An-Najah National University

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Graduation Project Report 1

"4G LTE Handover Parameter Optimization Using Machine Learning Techniques "

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Table of Contents

List of Figures (LOF)

List of Tables (LOT)

Nomenclature or list of symbols

1G	First generation
2G	Second generation
3G	Third generation
3GPP	Third Generation Partnership Project
3GPP2	Third Generation Partnership Project 2
4G	Fourth generation
AM	Acknowledged mode
APN	Access point name
ARQ	Automatic repeat request
CDMA	Code division multiple access
CP	Cyclic Prefix
CS	Circuit switched
DCCH	Dedicated control channel
DL	Downlink
DTCH	Dedicated traffic channel
DSSS	Direct Sequence Spread Spectrum
eAN	Evolved access network
EDGE	Enhanced Data Rates for GSM Evolution
EIR	Equipment identity register
eNB	Evolved Node B
EPC	Evolved packet core
EPS	Evolved packet system
E-UTRAN	Evolved UMTS terrestrial radio access network
FDD	Frequency division duplex
FDMA	Frequency division multiple access
GGSN	Gateway GPRS support node
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GTP	GPRS tunneling protocol
HARQ	Hybrid ARQ
HSDPA	High speed downlink packet access
HSPA	High speed packet access
HSS	Home subscriber server
HSUPA	High speed uplink packet access
IEEE	Institute of Electrical and Electronics Engineers
ISI	Inter-Symbol Interference
IMT-Advanced	International Mobile Telecommunications Advanced
ITU	International Telecommunication Union
LTE	Long term evolution
LTE-A	LTE-Advanced
MAC	Medium access control
MIMO	Multiple-Input Multiple-Output
ME	Mobile equipment
MME	Mobility management entity

MT	Mobile termination
NAS	Non-access stratum
NS-3	Network simulator -3
OFDM	Orthogonal frequency division multiplexing
OFDMA	Orthogonal frequency division multiple access
PCRF	Policy and charging rules function
PDCP	Packet data convergence protocol
PDU	Protocol data unit
P-GW	Packet data network gateway
PAPR	Peak-to-Average Power Ratio
QoS	Quality of service
QPSK	Quadrature Phase Shift Keying
RAT	Radio Access Technology
RSCP	Received signal code power
RSRP	Reference signal received power
RSRQ	Reference signal received quality
RSSI	Received signal strength indicator
RB	Resource block
RLC	Radio link control
RRC	Radio resource control
SC-FDMA	Single carrier frequency division multiple access
SGSN	Serving GPRS support node
S-GW	Serving gateway
SIM	Subscriber identity module
SINR	Signal to interference plus noise ratio
SON	Self-organizing network
SRB	Signaling radio bearer
TB	Transport blocks
TCP	Transmission control protocol
TDD	Time division duplex
TDMA	Time division multiple access
TM	Transparent mode
TTI	Transmission time interval
TTT	Time to trigger
UDP	User datagram protocol
UE	User equipment
UICC	Universal integrated circuit card
UL	Uplink
UM	Unacknowledged mode
UMTS	Universal Mobile Telecommunication System
USIM	Universal subscriber identity module
UTRAN	UMTS terrestrial radio access network
WCDMA	Wideband code division multiple access
WiMAX	Worldwide Interoperability for Microwave Access
X2-AP	X2 application protocol

Abstract

The current project simulates an LTE network, LTE (Long Term Evolution) technology has emerged as a new standard in mobile communications. Due to barriers such as high initial costs and the need to maintain existing networks which are still widely used and profitable for Telcos, LTE network rollouts have been slow in some areas of the world. Although rollout has been slow in some areas, LTE coverage is continuing to grow and is set to become the first truly global mobile network standard. For this challenge, we use NS-3, a discrete-event network simulator that is regularly updated and maintained. First, we discuss the overall architecture of LTE and its components.

In addition, we describe some utilities of NS-3, as the latter we used the LTE-EPC model to create our topology with a script completely written in C++ using the LTE-EPC module as described by the NS-3 documentation. The topology consists of eNBs, femtocells, buildings, and UEs followed by propagation model and mobility model. Subsequently, we run some simulation scenarios using different values for specific variables. Finally, the output data for different case will analyze using MATLAB which is a powerful tool for realistic understanding, we plot the output result and compare it to understand the effect of each parameter we change it on the throughput.

Chapter 1: Introduction

1.1 History of Mobile Telecommunication Systems

The number of the mobile cellular subscribers has explosively grown in the last decade. The international Telecommunication Union (ITU) Statistics shows that there were six billion global mobile cellular subscribers in 2011 and is excepted to be more than six billion global mobile cellular subscribers in 2013 as shown in Figure 1.1.

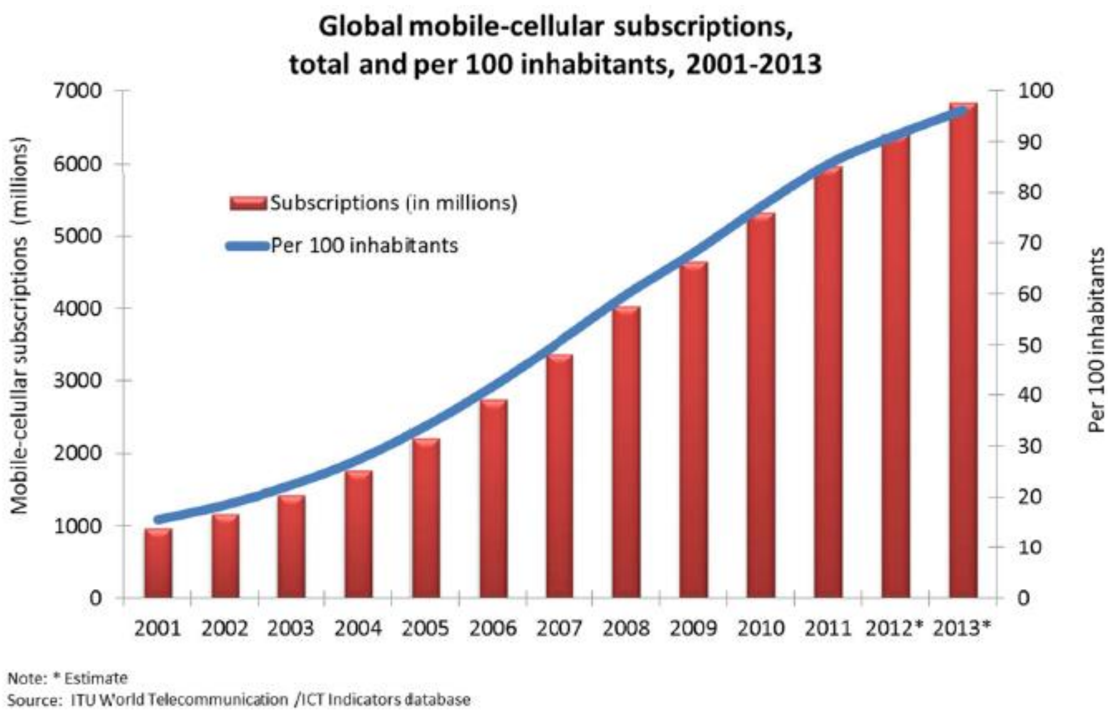


Figure 1.1 Global Mobile-Cellular Subscriptions (2001-2013)

Figure 1.2 3GPP Family Technology Evolution (1990 – 2014)

Figure 1.2 shows LTE and LTE-Advanced are parts of the technology evolutionary path beyond third generation (3G) technology, following GSM, GPRS, EDGE, UMTS, HSPA (HSDPA and HSUPA combined) and HSPA Evolution (HSPA+)

The first generation (1G) mobile system based on circuit switch technology was developed in early 1980. The 1G mobile cellular system was designed for voice telephony. Frequency Division Multiple Access (FDMA) technology was adopted to combine different telephony channels.

The second generation (2G) mobile cellular systems based on digital technology was developed in early 1990s. The 2G mobile cellular systems was designed for better call quality, security and more efficient usage of radio spectrum compared with the 1G systems. A number of multiple access methods were introduced Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) technologies.

The GSM is by far the most successful commercial mobile cellular system with 80.42% mobile cellular subscribers worldwide in September 2008. However, due to the increasing demand of the Internet access, these 2G mobile cellular systems, including GSM, could not satisfy the quality of service (QoS) of high-speed multimedia services due to their low data rate (i.e. up to 9.6 Kbps) of circuit switched services. Therefore, several mobile cellular system enhancements were standardized to overcome the limitation of 2G systems. General Packet Radio Services (GPRS) is a packet-switch based system which was known as 2.5G and it provides significant improvement in data rates compared with 2G mobile cellular systems.

The third generation (3G) mobile cellular system standardized by 3GPP is Universal Mobile Telecommunication System (UMTS). UMTS uses Wideband CDMA (WCDMA) technology based on Direct Sequence Spread Spectrum (DSSS) , and it was standardized in 3GPP Release 99 standard. UMTS was designed and deployed to be backward compatible with existing GSM and GPRS systems. A 3G mobile cellular system known as CDMA2000 was introduced by the 3GPP2 organization and it was backward compatible with existing CDMA One system.

1.2 The Need for LTE

For many years, voice calls dominated the traffic in mobile telecommunication networks. The growth of mobile data was initially slow, but in the years leading up to 2010 its use started to increase dramatically. To illustrate this, Figure 1.3 shows measurements by Ericsson of the total traffic being handled by networks throughout the world, in petabytes (million gigabytes) per month. The figure covers the period from January 2007 to July 2011, during which time the amount of data traffic increased by a factor of over 100. This trend is set to continue. For example, Figure 1.4 shows forecasts by Analysis the growth of mobile data by the introduction of flat rate charging schemes that permitted unlimited data downloads. That led to a situation where neither developers nor users were motivated to limit their data consumption. As a result of these issues, 2G and 3G networks started to become congested in the years around 2010, leading to a requirement to increase network capacity.

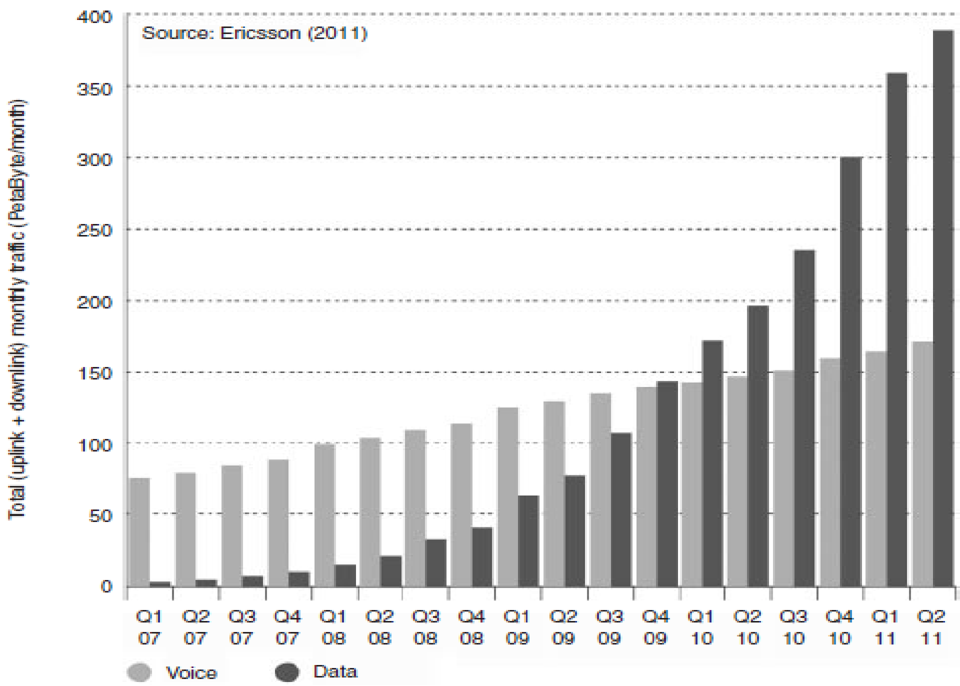


Figure 1.3 Measurements of voice and data traffic in worldwide mobile telecommunication networks

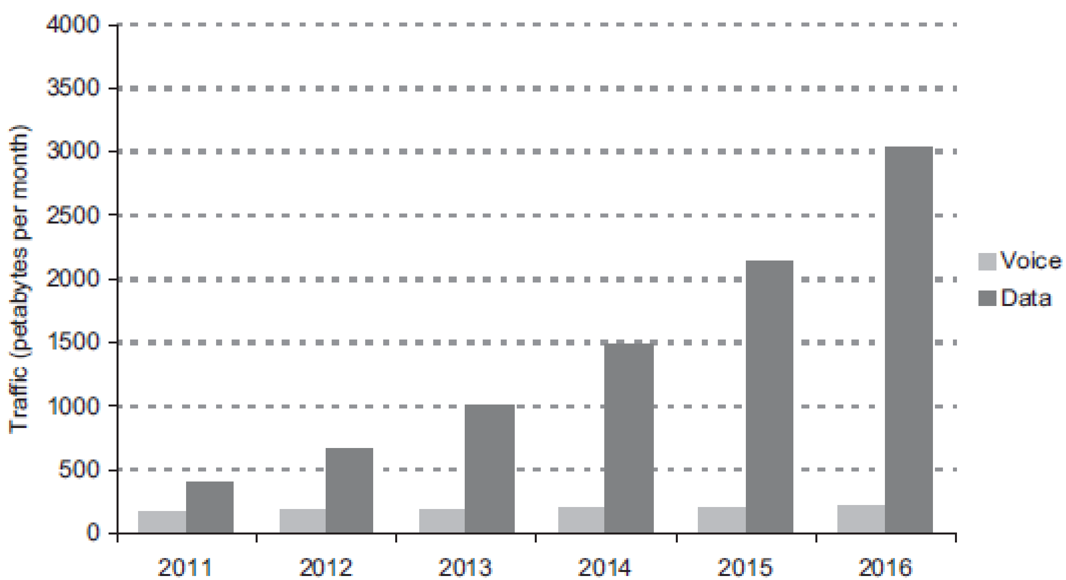


Figure 1.4 Forecasts of voice and data traffic in world wide mobile telecommunication networks.

LTE was required to deliver a peak data rate of 100 Mbps in the downlink and 50 Mbps in the uplink. This requirement was exceeded in the eventual system, which delivers peak data rates of 300 Mbps and 75 Mbps respectively. For comparison, the peak data rate of WCDMA, in Release 6 of the 3GPP specifications, is 14 Mbps in the downlink and 5.7 Mbps in the uplink. It cannot be stressed too strongly, however, that these peak data rates can only be reached in idealized conditions, and are wholly unachievable in any realistic scenario. A better measure is the spectral efficiency, which expresses the typical capacity of one cell per unit bandwidth. LTE was required to support a spectral efficiency three to four times greater than that of Release 6 WCDMA in the downlink and two to three times greater in the uplink. Latency is another important issue, particularly for time-critical applications such as voice and interactive games. There are two aspects to this. Firstly, the requirements state that the time taken for data to travel between the mobile phone and the fixed network should be less than five milliseconds, provided that the air interface is uncongested. There are also requirements on coverage and mobility. LTE is optimized for cell sizes up to 5 km, works with degraded performance up to 30 km and supports cell sizes of up to 100 km. It is also optimized for mobile speeds up to 15 km hr − 1, works with high performance up to 120 km hr − 1 and supports speeds of up to 350 km hr − 1. Finally, LTE is designed to work with a variety of different bandwidths, which range from 1.4 MHz up to a maximum of 20 MHz.

1.3 From LTE to LTE-Advanced

The design of LTE took place at the same time as an initiative by the International Telecommunication Union. In the late 1990s, the ITU had helped to drive the development of 3G technologies by publishing a set of requirements for a 3G mobile communication system, under the name International Mobile Telecommunications (IMT) 2000. The 3G systems noted earlier are the main ones currently accepted by the ITU as meeting the requirements for IMT-2000. The ITU launched a similar process in 2008, by publishing a set of requirements for a fourth generation (4G) communication system under the name IMT-Advanced. According to these requirements, the peak data rate of a compatible system should be at least 600 Mbps on the downlink and 270 Mbps on the uplink, in a bandwidth of 40 MHz. We can see right away that these figures exceed the capabilities of LTE.

Driven by the ITU’s requirements for IMT-Advanced, 3GPP started to study how to enhance the capabilities of LTE. The main output from the study was a specification for a system known as LTE-Advanced, in which the main requirements were as follows.

LTE-Advanced was required to deliver a peak data rate of 1000 Mbps in the downlink, and 500 Mbps in the uplink. In practice, the system has been designed so that it can eventually deliver peak data rates of 3000 and 1500 Mbps respectively, using a total bandwidth of 100MHz that is made from five separate components of 20MHz each. Note, as before, that these figures are unachievable in any realistic scenario. Finally, LTE Advanced is designed to be backwards compatible with LTE, in the sense that an LTE mobile can communicate with a base station that is operating LTE-Advanced and vice-versa.

Originally, the ITU intended that the term 4G should only be used for systems that met the requirements of IMT-Advanced. LTE did not do so and neither did mobile WiMAX 1.0 (IEEE 802.16e). Because of this, the engineering community came to describe these systems as 3.9G. These considerations did not, however, stop the marketing community from describing LTE and mobile WiMAX 1.0 as 4G technologies. Although that description was unwarranted from a performance viewpoint, there was actually some sound logic to it there is a clear technical transition in the move from UMTS to LTE, which does not exist in the move from LTE to LTE-Advanced.

1.4 Statement of the problem:

4G LTE is the future of new wireless technology for accessing high bandwidth data for various applications and voice call over VoIP. A major issue in 4G systems is to make the high bit rates available in a larger portion of the cell, especially to users in an exposed position in between several base stations. Certain components such as the circuit-switching elements are removed and Wireless LAN connectivity is added. Mobility control, Location management, Hand-overs, etc. have to be performed more efficiently in 4G. LTE is the technological path followed to achieve 4G network speeds. This project explains the LTE technology in details then use Ns-3 simulator to simulate a LTE network. in addition, use Matlab codes to analyze the output data.

1.5 Objectives of the work:

This project has been presented to optimize the LTE throughput through study different cases. The future work target to optimize handover parameter and the analyzed data will be used as input training data to the ML algorithms.

1.6 Organization of the report:

The 2nd chapter of this project present the architecture, protocol, access technique of LTE and the handover Mechanisms.

The 3rd chapter describes NS-3 simulation features and show simulation script run for this project.

In the 4th chapter, show the output results for different running cases and discuss the main point that affect the performance.

Finally, the 5th chapter concludes this project and discusses future work potential.

Chapter 2: System Architecture Evolution

This chapter covers the high-level architecture of LTE. It begins by describing the hardware components in an LTE network and by reviewing the software protocols that those components use to communicate. Then look in more detail at the techniques used for data transport in LTE, before discussing the state diagrams and the use of radio spectrum.

2.1 LTE and LTE-A Overview

Both LTE and LTE-A are purely packet switch radio access technologies that focus on providing a better quality of mobile services. LTE specification was designed to provide downlink peak rates of 100 Mbps, an uplink peak rates of 50Mbps, and increase the capacity, coverage, and speed of mobile wireless networks compared to previous 3G technologies. LTE-A supports even higher capacity, coverage and data rates (up to 1Gbps in downlink and up 500 Mbps in uplink) than LTE system.

LTE and LTE-A are designed to support spectrum flexibility in the following three ways:

a) LTE and LTE-A can be deployed with different duplexity: Frequency Division Duplexing (FDD), Time Division Duplexing (TDD) and half-duplex FDD. FDD made allows downlink and uplink transmission simultaneously working in different frequency bands while TDD made allows downlink and uplink transmission working in the same frequency band with different time slots, FDD are commonly deployed in paired spectrum., while TDD is commonly deployed in un-paired spectrum.

b) LTE and LTE-A support flexible standardized bandwidth in 1.25 MHz, 2.5 MHz,5 MHz,10 MHz, 15 MHz and 20 MHz as shown in Figure 1.5. Depending on the available bandwidth, the transmission bandwidth can be chosen by operators. A smaller bandwidth is suitable for LTE deployment using legacy mobile cellular bands whereas a larger bandwidth aims to provide higher data rates.

c) LTE and LTE-A support operation on different frequency bands and are compatible with any system deployed within 900 MHz, 2.1 GHz and 2.6 GHz spectrums.

