Evaluating Quality of Services of 4G LTE Cellular Data Network: The Case of Addis Ababa

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Accepted by the School of Graduate Study, St. Mary's University, in partial fulfillment of the requirements for the Degree of Master of Science in Computer Science

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DECLARATION

I, the undersigned, declare that this thesis work is my original work, has not been

presented for a degree in this or any other universities, and all sources of materials used

for the thesis work have been duly acknowledged.

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Table of Contents

List of Acronyms v

List of Figures ix

List of Tables xi

Chapter One:Introduction 1

1.1 Background of 4G LTE 4

1.2 Research Motivation 6

1.3 Statement of the Problem 6

1.4 Objective of the Thesis 7

1.4.1 General Objective 7

1.4.2 Specific Objectives 7

1.5 Methodology 8

1.6 Preliminary Investigations 8

1.7 Expected Results and Contributions 8

1.8 Scope 9

1.9 Thesis Organization 9

Chapter Two:Literature Review and Review of Related works 10

2.1 4G Network Introduction 10

2.2 4G LTE Key Technologies 10

2.2.1 OFDMA 11

2.2.2 SC-FDMA 13

2.2.3 MIMO 13

2.2.4 Modulation and Demodulation 14

2.2.5 Power Control 17

2.2.6 Handover 20

2.2.7 Resource allocation in 4G LTE 21

2.2.8 Call Admission Control in LTE 23

2.2.9 Congestion Control in 4G LTE 25

2.3 Architecture of 4G LTE and Interface Protocol 26

2.3.1 The core networks 28

2.3.2 The access network 31

2.3.3 Roaming architecture 33

2.3.4 General protocol model for E-UTRAN interfaces 34

2.3.5 Control plane 35

2.3.6 User plane 35

2.4 Review of Related Works 36

2.4.1 QoS solutions proposed Based on the Layer 36

2.4.2 Analytical Evaluation of QoS in the Downlink of OFDMA Wireless Cellular Networks 41

2.4.3 Path Loss evaluation for 4G LTE network 41

2.4.4 Throughput and Round-Trip Time Performance evaluation for 4G LTE network 43

2.4.5 A Comparison of 3G and 4G network 44

2.4.6 Studies on efficient resource block allocation in LTE system 44

2.4.7 Main principles of the LTE network architecture 45

2.4.8 Study on cross layer scheduling algorithm. 45

2.4.9 Adaptive proportional fair scheduling algorithm for LTE 46

2.4.10 Analyzing network capacity performance by using MATLAB for real-time simulations 46

Chapter Three:Quality of Service in 4G LTE network 47

3.1 Quality of Service and Quality of Experience 47

3.2 4G LTE QoS Architecture 48

3.3 4G Bearer and QoS classes 50

3.4 QoS Performance Indicator Parameters 52

3.4.1 Network Geographic Observation Parameters 53

3.4.2 Network Coverage and Quality Analysis Parameters 53

3.4.3 Network Performance Analysis Parameters 54

3.4.4 Drive Test Service Quality Analysis Parameters 55

Chapter Four:Control and User Plane Management Tools 60

4.1 Introduction of Control Plane Management Tools 60

4.1.1 Introduction to U2000 61

4.1.2 Introduction of the Performance Surveillance (PRS) 62

4.1.3 Service Experience Quality (SEQ) analyst solution. 63

4.1.3.1 SUI Model 64

4.1.3.2 Okumura Model 65

4.1.3.3 Standard Propagation Model 66

4.1.3.4 Interference Model 67

4.1.3.5 Mobility Model 70

4.1.3.6 Traffic Model 70

4.2 Introduction of User Plane Management Tools 70

Chapter Five:Data Collection and Analysis Results 73

5.1. Control Plane System Data Collection and Analysis Results 73

5.1.1 Addis Ababa 4G LTE S1-MME attach delay Analysis 73

5.1.2 Handover Resource Allocation Delay Analysis 75

5.1.3 S11 Default Bearer Creation Delay analysis. 77

5.1.4 S6a Insert Subscriber Data Delay Analysis 78

5.1.5 MME Paging Success Rate Analysis 79

5.1.6 E2E Delay Analysis 81
5.2. User Plane System Data Collection and Analysis Results 82
5.2.1 Data DT Testing Information 83
5.2.2 Addis Ababa LTE Network Information 83
5.2.2.1 Black Lion Hospital(BLH) Coverage Analysis 84
5.2.2.2 Black Lion Hospital LTE_UE_RSSI Strength 85
5.2.2.3 Black Lion Hospital LTE_UE_RSRQ 86
5.2.2.4 Black Lion Hospital LTE_UE_SINR 87
5.2.2.5 Black Lion Hospital LTE_UE_Throughput_DL 88
5.2.2.6 Black Lion Hospita LTE_UE_Throughput_UL 89
5.2.2.7 Ethiotelecom Microwave Office (EMWO) LTE_UE_RSRP Coverage Analysis 90
5.2.2.8 Ethiotelecom Microwave Office LTE_UE_RSSI Strength Analysis 91
5.2.2.9 Ethiotelecom Microwave Office LTE_UE_RSRQ 92
5.2.2.10 Ethiotelecom Microwave Office LTE_UE_SINR 93
5.2.2.11 Ethiotelecom Microwave Office LTE_UE_Throughput_DL Analysis 94
5.2.2.12 Ethiotelecom Microwave Office LTE_UE_Throughput_UL 95
5.2.2.13 Ethiotelecom Head office (EHO)LTE_UE_RSRP Coverage Analysis 96
5.2.2.14 Ethiotelecom Head office LTE_UE_RSSI Signal Strength Analysis 96
5.2.2.15 Ethiotelecom Head office LTE_UE_RSRQ Quality Analysis 97
5.2.2.16 Ethiotelecom Head office LTE_UE_SINR Signal Quality Analysis 98
5.2.2.17 Ethiotelecom Head office LTE_UE_Throughput_DL Analysis 98
5.2.2.18 Ethiotelecom Head office LTE _UE_Throughput_UL Analysis 99
5.2.2.19 Getu Commercial center LTE_UE_RSRP Coverage Analysis 100
5.2.2.20 Getu Commercial center(GCC) LTE_UE_RSSI Signal Strength Analysis 101
5.2.2.21 Getu Commercial center LTE_UE_RSRQ Quality Analysis 102

5.2.2.22 Getu Commercial center LTE_UE_SINR Signal Strength Analysis 103

5.2.2.23 Getu Commercial center LTE_UE_Throughput_DL Analysis 104

5.2.2.24 Getu Commercial center LTE_UE_Throughput_UL Analysis 104

5.2.2.25 Black Lion Hospital LTE_UE_Path Loss Analysis 105

5.2.2.26 Ethiotelecom Microwave Office LTE_UE_Path Loss Analysis 106

5.2.2.27 Ethiotelecom Head Office LTE_UE_Path Loss Analysis 107

5.2.2.28 Getu Commercial Center LTE_UE_Path Loss Analysis 107

5.2.2.29 Black Lion Hospital LTE_UE_Block Error Rate(BLER) Analysis 108

5.2.2.30 Ethiotelecom Microwave Office LTE_UE_Block Error Rate(BLER) Analysis 110

5.2.2.31 Ethiotelecom Head Office LTE_UE_Block Error Rate(BLER) Analysis 111

5.2.2.32 Getu Commercial Center LTE_UE_Block Error Rate(BLER) Analysis. 112

5.3 Discussion 113

Chapter Six:Conclusion and Recommendation 114

6.1 Conclusion 114

6.2 Recommendation 115

6.3 Future Works 115

References 116

List of Acronyms

2G	2nd Generation
3G	3rd Generation
3GPP	Third Generation Partnership Project
4G	4th Generation
AMC	Adaptive Modulation and Coding
AS	Access Stratum
BBH	Bearer Busy Hour
BH	Busy Hour
BLER	Block Error Rate
CDMA	Code Division Multiple Access
CP	Cyclic Prefix
CS	Circuit Switching
DL	Downlink
DL-SCH	Downlink Shared Channel
E2E	End-to End
EDGE	Enhanced Data Rates for GSM Evolution
eGBTS	Evolved Gateway BTS
eNB	Enhanced NodeB (interchangeably used as base-station)
EPC	Evolved Packet Core
EPCN	Evolved Packet Core Network
EPS	Evolved Packet System
EUTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FTP	File Transfer Protocol
GGSN	Gateway GPRS Serving Node
GPRS	General Packet Radio Service

