People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

University M'Hamed BOUGARA – Boumerdes

Institute of Electrical and Electronic Engineering
Department of Electronics

Project Report Presented in Partial Fulfilment of
the Requirements of the Degree of

MASTER

In **Telecommunication**
Option: **Telecommunications**

Title

Optimizing Long Term Evolution (LTE) Performance Using Massive Multiple-Input Multiple-Output (MIMO) Technique

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Registration Number:………./2023

Abstract

With the growing demand for high-speed data rate and reliable wireless communications, LTE has become the dominant cellular network technology. However, as the number of connected devices and data-intensive applications continue to increase, there is a need to improve network capacity, spectral efficiency, and overall user experience.

This final year project focuses on the implementation and evaluation of Massive MIMO, a cutting-edge technology that utilizes a large number of antennas at the eNodeB to serve multiple users simultaneously. It uses beamforming and multi user MIMO to enhance the overall user experience. The report aims to assess the impact of Massive MIMO on various performance metrics of LTE networks, including coverage, capacity, data rates, and interference management.

To achieve these objectives, a comprehensive experimental setup is established involving real-world measurements. The performance of LTE networks with and without Massive MIMO is evaluated under different scenarios, including varying user densities, traffic patterns, and throughput rates. Key performance indicators such as accessibility, retainability, mobility, integrity and user throughput are analysed and compared.

Overall, this report sheds light on the potential of Massive MIMO technology to address the ever-increasing demands of LTE networks and paves the way for future advancements in wireless communication systems.

The keywords: Long Term Evolution (LTE), Multiple-Input Multiple-Output (MIMO), Massive Multiple-Input Multiple-Output (Massive MIMO), Key Performance Indicator (KPI), Coverage, Throughput, iMaster MAE software.

Dedication

Firstly, I dedicate this project to My Father may his soul rest in peace who raised,loved,protected in the best possible way he could. I wish I kept my promise to you and your little daughter became an engineer.

Secondly, I dedicate this to you my beloved family. My Mom that ones told me " i will rest only when i see you arrived" and my sisters ; Siham your presence made me who I am, ,Nassima my ambitious sister who I'm always proud of ,Ahlem the pure hearted sister this project mostly is for you .Thank you for everything I always felt blessed and grateful

Thirdly , to My friends ; each one of you knows exactly what she/he means to me thank you for all the support, presence and patience .I couldn't ask for more truthful,uncomplicated and lifelong friendships.

Finally, I dedicate this work to the best partner I ever had; a friendship that will last for life and moments I will never replace by anything in the world. Nabila thank you for everything.

It wasn't easy ,it took me time,energy and courage and but i can finally say : I DID IT

Rayane

Dedication

First, I would like to thank myself for making so far; the journey was not easy, full of ups and down but worth it at end.

Second, I would like to dedicate this project to my father, who used to tell me that I would achieve great things when I grow up. I wish you were here to witness your daughter graduating as a Telecom engineer.

Thirdly, I dedicate this work to my mother, grandparents,siblings, aunts, uncles, and the rest of my family. They have been my constant support, encouragement, and motivation throughout the years, helping me become who I am today.

In addition, I would like to extend my heartfelt dedication to my cherished friends who know what they mean to me. The bond we share goes beyond words, and the memories we've forged together are etched deeply in my heart. Your presence, support, endless patience, have been the pillars that have uplifted me throughout my journey.

Last but not least, to the person with whom I shared and made this project. Rayane, you have been an exceptional partner, and the experiences we shared together have been truly extraordinary. These cherished moments will forever hold a special place in my memory. Thank you for everything.

Nabila

Acknowledgement

First and foremost, we would like to thank Allah, the Most Gracious and Merciful, for providing us with the patience, courage, and determination, as well as guidance, in carrying out this project study.

We would like to express our heartfelt gratitude to our supervisor, Mr. A. MOHAMMED-SAHNOUN for directing this work, as well as for his supervision and ongoing assistance, his constructive feedback and insightful suggestions to help complete this project.

We are deeply grateful for the exceptional support and guidance we received from our co-supervisor, AYACHE Sohaib Ahmed, during our internship. His unwavering assistance and mentorship were instrumental in leading us to significant and valuable outcomes.

We would like to thank the institute's teachers for their guidance over the last five years and for all of the valuable knowledge we have gained from them.

Finally, we want to express our heartfelt appreciation to our parents and family members for their love and support. To everyone who has helped us, directly or indirectly,finish this project.

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1G	First Generation
2G	Second generation
3G	Third generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
6G	Sixth Generation
CQI	Channel Quality Indicator
CP	Cyclic Prefix
CSFB	Circuit Switched Fall-back
DL	Downlink
DR	Drop Rate
DT	Drive Test
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
EPC	Evolved Packet Core
ERAB	Establishment Radio Access Bearer
FTP	File Transfer Protocol
FDD	Frequency Division Duplex
GSM	Global System for Mobile Communications
GPS	Global Positioning System
GP	Guard Period
HOSR	Handover Success Rate
HSS	Home Subscriber Server
LTE	Long-Term Evolution
MAC	Medium Access Control
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
MISO	Multiple-Input Single-Output
MU-MIMO	Multi-User MIMO
NAS	Non Access Stratum
OFDMA	Orthogonal Frequency Division Multiple Access
OSS	Operations Support Systems
PAPR	Peak-to-Average Power Ratio
PCRF	Policy and Charging Rules Function
PDCP	Packet Data Convergence Protocol
PCI	Physical Cell ID
P-GW	Packet Gateway
PRB	Physical Resource Block
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RB	Resource Block
RE	Resource Element
RACH	Random Access Channel
RAB	Radio Access Bearer
RRC	Radio Resource Control
RSRP	Reference Signal Received Power

RSRQ	Reference Signal Received Quality
R_x	Receiver
SC-FDMA	Single Carrier Frequency Division Multiple Access
SIM	Subscriber Identity Module
SINR	Signal-to-Interference-plus-Noise Ratio
SISO	Single-Input Single-Output
SIMO	Single-Input Multiple-Output
SNR	Signal-to-Noise Ratio
STS	Software-defined Transport Solution
SU-MIMO	Single-User MIMO
TAC	Tracking Area Code
T_x	Transmitter
TDD	Time Division Duplex
UE	User Equipment
UL	Uplink
VoLTE	Voice over LTE

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General introduction

In today's rapidly growing telecommunications sector, there is a constant emergence of new technologies that provide high-demand services in terms of speed and capacity, catering to the evolving needs of customers. Therefore the deployment of LTE technology has undoubtedly been the most dynamic, profitable, and innovative sector in the development of mobile telecommunications in Algeria.

In the context of optimizing the performance of LTE networks many techniques such as spatial multiplexing, beamforming, Channel State Information (CSI), precoding and equalization, and interference alignment were evolved. These technologies laid the groundwork for the development of Massive MIMO technology.

The main objective of this project titled "Optimizing LTE Performance Using Massive MIMO Technique" is to assess and enhance the performance of LTE systems through the implementation of Massive MIMO technology. The project focuses on monitoring the key performance indicators (KPIs) to evaluate the effectiveness of Massive MIMO. Additionally, a drive test is conducted to gather real-world data and validate the results obtained from monitoring. The present report documents the work carried out during our final year internship. The objective of our work is to carry out monitoring and optimization steps on a site proposed by the operator (Biskra). This monitoring process is done using professional tool iMaster MEA.

The manuscript is divided into four chapters as follows:

- The first chapter provides an in-depth understanding of the LTE architecture and the LTE air interface. Additionally, the frequency dimension in LTE is discussed, emphasizing the use of frequency bands and channel allocation techniques. Furthermore, the LTE frame structure and radio and the importance of efficient modulation schemes in LTE is emphasized.
- The second chapter focuses on Massive MIMO technology, which is a key aspect of this project thesis. The chapter delves into the main characteristics of Massive MIMO and provides a comprehensive overview of its classifications. The capacity of the channel in Massive MIMO systems is explored. Moreover, a detailed comparison between Massive MIMO and traditional MIMO is presented
- The third chapter examines the key performance indicators (KPIs) used to evaluate the performance of LTE systems, with a specific focus on Massive

MIMO. The chapter discusses the importance of monitoring KPIs and presents the results obtained from monitoring the KPIs using OSS iMaster MEA software in a specific geographical area (Biskra). The analysis of these results provides insights into the performance enhancements achieved through the implementation of Massive MIMO in the LTE network.

- The last chapter presents a real-life collected data called the drive test, conducted to assess the signal strength, signal quality, Signal-to-Interference-plus-Noise Ratio (SINR), and other relevant KPIs. The analysis of the drive test results provides valuable information on the real-world performance of the LTE network with Massive MIMO implementation.

The results will be used to validate the performance of the Massive MIMO and optimize LTE communication systems.

Chapter 1

Introduction to LTE networks

1.1 Introduction

Over the last decade, 3GPP standardized the 4th generation of mobile communications, commonly referred to as 4G, starting from Release 10. As a result, most countries worldwide have deployed this technology in recent years. Long Term Evolution (LTE) was designed to improve the spectral efficiency that enables high-speed data transfer. In this first chapter, we will start by presenting the evolution of mobile networks. Then, we will present the architecture of the LTE network. Finally, we will give some basic characteristics of the LTE network.

1.2 Evolution of wireless communication networks

The evolution of mobile connectivity from 1G to 5G has been a rapid process that has taken just over 40 years. Each successive generation of wireless standards has introduced significant advances in data-carrying capacity and speed. The first generation (1G) was introduced in the late 1970s and was an analog system. Second-generation (2G) communication systems like global system mobile (GSM) were introduced in the early 1990s, followed by third generation (3G) systems that enabled mobile internet access. Fourth-generation (4G) networks were introduced in the late 2000s, providing faster data transfer rates than previous generations. Fifth-generation (5G) networks offer even faster speeds, lower latency, and greater capacity than previous generations [1].The sixth generation (6G) mobile and wireless communication network can integrate the satellite communication networks and 5G to provide global coverage.

The following figure illustrate the evolution of the wireless generations and their different applications.

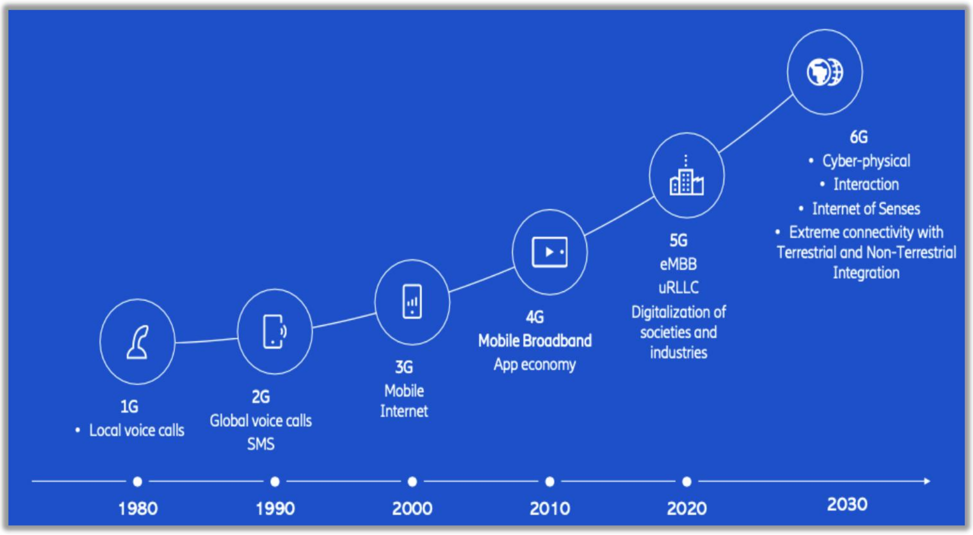

Figure 1.1: The evolution of wireless communication networks [2].

1.3 LTE architecture

The architecture of a typical LTE system comprises of three main components, namely:The User Equipment (UE), Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC) . To gain a comprehensive understanding of LTE architecture, it is important to distinguish between the control plane and user plane. This will be discussed in the section 1.4. The upcoming picture will illustrate the LTE structure.

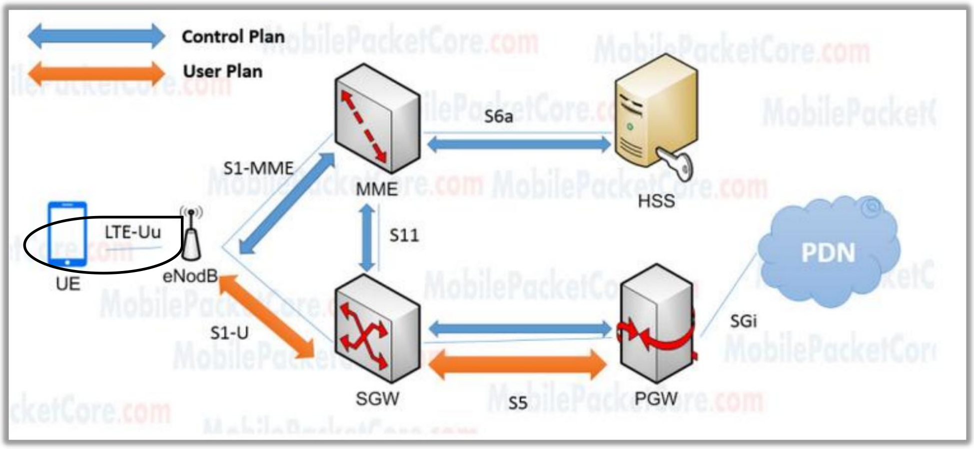

Figure 1.2: Depiction of LTE architecture [3].

In the following, we will explain each entity of the LTE architecture.

1.3.1 User equipment (UE)

It is also known as the LTE device. The UE is the endpoint used by the user to access LTE networks. It can be a smartphone, tablet, or any other LTE-enabled device [3].

1.3.2 The access network (E-UTRAN)

It represents the radio access network component of LTE system. It is responsible for providing wireless connectivity between UE and the core network. It is comprised two entities with are Evolved NodeB (eNodeB) and the UE [3].

a. Evolved NodeB (eNodeB)

It is also referred to as the base station or cell tower. It is responsible for managing the radio interface between the UE and the LTE network. It handles tasks such as radio resource allocation, modulation/demodulation, and handover [3].

The following figure illustrates the architecture of E-UTRAN.

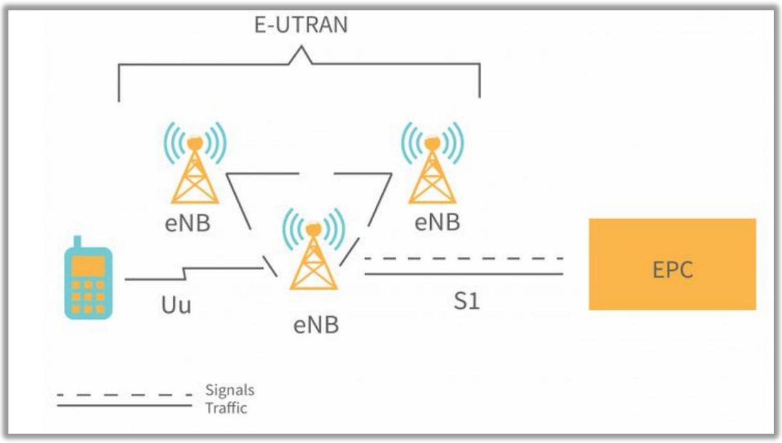

Figure 1.3: Representation of E-UTRAN Architecture [4].

1.3.3 The Evolved Packet Core (EPC)

EPC is the core network architecture that provides the packet-switched backbone for LTE. It comprises various components that handle key functionalities such as mobility management, packet routing, authentication, and connectivity to external networks. The architecture of EPC is illustrated below.

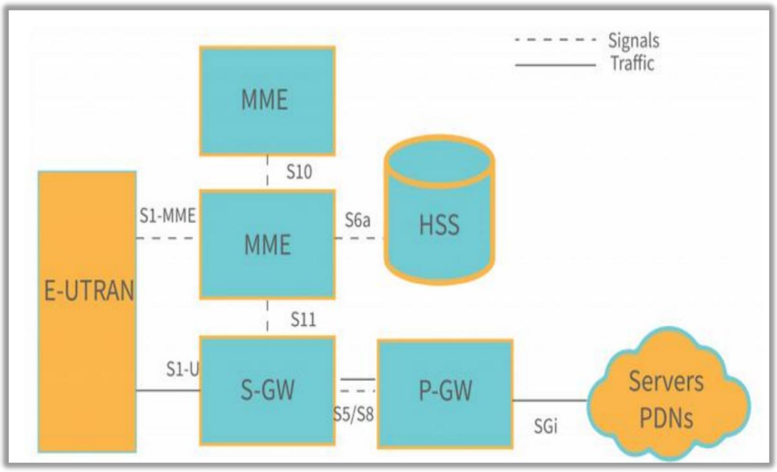

Figure 1.4: Representation of EPC Architecture [4].

In the following, we will present the main components and functions of the EPC.

a. Mobility Management Entity (MME)

It is responsible for managing the mobility of user devices within the network. It handles tasks such as user authentication, security, tracking the location of devices, and managing handover between eNodeBs [3].

b. Serving Gateway (SGW)

Within the EPS, every UE is linked to a specific SGW at any given time. The SGW assumes the role of a local mobility entity during handover between base stations. It plays a critical role in routing and forwarding packets between the base station and the Packet Data Network (PDN) gateway, as well as buffering downlink packets. The eNodeB is responsible for marking uplink packets, while the SGW takes care of marking downlink packets [5].

c. Packet Gateway (PGW)

The PGW serves as the interface between the EPC and external PDNs, such as the internet. It handles IP address allocation, packet routing, policy enforcement, and charging for data services. Furthermore, the PGW interacts with the Policy and Charging Rules Function (PCRF) to establish Quality of Service (QoS) parameters for bearers (logical or physical connection that enables the transmission of data within a network), while also ensuring that uplink and downlink transmission rates are enforced [5].

d. Home Subscriber Server (HSS)

The HSS stores subscriber-related information, such as user profiles, authentication credentials, and mobility data. It plays a crucial role in user authentication, authorization, and service provisioning. Additionally, it stores information regarding the PDNs that a user can connect to. The HSS also contains dynamic data, such as the identity of MME currently associated with or registered to the user [5].

e. Policy and Charging Rules Function (PCRF)

The PCRF is responsible for policy control and charging within the EPC. It manages quality of service (QoS) policies, enforces charging rules, and provides dynamic policy control for data flows [5].

1.4 Control and User plane

The protocol architecture of the radio interface related to LTE technology is composed of two planes: Control Plane and User Plane.

The control plane manages the operation and control of the network. It handles signalling and management messages for network set-up, maintenance, and termination. On the other hand, user plane handles the actual user data transmission within a network. It carries the information exchanged between users, such as voice calls, video streams, and application data. The user plane is responsible for forwarding data packets, ensuring quality of service, and applying encryption if required [6].

The following figure will present the two planes:

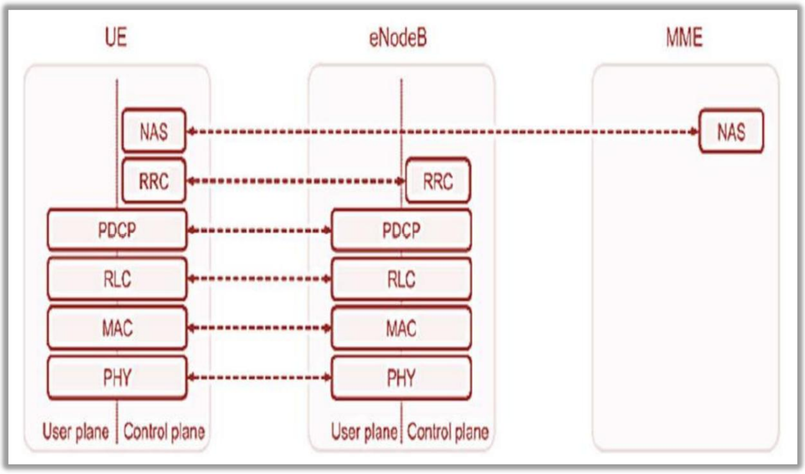

Figure 1.5: The protocol stack in LTE [7].

Each layer in the protocol stack uses the services of the lower layer and provides services to the upper layer. The packets exchanged between these layers are usually segmented into smaller units for transmission. Data packets received by a layer are called Service Data Units (SDUs), while the packets that leave the layers are called Protocol Data Units (PDUs).

1.4.1 Physical layer

The physical layer forms the complete layer of the protocol stack and provides basic signal transmission functionalities over the air. It uses the OFDMA technique in the downlink and SC-FDMA in the uplink , and also offers the possibility of using two transmission modes: FDD and TDD (depending on the capacity of the UE). The physical layer uses physical channels to transmit data over the radio path, and these channels are dynamically mapped to available resources (resource blocks and antenna ports). These principles will be discussed in details in the upcoming sections [7].

1.4.2 Second layer

This layer is divided into three sub-layers MAC, RLC and PDCP [7].

a. Medium Access Control (MAC)

The MAC sub-layer is among the most important layers of the model. It ensures the mapping of data between logical channels and transport channels.

b. Radio Link Control (RLC)

The main objective of the RLC sub-layer is to receive/deliver data packets from/to other RLC entities.

c. Packet Data Convergence Protocol (PDCP)

The PDCP sub layer ensures the reordering of RLC packets and compression/decompression of IP packet headers.

1.4.3 Radio Resource Control (RRC)

The RRC layer is the key layer in the signalling process. It supports several functions between the UE and eNodeB, such as RRC connection management, establishment, and release of radio resources.

1.4.4 Non Access Stratum (NAS)

The NAS operates above the Radio Access Network (RAN) and below the core network. It is responsible for managing signalling and control procedures between the UE and the core network in LTE networks.

1.5 LTE air interface

The air interface in LTE is the wireless communication link between the UE and the eNodeB; it is also known as the Radio Access Network (RAN). The air interface in LTE is designed to provide high-speed data transfer rates, low latency, and improved spectral efficiency. It enables the transmission of multimedia content such as video and audio, as well as high-speed internet access and other data services.