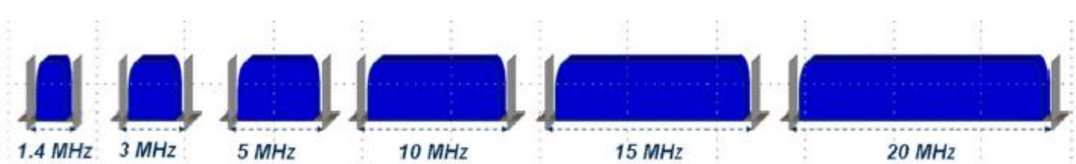


Figure 2.1 Scalable bandwidth in LTE

2.2 Architecture of LTE

2.2.1 High Level Architecture

Figure 2.2 reviews the high-level architecture of the evolved packet system (EPS). There are three main components, namely the user equipment (UE), the evolved UMTS terrestrial radio access network (E-UTRAN) and the evolved packet core (EPC). In turn, the evolved packet core communicates with packet data networks in the outside world such as the internet, private corporate networks or the IP multimedia subsystem. The interfaces between the different parts of the system are denoted Uu, S1 and SGi. The UE, E-UTRAN and EPC each have their own internal.

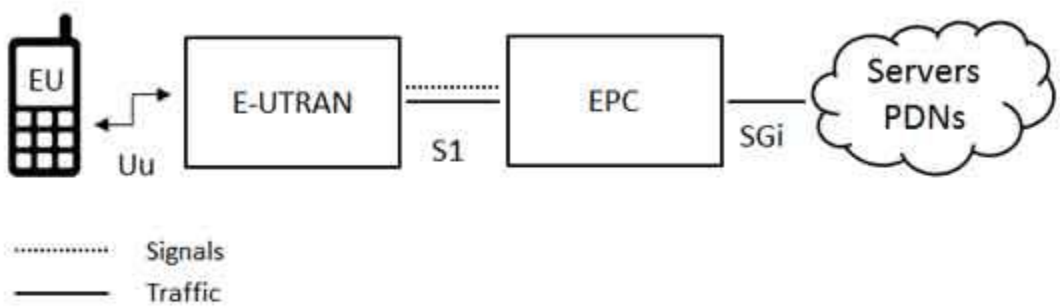


Figure 2.2 High level architecture of LTE.

2.2.2 User Equipment

Figure 2.3 shows the internal architecture of the user equipment. The internal architecture of the user equipment for LTE is identical to the one used by UMTS and GSM which is actually a Mobile Equipment (ME). The mobile equipment comprised of the following important modules:

- Mobile Termination (MT) : This handles all the communication functions.
- Terminal Equipment (TE) : This terminates the data streams.
- Universal Integrated Circuit Card (UICC) : This is also known as the SIM card for LTE equipments. It runs an application known as the Universal Subscriber Identity Module (USIM).

A USIM stores user-specific data very similar to 3G SIM card. This keeps information about the user's phone number, home network identity and security keys etc.

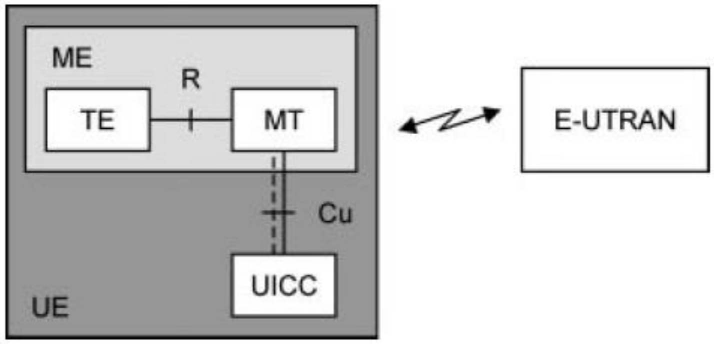


Figure 2.3 Internal architecture of the UE

2.2.3 Evolved UMTS Terrestrial Radio Access Network

The architecture of evolved UMTS Terrestrial Radio Access Network (E-UTRAN) has been illustrated in Figure 2.4.

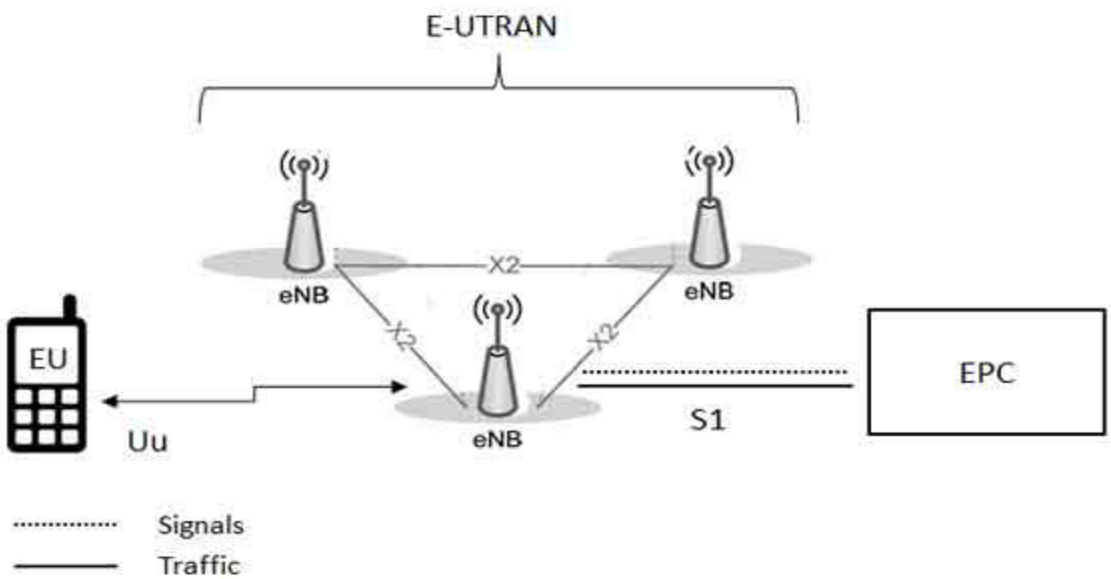


Figure 2.4 Architecture of (E-UTRAN)

The E-UTRAN handles the radio communications between the mobile and the evolved packet core and just has one component, the evolved base stations, called eNodeB or eNB. Each eNB is a base station that controls the mobiles in one or more cells. The base station that is communicating with a mobile is known as its serving eNB.

LTE Mobile communicates with just one base station and one cell at a time and there are following two main functions supported by eNB:

- The eBN sends and receives radio transmissions to all the mobiles using the analogue and digital signal processing functions of the LTE air interface.
- The eNB controls the low-level operation of all its mobiles, by sending them signaling messages such as handover commands.

Each eBN connects with the EPC by means of the S1 interface and it can also be connected to nearby base stations by the X2 interface, which is mainly used for signaling and packet forwarding during handover.

A home eNB (HeNB) is a base station that has been purchased by a user to provide femtocell coverage within the home. A home eNB belongs to a closed subscriber group (CSG) and can only be accessed by mobiles with a USIM that also belongs to the closed subscriber group.

2.2.4 The Evolved Packet Core (EPC) (The core network)

The architecture of Evolved Packet Core (EPC) has been illustrated in Figure 2.5. There are few more components which have not been shown in the diagram to keep it simple. These components are like the Equipment Identity Register (EIR) and Policy Control and Charging Rules Function (PCRF).

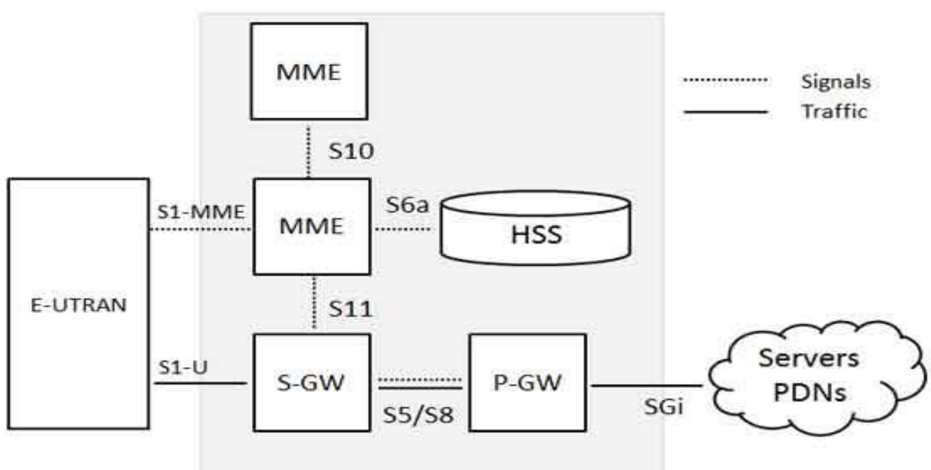


Figure 2.5 Architecture of Evolved Packet Core (EPC).

Below is a brief description of each of the components shown in the above architecture:

- The Home Subscriber Server (HSS) component has been carried forward from UMTS and GSM and is a central database that contains information about all the network operator's subscribers.
- The Packet Data Network (PDN) Gateway (P-GW) communicates with the outside world i.e. packet data networks PDN, using SGi interface. Each packet data network is identified by an access point name (APN). The PDN gateway has the same role as the GPRS support node (GGSN) and the serving GPRS support node (SGSN) with UMTS and GSM.
- The serving gateway (S-GW) acts as a router, and forwards data between the base station and the PDN gateway.
- The mobility management entity (MME) controls the high-level operation of the mobile by means of signalling messages and Home Subscriber Server (HSS).
- The Policy Control and Charging Rules Function (PCRF) is a component which is not shown in the above diagram but it is responsible for policy control decision-making, as well as for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF), which resides in the P-GW.

The interface between the serving and PDN gateways is known as S5/S8. This has two slightly different implementations, namely S5 if the two devices are in the same network, and S8 if they are in different networks.

2.2.5 LTE interfaces

Table 2.1. lists the reference points of the LTE network and gives a description of interfaces between EPS entities.

Reference point	Protocol	Description
LTE-Uu	E-UTRA (control plane and user plane)	An interface for the control and user planes between a UE and an E-UTRAN (eNB). The signaling connection over the LTE-Uu is the RRC connections represented by Signaling Radio Bearers (SRBs), and the user plane connection is the logical channels represented by Data Radio Bearers (DRBs).
X2	X2-AP (control plane) GTP-U (user plane)	An interface for the control and user planes between two eNBs. It is used during X2 handover and/or for Self Organizing Network (SON)-related functions. X2-AP protocol is used in the control plane and a GTP-U tunnel per bearer is provided for data forwarding in the use plane.
S1-U	GTP-U	An interface for the user plane between an E-UTRAN (eNB) and an S-GW. It provides a GTP tunnel per bearer.
S1-MME	S1-AP	An interface for the control plane between an E-UTRAN (eNB) and an MME.
S11	GTP-C	An interface for the control plane between an MME and an S-GW. It provides a GTP tunnel per user.
S5	GTP-C (control plane) GTP-U (user plane)	An interface defined between an S-GW and a P-GW for the control plane and user plane. The S5 interface provides a GTP tunnel per bearer for the user plane and GTP tunnel management (creation, modification and deletion) per user for the control plane. For inter-PLMN, however, an S8 interface is used instead. The S8 interface is out of the scope of this document and will be described in other LTE interworking document to follow.
S6a	Diameter	An interface for the control plane between an HSS and an MME. It exchanges user subscription and authentication information.
Sp	Diameter	An interface for the control plane between an SPR and a PCRF.
Gx	Diameter	An interface for the control plane between a PCRF and a P-GW. It transfers policy control and charging rules from the PCRF to the P-GW to support QoS policy and charging control.
Gy	Diameter	An interface for the control plane between an OCS and a P-GW.
Gz	GTP’	An interface for the control plane between an OFCS and a P-GW.
SGi	IP	An interface for the control and user planes between a P-GW and a PDN. The IETF-based IP packet forwarding protocols are used in the user plane while DHCP and RADIUS/Diameter protocols are used in the control plane.

Table 2.1 LTE interface

2.2.6 LTE Radio Protocol Architecture

The radio protocol architecture for LTE can be separated into **control plane** architecture and **user plane** architecture as shown in Figure 2.6:

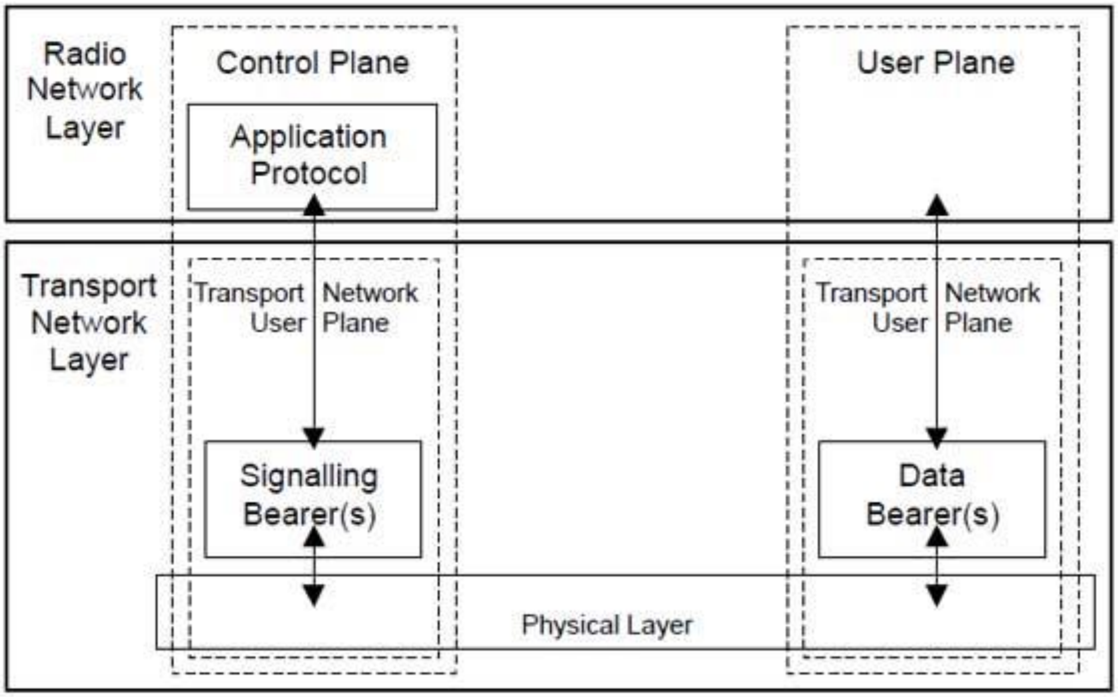


Figure 2.6 Radio protocol architecture for LTE

At user plane side, the application creates data packets that are processed by protocols such as TCP, UDP and IP, while in the control plane, the radio resource control (RRC) protocol writes the signalling messages that are exchanged between the base station and the mobile. In both cases, the information is processed by the packet data convergence protocol (PDCP), the radio link control (RLC) protocol and the medium access control (MAC) protocol, before being passed to the physical layer for transmission.

2.2.6.1 User Plane

The user plane protocol stack between the e-NodeB and UE consists of the following sub-layers:

- PDCP (Packet Data Convergence Protocol)
- RLC (radio Link Control)
- Medium Access Control (MAC)

On the user plane, packets in the core network (EPC) are encapsulated in a specific EPC protocol and tunneled between the P-GW and the eNodeB. Different tunneling protocols are used depending on the interface. GPRS Tunneling Protocol (GTP) is used on the S1 interface between the eNodeB and S-GW and on the S5/S8 interface between the S-GW and P-GW.

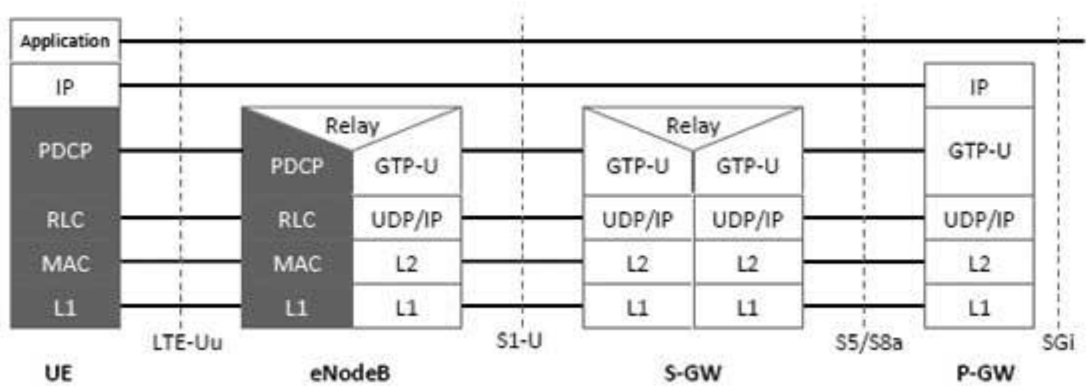


Figure 2.7 User plane protocol stacks

Packets received by a layer are called Service Data Unit (SDU) while the packet output of a layer is referred to by Protocol Data Unit (PDU) and IP packets at user plane flow from top to bottom layers

2.2.6.2 Control Plane

The control plane includes additionally the Radio Resource Control layer (RRC) which is responsible for configuring the lower layers.

The Control Plane handles radio-specific functionality which depends on the state of the user equipment which includes two states: idle or connected.

- Idle: The user equipment camps on a cell after a cell selection or reselection process where factors like radio link quality, cell status and radio access technology are considered. The UE also monitors a paging channel to detect incoming calls and acquire system information. In this mode, control plane protocols include cell selection and reselection procedures.
- Connected: The UE supplies the E-UTRAN with downlink channel quality and neighbour cell information to enable the E-UTRAN to select the most suitable cell for the UE. In this case, control plane protocol includes the Radio Link Control (RRC) protocol.

The protocol stack for the control plane between the UE and MME is shown below. The grey region of the stack indicates the access stratum (AS) protocols. The lower layers perform the same functions as for the user plane with the exception that there is no header compression function for the control plane.

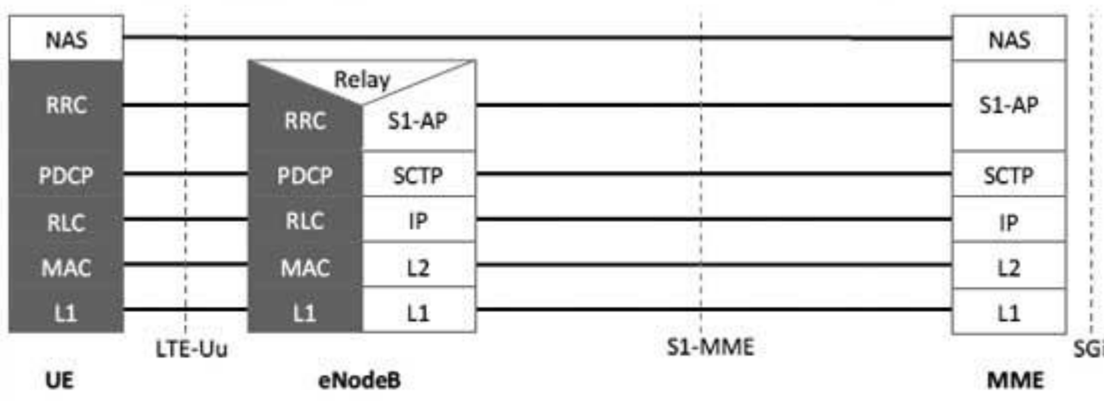


Figure 2.8 Control plane protocol stacks

2.2.7 LTE Protocol Stack Layers

Figure 2.9 shows all the layers available in E-UTRAN Protocol Stack.

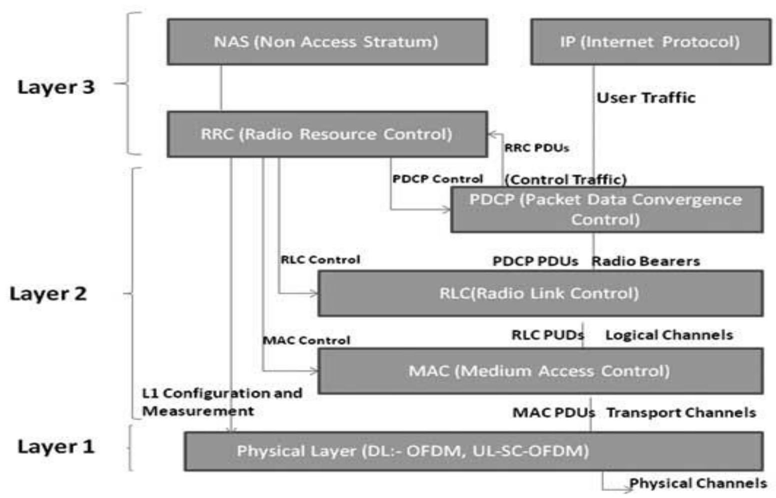


Figure 2.9 LTE Protocol Stack Layers

Physical Layer (Layer 1)

Physical Layer carries all information from the MAC transport channels over the air interface. Takes care of the link adaptation (AMC), power control, cell search (for initial synchronization and handover purposes) and other measurements (inside the LTE system and between systems) for the RRC layer.