GSM	Global System for Mobile Communications
GTP	Growth and Transformation Plan
HSPDA	High-Speed Downlink Packet Access
HSS	Home Subscriber Service
ITU	International Telecommunication Union
IP	Internet Protocol
KPI	Key Performance Indicators
LTE	Long Term Evolution
MAC	Media Access Control
MBBH	Mobile Broadband Backhaul
MBMS	Multimedia Broadcast Multicast Services
MBSC	Multimode Base Station Controller
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
NAS	Non Access Stratum
NBH	Network Busy Hour
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
PAPR	Peak-to-average Power Ratio
PDN	Packet Data Network
PDR	Packet Delivery Ratio
P-GW	Packet Data Gateway
PRB	Physical Resource Block
PS	Packet Switching
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
RF	Radio Frequency
RLC	Radio Link Control
RSRP	Reference Signal Received Power

RSRQ	Reference Signal Received Quality
RSSI	Reference Signal Strength Indicator
SAE	System Architecture Evolution
SC-FDMA	Single-Carrier Frequency-Division Multiple Access
S-GW	Service Gate Way
SINR	Signal to Interference and Noise Ratio
SNR	Signal-to-Noise Ratio
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TTI	Transmission Time Interval
UDP	User Datagram Protocol
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication Systems
VoIP	Voice over Internet Protocol
VoLTE	Voice over LTE
WCDMA	Wideband Code Division Multiple Access
WIMAX	Worldwide Interoperability for Microwave Access

List of Figures

Figure 1.1 shows the E2E QoS support and EPS bearer establishment in the LTE networks 2

Figure 2.1 MIMO system diagram[6].. 14

Figure 2.2 Shows the comparative between OFDM and OFDMA[7]. 15

Figure 2.3 Shows in OFDM, each frequency component carries unique information. 16

Figure 2.4 Show different types of Modulation schemes[6]. 16

Figure 2.5 Schematic of open loop power control scheme 18

Figure 2.6 Schematic of closed loop power control scheme. 18

Figure 2.7 Illustration of a scheduling block in LTE downlink 22

Figure 2.10 Overall E-UTRAN architecture.. 32

Figure 2.11 Roaming architecture for 3GPP accesses with P-GW in home network.............................. 34

Figure 2.12 The general protocol model for E-UTRAN interfaces... 34

Figure 2.13 Control plane protocol stack... 35

Figure 2.14 The E-UTRAN user plane protocol stack 36

Figure 3.2 QoS Bearer/Architecture in 4G network. 49

Figure 3.3 QoS Bearer 50

Figure 4.1 Shows the performance management architecture [37] 61

Figure 4.2 SEQ platform, PS and CS Probes Deployment [40] 63

Figure 5.2 Addis Ababa 4G LTE sites S1-MME High Handover Resource Allocation Delay(ms) simulation snapshot 76

Figure 5.3 S11 Default Bearer Creation Delay analysis snapshot... 77

Figure 5.4 S6a Insert Subscriber Data Delay Analysis snapshot 78

Figure 5.6 E2E delay Analysis snapshot 81

Figure 5.2.2.1 Black Lion Hospital LTE network DT coverage performance analysis 85

Figure 5.2.2.2 Black Lion Hospital LTE network DT signal strength performance analysis snapshot. ... 86

Figure 5.2.2.3 Black Lion Hospital LTE network DT signal quality performance analysis snapshot. 87

Figure 5.2.2.5 Black Lion Hospital LTE network DT downlink performance analysis snapshot. 89

Figure 5.2.2.6 Black Lion Hospital LTE network DT uplink performance analysis snapshot. 90

Figure 5.2.2.7 Ethiotelecom Microwave Office (EMWO) LTE_UE_RSRP Coverage Analysis snapshot 91

Figure 5.2.2.8 EMWO LTE network DT signal strength performance analysis snapshot 92

Figure 5.2.2.9 EMWO LTE network DT signal quality performance analysis snapshot 93

Figure 5.2.2.10 Shows EMWO LTE network DT SINR signal quality performance analysis snapshot. 94

Figure 5.2.2.11 EMWO LTE network DT downlink performance analysis snapshot 95

Figure 5.2.2.12 EMWO LTE network DT uplink performance analysis snapshot 96

Figure 5.2.2.13 EHO LTE network DT coverage performance analysis snapshot 96

Figure 5.2.2.14 EHO LTE network DT signal strength performance analysis snapshot 97

Figure 5.2.2.15 EHO LTE network DT signal quality performance analysis snapshot 98

Figure 5.2.16 EHO LTE network DT SINR signal quality performance analysis snapshot 98

Figure 5.2.2.17 EHO LTE network DT downlink performance analysis snapshot 99

Figure 5.2.2.19 EHO LTE network DT coverage performance analysis snapshot 101

Figure 5.2.2.20 GCC LTE network DT signal strength performance analysis snapshot 102

Figure 5.2.2.21 GCC LTE network DT signal quality performance analysis snapshot 103

Figure 5.2.2.22 GCC LTE network DT SINR signal quality performance analysis snapshot 104

Figure 5.2.2.23 Getu Commercial LTE network DT downlink performance analysis snapshot 104

Figure 5.2.2.24 GCC LTE network DT uplink performance analysis snapshot 105

Figure 5.2.2.26 Ethiotelecom Microwave Office LTE_UE_Path Loss Analysis Snapshot 107

List of Tables

Table 2.1: Different bandwidth with different resource blocks. 12

Table 2.2: LAYER WISE APPROACHES [13] 37

Table 3.2 E-UTRAN Radio Interface characteristics/ QoS classes[12]. 52

TABLE 3.4. RSRP Reference Range. 59

TABLE 4.1: Different Terrains & Their Parameters[41] 64

Table 5.4 S6a Insert Subscriber Data Delay 79

Table 5.5 MME Paging Success Rate Analysis description 80

Table 5.2: Shows the data DT test information. 83

Abstract

In mobile communication systems the demand for high-quality services, such as VoIP, data service is on the rise. Long Term Evolution (LTE) is designed to revolutionize mobile broadband technology with key considerations of higher data rate, improved power efficiency, low latency and better quality of service.

The current LTE network infrastructure deployed in the Addis Ababa city, which is solely managed by Ethiotelecom, is undergoing major expansions in the last 5 years and resulted in a tangible improvement of coverage and quality. However, there are complaints from subscribers from various parts of the city. This thesis work analyzes the QoS of 4G LTE data network in Addis Ababa. To investigate the problem, the measurement was conducted on control plane and user plane of the LTE system being used by Ethiotelecom. Control plane system parameters such as network attach success rate, paging success rate; end to end connection delay analysis are collected and analyzed by using Service Experience Quality(SEQ) analyst Tool. The results of some parameters are below company's target.

The user plane system, on the other hand, generates QoS indicator parameters such as coverage analysis; quality analysis; downlink throughput, uplink throughput parameters. Data collection is done by using Nemo Handy then the simulation is done by using Actix Analyzer and evaluations were carried out by using SEQ Analyst tool. The target coverage 4G LTE of Ethiotelecom is 95% to 98%, but from simulation result we found 89.5% in average. So this indicates problem of coverage. The target of Ethiotelecom maximum downlink and uplink 4G LTE is 40Mbps and 20Mbps, respectively. But the simulation results from Actix Analyzer, in all of the sites, is 93.5% and 97% of downlink and uplink, respectively which is good. However, this result is below the company target. The analysis results show that, in general, there are some disparities between the Ethiotelecom targets and analysis results, which indicate the need to further improve the data QoS. To improve the quality of data transmission the recommended interventions include: Installing distributed antenna in each of building, implementation of QoS manager in different levels of network, appropriate resource allocation in the network, among others.

Keywords: 4G LTE; QoS, QoE, Network Performance Evaluation.

Chapter One

Introduction

Data services are changing our life in a profound way. Cellular providers make Internet connectivity available anywhere and anytime [1]. This allows for instantaneous access to social networks, employment Intranet, academic environments, shopping, Internet browsing, entertainment etc. From the user perspective, it is important that regardless of the access platform, there is a guarantee of the QoS with respect to the experience.

Cellular companies strive to improve service and provide better experience to their users. Research and development in various areas of cellular technologies has allowed for growth, and advanced development of cellular broadband services. Cellular telecommunication services became a valid alternative of traditional broadband landline connection service. There are two types of switching models in network communication. They are circuit switching and packet switching. In the circuit switched (CS) mode, the physical channel (from the network input to the output) is reserved until data transmission starts [61]. When the message subject is being transmitted through the network, it reserves (occupies) the path for the message transmission. Furthermore, this method, as compared with packet switching(PS), eliminates the need to transmit the service information (head flit and tail flit) for each packet [61]. The PS no need dedicated channel. The main advantage that packet switching has over circuit switching is its efficiency. Packets can find their own paths to their destination without the need for a dedicated channel. In contrast, in circuit switching networks devices can't use the channel until the voice communication has been terminated. Packet Switching is efficient use of network. It easily gets around broken bits or packets. Circuit Switching charges user on the distance and duration of connection but Packet switching charges users only on the basis of duration of connectivity.