The air interface uses Orthogonal Frequency Division Multiple Access (OFDMA) modulation technique for downlink (from eNodeB to UE) in which it uses multiple subcarriers to transmit data to multiple users simultaneously. The subcarriers are orthogonal to each other, which means that they do not interfere with each other. Each user is assigned a subset of subcarriers for data transmission. It uses also Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink (from UE to eNodeB) . SC-FDMA uses a single carrier waveform to transmit data to multiple users, the data is spread across multiple subcarriers in a way that minimizes the peak-to- average power ratio (PAPR) of the transmitted signal. This makes SC-FDMA more power-efficient than OFDMA, especially in uplink transmission, where the mobile devices have limited battery power.

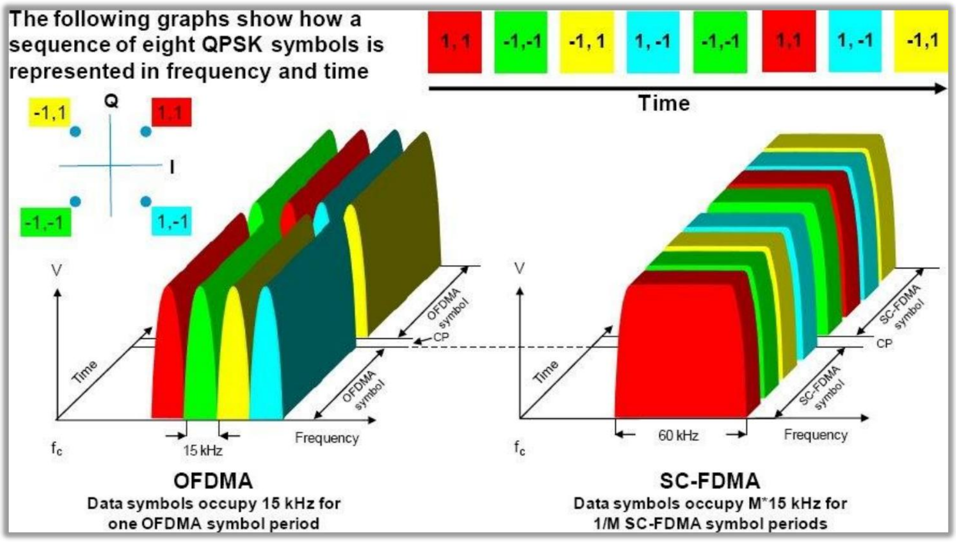

Figure 1.6: Air interface in the downlink and uplink modes in LTE [8].

1.7 Frequency dimension in LTE

With the frequency dimension introduced by OFDM and SC-FDMA, resource allocation in LTE is done in both the time and frequency dimensions.

The smallest transmission unit in the LTE downlink system is known as Physical Resource Block (PRB), which consists of element resource blocks (REs). A PRB has 12 sub-carriers with a bandwith of 15 kHz for each; so this gives us a total bandwidth of 180 kHz in a PRB. A downlink time slot has a duration of 0.5ms and contains either six or seven OFDMA symbols depending on the use of long or normal CP (cyclic prefix), respectively. A resource element is the basic unit of physical resources in LTE. Each RB contains 72 REs when long CP is used, while it contains 84 REs when normal CP is used [8].

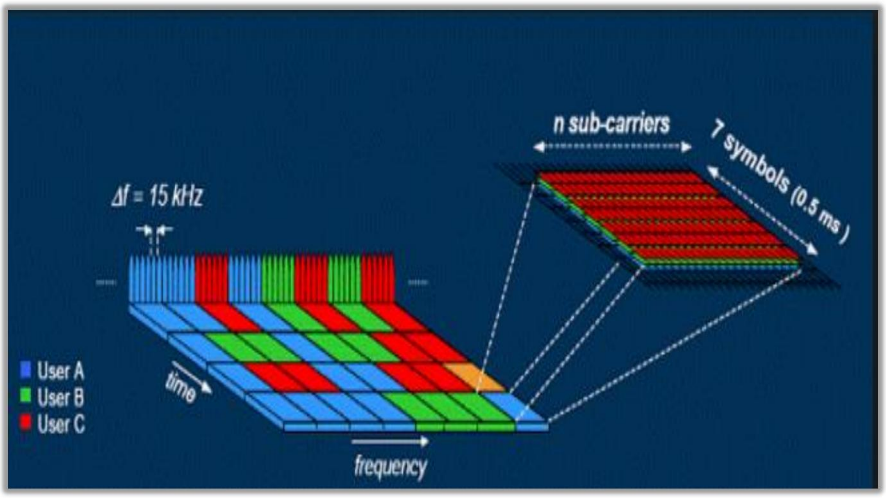

Figure 1.7: Physical Resource block allocation [7].

1.8 LTE frame structure

In time domain, the transmission of a message in LTE is organized in frames. The frame structure is organized into radio frames of 10 ms each, which are divided into ten equally sized subframes. Each subframe has a duration of 1 ms and is further divided into two equally sized time slots, with each slot being 0.5 ms. We fill the subframes with pairs of RB. A pair of RB is a set of 12 subcarriers in frequency space and 2 x 7 successive symbols.
To transmit a block of data, a minimum of one pair of RB must be used. This means that a data transmission takes at least 1 millisecond on the radio channel. The frame structure differs between the Time Division Duplex (TDD) and the Frequency Division Duplex (FDD) modes [9].

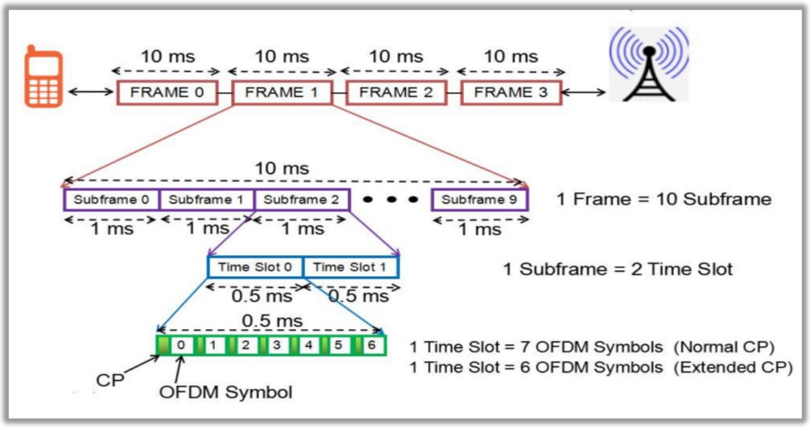

Figure 1.8: Depiction of LTE frame structure [10].

- **Cycle Prefix (CP)**

During a transmission, an interference between symbols can happen.This interference is caused by multipath propagation occurs when a transmitted signal is reflected by objects in the environment and arrives at the receiver via multiple paths with different delays, resulting in time dispersion of the signal. To avoid this phenomena, cyclic prefix (CP) is introduced. It is a guard time added to an OFDM . It consists of copying the end of a transmitted symbol to its beginning , creating a cyclic extension of the symbol that will be transmitted along with this symbol. At the receiver, the CP is removed from the beginning of the received symbol and discarded, and the remaining symbol is processed. The length of the cyclic prefix is chosen to be longer than the maximum expected delay spread of the channel, which is the time difference between the arrival of the first and last signal paths.This ensures that the guard interval is sufficient to eliminate symbols interference and maintain signal quality [11].

The frame structures for LTE differ between the TDD and the FDD modes as there are different requirements on segregating the transmitted data.

1.8.1 FDD Frame Structure

LTE FDD is a system that allows for simultaneous downlink and uplink transmissions to occur at different frequencies, making it a full-duplex system.

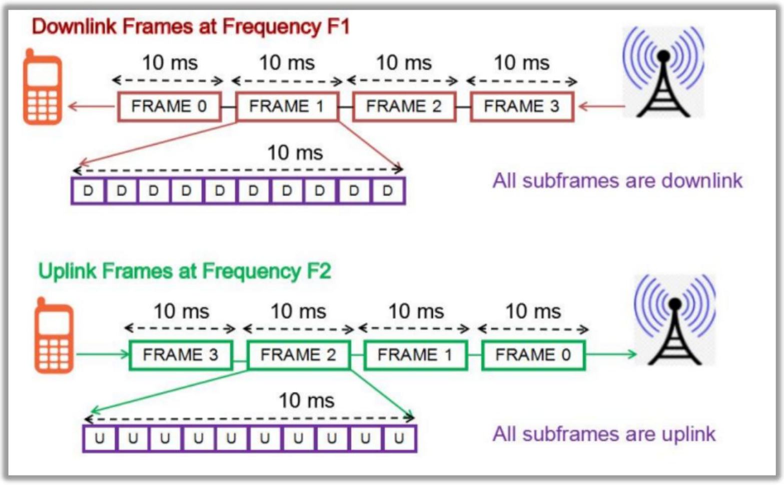

Figure 1.9: Representation of FDD frame structure [10].

1.8.2 TDD Frame Structure

When operating in TDD mode, uplink and downlink transmissions share the same frequency band, but they are separated by time slots within a single radio frame.The 10 ms LTE TDD frame consists of two half-frames, each of length 5 ms and each consisting of five subframes. Each subframe has a duration of 1 ms and is further divided into two equally sized time slots, with each slot being 0.5 ms.

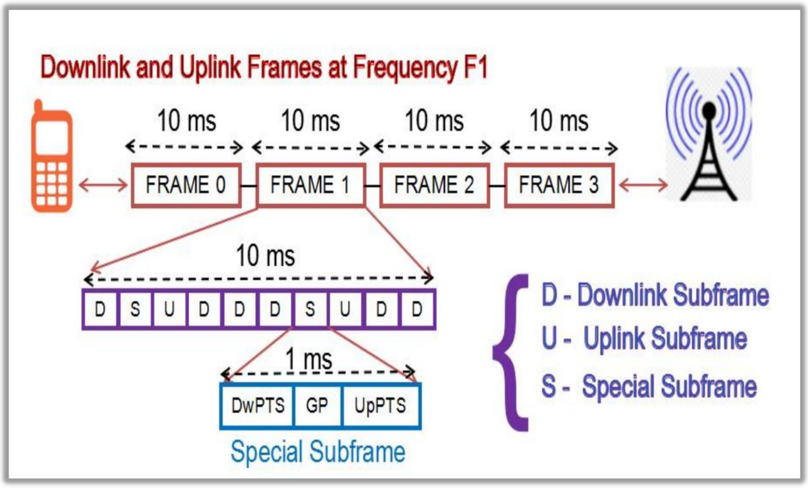

Figure 1.10: Representation of TDD frame structure [10].

The special subframe is a particular time division that is used to handle the switch between downlink and uplink transmission. It is divided into three parts:

a. Downlink Pilot Time Slot (DwPTS)

It provides downlink synchronization, and it carries reference signals, control information, and data for those cases when sufficient duration is configured [10].

b. Guard Period (GP)

It is used to control switching between uplink and downlink transmissions [10].

c. Uplink Pilot Time Slot (UpPTS)

It is a designated time slot within the special subframe that is used for uplink transmission and includes the transmission of pilot signals.These pilot signals transmitted during the UpPTS are used for channel estimation at the receiver [10].

1.9 Duplex mode

When two devices are capable of transmitting and receiving data simultaneously over a communication channel, then we can say that we are in the duplex mode. There are two forms of duplex that are commonly used in cellular communication:

- Frequency Division Duplex (FDD): Frequency Division Duplex.
- Time Division Duplex (TDD): Time Division Duplex.

1.9.1 FDD

FDD needs two separate frequency bands or channels. A sufficient guard band needs to separate the transmitting and receiving channels, so they do not interfere with one another and guarantee clear and uninterrupted transmission. A large guard band does not impact capacity. The frequency allocation for the UL /DL capacity is predetermined based on the system needs so that it is the same in either direction [12]. It is not possible to dynamically change capacity. Continuous transmission and high performance are guaranteed with FDD.

Figure 1.11: Demonstration of transmission principle of FDD [12].

1.9.1 TDD

TDD systems use a single frequency band for both transmit and receive. A system shares the same band and assigns alternative time slots for transmit and receive operations. Any data that is transmitted could be 1 byte long or a frame of multiple bytes. Time slots could be dynamically allocated and variable in length based on network needs. A guard period is needed to ensure that UL and DL transmissions do not collide. Swapping capacities in UL/DL degrades the performance of the network [12].

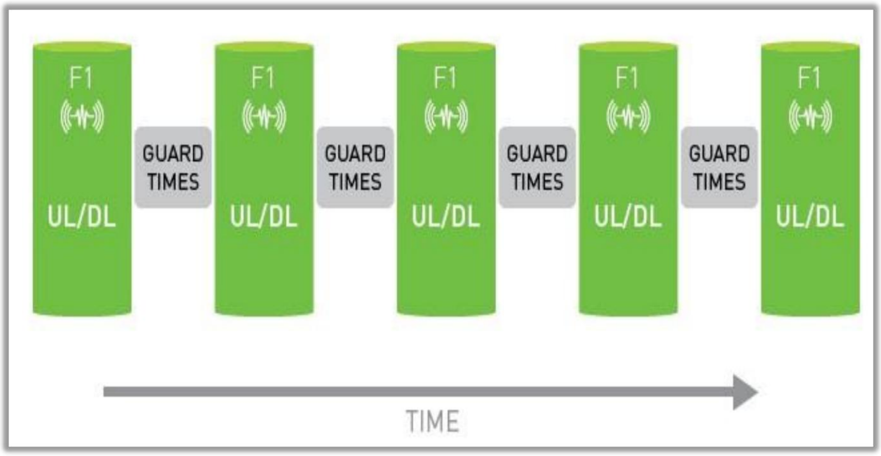

Figure 1.12: Demonstration of transmission principle of TDD [12].

1.10 Radio channels in LTE

LTE channels can be categorized into three main types: logical channels, transport channels, and physical channels. Logical channels define the type of information being conveyed, transport channels dictate how this information is transported, and physical channels determine the destination where this information is sent.

1.10.1 Logical channels

LTE uses logical channels that can be classified into two types based on the information they carry. The first type is logical traffic channels, which carry user data, and the second type is logical control channels, which carry signalling messages. The logical channels used by LTE are listed in the following table:

Table 1.1: Classification of logical channels in LTE [13].

Channel Name	Acronym	Control channel	Traffic channel
Broadcast Control Channel	BCCH	X	
Paging Control Channel	PCCH	X	
Common Control Channel	CCCH	X	
Dedicated Control Channel	DCCH	X	
Multicast Control Channel	MCCH	X	
Dedicated Traffic Channel	DTCH		X
Multicast Traffic Channel	MTCH		X

1.10.2 Transport channels

LTE transport channels differ between the uplink and downlink, as they have distinct requirements and operate differently. The transport channels of the physical layer provide a means of information transfer to higher layers such as the medium access control (MAC) layer. The channels are classified as :

Table 1.2: Classification of transport channels in LTE [13].

Channel Name	Acronym	Downlink	Uplink
Broadcast Channel	BCH	X	
Downlink Shared Channel	DL-SCH	X	
Paging Channel	PCH	X	
Multicast Channel	MCH	X	
Uplink Shared Channel	UL-SCH		X
Random Access Channel	RACH		X

1.10.3 Physical channels

Physical channels in LTE are divided into downlink and uplink directions, and each direction consists of physical data channels and physical control channels. Physical data channels carry user data between the eNodeB and the UE, while physical control channels carry control information between the eNodeB and the UE for the purpose of managing the radio resource allocation and controlling the communication protocol.

a. Physical data channels

Physical data channels in LTE are distinguished by the methods by which they are processed by the physical channel processor, as well as by the ways in which they are mapped onto the sub-carriers and symbols used by OFDM modulation. This helps to ensure efficient and reliable data transmission in LTE networks. LTE utilizes physical data channels that are listed in a table:

Table 1.3: Classification of Physical data channels in LTE [13].

Channel Name	Acronym	Downlink	Uplink
Physical downlink shared channel	PDSCH	X	
Physical broadcast channel	PBCH	X	
Physical multicast channel	PMCH	X	
Physical uplink shared channel	PUSCH		X
Physical random access channel	PRACH		X

b. Physical control channels

The transport channel processor generates control information to facilitate the physical layer's low-level functions and transmits this data to the physical channel processor via physical control channels, This Channels are listed in the below table:

Table 1.4: Classification of Physical control channels in LTE [13].

Channel Name	Acronym	Downlink	Uplink
Physical control format indicator channel	PCFICH	X	
Physical hybrid ARQ indicator channel	PHICH	X	
Physical downlink control channel	PDCCH	X	
Relay physical downlink control channel	R-PDCCH	X	
Physical uplink control channel	PUCCH		X

1.11 Modulation

In LTE, modulation refers to the process of converting digital information into an analog radio wave that can be transmitted wirelessly. The modulation scheme used in LTE is based on Orthogonal Frequency Division Multiplexing (OFDM), which is a digital modulation technique that divides a high-speed data stream into multiple lower-speed sub-carriers. LTE networks utilize digital modulation techniques such as Quadrature Amplitude Modulation (QAM) and Quadrature Phase Shift Keying (QPSK) to transmit data.

1.11.1 Quadrature Phase Shift Keying (QPSK)

A digital modulation scheme used to transmit data over radio waves or other communication channels. QPSK is a type of phase shift keying (PSK) that uses four different phases to encode data bits. Each of the four possible phase states represents four phases are used to distinguish waveforms. The values π/4, π3/4, π5/4, and π7/4 are used to represent binary bits 00, 01, 11, and 10 [14].

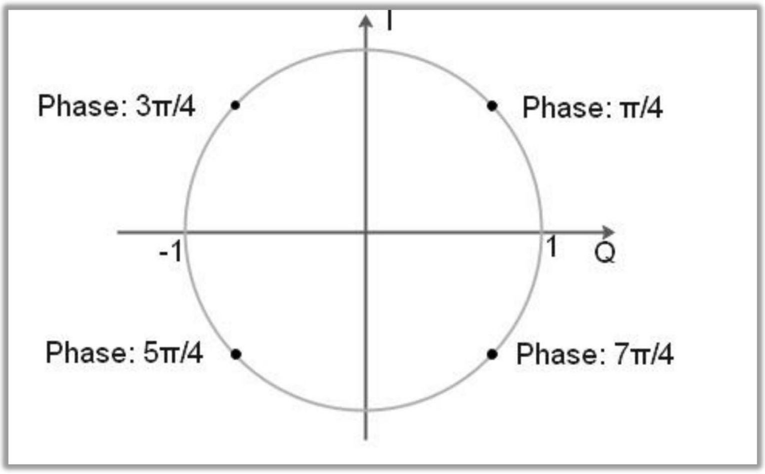

Figure 1.13: QPSK modulation scheme [14]

1.11.2 Quadrature Amplitude Modulation (QAM)

A digital modulation technique used for transmitting data over radio waves or other communication channels. QAM is a combination of both amplitude modulation (AM) and phase shift keying (PSK) techniques.In QAM, the amplitude and phase of the carrier signal are both modulated to encode digital information. The amplitude and phase modulations are performed using two separate signal channels, which are typically 90 degrees out of phase with each. The number of amplitude and phase levels used in QAM determines the number of bits that can be transmitted per symbol. For example, 16-QAM uses 16 different combinations of amplitude and phase levels to transmit 4 bits per symbol, while 64-QAM uses 64 different combinations to transmit 6 bits per symbol [14].

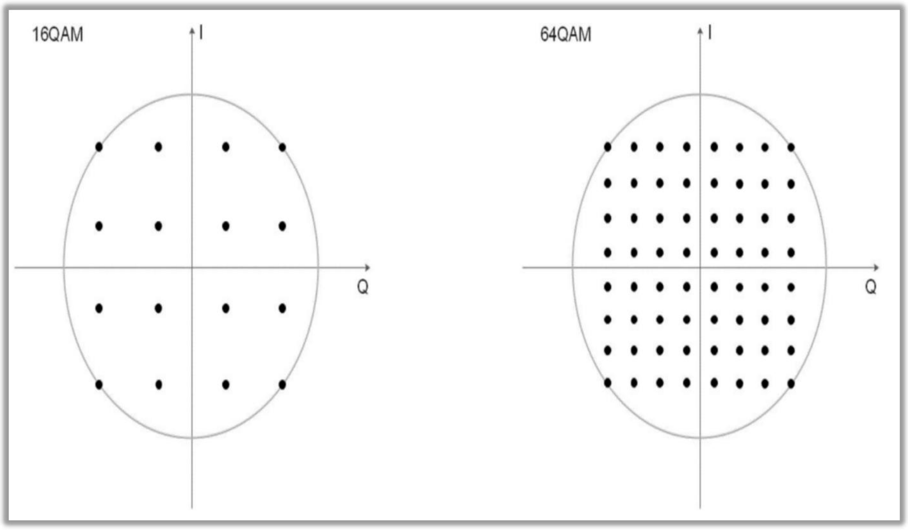

Figure 1.14 16QAM and 64QAM modulation scheme [14].

If we consider the available modulations are QPSK and 16-QAM, in the case where the channel is marked as good, we will use 16-QAM modulation, which offers higher data rate but lower robustness. On the other hand, if the channel is marked as degraded, we will use QPSK modulation, which allows for a lower data rate but is more robust.

1.12 Conclusion

A good understanding of network architectures allows operators to manage resources effectively, facilitate network evolution by integrating more advanced technologies, which enable them to provide a full range of services with good QoS. This chapter covered the main points related to establish an LTE network. In the next chapter; we will introduce MIMO and massive MIMO techniques, which are concepts that have been used to improve the quality and speed of data transmission.

Chapter 2

MIMO and Massive MIMO techniques

2.1 Introduction

In recent times, there has been a significant increase in the number of wireless device users, resulting in the creation of densely populated areas. To enhance the user experience in such environments, it has become necessary to develop new techniques that can improve coverage, throughput, and ensure a high quality of service for each individual user. In this chapter, we will discuss the concept of Multiple-Input Multiple-Output (MIMO) techniques and explore the key parameters that need to be adjusted in order to achieve the desired outcomes.