Medium Access Layer (MAC)

MAC layer is responsible for Mapping between logical channels and transport channels, Multiplexing of MAC SDUs from one or different logical channels onto transport blocks (TB) to be delivered to the physical layer on transport channels, de multiplexing of MAC SDUs from one or different logical channels from transport blocks (TB) delivered from the physical layer on transport channels, Scheduling information reporting, Error correction through HARQ, Priority handling between UEs by means of dynamic scheduling, Priority handling between logical channels of one UE, Logical Channel prioritization.

Radio Link Control (RLC)

RLC operates in 3 modes of operation: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM).

RLC Layer is responsible for transfer of upper layer PDUs, error correction through ARQ (Only for AM data transfer), Concatenation, segmentation and reassembly of RLC SDUs (Only for UM and AM data transfer).

RLC is also responsible for re-segmentation of RLC data PDUs (Only for AM data transfer), reordering of RLC data PDUs (Only for UM and AM data transfer), duplicate detection (Only for UM and AM data transfer), RLC SDU discard (Only for UM and AM data transfer), RLC re-establishment, and protocol error detection (Only for AM data transfer).

Radio Resource Control (RRC)

The main services and functions of the RRC sublayer include broadcast of System Information related to the non-access stratum (NAS), broadcast of System Information related to the access stratum (AS), Paging, establishment, maintenance and release of an RRC connection between the UE and E-UTRAN, Security functions including key management, establishment, configuration, maintenance and release of point to point Radio Bearers.

Packet Data Convergence Control (PDCP)

PDCP Layer is responsible for Header compression and decompression of IP data, Transfer of data (user plane or control plane), Maintenance of PDCP Sequence Numbers (SNs), In-sequence delivery of upper layer PDUs at re-establishment of lower layers, Duplicate elimination of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM, Ciphering and deciphering of user plane data and control plane data, Integrity protection and integrity verification of control plane data, Timer based discard, duplicate discarding, PDCP is used for SRBs and DRBs mapped on DCCH and DTCH type of logical channels.

Non-Access Stratum (NAS) Protocols

The non-access stratum (NAS) protocols form the highest stratum of the control plane between the user equipment (UE) and MME.NAS protocols support the mobility of the UE and the session management procedures to establish and maintain IP connectivity between the UE and a PDN GW.

2.2.8 LTE Communication Channels

The information flows between the different protocols are known as channels and signals. LTE uses several different types of logical, transport and physical channel, which are distinguished by the kind of information they carry and by the way in which the information is processed.

- **Logical Channels**: Define **what type** of information is transmitted over the air, e.g. traffic channels, control channels, system broadcast, etc. Data and signalling messages are carried on logical channels between the RLC and MAC protocols.
- **Transport Channels**: Define **how is** something transmitted over the air, e.g. what are encoding, interleaving options used to transmit data. Data and signaling messages are carried on transport channels between the MAC and the physical layer.
- **Physical Channels**: Define **where is** something transmitted over the air, e.g. first N symbols in the DL frame. Data and signalling messages are carried on physical channels between the different levels of the physical layer.

2.3 MIMO (Multiple Input Multiple Output –or spatial multiplexing

One of the main problems that previous telecommunications systems have encountered is that of multiple signals arising from the many reflections that are encountered in antenna deployments. By using MIMO, these additional signal paths can be used to advantage and are able to be used to increase the throughput.

MIMO is used to increase the overall bitrate through transmission of two (or more) different data streams on two (or more) different antennas - using the same resources in both frequency and time, separated only through use of different reference signals - to be received by two or more antennas, see figure 2.10.

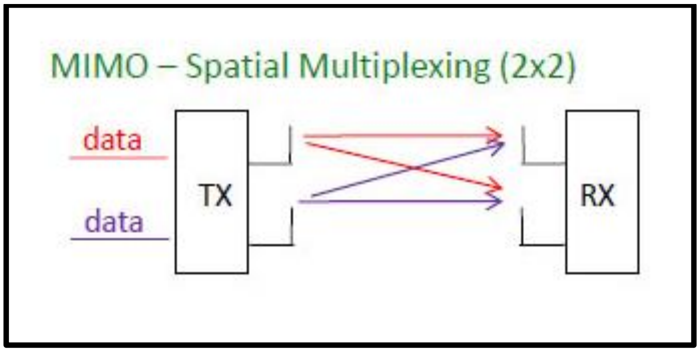


Figure 2.10 Simplified illustration of 2x2 MIMO (Spatial Multiplexing)

Two different data streams are transmitted on two TX antennas and received by two RX antennas, using the same frequency and time, separated only by the use of different reference signals.

One or two transport blocks are transmitted per TTI. A major change in LTE-Advanced is the introduction of 8x8 MIMO in the DL and 4x4 in the UL.

MIMO can be used when S/N (Signal to Noise ratio) is high, i.e. high-quality radio channel. For situations with low S/N it is better to use other types of multi-antenna techniques to instead improve the S/N, e.g. by means of TX-diversity, see figure 2.11.

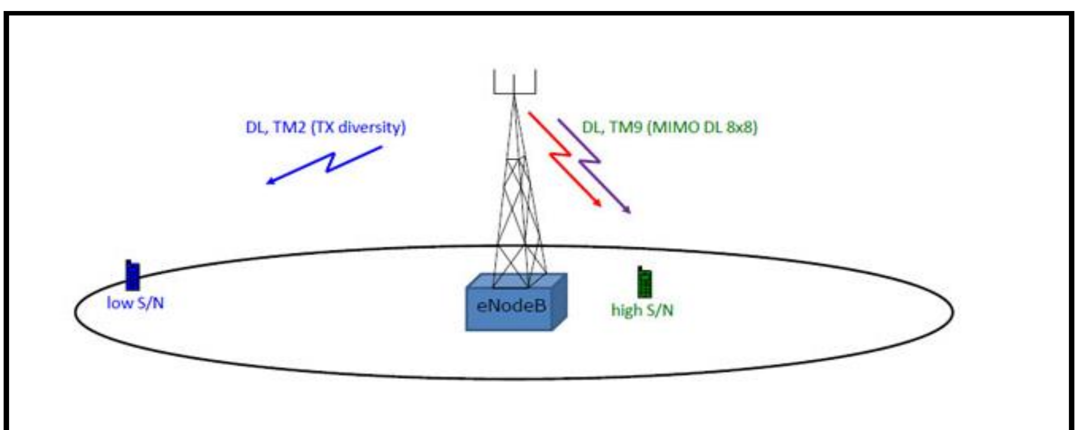


Figure 2.11 MIMO is recommended for high S/N and TX diversity is preferably used for low S/N scenarios

In multi-antenna techniques precoding is used to map the modulation symbols onto the different antennas. The type of precoding depends on the multi-antenna technique used as well as on the number of layers and the number of antenna ports. The aim with precoding is to achieve the best possible data reception at the receiver.

Note that the signal will be influenced by fading of various types, which can also be seen as some type of coding caused by the radio channel. To handle this, known reference signals will be transmitted together with the data, and used by the receiver for demodulation of the received signal.

From the beginning, LTE was designed so that the base station and mobile could both use multiple antennas for radio transmission and reception.

The most familiar is diversity processing, which increases the received signal power and reduces the amount of fading by using multiple antennas at the transmitter, the receiver or both. Diversity processing has been used since the early days of mobile communications.

In spatial multiplexing, the transmitter and receiver both use multiple antennas so as to increase the data rate. Spatial multiplexing is a relatively new technique that has only recently been introduced into mobile communications.

2.4 OFDMA AND SC-FDMA:

LTE and LTE-A use Orthogonal Frequency Division Multiple Access (OFDMA) which is a variant of OFDM (Orthogonal Frequency Division Multiplex) as a downlink access technology, while Single Carrier Frequency Division Multiple Access (SC-OFDMA) is adopted as the uplink access technology. The OFDMA is robust to Inter-Symbol Interference (ISI) and has immunity to frequency-selective fading of the mobile cellular channels. Figure 2.12 shows the difference between OFDMA and SC-FDMA when a series of Quadrature Phase Shift Keying (QPSK) data symbols are being transmitted.

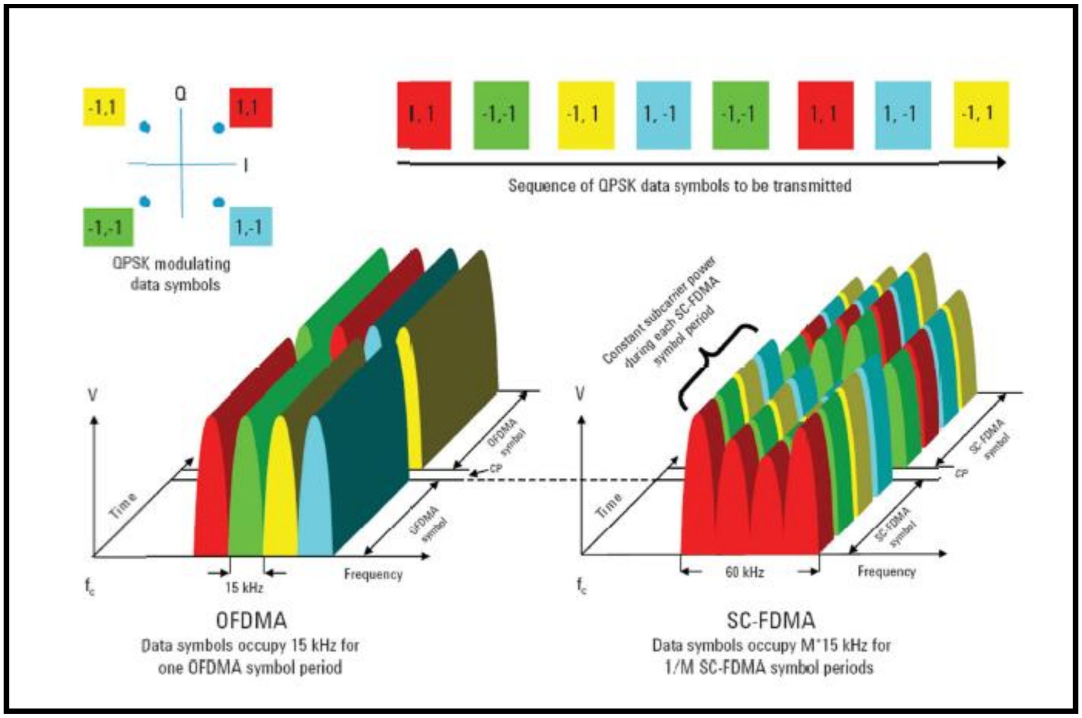


Figure 2.12 The difference between OFDMA and SC-FDMA Transmitting a Series of QPSK Data Symbols.

OFDMA divides the available bandwidth into multiple narrow-band equally spaced mutually orthogonal sub-carrier as shown in figure 2.13. Each sub carrier has a zero value at the sampling point of all other subcarriers. All sub-carriers in LTE have 15 KHz spacing regardless of the total bandwidth.

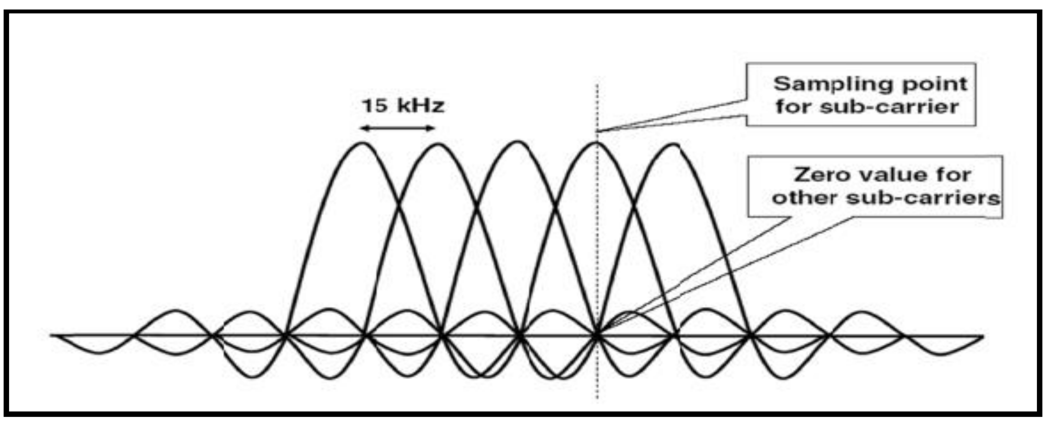


Figure 2.13 Sub-carrier orthogonally

In the time domain. A guard interval known as Cyclic Prefix (CP) is inserted between each OFDMA symbol in order to combat the ISI due to channel delay spread. Each time slot consists of seven OFDM symbols with short/normal CP or six OFDM symbols with long/extended CP. The frequency and time domain of an OFDM signal is represented in Figure 2.14. Note that OFDMA signal in the time domain and frequency domain refers to OFDMA symbol and sub-carrier, respectively.

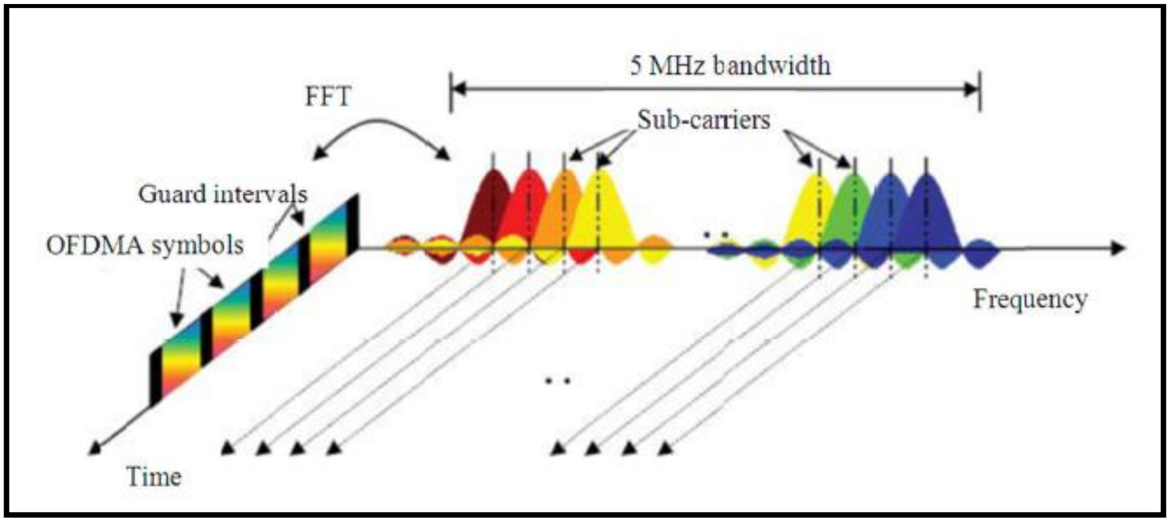


Figure 2.14 Time and frequency domains representation of the OFDMA signals

In mobile cellular systems, the UE is always power-limited. OFDMA has a high peak-to-average power (PAPR) ratio which leads to power-amplifier in-efficiency. This condition needs to be avoided in the UE side. Therefore, SC-FDMA technology was selected because it provides a more efficient usage of the battery in the UE is better suited for the uplink LTE.

2.5 Carrier frequency and EARFCN

The carrier frequency in the uplink and downlink is designated by the E-UTRA Absolute Radio Frequency Channel Number (EARFCN) in the range 0 – 262143. The relation between EARFCN and the carrier frequency in MHz for the downlink is given by the following equation, where FDL_low and NOffs-DL are given in Table 2.2 and NDL is the downlink EARFCN.

$$F_{DL} = F_{DL\_low} + 0.1(N_{DL} - N_{Offs\text{-}DL})$$

The relation between EARFCN and the carrier frequency in MHz for the uplink is given by the following equation where FUL_low and NOffs-UL are given in Table 2.2 and NUL is the uplink EARFCN.

$$F_{UL} = F_{UL\_low} + 0.1(N_{UL} - N_{Offs\text{-}UL})$$

E-UTRA Operating Band	Downlink			Uplink		
	F_{DL_low} (MHz)	$N_{Offs\text{-}DL}$	Range of N_{DL}	F_{UL_low} (MHz)	$N_{Offs\text{-}UL}$	Range of N_{UL}
1	2110	0	0 – 599	1920	18000	18000 – 18599
2	1930	600	600 – 1199	1850	18600	18600 – 19199
3	1805	1200	1200 – 1949	1710	19200	19200 – 19949
4	2110	1950	1950 – 2399	1710	19950	19950 – 20399
5	869	2400	2400 – 2649	824	20400	20400 – 20649
6	875	2650	2650 – 2749	830	20650	20650 – 20749
7	2620	2750	2750 – 3449	2500	20750	20750 – 21449
8	925	3450	3450 – 3799	880	21450	21450 – 21799
9	1844.9	3800	3800 – 4149	1749.9	21800	21800 – 22149
10	2110	4150	4150 – 4749	1710	22150	22150 – 22749
11	1475.9	4750	4750 – 4949	1427.9	22750	22750 – 22949
12	729	5010	5010 – 5179	699	23010	23010 – 23179
13	746	5180	5180 – 5279	777	23180	23180 – 23279
14	758	5280	5280 – 5379	788	23280	23280 – 23379
…						

Table 2.2: E-UTRA channel numbers

2.6 Resource Block (RB)

The smallest transmission unit in the downlink LTE-A system is known as a physical resource block (PRB) which consist of a pair resource blocks (RB). A PRB has a bandwidth of 180 KHz (12 sub-carrier) and a duration of 1ms (TTI) and a RB has a bandwidth of 180 KHz and a duration of 0.5 ms. A downlink time slot has a duration of 0.5 ms and contain either 6 or 7 OFDM symbols depending on the usage of long or short CP, respectively. A Resource element is the basic unit of Physical Resource in LTE. Each RB contains 72 resource element (Res) when long CP is used, while 84 RE when normal CP is used. The graphical representation of the downlink RB in LTE and available downlink bandwidth with associated number of RBs in LTE is shown in Figure 2.15 and Table 2.3, respectively.

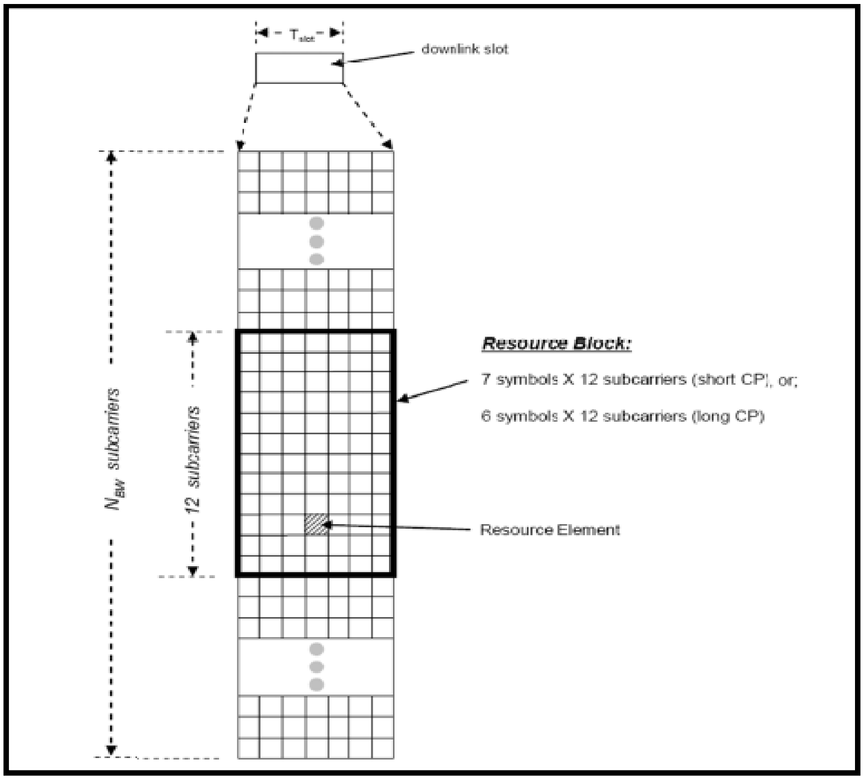


Figure 2.15 Downlink Resource Block in LTE.

