Research and Postgraduate Studies (RPGS) Unit

Thesis Title: "**Advancements in Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiple Access (OFDMA) as LTE-Advanced enabler in 4G Network**".

Submitted by

KATAMBIRE N. Vienna

College of Science and Technology

School of Information and Communication Technology (SoICT)

Master of Science in Information and Communication Technology (Specialization in Operation Communication)

Year: 2016/2017

Research and Postgraduate Studies (RPGS) Unit

Thesis Title: "Advancements in Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiple Access (OFDMA) as LTE-A enabler in 4 G Network".

Submitted by

KATAMBIRE N. Vienna

(**Ref No: 216350298**)

A dissertation submitted in partial fulfilment of the requirements for the award of degree of Master of Science in Information and Communication Technology

In the College of Science and Technology

Supervisor: **Dr. Luc NGEND**

June 2017

Declaration

I, **Vienna N.KATAMBIRE**, hereby declare that this dissertation is a product of an original research, which I conducted under the Supervision of **Dr. Luc NGEND** of the UNIVERSITY OF RWANDA, COLLEGE OF SCIENCE AND TECHNOLOGY (UR-CST). I also declare that I have not submitted this dissertation to any other institution. All references have been duly acknowledged.

…………………………………

VIENNA N. KATAMBIRE

(STUDENT)

DATE: ……………………

C e r t i f i c a t e

This is to certify that the research Work entitled **“Advancements in Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiple Access (OFDMA) as LTE-Advanced Enabler in Modern 4G Network”** is a record of the original bonafide work done by **Vienna N. KATAMBIRE (Ref No:216350298)** in partial fulfillment of the requirement for the award of Master of Science Degree in Information and Communication Technology, Specialization in Operation Communication from College of Science and Technology, during the Academic Year 2015-2016.

…………………………… …………………………….

Dr. Luc NGEND **Dr. Henry Kirya**

Supervisor HoD of IT

Acknowledgements

I am eternally grateful to my wife, Mukarugaza Rugambya Alice, for her love, warmth and strength that kept us going through hardship. I am grateful to God for giving me wisdom and strength to conduct this research.

I also extend my deep appreciation to the leadership of Rwanda for the moral and material support in the conduct of the whole Master’s Program and research.

Let me also thank the whole academic community of Rwanda, especially University of Rwanda management and lecturers who spare no efforts to provide education of quality to me and other students in Rwanda.

My greatest thanks go to Dr. Luc NGEND, my supervisor, for his intellectual guidance, support and dedication throughout the entire work. He inspired and encouraged me to stay the course.

.

Abstract

Today, the demand for multimedia data services has grown up rapidly. Wireless systems face the challenges of the growing demand of higher data rates, spectral efficiency, better quality of services, increased network capacity including limited availability of radio frequency and transmission problem caused by various factors like fading and multipath distortion. The need for more sophisticated technology is possible with higher and faster data transmissions and reception.

An important challenge of wireless networks is to boost the data rate and quality of services, where space-frequency resource allocation and multiuser beam forming are crucial techniques to obtain high spectral efficiency. Based on advancement in LTE-Advanced MIMO-OFDMA network in ITU-R specific higher data rate and spectral efficiency can be achieved.

To have better understanding of the key technologies used in LTE-Advanced and important role they play in improving performance as well as meeting IMT-requirement, this thesis carried out a performance evaluation of enhanced uplink for both Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiple Access (OFDMA) under LTE-A parameter.
This thesis gives the background and methodology that investigates the advancements in MIMO technique and OFDMA technology in terms of LTE-A enabled technologies.

Based on the results obtained in this report through different simulation, the options presented in this thesis for both managing interference and dealing with increased users and meeting their demand of high data rate, increased capacity, coverage, spectral efficiency and reduce latency under the advancements of MIMO-OFDMA as LTE-A enabler technologies in 4G network can be seen as positive solutions.

Keywords: LTE-A, 4G, Spectrum, MIMO. OFDMA, SC-FDMA SISO, SIMO, MU-MIMO, CoMP. UP/Down Link,

Table of Contents

Table of Figures

List of Acronyms

1G: First Generation

2G: Second Generation

3G: third generation

4 G LTE: Fourth generation long term evolution

3GPP:3rd Generation Partnership Project

BS: base station

DL: Downlink

HSPA: High Speed Packet Access

IMT-A: the International Mobile Telecommunication –Advanced

ITU-R: International Telecommunication Union Radio communication Sector

LTE: long term evolution

LTE-A: Long Term Evolution – Advanced

MIMO: Multiple Input Multiple Output

MIMO-OFDMA: Multiple Input Multiple Output use to get with Orthogonal Frequency Division Multiple Access

MU-MIMO: Multiple User Multiple Input Multiple Output

OFDM: orthogonal frequency division multiplexing

SC-FDMA: Single Carrier Frequency Division Multiple Access

SINR: signal interference ratio

SU-MIMO: Single User Multiple Input Multiple Output

UEs: user equipment

UL: uplink

WCDMA: Wide Code Division Multiple Access

Chapter 1: Introduction

1.1 Introduction

The evolution of mobile wireless networks during the last several years has raised great expectation for higher data rates to the mobile users. The demand for high speed and widespread network access in mobile communication increases everyday as the number of users' increase and expected to continue growing even more in the future, driven by unlimited possibilities in internet services and application, and advance in handheld and portable equipment. To meet with current and future demands for reliable high data rates over the mobile networks, the International Telecommunication Union (ITU) started working since October 2005 to set a definition and standards for the Fourth-Generation (4G) mobile system also known as IMT-Advanced. One of the key features in IMT-Advanced is to provide enhanced peak data rates up to 100 Mbps (outdoors) and 1 Gbps (in doors) [1,2].

In response to the ITU call for proposals on IMT-Advanced, The 3GPP Long Term Evolution (LTE) is the system that marks the evolutionary move from third generation of mobile communication (UMTS) to fourth generation mobile technology. With the standards definitions now available for LTE, the 3GPP eyes are now turning towards the next development that of the truly 4G technology named IMT Advanced. The new technology being developed under the auspices of 3GPP to meet those requirements is often termed LTE-Advanced. The driving force to further develop LTE towards LTE-Advanced or LTE release 10 was to provide higher bit rates in a cost efficiently way and, at the sometime completely fulfill the requirements set by ITU for IMT Advanced, also referred to as 4G [3].

The Important technology of the LTE-Advanced for meeting IMT Advanced requirements include Carrier Aggregation (CA), enhanced use of Multi-Antenna techniques and support for Relay Nodes (RN) but not limited to MIMO techniques and OFDMA. LTE and LTE-Advanced have to co-exist with LTE, 2G and 3G cellular systems for some time, so interworking necessities and potential interference remain important issues. By using multiple antennas at the transmitter and receiver along with some complex digital signal processing, MIMO technology enables the system to set up multiple data streams on the same channels, thereby increasing the data capacity of a channels. OFDMA technology is more advance form of OFDM that promises to be a key technology for achieving the high data rate, increased network capacity and spectral efficiency requirement for wireless communication system where sub carriers are allocated to different users in time of frequency domain.

This thesis analyzed the advancement in MIMO and OFDMA technologies to meet ITU requirement for 4G wireless communication. MIMO and OFDMA have a natural symbiotic relationship due to the frequency flat nature of each resulting sub-channel. This interaction examined in this thesis and commented upon in the results section how those technologies has enabled LTE-A. Moreover, the impact of advancement of MIMO and OFDMA in the enhancing spectral efficiency which leads to the improvement of system throughput was analyzed.

The main limitations with the combination of MIMO and OFDMA are inter-operability necessities, and potential interference and the peak-to average power ratio (PAPR) associated with OFDMA. This research thesis attempted to explain the promise of advancement of MIMO techniques and explained the mechanisms behind it. It highlighted the specifics and the interoperability of MIMO system and OFDMA technology as LTE-A enabler technologies.

1.2 Background and Motivation

During the last decades, communication systems evolved continuously at an impressive speed. With the first (1G) and second generation (2G) communication were restricted to voice and text messages, the introduction of third generation (3G) allowed the use of broadband data granting access to browse the internet and enabled location-aware services. The fourth generation (4G) aims at higher speeds. With the advanced deployment of marked development of mobile broadband and data oriented devices such a smart phones and USB modems, the desire to communicate with anyone, anywhere at any time becomes stronger.

These devices and user demands are responsible for a fast growth in mobile data traffic [4]. In 2012, global mobile data traffic grew 70 percent and it is expected to increase 13-fold between 2012 and 2017. Moreover, given the current growth, the estimated data traffic in wireless mobile network in 2020 might be 1000 times higher than that in 2010 [5]. In additional, the number of tablets mobile-connected is increasing exponentially and this means even more growth in mobile data traffic.

In order to meet these challenging demands, mobile networks have to deal with the increase of the number of devices and also the demands of users for higher speed. Therefore, mobile networks have to adopt several concepts in combination. Back in days, to meet this challenge required only the increase in capacity and this would be achieved by adding more macro nodes in the network. However, the high costs and the space needed for such an approach represent an important problem for the operators. Moreover, spectral efficiency per link is reaching theoretical limits [6, 7]. At the sight of this and in response to ITU call on IMT-Advanced, the 3GPP first work on 4G began in LTE release 7. This release included further improvement on High Speed Packet Access (HSPA), currently working in progress for the enhancement of LTE which is featured in release 10 named LTE-Advanced (LTE-A).

One of the key requirements in next generation mobile communication systems is to design robust air interface techniques that are capable to provide data rate. Majority of the world's operators and vendors are already committed to LTE deployments and developments, making LTE the market leader in the upcoming evolution to 4G wireless communication systems. Multiple Input Multiple Output (MIMO) technologies introduced in LTE-A such as spatial multiplexing, transmit diversity, and beam forming are key components for providing higher peak rate at a better system efficiency, which are essential for supporting future broadband data service over wireless links.

Further extension of LTE-A MIMO technologies have been studied under the 3GPP study item "LTE-Advanced" to meet the requirement of IMT-Advanced set by International Telecommunication Union Radio communication Sector (ITU-R). LTE-A is a technology that was designed to meet the demands of the growing traffic. As mentioned before, it includes several advanced techniques such as carrier aggregation, Multiple Input Multiple Output (MIMO), and the introduction of HetNets.

While intensive researches are being conducted to develop the 1 Gbps peak data rate required by the ITU in LTE-Advanced using 4x4 MIMO and transmission bandwidths wider than approximately 70 MHz, it is time to start thinking about how to avoid milt-user interferences which caused by the limited frequency resources on the market. This is one of the earlier works which is trying to raise the awareness of the problems of interference which is associated to the limited frequency spectrum and try to investigate technologies that enables the required high data rate, channel capacity coverage, and spectral efficiency that helps to fight those interferences. Therefore, it is imperative to evaluate the performance and stability of MIMO system and OFDMA at an early stage in order to promote its smooth and cost efficient introduction and deployment.

This is to try to anticipate the problems which may be caused by the introduction MIMO systems and OFDMA rather than trying to solve them when MIMO System and OFDMA modulation are already on the market.

1.3 Statement of Problem

The last few years have witnessed a staggering growth in the demand for high speed broadband services including internet access over mobile devices. To address this problem, the wireless telecommunication industry has been scrambling to define a new air interface for mobile communication so as to provide a framework for these high mobility broadband services and increase the overall system capacity, reducing latency, and improving spectral efficiency and cell-edge performance. This thesis is to investigate the deployment of MIMO and OFDMA technologies as enabler of LTE-A to achieve high data rate and increased bandwidth.

As mentioned before, to meet those challenges of fast grow data traffic; several concepts have to be combined. So, in combination with orthogonal frequency-division multiplexing Access (OFDMA), the assigned bandwidth is used efficiently. Unfortunately, the available radio spectrum is limited and an efficient use is therefore of much importance. The utilization of multiple antennas at both the transmitter side and the receiver side constitute a Multiple-Input Multiple-Output (MIMO) system, which increases the achievable capacity linearly as a function of the number of transmit and receive antennas. In current research, MIMO systems attract considerable interest of research, since the available physical space is typically constrained to ensure uncorrelated transmit and receive antennas. This especially true at the mobile station, massive MIMO systems target this problem by deploying a large number of antennas at the base station and assume single-antenna mobile station. Moreover, advanced forward error correction codes, such as turbo codes have made a substantial progress and are able to approach the Shannon limit [8, 9]. While MIMO-OFDMA promise substantial diversity and capacity gains to improve communication performance by offering significant increases in data throughput and link range without addition bandwidth or transmit power, the required pilot overhead grows in proportion to the number of transmit antenna.

By using Orthogonal Frequency Division Multiple Access (OFDMA), for the highest category terminals LTE was able to provide download rates of 150 Mbps for multi-antenna (2x2) Multiple Input Multiple Output (MIMO). The non-compatibility of the 3G standards and demand for higher data rates has shifted industry focus to fourth generation (4G) wireless network and it finally support data rates above 100 Mbps. To develop the 1 Gbps peak data rate required by the ITU in LTE-Advanced, advancement in MIMO techniques together with OFDMA has to be achieved. The use of OFDMA technology helps resources to be split into smaller granular units which can be allocated for various services as required. This thesis studied advancement in MIMO techniques to meet ITU requirement for LTE-A by considering OFDMA as a vital for achieving high spectral efficiencies in LTE-A mobile communication because of its ability to integrate well with MIMO technology (also called as MIMO-OFDMA). In response to ITU requirement for LTE-A, this thesis considered the advancement of MIMO system by studying the performance of MIMO techniques in wireless mobile network, from Single cell (MIMO) systems to single-Cell coordinated Multi-user (MU-MIMO) system as shown by Figure 1. The advancement in MIMO system was evaluated based on the performance of LTE-A under varying channel conditions for different MIMO antenna transmission schemes. The compatibility of MIMO and OFDMA was studied and the performance of OFDMA access techniques in terms of single hop and two hop transmission scenario.

Single cell MIMO system **Single cell MU-MIMO system**

Source: [9] ***Figure 1 MIMO system***

This thesis investigated the advancement in MIMO antenna and OFDMA technologies as the key enabler of LTE-Advanced to achieve higher data rate and increased capacity, the IMT advanced requirements.

1.4 Study Objectives

1.4.1 General Objective

The general objective is to analyze the deployment of MIMO and OFDMA techniques as enabler technologies of *LTE-Advanced* to achieve high data rate, wider bandwidth and backward compatibility within the limited availability of spectrum resources.

1.4.2 Specific Objectives

1. To figure out the current LTE spectrum resources that are now formally included in LTE Advance specifications
2. To evaluate the current and advancements in MIMO and OFDMA.
3. To examine wider bandwidth, enabled by carrier aggregation.

4. To verify high data rate and higher efficiency, enabled by enhanced downlink multiple accesses (OFDMA) and enhanced multiple antenna transmission (advanced MIMO techniques).

1.5 Hypotheses

The problematic presented in I.2 and I.3 has motivated the definition of several hypotheses:

- Hypothesis 1: The advancement in MIMO-OFDMA techniques can be achieved based MIMO system and OFDM techniques used in LTE-A.
- Hypothesis 2: Achievement of high spectral efficiency in LTE-A can be due to the ability to integrate MIMO and OFDMA
- Hypothesis 3: High data rate can be improved by enhancing MIMO technique in LTE-A
- Hypothesis 4: Efficient resources spectrum scheduling can be achieved in combination advancement in MIMO system with OFDMA in LTE-A.

1.6 Study Scope

This thesis discussed the important technologies of the LTE-Advanced such as MIMO and OFDMA and other key technologies under consideration for LTE-Advanced such as carrier aggregation, enhanced uplink multiple access and enhanced multiple antenna transmission. The advancement in MIMO system together with OFDMA have been analyzed and a depth discussion has been conducted to examine how MIMO-OFDMA are LTE-A enabler technologies. LTE-Advanced technologies like enhanced inter-cell interference coordination (eICIC), Cloud Radio Access Network(CRAN), heterogeneous networks (HetNet), LTE self-optimizing networks (SON) and HNB and HeNB mobility enhancements was not discussed in this thesis.

1.7 Significance of the Study

This study benefited the researcher, the researcher has been able to fulfill partial requirement of completing a Master's degree in information and Communication Technology (Specialization Operation Communication). The researcher has been able to improve or increase his understanding in MIMO-OFDMA as enabler of LTE-A.

Therefore, the study clarified all the aspect in advancements in multiple input and multiple output antenna and OFDMA technologies as enabler in LTE-A. The study document has as well served as guide for future researcher and student who may intend to make a further research on the same dissertation topic.

1.8 Organization of the Study

This thesis is divided into six chapters. The first chapter is an introduction which provides a general overview of the work. It provides an overview on the background of the work, problem statement of the work and illustrates general objectives and specific objectives of the work. This chapter also provides the scope and a significance of study.

The second chapter is literature review. In this chapter all research works related to this study were critically summarized. In this chapter, all works related to advancements in MIMO and OFDMA were discussed. The chapter ends by providing an understanding of all terms and technologies related to advancements in MIMO and OFDMA enabler technologies of LTE-A.

The third chapter is research methodology which describes all steps and procedures used to efficiently conduct the work. In this chapter source and size of data are indicated and analyzed. The forth chapter is the system analysis and design. In this chapter, MIMO system design and respective mathematical model were explained. Some equation for both MIMO and bandwidth efficiency in OFDMA technology were derived and explained. In this thesis, analyses were based on the existing models and basically Shannon equations for capacity. It also discussed principals of OFDMA in LTE-A.

The fifth chapter provides the results evaluation and discussion. Under this chapter, the detailed information on the simulation results was given. It showed the recent advancement in MIMO technology. The last but not the least is chapter 6; conclusion and recommendations, which concludes the work and provides further recommendations for future works related to this research.

1.9 Conclusion

In this chapter, we presented a background as well as motivation of this study, a detailed problem statement has been given, and some contribution that this study will bring. With the general and specific objectives described in this chapter, we focused on investigation of the deployment and operation of MIMO and OFDMA techniques as enabler technologies of *LTE-Advanced* to achieve high data rate and bandwidth enabled by carrier aggregation.

Chapter 2: Literature Review

Introduction

This chapter provides literature review of LTE releases, highlight theoretical review on Multiple Input Multiple Output (MIMO) in LTE releases and Multiple Input Multiple Output use together with Orthogonal Frequency Division Multiple Access (MIMO-OFDMA).