2.2 MIMO Technology

Multiple Input Multiple Output (MIMO) is a technology used in wireless communication systems to improve the performance of the system by utilizing multiple antennas at both the transmitter and receiver sides of the communication link. Traditionally, wireless communication systems used a single antenna at both the transmitter and receiver sides, and the data was transmitted over a single radio frequency channel. However, with the increasing demand for higher data rates, better quality of service (QoS), and improved system reliability, multiple antennas have been employed to enhance the wireless communication system's performance.

MIMO technology works by using multiple antenna arrays to transmit and receive multiple data streams simultaneously. By doing so, it can increase the system capacity, improve the data throughput, and enhance the system's reliability by reducing the error rate and mitigating the impact of fading [15].

2.3 MIMO Classification

MIMO technology can be categorized according to several criteria. In this section, we will explore three key classification methods: antenna configuration, number of client devices, and the method of data transmission across the channel.

2.3.1 Antenna configuration

The transition from Single-Input Single-Output (SISO) to Multiple-Input Multiple-Output (MIMO) technology has marked a significant advancement in the field of wireless communication. Below, we will outline the key developments associated with this evolution.

a. Single-Input Single-Output (SISO)

In a SISO system, there is only one transmission path between the transmitter (Tx) and receiver (Rx), and only one signal can be transmitted at a time over one spatial stream. However, this type of transmission can be unreliable and limited in terms of data rate due to the lack of multiple antennas to transmit and receive signals.

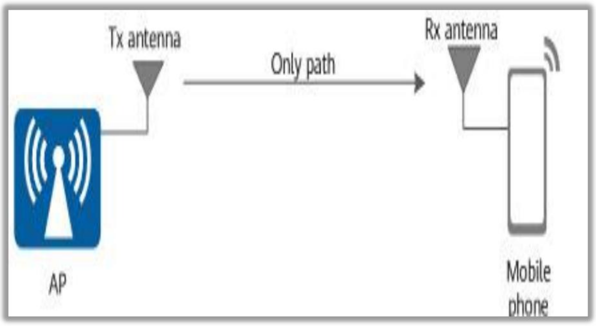

Figure 2.1: SISO configuration [16].

b. Single-Input Multiple-Output (SIMO)

To enhance reliability, SIMO is implemented, which involves adding an antenna to the receiver, allowing for the reception of two signals simultaneously. As depicted in the accompanying figure, two signals carrying identical data are transmitted from a single transmitter antenna. If one signal experiences partial loss during transmission, the receiver can still retrieve complete data from the other signal. This approach, also referred to as receive diversity, doubles the reliability of the system, even though the capacity (i.e., the number of paths in use) remains the same.

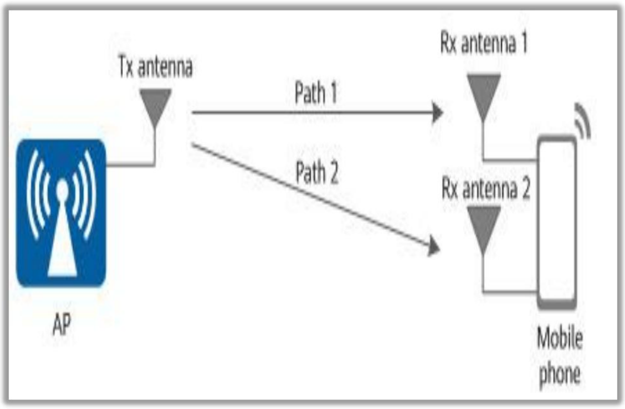

Figure 2.2: SIMO Implementation [16].

c. Multiple-Input Single-Output (MISO)

When there is only one Rx antenna, the signals transmitted from the two Tx antennas have to contain identical information and then merged into a single signal when received. This operation is known as multiple-input single-output (MISO) or transmit diversity, and it provides a similar outcome as SIMO.

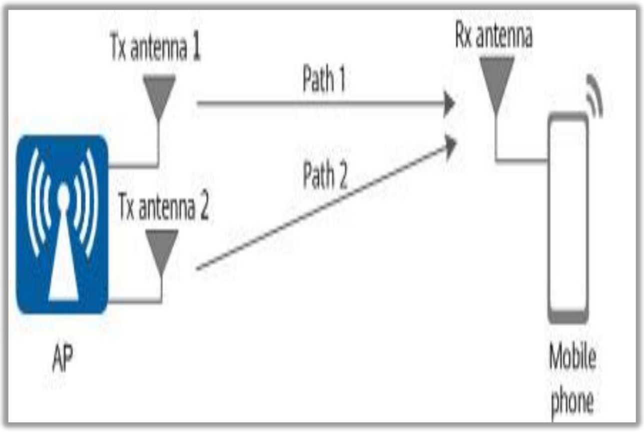

Figure 2.3: MISO configuration [16]

d. Multiple-Input Multiple-Output (MIMO)

The analysis conducted on SIMO and MISO demonstrates that the transmission capacity is reliant on the number of transmitting (Tx) and receiving (Rx) antennas. Consequently, utilizing two antennas on both the transmitter and receiver can double the rates by transmitting and receiving two signals independently. This method of utilizing multiple antennas on both the transmitter and receiver is referred to as MIMO. MIMO technology allows for the transmission and reception of multiple spatial streams (signals) simultaneously through the use of multiple antennas, while also distinguishing signals sent to or received from distinct spatial positions. By utilizing technologies like spatial multiplexing and space diversity, MIMO enhances system capacity, coverage range, and signal to noise ratio (SNR) without consuming extra bandwidth.

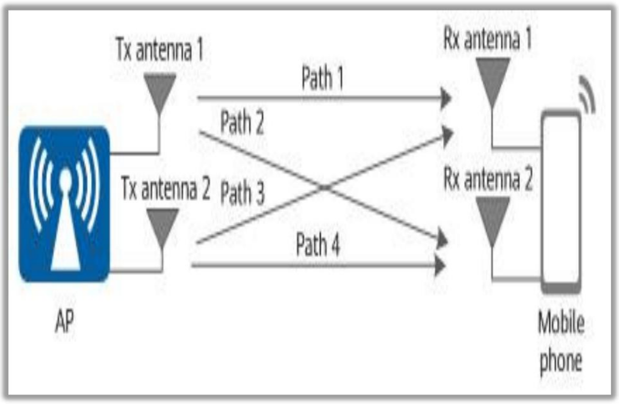

Figure 2.4: MIMO configuration [16].

2.3.2 Number of client devises

In a general sense, MIMO systems can be classified into two primary categories: Single-User MIMO (SU-MIMO) and Multi-User MIMO (MU-MIMO).

a. SU-MIMO

Single-User MIMO, also known as Single-Stream MIMO, involves communication between a single transmitter and a single receiver. In SU-MIMO, the system uses multiple antennas at both the transmitter and receiver sides to improve the performance of the communication link. It achieves this by exploiting the spatial dimension of the channel to increase data throughput, enhance reliability, and improve the quality of the received signal. SU-MIMO is typically employed in scenarios where a single user device is communicating with a base station or access point [17].

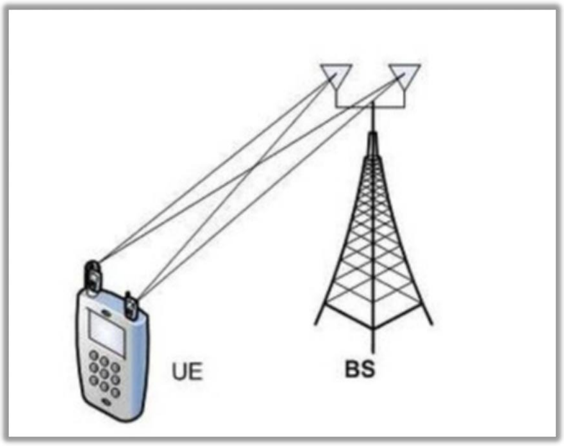

Figure 2.5: SU-MIMO configuration [18].

b. MU-MIMO

Multi-User MIMO, as the name suggests, involves communication between a single transmitter with multiple antennas and multiple receivers or user devices simultaneously. MU-MIMO allows for the simultaneous transmission of multiple data streams to different users using spatial multiplexing. This technique improves the spectral efficiency and capacity of the system by serving multiple users in the same frequency band and time slot. MU-MIMO is particularly useful in scenarios where there are multiple users or devices in close proximity, such as crowded environments or areas with high user density[19].

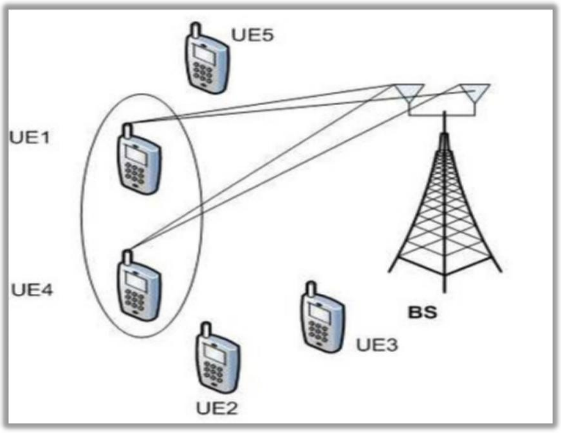

Figure 2.6: MU-MIMO configuration [18].

2.3.3 Methods of data transmission across the channel

MIMO systems employ multiple antennas at the transmitter and receiver ends to exploit spatial dimensions for increased capacity and reliability. Techniques like space diversity and spatial multiplexing optimize data transmission in these systems.In the following, we will describe these two techniques.

a. Space diversity

It is a method that employs multiple antennas at the receiver to counteract fading and enhance signal quality. By receiving identical data via various spatial paths, space diversity combats signal attenuation, multipath fading, and interference. A spatial equalizer is employed at the receiver to separate signals, enabling demodulation and decoding. By combining signals from the same data stream, the original signals can be restored [20].

b. Spatial multiplexing

Spatial multiplexing is a technique that enhances transmission rates by splitting data into multiple streams. These streams are encoded, modulated, and transmitted through separate antennas. Each antenna operates independently, creating distinct transmission channels. The

independent data streams are transmitted within the same frequency band and time slot. To receive these signals, a spatial equalizer at the receiver separates, demodulates, and decodes the signals. The data streams are then combined to restore the original signals [21].
The following figure will illustrate space diversity and spatial multiplexing methods.

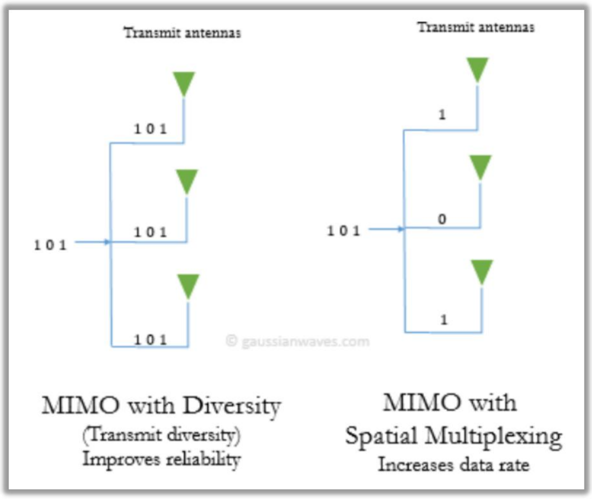

Figure 2.7: Diversity and spatial multiplexing configuration [22].

To summarize, space diversity enhances the reliability of data transmission and is suitable for long distance transmission scenarios that do not require high rates. On the other hand, spatial multiplexing is a technique that increases data transmission rates and is ideal for short-distance transmission scenarios with high rate requirements.

2.4 Massive MIMO technique

Massive MIMO was implemented as a response to the growing demand for accelerated data rates, augmented network capacity, and improved spectral efficiency. It consists of utilizing a large number of antenna array at both the transmitter and receiver, and the exact number can count in the range 32 to 256 antennas or even higher. This enables the system to transmit and receive multiple independent data streams simultaneously, thereby increasing the capacity and spectral efficiency [23].

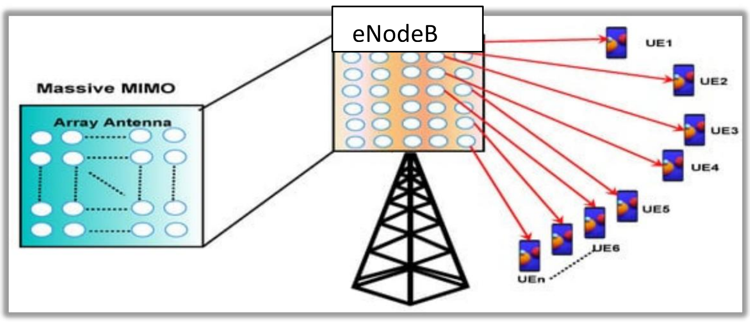

Figure 2.8: Pictorial representation of Massive MIMO [24].

2.4.1 Antenna arrangement in massive MIMO system

The configuration of antennas in Massive MIMO systems can differ based on the implementation and network requirements. However, a typical approach involves utilizing a dense array of antennas with a high number of elements, ranging from several hundred to thousands. These antennas are commonly organized in a rectangular or circular grid, positioned in close proximity to each other [25]. This dense arrangement allows for efficient beamforming and interference mitigation. The spacing between antennas is usually less than half a wavelength to minimize interference and enhance beamforming accuracy. Additionally, the antenna arrangement can be optimized considering the propagation characteristics and the desired coverage area.

The following figure will illustrate an example of a circular grid arrangement of the antennas in a base station.

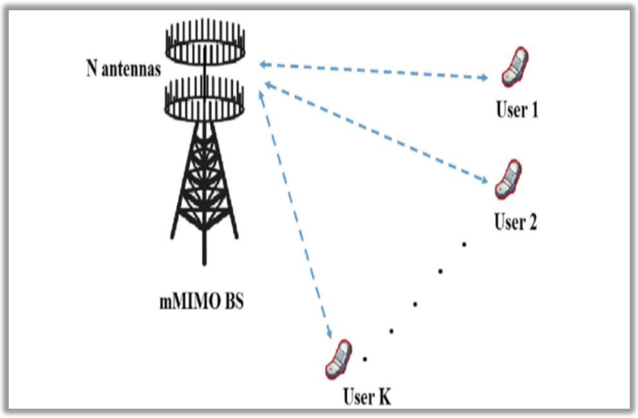

Figure 2.9: Circular arrangement of massive MIMO antennas [26].

Massive MIMO proposes two major criterias:

2.4.2 Beamforming

Beamforming is a technique used to direct the transmission and reception of signals in a particular direction. It is achieved by adjusting the phase and amplitude of the signals transmitted or received by multiple antennas, so that they constructively interfere in a particular direction, while destructively interfering in other directions. By directing the transmission and reception of signals in a particular direction. Beamforming can increase the signal strength, reduce interference, and improve the signal-to-noise ratio, which results in higher data rates and better spectral efficiency [27].

Beamforming is particularly useful in crowded environments with multiple users, where it can improve the coverage and capacity of wireless networks.

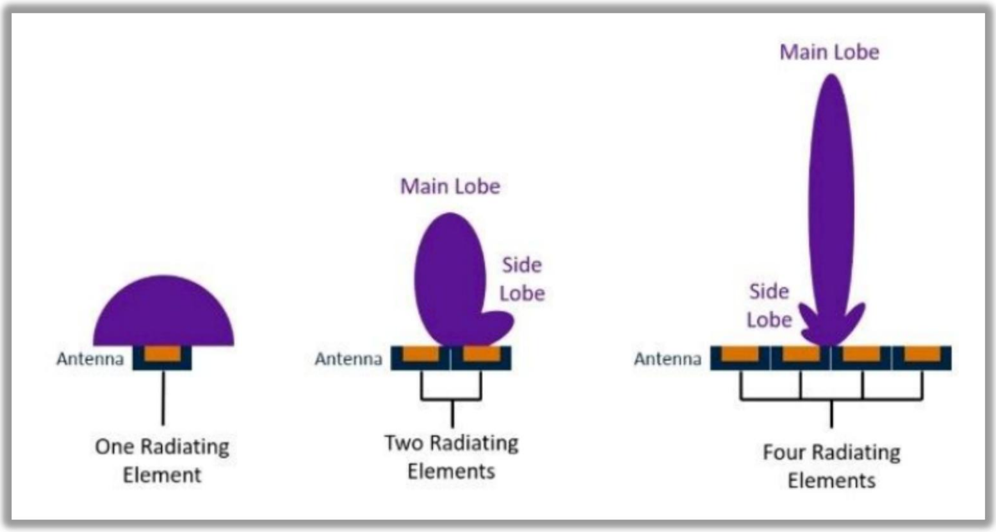

Figure 2.10: Effect of the number of radiating elements on the main lobe [28].

As shown in Figure 2.10, when the number of radiating elements in an antenna array increases, the main lobe of the radiation pattern tends to become narrower and more directional.

Figure 2.11 illustrates how the radio signals from an array of antennas are directed towards specific user devices, rather than broadcasting the signal in all directions.

This ensures more reliable and faster connection, while also minimizing interference with other devices and reducing power consumption.

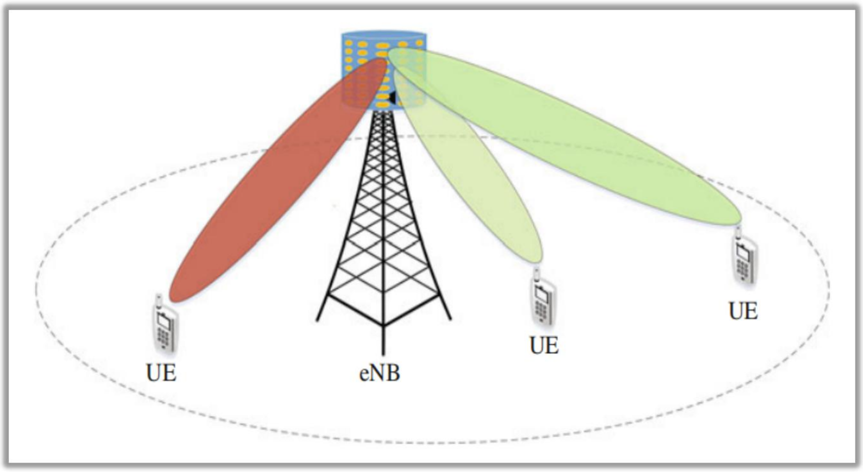

Figure 2.11: Demonstration of beamforming directions [29].

2.4.3 MU-MIMO

MU-MIMO enables multiple users to simultaneously transmit and receive data over the same frequency channel using multiple antennas at eNodeB.

In traditional MIMO systems, the multiple antennas are used to improve the performance of a single user's transmission by creating multiple independent data streams. In MU-MIMO, the multiple antennas are used to serve multiple users simultaneously by dividing the available spatial resources among them. MU-MIMO works by using beamforming techniques to create individual transmission beams for each user, which are directed towards their respective devices [30]. The eNodeB uses channel state information and advanced scheduling algorithms to allocate resources to each user and optimize the overall system performance.MU-MIMO reduces the latency and improves the user experience.

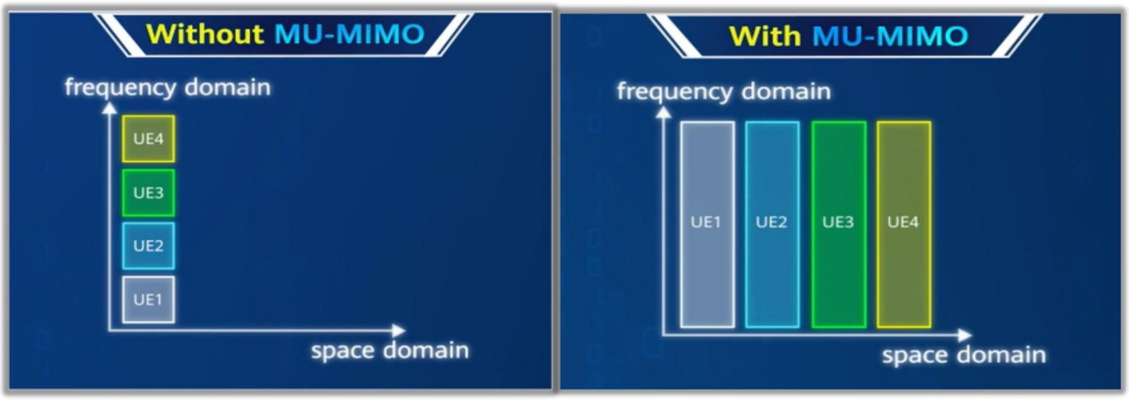

Figure 2.12: Utilizing the frequency resources with and without using MU-MIMO

2.4.4 TDD and FDD mode usage in massive MIMO

Massive MIMO can be implemented in both TDD and FDD modes.The choice depends on several factors, including the network requirements, spectrum availability, and specific deployment scenarios.

- TDD offers the advantage of flexibility in dynamically allocating time slots for uplink (UL) and downlink (DL) transmissions based on the traffic demand. This flexibility allows for efficient utilization of the spectrum and adaptation to varying traffic conditions. TDD is particularly suitable for asymmetric traffic patterns, where the UL and DL traffic volumes differ significantly. Massive MIMO in TDD mode can dynamically adjust the UL/DL ratio to optimize the system capacity and overall performance [31].
- FDD provides dedicated frequency bands for UL and DL transmissions, ensuring simultaneous UL and DL communication. It offers a constant UL/DL resource allocation, which can be advantageous in scenarios with balanced traffic demands and when regulatory requirements or spectrum availability favors FDD. FDD may be preferred in cases where separate spectrum bands for UL and DL are allocated and when the traffic patterns are relatively symmetrical [31].

Overall, TDD mode is better in performance due to using the same frequency for downlink and uplink, and it requires less channel estimation time, hence has more time for data transmission, therefore, increasing system spectral efficiency. However, FDD mode can also be used in Massive MIMO systems, especially in systems where the uplink and downlink traffic is not balanced.