In contrast to the circuit-switched model of previous cellular systems, Long Term Evolution (LTE) has been designed to support only packet-switched services. It aims to provide seamless Internet Protocol (IP) connectivity between user equipment (UE) and the packet data network (PDN), without any disruption to the end users' applications during mobility.

While the term “LTE” encompasses the evolution of the Universal Mobile Telecommunications System (UMTS) radio access through the Evolved UTRAN (E-UTRAN), it is accompanied by an evolution of the non-radio aspects under the term “System Architecture Evolution” (SAE), which includes the Evolved Packet Core (EPC) network. Together LTE and SAE comprise the Evolved Packet System (EPS).

EPS uses the concept of EPS bearers to route IP traffic from a gateway in the PDN to the UE. A bearer is an IP packet flow with a defined quality of service (QoS) between the gateway and the UE. The E-UTRAN and EPC together set up and release bearers as required by applications. In LTE networks, the E2E QoS is established from UE to the PDN-GW in a core network.

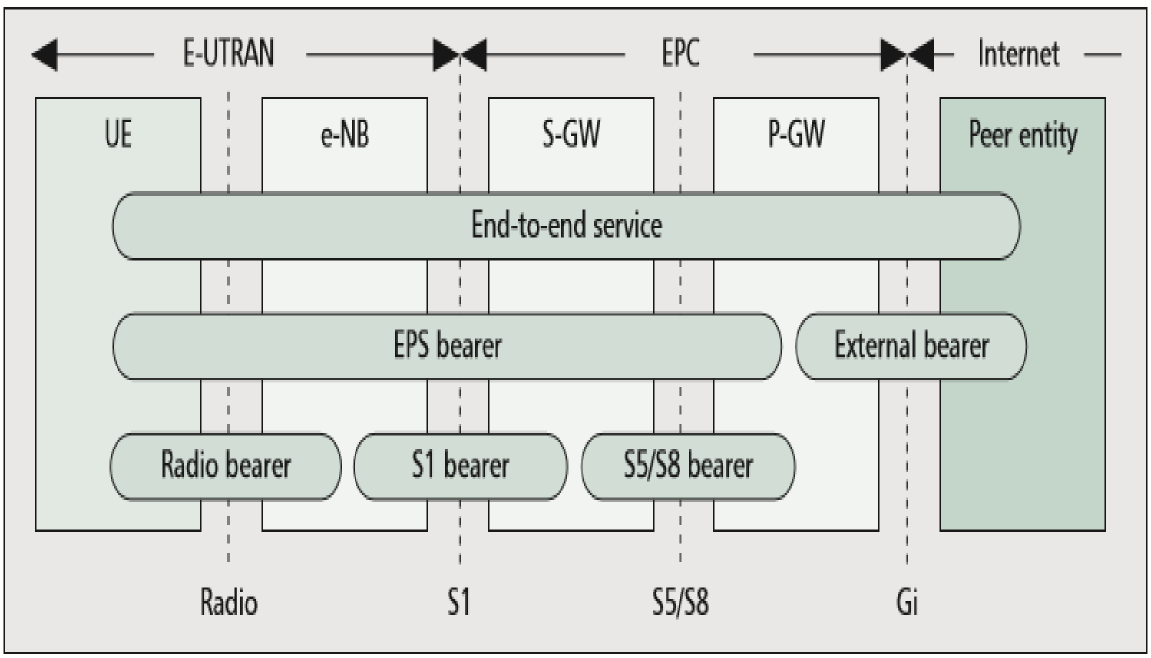


Figure 1.1: shows the E2E QoS support and EPS bearer establishment in the LTE networks

Currently deployed advanced cellular standard is 4G Long Term Evolution (LTE) which allows cellular companies to provide even more advanced services in an efficient manner. With the development of LTE, the speed of the data transmission has increased with respect to the mobile and fixed broadband. The LTE offers support for more services such as voice, data, video and multimedia. It is based on OFDM/OFDMA (Orthogonal Frequency Division Multiplexing / Orthogonal Frequency Division Multiple Access) which is well suited to achieve high peak data rates in high spectrum bandwidth and multipath fading channel [1]. LTE has the capability to use packet data at higher bit rates. The usage of advanced access, and transmission techniques for both the transmission bandwidth and QoS of cellular networks have been improved.

It is a much better indication of the performance of the network. QoS is a measure of the network quality as it relates to the user experience. Some examples of the QoS parameters would be achieved with the success rate, average throughput, and throughput jitter. One may attempt to characterize QoS of a network is by using these three significant parameters. The area of study proposed in this paper is the evaluation of QoS of 4G cellular data network. At present, this is a problem that exists despite the fact there are large volumes of measured performance data collected on various nodes of cellular networks. There is still no unified approach that is endorsed by the community on how these data are to be analyzed, processed and presented.

The main idea behind 4G is to prepare a universal infrastructure that is able to support both existing and future services. It aims at meeting the future demand for mobile user capacity, providing mobile data, multimedia communication services and also providing global roaming.

For the consumers it provides video streaming, television broadcast, video calls, video clip news, music, sports, enhanced gaming, chat, location services, different data services etc.

And for the business it provides high speed teleporting access, sales force automation, video conferencing and real-time financial information. It also has greater capacity with higher efficiency than second and third-generation systems. The real time applications such as voice, video, voice conferencing and video conferencing are highly delay and loss sensitive. These applications require high data rate and high band width to guarantee QoS to the end users. QoS is the capability of the mobile communication systems' service providers to provide a satisfactory service, which includes voice quality, video quality, signal strength, low call blocking and dropping probability, high data rates for multimedia and data applications, etc. It determines how satisfied the users are with the services provided by the telecom operator. Also, it refers to the ability of the network to deliver predictable and guaranteed performance for the applications that are running over the network.

Offering the required end-to-end QoS for mobile communication systems is one of the challenges for service provider and telecom operators.

1.1 Background of 4G LTE

During 2004 3rd Generation Partnership Project (3GPP) started to investigate requirements for UMTS Terrestrial Radio Access Network (UTRAN) LTE. Workshops were held with many telecommunications industry players. During these workshops it was agreed that feasibility study for new packet-only radio system will be started. During the feasibility study following key requirements was defined for the new system [6]:

- Packet-switched domain optimization
- Roundtrip time between server and user equipment (UE) must be bellow 30ms and access delay below 300 ms
- Uplink peak rate 75 Mbps
- Downlink peak rate 300Mbps
- Improvements to mobility and security
- Terminal power efficiency improvements
- Wide frequency flexibility with 1.25/2.5, 5, 10, 15 and 20MHz allocations
- Capacity increase compared to 3GPP release 6 (HSDPA/HSUPA)
- Control plane latency (Transition time to active state) less than 100ms both in idle and active.
- User plane latency less than 5ms [28].
- Control plane capability more than 200 users per cell for 5MKz spectrum
- Cell size (coverage) 5-100km with minor degradation following 30km [28].

LTE technology has many benefits when compared to current 3G networks. UMTS Forum [6] describes that from a technical point of view, the main objective of the LTE project is to offer higher data rates for both down- and uplink transmission. Another main improvement for LTE is to reduce packet latency. By reducing latency responsiveness of gaming, VoIP, videoconferencing and other real-time services are improved greatly. Dr. Michael Schopp[62] defines that the main benefit of LTE is that it can deliver services at fixed line quality with cost of IP technologies. 3G Americas (3gamericas) argues that main benefit of LTE is the simplified and flat all IP architecture which helps to reduce both latency and cost of the network. Dahlman et all [6] defines that the benefits of LTE come from increased data rates, improved spectrum efficiency, improved coverage, and reduced latency.

Table 1.1 Uplink and downlink data rates compared for HSPA and LTE [6].

	HSDPA(MHz)	HSDPA / HSUPA	HSPA +	LTE (20 MHz)
Uplink	384 kbit/ s	5.76 Mbit/s	11.5Mbit/s	75 Mbit/s
Downlink	14.4 Mbit/s	14.4 Mbit/s	28 Mbit/s	300 Mbit/s

Based on all of these we can say that the LTE will bring benefits for many areas compared to current telecommunications networks. However, the biggest competitive affect from the network operator point of view will be its reduced cost per bit.