2.1 Overview of LTE and LTE-Advanced Systems

As mentioned before, mobile data traffic is growing fast. This is mainly due to the introduction of new devices that are capable of providing a variety of data-oriented services such as web browsing, video and audio streaming, online gaming, etc. This represents a huge challenge for the operators since they are responsible for carrying most of these data.

The advance towards high speed mobile wireless access can be divided into two main migration paths. The first path represents the evolution of the current 3G mobile cellular system towards the IMT-Advanced. It includes system specified by 3GPP such as Wideband Code Division Multiple Access (WCDMA), High-Speed Downlink Packet Access (HSDPA), High-speed Uplink Packet Access (HSUPA), High Speed Packet Access Plus (HSPA+) and LTE/LTE-Advanced, and other cellular systems specified by the 3GPP2 such as CDMA20001x and Ultra Mobile Broadband (UMB).

The second evolution path depends on modifying some existing fixed wireless system to incorporate mobility standards which is represented by the IEEE roadmap towards IEEE802.16e and its amended version IEEE802.16m [10, 11]. LTE introduces new features, such as flexible spectrum and a flat network architecture, which help to achieve much higher performance over previous 3GPP (e.g HSPA), especially in terms of down link(DL) and uplink (UL) peak data rates, spectral efficiency and latency. However, these improvements do not meet the needs for

the expected demands, and, for that reason, at the end of 2010, the 3GPP submitted LTE-Advanced as a proposal to fulfil the International Mobile Telecommunication –Advanced (IMT-A) requirement issued in 2008[12]. In some of these requirements are:

- 100 Mbps peak rate support for high mobility and up to 1 Gbps peak data rate for low mobility case;
- Allow inter-working with other radio access systems;

- Cell spectral efficiency, ranging from the 3 bits/Hz/cell in the indoor downlink scenario, to the 0.7 bits/Hz/cell in the high speed uplink scenario;
- Peak spectral efficiency, ranging up to 15 bits/s/Hz
- Bandwidth scalability up to and including 40MHz, up to 100 MHz should also be considered.
- Latency requirement for control plane to achieve 100 ms transition time between idle and active state, and respectively to enable 10 ms user plane latency (in unloaded conditions)
- Mobility support up to 350 km/h

Many of these demands were already met by LTE. For that reason, 3GPP also defined its own requirement for LTE-Advanced. This ensures an incremental step of performance and capabilities between the successive releases. Some relevant technology in order to improve the performance provided by LTE-Advanced include carrier aggregation, advanced MIMO techniques, wireless relays, enhanced inter-cell interference coordination (eICIC) or coordinated multipoint (CoMP) transmission and reception [14, 15].

The development of LTE Advanced /IMT Advanced could be seen with evolution from the 3G services that were developed using UMTS/ W-CDMA technology. Table 1 gives comparison of LTE-A with other cellular technologies.

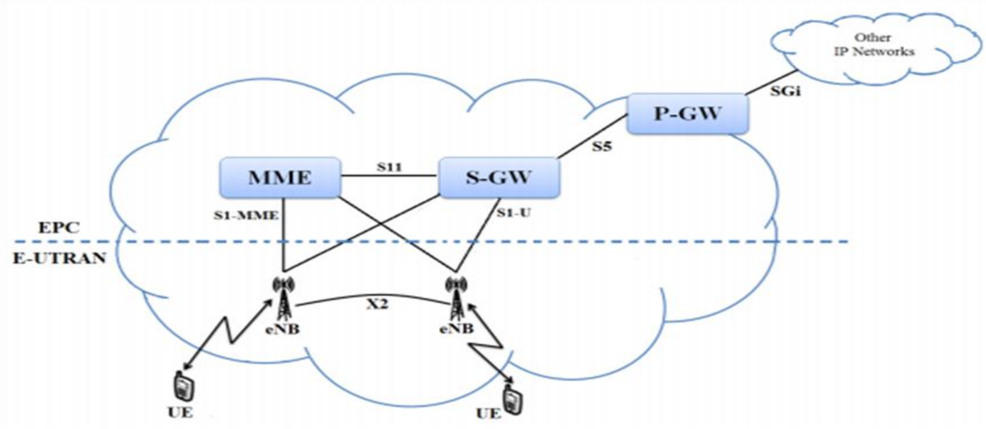
COMPARISON OF LTE-A WITH OTHER CELLULAR TECHNOLOGIES					
	WCDMA (UMTS)	HSPA HSDPA / HSUPA	HSPA+	LTE	LTE ADVANCED (IMT ADVANCED)
Max downlink speed bps	384 k	14 M	28 M	100M	1G
Max uplink speed bps	128 k	5.7 M	11 M	50 M	500 M
Latency round trip time approx	150 ms	100 ms	50ms (max)	~10 ms	less than 5 ms
3GPP releases	Rel 99/4	Rel 5 / 6	Rel 7	Rel 8	Rel 10
Approx years of initial roll out	2003 / 4	2005 / 6 HSDPA 2007 / 8 HSUPA	2008 / 9	2009 / 10	2014 / 15
Access methodology	CDMA	CDMA	CDMA	OFDMA / SC-FDMA	OFDMA / SC-FDMA

Source: [18] ***Figure 2 Comparison of LTE-A with other cellular technologies***

2.1.1 Basic Concepts

From the LTE architecture, the main role of the LTE physical layer is to translate data into reliable signal for transmission across a radio interface between the e-NodeB (enhanced NodeB) and the user equipment as shown in figure 2. It involves basic modulation, protection against transmission errors and multiplexing schemes. Multiplexing is a technique for sending multiple signals or streams of information on a carrier at the same time.

The antenna technology involves the different configuration, schemes and techniques that can be incorporated into antenna systems to fulfill recommended requirement [16]. SC-FDMA is the multiplexing schema used for uplink transmission in LTE-A and OFDMA has been discovered to be a beneficial multiplexing schema for LTE-A downlink with many advantages such as improved spectral efficiency and flexible bandwidth adaptation. LTE-A also introduces MIMO antenna technologies, advanced inter-cell interference mitigation techniques, low latency channel structure by reducing the number of nodes in the access network and single-frequency network broadcast techniques. With respect to antenna technology, MIMO antennas play a significant role in the attainment of the performance goals of 3GPP LTE-A [17, 18, and 19].



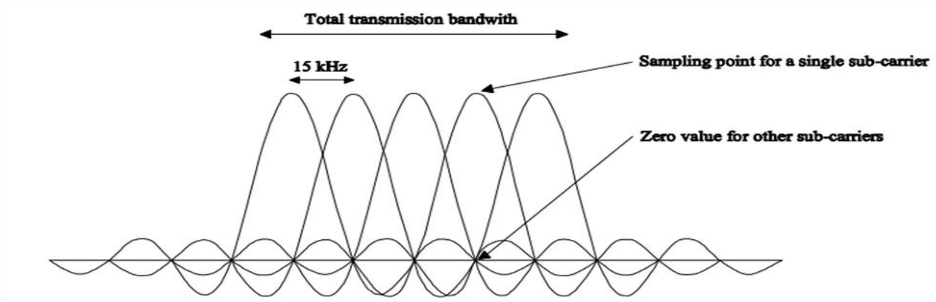
Source: [18]

Figure 3 LTE-A network structure

2.1.2 The 3rd GPP LTE Radio Interface Techniques: OFDMA & SC-FDMA

In wireless standards of GSM family before LTE, Wide-band Code Division Multiple Access (WCDMA) within 5 MHz was used as a radio interface for both uplink and downlink. Due to the presence of multi-path propagation effect which was inherent in wireless communication, the Walsh codes used were no longer orthogonal and interference with each other resulted in Inter-Symbol Interference (ISI). In WCDMA systems, the impact of multi-path can be overcome using advanced receivers which come at the expense of receiver complexity. Multi-path interference problem of WCDMA based systems escalates for larger bandwidths such as 10MHz and 20MHz required by LTE for the support of higher data rates. The chip rate increases for large bandwidth and receiver complexity grows as well due to increase of multi-path intensity.

In addition, it is difficult to implement a system with flexible resource allocation using WCDMA system yet LTE requires the support of smaller bandwidth less than 5MHz. As a result new multiple access schemes are introduced in LTE-A: OFDMA in downlink and SC-FDMA in uplink

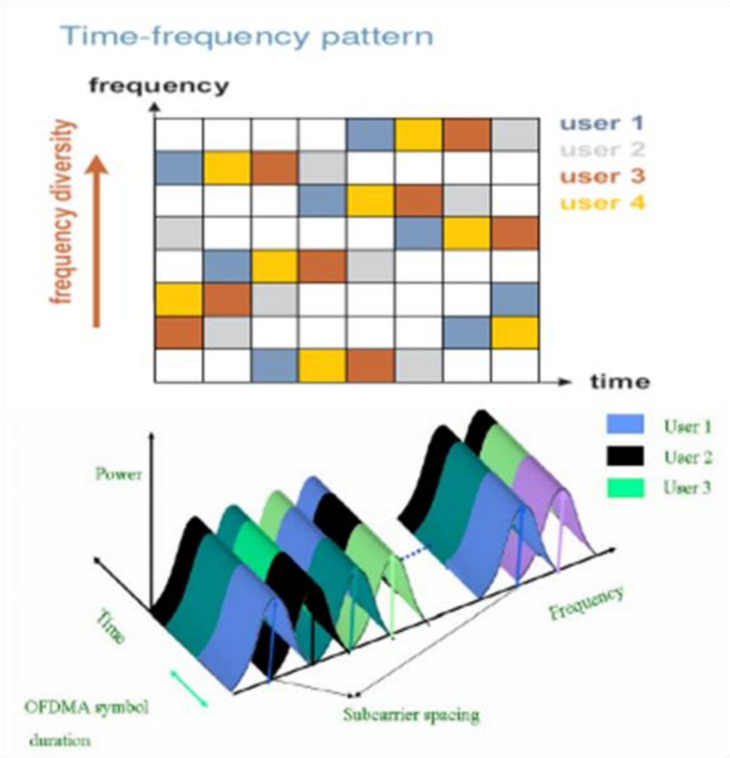


Source: [21] ***Figure: 4 OFDMA Spectrum***

a. Orthogonal Frequency Division Multiple Access (OFDMA)

In OFDMA system, the available bandwidth is broken into many narrow subcarriers and the data is divided into parallel streams, one for each subcarrier each of which is then modulated using varying levels of QAM modulation or higher orders as required by the desired signal quality. The spectrum of OFDMA is depicted in figure 4, now OFDMA is simply the multi-user version of the popular OFDM digital modulation techniques.

Based on the various requirement for LTE-A that have been mentioned in the preceding sections, OFDMA is considered as an excellent multiple access scheme for the 3GPP LTE-A downlink. Multiple access is achieved in OFDMA by assigning a group of sub-carriers to each individual users. As illustrated in Figure 4, the OFDMA can be seen as a hybrid technique of the FDMA and TDMA techniques. As mentioned before, the basic principle of OFDMA is to divide the available bandwidth into narrow band parallel channel known as sub-carriers, and information/symbol is transmitted using these channels at a reduced rate. OFDMA use multiple orthogonal subcarrier each of which is modulated separately. OFDMA distribute subcarriers to different users at the same time so that multiple users can be scheduled to receive data simultaneously [20, 21].



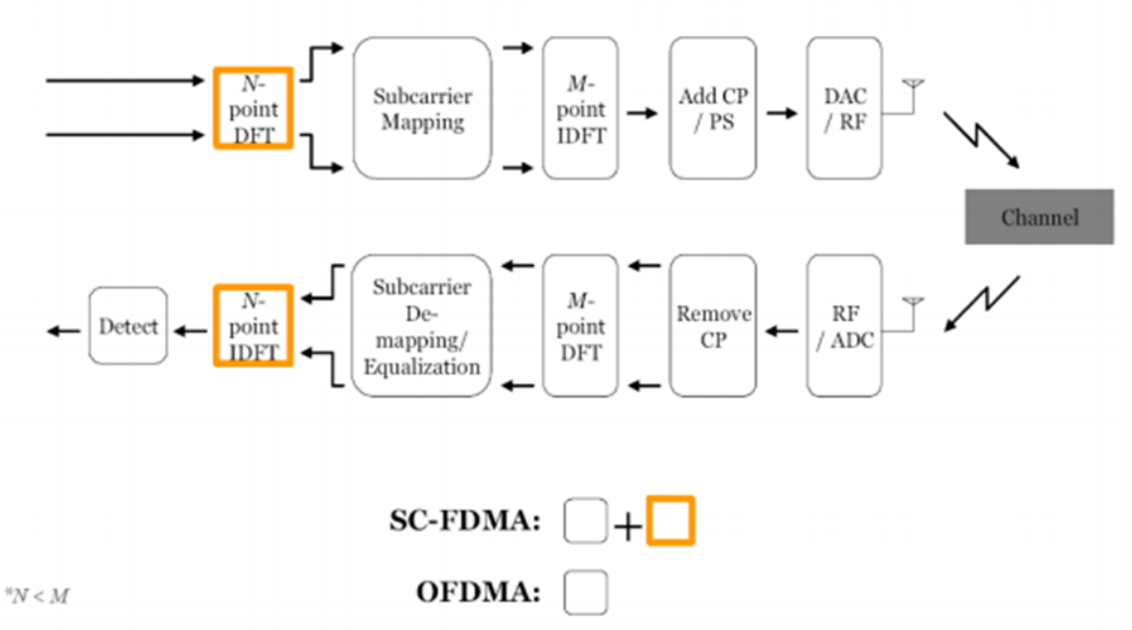
Source: [20]

Figure ***5 OFDMA basic Operation***

In additional, in this technique each user is provided with a unique fraction from the system bandwidth (OFDMA subcarrier) per each specific time slot. Many of OFDMA advantage are inherited from OFDM techniques, it is robust to multipath fading and interference, offers opportunities to exploit multi-user diversity, can be easily adapted to different bandwidths. OFDMA also has the ability to perform the resource scheduling based on the channel time and frequency responses which allow assigning of different subcarriers to each user based on channel condition and this is known as multiuser diversity [22].

b. Single Carrier Frequency Division Multiple Access (SC-FDMA)

SC-FDMA can be considered as linearly pre-coded OFDMA as it uses addition DFT processing preceding the OFDMA processing, where time domain data symbols are transformed to frequency domain by DFT before going through OFDMA modulation as illustrated in figure 5. The feature that distinguishes SC-FDMA from OFDMA is the single carrier form of transmit signal. The other difference between OFDMA and SC-FDMA is the introduction of an addition DFT module at the transmitter side and IDFT at the receiver side [23].

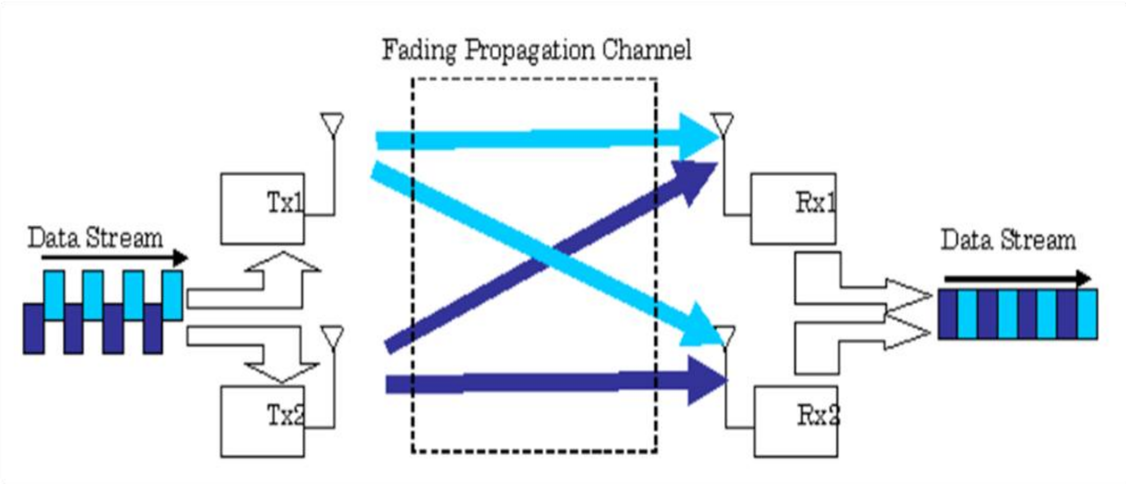


Source: [24] ***Figure 6: OFDMA & SC-FDMA transceiver comparison***

While equalization is performed in frequency domain in both cases, OFDMA performs modulation and demodulation operation in the frequency domain and SC-FDMA performs these operations in the time domain. Since SC-FDMA effectively spreads each modulated symbol across the entire channel bandwidth that makes it less sensitive to the channel frequency-selective fading effects as compared to OFDMA. However, the use of narrower bandwidth adds advantage to OFDMA over SC-FDMA by allowing possible adaptation of the modulation techniques and power resource per individual subcarrier [24].

2.2 Multiple Input Multiple Output (MIMO)

The concept of diversity, which improves link reliability, is central to the principles of wireless communication. The use of spatially separated multiple antennas enables the application of principles of diversity. Multiple antenna systems commonly referred to as Multiple Input Multiple Output (MIMO). MIMO is one of the new features in the LTE Release, its operation including spatial multiplexing as well as pre-coding and transmit diversity. The basic principle of MINO is shown in figure 7; MIMO technology uses multiple antennas at transmitters and receiver to improve performance of a communication system as it offers significant increase in data throughput and link quality without additional bandwidth and increased transmit power. Base station and terminals are equipped with multiple antenna elements planned to be used in transmission and reception in order to make MIMO functionalities available at the downlink and the uplink. The use of additional antenna elements at either the base station (eNodeB) or User Equipment side (on the uplink and /or downlink) opens an extra spatial dimension to signal pre-coding and detection as mentioned before. As a huge number of UEs with high data rates requirements have to be provided by the future cellular systems, MIMO transmission and detection becomes a broad topic that requires separate details for proper understanding [25].