2.4.5 Capacity of massive MIMO system

The capacity of a channel is defined as the maximum amount of information or data that can be reliably transmitted through the channel over a given period of time. This data is transmitted in the form of symbols; and to know the average information per symbol generated by the source, we introduce the concept of entropy.

a. Entropy

We consider a message generated by the source where the symbols are taken from the alphabet $X=\{x_1,x_2,...,x_M\}$ having probabilities denoted by a probability mass function $p(x)=\{p_1,p_2,...,p_M\}$. The information provided by the message is the sum of the amount of information of the individual symbols. The entropy denoted H(X) is defined as the average information per symbol generated by the source [32], and it it is expressed as follow:

$$H(X)= \sum_{k=1}^{M} P_k \log_2(1/P_k) \qquad \textbf{(2.1.a)}$$

$$H(X)= - \sum_{k=1}^{M} P_k \log_2(P_k) \qquad \textbf{(2.1.b)}$$

M: The number of symbols

$\log_2(x) = \log(x) / \log(2)$

The entropy is measured in bits/symbol.

We have : $0 < H(X) < \log_2(M)$

Entropy hits the lower bound of zero when there is no information transmitted. It reaches the upper bound when the input symbols are equiprobable. Equiprobable symbols from a binary source produce 1 bit of information at every occurrence of a symbol [32].

b. Capacity of massive MIMO

The capacity of a massive MIMO system depends on several factors, including the number of antennas at the base station, the number of users being served, the channel conditions, and the interference level.

The channel capacity of a massive MIMO system can be approximated by using the following formula:

$$\text{Capacity} = \min(N, K) * \log_2(1 + \frac{S}{N}) \qquad \textbf{(2.2)}$$

Such that:

N: The number of antennas at the eNodeB.

K: The number of users being served simultaneously.

S: The average received signal power (dB).

N: The average power of the noise or interference.

$\frac{S}{N}$: The signal to noise ratio (dB).

Capacity is expressed in Bits per seconds (bps) or its multiples.

We will illustrate the capacity for different MIMO systems in the following graphs.

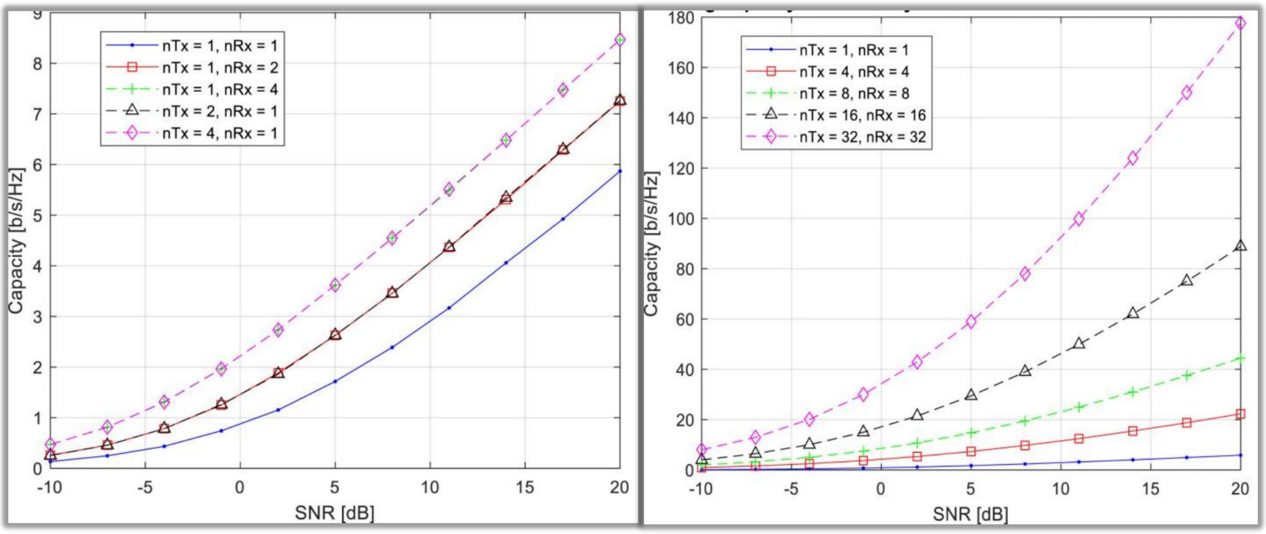

Figure 2.13: Average capacity of SISO,SIMO,MISO and MIMO systems [33].

It can be seen that SISO system has the lowest average capacity. This is because it utilizes only a single antenna at both the transmitter and the receiver, and this lead to limited spatial diversity. This lack of spatial diversity limits the system's ability to combat fading, interference, and noise, resulting in lower capacity.

On the other hand, while we increment the number of antennas at the receiving end (SIMO), the capacity increases. This is because the receiving ends can capture multiple copies of the transmitted signal, each experiencing a different fading and interference environment. This spatial diversity enables the system to mitigate the effects of fading and enhance the overall communication quality.

In MISO system, we notice that the capacity increases because each transmit antenna can be used to transmit a separate data stream, taking advantage of the available spatial dimension. This transmission is done simultaneously.

To show more how the number of antennas in both ends affect the capacity of the system, we present the following figure which shows the capacity of Shannon, MIMO and massive MIMO systems.

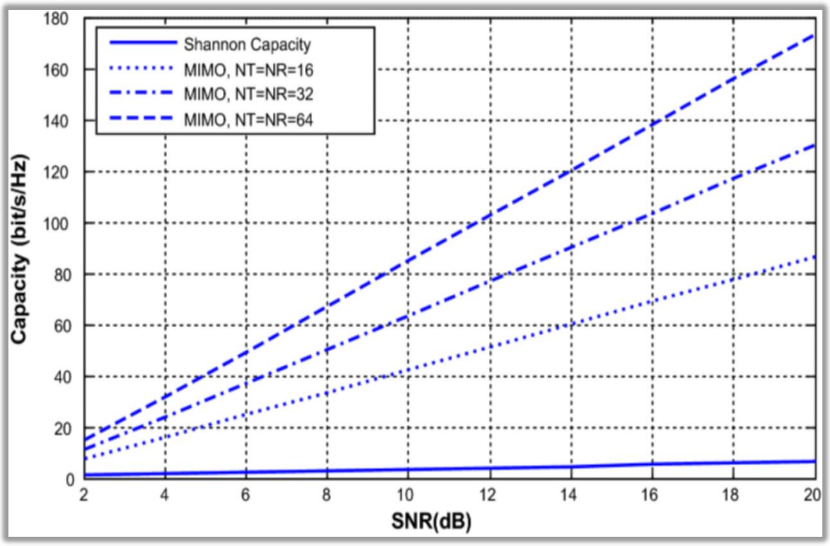

Figure 2.14: The capacity of MIMO and massive MIMO systems

Before going to the comparisons, let's begin by introducing the concept of Shannon capacity.

Shannon capacity

It represents the maximum data rate at which information can be reliably transmitted over a communication channel without errors. It is determined by several factors, including the bandwidth of the channel and the level of noise or interference present in the channel. Shannon's theorem provides a mathematical formula to calculate the theoretical maximum capacity of a channel, and it is given by:

$$C = B * \log_2(1 + \frac{S}{N}) \quad \text{(bits/s)} \tag{2.3}$$

Where:

B: The bandwidth of the channel in hertz.

S: The average received signal power.

N: The average power of the noise or interference.

The Shannon capacity has the lowest values because it is derived based on the assumption of a SISO system, where there is only one transmitter and one receiver; and this lead to limited spatial diversity. This lack of spatial diversity limits the system's ability to combat fading, interference, and noise, resulting in lower capacity.

MIMO systems, including massive MIMO, optimize data throughput and achieve high capacity by utilizing the spatial dimension for increased data throughput. They accomplish this by employing multiple antennas at both the transmitter and receiver, enabling simultaneous transmission of multiple data streams through spatial multiplexing. This technique significantly enhances capacity compared to SISO systems. Massive MIMO takes this concept further by utilizing a large number of antennas at both ends, resulting in even greater capacity gains.

2.6 Comparaison between MIMO and massive MIMO systems

The following table will present Comparaison between MIMO and massive MIMO systems based on several factors.

Table 2.1: Comparaison between MIMO and massive MIMO systems.

Aspect	MIMO	Massive MIMO
Deployment	Suitable for small to medium-scale deployments.	Well-suited for dense deployments (urban areas, stadiums, etc.)
Number Of Antennas	It ranges from 2 to 8 antennas at the base station.	The exact number can count in the range 32 to 256 antennas or even higher .
Hardware complexity	Moderate hardware complexity.	Higher hardware complexity due to a larger number of antennas.
Coverage Network	Provides coverage improvement in small to medium-sized cells.	Offers coverage improvement, particularly at cell edges and in dense environments.Horizontal coverage from 1 to 2 dB, and the vertical coverage can reach 3dB.
Spatial Multiplexing	Supports spatial multiplexing with a moderate number of spatial streams	Enables significant spatial multiplexing with simultaneous transmission to multiple users
Spectrum Efficiency	Moderate spectrum efficiency gains.	Offers significant spectrum efficiency gains by serving multiple users simultaneously.
Throughput	It ranges from several megabits per second (Mbps)	It range from several hundred megabits per second (Mbps) to

	to several gigabits per second (Gbps), it depends on various factors.	multiple gigabits per second (Gbps).
Frequency Reuse	Limited frequency reuse capabilities.	Allows for more efficient frequency reuse due to spatial nulling and beamforming.
Energy Efficiency	Offers moderate energy efficiency improvements.	Provides enhanced energy efficiency due to advanced signal processing techniques.
Interferance reduction	Basic interference reduction techniques.	It effectively reduce interference between users by using advanced signal processing algorithms.
Interference Mitigation	Basic interference mitigation techniques.	Advanced interference suppression and nulling capabilities.
Cost	Affordable cost	Requires a large number of antennas and advanced signal processing algorithms, which can make it more expensive.

2.7 Key Performance Indicators analysis in LTE network

Key Performance Indicators (KPIs) play a crucial role in monitoring and optimizing the performance of LTE networks. With the rapid expansion of mobile data traffic and the growing demand for seamless connectivity, network operators rely on KPIs to evaluate the efficiency, reliability, and quality of their LTE networks. These indicators provide quantitative measurements and metrics that enable operators to assess various aspects of network performance, such as coverage, capacity, throughput, mobility, and call/session management. A set of KPIs that we find in a LTE network are illustrated in Figure 2.15. In the following we will present the most relevant KPIs that have been used to monitor our data.

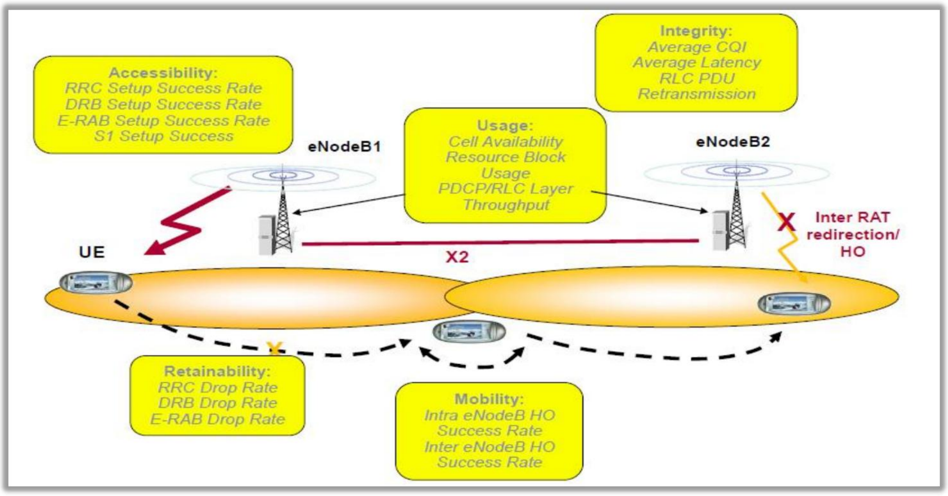

Figure 2.15: A depiction of Key Performance Indicators within a network [34].

2.7.1 Accessibility KPI

Accessibility KPI refers to metrics used to evaluate the level of accessibility and availability of network services to users. These KPIs focus on measuring the network's ability to provide reliable and uninterrupted connectivity to subscribers. Accessibility involves the following KPIs:

a. Radio Resource Control (RRC) Connection Setup Success Rate

To establish a connection with the network, the UE must first synchronize in the uplink and then initiate an RRC connection which is a signalling protocol responsible for establishing and maintaining the radio link between a UE and the eNodeB in LTE. This involves sending a random access channel (RACH) preamble (Msg1) to the eNodeB , which responds with a random access response (RAR) or (Msg2). The UE then sends a Msg3, also known as the RRC Connection Request, which marks the attempt for the RRC Success Rate KPI [35]. The procedure is illustrated bellow:

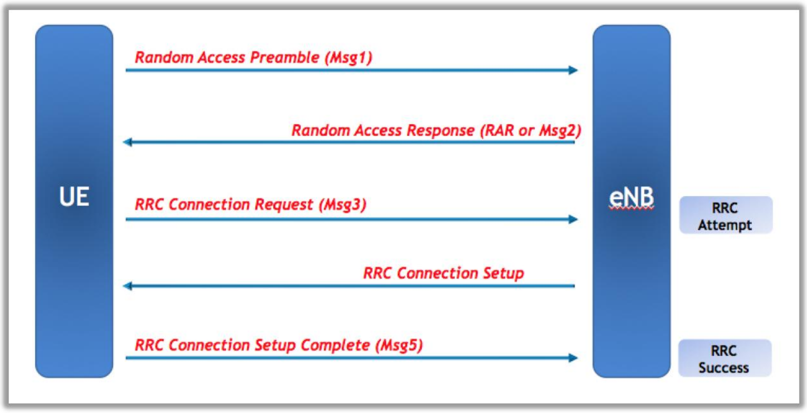

Figure 2.16: RRC establishment procedure [35].

This KPI is calculated using the following formula:

RCC-Con-SSR = (RRC connection setup / RRC connection attempt)*100% **(2.4)**

A high RRC Connection Setup Success Rate is desirable as it ensures that UEs can efficiently connect to the network and access services.

b. Establishment Radio Access Bearer (E-RAB) Success Rate

After the UE has completed the RRC Connection, it needs to get a bearer assigned to it to initiate services. The bear is a logical or virtual communication channel that allows the transmission of data between a UE and the core network.

After the UE sends the RRC Setup Complete message to the eNB, the eNB sends a S1 Initial UE Message to the MME indicating the purpose of the UE and its credentials. Once the MME receives this message and it decides that a bearer is required, it will send an Initial Context Setup Request to the eNB. This message is considered as the ERAB attempt as it contains the bearers to be added [36]. The following figure will show the the necessary actions to be taken to complete the E-RAB procedure.

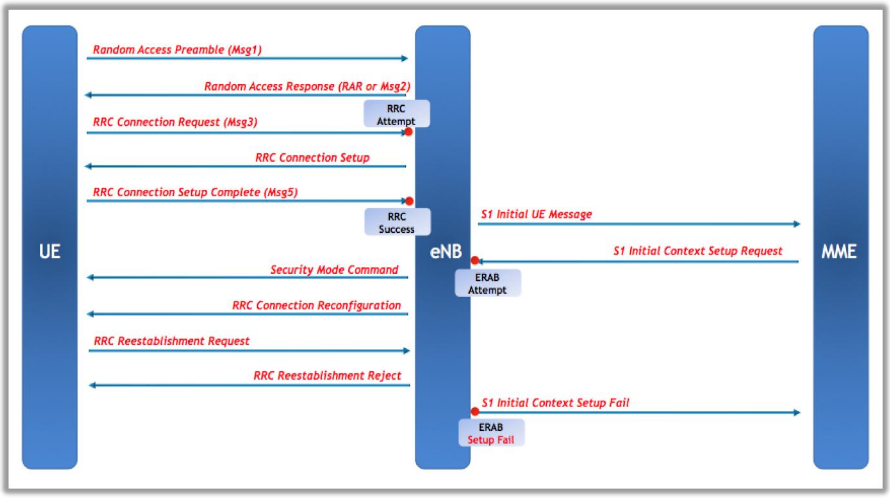

Figure 2.17: E-RAB establishment procedure [36].

RAB reflects the effectiveness of the procedure for establishing and maintaining the radio access bearers between the UE and the network.

This KPI is calculated using the following formula:

E-RAB SR =(E-RAB establishment succes/ E-RABs establishment attempts)*100% **(2.5)**

Operators monitor the E-RAB success rate to assess the quality and reliability of the E-RAB establishment process.

2.7.2 Retainability KPI

This KPI measures the ability of a network to maintain an ongoing connection with users over a specific period. It is a metric that evaluates the network's capability to sustain stable and uninterrupted service for users. Under this KPI we find:

a. Evolved Radio Access Bearer (E-RAB) Drop Rate

In a mobile network, an E-RAB is established between the UE and the EPC to provide end-to-end data connectivity. E-RAB Drop Rate refers to the percentage of E-RABs that are dropped during the session setup or maintenance process,which can result in degraded user experience.

It can be calculated using the following formula:

RB DR= (abnormal RB releases / total RB releases)*100% **(2.6)**

Figure 2.18 shows the different bearers established between the entities including the E-RAB.

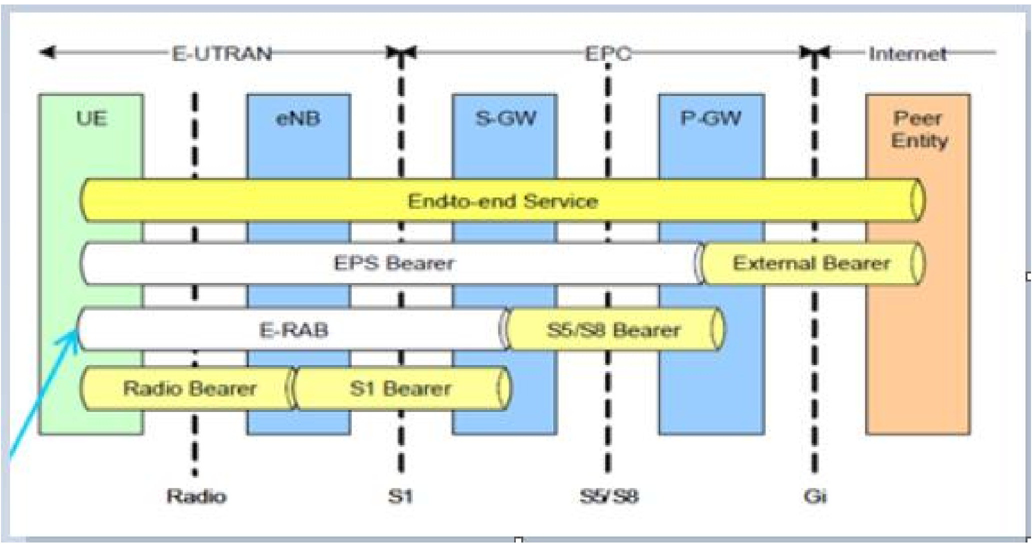

Figure 2.18: Architecture Bearer E-UTRAN / EPC [37].

By reducing the E-RAB drop rate, operators can minimize service interruptions, improve call reliability, and provide a seamless user experience.

2.7.3 Mobility KPI

This KPI utilized to measure the performance of a network in handling user mobility within and between cells while maintaining continuous service without disruptions or degradation. This KPI involves the following:

a. Intra-Frequency Handover Success Rate (HOSR)

In a mobile network, handover is the process by which a mobile device (UE) is transferred from one cell to another while maintaining an active connection to the network. The Intra-frequency HOSR specifically focuses on evaluating the effectiveness and reliability of handovers between different cells on the same frequency [38].

It is measured using the following formula:

Intra HO SR = (successful intra eNB HOs/ intra eNB HO attempts)*100% **(2.7)**

A high HOSR indicates a smooth and efficient handover process, ensuring uninterrupted connectivity and a seamless user experience as users move within the network.

b. Inter-Frequency Handover Success Rate (HOSR)

Inter-Frequency HOSR focuses on assessing the effectiveness and reliability of handovers between cells on different frequencies [38].

It is measured using the following formula:

Inter HO SR = (successful inter eNB HOs/inter eNB HO attempts)*100% **(2.8)**

A high Inter-Frequency HOSR indicates a robust and efficient handover process, ensuring seamless connectivity and a smooth user experience as users move between cells operating on different frequencies.

c. Circuit Switched Fall-back (CSFB) Preparation Success Rate

CSFB is a mechanism used in LTE networks to allow a UE to fall back to a 2G or 3G network for voice calls when LTE coverage is not available or when the UE does not support Voice over LTE (VoLTE). When a UE initiates a voice call, the network must prepare for circuit-switched fall-back by establishing a circuit-switched connection in the 2G or 3G network [38]. It is measured using the following formula:

CSFB =(successful preparations for CSFB/the total number of preparations attempted)*100% **(2.9)**

2.7.4 Integrity KPI

It is a metric used to assess the level of data integrity within a network system. It refers to the assurance that information remains unchanged and uncorrupted during storage, transmission, and processing stages. To know the state of the channel and the latency of data delivery measured by the UE in the downlink, we rely on Channel Quality Indicator (CQI).

Average CQI

It is a feedback signal sent from the receiver to the transmitter. It provides an estimate of the quality or reliability of the channel between the receiver and transmitter. The CQI reflects the receiver's perception of the channel conditions based on measurements and signal processing. The values of CQI ranges from 0 to 15. It value should be higher than 7, a value around 7 may be acceptable, a value around 8 may be considered good, and a value higher than 9 is considered excellent.

2.7.5 Usage KPI

This KPI provide insights into how effectively and efficiently resources are being utilized and how services are being accessed or consumed by users within a network or system.This KPI involves the following:

a. Average user throughput

It refers to the average amount of data that is delivered to each user connected to a particular cell in a mobile network in the UL or DL direction, over a given time period.
It is measured using the following formula:

Avg user throughput=(data transmitted in UL/DL direction/ active users)*100% **(2.10)**

By monitoring and optimizing the DL average user throughput, mobile network operators can improve the overall user experience, reduce churn, and increase revenue. Additionally, DL average user throughput is also an important factor in the design and planning of the mobile network, as it helps to determine the required network capacity and configuration to support the expected user traffic.

b. Cell Packet Data Convergence Protocol (PDCP) Traffic Average Throughput

It refers to the average amount of data that is transmitted over a particular cell in a mobile network in UL or DL direction, between the PDCP layer and the UE over a given period of time. The PDCP layer is responsible for the compression and encryption of user data, as well as for the segmentation and reassembly of data packets to enable their transfer over the radio interface [38].
Therefore, the UL/DL PDCP traffic throughput is an important indicator of the performance and efficiency of the mobile network.