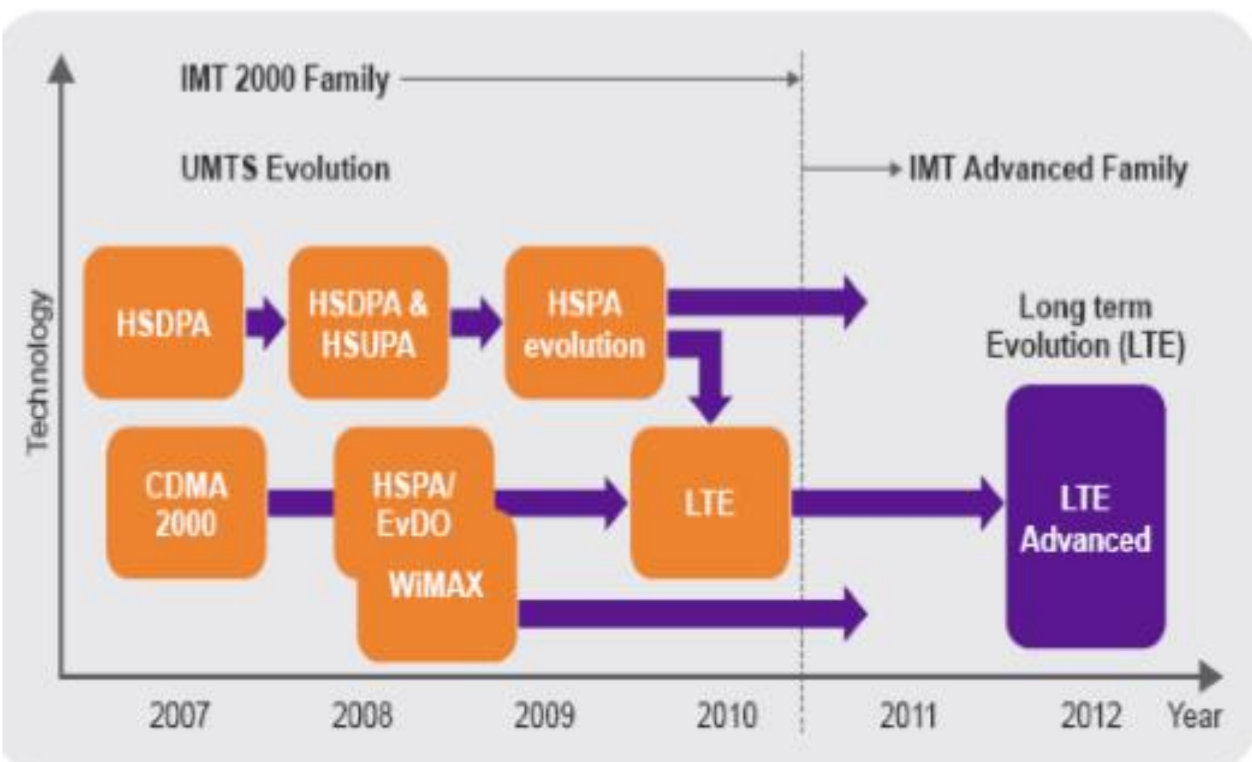


Figure 1.2: Evolution timeframe for network systems (Nokia Siemens Networks) [2]

Market for UMTS/HSPA is estimated to grow until 2013 but it is good to remember that LTE networks are not in that far in the future. Some LTE networks are already ramped-up e.g. DoCoMo in Japan has a prototype LTE network [2] Figure 1.2 presents a basic timeframe for different network improvements.

1.2 Research Motivation

The rapid increase of mobile data usage and emergence of new applications such as online gaming, mobile TV, data services and streaming contents have motivated the 3GPP to work on the LTE on the way towards 4G mobile networks. The need to ensure the continuity of competitiveness of the Third Generation (3G) system in the future, the user demand for higher data rates and quality of service and continued demand for cost reduction are also some of the motivations.

This research work tries to examine the performance of non-real-time application i.e. downlink and uplink the LTE network. Investigation of the QoS performance opens more researches to create an adaptive measure to data streamline the provisioning of bandwidth to various applications across the network and help to think of the better strategies to treat data service applications to give better service and QoS required by the end users.

1.3 Statement of the Problem

The continuing growth of wireless devices and multimedia services create challenges for providing Quality of Service (QoS) support to users. In the Ethiotelecom Addis Ababa city, the 4G system is one of the features of mobile communication system which is able to give quality services for end users. The current 4G network infrastructure deployed in the Addis Ababa city, which is solely managed by ethio telecom, is undergoing major expansions in the last 5 years and resulted in a tangible improvement of coverage and quality performances. However, there is problem from different types of problems exists in this cellular network as the following:

- Mobile data traffic congestions due to large numbers of data user's request since the volume of data carried over mobile networks remains a small proportion in operator side.
- Data revenue loss on company side and data service using complaints from end users from various parts of the city.

- The preliminary analysis or from daily network monitoring and analysis results show that, there is some disparities between the ethio telecom targets and analysis results.
- Lack of good E2E QoS Monitoring system, this means there is no network monitoring tool that shows network quality of Radio part performance with user satisfaction level link to the core network performance at same time.
- Improper optimization this mean optimization done by company is not meet the international standards, on such as shortage of resources (i.e. channel element (CE) licenses, power license, etc), power interruption, and weak coverage due to dispraised mobile tower sites, deflection and reflection of signals between the buildings especially around condominium and between different buildings.

  To correctly resolve these problems the evaluation of QoS of data over 4G LTE and Solution Recommendation for 4G LTE will be done in this research.

1.4 Objective of the Thesis

1.4.1 General Objective

The General objective of this thesis is to evaluate the existing QoS of data in the 4G LTE network in case of Addis Ababa and Recommend Solution for LTE Data service that can be used for future improvement of the QoS of data service in 4G network.

1.4.2 Specific Objectives

The specific objectives of the thesis are:

- Survey of existing literatures on QoS of data over 4G network system.
- Determining QoS internet data parameters and discussing them
- Collection of control and user plane systems' data for visualization of current status of QoS and QoE.
- Evaluate the QoS of data in 4G network.
- Based on analysis results, recommend the possible solutions to improve the QoS of data.

1.5 Methodology

Due to financial constraints and equipment limitations, the simulation of a sample network, especially in academic research, is very important in the fields of computer networking and telecommunication. Not only does it help to get the perspective view of a network, it also provides guidance for the future. To do this thesis we use the following Instruments: Control and user plane systems' data collections of the existing Addis Ababa 4G network have been done, by using control plane tools (i.e., SEQ analyst, PRS, and user plane tools (i.e. nemo handy, GPS, scanner, google earth, and actix analyzer). After that, data analyses have been done to identify the performance of QoS of data 4G LTE network. Based on the analysis results, the possible solutions have been recommended.

In general, the method is formulated as:

- Data collected from 4G network control and user plane systems;
- Collected data analyzed;
- Analyzed data discussed in different statistical plots and tables;
- Finally recommend the possible solutions to improve the internet data QoS.

1.6 Preliminary Investigations

We have seen that from our daily 4G network dashboard report there is the problem on Availability from KPI. This availability parameter shows bellow the target setup by Ethiotelecom, so it need new QoS assessment that investigate the root cause of availability limitation.

Network Availability: Network Availability Total (Radio 24 hrs), Network Availability Total (NBH hrs) Radio. In ethio telecom target is >=99.5%, however in this time the availability sometimes shows between 80.84% - 96.5%. This indicate the availability issue.

Secondly there is limited number of 4G user as a whole in Ethiopia. This also needs its own of research area.

1.7 Expected Results and Contributions

The contributions of this thesis work are:

- Practically the entire 4G network of Addis Ababa city's QoS of data is evaluated, this useful for ethio telecom to see its services current status,
- Theoretically the possible solutions to improve the QoS of data in the city are recommended,
- Provides good bandwidth estimation results for content delivery in conditions with different packet sizes

1.8 Scope

The scopes of this thesis are:

- Evaluate the existing QoS of data over 4G network in the city.
- Recommend the possible solutions to improve the QoS of data in the city.

1.9 Thesis Organization

The thesis work is organized in such a way that it gives a clear flow and understanding regarding the subject matter. Chapter one presents the introduction, Research Motivation, statement of the problems, objective of the thesis, literature review, methodologies, thesis scope and limitation, contribution and thesis layout. Chapter two presents literature review of 4G network introduction, 4G key technologies and 4G architecture and interface protocol, and Review of Related Works. Chapter three presents and discussion Quality of Service and QoE in 4G LTE network. Chapter four presents the introduction Control and User Management Tools. Chapter five presents the control and user plane systems' data collection and analysis and both analysis results are presented with reasonable explanation. Finally, discussion, conclusion is given followed by points of recommendation in chapter six.