Source: [26] ***Figure 7 Basic principle of MIMO communication system***

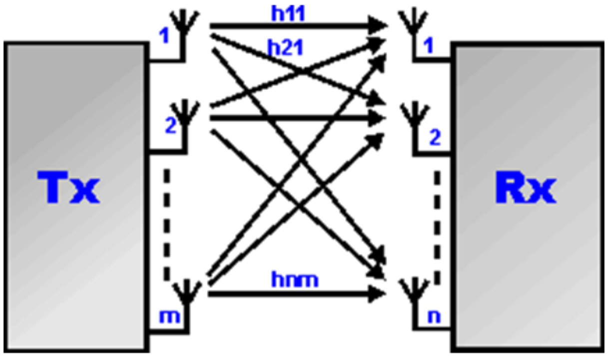
2.2.1 LTE-MIMO Basic

The basic concept of MIMO utilizes the multiple signal propagation that is present in all terrestrial communication. Rather than providing interference, their paths can be used to advantage. The antennas in MIMO techniques are able to utilize the different paths that exist between two entities to provide improvement in data rate of signal to noise as shown by figure 8. The antennas at each end of the communication circuit are combined to minimize errors and optimize data speed. Depending on the availability of these antennas at the transmitter and/or receiver, the following classifications exist [26].

- Single-Input Multiple-Output (SIMO): A simple scenario of this is an uplink transmission whereby a multi-antenna based station (eNodeB) communicates with a single antenna User Equipment (UE).

- Multiple-Input Single-Output (MISO): A downlink transmission whereby a multi-antenna base station communication with a single antenna User Equipment (UE) is a scenario.
- Single-User MIMO (SU-MIMO): This is a point-to-point multiple antenna link between a base station and one UE.
- Multi-User MIMO (MU-MIMO): This features several UE's communicating simultaneously with a common base station using the same frequency and time domain resources.

As a result of the requirements on coverage, capacity and data rates, integration of MIMO as part of the LTE-A physical layer is highly imperative since it necessitates the incorporation of



Source: [25] ***Figure 8 Generic outline of MIMO System***

transmission schemes like transmit diversity, spatial multiplexing and beam forming. For LTE releases, the use of MIMO is likely to involve further and more advanced techniques including the use of additional antennas in the matrix to enable additional paths to be used, although as the number of antennas increase, the overhead increases and the return per additional path is less. An important component in meeting the goals of LTE-Advanced is multi-antenna technology. These include things like beam forming and spatial multiplexing, which are already playing major roles in LTE. Enhancements of MIMO technologies for LTE-Advanced are driven by the need for increased peak rates, improvement of system level performance and support of various transmission schemes with a universal structure. The scope of MIMO in LTE-Advanced will include the following [27]:

- Downlink (DL) higher-order MIMO
- Enhanced DL multi-user MIMO (MU-MIMO)
- Uplink spatial multiplexing

- Uplink transmit diversity with multiple transmit (TX) antennas
- Coordinated Multi-Point (CoMP) transmission/reception.

2.2.2 LTE MIMO Mode

There are several ways in which MIMO is implemented in LTE. These vary according to the equipment used, the channel function and the equipment involved in the link [28]. *Single antenna*: This is the form of wireless transmission used on most basic wireless links. A single data stream is transmitted on one antenna and received by one or more antennas. It may also be referred to as Single Input Single Output (SISO) and Single Input Multiple Output (SIMO) dependent upon the antennas used. SIMO is also called receive diversify. *Transmit diversity*: This form of LTE MIMO schema utilizes the transmission of the same information stream from multiple antennas. LTE supports two or four for this technique. The information is coded differently using Space Frequency Block Codes. This mode provides an improvement in signal quality at reception and does not improve the data rate.

Accordingly, this form of LTE-A MIMO is used on the Common Channels as well as the Control and Broadcast channels. *Closed loop with pre-coding*: This is another form of LTE MIMO, but where a single code word is transmitted over a single spatial layer. This can be used as a fall-back mode for closed loop spatial multiplexing and it may also be associated with beam forming as well. *Multi-user MIMO*: This form of LTE-A MIMO enables the system to target different spatial streams to different users. *Beam-forming*: This is most complex form of the MIMO modes and it is likely to use a linear array that enables the antenna to focus on a particular area. This reduces interference, and increase capacity as the particular user equipment gets a beam formed in their particular direction. In this a single code word is transmitted over a single spatial layer. A channel quality forms the common reference signals on the antennas.

2.2.3 LTE-A MIMO Transmission

MIMO operations literally include spatial multiplexing, pre-coding and transmit diversity. The very foundation principle behind spatial multiplexing is the sending signals from two or more different antennas with different data streams and separating the data streams with advanced signal processing techniques at the receiver, hence increasing the peak data rates by a positive multiple factor (theoretically 2 for 2x2 and 4 for 4x4 antenna configuration) [29]. *Open loop spatial multiplexing* is the form of MIMO used within the LTE system involves sending two information streams which can be transmitted over two or more antennas. Although transmit rank indicator transmitted for the user equipment can be used by the base station to determine the number of spatial layers, there is no feedback from the user equipment. In contrast, *Closed loop spatial multiplexing*: This is a form of LTE-A MIMO is similar to the open loop version, but as the name indicates it has feedback incorporated to close the loop. A pre-coding matrix indicator is fed back from the user equipment to the base station. This enables the transmitter to pre-code the data to optimize the transmission and enable the receiver to more easily separate the different data streams [30].

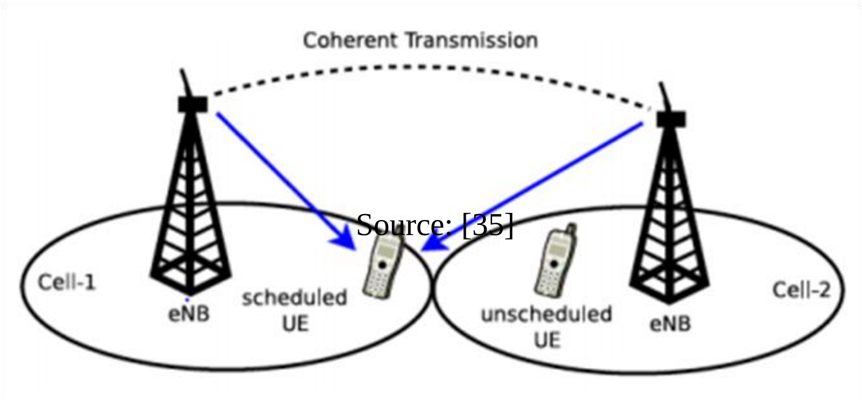
LTE-A MIMO utilizes the transmission of the same information stream from multiple antenna to obtain transmit diversity. LTE-A supports 2-antenna or 4-antenna arrays for this technique. Using space-time or space-frequency block codes, information is coded at the transmitter to combat multipath channel effects. With such encoding schemes, signal quality improves at the receiver but the rate stays at unity. Hence transmit diversity strategies are not spectrally efficient but robust against channel impairment. The first release of the LTE system does not support single-user MIMO spatial multiplexing in the uplink. However, multi-user MIMO operation where two user equipment are scheduled on the same resource block in the same sub-frame is permitted in the latest release of LTE-A. Multiple receive antennas give eNodeB degrees of freedom to separate release from the two user equipment by using techniques such as Minimum mean square error (MMSE) algorithm. The multi-user MIMO operation in the uplink can improve over all cell capacity and significantly enhance cell edge users' throughput [31].

2.2.4 Cooperative MIMO in LTE-A

In early stages, LTE included full support of single user MIMO for downlink using maximum of four antenna ports and transmission layers. Later in Release 9, dual layer beam-forming was introduced to enable eNodeB transmit to two receive antenna that can be located on one or two mobile. As part of release 10, dual layer beam-forming technique is extended to provide full support for downlink MU-MIMO by increasing the maximum number of base station antenna ports to eight. SU-MIMO support is achieved by utilizing the eight antennas with help of eight layer transmission method. This enables the network to choose between SU-MIMO when the channel is uncorrelated (maximize single UE data rate) and MU-MIMO is correlated channel condition (maximize overall cell throughput).

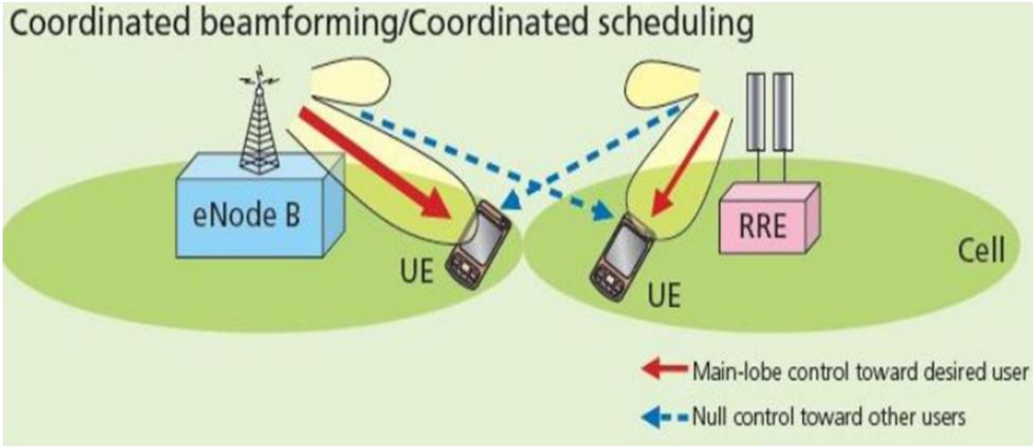
Peak data rate and cell-edge user throughput can be enhanced greatly by the help of coordinated multi-point (CoMP). CoMP works in a way that user equipment (UE), or a terminal in a cell region would be capable of receiving signals from several cell sites and by coordinating these signals using techniques like interference avoidance. CoMP techniques can be seen as CoMP transmission for downlink (DL) coordination and CoMP reception for uplink (UP) coordination. For DL transmission, coordinated scheduling / beam-forming (CS/CB) and join transmission (JT), as in figure 9 are the most briefly studies cooperative techniques. Unlike the case of MIMO where antennas are deployed on a single site, CoMP interconnects antennas deployed at a number of sites that are in proximity to one another [32].

CoMP allows the cell edge users to coordinate and simultaneously receive and send signals from/ to the users of multiple cells. The performance of downlink can be significantly improved if the signals from multiple cells coordinate in order to avoid mutual interference.



Source: [32] ***Figure 9 CoMP join transmission in downlink***

On the uplink side, the signals of multiple cells are received and combined. If multiple cells are coordinated and scheduled at the same time, interference among cells can be suppressed and the signal to noise ration of the received signals can be increased. Downlink CoMP transmission adopts two forms of collaboration, Co- Scheduling / beam-forming which depends on whether service data is obtained on multiple coordinated points and joint processing. Figure10.

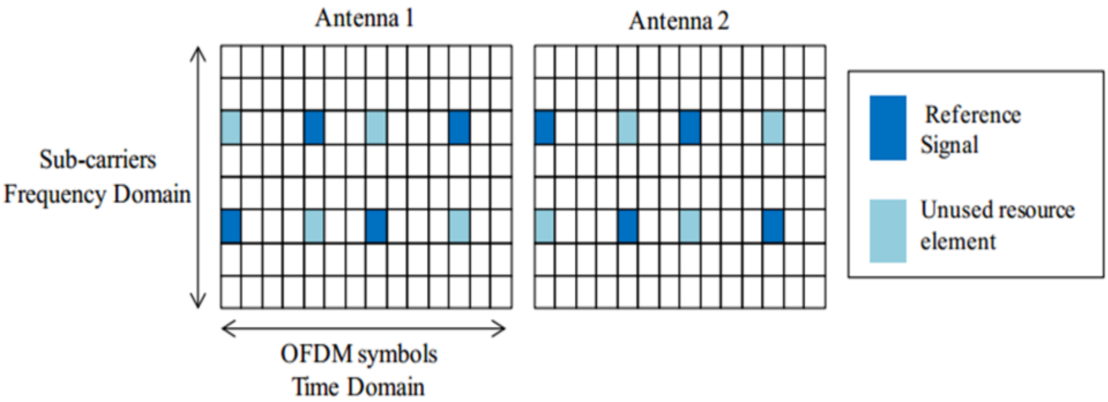


Source: [33] **Figure 10 CoMP transmission collaboration forms**

Collaborative dispatch/beam forming coordinates the transmission weights and corresponding scheduling to minimize interference among multiple cells and dynamic exchange information among multiple cells. The terminals must measure the channels of multiple cells and provide feedback, including the interference pre-coding vector form the neighboring cells that produce strong interference and the expected pre-coding vector from serving cell. When transmitting beams, coordinating the schedulers of multiple cells assists each cell to reduce interference on its neighboring cells [33].

2.3 MIMO-OFDMA in LTE Release

LTE (Release 8, 9) has been evolved by 3GPP group and was designed to have a highly flexible radio interface. OFDM forms the core of LTE downlink radio transmission, while SC-FDMA is deployed for the uplink due to power efficiency. The promise of high data rates in the LTE-A system can be then fulfilled by use of MIMO configuration in both uplink and downlink. In order to support general MIMO systems, several receiver designs are proposed for SC-FDMA and OFDMA system with linear and non-linear complexity. In each design, in order to avoid transmission from another antenna that may corrupt the channel estimation needed to separate the MIMO streams, each reference symbol resource can be only used by a single transmit antenna. This principle is shown in figure 9, where the reference symbols and empty resource elements are depicted to alternate between both antennas [34]. In order to improve the spatial efficiency of the downlink, extension of LTE downlink spatial multiplexing (SM) up to eight layers is considered part of the LTE evolution and in the case where carrier aggregation is used, SM with eight layers per component carrier was supported.



Source: [35] ***Figure 11 OFDMA reference symbol in 2x2 MIMO***

2.4 Critical Review on MIMO-OFDMA

In conventional wireless communication, a single antenna is used at the source, and another single antenna is used at the destination. In some cases, this gives rise to problems with multipath effects. When electromagnetic fields meet with obstruction such as hills, buildings and utility wires, the wave fronts are scattered, and thus they take many paths to reach the destination. The late arrival of scattered portion of the signal causes problems such as fading, cut-out (cliff effect), and intermittent reception (Picket fencing). In digital communication such as wireless Internet, it causes a reduction in data speed and an increase in the number of errors. The use of two or more antennas (MIMO), along with the transmission of multiple signals (one for each antenna) at the source and the destination, eliminates the trouble caused by multipath wave propagation and even take advantage of this effect.

In Previous section, we mentioned that MIMO techniques are utilized in order to achieve a Capacity gain, a diversity gain or an antenna gain. Hence it improves the performance by enhancing the bit rate or the signal-to-noise-ratio of the wireless system, provided the wireless links experience, independent fading. As said, the MIMO techniques are classified into Spatial Diversity, transmit diversity, Spatial Multiplexing and Beam-forming. Spatial Diversity aims to achieve diversity gain, which refers to an improved error performance. Spatial Multiplexing accomplishes Multiplexing Gain that implies the achieved gain in bit rate as compared to single antenna system. Beam-forming techniques accomplish an enhanced Signal-to-Noise-Ratio (S/N) by steering the beam pattern of transmit and receive antennas in a desired direction while suppressing in the direction where the signal is not required [35, 36].

The advantage of multiple antenna techniques depends upon the same multipath fading effect which is considered deleterious in single antenna system. There exist a trade-off between spectrum efficiency and power efficiency in the form of high bit rate and small error rate. Both these technologies, OFDMA and MIMO are blended together to reap their combined benefit.

Thus MIMO-OFDMA has become the air interface for Fourth Generation (4G) technologies.

In the case where there are a large number of terminal in a cell, the cell spectral efficiency further increase through the use of MU-MIMO. Current LTE designs which support up to four antenna ports and hence spatial multiplexing of up to four layers, results in peak-data rates of 300 Mbits/s. When this is combined with a total bandwidth of 100 MHz, as a result of carrier aggregation discussed earlier, the spatial multiplexing schemes being considered for LTE would increase the peak data rates to about 1.5 Gbit/s, which goes beyond the requirement of LTE-Advanced.

In addition to the steps above, the LTE uplink must be also extended with the support of uplink MIMO for it to be fully compliant with IMT-Advanced. Under consideration by 3GPP, on one hand, are techniques that depend on channel reciprocity and on the other hand, techniques that do not rely on channel reciprocity. Techniques under the first group include beam-forming and MU-MIMO. For these, the enhanced NodeB by using a sounding reference signal from the terminal that is able to determine the state of the channel while assuming that the channel is seen in the same way by both the eNodeB and the terminal, and then forms transmission beams accordingly.

Techniques which do not rely on channel reciprocity fall into three groups:

- Open-loop MIMO (OL-MIMO) which is used in cases where the transmitter has no knowledge of the channel-sate information (CSI). Since the terminal has no knowledge of the CSI from the eNB, these techniques cannot be optimized for the specific channel condition seen by the eNB received but they are robust to channel variations. As a result, these techniques are well suited to high-speed mobile communication.
- Closed-loop MIMO (CL-MIMO) is used when the eNodeB sends CSI to the terminal and can be used to significantly increase the spectral efficiency. In general, it is assumed that

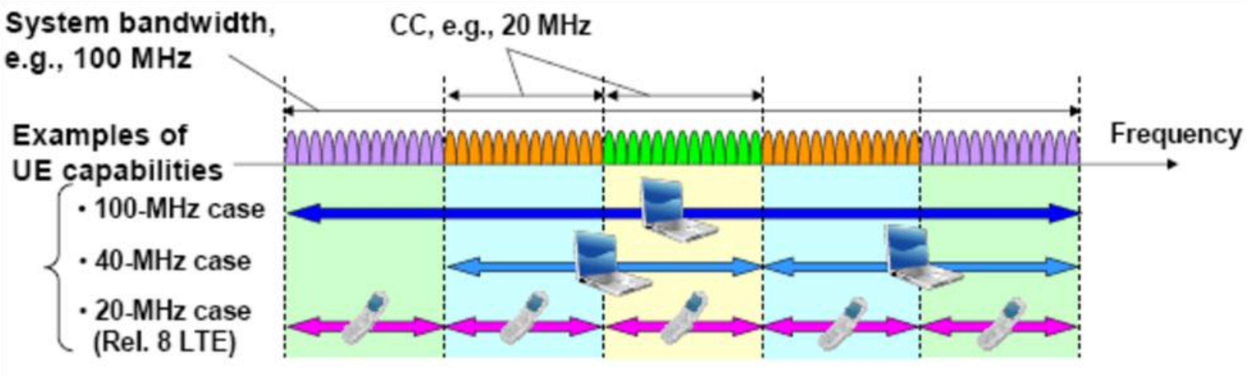
- CL-MIMO has better performance than OL-MIMO in low-speed environment but has worse performance than OL-MIMO in high-speed environment.
- MU-MIMO which when enhanced can greatly improve the spectral density and it is also possible to carry out joint processing within a single base station or across multiple base stations.