2.8 Conclusion

A good understanding of MIMO techniques and the keys performance indicators will give operators better vision in terms of gaining valuable insights to enhance network efficiency, make informed decisions, and ensure a superior user experience. In the next chapter will be analysing the available data using iMaster MAE software, this will allow us to see the difference in the network performance before and after applying massive MIMO techniques. This difference will be visualized through analysing the different KPIs.

Chapter 3

Results and discussions

3.1 Introduction

In the preceding chapter, we presented the KPIs which we will focus on in our project in order to see the effect of MIMO and massive MIMO techniques on their performance. To monitor the data provided by HUAWEI company, Mobilis utilizes iMaster MAE software. This chapter focuses on the examination of specific KPIs to observe the notable disparities before and after the implementation of massive MIMO. Additionally, we will discuss the specific site on which our analysis is conducted.

3.2 Presentation of the software

iMaster MAE is a software platform developed by Huawei, it offers network automation and intelligent capabilities. Its primary purpose is to expedite the deployment of RAN and minimize operator operational expenses. Additionally, iMaster MAE is utilized for automating mobile broadband processes and seamlessly combines management, control, analysis, and AI functionalities. This platform serves as a comprehensive solution for network automation, enabling simultaneous control of software and network functions.
iMaster MAE can be categorized into two sections and they will be presented in the following

3.2.1 Software-defined Transport Solution (STS)

STS refers to a software-based approach for managing and controlling network transport infrastructure. It aims to virtualize and centralize the control and management of transport networks, enabling operators to optimize network resources, improve flexibility, and simplify operations.

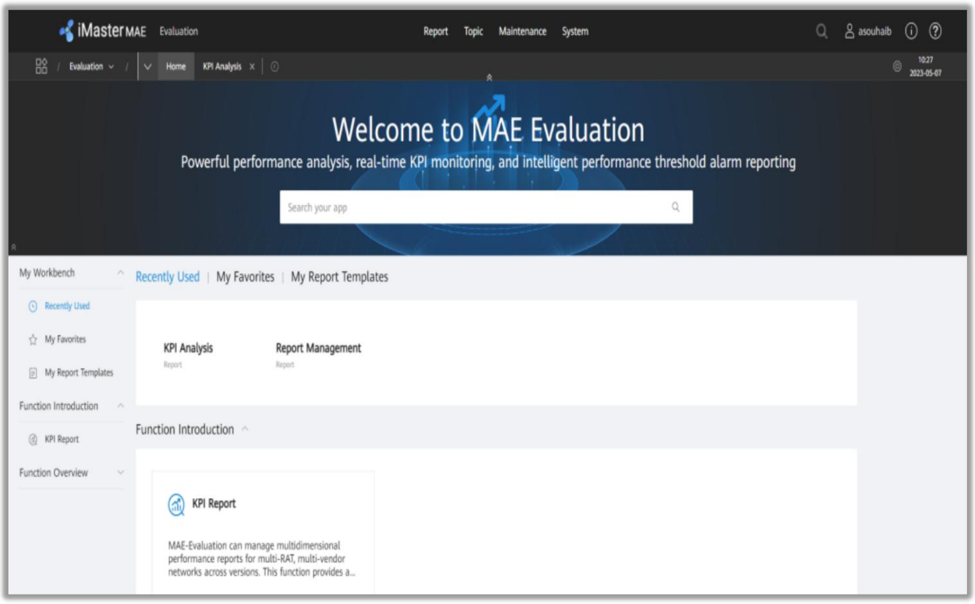

Figure 3.1: STS software interface.

After choosing the KPI analysis option, we will be able to select distinct options. We start first by choosing the appropriate vendor which is in our case Huawei company. Then we go further to select the network element type. This is illustrated in the following figure.

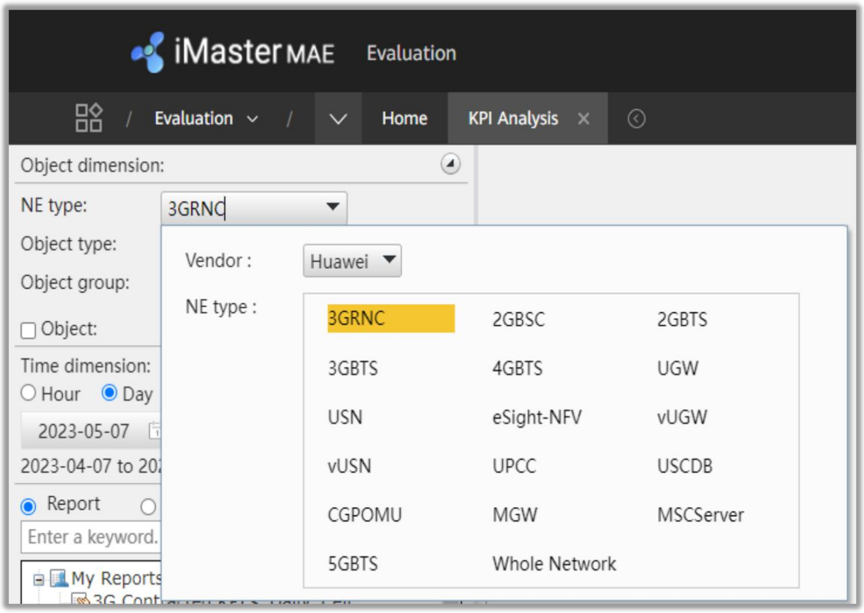

Figure 3.2: Network type selection in STS.

After selecting the network type, we determine the desired object type that we want to study. The available options are listed in the successive figure.

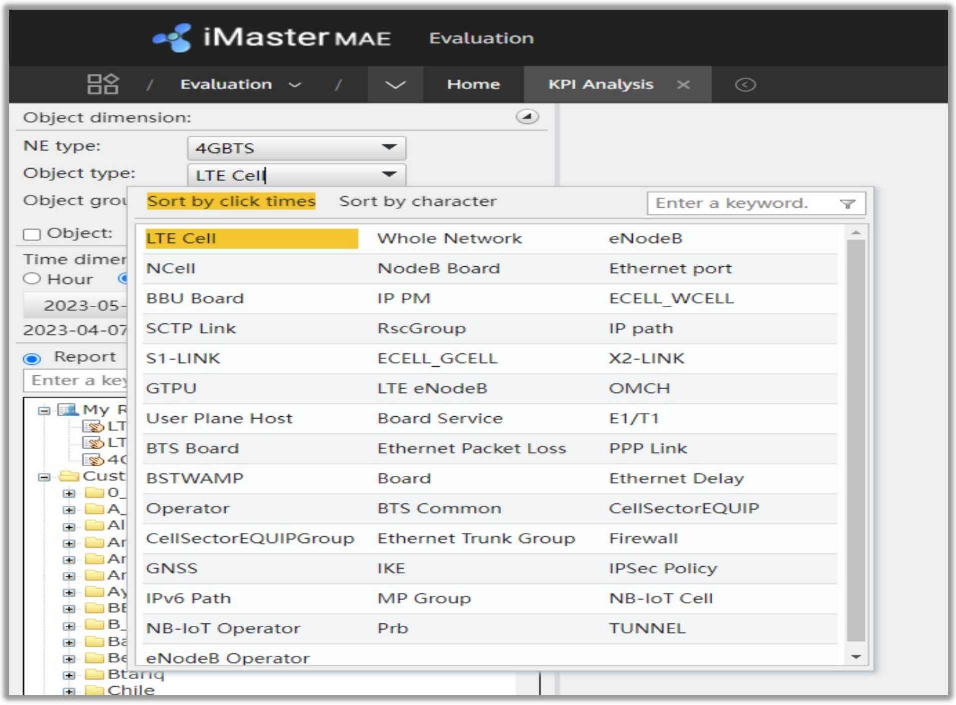

Figure 3.3: Object type selection in STS.

We can also choose the duration in which we want to see the performance of the KPIs. We can select the starting time and the format by which we want to visualize our data. The following figure demonstrates that.

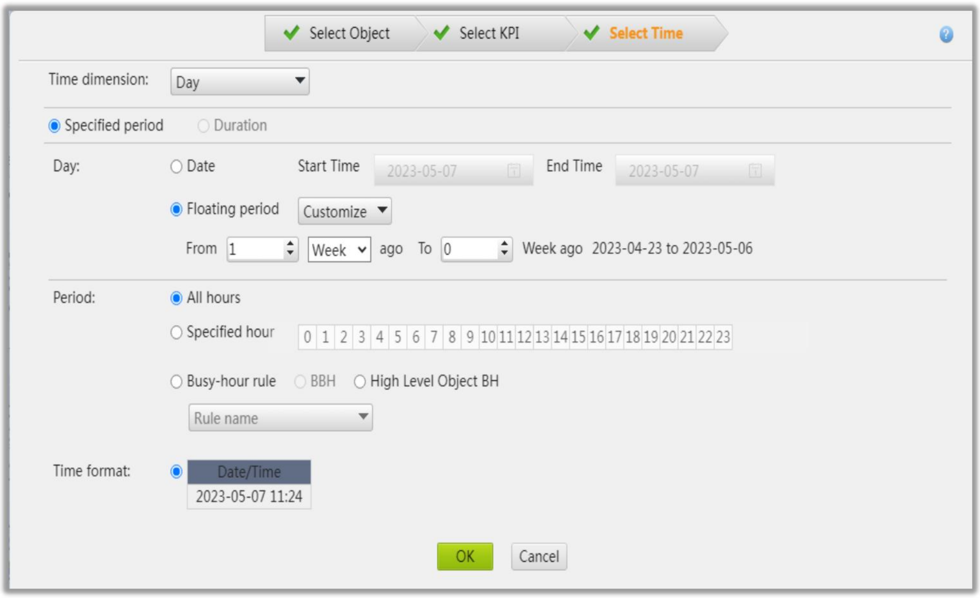

Figure 3.4: Time selection in STS.

3.2.2 Operations Support Systems (OSS)

The OSS optimization tool for iMaster MAE is a comprehensive software solution designed to enhance the performance and efficiency of network operations. It provides a range of functionalities and capabilities to optimize the network and improve key performance indicators (KPIs) in various domains. It will be discussed in details in the next title.

3.3 Optimization of LTE network

Radio optimization within the operator is carried out by a team of radio engineers. By utilizing iMaster MAE, Mobilis gains access to a comprehensive set of tools for monitoring and analyzing KPIs. These KPIs serve as metrics to assess the effectiveness of massive MIMO before and after optimization efforts. The software enables Mobilis to track and evaluate various performance parameters such as signal quality, throughput, coverage, interference, and user experience.

3.3.1 Presentation of the OSS iMaster MAE optimization tool

OSS represents a set of software applications and systems used by telecommunications service providers to manage and support their network operations. OSS encompasses various functionalities, including network monitoring, provisioning, fault management, performance analysis, inventory management. The primary purpose of OSS is to ensure smooth network operations, reduce downtime, and enhance overall service quality.

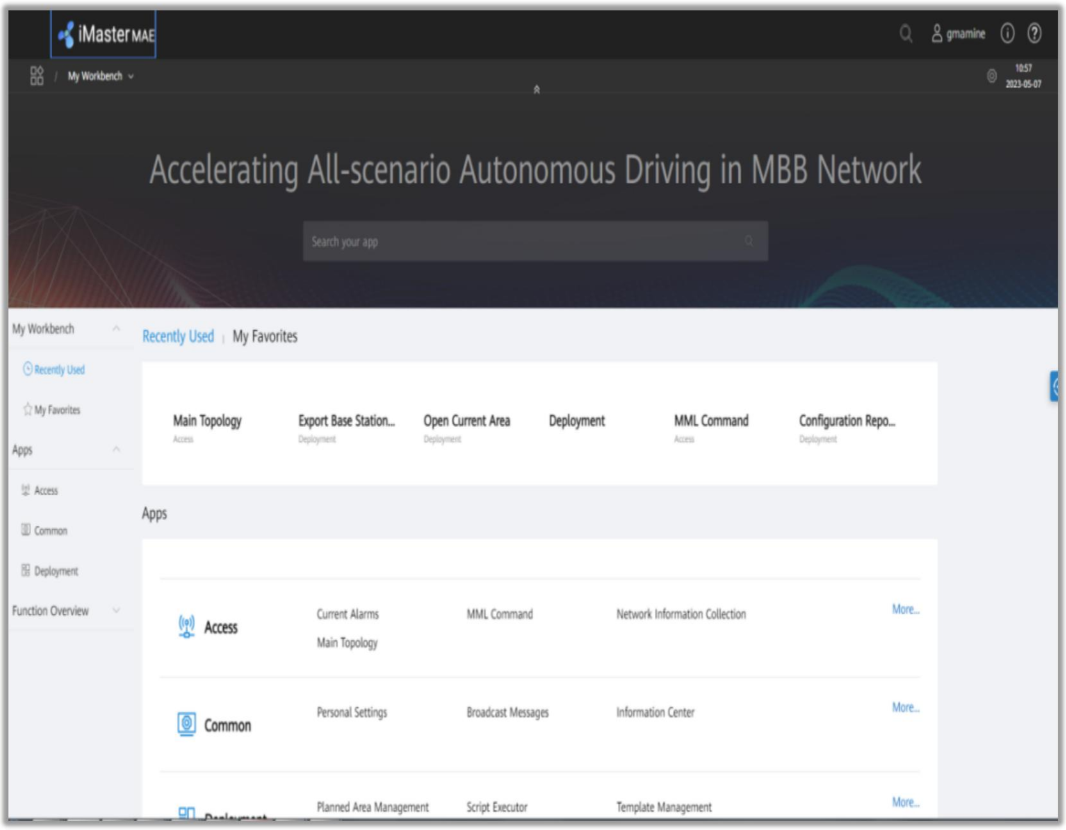

Figure 3.5: OSS software interface.

The above figure displays the different services that OSS offers. Among the functions that OSS proposes is fault detection in a specific cell. It enables the detection and evaluation of any degradation or malfunctioning of specific cells within the massive MIMO network, indicating the presence of a down cell situation. We will choose a cell in the city of Biskra which has 7617 as a reference where 7 represents the city in which the study is done, and 617 the ID of the sector.

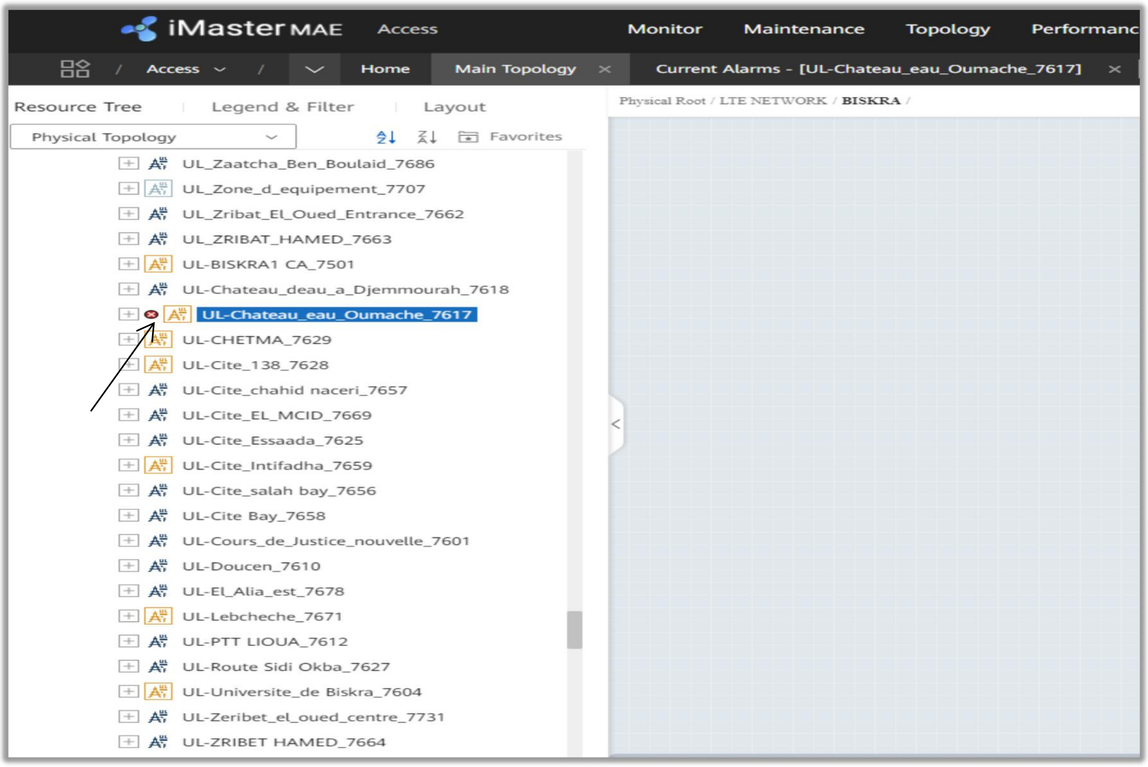

Figure 3.6: Example of a down cell.

The above figure shows a down cell which has a red mark. There are many reasons for this phenomena and they will be depicted in the following figure.

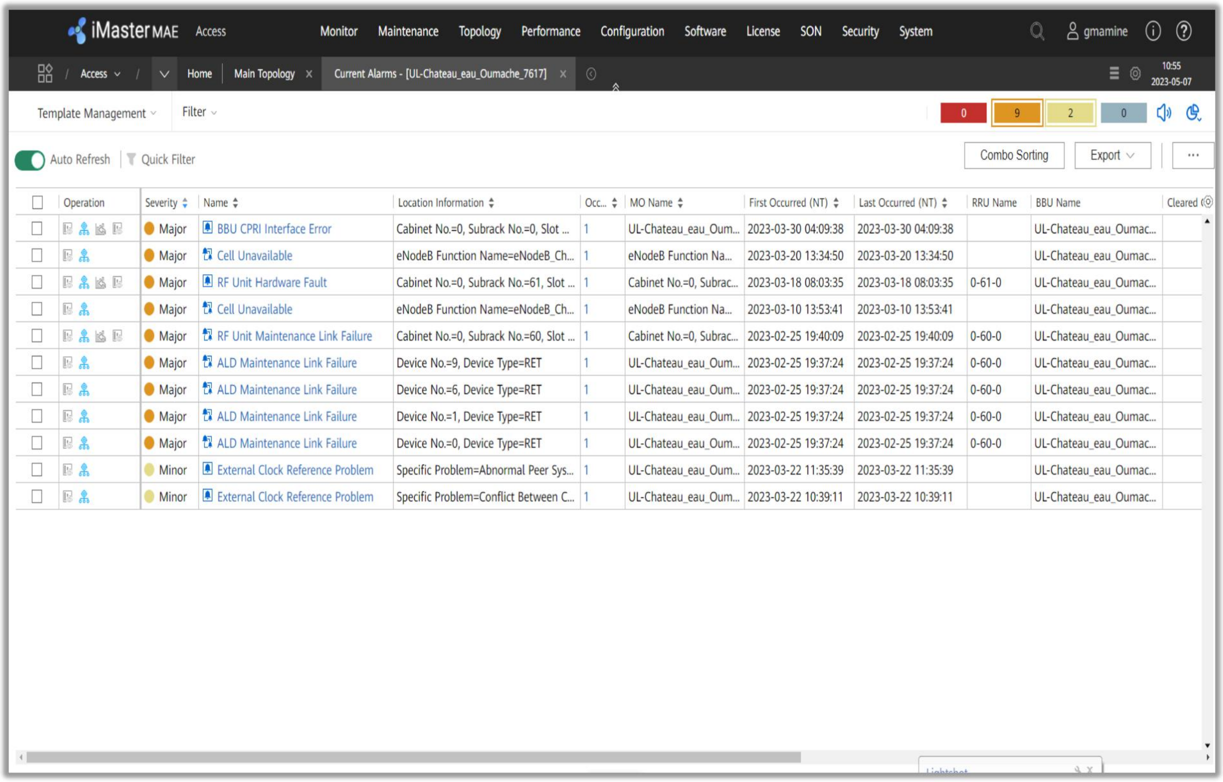

Figure 3.7: Current alarms in the 7617.

The above picture classifies the reasons that led the cell to fall. We can see that there are major and minor reasons and they will be reported to concerned field engineers to see whether it will be fixed on-site or off-site.

3.4 Results and discussion

In this section we will present the result that we got after deploying the massive MIMO technology by the date 02/04/2023. The effect will be seen in the performance of different KPIs. The site that have been chosen to be studied is 7504 which is in the city of Biskra. We select 4GBTS for NE network, and it will be examined on sector level. We picked the date 18/05/2023 and we chose to analyse the data 26 weeks earlier from this date to assess the impact of massive MIMO. After that, we select the appropriate template and the desired KPI. We can visualize the graphs by pressing on Query bottom. UL_O_DJELLAL_7504 and and 7504-TMM represents respectively the name of the same sector before and after deploying massive MIMO technology.

The following figure illustrates the different option that we selected, as well as the graph obtained after selecting RRC Setup Success Rate (signalling) KPI.