Chapter Two

Literature Review and Review of Related works

2.1 4G Network Introduction

With the rise of adoption of smartphones, the area of telecommunication especially the mobile device and standards industry are encountering a new paradigm of technological advancement. The present paper has discussed the emergence of LTE (Long-Term Evolution) that acts as the standard for the wireless communication system for high-speed data transmission for catering to the needs of dynamic mobile users [46]. The concept of LTE is basically based on the existing technologies e.g. GSM/EDGE (Global System for Mobile Communications/ Enhanced Data Rates for GSM Evolution) as well as UMTS (Universal Mobile Telecommunications System) for the purpose of enhancing the capabilities of mobile network. Different countries use different frequencies as well as bands for LTE network due to which a mobile device with support for multiband is required. Essentially, the architecture designed for LTE protocol consists of user plane and control plane. The user plane is responsible for furnishing function between user device and Evolved Universal Terrestrial Radio Access (EUTRAN), (UMTS-Universal Mobile Telecommunication System) Terrestrial Radio Access Network) while control plane is used for providing the access policies. The LTE network is essentially designed using Evolving Packet System (EPS) that consists of multiple radio access resources called and network of IP cores.

2.2 4G LTE Key Technologies

To reach the higher data rates and faster connection times LTE contains a new radio interface and access network. During 3GPP organized workshops it was agreed that the technology solution chosen for the LTE air interface uses Orthogonal Frequency Division Multiplexing (OFDM) and Single Carrier Frequency Division Multiple Access (SC-FDMA). Also to reach the agreed data levels multiple input / multiple output (MIMO) technologies, together with high rate modulation were agreed [6].

LTE uses the same principles as HSPA for scheduling of shared channel data and fast link adaptation. This enables the network to optimize cell performance dynamically. LTE does not contain dedicated channels carrying data to specific users because it is based entirely on shared and broadcast channels. This increases the efficiency of the air interface as the network no longer has to assign fixed levels of resource to each user but can allocate air interface resources according to real time demand [6]

Some of the key technologies required for 4G LTE are briefly described below:

2.2.1 OFDMA

OFDMA used in the downlink. The OFDM signal used in LTE comprises a maximum of 2048 different sub-carriers having a spacing of 15 kHz[64]. Although it is mandatory for the mobiles to have capability to be able to receive all 2048 sub-carriers, not all need to be transmitted by the base station which only needs to be able to support the transmission of 72 sub-carriers. In this way all mobiles will be able to talk to any base station.

Within the OFDM signal it is possible to choose between three types of modulation for the LTE signal [64]:

1. ***QPSK (= 4QAM)*** 2 bits per symbol
2. ***16QAM*** 4 bits per symbol
3. ***64QAM*** 6 bits per symbol

- Note on QAM, Quadrature Amplitude Modulation: Quadrature amplitude modulation, QAM is widely sued for data transmission as it enables better levels of spectral efficiency than other forms of modulation. QAM uses two carriers on the same frequency shifted by 90° which are modulated by two data streams - I or In phase and Q - Quadrature elements.

The exact LTE modulation format is chosen depending upon the prevailing conditions. The lower forms of modulation, (QPSK) do not require such a large signal to noise ratio but are not able to send the data as fast. Only when there is a sufficient signal to noise ratio can the higher order modulation format be used.

- **Downlink carriers and resource blocks**

In the downlink, the subcarriers are split into resource blocks. This enables the system to be able to compartmentalize the data across standard numbers of subcarriers.

Resource blocks comprise 12 subcarriers, regardless of the overall LTE signal bandwidth.

They also cover one slot in the time frame. This means that different LTE signal bandwidths will have different numbers of resource blocks.

Table 2.1: Different bandwidth with different resource blocks.

Channel bandwidth (MHz)	1.4	3	5	10	15	20
Number of resource blocks	6	15	25	50	75	100

3GPP needed to make quite radical changes to LTE radio interface because enhancements to WCDMA technology could cause major problems with power consumption. Also the processing capability required in LTE would have made the resulting technology unsuitable for handheld mobile devices. OFDM-based technology was chosen because it can achieve the targeted high data rates with simpler implementations involving relatively low cost and power-efficient hardware [6].

It is good to notice that OFDMA is used in the downlink of LTE but for the uplink Single Carrier – Frequency Division Multiple Access (SC-FDMA) technology is used. SC-FDMA is technically similar to OFDMA but it suits better for handheld devices because it is less demanding on battery power [6].

5 MHz channel width causes constrains in data rates of WCDMA networks. To overcome these limitations in LTE networks bandwidths up to 20 MHz are deployed. If wider RF band such as 20 MHz would be used in WCDMA it could cause a group of delay problems which limits the achievable data rates in WCDMA. LTE removes these limitations by deploying OFDM technology to split the 20 MHz channel into many narrow sub-channels. Total data throughput is generated by combining these sub-channels together [6]

In Orthogonal Frequency Division Multiple Access (OFDMA) system different sub-channels are assigned to different users. Thousands of these narrow sub channels are deployed to send many messages simultaneously. Then those are combined at the receiver to make up one high speed message [6].

2.2.2 SC-FDMA

For the LTE uplink, a different concept is used for the access technique. Although still using a form of OFDMA technology, the implementation is called Single Carrier Frequency Division Multiple Access (SC-FDMA).

One of the key parameters that affect all mobiles is that of battery life. Even though battery performance is improving all the time, it is still necessary to ensure that the mobiles use as little battery power as possible. With the RF power amplifier that transmits the radio frequency signal via the antenna to the base station being the highest power item within the mobile, it is necessary that it operates in as efficient mode as possible. This can be significantly affected by the form of radio frequency modulation and signal format. Signals that have a high peak to average ratio and require linear amplification do not lend themselves to the use of efficient RF power amplifiers. As a result, it is necessary to employ a mode of transmission that has as near a constant power level when operating. Unfortunately, OFDM has a high peak to average ratio. While this is not a problem for the base station where power is not a particular problem, it is unacceptable for the mobile. As a result, LTE uses a modulation scheme known as SC-FDMA - Single Carrier Frequency Division Multiplex which is a hybrid format. This combines the low peak to average ratio offered by single-carrier systems with the multipath interference resilience and flexible subcarrier frequency allocation that OFDM provides.

2.2.3 MIMO

Today's mobile networks are very noisy environments. Noise in the mobile networks is created by other users, neighboring cell sites and thermal background noise. Without noise, an infinite amount of information could be transmitted over a finite amount of spectrum. Shannon's Law formulated by mathematician Claude Shannon, states that there is a fundamental limit to the amount of information that can be transmitted over a communications link. The volume of error-free data that can be transmitted over a channel of any given bandwidth is limited by noise [6].

To minimize the effects of noise and to increase the spectrum utilization and link reliability LTE uses Multiple Input Multiple Out Put(MIMO) technique to send the data. The basic idea of MIMO is to use multiple antennas at receiver end and use multiple transmitters when sending the data. Before sending the data transmitter converts serial bit streams output by the source into multiple parallel sub streams. Then transmitter sends them via different transmit antennas using the same time slot and the same frequency band. After receiving data receiver separates out the original sub streams from the mixed signals using the non-correlation of signals on multiple receive antennas caused by multipath in the transmission. This leads to significant increases in achievable data rates and throughput. Shannon's Law applies to a single radio link between a transmitter and a receiver. By using MIMO technique Shannon's law can be bended a little bit. In MIMO each individual radio link is limited by Shannon's Law but collectively they can exceed it [6]

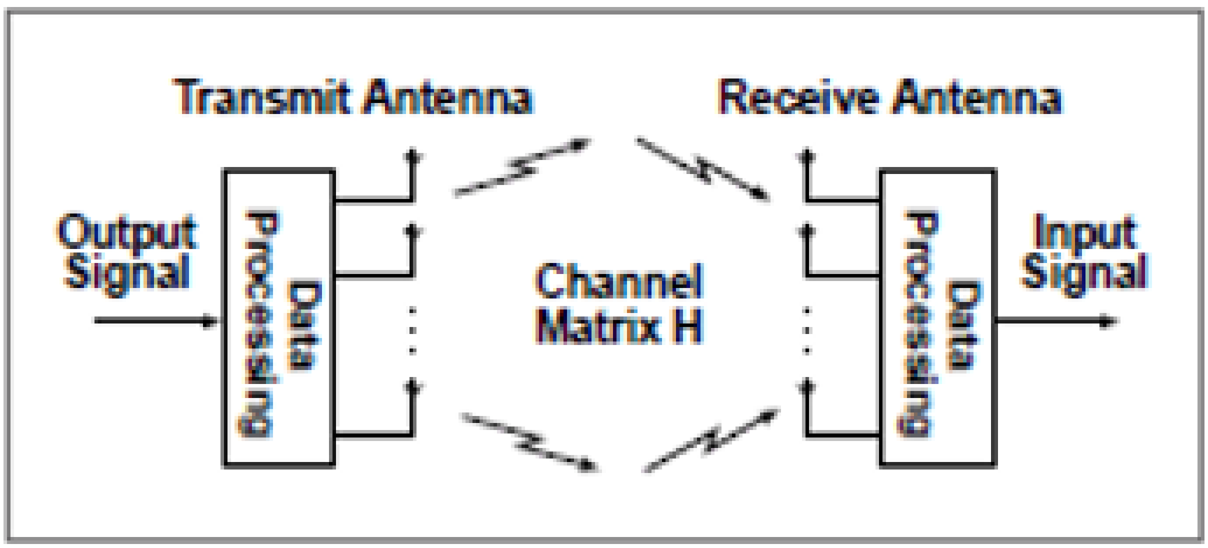


Figure 2.1 MIMO system diagram[6]