2.5 Carrier Aggregation Brief Review

Carrier Aggregation (CA) is being cited as a major technology enhancement that is essential if LTE-Advanced is to meet the requirement for IMT-Advanced, particularly the requirement for the support of larger bandwidths than those currently supported in LTE while at the same time maintaining backward compatibility with 2G,3G and LTE. Thus, the bandwidth performance that is enabled by carrier aggregation was examine,

This consists of the aggregation of multiple component carriers of smaller bandwidth making possible the transmission of data in large bandwidths. Recall that in LTE Rel-8 (the first LTE release), there was extensive support for deployment in spectrum allocation ranging from 1.4 MHz to 20 MHz in both paired and unpaired bands. One of the goal for LTE-A is to exploit spectrum allocation up to 100 MHz so as to meet the expectation of very high peak data rates. This can only be possible by increasing the transmission bandwidth provided by the first release of LTE, hence carrier aggregation. Carrier aggregation simply combines or aggregates multiple component carriers on the physical layer to provide the required bandwidth [37].

In the specific case of LTE-A, up to 5 components carriers of 20 MHz are used simultaneously which leads to a substantial increase in data rates. There are three possible carrier aggregation scenarios: contiguous aggregation of carriers in a single band, non-contiguous aggregation of carrier in a single band and non-contiguous aggregation of component in multiple bands which, in principle, are different bandwidth. In figure 12, the case of contiguous component carriers is illustrated even through, from a baseband perspective; this might not always be the case.



Source: [37] ***Figure 12 Carrier aggregation for LTE-A system illustration the flexibility of spectrum usage***

LTE-A could, therefore allow for aggregation of non-contiguous component carriers in, possibly separate spectrum to handle situation where large amounts of contiguous spectrum are not available and in this case we talk of spectrum aggregation. The implementation of carrier aggregation is not straightforward and requires some modification in the user equipment and base station protocol stack [38, 39].

2.6 Conclusion

In this chapter, the detailed literature study was given in each sub-section. Key definitions and related information was detailed in this chapter. In this section LTE-Advanced cellular network requirement was discussed with emphasis on two different enabler technologies such as Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiple Access (OFDMA) which were used in this thesis, therefore the specific critical review on MIMO-OFDMA was also presented. In general this chapter describes key words and terminologies that were used during the analysis part of this thesis.

Chapter 3: Research Methodology

3. 1 Introduction

This part gives an overview of the research methods that are used during the course of this work. It highlights the methods and approaches to be used and shows how the analyzed results were presented throughout the whole project. Mainly scientific methods for conducting research are used, however both qualitative and quantitative approaches are rarely used and data analysis is part of this research. Experimental research approach was also considered because several simulation results were presented and these resulted from several experiments that were conducted. This research approach lies under scientific research methods and this indicates that scientific type of research covered almost the whole project and other methods were just used for clarification.

3.2 Fundamentals of evaluation methodology

This thesis focused on the study of advancements in Multiple Input Multiple Output (MIMO) antenna and Orthogonal Frequency Division Multiple Access (OFDMA) technologies as LTE-A enabler in modern 4G networks. In order to perform any assessment, it is necessary to have a deep knowledge of the system under study and to define an evaluation methodology. The definition of the evaluation methodology involves the selection of evaluation objectives, conditions (scenario, system configuration) methods, procedures, metrics and also the definition of assumptions and system models.

In this thesis, MIMO technologies were evaluated under both optimal and normal operation conditions. Concerning optimal conditions, spectrum utilization was analyzed, that is to say, the increase in data throughput and link quality without additional bandwidth and increased transmit power. Although this is an interesting metric, the focus of this study was on the performance evaluation under normal operation condition. One part of this evaluation concerns the performance analysis of Single Cell Multiple Input Multiple Output (MIMO) system and Single Cell Multiple User-Multiple Input Multiple Output (MU-MIMO) system. Due to the existing trade-off between spectrum efficiency and power efficiency in the form of high bit rate and small error rate, however, special attention is paid to the performance analysis of the enhancement brought by the blended together of MIMO and OFDMA technologies; Where MIMO-OFDMA has become the air interface of 4G technologies.

3.3 Development Research approaches

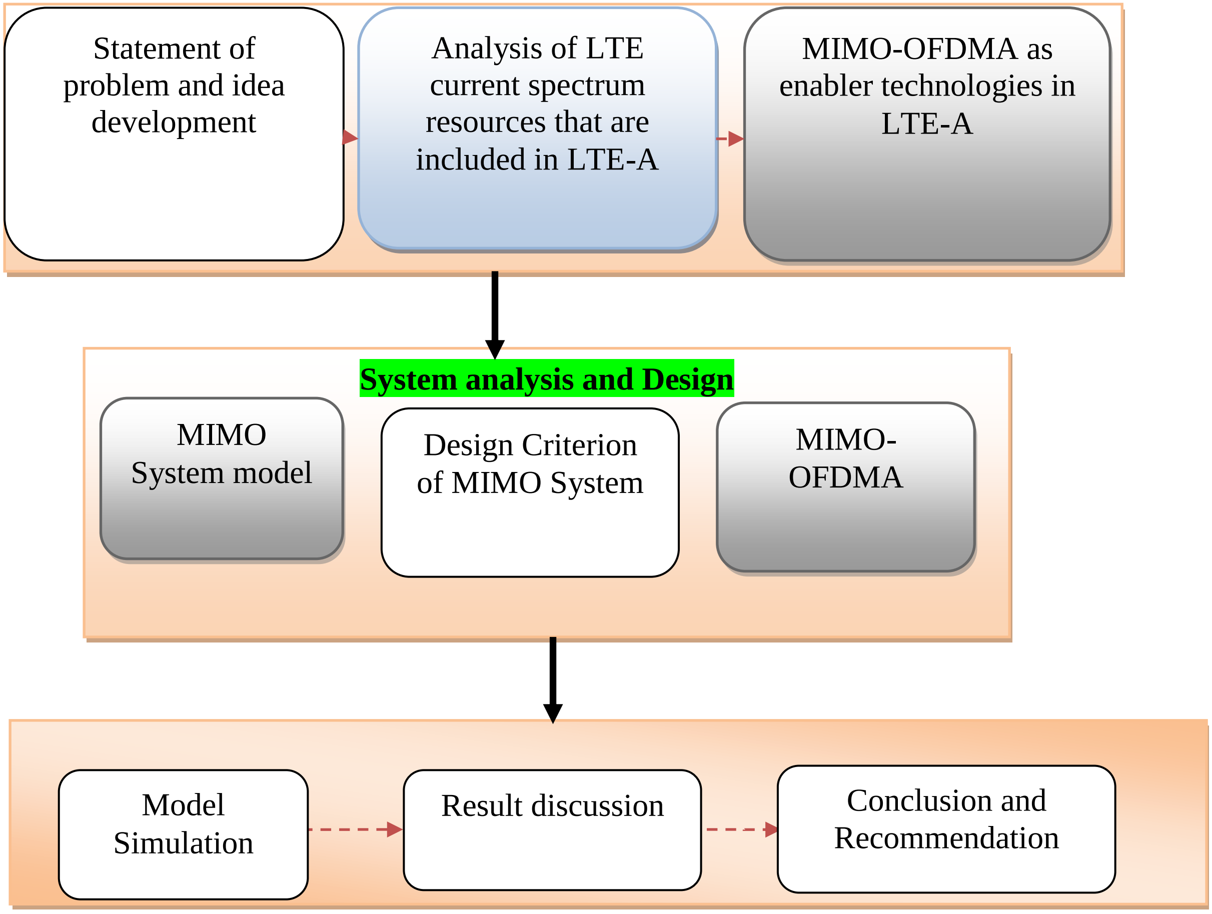


Figure 13: Research Development Approach

Our primary goal is to investigate the deployment and operation of MIMO and OFDMA technologies as enabler of LTE-Advanced to achieve high data rate, wider bandwidth and backward compatibility within the limited availability of spectrum resources. In this works, the current LTE spectrum resources that are included in LTE-A were analyzed and then evaluated the advancement in MIMO-OFDMA technologies as LTE-A radio interface, some mathematic model were derived based on the Shannon's equation for capacity in communication system. In the figure 1 detailed approach is shown on how this research was carried out.

3.3.1 Scientific research methods

During the course of this research, several scientific methods were used to conduct this research. The existing schemes have been found in qualitative research methods and design, analysis and simulation and experimental approach were used. It began with ideas used from scratch and slowly developed into the objectives, statement of problem and proposed solution. In the existing schemes, we came up with knowledge about the research ideas. In this case, the existing schemes seized the opportunity to discover the existing knowledge and to propose the solution on the stated problem.

To be specific, a quantitative approach has been taken to evaluate how other existing schemes work, their weaknesses and what should have been done to improve its performance. Several ideas were developed and considered like the idea of spatial multiplexing and OFDMA to increase system spectrum capacity were discussed in this thesis.

3.3.2 Experimental Approach

The experiments were done in deferent cases such as Single Cell MIMO system and Single Cell Multiple Users MIMO (MU-MIMO) both in OFDMA methods. Under this method, the simulation results considering different parameters were discussed. We presented some tables for simulation, system and mathematical models used basically derived from Shannon’s equation for capacity calculation.

3.3.3 Project Requirements

Referring to the literature review done in the second chapter of this project and following the adopted model in order to achieve the main goal of this work, requirements have been identified and gathered using documentation review and existing resources such as journals, research papers, technical reports and books available in hardcopy as well in softcopy.

Documentation review: Documentation that were used were reading extensively other important materials related to this research such as books, and online information available from different web sites to find more information related to this work to find how data packet rate and throughput can be increased through the use of MIMO-OFDMA technologies as enabler in LTE-A radio interface.

For simulation of the results, we only used Matlab software. The simulation done in Matlab R2014a. The Matlab software ran on a levovo ThinkPad E40, i5 TB of storage and 4GB of RAM and windows 7 operating systems.

3.4 Analysis

The purpose of this stage was to analyze different scenario as detailed in chapter 2. Another purpose is to identify the best option available to achieve the better system performance by increasing data throughput and link quality. This involved carrying out a detailed study of the OFDMA-MIMO technologies as enabler in LTE-A and the achievement of ITU 4G requirements.

Based on this study of advancements in MIMO-OFDMA technologies as enabler in LTE-A cellular network. Analysis phase is the next step we considered after realizing the problem, the requirements analysis, and feasibility study conducted ensured better performance of the system and for proper design. For this project, the requirement such as simulation parameter was examined and analysis was done and also documentations were prepared for design and development process. Different aspects considered during this stage included:

- Identifying the current LTE spectrum resources that are now formally included in LTE Advance specifications.
- Conducting the feasibility study for wider bandwidth achieved in LTE-A, based on carrier aggregation.
- Development of proper plan to carry out this project and to analyze the available requirement.
- Develop potential scenario for the system design and prepare for simulation results.
- Determine the proper strategy for implementation. In this case simulation in Matlab was done and results were discussed in chapter 5.

3.5 Design Process

The design criteria of MIMO-OFDMA system as enabler technologies used in LTE-A radio interface, is very important phase after gathering the requirement and conducting the feasibility study. The design was specifically done after analyzing the existing schemes and then the new proposed advancements in MIMO technology intended to achieve our objectives.

3.6 Information Used

The information used in this work was from journals, papers, books and other information available on internet. This includes the existing schemes that were presented in different past work and to see the ideas of different authors about MIMO-OFDMA technologies in LTE-A cellular network. Although telecom operators are to be asked on their current challenges, we decided to investigate the improvement brought by advanced MIMO antenna technologies and this does not need any interview from telecom operators. We only needed to know the existing schema and advancement platform model that can increase its performance done in this thesis.

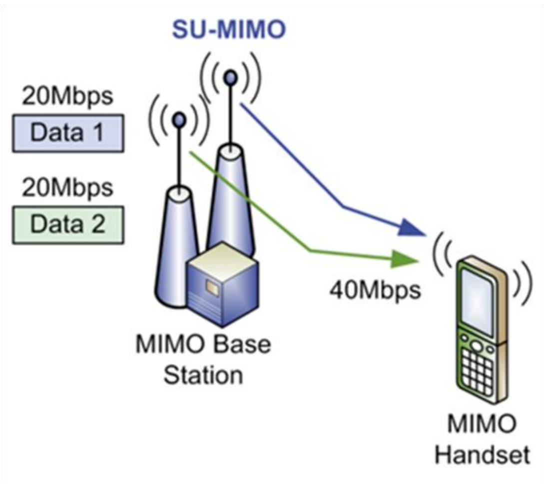
3.7 Conclusion

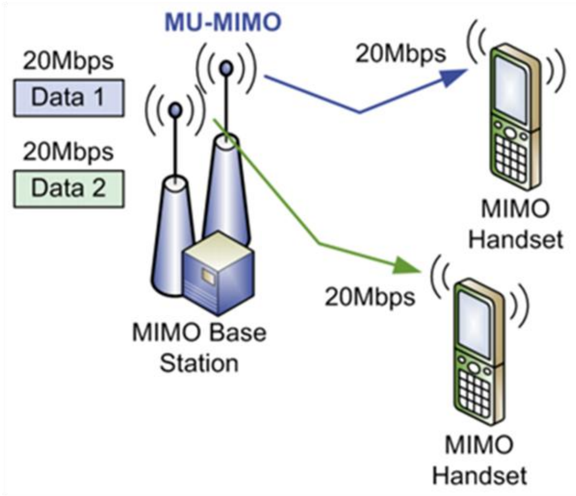
In this chapter, a detailed research development approach was illustrated and research requirement were highlighted. The aim was to show the approaches that were considered during the process of conducting this research work. It showed how the analysis was done and how the system was designed. It also indicated the methods used during the information gathering and data collection. In brief, it gave an overview of how the project was carried out.

Chapter 4: System Analysis and Design

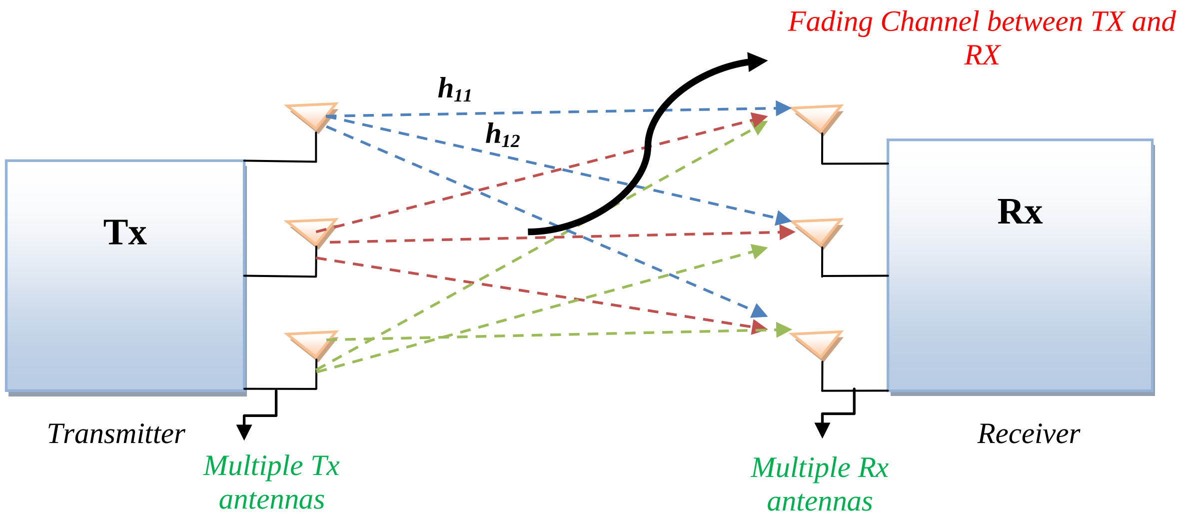
4.1 MIMO System

As mentioned before, Multiple Input Multiple Output refers to the use of multi antenna technique at both transmitter and receiver side see figure 2. In order to achieve the ambitious requirements for throughput and spectral efficiency in LTE-A, MIMO system form an essential part. High-order Single User-MIMO (SU-MIMO) is necessary to achieve the targeted peak spectral efficiency in LTE-A which is 30 bit/s/Hz [40, 41]. In downlink (OFDMA), improved MU-MIMO schemes are studied in order to provide a higher degree of frequency domain scheduling flexibility and enhanced multiuser interference suppression [42]. As it was explained before, in this system model two types of multiple antenna operations are defined Single-User MIMO (SU-MIMO) for Single User and Multi-User MIMO (MU-MIMO) for multiple UE as shown by figure 14.





Source: [42] ***Figure 14 Multiple Antenna Operation***



Source: [43] ***Figure 15 System model***

4.1.1 System Model

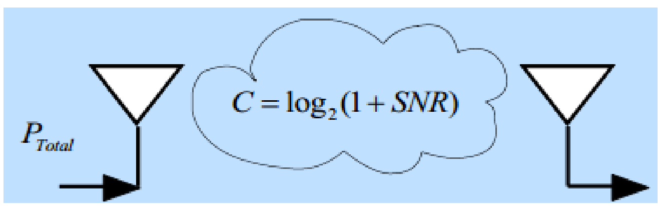
Given a unit of BW (Hz), the max error-free transmission rate is [43]:

$$C = log_2\,(1 + SNR)\;\; bits/s/Hz \qquad (4.1)$$

Shannon's Capacity formula theoretically approximated the maximum achievable transmission rate for a given channel with bandwidth *B*, transmitted signal power *P* and single side noise spectrum N_O, based on the assumption that the channel is white Gaussian (i.e fading and interference effects are not considered explicitly).

$$C = log_2\,(1 + \frac{P}{BN_O}) \qquad (4.2)$$

In practice, this is considered to be a Single input Single Output (SISO) scenario and Equation 4.2 gives an upper limit for the achieved error-free SISO transmission rate.