Bandwidth (MHz)	1.25	3	5.0	10	15.0	20.0
Number of available RBs	6	15	25	50	75	100
Sub-carrier bandwidth (kHz)	15					
RB bandwidth (kHz)	180					

Table 2.3 Available Downlink Bandwidth Associated Number of RBs in LTE.

2.7 Geographical Coverage of 4G

4G will provide varied service quality according to distance from dense urban areas. Data rates in rural areas are expected to be lower than those enjoyed in dense urban areas. In the most likely case 4G coverage will extend to metropolitan areas and 3G systems will be utilized beyond them. The reason is partly economical, but cell-sizes also play a role in this. The 4G cell radius will, in general, most likely be smaller because the propagation loss is increased by operating at higher frequencies and at higher transmission bit rates the received signal level threshold must be higher than at lower bit rates, in order to compensate for the greater effect of noise at higher bit rates i.e to receive the signal at an adequate SNR (Signal to Noise Ratio).

2.8 Propagation models

The most important thing of designing and developing a mobile communication system is to get the knowledge about the characteristics of wireless communication, establish suitable propagation models and modeling the channels.

There are some well-known conventional prediction models such as the Okumura-Hata model, COST231-Hata model, ITU Terrain Model, Egli model, and Sakagami model.

The Okumura-Hata model is the most popular and classical model to predict the signal of the urban areas. This model is applicable for frequencies in the range 150–1920 MHz (although it is typically extrapolated up to 3000 MHz) and distances of 1–100 km. It can be used for base-station antenna heights ranging from 30–1000 m.

2.9 Handover

The handover procedure provides transferring a connected user's session from a base station to another base station without disconnecting the session. Handover is an important concept in mobile networks. The system must provide mobility to the users reliably and without dropping any of their calls / losing their data.

In mobile networks, there are two types of handover, hard and soft. In hard handover, the user disconnects from the source cell before connecting to the target cell. In soft handover, the user connects to the target cell before disconnecting from the source cell. In LTE, only hard handover is supported.

According to the characteristics of the source and target cells, there are two types of handover defined in LTE. These are:

- Intra E-UTRAN: In Intra E-UTRAN handover, handovers are performed between eNodeBs in LTE network. Handovers can be done over S1 or X2 interface.

- Inter RAT (Radio Access Technology): In Inter RAT Handover, handovers are performed between E-UTRAN and other 3GPP radio access technologies.

X2 Handover Procedure

- The source cell forwards the RRC Connection Reconfiguration message to the UE.
- The source cell forwards user data packets to the target cell with using X2 or S1 interface according to the interface used in the handover.
- After receiving the RRC Connection Reconfiguration message, the UE releases the resources of the source cell, synchronizes with the downlink of the target cell and tries to access the target cell with using the random-access procedure.
- If the UE can access the target cell, it sets a secure RC Connection Reconfiguration Complete message to the target cell to confirm the handover.

Measurement Reporting

In LTE, the responsibility of the handover decision is on the serving cell. To assist these decisions, UEs send measurement reports on specific conditions. There are two measurement metrics defined in LTE. These metrics are Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ) .

RSRP is defined as the average received power of all resource elements that carry cell specific reference signal. RSRP is calculated from the source eNodeB transmit power (Ps), the path-loss values from UE to the source eNodeB (Lue) and additional shadow fading.

RSRP values which UE receives is as follows:

$RSRP_{s,ue} = P_s - L_{ue} - L_{fad}$

RSRQ is defined as the ratio:

$N \times (RSRP/RSSI)$

Where N is the number of Resource Block (RB) and RSSI is Received Signal Strength Indicator. RSSI is the total received wideband power observed by the UE from all sources including thermal noise and interference generated in the target eNodeB, so RSRQ can express the relation between signal and interference plus noise. The RSRQ measurement provides additional information when RSRP is not sufficient to make a reliable handover or cell re-selection decision. In the procedure of handover, the LTE specification provides the flexibility of using RSRP, RSRQ, or both.

Reporting Criterion

The reporting criterion can be event triggered or periodic, for event-based triggers, the events defined in the specification are listed in Table 2.4

Event	Triggering Condition
A1	Serving becomes better than threshold
A2	Serving becomes worse than threshold
A3	Neighbor becomes offset better than serving
A4	Neighbor becomes better than threshold
A5	Serving becomes worse than threshold1and neighbor becomes better than threshold2

Table 2.4 Events and triggering conditions

This project simulate X2 Handover based on A3 event. In this type, handover is triggered at the UE on the basis of triggers defined by the network. Two triggers controlled the handover process, first one is named hysteresis, or "HO hysteresis", and the second one is called "Time to Trigger" (TTT). The UE makes periodic measurements of RSRP and RSRQ based on the RS received from the serving cell and from the strongest adjacent cells. In case the handover algorithm is based on RSRP values, handover is triggered when the RSRP value from an adjacent cell is higher than the one from the serving cell by a number of dBs equal to HO hysteresis; this condition has to be satisfied for a period equal to the TTT.

Chapter 3: Constraints, Standards/ Codes and Earlier course work

3.1 Constraints:

In this project, a module for the simulation of the LTE technology with the ns-3 simulator has been presented. NS3 simulator installed in Ubuntu which is a complete Linux operating system, freely available with both community and professional support. When using ubuntu for the first time some of difficulties will faced about how to deal with and be comfortable with it. NS3 is the best choice for simulating LTE Projects, nevertheless there are limitations to it. The output data files from this simulation is a numeric array have too much size exceeded 3 million rows and 7coulmns, So the running time for simulation script is too long, Due to this response for laptop became very slow. Even though the aims from this project is achieved.

3.2 Standards/Codes:

LTE standard is developed by the 3GPP (3rd Generation Partnership Project) and is specified in its Release 8 document series and LTE Advanced standard Which meeting the requirements of the IMT-Advanced standard, and was standardized by the (3GPP) as 3GPP Release 10.

The 3GPP 36 series of specifications, covers the "Evolved Universal Terrestrial Radio Access (E-UTRA)".

The 3rd Generation Partnership Project (3GPP) unites telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC), known as “Organizational Partners” and provides their members with a stable environment to produce the Reports and Specifications that define 3GPP technologies.

The project covers cellular telecommunications network technologies, including radio access, the core transport network, and service capabilities - including work on codecs, security, quality of service - and thus provides complete system specifications. The specifications also provide hooks for non-radio access to the core network, and for interworking with Wi-Fi networks.

For this project Ubuntu 18.04 LTS and ns-3 latest release 3.29 was used the goal of the ns-3 project is to develop a preferred, open simulation environment for networking research: it should be aligned with the simulation needs of modern networking research and should encourage community contribution, peer review, and validation of the software.

3.3 Earlier coursework:

Many of the experiences and skills gained through this project, by dealing with the Ubuntu operating system and Ns-3 simulator for the first time. Also, some of the courses that were studied during five years at the university, such as the programming course C++ that is helped to write a C++ simulation script in Ns-3 and mobile course which was focused in GSM and UMTS that enabled to understand the LTE. Finally, the MATLAB course, which make analysis and drawing data easier.

Chapter 4: Literature Review

Given the scarcity of the radio resources, the dynamic nature of the propagation environment and the variety of user mobility, maximizing the possible system throughput and minimizing the system delay are the major challenges that need to be addressed in the handover mechanisms in LTE and LTE-A systems. There are a number of studies which are focused on handover parameters optimization method.so there is enough information about handover in 4G that offers the opportunity to study handover deeply in project 2.

Machine learning (ML) is a category of algorithm that allows software applications to become more accurate in predicting outcomes without being explicitly programmed. The basic premise of machine learning is to build algorithms that can receive input data and use statistical analysis to predict an output while updating outputs as new data becomes available.

The aims of second project is using ML to optimize handover parameters. An NS3 network simulator will be used to simulate different 4G LTE handover scenarios, and the output of the NS3 will be used as input training data to the ML algorithms.

Chapter 5: Methodology

This project uses NS-3, a discrete event network simulator, to simulate LTE network topology by writing a simulation script using the LTE-EPC model, the ns-3 LTE model is a software library that allows the simulation of LTE networks, optionally including the Evolved Packet Core (EPC). The output data files from this simulation was analyzed using matlab codes to provide more clearly explanation about the relation between parameters.

5.1 NS-3

5.1.1 NS-3 Overview

NS-3 is a very strong and flexible tool that simulates network topologies. NS-3 has been developed for networking research and for education. NS-3 provides models of how packet data networks work and perform in a wide range of well-known networks. The most notable feature of NS-3 is that it is not limited to Internet Systems but also several users use NS-3 to model non-Internet-based systems. Going more in-depth, NS-3 is built as a system of software libraries that work together. User programs can be linked with these libraries giving the user the ability to expand them. For that reason, NS-3 is distributed in two releases: the source code and the development builds.

5.1.2 NS-3 Terminology

Before actually starting to write NS-3 code we should explain a few core concepts that are commonly used in networking and what meaning they have in NS-3.

A device that connects to a network is called a host or end-to-end system point. At NS-3 we call them nodes, as NS-3 is not specifically an Internet simulator, and are represented in C++ from the class Node and the provided methods. Usually, such devices are separated to system software and application software. The following figure shows how a Node is divided.

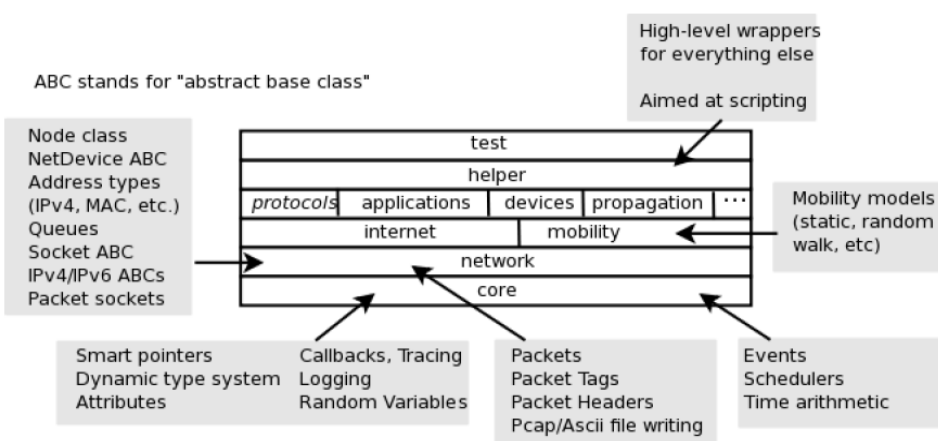


Figure 5.1 Node abstraction

5.2 Project Simulation Script Structure

In this section, an overview of the NS-3 network simulation script which has been used to create our LTE network topology using the Ns-3 LTE-EPC module. The network topology consists of a specific number of eNBs divided into 3 sectors, constant number of users, which can be change depend on running case. Most of the utilities described in the design documentation of the LTE-EPC module will be used giving more emphasis on how we will evaluate our LTE network rather than the design of the LTE-EPC module itself. Our simulation script is written in C++ program language and we will use figures that show an overview of the commands we used.

5.2.1 Basic Simulation Program:

In this project a simulation program writing using LTE-EPC model supported by NS-3. Configure the LTE-EPC parameter to give data files, here is some of the simulation program parameter that is needed to do an LTE-EPC simulation

- Create Hexagonal Topology which take several parameters such as:
    - Implement an EPC based on Point-to-Point links: use Point-to-Point links for the connection between the eNBs and SGW (S1-U interface) and among eNBs (X2-U and X2-C interface).
    - Mobility: configure the mobility model for all the nodes
    - macroUeBox that position users in random location
    - ltehelper: this will instantiate some common objects (e.g., the channel object) and provide the methods to adds eNBs and UEs and configure them.
    - number of eNB: changed depended on study case
    - nEnbsx: the macrocell position
    - inter site distance: distance between adjacent macrocell sites.
    - Epc: enable EPC mode
    - Transmission power for each macrocell which has a constant value of 43 dBm
    - EUTRA band selection: the selection of the working frequency of the propagation model has to be done with the standard ns-3 attribute system by means of the DlEarfcn and UlEarfcn.
    - eNB bandwidth

```
static void
CreateHexagonalTopology(Ptr<PointToPointEpcHelper>& epcHelper, MobilityHelper& mobility,
Box& macroUeBox, Ptr <LteHelper> lteHelper, uint32_t nEnbs, uint32_t nEnbsX, double
interSiteDistance,bool epc, double enbsTx, uint16_t enbEARFCN, uint16_t enbBandwidth)
```

Figure 5.2 Configure Hexagonal Topology

- **Configure eNB:**
  - each eNB has 3 sector(cell)
  - mobility model for each eNB is constant position mobility
  - use OkumuraHata propagation loss model in urban environment
  - set spectrum channel type as multimodel spectrum channel
  - configure air interface between eNBs which is X2 interface
  - use parabolic antenna model with beamwidth 70 º and maximum attenuation 20 dB
  - DlEarfcn and UlEarfcn which are set to 100 MHz and 18100 MHz respectively.
  - Downlink/uplink bandwidth configuration: configure to 25 MHz in both of them.

```
NodeContainer macroEnbs;
macroEnbs.Create (3 * nEnbs);
mobility.SetMobilityModel ("ns3::ConstantPositionMobilityModel");
lteHelper->SetAttribute("PathlossModel",StringValue("ns3::OkumuraHataPropagationLossModel"));
lteHelper->SetPathlossModelAttribute("Environment", StringValue("Urban"));
lteHelper->SetSpectrumChannelType ("ns3::MultiModelSpectrumChannel");
lteHelper->SetEnbAntennaModelType ("ns3::ParabolicAntennaModel");
lteHelper->SetEnbAntennaModelAttribute ("Beamwidth",   DoubleValue (70));
lteHelper->SetEnbAntennaModelAttribute ("MaxAttenuation",     DoubleValue (20.0));
lteHelper->SetEnbDeviceAttribute ("DlEarfcn", UintegerValue (enbEARFCN));
lteHelper->SetEnbDeviceAttribute ("UlEarfcn", UintegerValue (enbEARFCN + 18000));
lteHelper->SetEnbDeviceAttribute ("DlBandwidth", UintegerValue (enbBandwidth));
lteHelper->SetEnbDeviceAttribute ("UlBandwidth", UintegerValue (enbBandwidth));
lteHelper->AddX2Interface (macroEnbs);
```

Figure 5.3 Configure eNB

- **Configure user measurements:**
  - The active UE measurement configuration in a simulation is dictated by the selected so called "consumers". To select it createUsers is defined to take some parameters:
  - Attach user to eNB
  - Configure mobility user model which is "Steady State Random Way Point Mobility Model"
  - MacroUeBox: user position in random location
  - Ltehelper
  - Number of users per cell

- User's speed and here it assumed to be 16.67 m/s which almost equal 60Km/h

```
static void
CreateUsers(NodeContainer& macroUes, MobilityHelper& mobility,
Box& macroUeBox,Ptr <LteHelper> lteHelper, uint32_t nUes, double uesSpeed)
const int NUMBER_OF_UES = 151;
mobility.SetMobilityModel ("ns3::SteadyStateRandomWaypointMobilityModel");
DemoHelperII::CreateUsers(macroUes, mobility, macroUeBox, lteHelper, NUMBER_OF_UES, 16.67);
```

Figure 5.4 Configure UE Measurements

- **Configure Evolved Packet Core (EPC)**

The use of EPC allows to use IPv4 and IPv6 networking with LTE devices. In other words, you will be able to use the regular ns-3 applications and sockets over IPv4 and IPv6 over LTE, and also to connect an LTE network to any other IPv4 and IPv6 network you might have in your simulation.

In EPC the traffic used is "non-guaranteed bit rate video TCP default"

```
static void
CreateEPC(Ptr<PointToPointEpcHelper>& epcHelper, Ptr <LteHelper> lteHelper,
NodeContainer& macroUes, bool useUdp, bool epcDl, bool epcUl, uint16_t nBearersPerUe)
```

Figure 5.5 Configure EPC

- **Configure Handover**

Handover procedure can also be triggered "automatically" by the serving eNodeB of the UE. The logic behind the trigger depends on the handover algorithm currently active in the eNodeB RRC entity. Programmer may select and configure the handover algorithm that will be used in the simulation.

In this simulation the type of handover algorithm used is the "Strongest Cell" handover algorithm named as "A3 Rsrp handover algorithm"

```
Ptr <LteHelper> lteHelper = CreateObject<LteHelper> ();
lteHelper->SetHandoverAlgorithmType("ns3::A3RsrpHandoverAlgorithm");
```

Figure 5.6 Configure Handover

5.2.2 Configuration Parameters

In this section configuration parameters of the objects that are being used for the simulation will be specified.

This simulation the interested parameters that changed to read theirs effect on throughput, sinr and capacity values are:

- Distance between adjacent macrocell sites.
- Number of users per cell.
- Number of eNB.

5.2.3 Configure the desired output

There are many output data files produced but the desired outputs from this simulation:

- The users' distribution over cells.
- The received bytes for each cell that's need to measure the throughput
- SINR

This output is existing in "DlRlcStats" & " DlRsrpSinrStats" files.