2.2.4 Modulation and Demodulation

Modulation is the process to use one signal (know as modulation signal) to control another signal of carrier (known as carrier signal), so that a characteristic parameter of the later changes with the former. At the receiving end, the process to restore the original signal from the modulated signal is called demodulation. During signal modulation, a high-frequency sine signal is often used as the carrier signal. One sine signal involves three parameters: amplitude, frequency and phase. Modulation of each of these three parameters is respectively called amplitude modulation, frequency modulation, and phase modulation.

OFDMA

LTE takes advantage of OFDMA, a multi-carrier scheme that allocates radio resources to multiple users [7]. OFDMA uses Orthogonal Frequency Division Multiplexing (OFDM). For LTE, OFDM splits the carrier frequency bandwidth into many small subcarriers spaced at 15 kHz, and then modulates each individual subcarrier using the QPSK, 16-QAM, or 64QAM digital modulation formats. OFDMA assigns each user the bandwidth needed for their transmission. Unassigned subcarriers are off, thus reducing power consumption and interference. OFDMA uses OFDM; however, it is the scheduling and assignment of resources that makes OFDMA distinctive. The OFDM diagram in Figure 2 below shows that the entire bandwidth belongs to a single user for a period. In the OFDMA diagram, multiple users are sharing the bandwidth at each point in time.

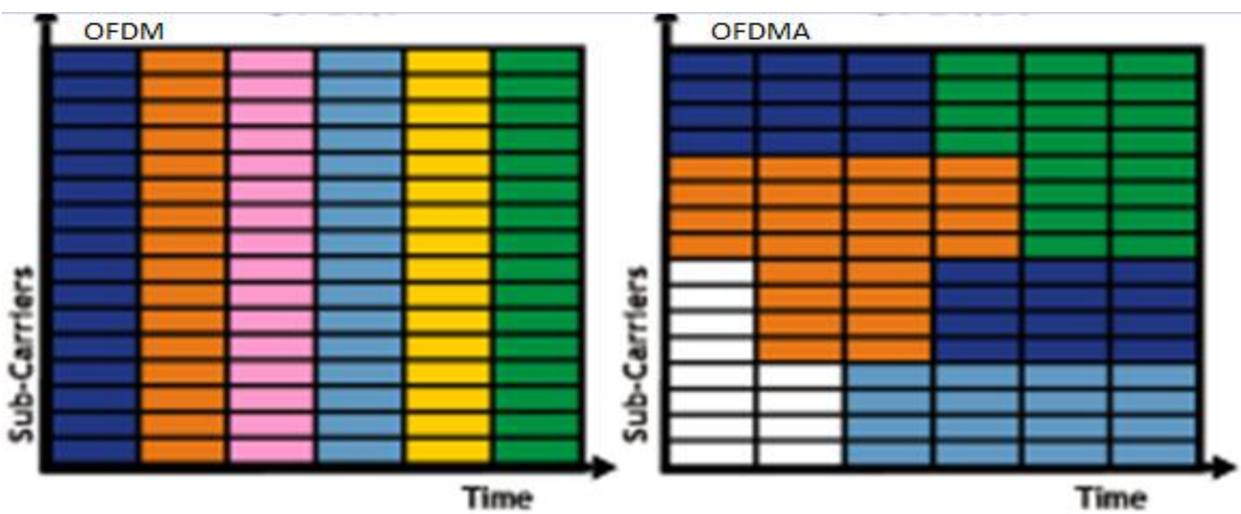


Figure 2.2 : Shows the comparative between OFDM and OFDMA[7].

Each color represents a burst of user data. In a given period, OFDMA allows users to share the available bandwidth.

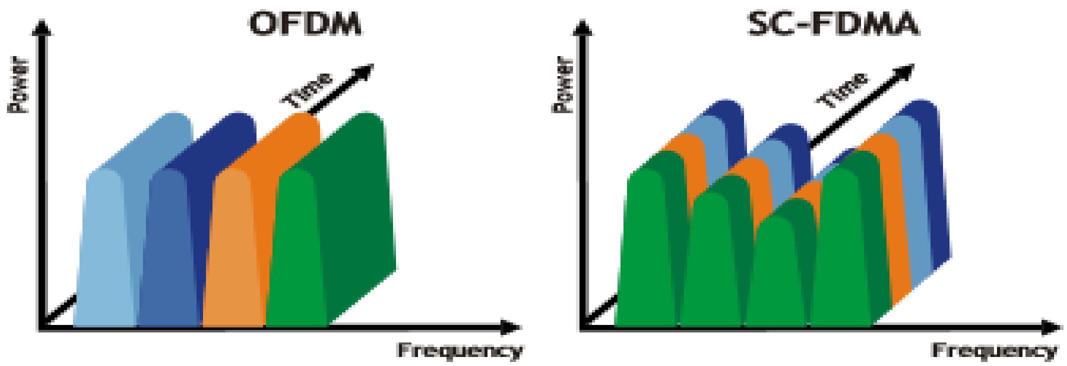


Figure 2.3: Shows in OFDM, each frequency component carries unique information.

In SC-FDMA, the information is spread across multiple subcarriers.

Adaptive Modulation and Coding (AMC)

Adaptive Modulation and Coding refers to the ability of the network to determine the modulation type and the coding rate dynamically based on the current RF channel conditions reported by the UE in Measurement Reports.The RF digital modulation used to transport the information is QPSK, 16-QAM, and 64-QAM. The pictures below show the ideal constellations for each modulation where each dot represents a possible symbol. In the QPSK case, there are four possible symbol states and each symbol carries 2 bits of information [7]. Figure 2.4 Show different types of Modulation schemes. In 16-QAM, there are 16 symbol states. Each 16-QAM symbol carries 4 bits. In 64-QAM, there are 64 symbol states. Each 64-QAM symbol carries 6 bits.

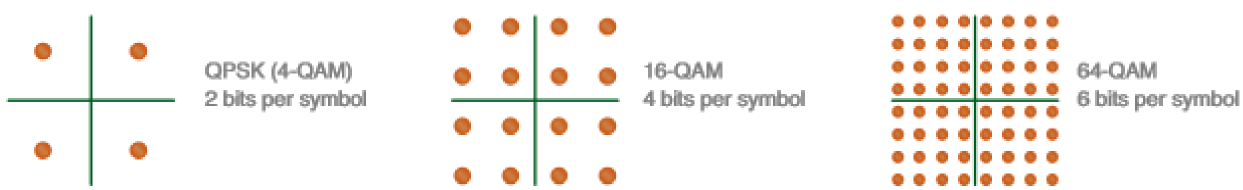


Figure 2.4 Show different types of Modulation schemes[6].

Higher-order modulation is more sensitive to poor channel conditions than the lower-order modulation because the detector in the receiver must resolve smaller differences as the constellations become denser. Specified as fractions, Code Rates specify the number of data bits in the numerator and the total number of bits in the denominator. Thus if the Code Rate is 1/3, protection bits are added so one bit of data is sent as three bits.

- **SC-FDMA**

In the uplink, LTE uses a pre-coded version of OFDM called SC-FDMA. SC-FDMA has a lower PAPR (Peak-to-Average Power Ratio) than OFDM [7]. This lower PAPR reduces battery power consumption, requires a simpler amplifier design and improves uplink coverage and cell-edge performance. In SCFDMA, data spreads across multiple subcarriers, unlike OFDMA where each subcarrier transports unique data. The need for a complex receiver makes SC-FDMA unacceptable for the downlink.