For the case of multiple antennas at both the transmitter and receiver ends as shown by figure 2, the channel exhibits multiple inputs and multiple outputs and its capacity can be estimated by the extended Shannon's capacity formula.

Let's consider MIMO systems with nr receive and n_t transmit antenna as shown in figure 2. It is now well accepted fact that we can increase capacity without increasing the bandwidth and transmit power rather by just putting more antennas at the transmitter and receiver side. The most important part to understand and deal with MIMO capacity is the channel matrix. The impulse response of the channel between the j^{th} transmitter element and the i^{th} receiver element is denoted as $h_{j,I}(\lambda,t)$

$$\text{Where } H=\begin{bmatrix} h_{11}(\lambda,t) & h_{21}(\lambda,t) & \ldots\ldots\ldots & h_{M1}(\lambda,t) \\ h_{12}(\lambda,t) & h_{22}(\lambda,t) & \ldots\ldots & h_{M2}(\lambda,t) \\ . & . & \ldots\ldots & .\ldots\ldots \\ h_{1M}(\lambda,t) & h_{2M}(\lambda,t) & \ldots\ldots & h_{MM}(\lambda,t) \end{bmatrix}$$

The matrix elements are complex numbers that correspond to the attenuation and phase shift that the wireless channel introduces to the signal reaching the receiver with delay λ . The input-output notation of the MIMO system can be expressed:

$$\boldsymbol{y}(t) = \boldsymbol{H}(\lambda,t) \oplus \boldsymbol{S}(t) + \boldsymbol{n}(t) \qquad (4.3)$$

Where $\oplus$ denotes convolution, $\boldsymbol{S}(t)$ is a n_tx1 vector corresponding to the n_t transmitted signals, $\boldsymbol{y}(t)$ is a n_r x1 vector corresponding to the n_r received signals and $\boldsymbol{n}(t)$ is the additive white noise.

If we assume that the transmitted signal bandwidth is narrow enough that the channel response can be treated as flat across frequency, then the discrete time description corresponding to equation 4.3 is

$$\boldsymbol{y} = \boldsymbol{H}\boldsymbol{s}_{\lambda} + n_{\lambda} \qquad (4.4)$$

a. Single User MIMO (SU-MIMO)

While most wireless systems today support multiple users, single-user results are still of much interest for the insight they provide and their application to channelized systems where users are allocated orthogonal resources. MIMO channel capacity is also much easier to derive for single users than for multiple users. This section discusses fundamental capacity limits for single-user MIMO channel with particular focus on special cases of Channel Distribution Information (CDI) at the transmitter as well as the receiver.

From equation 4.4, with perfect Channel State Information (CSI) at the transmitter or receiver, the channel matrix ***H*** is assumed to be known perfectly and instantaneously at the transmitter or receiver respectively. When the transmitter or receiver knows the channel state perfectly, we also assume that it knows the distribution of this state perfectly, since the distribution can be obtained from the state observations.

b. Multiple Users MIMO (MU-MIMO)

From equation 4.1, given single channel corrupted by an additive white Gaussian noise (AWGN), at a level of SNR denoted by $\boldsymbol{\rho}$, the capacity can be:

$$C = log_2(1+\rho)\ bit/sec/Hz \tag{4.5}$$

We can now consider a full MIMO links as in figure 2 with respectively ***M*** transmit and ***N*** receive antenna. The channel is represented by a matrix of size ***M x N*** with random independent elements denoted by ***H***. The capacity still in the absence of transmits channel information, can be derived from 4.5:

$$C = log_2\left[\det\left(\boldsymbol{I}_M + \frac{\rho}{N}\ \boldsymbol{HH}^*\right)\right] \tag{4.6}$$

In this equation, “det” means determinant, I_M means M x M identity matrix, “ *” means transpose conjugate and where ρ is the average SNR at any receiving antenna. The capacity of a MIMO channel can then be provided by equation 4.4 and 4.6:

$$C = maxlog_2\left[\det\left(\boldsymbol{I}_M + \frac{\rho}{N}\ \boldsymbol{HH}^*\right)\right] \tag{4.7}$$

The advantage of the MIMO case is significant, both in average and outage capacity. In fact, for a large number ***M=N*** of antennas the average capacity increases linearly with M:

$$C_a \approx Mlog_2(1+\ \rho) \tag{4.8}$$

4.2 Orthogonal Frequency Division Multiple Access (OFDMA)

One way to increase system capacity is by transmitting data parallel on different frequencies. In classical parallel data systems, the total signal frequency band is divided into ***N*** non-overlapping frequency sub channel. In such system, there is sufficient guard space between adjacent sub channels to isolate them at the receiver with ***N*** demodulation. This solution, however, is very bandwidth inefficient. A more efficient use of bandwidth can be obtained with a parallel system if the spectra of the individual sub channels are permitted to overlap, with specific orthogonally constraints imposed to facilitate separation of the sub channels at the receiver [44]. In OFDMA the sub carrier pulse used for transmission is chosen to be rectangular. This has the advantage that the task of pulse forming and modulation can be performed by a simple Discrete Fourier Transform (DFT) which results in a remarkable reduction in equipment complexity (filters, modulators, etc) and a bank of coherent demodulators at the receiver is effectively an inverse Fourier transform.

It is now said that data signal is effectively the inverse Fourier transform of the original data stream, and that a bank of demodulators is effectively a Fourier transform. Note that the (Inverse) Discrete Fourier Transform (IDFT) can be implemented very efficiently as an (Inverse) Fast Fourier Transform ((IFFT) see figure 3.

In LTE-A the number of subcarriers is fixed based on the bandwidth used for transmission. As [1.25 MHz, 2.5 MHz, 5 MHz, 10 MHz and 20 MHz] bandwidths are used in LTE systems, the corresponding numbers of subcarriers are [72, 180, 300, 600, 900 and 1200]. Each subcarrier is centered at frequencies that are orthogonal to each other.

The data has to be first converted from serial stream into parallel stream depending on the number of subcarriers (***N***). The serial to parallel converter takes the serial stream of input bits and outputs ***N*** parallel streams (indexed from 1 to N). The second design parameter is the modulation format that is used. An LTE-OFDM signal can be constructed using any of the following digital modulation techniques namely QPSK, 16QAM, 64QAM, more detail about those modulation techniques is presented in chapter 5.

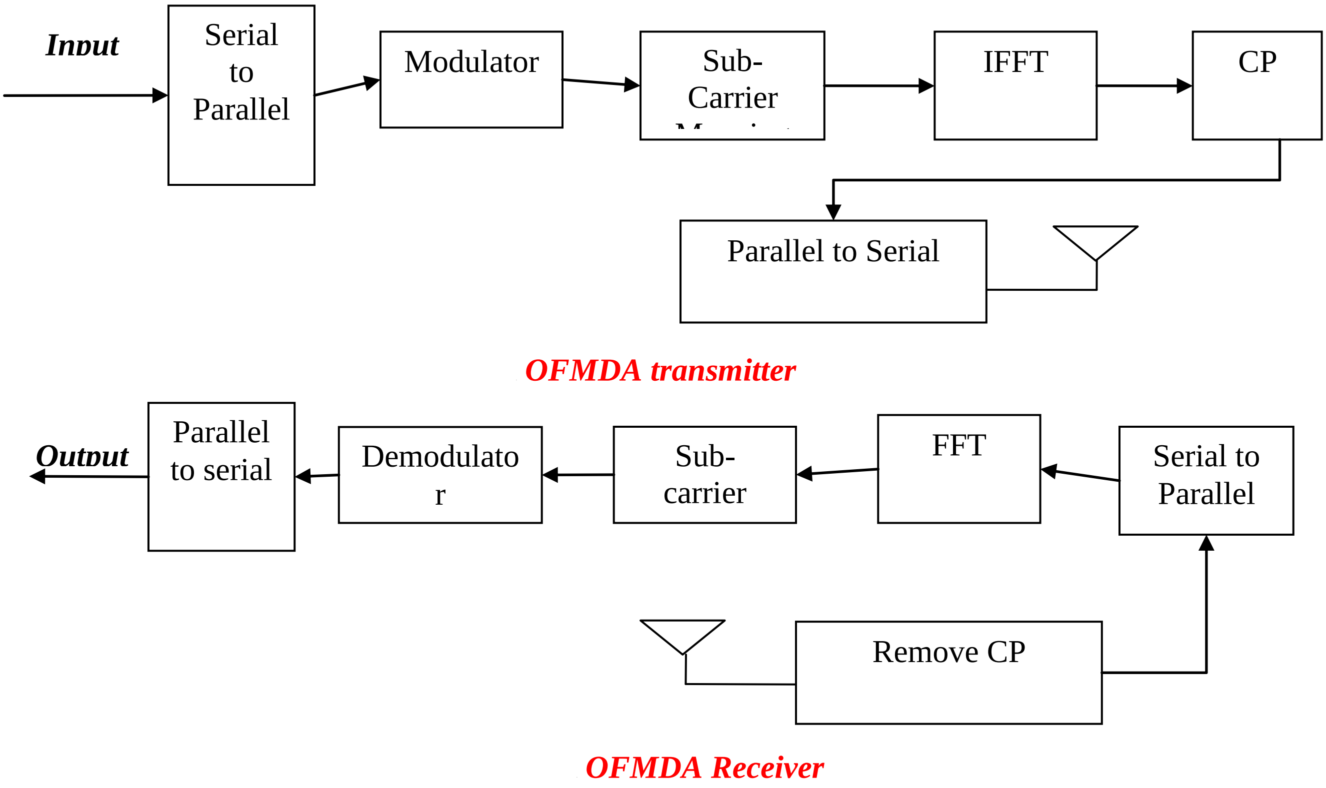


Figure 16 OFDMA System

The transmitter of an OFDMA system uses IFFT block to create the signal. The FFT operation moves the signal from time domain representation to frequency domain representation. The FFT operation can be carried out back and forth without losing any of the original information. Modulated data feeds to the IFFT block. The IFFT stage converts these complex data symbols into time domain and generates OFDM symbols. For LTE the necessary FFT/IFFT lengths tend to be powers of two, such as 512, 1024, etc. From the implementation point of view, it is better to have, for example, a FFT/IFFT size of 1024 even if only 600 outputs are used, than try to have another length for FFT/IFFT between 600 and 1024, thus the number of subcarriers should be extended until the number is a power of two. At the receiver, the CP is removed first and then subcarriers are converted from parallel to serial sequence by using Matlab function ***reshape()***. The FFT stage further converts the OFDM symbols into frequency domain followed by removing unused subcarriers and demodulation.

4.2.1 Bandwidth Efficiency

The spectrums of the sub carriers are not separated but overlap. Due to this overlapping, the bandwidth is much more efficiently used that in the classical multicarrier systems. Theoretically, M-ary digital modulation schemes using OFDM can achieve bandwidth efficiency, defined as bit rate per unit bandwidth, of $\log_2 M$ bits/s/Hz. Given the symbol rate of the serial data stream, the bit rate for a corresponding M-ary system

$$R_b = \log_2 M / \Delta t \tag{4.9}$$

However, in the case a guard time is added, the effective bit rate is equal to:

$$R_b = \frac{T}{T_G + T} \log_2 M / \Delta t = \frac{T}{T_G + N\Delta t} \log_2 M / \Delta t \tag{4.10}$$

From [6], the total bandwidth of the OFDMA system is:

$$B = N\Delta f = \frac{1}{\Delta f} \tag{4.11}$$

Therefore, the bandwidth efficiency becomes:

$$\beta = \frac{R_b}{B} = \frac{T}{T_G + T} \log_2 M \tag{4.12}$$

For an optimal system without guard time (i.e, TG = 0), the bandwidth efficiency becomes $\log_2 M$ bits/s/Hz. However, the guard time is inserted in order to make the system more robust against multipath distortion, so a practical system will not achieve this optimal bandwidth efficiency. Furthermore, in reality, it is impossible to make an ideal band pass filter, so in order to pass all sub carriers, the bandwidth B becomes larger, which implies another decrease in bandwidth efficiency.

4.2.2 Simulation methods

In the simulation case the process of extending the number of carrier are done by adding empty (filled with 0) rows to the modulated matrix. Each input for the IFFT block corresponds to the input representing a particular sub carrier (or particular frequency component of the time domain signal) and can be modulated independently of the other sub-carriers. In Matlab FFT/IFFT operations can be done by using ***fft()*** or ***ifft()*** functions. The functions ***y=fft(x)*** and ***y=ifft(x)*** implement the transform and inverse transform pair given for vectors of length N.

In practice, there are losses in the transmission channel. To simulate the background noise of the channel, the additive White Gaussian Noise must be considered in the simulation model. A built-in Matlab function ***awgn*** is used in which the noise level is described by SNR per sample, which is the actual input parameter to the ***awgn*** function.

4.3 Conclusion

In this chapter, MIMO system design and the respective mathematical model were explained. Some equation for both MIMO and bandwidth efficiency in OFDMA technology were derived and explained. In this thesis, analyses were based on the existing models and basically Shannon equations for capacity. It also discussed the principals of OFDMA in LTE-A.

Chapter 5: Evaluation Results and discussion

5.1 Introduction

Multi-User transmission is decided if the utility of any multi-user combination is higher than the single-user utility. The combination of users with the higher multi-user utility determines the set of multiplexed users [45, 46, 47 and 48]. It is worth noting that the utility of a user in multi-user transmission is different to that of a user in single-user transmission. In order to explain this difference and how the user multiple- user transmission leads to spectral efficiency, this chapter presented the simulation results for both MIMO System and OFDMA Technologies.

5.2 Simulation results for MIMO System

MIMO systems are increasingly being adopted in communication systems for the potential gains in capacity they realize when using multiple antennas. Multiple antennas use the spatial dimension in addition to the time and frequency ones, without changing the bandwidth requirements of the system. One of the main features of LTE-A is the use of multiple antennas or MIMO technology to enhance the throughput and system capacity in an unreliable wireless channel. Figure 17, show the results of a Nt x Nr MIMO system consists of Nt transmitter antennas and Nr receiver antennas. Various configurations are compared and the results shown, when multiple antennas are used both on transmitting antenna and receiving antenna there is a capacity gain.

Multiple antennas can be used either to obtain more reliable transmissions using Transmit Diversity (TD) or to obtain higher transmission rates through spatial Multiplexing (SM). Using diversity receiver is a well known technique to mitigate the effect of fading over a communications link [49, 50 and 51].

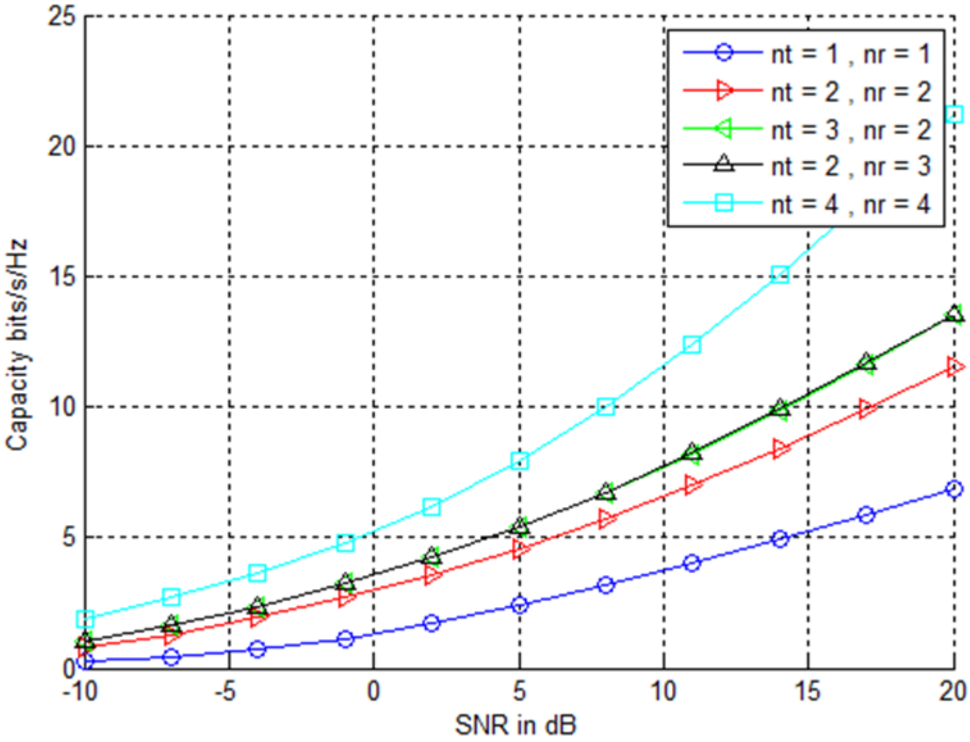


Figure 17 MIMO

Alamouti proposed a transmit diversity scheme that offers similar diversity gains, using multiple antennas at the transmitter. This was conceived to be more practical as it only require multiple antennas at the eNodeB in comparison to multiple antennas for every mobile.

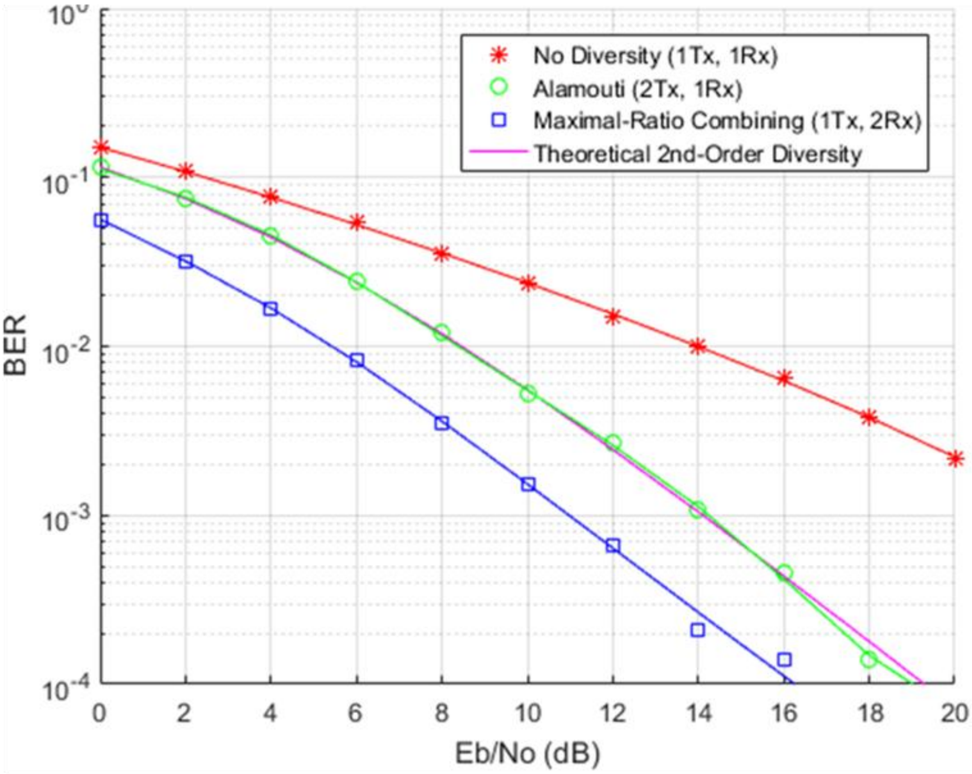


Figure 18 Transmit diversity and Receive diversity

Figure 18 shows the comparison of transmit vs receive diversity by simulating coherent binary phase-shift keying (BPSK) modulation over flat-fading Rayleigh channels. For transmit diversity, we use two transmit antennas and one receive antenna, while for receive diversity we use one transmit antenna and two receive antennas. The simulation covers an end-to-end system showing the encoded and transmitted signal, channel model, and reception and demodulation of the received signal.