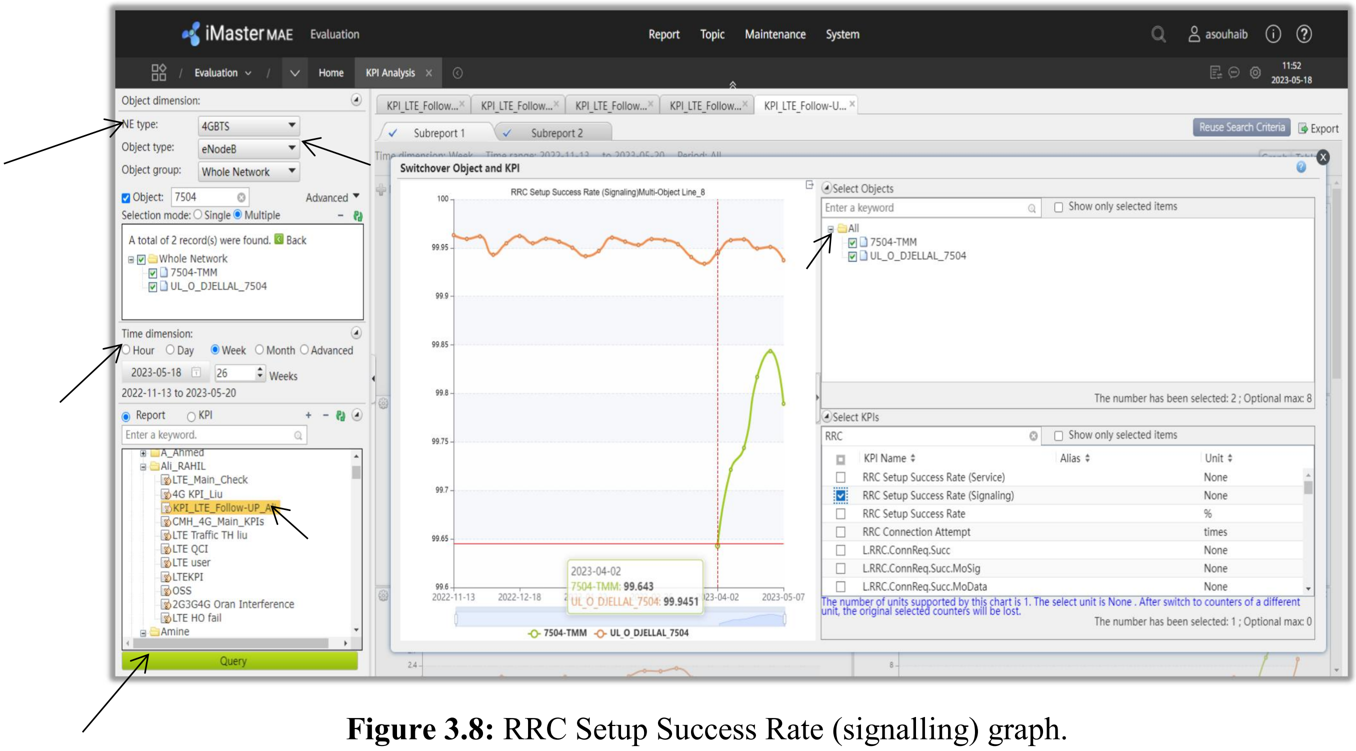

Figure 3.8: RRC Setup Success Rate (signalling) graph.

We can see that RRC setup success Rate multi object line performance when traditional MIMO was used had excessive value compared to the ones indicated after deploying Massive

MIMO. Since the number of users augmented, the rate that the eNodeB will let them to accede to the network will decrease.

To examine the network's ability to maintain a service, we will observe the E-RAB performance.

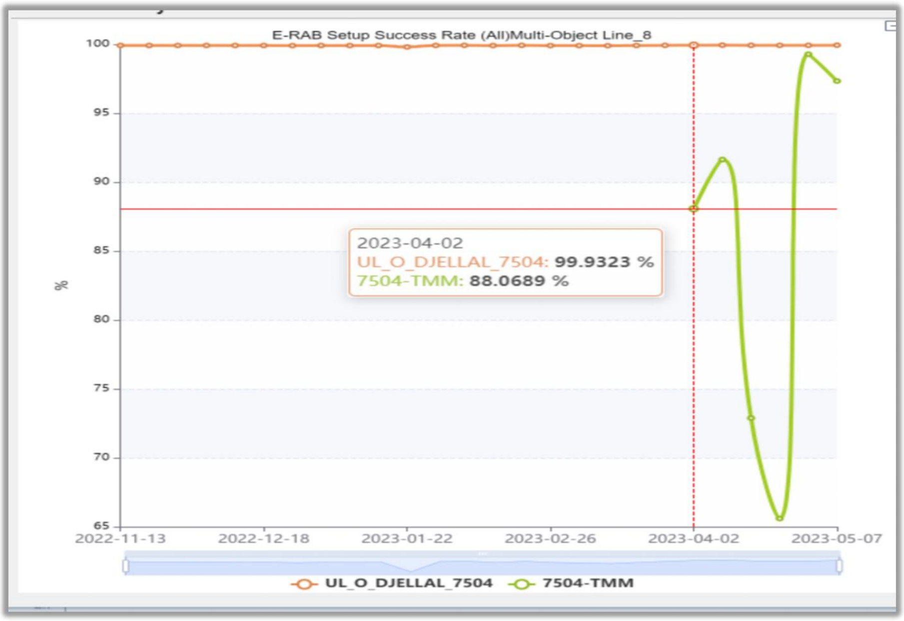

Figure 3.9: E-RAB performance before and after optimization.

Since the rate of RRC success rate decreased then E-RAB will decrease as well since they have direct relation between them.

Considering the UE inside the network, we see its usage of the resources and we will visualize that through PRB usage in DL modes.

Figure 3.10: DL PRB usage before and after optimization.

We notice that the PRB usage decreased in the downlink mode after deploying massive MIMO, and this occurred by spatially separating the signals through beamforming technique. Massive MIMO can effectively multiplex users in the spatial domain, reduce the need for additional PRBs to accommodate simultaneous transmissions. In addition to that, it eliminates interference by focusing transmission energy towards intended users and nullifying interference towards other directions, and this lead to minimize signal spillage and wastage.

Now, we will examine the usage of resources by observing the rate of throughput and traffic volume that UE is experiencing in the DL mode.

Figure 3.11: DL average throughput performance before and after optimization.

It appears in the above figure the considerable change in the average throughput for DL, and this is due to the technology upgrades from MIMO to massive MIMO that enables simultaneous transmission of multiple data streams. Moreover, optimized antenna configurations permit a stronger and more reliable signal reception can lead to higher throughput. Furthermore, ongoing network optimization efforts such us traffic management can contribute to increased average throughput by effectively managing network resources and prioritizing critical traffic.

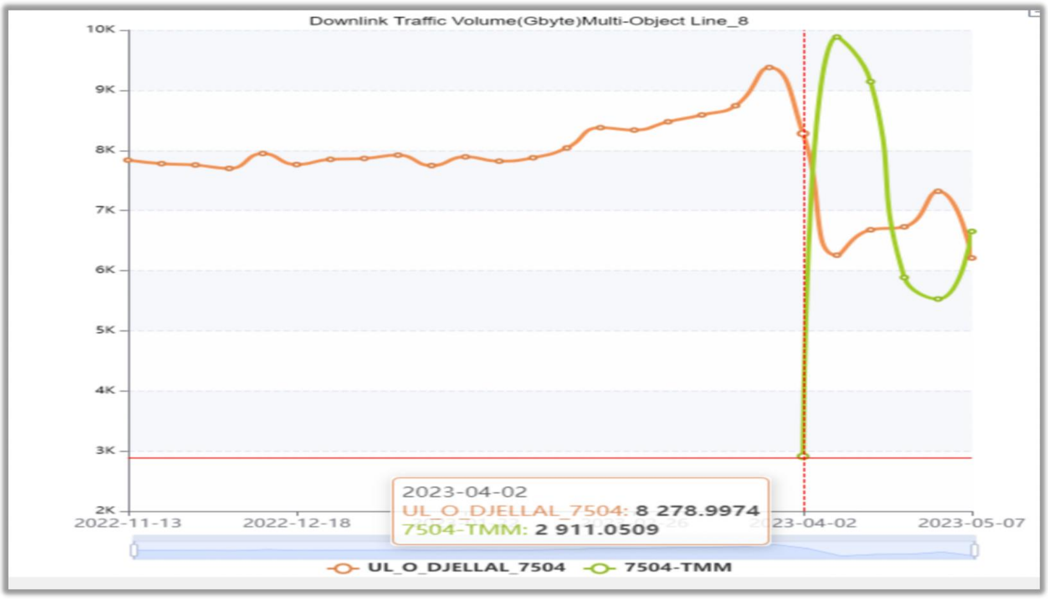

Figure 3.12: DL Traffic volume performance before and after optimization.

This KPI has direct relation with sum of cell throughput. As the throughput increases, more data can be transmitted, allowing for higher cell traffic volume. Conversely, if the throughput is low, the network may experience congestion or limited capacity, resulting in lower cell traffic volume.

The UE can move without interruption within and outside the cell when the inter and intra handover happen successfully. We will present the performance of the handover in the following illustrations.

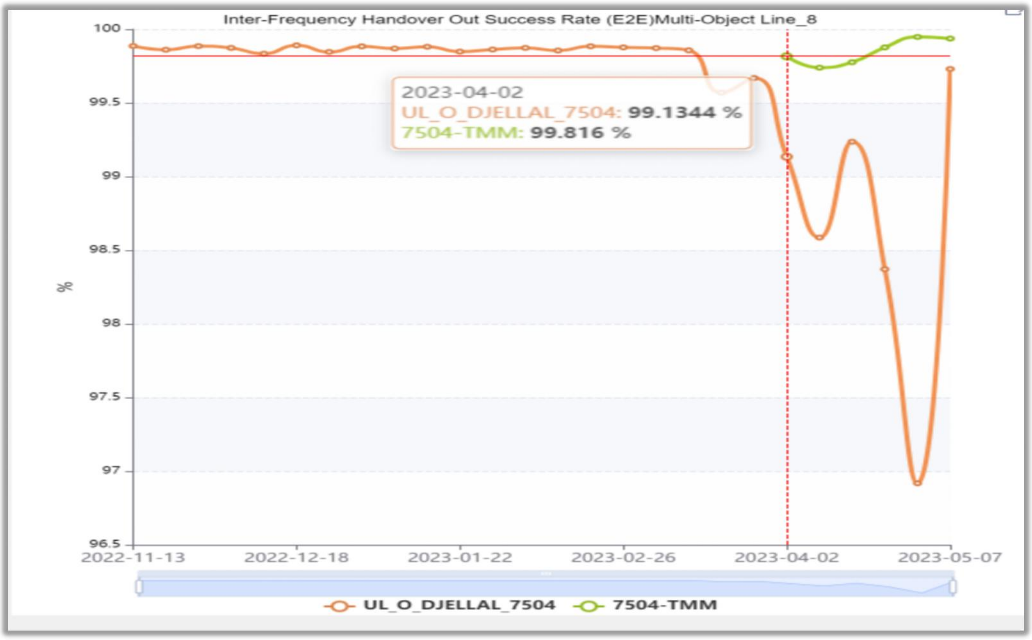

Figure 3.13: Inter handover performance before and after optimization.

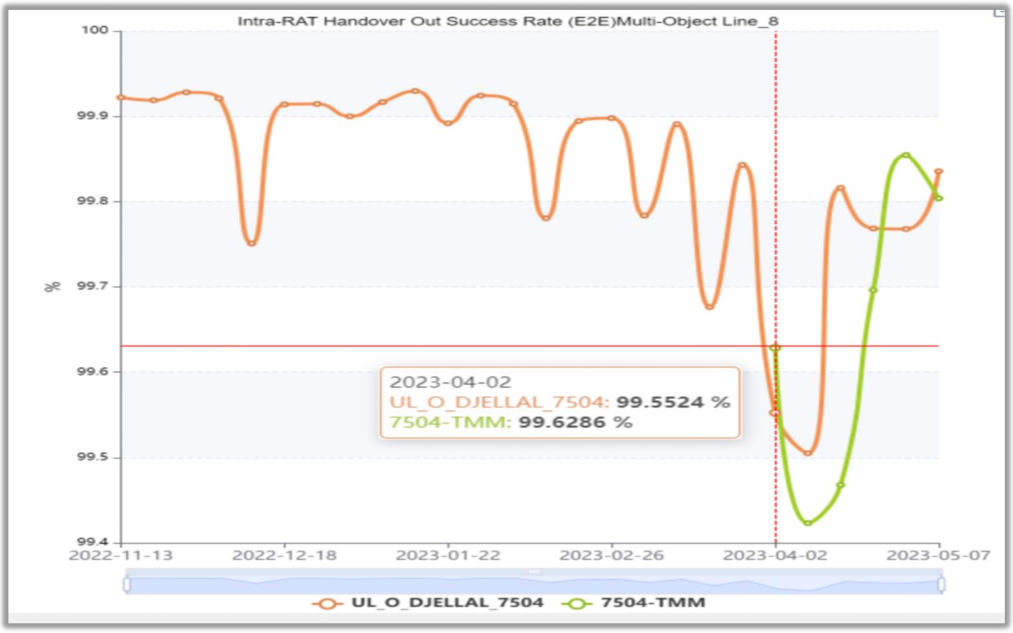

Figure 3.14: Intra handover performance before and after optimization.

From the resulting plots we can remark the increased rate for both inter and intra handover. spatial multiplexing techniques of MIMO gave noticeable improvement in the handover success percentage. However, the increased number of antennas and advanced beamforming capabilities of Massive MIMO enabled more efficient utilization of radio resources; and ensuring smoother and more reliable handover transitions for users.

During the mobility of the UE, it can be exposed to lower coverage and signal strength, and to maintain to avaibility of the service, the UE perform an automatic CSFB to basculate to lower generations.

Figure 3.15: CSFB performance before and after optimization.

With the introduction of MIMO, the spatial multiplexing gain and overall system capacity improve. This can positively affect CSFB as it allows for better signal quality, potentially leading to improved call establishment and handover performance during fall-back scenarios. On the other hand, with the implementation of massive MIMO, the benefits are even more pronounced and the execution success rate increased . Massive MIMO enables higher spatial multiplexing gain, increased coverage, and better interference management. These factors can contribute to smoother CSFB operations, providing improved voice call fall-back performance, reduced call drop rates, and enhanced overall user experience.

3.5 Conclusion

The results presented in this chapter show the significant impact of deploying massive MIMO on the performance of the network on the studied site. To validate the work accomplished in this chapter, a real life experiment will be explored in the next chapter.

Chapter 4

Analysis and exploitation of measurements (Drive Test)

4.1 Introduction

In the context of LTE single site verification, a drive test (DT) is conducted to assess the performance and coverage of a single LTE site Ouled Djellal with the eNodeB name 7504-TMM . The purpose is to verify and validate the network parameters including signal strength, signal quality, handover performance, data throughput, call quality, and coverage extent.

4.2 Drive Test (DT) experiment

Drive test is an essential tool for network planning, optimization and troubleshooting. It provides valuable insights into the performance of wireless networks and aid in identifying areas where network performance can be enhanced to ensure reliable and high-quality voice and data services for end-users.
During this test, three main mean radio KPIs will be taken into consideration which are Mean Reference Signal Received Power (RSRP), Mean Reference Signal Received Quality (RSRP), and Mean Signal-to-Interference-plus-Noise Ratio (SINR).

- **Mean RSRP**

It refers to the average value of the RSRP measurements collected over a specific period of time or within a particular area. It provides an overall indication of the average signal strength experienced by user equipment within a given region [39].

- **Mean RSRQ**

It refers to the average value of RSRQ measurements collected over a specific period of time or within a particular area. RSRQ is a metric used to assess the quality of the received signal in relation to the interference and noise levels in the network [39].

- **Mean SINR**

It represents the ratio of the signal power to the combined interference and noise power in the network. It provides an indication of the signal quality experienced by user equipment UE and is particularly relevant in evaluating the performance of LTE network [39].

The following table will provide the information about the site that have been studied in the previous chapter.

Table 4.1: LTE Single site verification identification information.

LTE Single Site Verification							
System	**LTE**	**Region**	**Ouled Djellal**			**Cluster**	**Ouled Djellal**
eNodeB ID	7504	**eNodeB Name**	7504-TMM	**Longitude**	5.06341	**Latitude**	34.4275
Test Date	4/23/2023			**Contract No.**	PO17: 00001222002120	**DU ID**	7504-PO17-TMM-tuning

The subsequent figure will illustrate a Google Map geographical area of Ouled Djellal where different sites of massive MIMO have been implemented.

Figure 4.1: Different massive MIMO sites deployed in Ouled Djellal region.

DT involves the collection of real-time data and measurements while driving through specific geographical area as it will be demonstrated in the following figure, it is performed using a specialized test vehicle equipped with measurement devices. Among them we find:

Drive Test Tool: A specialized software application TIMES installed on a laptop, tablet, or smartphone that collects and analyses network performance data during the drive test.

Mobile Measurement Scanner: A device specifically designed for drive testing, equipped with multiple antennas and receivers to measure various network parameters.

Global Positioning System (GPS) Receiver: used to track the precise location of the drive test vehicle and synchronize the collected data with the corresponding geographical coordinates.

Antennas and Antenna Mounts: External antennas are used to capture and measure network signals accurately.

Test SIM Cards: used to authenticate and access the network during the drive test.

Data Storage and Analysis System: a laptop or external hard drive.

The following figure represents the physical cell ID (PCI) of examined cell 7504-TMM.

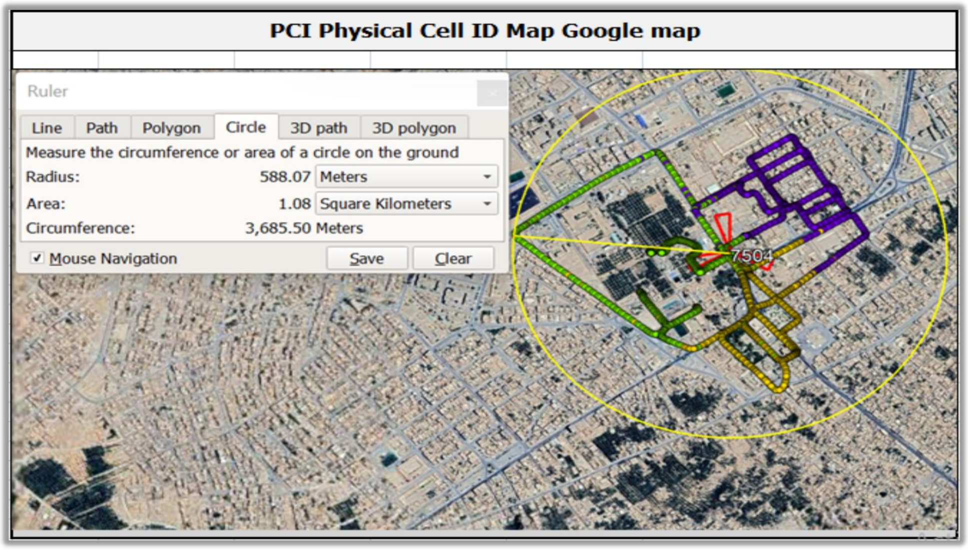

Figure 4.2: Physical Cell ID (PCI) Map Google map for 7504-TMM.

To ensure proper network operation, optimizing, and facilitating efficient mobility management within a cellular network; we require the following parameters :

Azimuth Check: Verifies the azimuth alignment or orientation of a cell's antenna.

M-Tilt Check: Evaluates the mechanical tilt angle of an antenna.

Cell ID Check: Validates the uniqueness and correctness of Cell IDs within a network.

TAC Check: Verifies the assignment and uniqueness of Tracking Area Codes (TAC)within a network.

PCI Check: Validates the assignment and uniqueness of Physical Cell Identity (PCI) values within a cellular network.

The following table will present the numerical values of the previous parameters for the three sectors of the site.

Table 4.2: Parameters Of Coverage test values .

Coverage Test	Sector 1	Sector 2	Sector 3
Azimuth Check (degree)	0	120	260
M-Tilt Check (degree)	7	6	5
Cell ID Check	31-41	32-42	33-43
TAC Check	7401	7401	7401
PCI Check	162	163	164

4.2.1 Static test

Our test commenced with the execution of a static test, where in the DT vehicle remained stationary at a predetermined location for the purpose of collecting measurements and evaluating network performance under controlled conditions.

By categorizing measurements or data based on two values of frequencies where the values of $f\,1$ and $f\,2$ are 150 MHz and 1680 MHz respectively, it becomes easier to compare and analyse the performance of different frequency bands or carriers within the network.

The following tables will present the numerical values of different parameters measured in both frequencies $f\,1$ and $f\,2$ for the three sectors.

Table 4.3: Measurements obtained when using $f\,1$.

Static Test	Sector 1	Sector 2	Sector 3
Attach success	ok	ok	ok
CSFB MOC	ok	ok	ok
CSFB MTC	ok	ok	ok
3G -> LTE Reselection	ok	ok	ok
Mean RSRP (dBm)	-59,52	-76,57	-65,91
Mean RSRQ (dB)	-12,52	-11,05	-10,48
Mean SINR (dB)	29,82	22,31	25,81
Mean Timing Advance (Metre)	3193,43	3263,46	3184,24
Peak throughput PDCP UL (Kbps)	8904,85	9956,1	7767,53
Peak throughput PDCP UL (Mbps) >= 7Mbps	8,90	9,96	7,77
Peak throughput PDCP DL(Kbps)	125016,50	111531,60	120935,40
Peak throughput PDCP DL(Mbps) >= 100Mbps	125,02	111,53	120,94
CSFB Call Setup Time(s) (from UE to PSTN) <=5s	6,5	5,86	5,81
Intra Frequency Handover success (S1->S2)	ok	ok	ok
Intra Frequency Handover success (S2->S3)	ok	ok	ok
Intra Frequency Handover success (S3->S2)	ok	ok	ok
Intra Frequency Handover success (S2->S1)	ok	ok	ok
Intra Frequency Handover success (S1->S3)	ok	ok	ok

Now we present the results obtained when $f\,2$ is utilized.

Table 4.4: Measurements obtained when $f\,2$ is utilized.