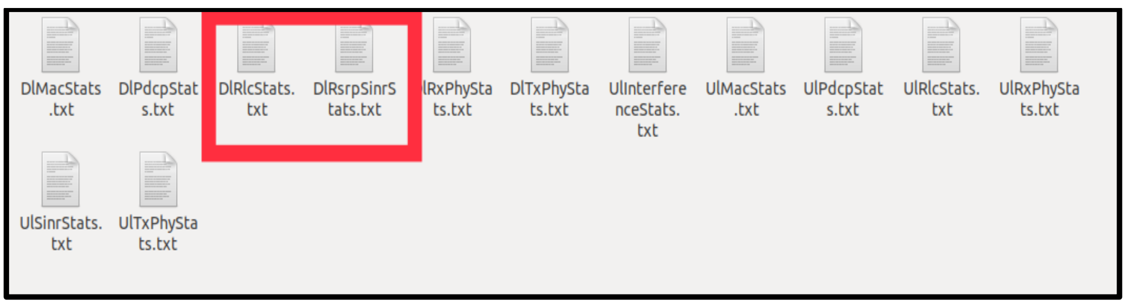


Figure 5.7 Output Data Files

% start	end	CellId	IMSI	RNTI	LCID	nTxPDUs	TxBytes	nRxPDU	RxBytes	delay	stdDev	min	max	PduSize	stdDev	min	max
3	3.25	6	1	1	4	6	2064	6	2064	008833	0.002858	0.003	0.01	344	474.387	56	1184
3	3.25	1	2	2	4	7	2066	7	2066	0.005	0.005292	0.003	0.017	295.143	426.329	56	1184
3	3.25	5	3	39	4	1	60	1	60	0.01	0	0.01	0.01	60	0	60	60
3	3.25	2	4	13	4	5	2008	4	824	.00825	0.006702	0.003	0.017	206	294.673	56	648
3	3.25	4	5	16	4	3	768	3	768	005333	0.004041	0.003	0.01	256	339.482	60	648
3	3.25	5	6	167	4	1	60	1	60	0.003	0	0.003	0.003	60	0	60	60
3	3.25	5	7	186	4	3	824	3	824	0.003	0	0.003	0.003	274.667	324.896	56	648
3	3.25	5	8	139	4	1	60	1	60	0.003	0	0.003	0.003	60	0	60	60
3	3.25	9	9	6	4	1	60	1	60	0.003	0	0.003	0.003	60	0	60	60
3	3.25	8	10	3	4	5	2008	5	2008	.0086	0.003131	0.003	0.01	401.6	506.38	56	1184
3	3.25	1	11	15	4	3	768	3	768	0.01	0.012124	0.003	0.024	256	339.482	60	648
3	3.25	5	12	153	4	3	769	3	769	007667	0.008083	0.003	0.017	256.333	296.169	60	597
3	3.25	2	13	18	4	6	2010	6	2010	005333	0.003615	0.003	0.01	335	361.217	56	903
3	3.25	5	14	127	4	1	60	1	60	0.003	0	0.003	0.003	60	0	60	60
3	3.25	5	15	141	4	1	60	1	60	0.01	0	0.01	0.01	60	0	60	60
3	3.25	5	16	85	4	1	60	1	60	0.003	0	0.003	0.003	60	0	60	60
3	3.25	1	17	1	4	1	60	1	60	0.003	0	0.003	0.003	60	0	60	60
3	3.25	9	18	7	4	6	2010	5	1791	.0156	0.011502	0.003	0.024	358.2	425.38	56	967
3	3.25	5	19	21	4	1	60	1	60	0.003	0	0.003	0.003	60	0	60	60
3	3.25	7	20	31	4	5	2008	5	2008	.0058	0.003834	0.003	0.01	401.6	506.38	56	1184
3	3.25	6	21	2	4	6	2064	6	2064	.0065	0.003834	0.003	0.01	344	474.387	56	1184
3	3.25	7	22	1	4	3	768	3	768	012333	0.008083	0.003	0.017	256	339.482	60	648
3	3.25	7	23	33	4	6	3839	5	2008	.0044	0.003131	0.003	0.01	401.6	506.38	56	1184
3	3.25	5	24	24	4	1	60	1	60	0.003	0	0.003	0.003	60	0	60	60

Figure 5.8 DlRlcStats File

% time	cellId	IMSI	RNTI	rsrp	sinr	ComponentCarrierId
0.200214	1	20	0	1.38907e-11	29284.1	0
0.200214	1	27	0	5.31797e-14	112.113	0
0.200214	1	35	0	6.86206e-15	14.4665	0
0.200214	1	64	0	4.59014e-14	96.7686	0
0.200214	1	70	0	9.11894e-14	192.244	0
0.200214	1	95	0	4.05727e-14	85.5348	0
0.200214	1	124	0	8.24175e-14	173.751	0
0.200214	1	127	0	1.19654e-14	25.2252	0
0.200214	1	129	0	1.56336e-14	32.9586	0
0.200214	1	137	0	8.48864e-15	17.8956	0
0.200214	1	144	0	7.94178e-15	16.7427	0
0.200214	1	151	0	1.93378e-13	407.676	0
0.200214	2	1	0	5.83455e-14	123.003	0
0.200214	2	15	0	1.03505e-14	21.8208	0
0.200214	2	16	0	7.67682e-15	16.1842	0
0.200214	2	21	0	1.67509e-13	353.14	0
0.200214	2	38	0	2.49239e-13	525.442	0
0.200214	2	54	0	7.76592e-15	16.372	0
0.200214	2	83	0	1.10078e-13	232.064	0
0.200214	2	96	0	3.75276e-15	7.91152	0
0.200214	2	113	0	3.83769e-13	809.055	0
0.200214	2	119	0	7.67942e-14	161.896	0
0.200214	2	120	0	2.00721e-13	423.158	0
0.200214	2	135	0	1.91508e-13	403.733	0
0.200214	2	145	0	8.58784e-14	181.048	0
0.200214	3	23	0	3.62537e-15	7.64294	0
0.200214	3	30	0	1.47002e-13	309.907	0
0.200214	3	52	0	6.75521e-14	142.412	0
0.200214	3	71	0	1.87637e-15	3.95574	0
0.200214	3	107	0	7.63749e-14	161.012	0
0.200214	3	121	0	2.89323e-14	60.9945	0
0.200214	3	126	0	1.1046e-14	23.287	0
0.200214	3	132	0	9.67659e-15	20.4	0
0.200214	4	3	0	1.73511e-13	365.794	0

Figure 5.9 DlRsrpSinrStats File

5.3 Matlab Code

After getting data files from NS-3 simulation, these files which contain data about cell id's, throughput and signal to interference and noise ratio (SINR) for each user. Now, MATLAB optimize these files to be clearer/more clarified.

MATLAB get the files and store it in arrays for illustration. It sorts the data for each value of cell id to get the average number of users for each cell.

And for these sorted it calculate the throughput from received bytes column -in data file- and store it in a new array for plotting.

MATLAB. get a new file from NS-3 simulation which is signal to interference and noise ratio (SINR) file and sort its data refers to cell id's then get the average values for each cell and convert it to decibel values.

Finally, MATLAB has arrays /vectors for average number of users for each cell, throughput, signal to interference and noise ratio and cell id. Now it can plot this file more sufficiently.

Chapter 6: Results and Analysis

In this chapter some scenarios have been run for LTE simulation, the first one when the number of eNBs is variable while the distance between them and number of users are constant. The second one when the distance between eNBs is variable while the number of eNBs and the number of users is constant. And the third is the number of users is variable while the number of eNBs and the distance between eNBs are constants. All the experiments have been executed on Ubuntu 18.04 LTS and NS-3 version 3.29.

❖ Case One: Variable eNB

In this case the number of eNBs is variable while the distance between it and number of users are constant as shown in Table 6.1.

Number of eNB	Distance between eNB	Number of users
3	500	151
7	500	151
9	500	151

Table 6.1 The parameters for variable eNB with distance 500m

Then the same scenario is repeated but with different distance (750m) as show in Table 6.2.

number of eNB	distance between eNB	number of users
3	750	151
7	750	151
9	750	151

Table 6.2 The parameters for variable eNB with distance 750m

CASE ONE:

- **The Average Number of User per Cell per Second for variable eNBs and distance 500m.**

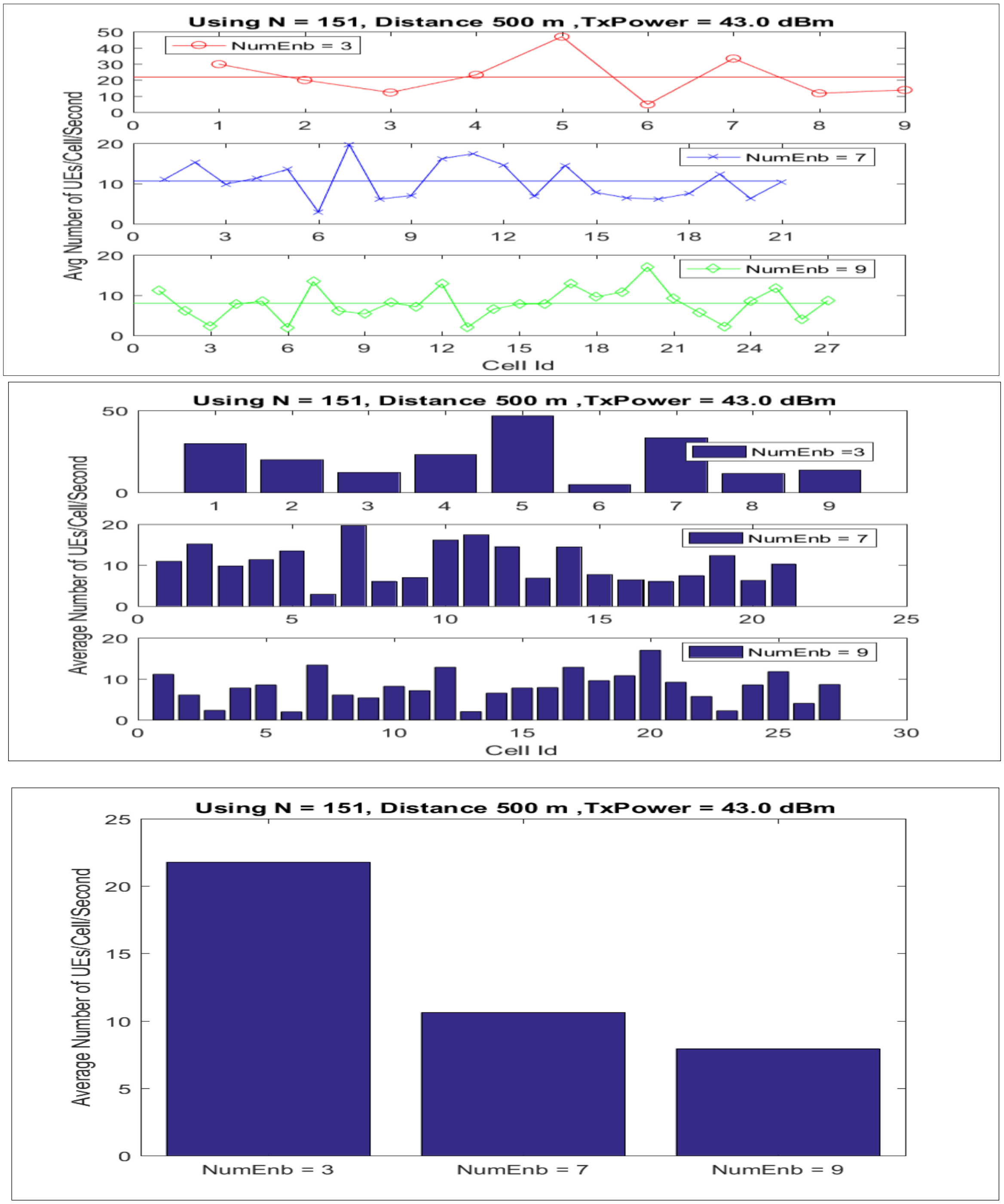


Figure 6.1 Average Number of User Per Cell with Variable eNBs and distance 500m

- **Average Throughput per cell for variable eNBs and distance 500m.**

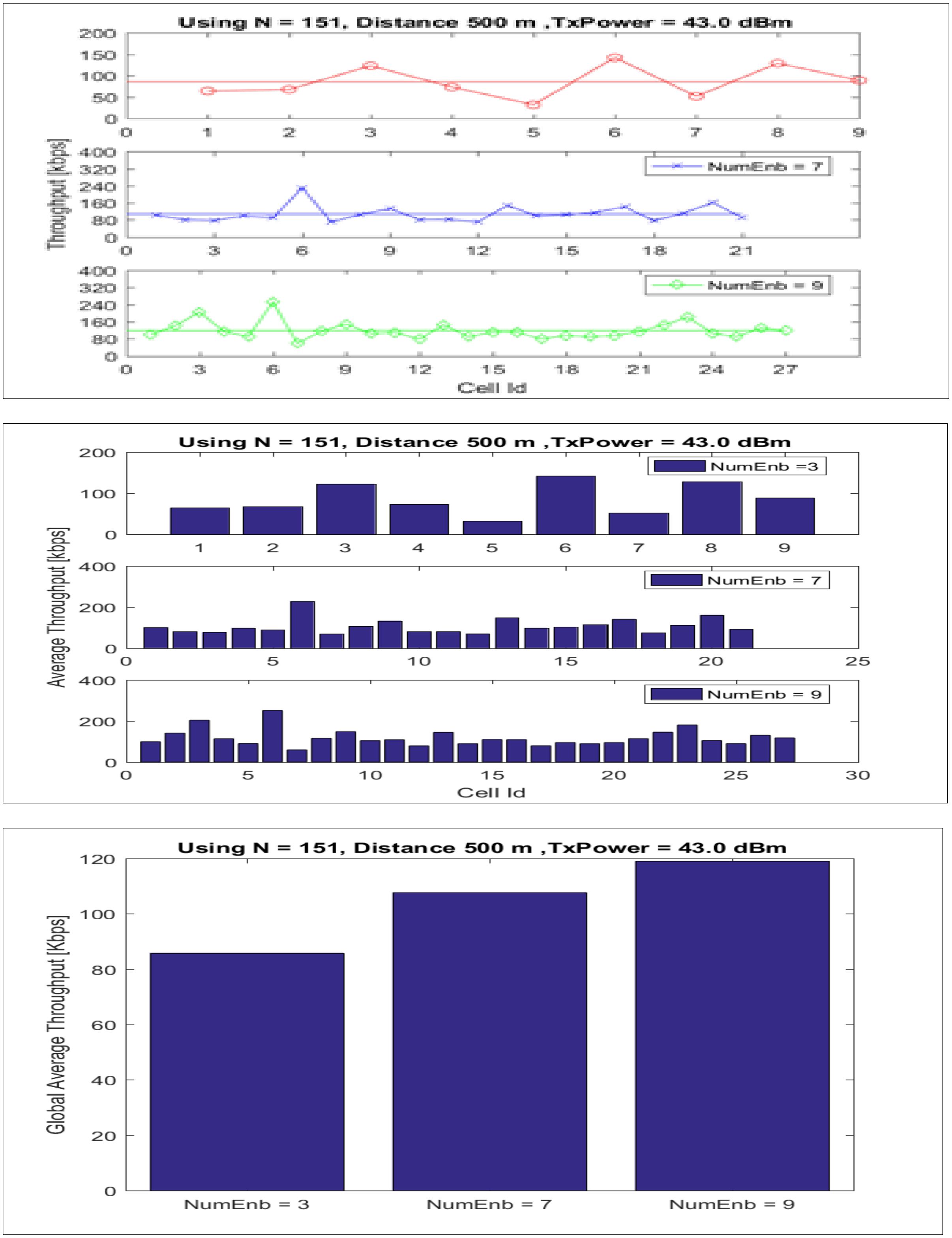


Figure 6.2 Average Throughput with Variable eNBs and distance 500m

- **Average SINR per cell for variable eNBs and distance 500m.**

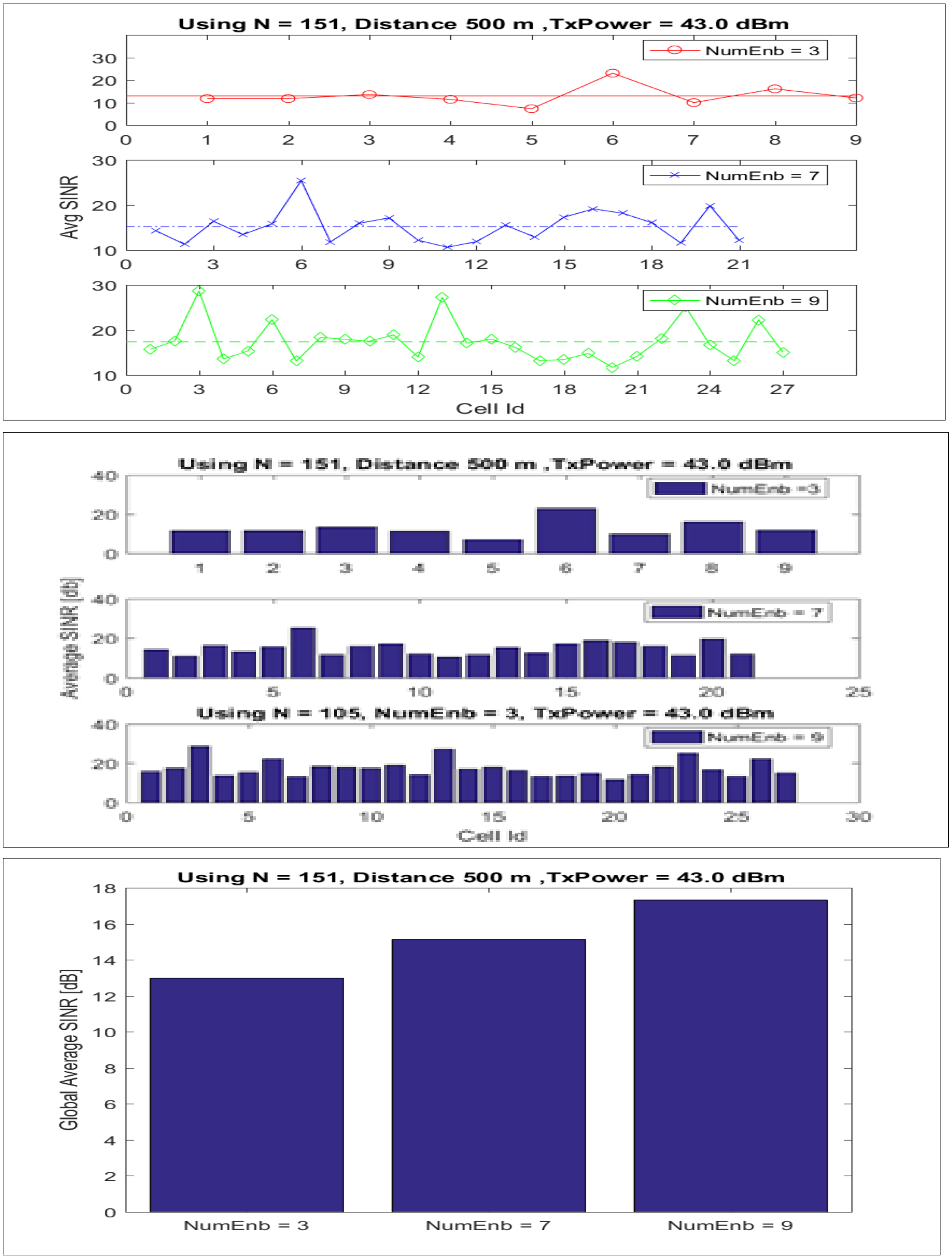


Figure 6.3 Average SINR with Variable eNBs and distance 500m

- **The Average Number of User per Cell per Second for variable eNBs and distance 750m.**