It also provides the no-diversity link (Single transmit-receive antenna case) and theoretical performance of second-order diversity link for comparison. It was assumed here that the channel is known well at the receiver for all system. We run the simulation over a range of Eb/No point to generate BER results that allow us to compare the different systems. As can be seen on figure 18, the transmit diversity system has a computation complexity very similar to that of the receiver diversity system.

5.3 Simulation results for OFDMA System

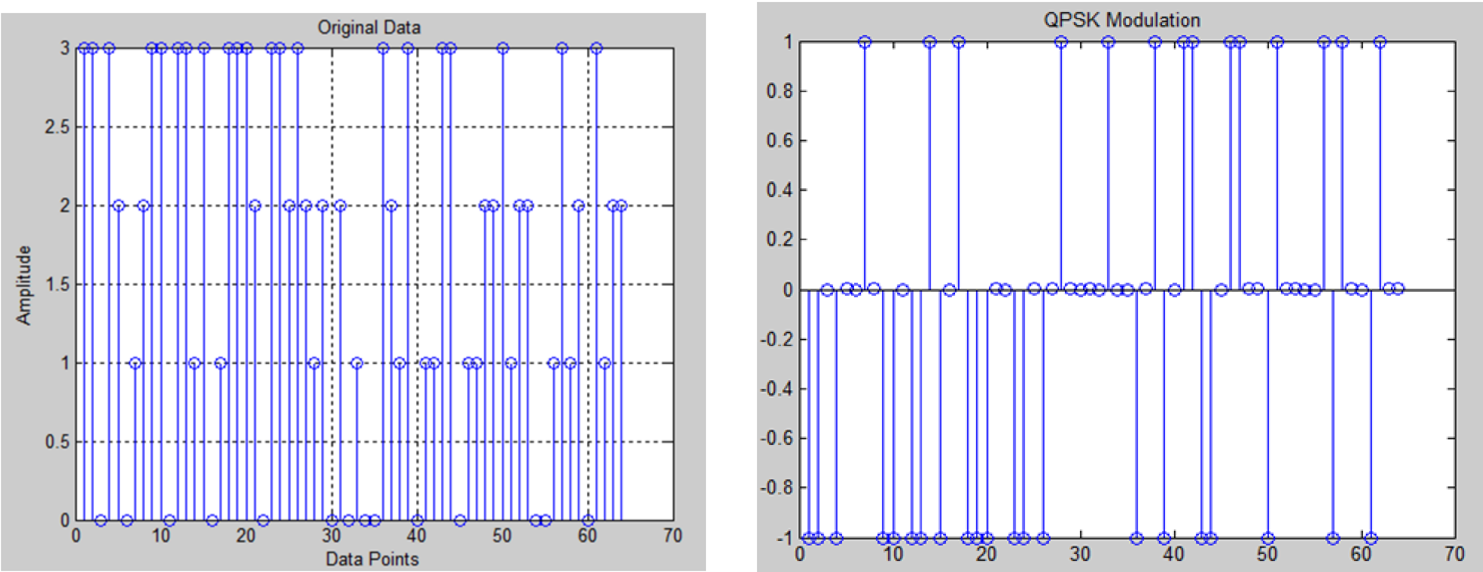


Figure 19 Original and Modulated OFDMA Signal

Due to high spectral efficiency and robust transmission in presence of multipath fading, the OFDMA is used as modulation scheme for downlink in LTE –A system, Figure 19.

In OFDMA transmitter, the available spectrum is dived into number of orthogonal subcarriers. The subcarrier spacing for LTE-A system is 15 KHz with 66.67us OFDMA symbol duration [52].

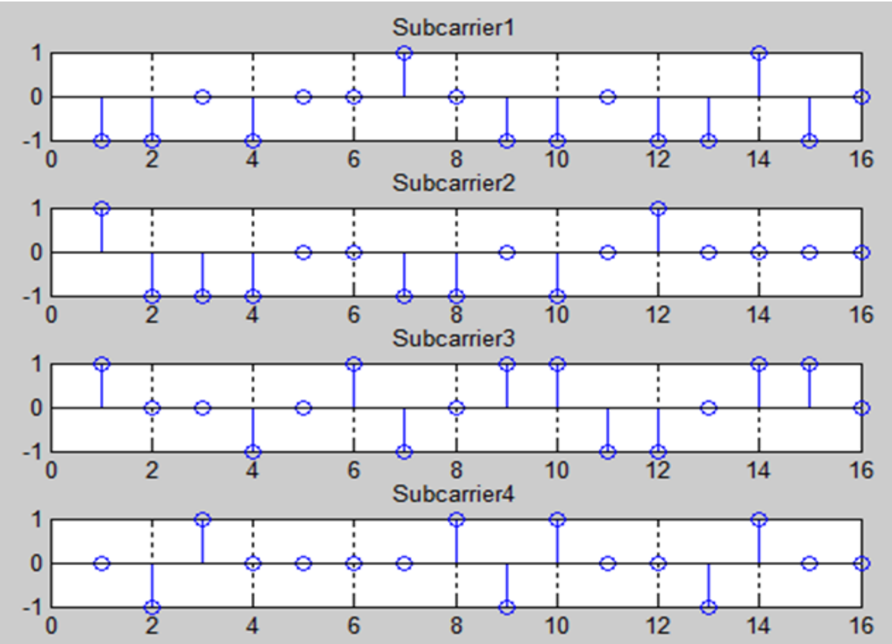


Figure 20 OFDMA subcarrier

This multilevel sequence of modulated symbol is converted into parallel frequency components (subcarriers) by serial to parallel converter as shown in figure 20. In figure 21, the IFFT stage converts these complex data symbols into time domain and generates OFDMA symbols.

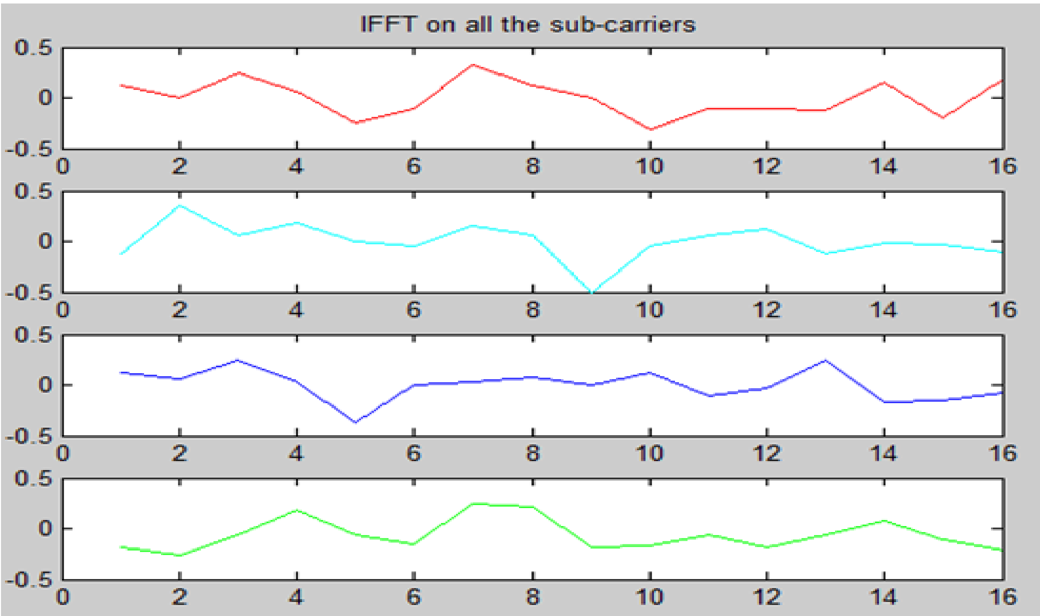


Figure 21 IFFT of four subcarriers

A guard band is used between OFDMA symbols in order to cancel the inter-symbol interference at receiver. In LTE-A, this guard band is called Cyclic Prefix (CP) and the duration of the CP needs to be greater that the channel impulse response or delay spread, as shown in figure 21.

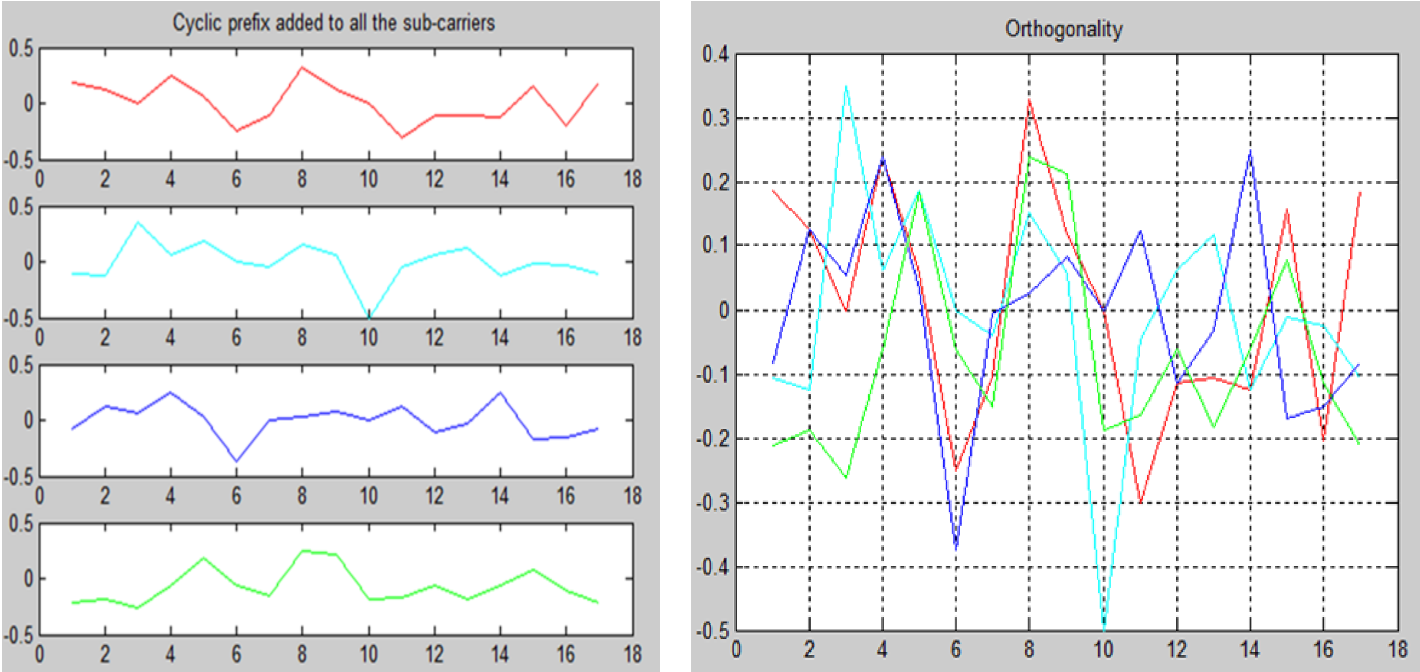


Figure 22 OFDMA symbols and Cyclic Prefix

The receiver does not deal with the ISI but still have to consider the channel impact for every single subcarrier that have experienced amplitude changes and frequency dependent phase, As shown in figure 22.

At the receiver the CP is first removed and the subcarrier are converted from parallel to serial sequence, see figure 23.

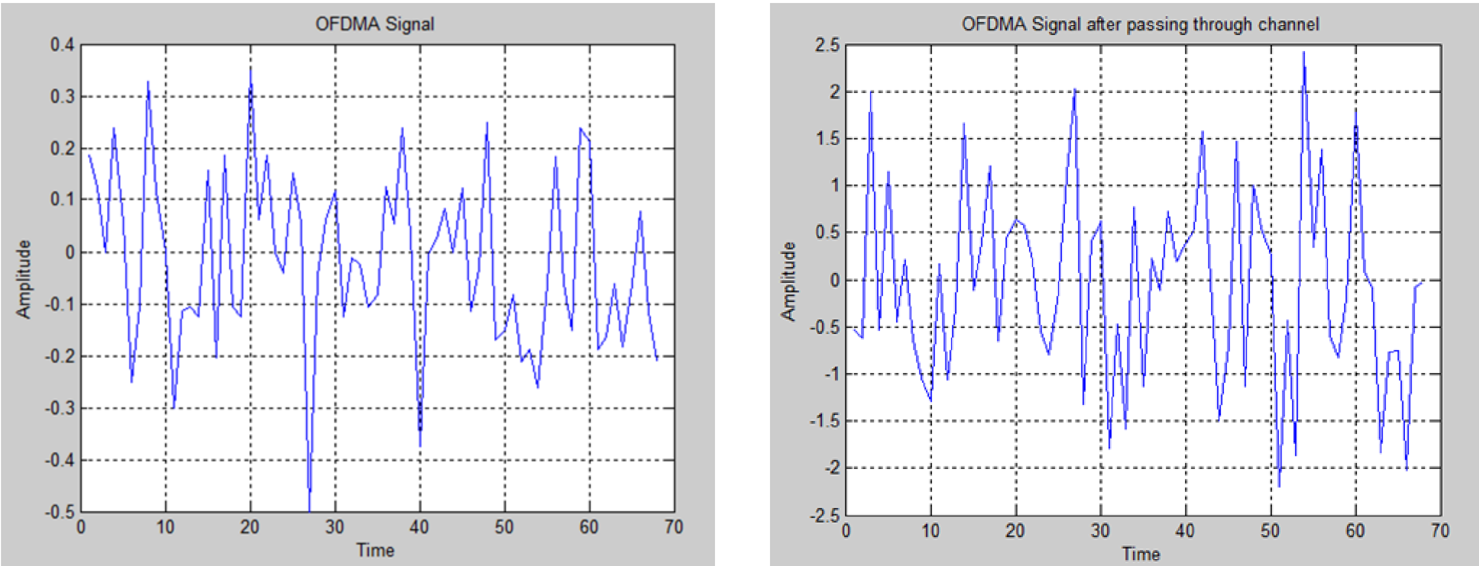


Figure 23 Original and Received OFDMA Signal

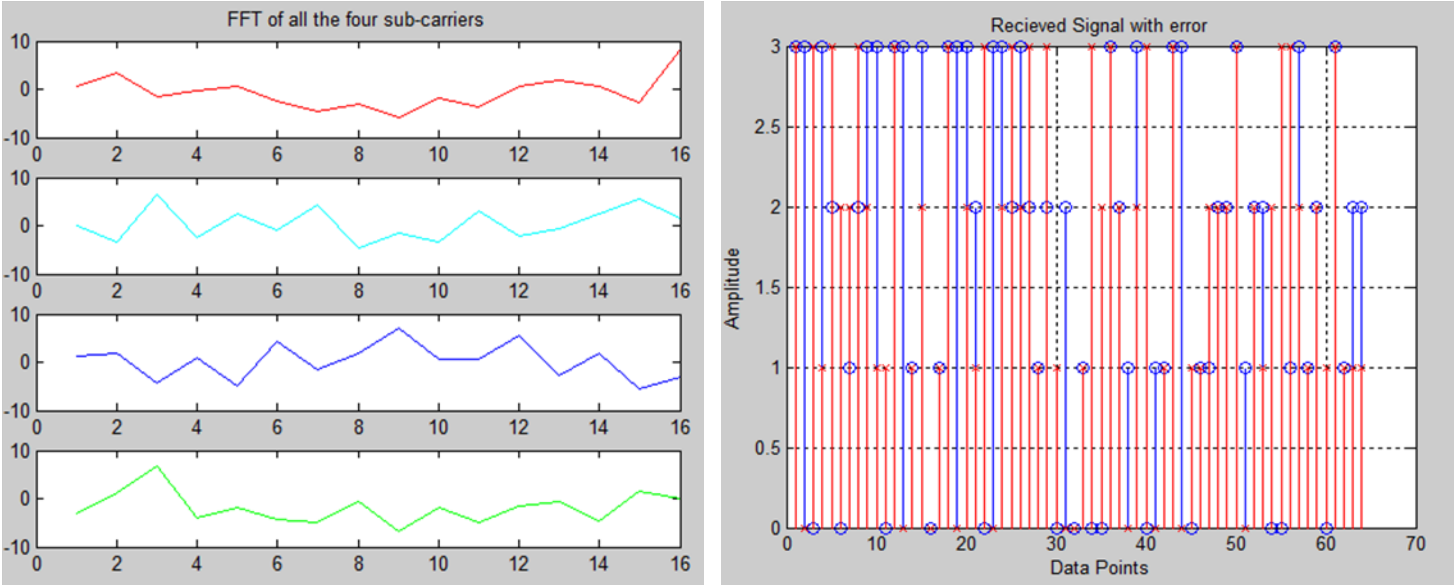


Figure 24 Received Signal

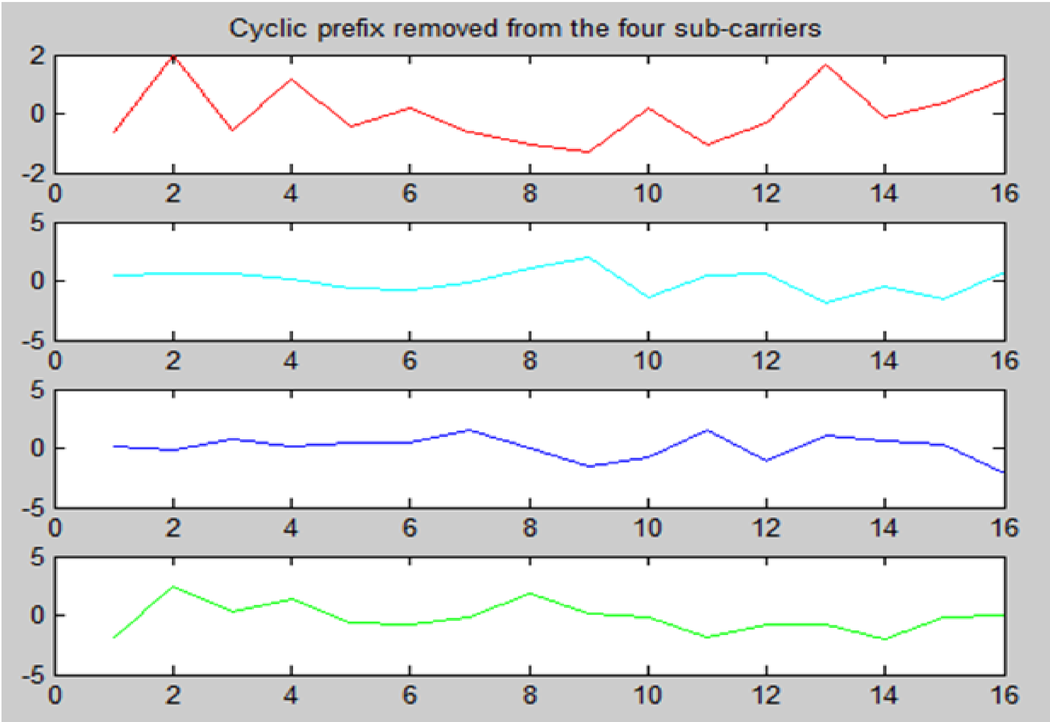


Figure 25 OFDMA symbols without Cyclic Prefix

The FFT stage further converts the symbols into frequency domain followed by equalizer and demodulation as shown in figure 24.