2.2.5 Power Control

Power control refers to setting output power levels of transmitters, base stations in downlink and mobile stations in uplink. In order to maximize the spectral efficiency, coverage and quality, 3GPP LTE is designed for frequency reuse both for downlink and uplink, which means that all cells in the network use the same frequency bands [10]. Thus with frequency reuse, both data and control channels are sensitive to inter-cell interference. The cell edge performance and the capacity of a cell site can be limited by the inter-cell interference. Since the LTE use a Orthogonal Frequency Division Multiplexing (OFDM) technology for downlink, the interference in a single cell is so low that hardly has a necessity to consider mainly. Therefore, the role of power control becomes decisive to provide the required SINR to maintain an acceptable level of communication between the eNB and the UE while at the same time controlling interference caused to neighboring cells.

Power control implementations in cellular systems often consist of Open-loop power control (OLPC) and Closed-loop power control (CLPC) [11]. The closed loop power control accomplishes close estimate to the desired level at the receivers of mobile stations. The receivers constantly observe the received signal quality (may be reflected by signal strength, i.e. signal to-interference ratio (SIR), bit error rate (BER), and delay) and determine appropriate power control commands. A feedback channel is necessary to transmit these commands to the senders for power adjustments. The open loop power control does not need a feedback channel. The transmitting power level adjustment is determined based on the estimation of the channel quality of the opposite direction stations. The estimation error of the open loop power control can be rather high, especially when the forward link and the reverse link are not highly correlated.

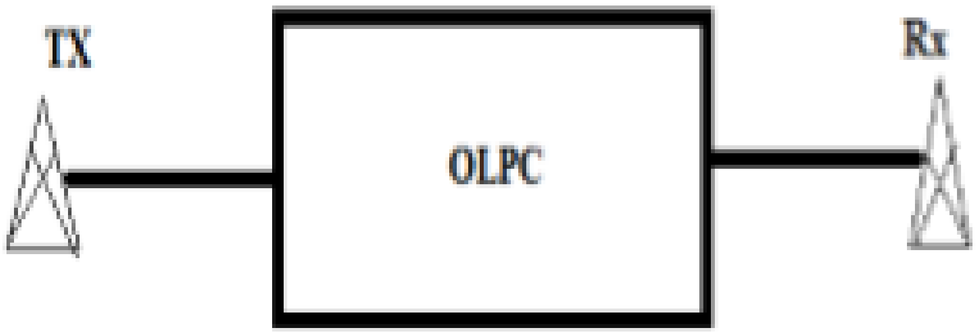


Figure 2.5: Schematic of open loop power control scheme

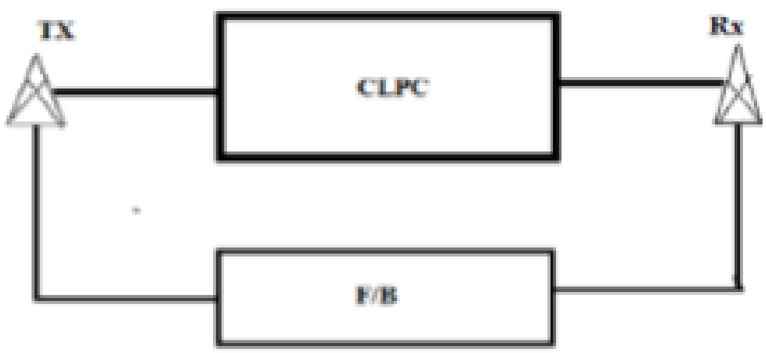


Figure 2.6: Schematic of closed loop power control scheme.

CLPC schemes are more expensive to implement and are most beneficial in the uplink communication or for a Frequency Division Duplex (FDD) system where uplink and downlink are on different frequencies and the channel on the two links are uncorrelated with respect to fast fading. Typically, tolerance levels for OLPC are in the range 9-12dB and tolerance levels for CLPC in the range 1-2dB [11].

- **Open-loop power control**: Decide a starting emission power of UE emission power as the basis for closed-loop control adjustment.
- **Closed-loop power control**: eNode B measures SINR of PUCCH/PUSCH/SRS signal, then compares SINR with SINRtarge to determine the TPC command (what's informed is power step size.), finally informs UE through PDCCH to determine the emission power of uplink sent signal on the corresponding sub-frame.
- **Outer-loop power control**: According to the change of environment, adjust the channel of received signal SINR target
- **Inner-loop power control**：To solve the near-far effect and loss, make the received signal maintain fixed SINR

Downlink Power Control

Transmission bandwidth consists of transmission power located in the Down-link inter cell. The downlink coordination facilitates the relative narrow band transmission power indicator where a cell can transmit information to the neighboring cells. Dictated by these neighboring cells, which upon receiving the indication can schedule its downlink transmission, it contributes to the overall reduction of the output of the spectrum. A reuse is possible on its fullest frequency in neighboring cells within the core part of the inter-cell interference coordination scheme in LTE . In case of 4G DL, rather than varying power in the Downlink, full power is distributed uniformly over the whole bandwidth. The same Power Spectral Density (PSD) is used on all DL channels. For example, PDSCH, PHICH, PDCCH etc.We calculate the PSD by the following way

PSD is the power of a signal divided by Bandwidth.
PSD = Power / Bandwidth.
In case of PSD, it is normalized to one resource block.

Uplink Power Control

One of the mechanisms that LTE uses is Uplink Power Control (UPC). Received signals stability of the expect cell is controlled by the mechanism as well as ensuring control interference in connect cells. One of the principle characteristics of the mechanism is that fractional path-lose compensation which can be supported by eventually leads to less interference and power transmission to neighbor cells

- LTE Uplink Power Control has the following functions:

  - UL power control described in 3GPP
  - Adjusts UE Tx to compensate for channel fading.
  - Reduces inter cell interference
  - Avoids UE from transmitting excessive power.
  - Maximizes uplink data rate.
  - eNB radio receive power maintained for optimum SINR.
  - Prolongs UE's battery life.
  - Power Control update rate: 1kHZ (1ms = TTI = 1 subframe).

- LTE uplink power control is a combination of an open-loop and a closed- loop mechanisms.
  - Open-loop: the terminal transmits power depends on estimate of the downlink path-loss and channel configuration.
  - Closed-loop: implying that the network can, in addition, directly control the terminal transmit power by means of explicit power-control commands transmitted in the downlink.
  - Open-loop power control is used for: PRACH at initial access (Random Access). . PUSCH and PUCCH as part of UL power control.
  - Close-loop power control is used for: . PUSCH and PUCCH as part of UL power control.

2.2.6 Handover

Handover is an essential part of Radio Resource Management (RRM) and it involves transfer of user equipment (UE) call or data session from one cell to another to facilitate continuous connection. The main aim of handover is the maintenance of quality of service and preservation of cellular system capacity. Handover in LTE is UE-assisted network controlled. The handover is of two types which are Intra Radio Access Technology (Intra-RAT) and Inter Radio Access Technology (Inter-RAT). LTE IntraRAT handover is purely hard handover and involves transfer between similar (LTE) technologies while Inter-RAT handover is soft handover involving dissimilar technologies. Soft handover is a category of handover procedures where the radio links are added and abandoned in such manner that the UE always keeps at least one radio link to the eUTRAN it is Connect-Before-Break.This also called vertical hand over between different networks.

LTE Intra-RAT handover is called hard handover .It also called horizontal hand over between homogeneous networks. . The hard handover, also called "break-before-make", implies termination of connection with serving eNodeB of the old cell before establishing a connection with target eNodeB in the new cell. The brief interruption in the user plane by hard handover may cause data loss. Therefore, a mechanism must be in place to reduce the amount of data loss. Seamless or lossless mode is used for downlink packet data forwarding to minimize the amount of data loss in the user plane [47].

Types of Handover in LTE network

- Intra-LTE Handover: In this case source and target cells are part of the same LTE network.
- Inter-LTE Handover: Handover happens towards other LTE nodes. (Inter-MME and Inter-SGW)
- Inter-RAT: Handover between different radio technologies. For example handover from LTE to WCDMA.

Intra-LTE Handovers

2.2.7 Resource allocation in 4G LTE

The radio transmissions in LTE are based on the Orthogonal Frequency Division Multiplexing (OFDM) modulation scheme. In particular, the Single Carrier Frequency Division Multiple Access

(SC-FDMA) and the OFDM Access (OFDMA) are used in uplink and downlink transmissions, respectively. Differently from basic OFDM, they allow multiple access by assigning sets of sub-carriers to each individual users. Moreover, OFDMA can exploit subsets of sub-carriers distributed inside the entire spectrum whereas SC-FDMA can use only adjacent subcarriers. OFDMA is able to provide high scalability, simple equalization, and high robustness against the time-frequency selective fading of the radio channel. On the other hand, SC-FDMA is used in the LTE uplink to increase the power efficiency of user equipment's (UEs) which are battery supplied. LTE has a frame duration of = 10 ms and it is divided into equally size sub-frame, called Transmission Time Interval (TTI), lasting 1 ms. The whole bandwidth is divided into 180 kHz physical RBs, each one lasting 0.5 ms and consisting of 6 or 7 symbols in the time domain (according to the OFDM prefix-code duration) and 12 consecutive sub-carriers in the frequency domain as shown in figure 2.7.