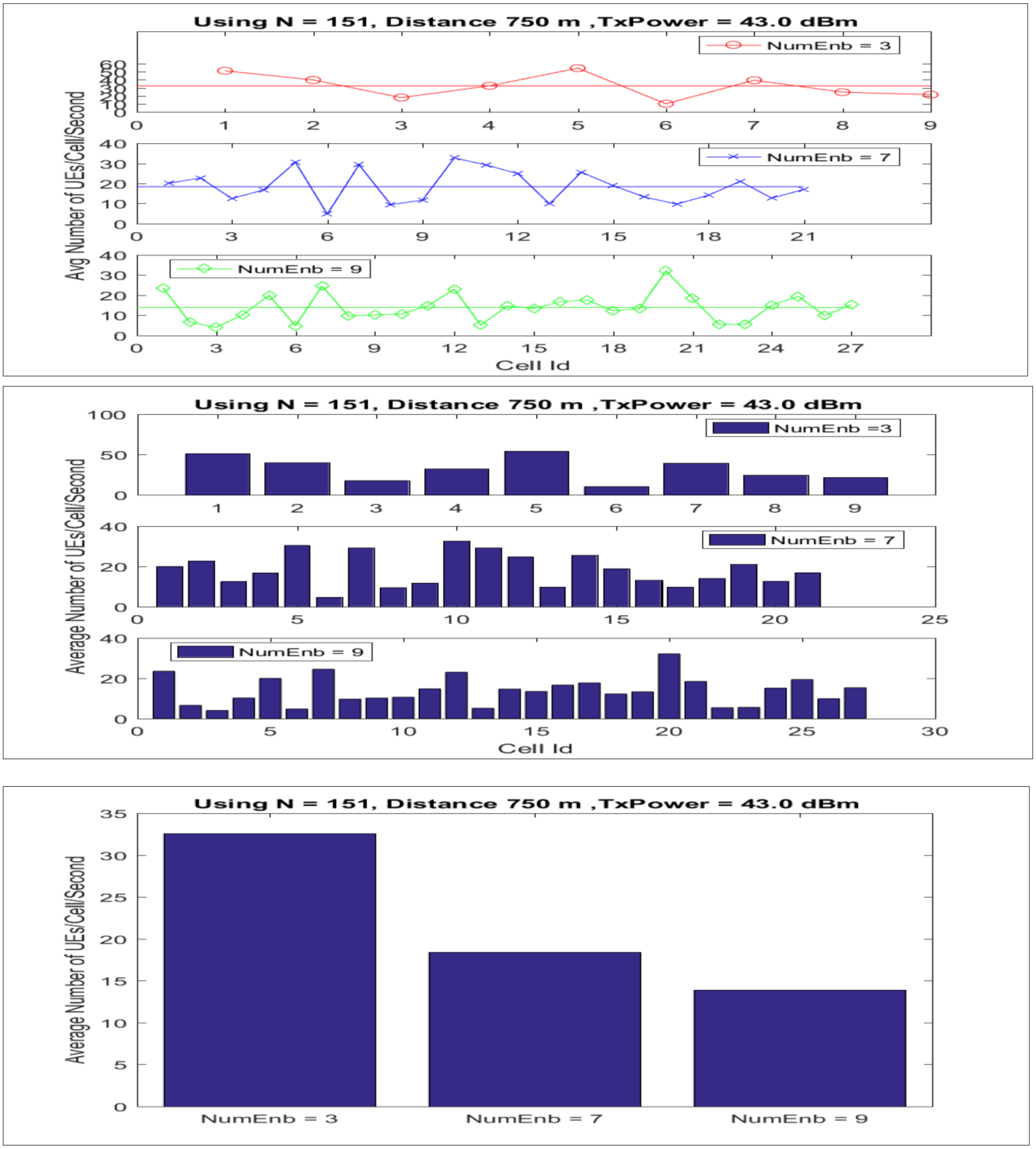


Figure 6.4 Average Number of User Per Cell with Variable eNBs and distance 750m

- **Average Throughput per cell for variable eNBs and distance 750m.**

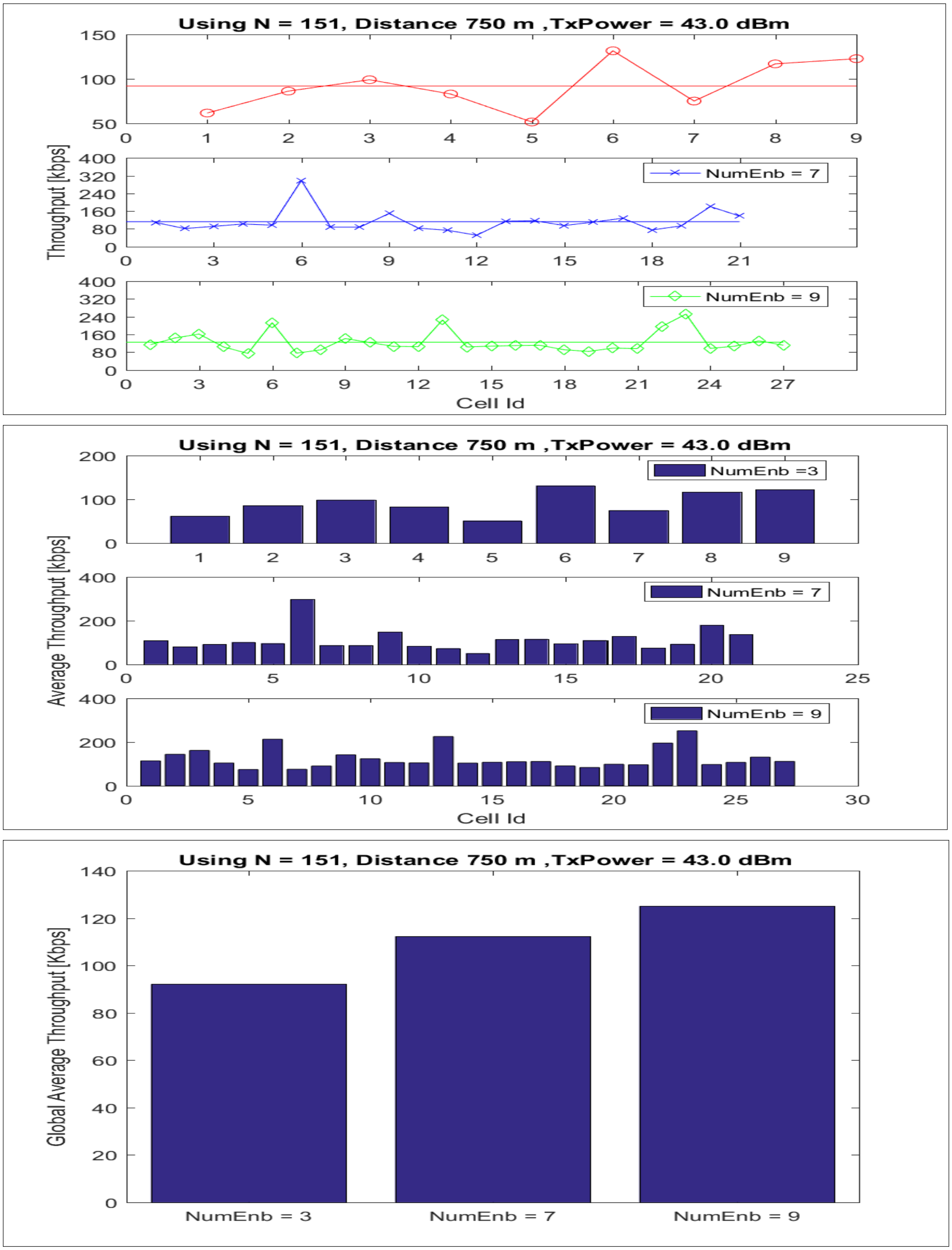


Figure 6.5 Average Throughput with Variable eNBs and distance 750m

- **Average SINR per cell for variable eNBs and distance 750m.**

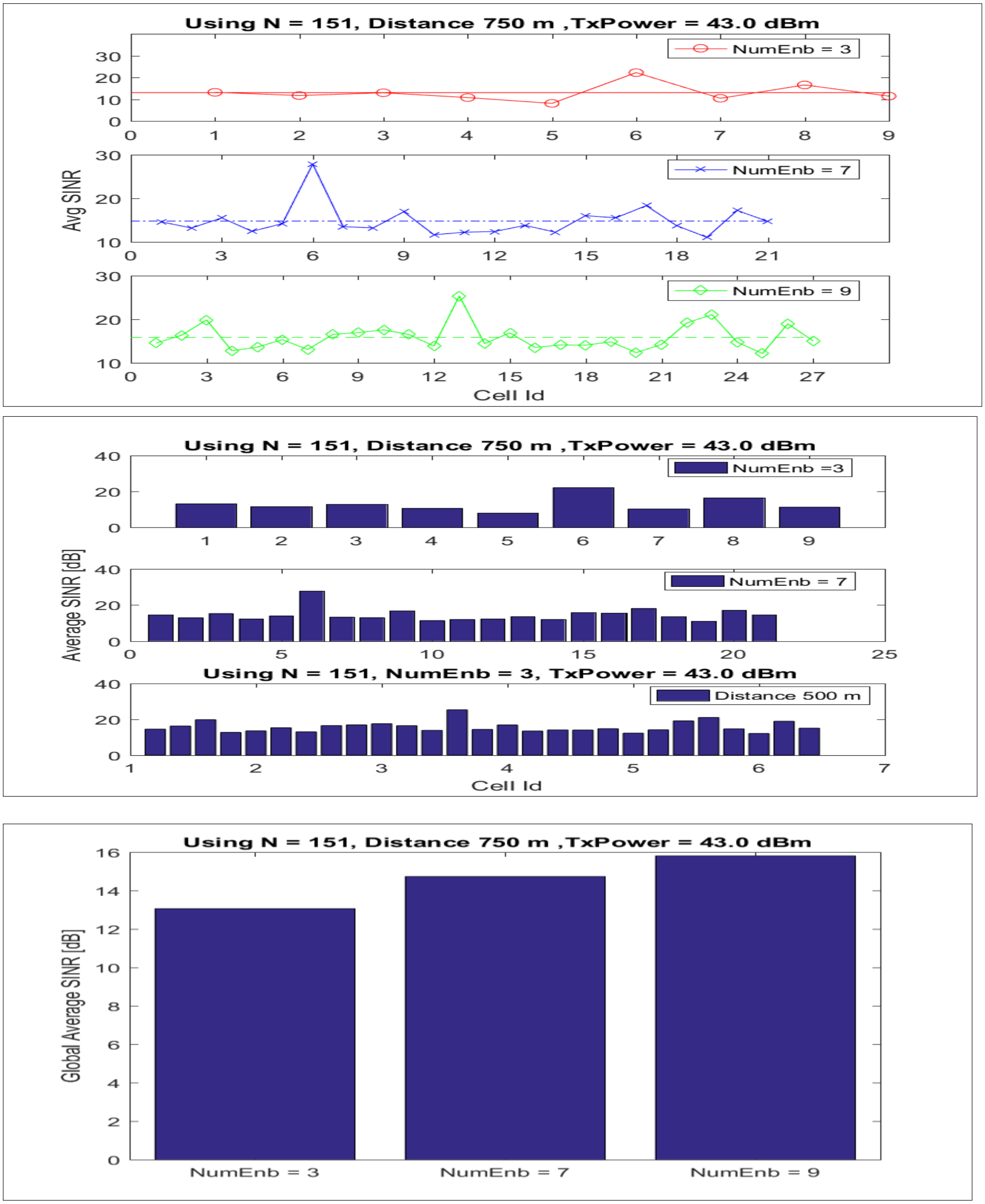


Figure 6.6 Average SINR with Variable eNBs and distance 750m

Figure 6.1 to 6.6 show the impact of changing the number of eNodeB on average number of users per cell, throughput and SINR. If number of eNB increase in one macro cell then the average number of users served by each eNB Will decrease until the total number of users keep constant, this means that the load on each eNB will decrease too, subsequently the average throughput will increase. In term of SINR as the bandwidth and number of RB stay constant, the interference due to the transmission on the same RB from other eNB will increase so SINR will decrease.

❖ <u>Case Two: Variable Distance</u>

This case discusses the output result when different distance between eNBs are identified while the number of eNB and the number of users is constant as shown in Table 6.3

Number of eNB	Distance between eNB	Number of users
3	500	151
3	750	151
3	1000	151

Table 6.3 The parameters for variable distance with 151 users

Then the same scenario is repeated but with different number of users (105) as shown in Table 6.4

Number of eNB	Distance between eNB	Number of users
3	500	105
3	750	105
3	1000	105

Table 6.4 The parameters for variable distance with 105 users

CASE TWO:

- **The Average Number of User per Cell per second for variable Distance and 151 users.**

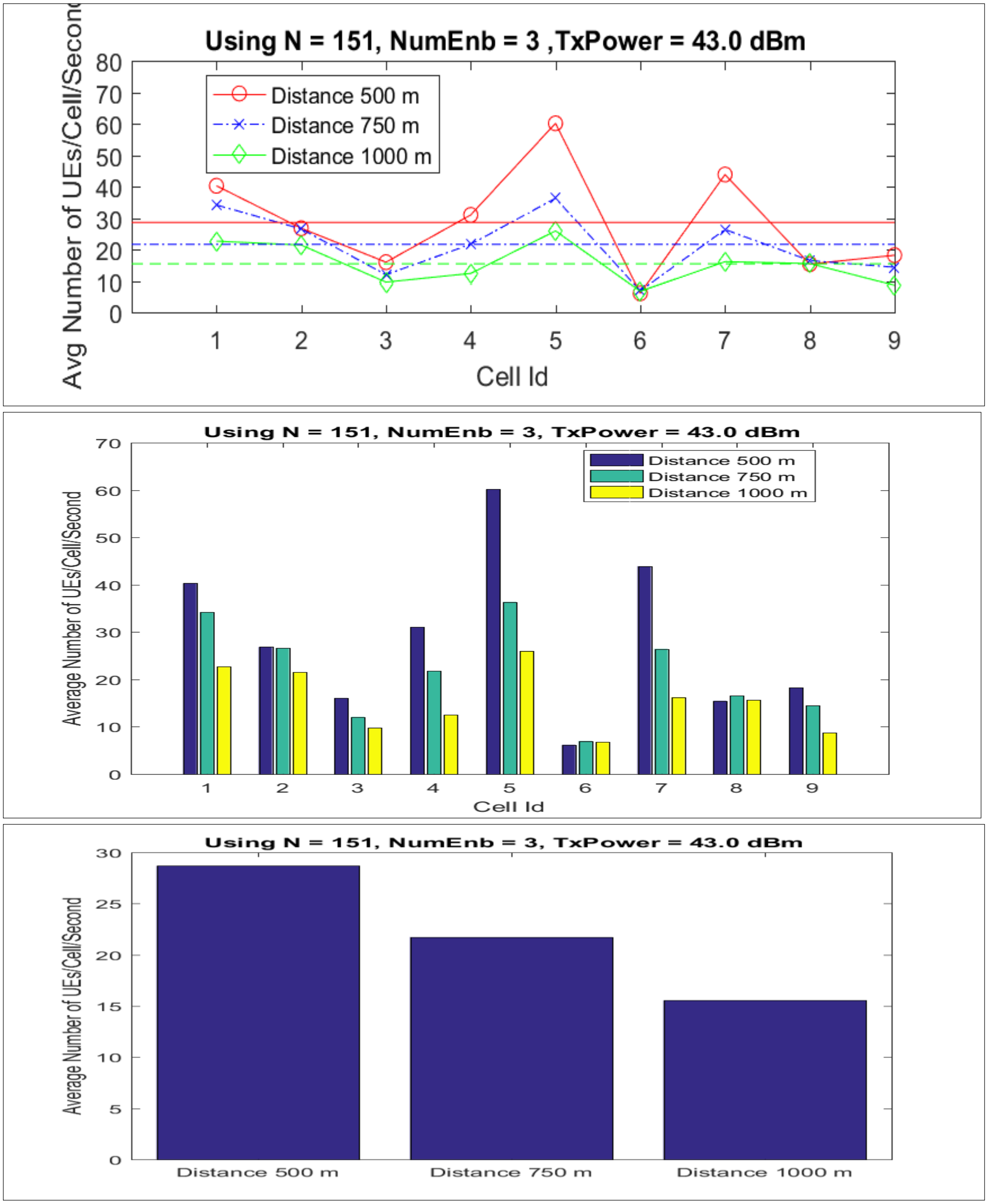


Figure 6.7 Average Number of User Per Cell with Variable distance 151 users

- **Average Throughput per cell for variable Distance and 151 users.**

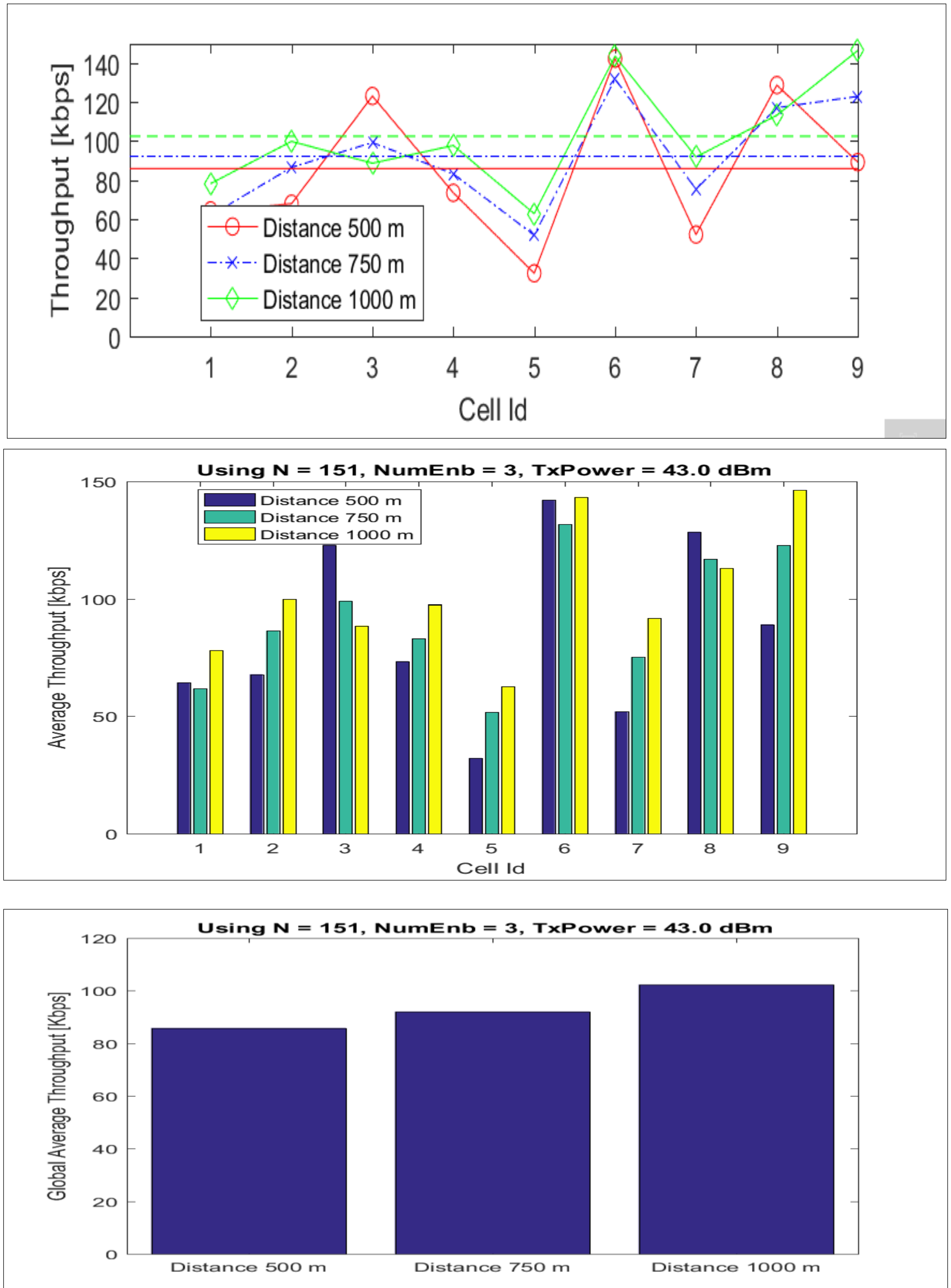


Figure 6.8 Average Throughput with Variable distance and 151 users

- **Average SINR per cell for variable Distance and 151 users.**

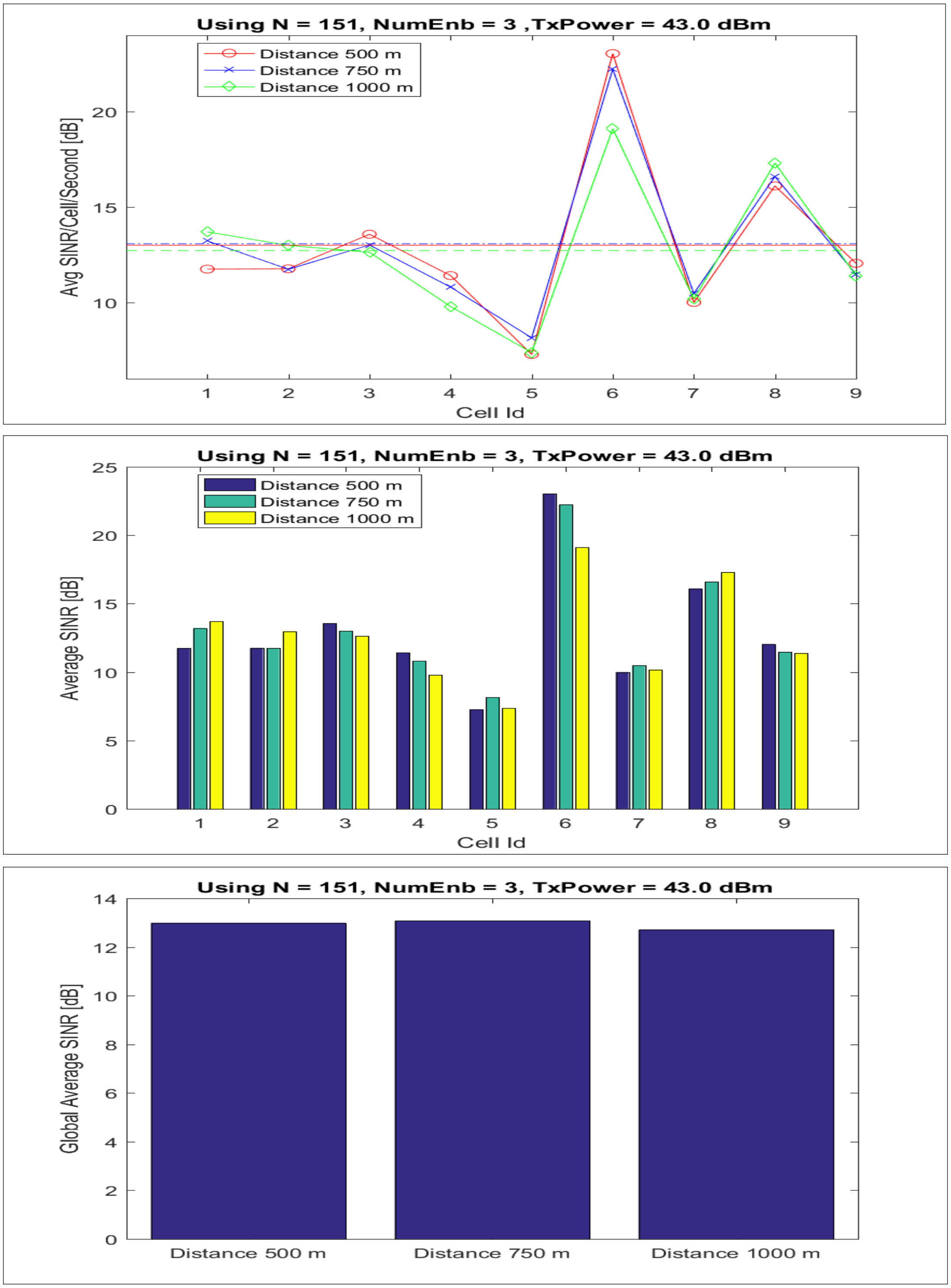


Figure 6.9 Average SINR with Variable distance and 151 users

- **The Average Number of User per Cell per second for variable Distance and 105 users.**