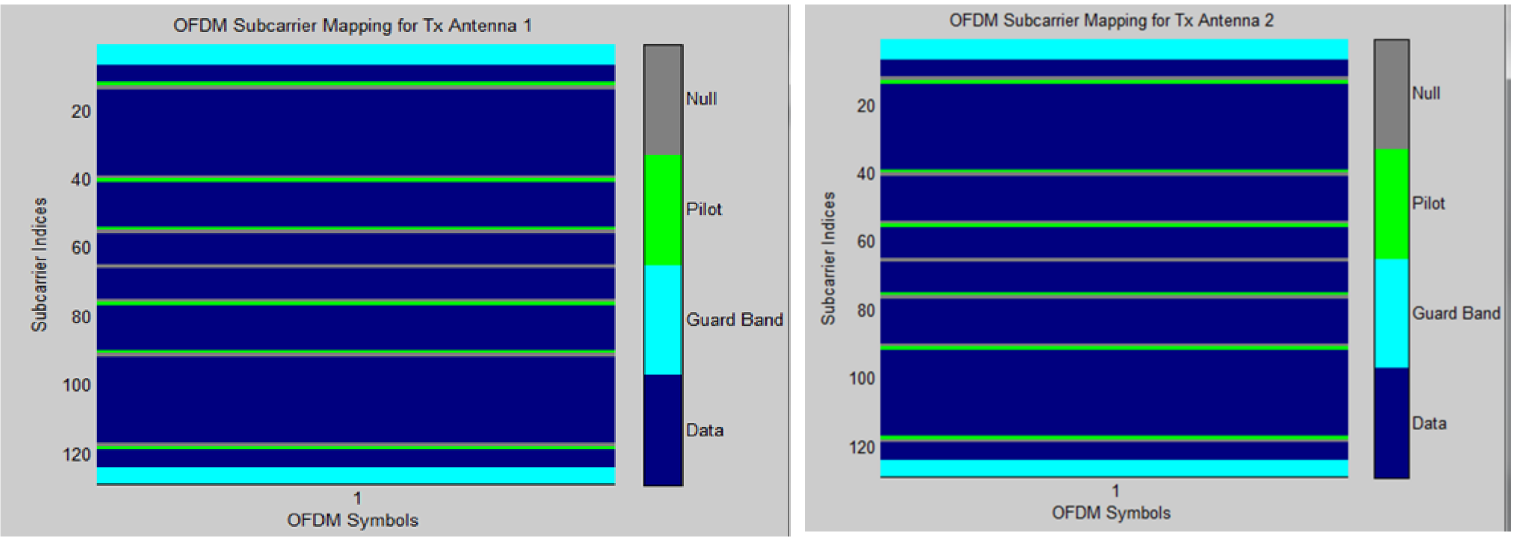


Figure 24 MIMO-OFDMA Systems

5.4 MIMO-OFDMA Systems

MIMO technology is used in broadband systems that exhibit frequency selective fading and, therefore, inter-symbol interference. OFDM modulation turns the frequency selective channel into a set of parallel flat fading channel and is, hence an attractive way of coping with inter-symbol interference. Figure 26 shows the principle of MIMO-OFDMA system; OFDMA is the insertion of a guard interval (cyclic prefix) which is a copy of the last part of the OFDMA symbol. The signaling schemes used in MIMO systems can be roughly grouped into spatial multiplexing [53], which improves link reliability through diversity gain.

5.5 Conclusion

Under this chapter, the detailed information on the simulation results was given. It showed the recent advancements in MIMO-OFDMA technologies. Moreover, it explained in details the process of OFDMA technology and MIMO-OFDMA system.

Chapter 6: Conclusion and Recommendation

6.1 Conclusion

In this thesis an overview of the LTE- A is provided. The overview focused on LTE-A requirements and targets, MIMO and OFDMA as enabler technologies, and the proposed research areas. The thesis also discussed few potential future research areas covering cloud radio access network, Heterogeneous Networks and 8x2 MIMO systems.

The 3rd Generation Partnership Project (3GPP) long Term Evolution-Advanced (LTE-A) aims at very high peak data rates such as 1 Gbps in local areas and 100Mbps in wide areas. To meet these goals, we carried out a performance evaluation of Single-Input-Multiple-Output, both for Orthogonal Frequency Division Multiple Access (OFDMA) and Single-Carrier Frequency Division Multiple Access (SCFDMA) under LTE-advanced parameters. Different MIMO schemes such as Single-Input Multiple-Output (SIMO), Spatial multiplexing, beam forming and transmit and receive diversity are investigated. The results showed that OFDMA tends to outperform SC-FDMA for 2 receive antennas. However, this gap is reduced when 4 antennas are considered at the receiver.

MIMO technology is an essential components of LTE-A and it’s a key technology for LTE-A where adaptive switching modes at e-NodeB provides higher throughput for user close to e-NodeB and broadens its coverage range at edges of cells. MIMO combined with OFDMA is a crucial change in air interface of 4 G and beyond as compared to 3 G.

Concurrently, advances in signal processing revealed several approaches to actually approach the promised gains of MIMO-OFDMA systems. In this thesis work, an effective study, analysis and evaluation of the LTE-A performance with MIMO and OFDMA technologies has been carried out. The performance evaluation was evaluated with respect to the recent advancements in MIMO technology and its performance together with OFDMA. In both technologies, for higher order of modulation (QAM), the fading channel performs better for low SNR regions for transmit diversity in MIMO systems.

LTE-A with MIMO due to its enhanced data throughput is gaining widespread deployment with mobile communication providers. In this thesis report, MIMO system was first examined.

The section on literature review provides a review of the different research found in this area of LTE-A with MIMO. MIMO simulation showed to have a better capacity over traditional communication (single antenna). This thesis evaluated performance of the network on end user side in a given channel to compare how well MIMO outperforms single antenna in LTE-A network. In this measurement, different scenarios of MIMO were used. Single Input Single Output (SISO) performance was taken as a reference for making comparison. Throughput results and gain of 4X4 MIMO showed an enhancement of spectral efficiency of 20% comparing to 2X2 MIMO system. Analysis of the results obtained reveals that the performance of 4X4 MIMO is better than 2X4 MIMO in channel model. When high order modulation is utilized, performance in the fading channel model is better.

In additional, it was shown that there is noise reduction by using OFDMA based Rayleigh channel. We simulated OFDMA for 16-PSK (M=16) and the assumption is that 4 number of OFDMA subcarriers were considered. As mentioned in previous chapters, the main target for this evaluation was to examine the improvement in spectrum efficiency brought by MIMO-OFDMA system. Therefore, the evaluation showed that there is an improvement of spectral efficient, system capacity, throughput and bandwidth when MIMO system is using alongside the OFDMA.

6.2 Recommendations

In this section we identify few potential future research areas: Cloud Radio Access Network, 8x2 MIMO network and Heterogeneous Network (HetNet). In the future work, we plan to conduct more simulations under various mobility cases. Additionally, more evaluations in the system level simulator and measurements over field trails would be required to validate our proposal.

Recent years have shown increasing research interest in Cloud Radio access Network (CRAN). Such approaches change the traditional cellular access network's architecture by taking advantages of cloud computing and advanced antenna techniques. Because of a constant increase of mobile users and high data service demand in wireless mobile communication, there is a requirement to support this extension of data service and applications.

In order to meet this demand, there is a requirement for future development strategies to cover-up all users and their demand. That is why CRAN is required to boost data service and application to meet this demand. One of these requirements is the total cost of ownership. Cloud Radio Access Network is seen to have capability to reduce the network upgrading cost for operators which leads to reduction on CAPEX and OPEX. It can also enhance the performance of MIMO and cooperative Multipoint (CoMP) by improved Base Station (BS) cooperation via centralized processing. The virtualized resource pool supports multi standards and allows radio resource being shared by different radio access technologies to improve the overall spectrum efficiency and flexibility.

Cloud Radio Access Network is also regarded as one of the key technology supporting energy efficiency. However, there are some challenges such as initial investment required to support the site, management of rentals, low BS utilization, low BS processing unit power and a need for network upgrade for the faster data service. The basic concept of addressing the above challenge is to move a unit called Base Band Processing Unit (BBU) from the BS to the Control Unit (CU) and then the BS will operate as Radio Unit (RU) [9].

Regarding the second future research area, it is interesting to note that the heterogeneous network are foreseen as the major capacity and improved performance enabler by increasing the spectral efficiency per unit area. In order to improve the performance of Heterogeneous Networks, several multi-cell cooperation technologies have been developed, including range Extension (RE) and enhanced Inter-cell Interference coordination for co-channel deployments and Inter-site carrier aggregation for dedicated deployments[6 7].

Last, regarding antenna's polarization measurement, directional antenna with different polarization pair can be the choices for extension and enhance the spectral efficiency of LTE-A band. Moreover, from the radio network planning point of view, the results obtained in this thesis can be considered as guidelines for network coverage planning and RF mode selection for optimization for network operators. Feature of 8X2 MIMO is a standard in next generation of mobile network and plays a significant role in improved data rates and include system capacity in cellular network services.

List References

[1] David Martın-Sacrist, Jose F. Monserrat, Jorge Cabrejas Penuelas, Daniel calabuig, Salvador Garrigas, and Narc Cardona (2009),"On the way towards Fourth-Generation Mobile: 3GPP LTE and LTE-Advanced", Hindawi Publishing Corporation EURASIP Journal on Wireless Communications and Networking.

[2] ITU-R (2008), "Requirements related to technical performance for IMT-Advanced radio interface(s)", [Online] Available: http://www.itu.int/publ/R-REP-M.734/en.

[3] Akyildiz, I.F, Gutierrez-Estevez, D.M, Reyes, E.C, (2013). The evolution to 4G cellular systems: LTE Advanced Phys Communication 4, 218–245

[4] Cisco White Paper (6 February 2013), "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017,".

[5] L. Hanzo, H. Haas, S. Imre, D. O´ Brien, M. Rupp, and L. Gyongyosi (May 2012), "Wireless myths, realities, and futures: From 3G/4G to optical and quantum wireless," Proceedings of the IEEE, vol. 100

[6] K. I. Pedersen, Y. Wang, S. Strzyz and F. Frederiksen (June 2013), "Enhanced Inter-Cell Interference Coordination in Co-Channel Multi-Layer LTE-Advanced Networks," IEEE Wireless Communications Magazine.

[7] A. Damnjanovic, J . Montojo, Y. Wei, T. Ji, T . Luo, M. Vajapeyam, T. Yoo, O. Song and D. Malladi (June 2011), "A Survey on 3GPP Heterogeneous Networks", IEEE Wireless Communications Magazine.

[8]E. G. Larsson, F. Tufvesson, O. Edfors, and T. L. Marzetta (May 2013), "Massive MIMO for next generation wireless systems," arXiv:1304.6690, pp. 1–19,.

[9] F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors, and F. Tufvesson (Jan. 2013), "Scaling up MIMO: Opportunities and challenges with very large arrrays," IEEE Signal Processing Magazine.

[10] Gang Shen, Jimin Liu, Dongyao Wang, Jikang Wang, and Shan Jin (2009)," Multi-Hop Relay for NextGeneration Wireless Access Networks", Bell LabsTechnical Journal 13(4), Alcatel-Lucent. Published by Wiley Periodicals.

[11] Tamio Satio,Yashionri Tanaka and Tsugou Kato (2009)"Trends in WiMaX/LTE system", Fujitsu scientific and technical journal.

[12] "ETSI TR 125 913 (2009) "Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (EUTRAN)",".

[13] ITU-R Rep. M.2134, 2008"Requirements Related to Technical Performance for IMT-Advanced Radio Interface(s),"

[14] ITU-R (2008). Requirements related to technical performance for IMT-Advanced radio Interface (s).

[15] 3GPP (March 2011). Requirements for further advancements for Evolved Universal Terrestrial Radio Access (E-UTRA) (LTE-Advanced).

[16] D. Martin-Sacristan, J. F. Monserrat, V. Osa, and J. Cabrejas, (2011) “LTEAdvanced System Level Simulation Platform for IMT-Advanced Evaluation,” WAVES.

[17] D. Martin-Sacristan, J. F. Monserrat, J. Cabrejas-Pe˜nuelas, D. Calabuig, S. Garrigas, and N. Cardona (2009), “3GPP Long Term Evolution: Paving the Way towards Next 4G,”.

[18] D. Martin-Sacristan, J. F. Monserrat, J. Cabrejas-Pe˜nuelas, D. Calabuig, S. Garrigas, and N. Cardona (Mar.2009), “On the way towards fourth generation mobile: 3GPP LTE and LTE-advanced,” EURASIP Journal on Wireless Communications and Networking.

[19] K. Safjan, V. D’Amico, D. Bultmann, D. Martin-Sacristan, A. Saadani, and H. Schoneich, (Feb. 2011) “Assessing 3GPP LTE-advanced as IMTadvanced technology: the WINNER+ evaluation group approach,” IEEE Communications Magazine.

[20] S. Sesia, I. Toufik, M. Baker (2009), LTE – The UMTS Long Term Evolution: From Theory to Practice. First Edition West Sussex: John Wiley & Sons.

[21] Jeffrey G. Andrews, ” Orthogonal Frequency Division Multiple Access (OFDMA), [Online] Available: http://wncg.org/ee381v/.

[22] Srikanth S. Kumarn V, Manikandan C and Murugesapandian, ”Orthhognal Frequency Divison Multiplexing : is it the Multiple Access System of the future?”, AU-KBC Research center, Anna University, Chennai, India,

[23] Farooq Khan (2009), “LTE for 4G Mobile Broadband: Air Interface Technologies and Performance”, Telecom R&D Center Samsung Telecommunications.

[24] Hyung G. Myung and David J. Goodman (2008),” Single Carrier FDMA: A New Air Interface for Long Term Evolution”, John Wiley & Sons Ltd.

[25] S. Suo, Y. Yang, Y. Tang, and Y. Wang(2009). “Evaluation of MIMO structure and channel model in LTE system” in Fourth International Conference on Communications and Networking, CHINACOM, China.

[26] Gessese Mengistu Kebede and Oladele Olayinka Paul (November 2010), “ Performance Evaluation of LTE Downlink with MIMO Techniques”, School of Engineering, Blekinge Institute of Technology, 37179 Karlskrona, Sweden.

[27] Lionel Fuependap Metuge Reya (7 May 2010),”4G Technology Features and Evolution towards IMT-Advanced”, Aalto University, School of Science and Technology.

[28] F. Khalid and J. Speidel (2014), "Advances in MIMO Techniques for Mobile Communications—A Survey," International Journal of Communications, Network and System Sciences, Vol. 5 No. 5.

[29] Dr Harri Holma and Dr Antti Toskala (2009). LTE for UMTS - OFDMA and SC-FDMA Based Radio Access. Wiley Publishing.

[30] C.F. Ball, R. Mullner, J. Lienhart, and H. Winkler (May 2009). Performance analysis of Closed and Open loop MIMO in LTE. In European Wireless Conference, 2009. EW 2009.

[31] Talha Faizur Rahman (December 2015), "Broadband Radio Interfaces Design for 4G and beyond Cellular Systems in Smart Urban Environments", university of degli di Trento, Department of Information Engineering and Computer Science, ICT International Doctoral School.

[32] 3G.co.uk (October 2009), "CoMP Increases 3G LTE Data Rates", , http://www.3g.co.uk/PR/Oct2009/CoMP-Increases-3G-LTE-Data-Rates-3G.html,

[33] Rohde & Schwarz (2009) LTE-Advanced Technology introduction Application note. [online] Available from Internet: http://www2.rohde-schwarz.com/file_13924/1MA169_2E.pdf

[34] Harri Holma and Antti Toskala (2009). LTE for UMTS: Evolution to LTE-Advanced, 2nd edition. Wiley, New York.

[35] S.M. Alamouti (8 October 1998),"A simple transmit diversity technique for Wireless Communications" IEEE journal on select areas in Communication, vol. 16, No.