Static Test	Sector 1	Sector 2	Sector 3
Attach success	ok	ok	ok
CSFB MOC	ok	ok	ok
CSFB MTC	ok	ok	ok
3G -> LTE Reselection	ok	ok	ok
Mean RSRP (dBm)	-56,73	-73,26	-65,07
Mean RSRQ (dB)	-7,99	-9,49	-9,69
Mean SINR (dB)	30	24,58	24,42
Mean Timing Advance (Metre)	3162,88	3186,96	3103,52
Peak throughput PDCP UL (Kbps)	9193,02	9449,36	8423,54
Peak throughput PDCP UL (Mbps) >= 3Mbps	9,19	9,45	8,42
Peak throughput PDCP DL(Kbps)	63098,60	78587,14	65110,94
Peak throughput PDCP DL(Mbps) >= 50Mbps	63,10	78,59	65,11
CSFB Call Setup Time(s) (from UE to PSTN) <=5s	6,43	5,79	5,13
Intra Frequency Handover success (S1->S2)	ok	ok	ok
Intra Frequency Handover success (S2->S3)	ok	ok	ok
Intra Frequency Handover success (S3->S2)	ok	ok	ok
Intra Frequency Handover success (S2->S1)	ok	ok	ok
Intra Frequency Handover success (S1->S3)	ok	ok	ok

We observe that the obtained results show relatively small differences between each other, particularly in terms of peak throughput for the PDCP UL. For $f\,1$, the peak throughput for PDCP UL was found to be greater than or equal to 7 Mbps, while for $f\,2$, it was greater than or equal to 3 Mbps. Conversely, in terms of peak throughput for the PDCP DL, $f\,1$ exhibited values greater than or equal to 100 Mbps, while *f* 2 exhibited values greater than or equal to 50 Mbps.These differences in peak throughput values could be due to various factors, such as variations in system configurations, antenna configurations, channel conditions, or other network parameters.

Subsequently, we proceeded to transition into the active mode during our DT in which it refers to the state where the mobile device is actively engaged in communication with the network, transmitting and receiving data in both clockwise and anticlockwise directions.

4.2.2 Clockwise active

It indicates that DT was conducted by moving in a clockwise direction along the predefined route. The test vehicle travels in a circular or looped path, typically starting from a specific location and following a clockwise direction. The following figure illustrates the radio mean analysis obtained for moving in this direction .

In the following figure, radio mean analysis conditions and results in clockwise direction will be presented.

MS1 ACTIF MODE

Radio Mean Analysis

Mean Radio KPI	Mobilis		Radio Condition	Condition
Mean RSRP (dBm)	-75,63		Mean RSRP > -97 (dBm)	OK
Mean RSRQ (dB)	-12,45		Mean RSRQ > -11 (dB)	NOK
Mean SINR (dB)	22,61			

Figure 4.3: Radio mean analysis conditions and results in clockwise direction.

It can be seen from the above figure, the condition of mean RSRP was satisfied, this means that the average signal strength experienced by user equipment was good. On the other hand, the condition of mean RSRQ was not satisfied; and one of the factors that can cause that is the increased level of the noise in that area.

The PCI physical cell will be show in the following figure.

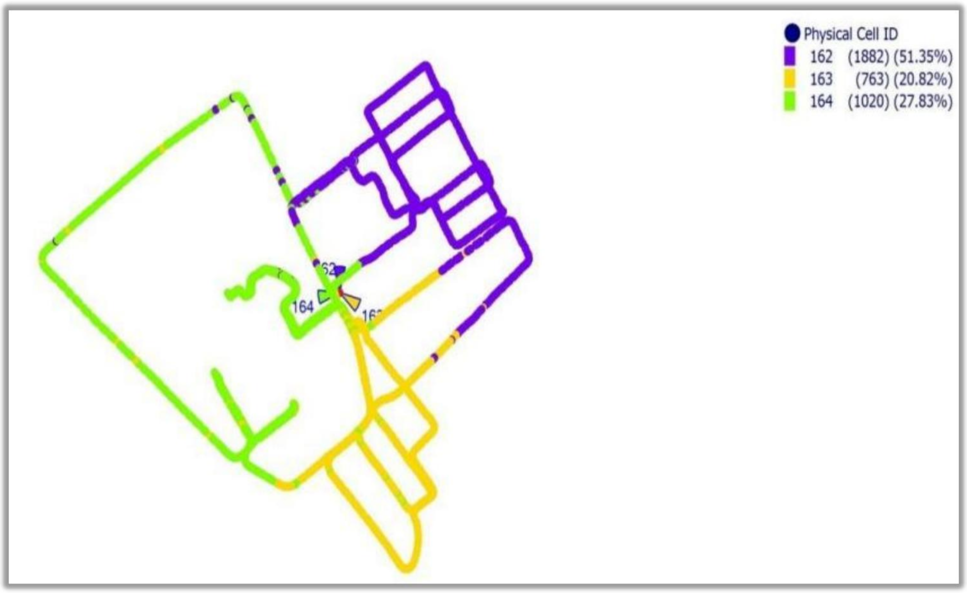

Figure 4.4: PCI Physical Cell ID map in clockwise direction.

a. Radio parameters analysis

- **RSRP**

The following table will present the different values obtained regarding RSRP parameter.

Table 4.5: RSRP parameter results in clockwise direction.

Serving Cell RSRP (dBm)	Mobilis
>=-80 (dBm)	690
-90 to -80 (dBm)	177
-97to -90 (dBm)	58
-97 to -110 (dBm)	21
<=-110 (dBm)	0
RSRP Distribution (%)	**Mobilis**
>=-80 (dBm)	72,94%
-90 to -80 (dBm)	18,71%
-97 to -90 (dBm)	6,13%
-97 to -110 (dBm)	2,22%
<=-110 (dBm)	0,00%

The above table shows that the value of RSRP served in 690 points in Ouled Djellal is higher or equal tol -80dBm , and it represents 72.94% of the overall distribution. It indicates the strongest and most reliable signal in the area . On the other hand, only 21 points are served by a value of RSRP that ranges from -97 to -110 dBm, and it represents only 2.22% of the whole distribution.

The subsequent figure will illustrate the percentage of actif RSRP distribution regarding the value of RSRP intervals.

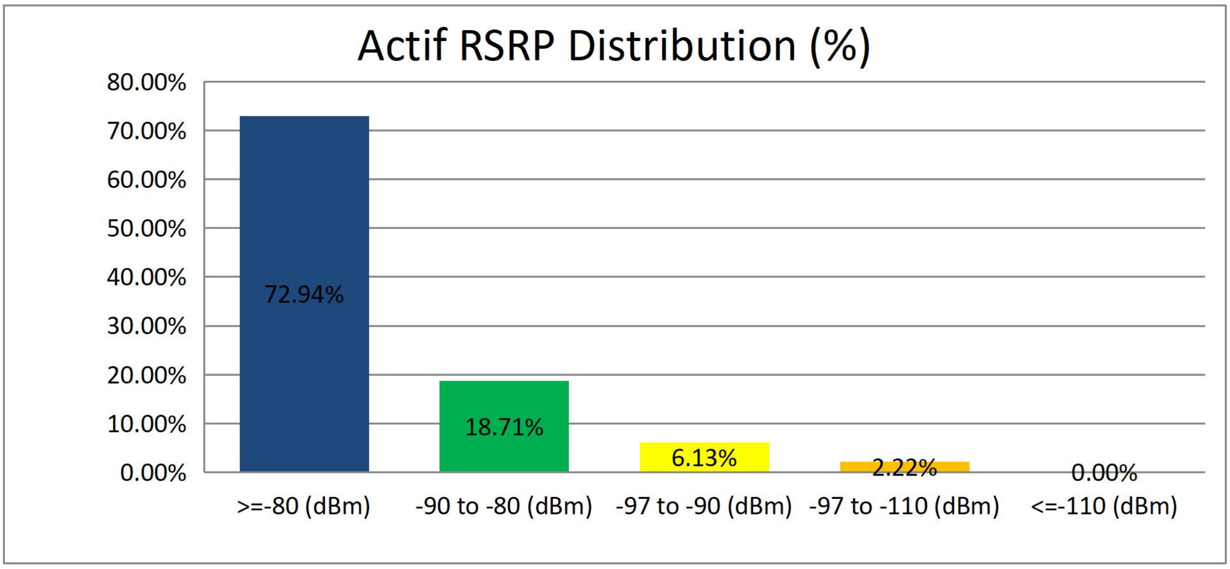

Figure 4.5: Histogram of active RSRP distribution in clockwise direction.

Since more than 90% of the RSRP is greater than -97dbm relative to a threshold of -97dB, then it suggests that the network has adequate signal power to ensure stable communication and satisfactory user experience in the area where the measurements were taken.

In the following figure a map distribution of RSRP in clockwise direction for different served cells will be presented.

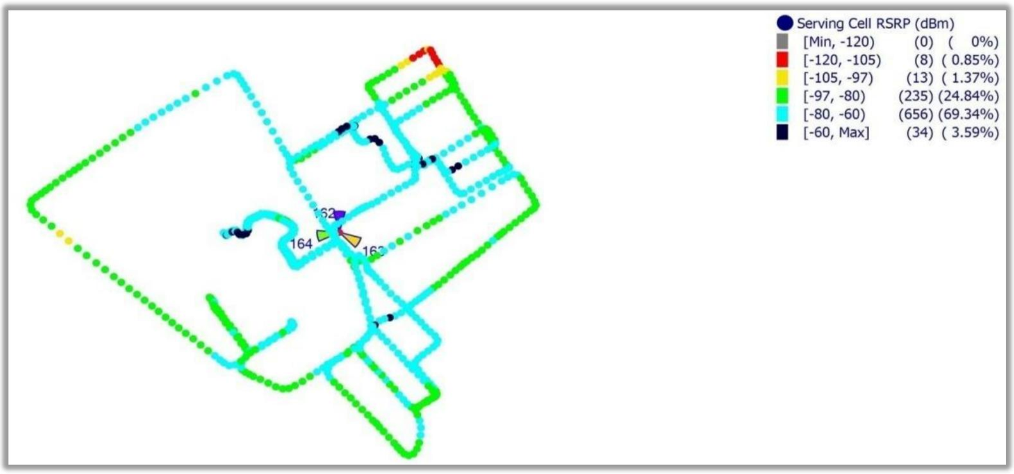

Figure 4.6: RSRP Map distribution in clockwise direction.

- **RSRQ:** During the DT, measurements of serving cell RSRQ are taken at different locations to analyse the signal quality and interference levels experienced by the of UE in the purpose of identifying areas with potential signal degradation or interference issues, and make informed decisions regarding network optimization or troubleshooting activities. The results obtained are listed in the following table.

Table 4.6: RSRQ parameter results in clockwise direction.

Serving Cell RSRQ (dB)	Mobilis
>=-5 (dB)	0
-5 to -8 (dB)	30
-8 to -11 (dB)	353
-11 to -15 (dB)	357
<-15 (dB)	206
Serving Cell RSRQ (dB)	**Mobilis**
>=-5 (dB)	0,00%
-5 to -8 (dB)	3,17%
-8 to -11 (dB)	37,32%
-11 to -15 (dB)	37,74%
<-15 (dB)	21,78%
% RSRQ >=-11	40,49%

We visualize the given results in the following histogram.

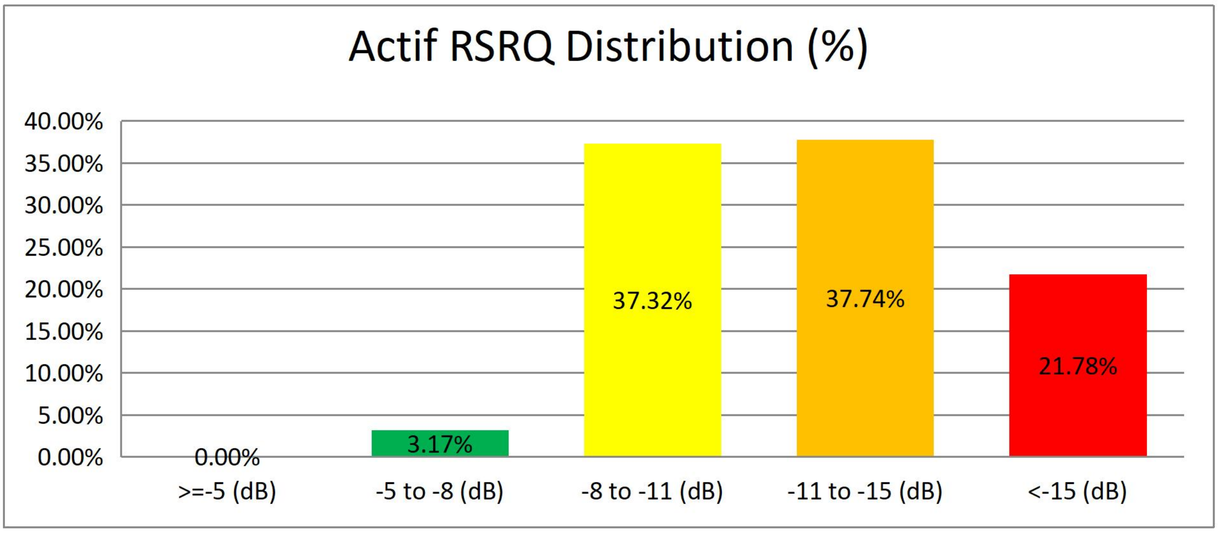

Figure 4.7: Histogram of actif RSRQ distribution in clockwise direction.

An RSRQ value of -11 dB or higher indicates a relatively good signal quality with low interference levels. It suggests a favorable signal-to-interference ratio and generally signifies a reliable and stable connection. However, since only 40.49% of the RSRQ values meet this threshold, it implies that a significant portion of the measurements show degraded signal quality or higher interference.

The subsequent diagram illustrates the clockwise distribution of RSRQ in varying served cells.

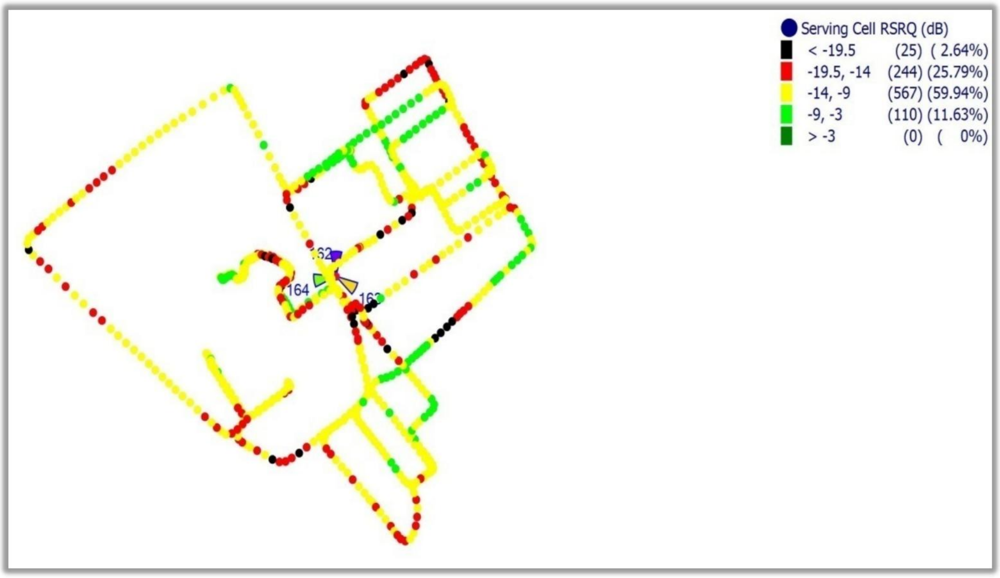

Figure 4.8: RSRQ Map distribution in clockwise direction.

- **SINR:** In DTs, measuring the serving cell SINR at different locations helps assess the signal quality and interference levels experienced by the user equipment. It provides insights into the robustness of the signal and the impact of interference and noise on the overall network performance. The obtained results are presented in the following table.

Table 4.7: SINR measurement results in clockwise direction.

Serving Cell SINR (dB)	Mobilis
30 to50 (dB)	163
25 to 30(dB)	300
20 to25 (dB)	158
15 to 20 (dB)	176
10 to 15 (dB)	102
0 to 10 (dB)	45
-20 to0 (dB)	2
Serving Cell SINR (dB)	**Mobilis**
30 to50 (dB)	17,23%
25 to 30(dB)	31,71%

20 to25 (dB)	16,70%
15 to 20 (dB)	18,60%
10 to 15 (dB)	10,78%
0 to 10 (dB)	4,76%
-20 to0 (dB)	0,21%
% SINR >=0 (dB)	99,79%

The provided results are graphically represented in the following histogram.

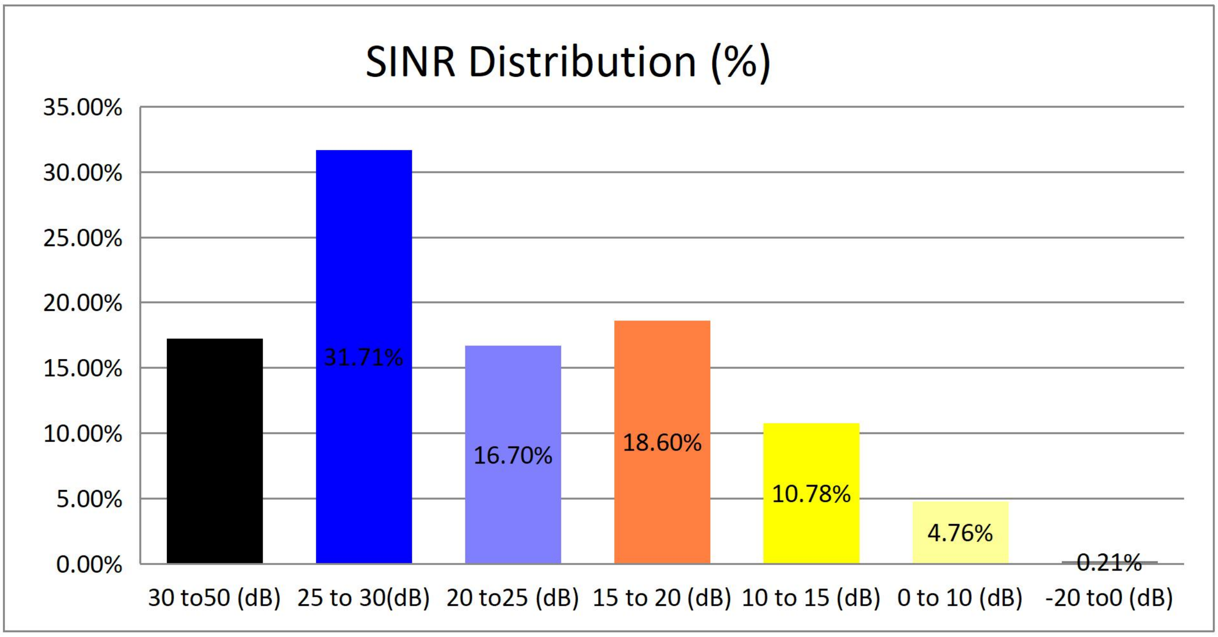

Figure 4.9: Histogram of actif SINR distribution in clockwise direction.

Finding that more than 99.79% of SINR values are greater than 0 dB, while it is expected to be more than 85% .Threshold greater than 0 dB suggests a positive signal quality characteristic in the network, it is an excellent finding as it indicates a high percentage of measurements with strong signal quality and low interference levels. This suggests that the network is capable of providing reliable and satisfactory user experiences across a significant portion of its coverage area.

The subsequent figure depicts a clockwise map distribution of SINR for different served cells.

Figure 4.10: SINR distribution map in clockwise direction.

4.2.3 Anti-clockwise direction

Now we go by the anticlockwise direction along the predefined route . It means that the test vehicle is moving in an anti-clockwise direction during the drive test.

The forthcoming figure will present the conditions and results of the radio mean analysis.

MS1 ACTIF MODE				
Radio Mean Analysis				
Mean Radio KPI	Mobilis		Radio Condition	Condition
Mean RSRP (dBm)	-77,87		Mean RSRP > -97 (dBm)	OK
Mean RSRQ (dB)	-9,12		Mean RSRQ > -11 (dBm)	OK
Mean SINR (dB)	17,07			

Figure 4.11: Radio mean analysis conditions and results in anti-clockwise direction.

It can be seen from the above figure, the condition of mean RSRP and RSRQ were satisfied, this means that the average signal strength experienced by user equipment in the area was good.

The forthcoming figure will display the physical cell identity (PCI) for each cell

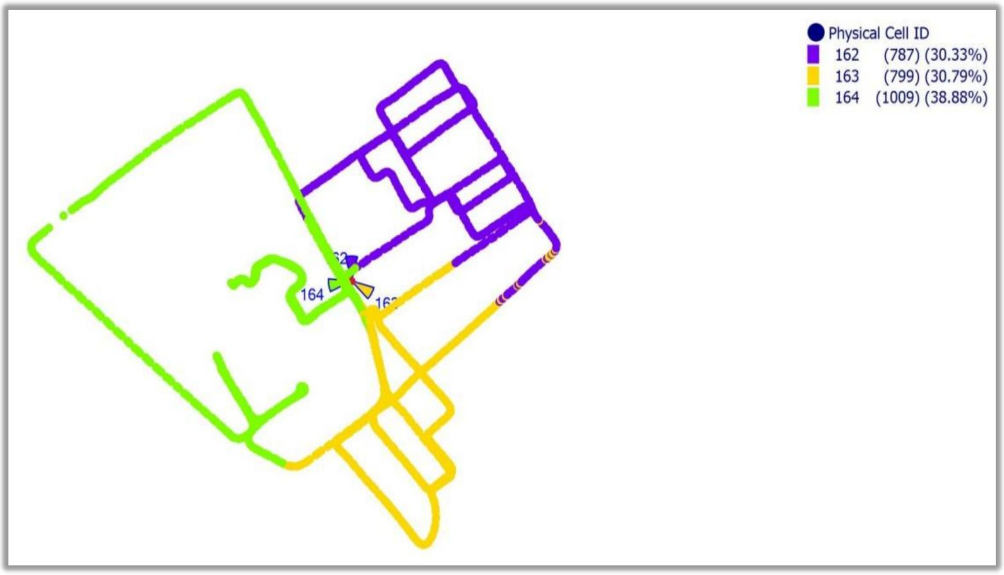

Figure 4.12: PCI Physical ID Cell Map in anti-clockwise direction

b. Radio parameters analysis

- **RSRP**

The subsequent table will present the various values obtained for the RSRP parameter.

Table 4.8: RSRP measurement results in anti-clockwise direction.