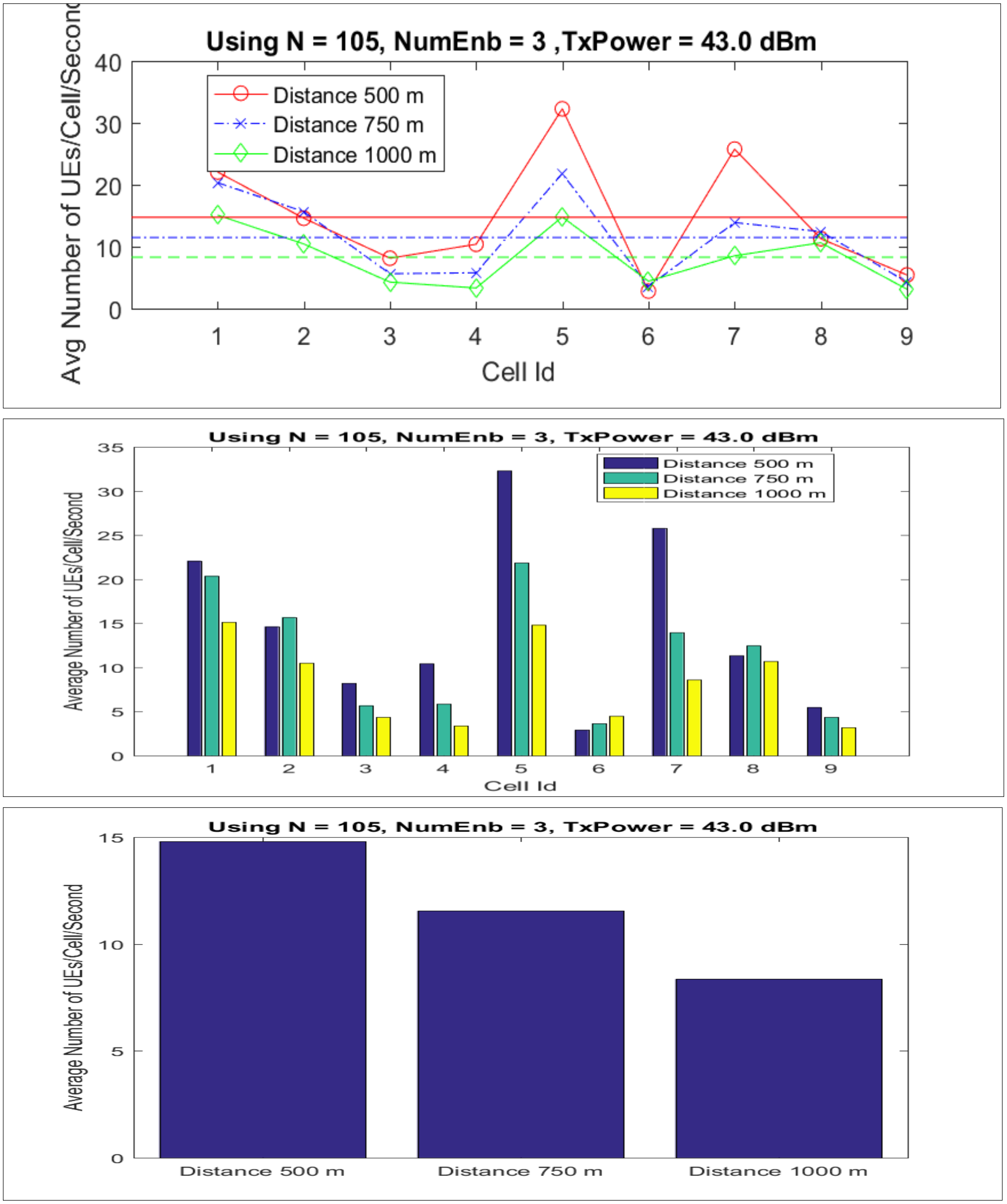
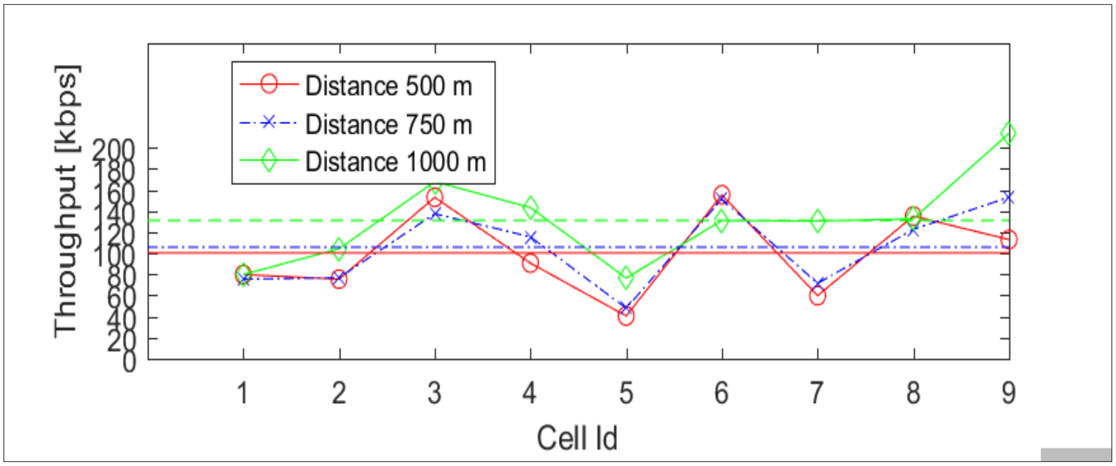
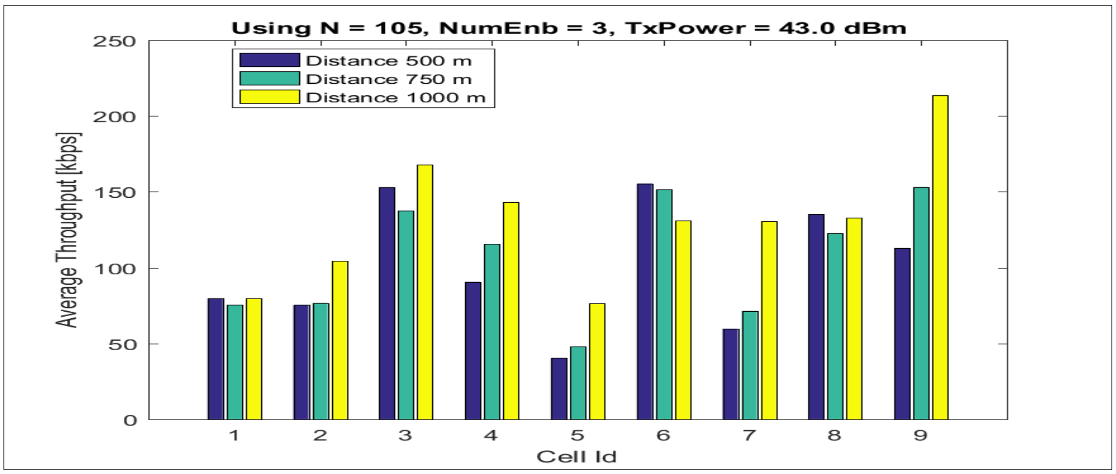


Figure 6.10 Average Number of User Per Cell with Variable distance and 105 users

- **Average Throughput per cell for variable Distance and 105 users.**





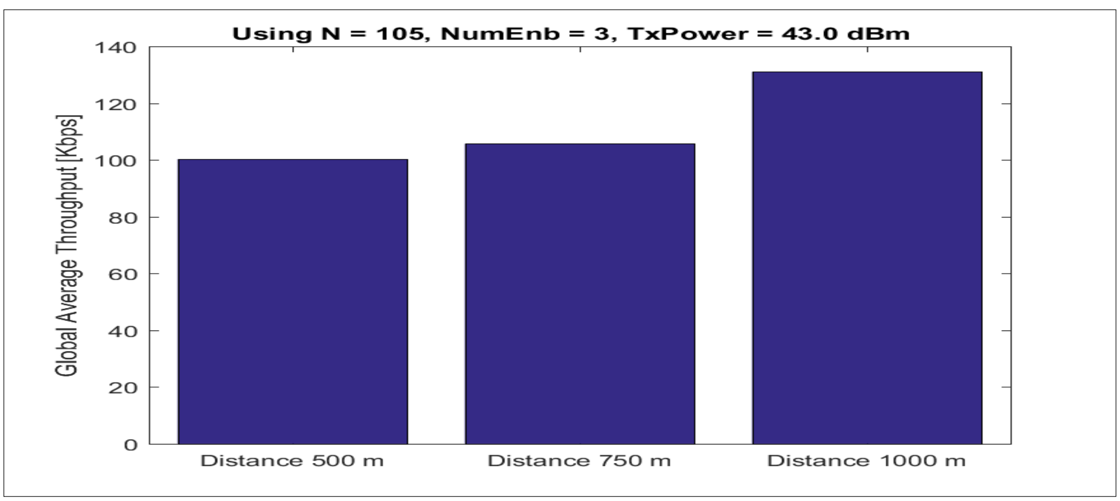


Figure 6.11 Average Throughput with Variable distance and 105 users

- **Average SINR per cell for variable Distance and 105 users.**

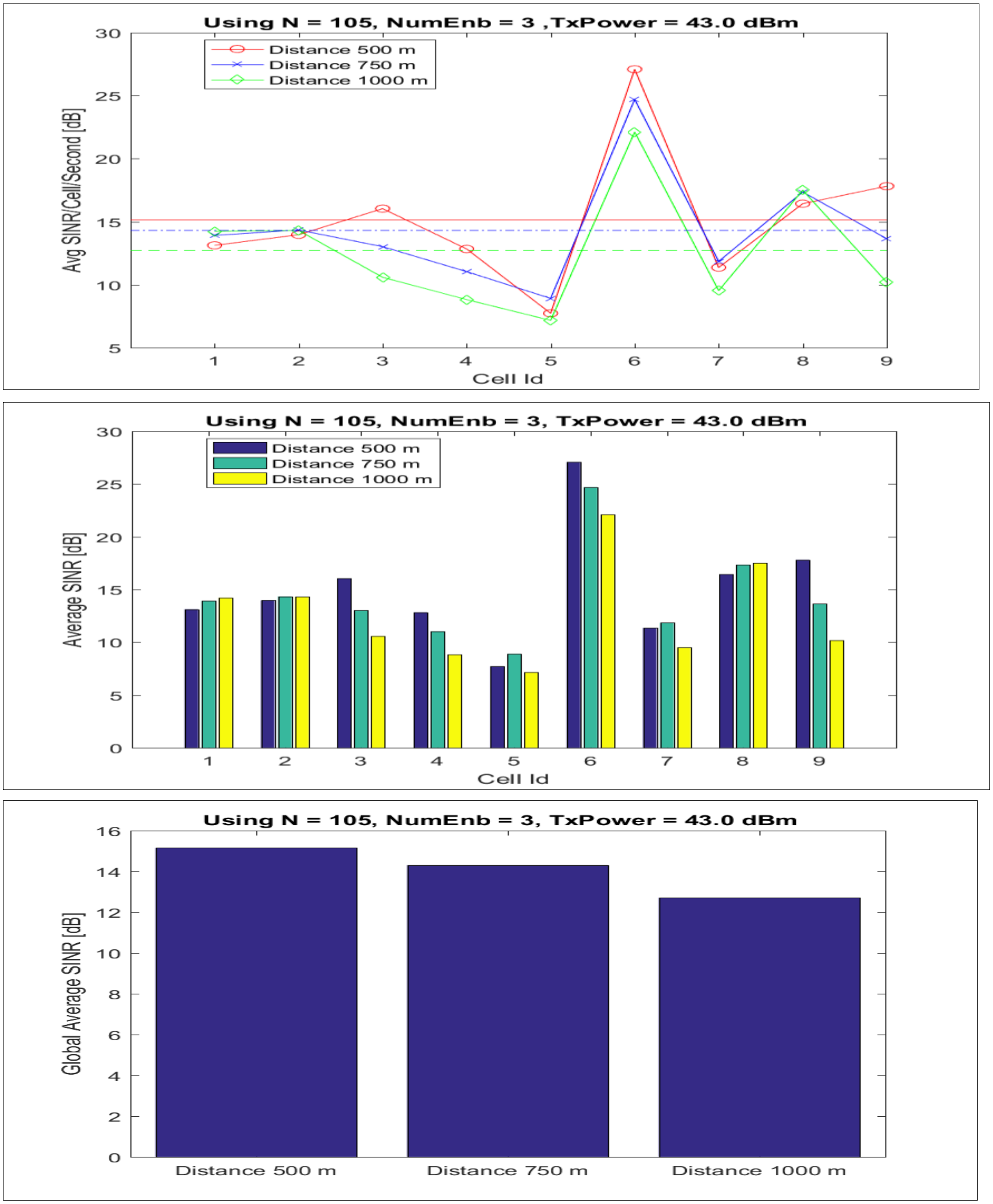


Figure 6.12 Average SINR with Variable distance and 105 users

Figure 6.7-6.12 presented the effect of changing distance on average number of users, throughput and SINR. As shown, increasing distance with constant RB and bandwidth will decrease number of users per cell because transmission power will not receive some of users thence the throughput will increase. With regard to SINR, as the received power decrease the SINR will also decrease.

❖ Case Three: Variable UE

Finally, this case is presented to study the performance of the cell when the number of users is variable while the number of eNB and the distance between eNBs are constants.

number of eNB	distance between eNB	number of users
3	500	105
3	500	151
3	500	250

Table 6.5 The parameters for variable Number of users with distance 500m

Then the same scenario is repeated but with different distance (750m) as shown in Table 6.6

Number of eNB	Distance between eNB	Number of users
3	750	105
3	750	151
3	750	250

Table 6.6 The parameters for variable Number of users with distance 750m

- **The Average Number of User per Cell per second for variable Number of Users and Distance 500m.**

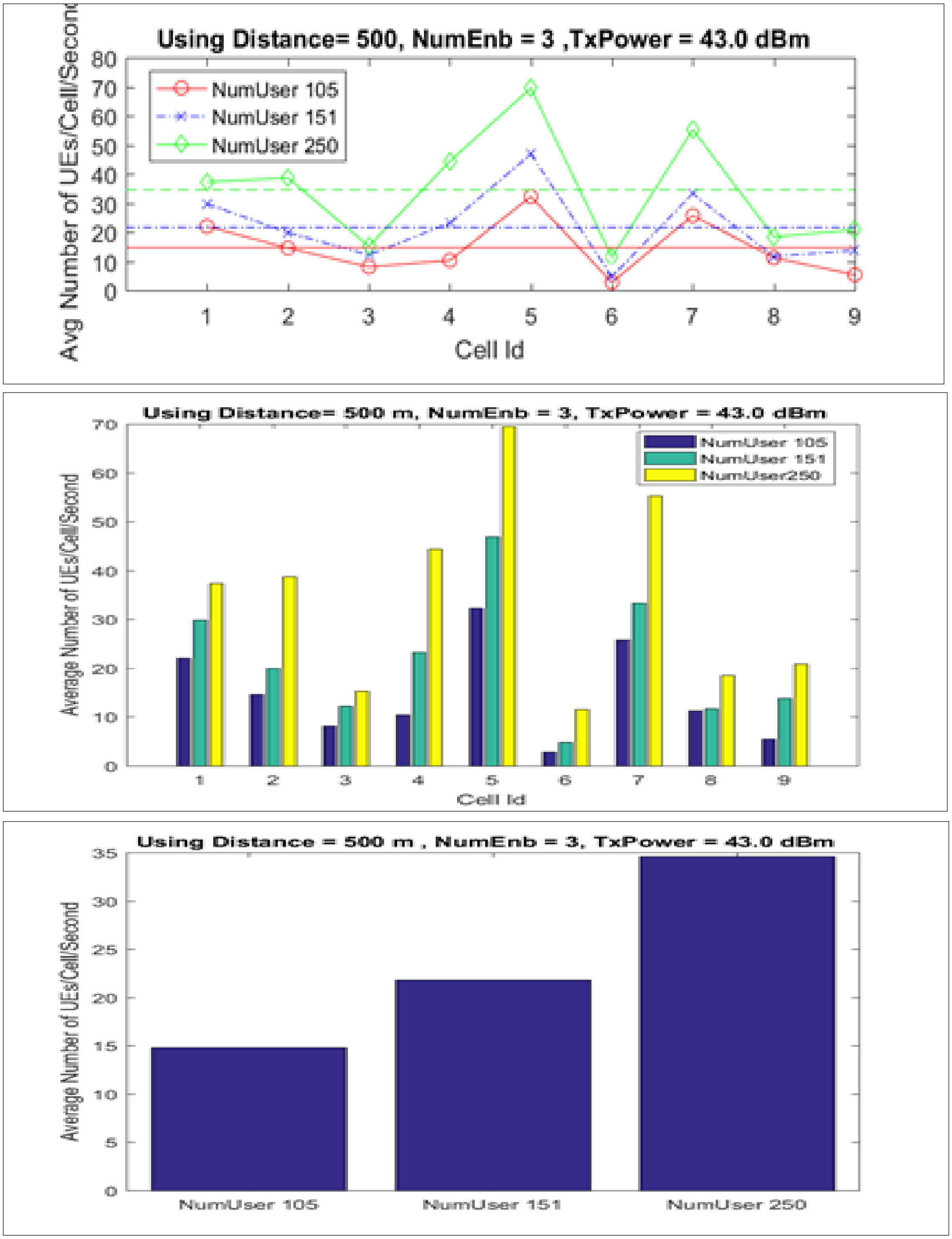


Figure 6.13 Average Number of User Per Cell with Variable number of user and distance 500m

- **Average Throughput per cell for variable Number of Users and Distance 500m.**