[36] Hajjar and Hanjo (April 2010), "Multifunctional MIMO systems: A combined diversity and Multiplexing Design Perspective" IEEE Wireless Communications.

[37] Jamshid Khun-Jush,(15.10.2009) "Qualcomm-Germany LTE-Advanced Activities", ITU-R WP 5D Meeting (Dresden).

[38] H. Wang, C. Rosa and P. Klaus,(September 2010) "Performance of Uplink Carrier Aggregation in LTEAdvanced Systems," in IEEE Vehicular Technology Conference (VTC), Ottawa, Canada.

[39] Z. Shen, A. Papasakellariou, J. Montojo, D. Gerstenberger and F. Xu (February 2012), "Overview of 3GPP LTE-Advanced Carrier Aggregation for 4G Wireless Communications," IEEE Communications Magazine.

[40] Gerard J. Foschini,"Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas", Bell Labs Technical Journal, Autumn 1996.

[41] Arogyasawami Paulraj, et al,"An overview of MIMO communications-A key to gigabit wireless," Proc. of the IEEE Feb. 2004.

[42] H. Bolcskei, D. Gesbert, and A .J. Paulraj, “On the capacity of OFDM-based spatial multiplexing systems” IEEE Trans. Commun., vol. 50, Feb 2002.

[43] A Mathematical Theory of Communications. Shannon, C. E. Vols. Bell Systems Technical Journal, vol. 27, 1948, pp. 379-423 and 623-656.

[44] Yong Soo-Cho Won Young Yan “MIMO - OFDM Wireless Communications with Matlab”. s.l. : IEEE Press, John Wiley and Sons, 2010.

[45] Yang, B., Letaief, K. B., Cheng, R. S., and Cao, Z., “Channel Estimation for OFDM Transmission in Multipath Fading channels Based on Parametric Channel Modeling,” IEEE Transactions on Communications, vol. 49, March 2001.

[46] 3GPP RP-091429,” Work Item Description: Enhanced Downlink Multiple Antenna Transmission,” Dec. 2009

[47] 3GPP RP-091430,” Work Item Decription: Uplink Multi-Antenna Transmission,” Dec 2010

[48] M. Tanno, Y. Kishiyama, H. Taoka, N. Miki, K. Higuchi, M. Sawahashi,” Requirements nad Technologies for LTE- Advanced Radio Access,” IEICE Technical Reports, RCS2008-136.

[49] J.G. Andrews, W, Choi and R.W Heath Jr,” Overcoming Interference in Spatial Multiplexing MIMO Cellular Networks,” IEEE Wireless Commun. Mag, Vol. 14

[50] 3GPP R1-074865, Nokia Siemens Network, Nokia,” UL DM RS for Multi-band-width Multi-User MIMO, “Nov.2007.

[51] Hidekazu Taoka, Satoshi Nagata and Xiaoming She,” MIMO and CoMP in LTE-Advanced”, Special Articles on LTE-Advanced Technology –Ongoing Evolution of LTE toward IMT –Advanced, NTT DOCOMO Technology Journal Vol. 12 No.2

[52] J. Lee et al,” Coordinated multipoint transmission and reception in LTE-Advanced system:’IEEE Communication Magazine, Nov.2012

[53] Murtadha Ali Nsaif Sukar and Maninder Pal,” SC-FDMA&OFDMA in LTE physical layer”, International Journal of Engineering Trends and Technology (IJETT) – Volume 12 Number 2- Jun 2014

[54] A.J. Paulraj. R.U.Nabar, and D.A.Gore,” Introduction to space-Time Wireless Communication”, Cambridge UK: Cambridge Univ. Press, 2003.

Appendix 1: Claude Shannon's equation for capacity calculation

The paper of 1948 by Claude Shannon of Bell Labs, has become the basis of the electronic communication industry which is called the Shannon channel capacity or Shannon information transmission capacity C. Shannon's capacity is calculated as

$C = W \log_2(1 + \frac{P}{N})$ In bits/second (1.1)

However, some authors rewrite this equation as Capacity=bandwidth * log2 (1 +SNR) but this does not make any change to the original equation, it is only for clarification.

In these equations, bandwidth W is the bandwidth of the channel, SNR is the signal-to-noise ratio, and capacity C is the capacity of the channel in bits per second where $SNR = \frac{P}{N}$ and P is power of the signal and N is the power of the background noise. In the Shannon formula there is no indication of the signal level, this means that no matter how many levels we have, we cannot achieve a data rate higher than the capacity of the channel; the formula defines a characteristic of the channel, not the method of transmission. Defines signal to noise ratio as $SNR = \frac{S}{(N-1)S}$ which is equal to $\frac{1}{N-1}$ hence the equation for capacity calculation in CDMA systems can be rewritten as

$C = W \, log_2 \left(1 + \frac{1}{N-1}\right)$ (1.2)

Basing on Shannon's equation for capacity calculation, several formulas were developed to provide increased capacity for better performance and to increase the quality of service to the cellular users.

Appendix 2: MIMO Matlab codes

a. Water Filling Algorithm

```
function [Capacity PowerAllo] = WaterFilling_alg(PtotA,ChA,B,N0)
%
% WaterFilling in Optimising the Capacity
%===============
% Initialization
%===============
ChA = ChA + eps;
NA = length(ChA);      % the number of subchannels allocated to

H = ChA.^2/(B*N0);  % the parameter relate to SNR in subchannels
% assign the power to subchannel
PowerAllo = (PtotA + sum(1./H))/NA - 1./H;
while(length(find(PowerAllo < 0 ))>0)
    IndexN = find(PowerAllo <= 0 );
    IndexP = find(PowerAllo > 0);
    MP = length(IndexP);
    PowerAllo(IndexN) = 0;
    ChAT = ChA(IndexP);
    HT = ChAT.^2/(B*N0);
    PowerAlloT = (PtotA + sum(1./HT))/MP - 1./HT;
    PowerAllo(IndexP) = PowerAlloT;
end
PowerAllo = PowerAllo.';
```

b. MIMO system simulation

```
nt_V = [1 2 3 2 4];
nr_V = [1 2 2 3 4];

N0 = 1e-4;
B  = 1;
Iteration = 1e4; % must be grater than 1e2

SNR_V_db = [-10:3:20];
SNR_V    = 10.^(SNR_V_db/10);

color = ['b';'r';'g';'k';'c'];
notation = ['-o';'->';'<-';'-^';'-s'];

for(k = 1 : 5)
    nt = nt_V(k);
    nr = nr_V(k);
    for(i = 1 : length(SNR_V))
        Pt = N0 * SNR_V(i);
        for(j = 1 : Iteration)
            H = random('rayleigh',1,nr,nt);
            [S V D] = svd(H);
            landas(:,j)  = diag(V);
            [Capacity(i,j) PowerAllo] = WaterFilling_alg(Pt,landas(:,j),B,N0);
        end
    end
```

```
            [S V D] = svd(H);
            landas(:,j)  = diag(V);
            [Capacity(i,j) PowerAllo] = WaterFilling_alg(Pt,landas(:,j),B,N0);
        end
    end

    f1 = figure(1);
    hold on
    plot(SNR_V_db,mean(Capacity'),notation(k,:),'color',color(k,:))

    f2 = figure(2);
    hold on
    [y,x] = hist(reshape(landas,[1,min(nt,nr)*Iteration]),100);
    plot(x,y/Iteration,'color',color(k,:));
    clear landas
end

f1 = figure(1)

legend_str = [];
for( i = 1 : length(nt_V))
    legend_str =[ legend_str ;...
        {['nt = ',num2str(nt_V(i)),' , nr = ',num2str(nr_V(i))]}];
end
legend(legend_str)
grid on
```

c. Diversity

```
frmLen = 100;           % frame length
numPackets = 1000;      % number of packets
EbNo = 0:2:20;          % Eb/No varying to 20 dB
N = 2;                  % maximum number of Tx antennas
M = 2;                  % maximum number of Rx antennas
% Create comm.BPSKModulator and comm.BPSKDemodulator System objects
P = 2;                  % modulation order
bpskMod = comm.BPSKModulator;
bpskDemod = comm.BPSKDemodulator('OutputDataType','double');

% Create comm.OSTBCEncoder and comm.OSTBCCombiner System objects
ostbcEnc = comm.OSTBCEncoder;
ostbcComb = comm.OSTBCCombiner;

% Create two comm.AWGNChannel System objects for one and two receive
% antennas respectively. Set the NoiseMethod property of the channel to
% 'Signal to noise ratio (Eb/No)' to specify the noise level using the
% energy per bit to noise power spectral density ratio (Eb/No). The output
% of the BPSK modulator generates unit power signals; set the SignalPower
% property to 1 Watt.
awgn1Rx = comm.AWGNChannel('NoiseMethod', 'Signal to noise ratio (Eb/No)',...
                           'SignalPower', 1);
awgn2Rx = clone(awgn1Rx);

% Create comm.ErrorRate calculator System objects to evaluate BER.
errorCalc1 = comm.ErrorRate;
errorCalc2 = comm.ErrorRate;
errorCalc3 = comm.ErrorRate;
H = zeros(frmLen, N, M);
ber_noDiver  = zeros(3,length(EbNo));
ber_Alamouti = zeros(3,length(EbNo));
ber_MaxRatio = zeros(3,length(EbNo));

fig = figure;
grid on;
hold on;
ax = fig.CurrentAxes;
ax.YScale = 'log';
xlim([EbNo(1), EbNo(end)]);
ylim([1e-4 1]);
xlabel('Eb/No (dB)');
ylabel('BER');
fig.NumberTitle = 'off';
fig.Renderer = 'zbuffer';
fig.Name = 'Transmit vs. Receive Diversity';
title('Transmit vs. Receive Diversity');
set(fig,'DefaultLegendAutoUpdate','off');

for idx = 1:length(EbNo)
    reset(errorCalc1);
    reset(errorCalc2);
    reset(errorCalc3);

    awgn1Rx.EbNo = EbNo(idx);
    awgn2Rx.EbNo = EbNo(idx);
```

```
        ber_MaxRatio(:,idx) = errorCalc3(data, demod12);

    end % end of FOR loop for numPackets

    % Calculate theoretical second-order diversity BER for current EbNo
    ber_thy2(idx) = berfading(EbNo(idx), 'psk', 2, 2);


    semilogy(EbNo(1:idx), ber_noDiver(1,1:idx), 'r*', ...
             EbNo(1:idx), ber_Alamouti(1,1:idx), 'go', ...
             EbNo(1:idx), ber_MaxRatio(1,1:idx), 'bs', ...
             EbNo(1:idx), ber_thy2(1:idx), 'm');
    legend('No Diversity (1Tx, 1Rx)', 'Alamouti (2Tx, 1Rx)',...
           'Maximal-Ratio Combining (1Tx, 2Rx)', ...
           'Theoretical 2nd-Order Diversity');

    drawnow;
end  % end of for loop for EbNo


fitBER11 = berfit(EbNo, ber_noDiver(1,:));
fitBER21 = berfit(EbNo, ber_Alamouti(1,:));
fitBER12 = berfit(EbNo, ber_MaxRatio(1,:));
semilogy(EbNo, fitBER11, 'r', EbNo, fitBER21, 'g', EbNo, fitBER12, 'b');
hold off;

% Restore default stream
RandStream.setGlobalStream(prevStream);
```

Appendix 3: OFDMA Matlab codes

a. OFDMA transmitter

```
close all;
no_of_data_bits = 64%Number of bits per channel extended to 128
M =4 %Number of subcarrier channel
n=256;%Total number of bits to be transmitted at the transmitter
block_size = 16; %Size of each OFDM block to add cyclic prefix
cp_len = floor(0.1 * block_size); %Length of the cyclic prefix
% Transmitter
data = randsrc(1, no_of_data_bits, 0:M-1);
figure(1),stem(data); grid on; xlabel('Data Points'); ylabel('Amplitude')
title('Original Data ')
% Perform QPSK modulation on the input source data
qpsk_modulated_data = pskmod(data, M);
figure(2),stem(qpsk_modulated_data);title('QPSK Modulation ')
% Converting the series data stream into four parallel data stream to form
% four sub carriers
S2P = reshape(qpsk_modulated_data, no_of_data_bits/M,M)
Sub_carrier1 = S2P(:,1)
Sub_carrier2 = S2P(:,2)
Sub_carrier3 = S2P(:,3)
Sub_carrier4 = S2P(:,4)
figure(3), subplot(4,1,1),stem(Sub_carrier1),title('Subcarrier1'),grid on;
subplot(4,1,2),stem(Sub_carrier2),title('Subcarrier2'),grid on;
subplot(4,1,3),stem(Sub_carrier3),title('Subcarrier3'),grid on;
subplot(4,1,4),stem(Sub_carrier4),title('Subcarrier4'),grid on;

% IFFT OF FOUR SUB_CARRIERS
number_of_subcarriers=4;
cp_start=block_size-cp_len;
```

```
% ADD-CYCLIC PREFIX %.........................................................
for i=1:number_of_subcarriers,
ifft_Subcarrier(:,i) = ifft((S2P(:,i)),16)% 16 is the ifft point
for j=1:cp_len,
cyclic_prefix(j,i) = ifft_Subcarrier(j+cp_start,i)
end
Append_prefix(:,i) = vertcat( cyclic_prefix(:,i), ifft_Subcarrier(:,i))
% Appends prefix to each subcarriers
end
A1=Append_prefix(:,1);
A2=Append_prefix(:,2);
A3=Append_prefix(:,3);
A4=Append_prefix(:,4);
figure(5), subplot(4,1,1),plot(real(A1),'r'),title('Cyclic prefix added to all the sub-carr
subplot(4,1,2),plot(real(A2),'c')
subplot(4,1,3),plot(real(A3),'b')
subplot(4,1,4),plot(real(A4),'g')
figure(11),plot((real(A1)),'r'),title('Orthogonality'),hold on ,plot((real(A2)),'c'),hold c
plot((real(A3)),'b'),hold on ,plot((real(A4)),'g'),hold on ,grid on
%Convert to serial stream for transmission
[rows_Append_prefix cols_Append_prefix]=size(Append_prefix)
len_ofdm_data = rows_Append_prefix*cols_Append_prefix
% OFDM signal to be transmitted
ofdm_signal = reshape(Append_prefix, 1, len_ofdm_data);
figure(6),plot(real(ofdm_signal)); xlabel('Time'); ylabel('Amplitude');
title('OFDMA Signal');grid on;
```

b. OFDMA Receiver

```
% Remove cyclic Prefix
recvd_signal_paralleled(1:cp_len,:)=[];
R1=recvd_signal_paralleled(:,1);
R2=recvd_signal_paralleled(:,2);
R3=recvd_signal_paralleled(:,3);
R4=recvd_signal_paralleled(:,4);
figure(8),plot((imag(R1)),'r'),subplot(4,1,1),plot(real(R1),'r'),
title('Cyclic prefix removed from the four sub-carriers')
subplot(4,1,2),plot(real(R2),'c')
subplot(4,1,3),plot(real(R3),'b')
subplot(4,1,4),plot(real(R4),'g'
% FFT Of recievied signal
for i=1:number_of_subcarriers,
% FFT
fft_data(:,i) = fft(recvd_signal_paralleled(:,i),16);
end
F1=fft_data(:,1);
F2=fft_data(:,2);
F3=fft_data(:,3);
F4=fft_data(:,4);
figure(9), subplot(4,1,1),plot(real(F1),'r'),title('FFT of all the four sub-carrie
subplot(4,1,2),plot(real(F2),'c')
subplot(4,1,3),plot(real(F3),'b')
subplot(4,1,4),plot(real(F4),'g')
% Conversion to serial and demodulationa
recvd_serial_data = reshape(fft_data, 1,(16*4));
qpsk_demodulated_data = pskdemod(recvd_serial_data,4);
figure(10)
```

Appendix 4: MIMO-OFDMA system Matlab codes

```
qpskMod = comm.QPSKModulator;
qpskDemod = comm.QPSKDemodulator;
ofdmMod = comm.OFDMModulator('FFTLength',128,'PilotInputPort',true
    'PilotCarrierIndices',cat(3,[12; 40; 54; 76; 90; 118],...
    [13; 39; 55; 75; 91; 117]),'InsertDCNull',true,...
    'NumTransmitAntennas',2);
ofdmDemod = comm.OFDMDemodulator(ofdmMod);
ofdmDemod.NumReceiveAntennas = 2;
showResourceMapping(ofdmMod)
ofdmModDim = info(ofdmMod);

numData = ofdmModDim.DataInputSize(1);   % Number of data subcarr
numSym = ofdmModDim.DataInputSize(2);    % Number of OFDM symbols
numTxAnt = ofdmModDim.DataInputSize(3);  % Number of transmit ante
nframes = 100;
data = randi([0 3],nframes*numData,numSym,numTxAnt);
modData = qpskMod(data(:));
modData = reshape(modData,nframes*numData,numSym,numTxAnt);
errorRate = comm.ErrorRate;
for k = 1:nframes

    % Find row indices for kth OFDM frame
    indData = (k-1)*ofdmModDim.DataInputSize(1)+1:k*numData;

    % Generate random OFDM pilot symbols
    pilotData = complex(rand(ofdmModDim.PilotInputSize), ...
        rand(ofdmModDim.PilotInputSize));

    % Generate random OFDM pilot symbols
    pilotData = complex(rand(ofdmModDim.PilotInputSize), ...
        rand(ofdmModDim.PilotInputSize));

    % Modulate QPSK symbols using OFDM
    dataOFDM = ofdmMod(modData(indData,:,:),pilotData);

    % Create flat, i.i.d., Rayleigh fading channel
    chGain = complex(randn(2,2),randn(2,2))/sqrt(2); % Random 2x2 channel

    % Pass OFDM signal through Rayleigh and AWGN channels
    receivedSignal = awgn(dataOFDM*chGain,30);

    % Apply least squares solution to remove effects of fading channel
    rxSigMF = chGain.' \ receivedSignal.';

    % Demodulate OFDM data
    receivedOFDMData = ofdmDemod(rxSigMF.');

    % Demodulate QPSK data
    receivedData = qpskDemod(receivedOFDMData(:));

    % Compute error statistics
    dataTmp = data(indData,:,:);
    errors = errorRate(dataTmp(:),receivedData);
end
fprintf('\nSymbol error rate = %d from %d errors in %d symbols\n',errors)
```