dB in different MIMO systems. BPSK using Rayleigh was also analyzed and focused on the performance of each channel estimator with its transmitter increasing from 1, 1, 2 and 2 and its receiver increasing by 1, 2, 5 and 8. The authors only considered BER and SNR when analyzing the MIMO and equalizers.

The authors of [48] proposed a system model that had one base station and made use of the multiple access which was achieved by allocating different number of subcarriers with the corresponding power level required for each user to maximize the overall energy efficiency of the system. The transmit power depended on the modulation order. With 180 subcarriers and 130dB as the path loss thus the authors allocated each subcarrier to one user exclusively.

The authors of [57] proposed two algorithms for comparison which included sub-optimal subcarrier allocation and one optimal power allocation. The second one was based on each user taking turns to transmit signals using OFDM based on round robin TDMA. The system had 1MHz, 10 users, 256 subcarriers, SNR range 0- 40dB, 2-4 antennas and adopted the spatial channel model in IEEE802.16m evaluation methodology.

The authors of [107] used a V-blast system model which used a de-multiplexer at the transmitter. The operation of the co-channel by the transmitter had a symbol rate of 1/T symbol/secs and each transmitter used a modulation scheme QAM for different arrays at M-QAM transmitter. In [3],four different resource blocks were proposed namely ; Adaptive Block-Level Resource Allocation technique (ABLRA) with the Fan scheme ,modulation coding scheme (MCS) Selection for Throughput Improvement in Downlink LTE Systems used the Jiancun scheme, Quality Of Service (QoS) Guaranteed RB Allocation Algorithm for LTE systems (QSRBA) used the Na scheme and Resource Allocation in an LTE cellular Communication System (RALDL) made use of the Kwan. The Fan scheme which was proposed significantly outperformed the others at -5dB<SINR<25dB and the rest of the schemes were at SINR 10dB.

The author of [42] made use of two types of power delay profile (PDP) which were extended vehicular (EVA) and exponential PDP. With a MIMO system used at the transmitter and receiver, there was no mobility and the system had separate antenna correlation. The system achieved a bandwidth of 20 MHz, FFT size of 2048, CP length of 144 samples, subcarriers of 1200 and the transmitter and receivers compared were 2x2, 4x2 and 4x4.

In [83] resources, the authors proposed the adaptive subcarrier allocation algorithm, sub-channel assignment algorithm and transmit power algorithm. The proposed system used MATLAB 2010 for simulation with a bandwidth of 1MHz, 32 users and 256 subcarriers.

The author in [98] reviewed information from a theoretic point of view. Mitigation of pilot contamination methods included Protocol based method. Despite the increase in the SINRs, frequency reuse makes a difference; the Precoding method was simulated in MATLAB using Monte-Carlo Simulations of massive MIMO systems consisted of 7 cells, the number of BS being N=64 and the number of users in each cell being K=10; AOA-based methods and the blind methods.

CHAPTER 5 : CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusion and recommendations of the study based on the research objectives.

5.1 Conclusions

The main challenge in implementing multiple antennas on the user equipment (UE) is having a limited battery power and limited size of mobile device. This usually limits the number of antennas at the user equipment (UE) there by making the system energy efficient. Therefore, this study was restricted to just two antennas at the user equipment (UE). Good management of resources in a wireless communication network is important as it assists in yielding an overall good performance of the system.

The performance analysis of the proposed system showed that despite having many users and antennas, the spectral efficiency (SE) and the energy efficiency (EE) were dramatically improved. The proposed model achieved 100 repeated random samples using Monte Carlo to obtain numerical results with a total transmit power of 20.2W in linear scale. Furthermore, the analysis of the Spectral Efficiency increases rapidly with a gradual increase of the service antennas and the number of users. The energy efficiency results shown in figure 4.3 show a rapid increase at first among ZF, MMSE and MRC with ZF showing the highest and then reduces gradually at a certain extent, this is because MMSE and MRC consumption a lot of power trying to prevent noise and interference hence reducing the energy efficiency. Obviously, the spectrum efficiency and energy efficiency are damaged greatly in the existence of hardware impairment.

The simulation results show that MMSE and MR performed better than ZF under similar conditions, but when the number of service antennas gradually increased, ZF and MMSE exceeded MR. From the results we can conclude that the multiple antennas increase data rates through multiplexing or diversity. Furthermore, it can be concluded that from the three considered equalizing techniques, ZF performs better maintaining the highest energy efficient results as compared to MMSE and MRC.

5.2 Recommendations and Future Work

This study focussed on spectral efficiency, energy efficiency, channel estimators, number of users and service antennas. The spectral efficiency looked at here only focussed on 2x2 MIMO system. In the future, it can be developed to Massive MIMO system. The distance between users and BS was not considered in this dissertation. This should be considered in the future for more accurate simulation results.

The performance analysis of these radio resources through focussing on channel estimators was mostly mathematical and software simulated. It did not compare the SNR and BER against the three channel estimators rather it compared against the users, service antennas, SE, and EE. Therefore, there is need to see and analyse how channel estimators can perform in the environment of SNR and BER.

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APPENDIX: SYSTEM SIMULATION CONFIGURATIONS

Parameter	Value
Antennas per User	2
Power per User	-5dBW
Subcarriers	1200
Subcarrier Bandwidth	15000Hz
FFT Size	2040
Monte Carlo repeated numerical calculations	100
Coherence Block Length	100