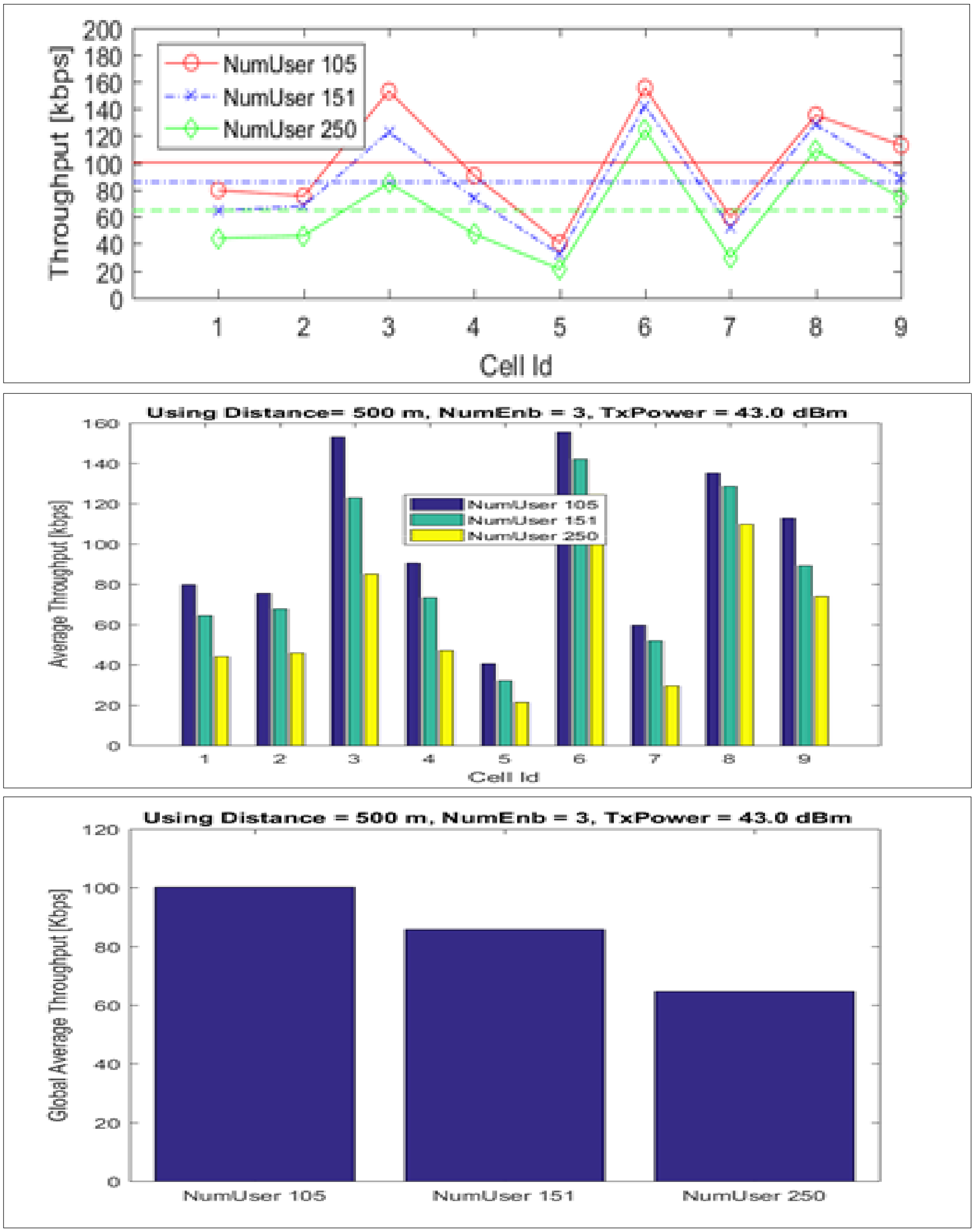


Figure 6.14 Average Throughput with Variable number of users and distance 500m

- **Average SINR per cell for variable Number of Users and Distance 500m.**

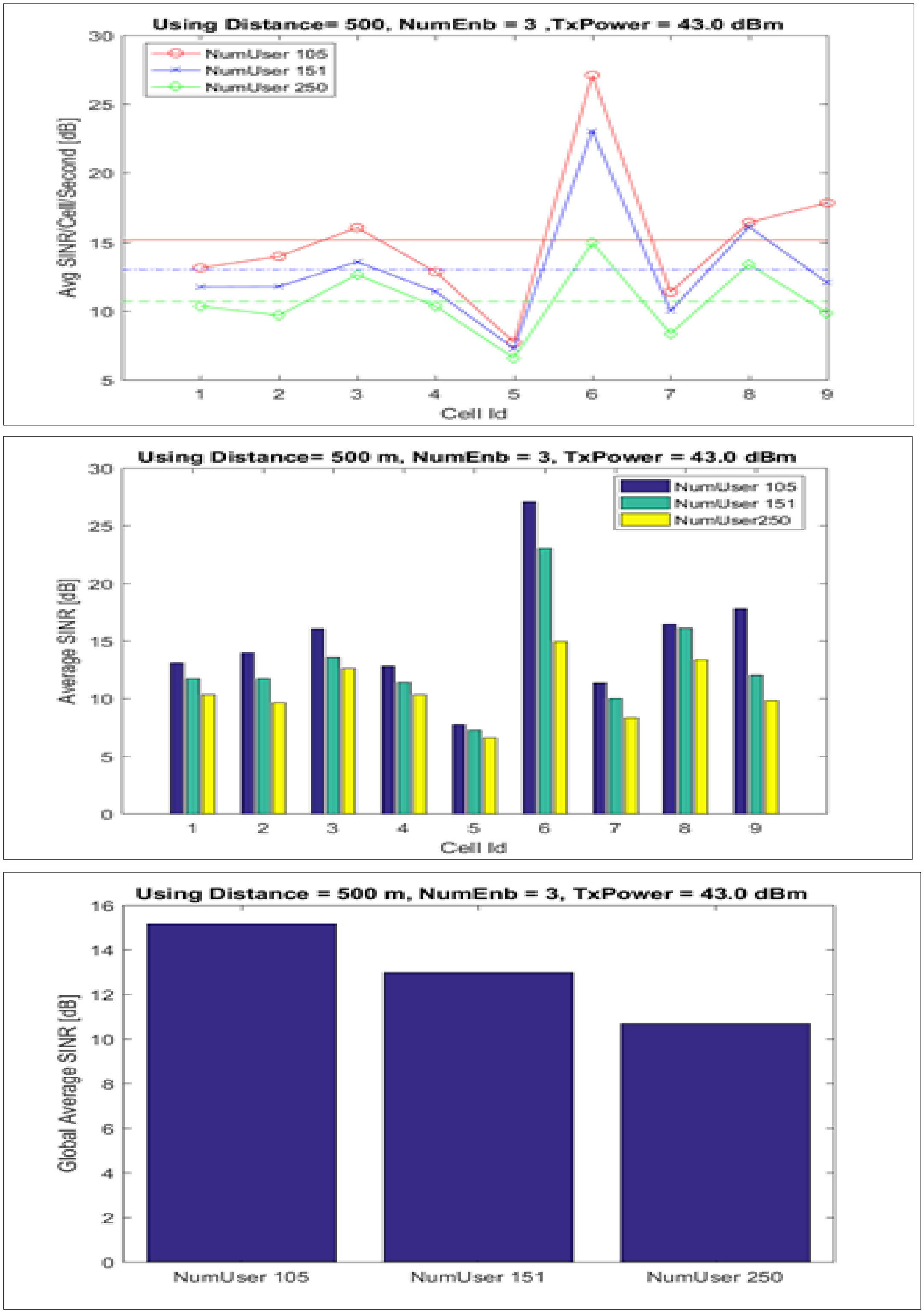


Figure 6.15 Average SINR with Variable number of users and distance 500m

- **The Average Number of User per Cell per second for variable Number of Users and Distance 750m.**

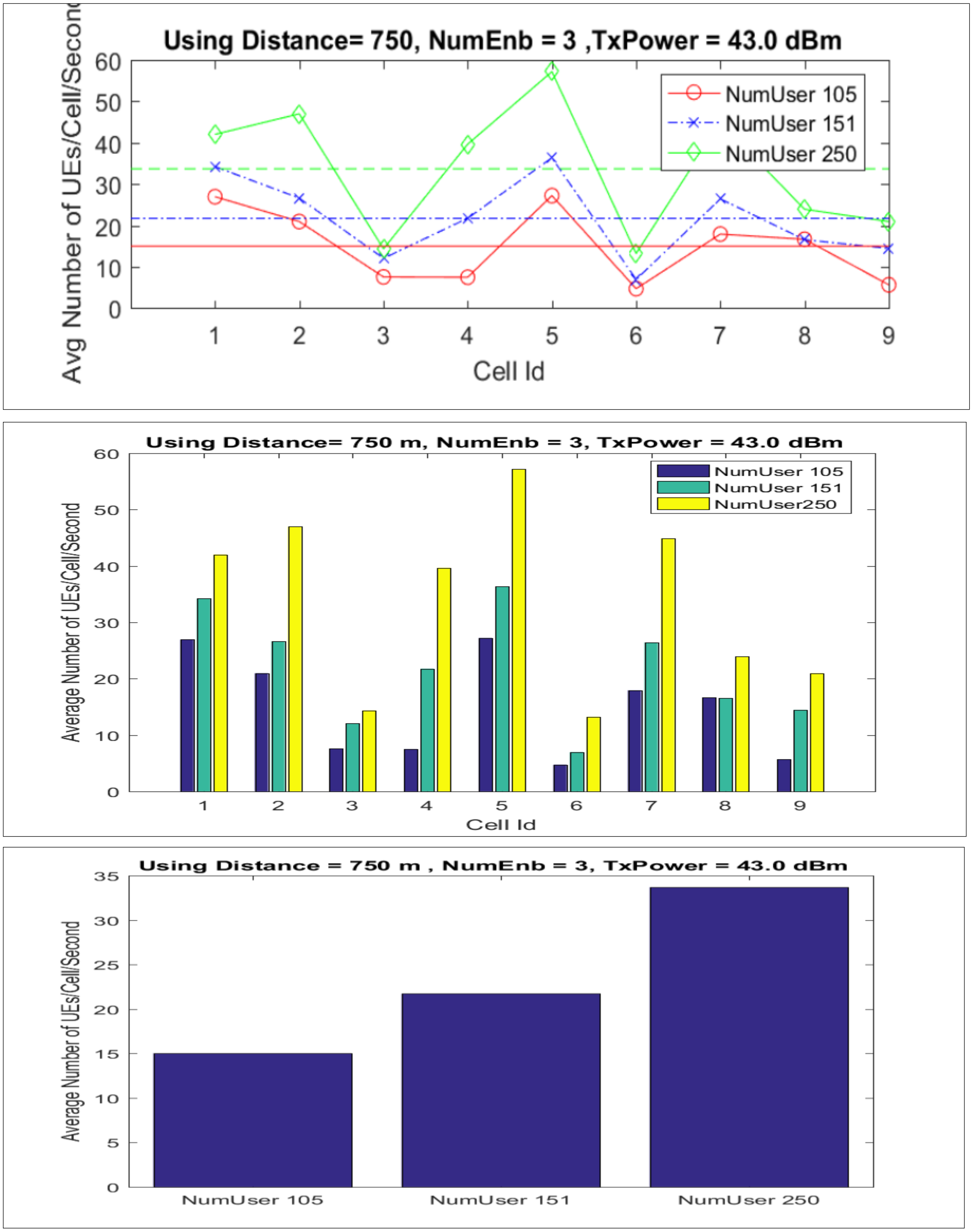
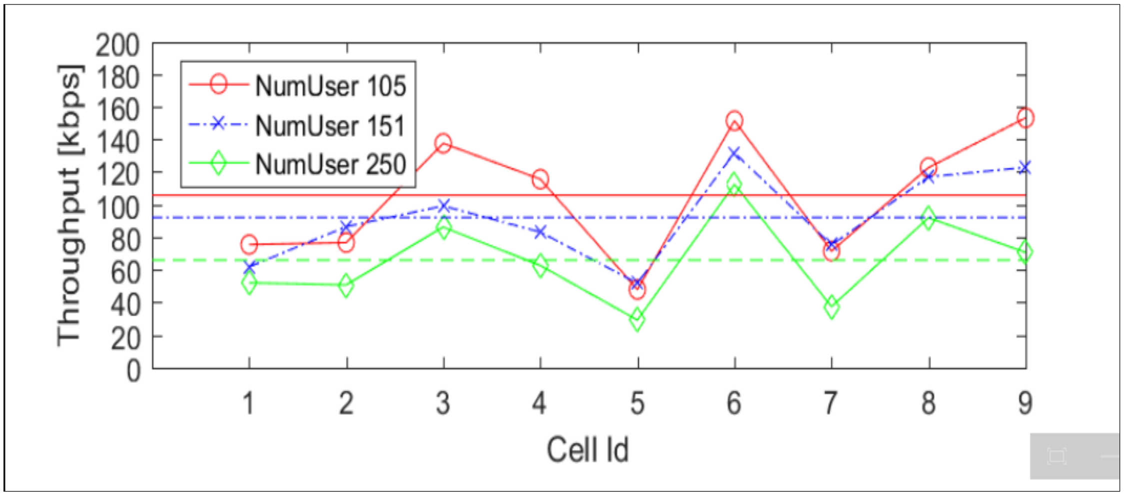
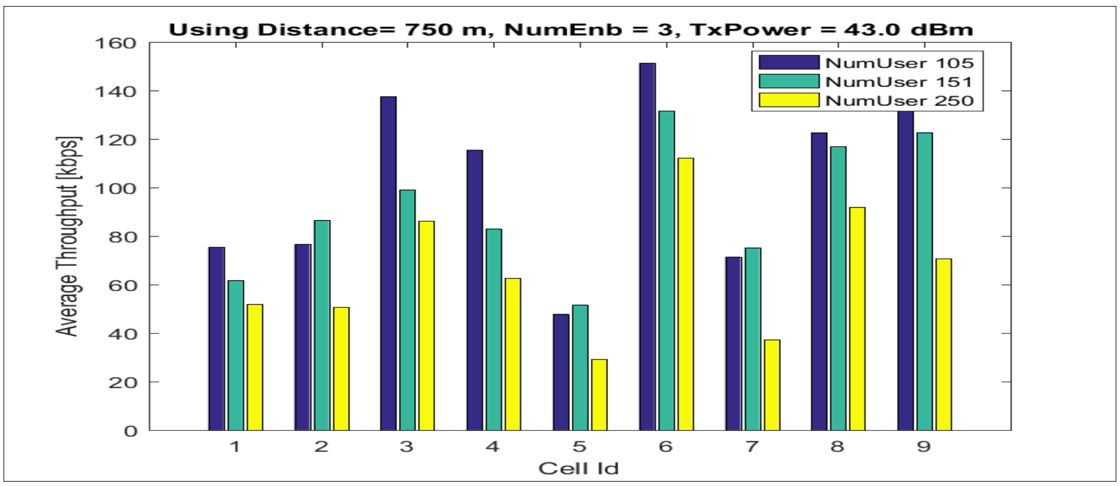


Figure 6.16 Average Number of User Per Cell with Variable number of user and distance750m

- **Average Throughput per cell for variable Number of Users and Distance 750m.**





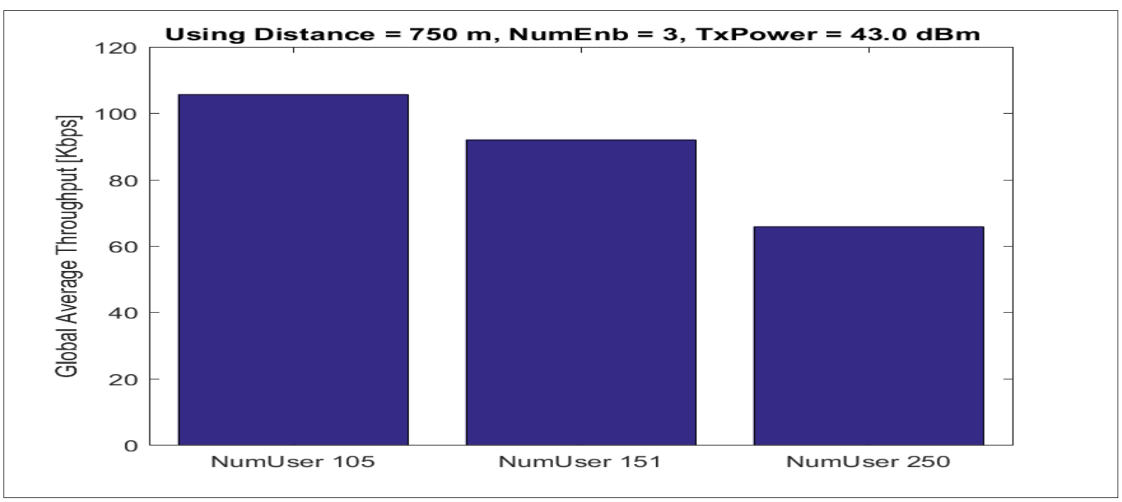


Figure 6.17 Average Throughput with Variable number of users and distance 750m

- **Average SINR per cell for variable Number of Users and Distance 750m.**

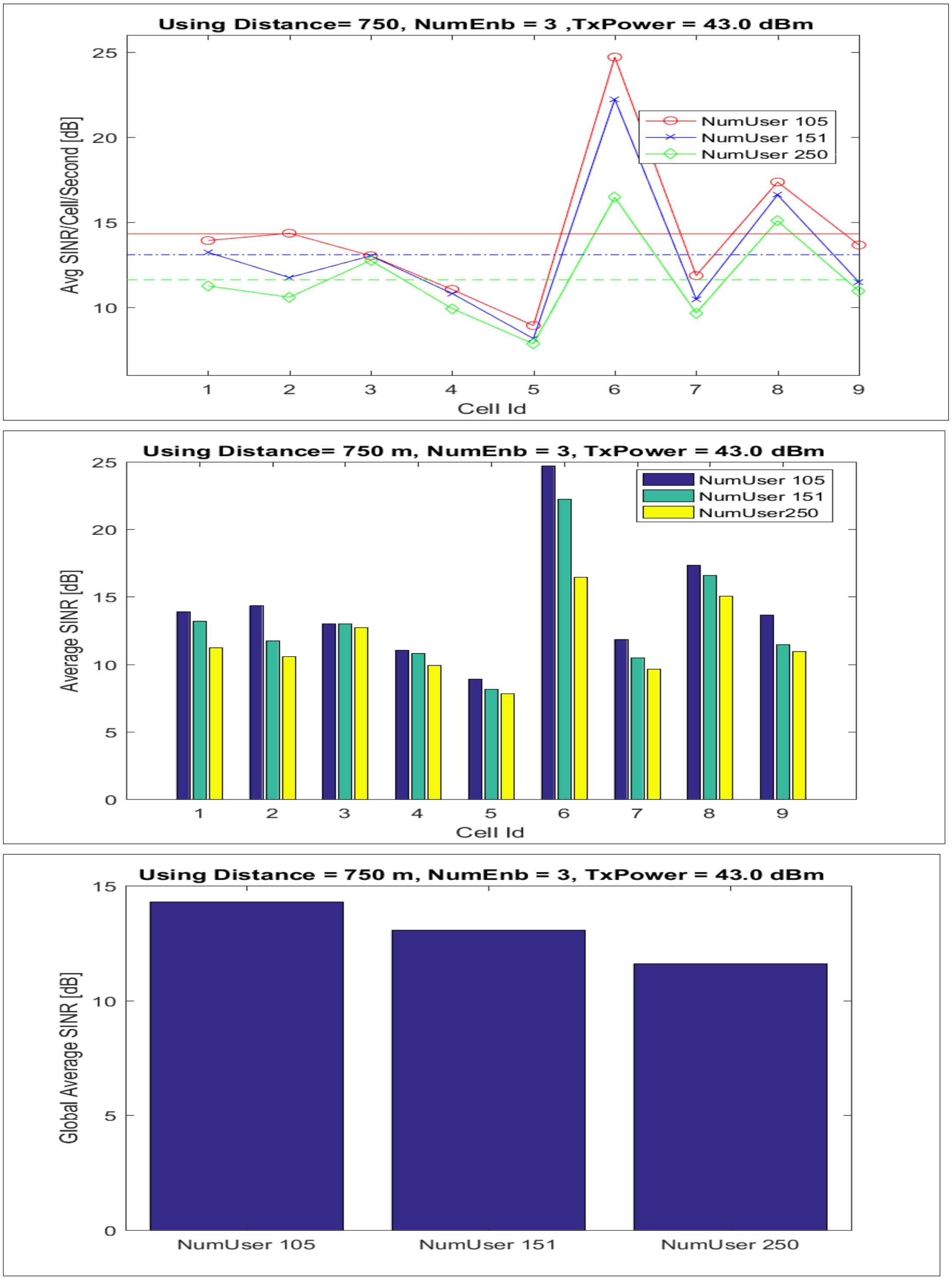


Figure 6.18 Average SINR with Variable number of users and distance 750m

In the last case as shown in figure 6.13 – 6.18, when the number of users increase with constant distance and eNB, axiomatically the average number of users per cell will increase and the load per cell will also increase, this will be causing decreasing in throughput. Respecting to SINR, as number of users increase with constant RB and bandwidth this induce some users to share the same RB and so on the interference will increase and consequently the SINR will decrease.

Chapter 7: Conclusions and Recommendation

In this project approach to the simulation of LTE by using LTE-EPC module of ns-3 has been presented. Some of features that added to the ns-3 simulator have described in order to make this possible, and discussed the details of the configuration of our simulation scenario. The simulation results have shown the impact of various factors on throughput.

Future Work

The objective of second project is provide the basis for improving handover performance in the LTE systems. A C++ simulation script will be written to configure proposed handover parameters optimization method to show how the handover parameters optimization method can effectively minimize the unnecessary number of handovers while maximizing the system throughput. Future works will focus on designing smart handover algorithms based on machine learning techniques that can predict and select the appropriate target cell in order to guarantee the best quality of experience for the user.

ML will be using to optimize the parameters that controls the User Equipments (UEs) handover between neighboring cells in 4G LTE mobile network. This is to give the 4G LTE system better ability to take a decision on whom and when to handover UE to a neighboring cell. An NS3 network simulator will be used to simulate different 4G LTE handover scenarios, and the output of the NS3 will be used as input training data to the ML algorithms. Moreover, will get deep understanding of the 4G LTE handover events and techniques. The performance of the 4G LTE with and without ML will study and compare. Different machine learning techniques over the 4G LTE case study will test and then compare between them

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