Serving Cell RSRP (dBm)	Mobilis
>=-80 (dBm)	427
-90 to -80 (dBm)	167
-97 to -90 (dBm)	55
-97 to -110 (dBm)	25
<=-110 (dBm)	2
RSRP Distribution (%)	**Mobilis**
>=-80 (dBm)	63,17%
-90 to -80 (dBm)	24,70%
-97 to -90 (dBm)	8,14%
-97 to -110 (dBm)	3,70%
<=-110 (dBm)	0,30%
% RSRP >-97 (dBm)	**96,01%**

Based on the above table, it can be observed that the RSRP value of -80 dBm or higher is served in 427 points in Ouled Djellal, accounting for approximately 63.17% of the total distribution. This signifies the presence of the strongest and most reliable signal in the area.

Conversely, only 2 points are served by an RSRP value lower than -110 dBm, which corresponds to a mere 0.30% of the entire distribution.

The subsequent figure will illustrate the percentage of actif RSRP distribution regarding the value of RSRP intervals.

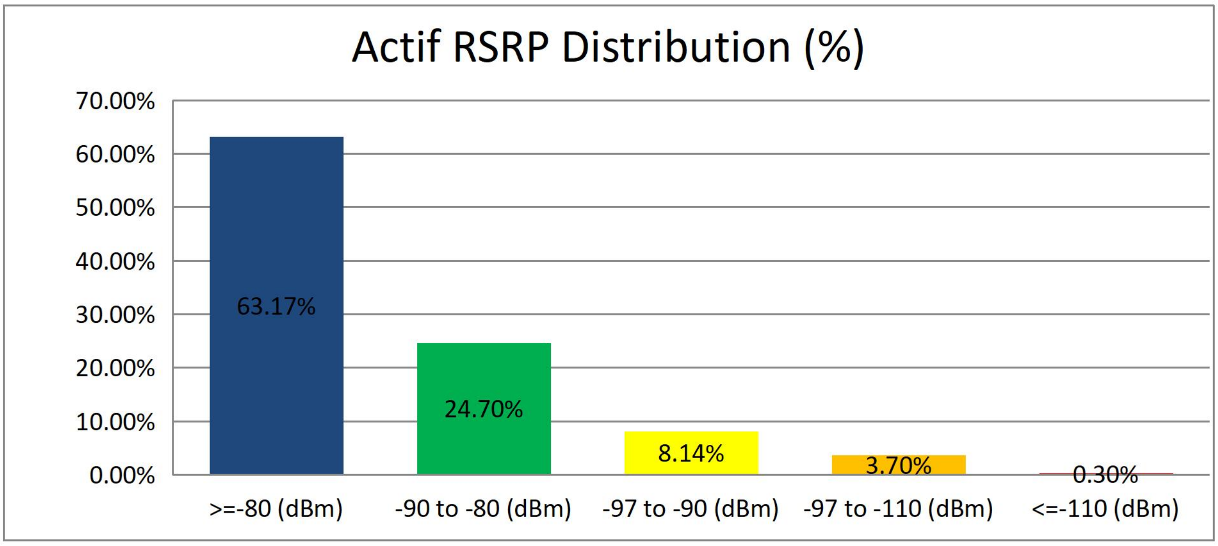

Figure 4.13: Histogram of Active RSRP distribution in anti-clockwise direction

As it appears, about 96.01% of the values of RSRP is higher or equal -97 dbm (threshold). This value represents more than 90% so the network coverage in the tested area is likely to be good, with a high proportion of signal samples showing strong signal reception thus the radio condition is satisfied.

The subsequent figure displays a counter-clockwise map distribution of RSRP for various served points.

Figure 4.14: RSRP distribution Map in anti-clockwise direction.

- **RSRQ:** The following table will present the different values obtained regarding RSRP parameter.

Table 4.9: RSRQ measurement results in anti-clockwise direction.

Serving Cell RSRQ (dB)	Mobilis
>=-5 (dB)	0
-5 to -8 (dB)	215
-8 to -11 (dB)	383
-11 to -15 (dB)	48
<-15 (dB)	30
Serving Cell RSRQ (dB)	**Mobilis**
>=-5 (dB)	0,00%
-5 to -8 (dB)	31,80%
-8 to -11 (dB)	56,66%
-11 to -15 (dB)	7,10%
<-15 (dB)	4,44%
% RSRQ >=-11	88,46%

Unlike in the clockwise direction, the RSRQ have a considerable percentage in the serving cell within the interval -5 to -8 (db), which represents 31.80% of the total area.As well serving 56.66% with a value of RSRP ranging from -8 to-11(db), this can be considered positive indicators of good signal quality and lower interference.

Various distributions can be visualized graphically in the following histogram.

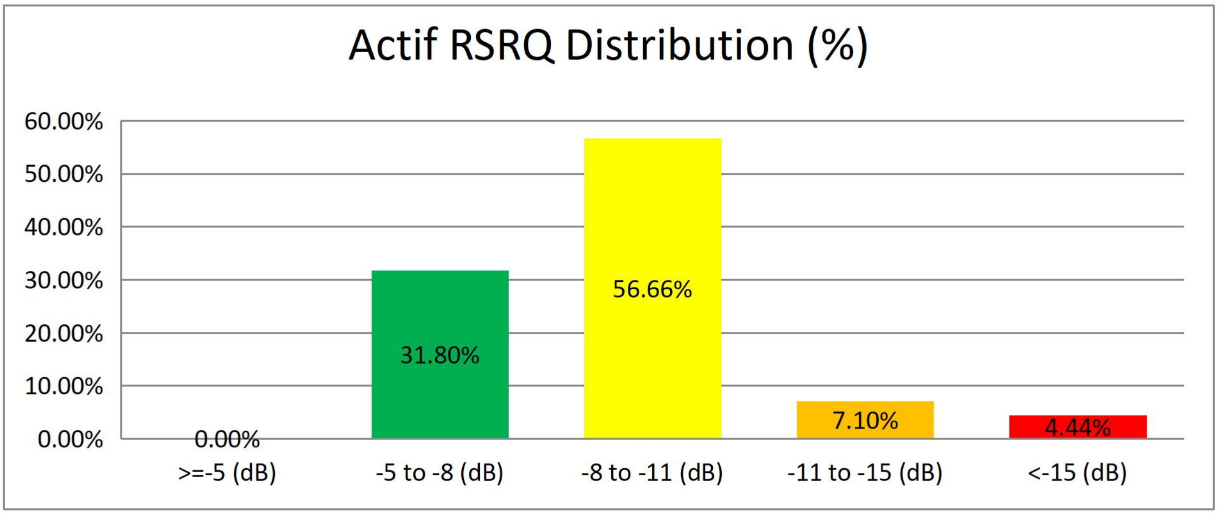

Figure 4.15: Histogram of RSRQ distribution.

In the contrast, the overall results for the RSRQ distribution in this direction accumulate about 88.46% , hence the desired percentage value was not attained (90% or more). The value of RSRQ should be better than -11dB, so the radio condition here is not fulfilled.

The following illustration represents map distribution of RSRQ.

Figure 4.16 : RSRQ map in anti-clockwise direction.

- **SINR:** There is a high degree of consistency among the percentages in the histogram of the serving cell's SINR distribution for the drive test in the anticlockwise direction, in which we can say that it closely clustered percentages as it appears that the highest obtained value is 22.19% in the rage of 20 to 25 db. The results are shown in the following table.

Table 4.10: SINR measurements results in anti-clockwise direction.

Serving Cell SINR (dB)	Mobilis
30 to50 (dB)	0
25 to 30(dB)	128
20 to25 (dB)	150
15 to 20 (dB)	142
10 to 15 (dB)	135
0 to 10 (dB)	101
-20 to(0) (dB)	20
Serving Cell SINR (dB)	**Mobilis**
30 to50 (dB)	0,00%
25 to 30(dB)	18,93%

20 to25 (dB)	22,19%
15 to 20 (dB)	21,01%
10 to 15 (dB)	19,97%
0 to 10 (dB)	14,94%
-20 to0 (dB)	2,96%
% SINR >=0 (dB)	97,04%

The graphical distribution will be presented in the following:

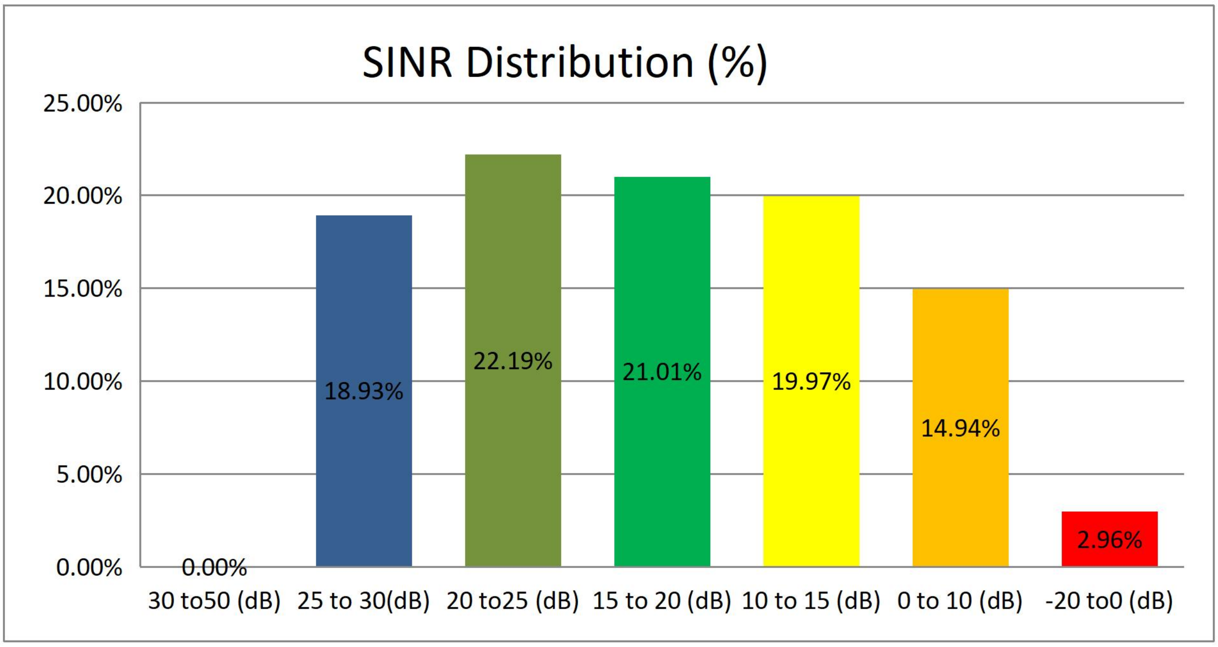

Figure 4.17: Histogram of SINR distribution in anti-clockwise direction.

Since the cumulative percentage attained is about 97.04% which is much more than 85% of t SINR that should be better than 0 db according to radio condition requirement, therefore the results suggests that the measured signal from the serving cell is strong and has a high power level compared to interference and noise so it provides reliable connectivity for users while moving in a mobile environment.

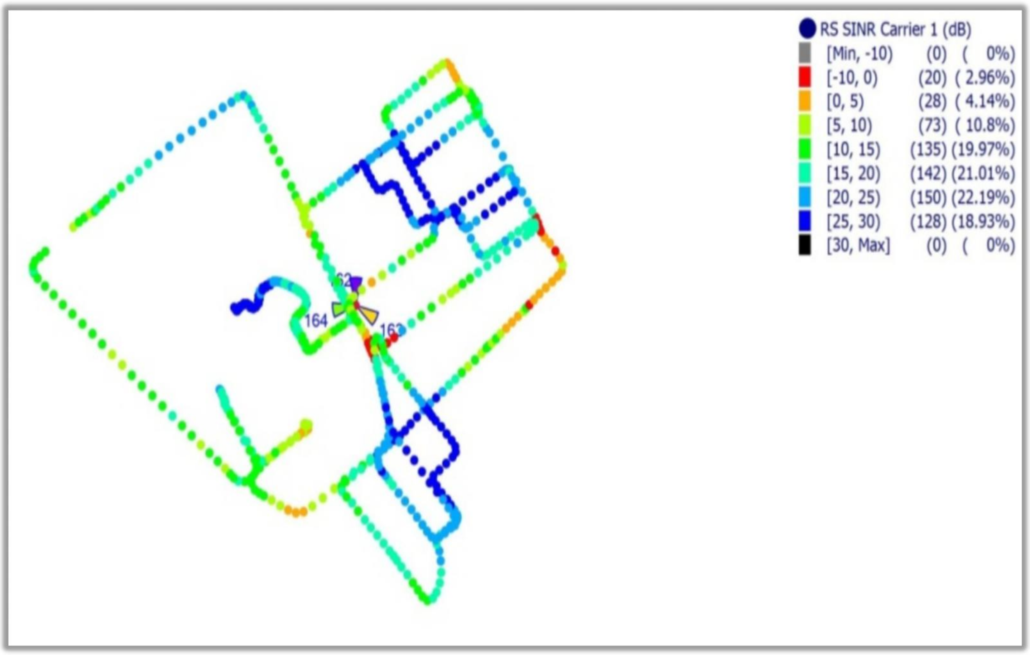

Figure 4.18: SINR map in anti-clockwise direction.

In the purpose of measuring the speed and performance of data transfer over this network, DL FTP throughput test was performed.

The following figure represents histogram which provides a visual representation of the DL FTP throughput (Mbps), encompassing the four RLC and PDCP measurements in the DT. It can be seen that observed that he maximum DL RLC throughput is nearly the same to the maximum DL PDCP throughput this is because the RLC layer handles additional functions such as segmentation/reassembly, error correction, and flow control, while the PDCP layer primarily focuses on header compression and encryption/decryption.

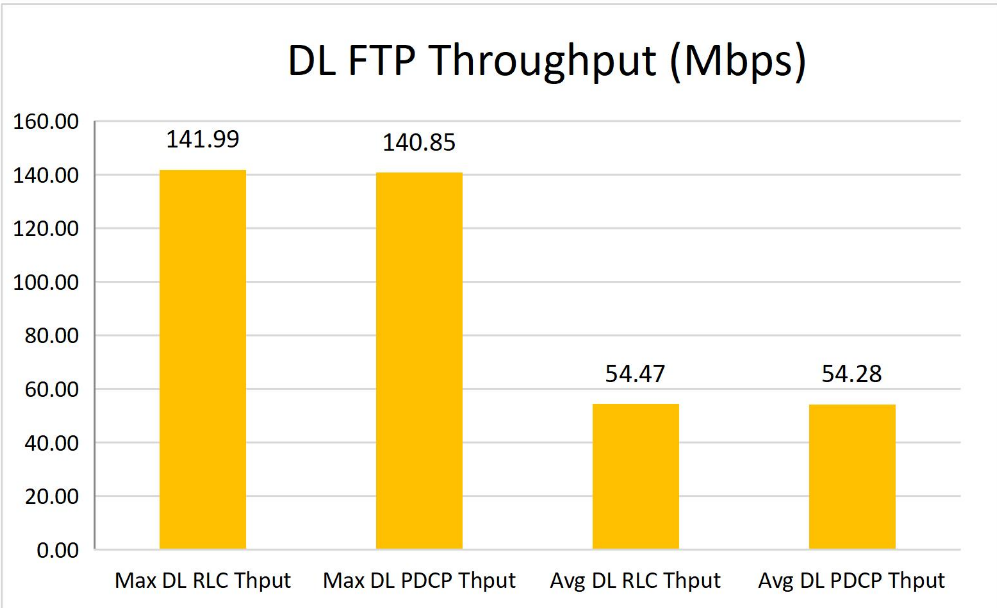

Figure 4.19: Histogram DL FTP throughput Clockwise direction

4.3 Conclusion

Performing drive test measurements allowed us to visualize the performance of the chosen site before and after the optimization. By collecting real time data, the results showed a significant increase in term coverage and throughput.

General conclusion

In conclusion, our project thesis aimed to assess and enhance the performance of LTE systems through the implementation of Massive MIMO technology. The objective was to monitor key performance indicators (KPIs) and conduct a drive test to evaluate the effectiveness of Massive MIMO in improving signal quality, strength Signal-to-Interference-plus-Noise Ratio (SINR) in LTE networks.

Through the comprehensive analysis of the results obtained, it is evident that Massive MIMO technology brings significant enhancements to LTE networks and it demonstrated that Massive MIMO outperforms traditional MIMO in all these aspects, leading to a more efficient and reliable wireless communication system. Moreover monitoring of KPIs using the OSS iMaster MEA software provided valuable insights into the performance improvements achieved in the specific geographical area of Biskra. Our internship was extremely beneficial to us both personally and professionally. We seized this opportunity to acquire new theoretical and practical knowledge in monitoring and optimization of a LTE network. Additionally, this project allowed us to gain proficiency in the OSS iMaster MEA optimization tool.

Overall, this project thesis successfully achieved its objectives by providing valuable insights into the impact of Massive MIMO on LTE performance. The findings contribute to the continuous improvement and development of mobile telecommunications in Algeria, ensuring that Mobilis remains at the forefront of technology advancements in the telecommunications market.

References

[1] T. Ali Khan et R. Babul , «Evolution of Mobile Communication Networks,» chez *National Conference on Recent Trends in Electronics and Communication Engineering* , Andhra Pradesh, 2020.

[2] P. MCLELLAN, «EDPS:Transitioning From 5G to 6G,» chez *Mobile is moving toward a convergence of connectivity, computing,control, and content.*, India, 2022.

[3] M. Salem, «Mobile Packet Core,» *LTE (4G) Network Architecture,* 8 June 2022.

[4] «LTE Architecture-Detailed Explanation,» 10 June 2022.

[5] O. Mangus, S. Shabnam, R. Stefan, F. Lars et M. Catherine, «SAE and the Evolved Packet Core,» *Driving the Mobile Broadband Revolution,* pp. 97, 99-140, 29 January 2010.

[6] M. Abdel Monem, «Communication Engineering Frontier Knowledge Base,» *What is the Difference between User Plane and Control Plane,* pp. 50-62, 30 November 2022.

[7] «HUAWEI,» *HCIA-LTE / 03-E-UTRAN protocol stack structure,* 27 01 2022.

[8] ERICSSON, «Long Term Evolution (LTE) : an introduction,» 2007.

[9] M. H, A. Iraj S, M. M.A et C. C.Y, «LTE physical layer: Performance analysis and evaluation,» 2019.

[10] B. Chacha, «LTE Frame Structure.pdf».

[11] L. S.B, G. Jyoti D et K. S.M, «Performance Evolution of SC-FDMA for Mobile Communication System,» 2016.

[12] Aviat NETWORKS, «Understanding FDD vs. TDD Microwave Systems,» 22 March 2023.

[13] «LTE Communication Channels,» *TutorialsPoint,* 2022.

[14] Z. Ali, A. Fedrik, M. Jonas, G. Ulf et D. Giuseppe, «Chapter 2 - NR Physical Layer: Overview,» *5G Physical Layer,* pp. 21-34, 2018.

[15] W. Eva, «MIMO (multiple input, multiple output),» *TechTarget,* 2021.

[16] «What is MIMO?,» *HUAWEI,* 2022.

[17] Q. Muammad, «Semi Round Robin Pairing qnd Scheduling for Uplink Virtual MultipleInput Multiple Output (VMIMO) Communications,» ISLAMABAD, 2017.

[18] G. Alexender S, «Singel-user MIMO,» *TechTarget,* 2021.

[19] T. Contributer, «multi-user MIMO,» *TechTarget,* 2021.

[20] D. N et M. G.D, «Space diversity for wireless communication system- A review,» *International Journal of Enginnering Science qnd Innovative Technology,* pp. 405-410, 2013.

[21] P. C.B, «Chapter 11 - MIMO communication for wireless networks,» chez *Transmission Techniques for Degital Communications*, 2016, pp. 399-433.

[22] Mathuranathan, «Diversity techniques and spatial multiplexing,» *GaussianWaves,* 6 Augest 2014.

[23] B. Emil, S. Luca, W. Henk et M. Thomas, «Massive MIMO is a Reality - What is Next? Five Promising Reasearch Directions for Antenna Arrays,» 2019.

[24] D. Ramraj, L. Praveen, C. Gaurav, Y. Ilsun et P. Giovanni, «Study and Invistigation on 5G Technology: A Systematic Review,» *MDPI,* 2021 December 2021.

[25] M. Jafar R, «Rectangular Grid Antennas with Various Boundary Square-Rings Array,» *GALE ACADEMIC ONEFILE,* February 2021.

[26] H. Sherief et M. Osamu, «Fast matrix inversion methods based on Chebyshev and Newton iteration for zero forcing precoding in massive MIMO systems,» *ResearchGate,* February 2020.

[27] S. Keith, «What is beamforming ang how does it make wireless better?,» *NETWORKWORLD,* 14 March 2022.

[28] «What is 5G beamforming, beam steering and beam switching with massive MIMO».*metaswitch.*

[29] Z. Long, Z. Hui, Z. Kan et X. Wei, Massive MIMO in 5G Networks:Selected Applications, Springers, 2018.

[30] «MU-MIMO Multi-user multiple-input multiple-output (antennas),» *TELECOM TRAINER,* 11 May 2023.

[31] «TDD or FDD is more Better for massive MIMO?,» *Moniem-Tech,* 9 September 2019.

[32] D. A, «Elements of Information Theory,» *Institute of Electric and Electronic Engineering ,* p. 5 - p. 6, 2022

[33] J. Yinji, X. Pengfei et G. Xinnian, «MIMO system capacity based on diffrent numbers of antennas,» *Results in Engineering,* September 2022.

[34] Mathuranathan, «Shannon theorem - demystified,» *GaussianWaves,* 23 April 2008.

[35] Nokia, «LTE Optimization Principles (RL50) Module 02,» p. 28, 2013.

[36] «LTE KPI Optimization : RRC Success Rate,» *Our Technology Planet,* 2023.

[37] «KPI Optimization: LTE ERAB Success Rate,» *Our Technology Planet,* 2023.

[38] Jessica, «Exploring The role Of Bearer Services In Telcommunication Networks,» *OpenWorldLearning,* 10 January 2023.

[39] *Our Technology Planet,* 2023.

[40] «Signal strength measure RSRP, RSRQ and SINR Refrence for LTE Cheat Sheet,» *POYTING,* 28 May 2021.