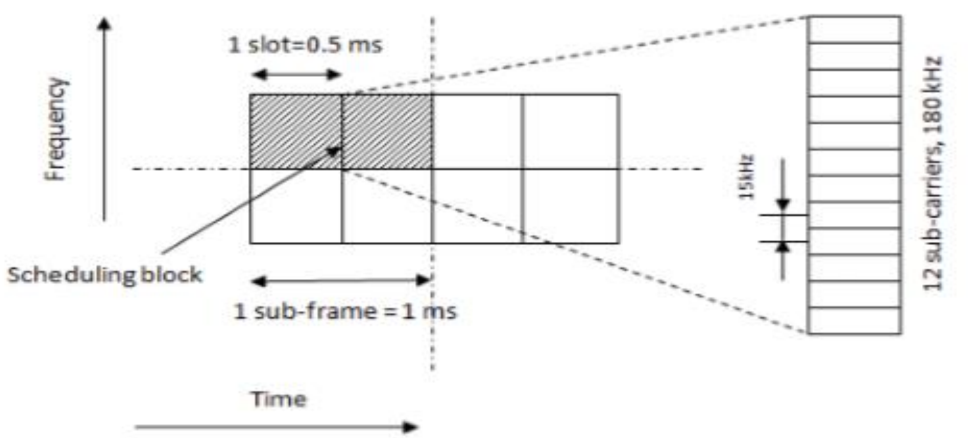


Figure 2.7 Illustration of a scheduling block in LTE downlink

The resources allocation is realized every TTI, that is exactly every two consecutive RBs; thus, resource allocation is done on a RB pair basis so during the remaining of this paper we use the term RB to denote two consecutive RBs in time domain that constitute one TTI.Every TTI, the Channel Quality Indicator (CQI) is reported by the user measurement entity to the base station (BS) to provide time and frequency channel quality information for better spectral efficiency and resource allocation. For downlink RBs, users use the Physical Uplink Control Channel (PUCCH) to convey channel quality information to the BS. BS conveys downlink RBs allocations and MCS assignments to all users using the Physical Downlink Control Channel (PDCCH) . For uplink RBs, the BS estimates the channel quality of the received uplink RBs and conveys uplink RB allocations to users using the PDCCH.

2.2.8 Call Admission Control in LTE

Call admission control is a process to ensure and maintain certain level of Quality of Service (QoS) for real time and non-real time call requests in the network. The main objective of CAC is to maintain the efficient resource allocation and to monitor the resource utilization in the high volume of traffic. CAC manages the total bandwidth with respect to the number of call request available in the base station.

The call requests are classified into new call or handoff call and real time or non real time call request. CAC allocates signal strength for eNB with a minimum threshold value, when an eNB's signal strength reaches below this threshold value the call request will be blocked.

The serving eNodeB carries out a cell selection process that consists of allocating the user to the cell with the lowest load level and fulfills the QoS requirements requested by the UE. In turn, an admission control may be performed by the selected target eNodeB according to the received quality of service information. In case that there is no capacity available for the handoff call in the selected cell (i.e. the admission control is not passed), another cell from the candidates cells will be selected instead. Once the decision of the handover is taken, the serving eNodeB informs the UE by the new eNodeB and orders him to ask the detachment and to achieve the handover. The target eNodeB can now start sending data to the UE and, at the same time, send a path switch message to the Serving Gateway to inform that the UE has changed cell.

The design of CAC for a fixed network is simple, as the call admission is based on the available resources and QoS requirements of the new calls. However, the mobile environment is more complicated than the fixed network, as the eNodeB may reserve some bandwidth to admit the handoff calls. If the eNodeB reserves some bandwidth for handoff calls, and the network happens to have few or no handoff calls, then those resources may be wasted or underutilized. On the other hand, if the eNB allocates minimum resources for handoff calls, then the handoff calls may be dropped. The available resources in the base station are distributed to the available

UE's in the network with maximum and minimum threshold value. When a call request is received by the base station the initial status of the available resources is checked. Quality of Service focuses on the guarantee of service provision based on the quality policy specified for the service request. The design of a call admission control depends on the following parameters;

- **Availability of Resources**

In eNB's new call and handoff call request are admitted based on the available resources. If the resources are limited, call admission decision is made with the acceptance of the available resources. While designing the call admission control mechanism, call admission criteria considers the load of the network. Prediction based decisions are employed to admit the new calls with respect to resource reservation.

- **Quality of The Network Parameters**

The connection quality plays the major role in the establishment of interference free transmission. Received signal strength (RSS) is used to evaluate the quality of the link between the network components of the system. Quality parameters for each network element is designed and taken into account for the design of the call admission process.

- **Quality Policies**

Qos requirements are categorized with regard to the parameters like throughput, delay, fairness and bandwidth utilization. The traffic characteristics are analyzed to find the parameters for the performance degradation on the network. QoS provision is to guarantee the user request with quality policies based on the Qos demands of the user. The traffic conditions of the network are predicted to ensure the need based service with the fulfillment of required network resources.

- **Call Prioritization**

The incoming call requests are classified into real time (rt) and non real time (nrt) calls, the real time call request are provided with highest priority when compared to the non real time calls. E.g. Live video streaming calls are more prioritized than the internet browsing. Highest priorities are provided for handoff calls and emergency related calls. Reservation schemes and queuing mechanisms are introduced to deploy the priority for call request.

- **Mobility Management**

In order to reduce the call blocking and call dropping probability, the mobility factors are considered to predict the movement UEs across the base station. Mobility prediction helps the call admission process to classify the call request either new call or handoff call, as a result it produces the efficient resource allocation.

- **Optimization Methodologies**

To enhance the performance of call admission process, wide range of optimization techniques are introduced. The main objective of the call admission framework is to provide end to end QoS with the ability to manage the transmission interference problems in the radio channel. In order to ensure the better QoS the transmission architecture involves operations like network planning, parameter configuration and optimization. Network architecture is modified based on the status of the network to generate the flow of data and control over error. Optimization process reduces the complexity of the call admission process and the parameters for each call request specified with the threshold value. The incoming calls or new calls are evaluated based on the threshold value, minimum and the maximum value for each parameter will be specified in the parameter list. An objective function is constructed by means of the objective function of the network transmission parameter.

2.2.9 Congestion Control in 4G LTE

Congestion Control in the LTE wireless network is divided into Congestion Control at the end system and Congestion Control at the network side. Congestion Control at the end system mainly rely on various versions of TCP protocol. While Congestion Control at the network side is achieved by carrying on active queue management in buffer queue of router, dropping packets predictably before the formation of a full queue, avoiding deadlock, full queue and global synchronization caused by packet loss. Active queue management mechanism can be divided into two categories. One based on real queue and the other based on virtual queue. Active queue management mechanism based on real queue contains Reciprocating Equipment Management (REM) and Proportional-Integral (PI) control. Based on virtual queue and corresponding to real queue, queue management has a rate less than real queue. Packet drop or mark is based on whether the virtual queue is full or not. Researcher studied the congestion control mechanism combined by virtual queue and real queue. Through simulation, there comes the conclusion that dealing with burst data's robustness, queuing delay and jitter, active queue management mechanism based on virtual queue has the original active queue management mechanism.

2.3 Architecture of 4G LTE and Interface Protocol

Long Term Evolution (LTE) has been designed to support only packet-switched services [8] [9]. It aims to provide seamless Internet Protocol (IP) connectivity between user equipment (UE) and the packet data network (PDN), without any disruption to the end users' applications during mobility.

The functionality of the core network and the radio access network together included in the Evolved Packet System (EPS).The core network of 4G is called Evolved Packets Core(EPC) and the radio access part of 4G is called Evolved UTRAN (E-UTRAN).

EPS uses the concept of EPS bearers to route IP traffic from a gateway in the PDN to the UE.

EPS provides the user with IP connectivity to a PDN for accessing the Internet, as well as for running services such as Voice over IP (VoIP). An EPS bearer is typically associated with a QoS. Multiple bearers can be established for a user in order to provide different QoS streams or connectivity to different PDNs. For example, a user might be engaged in a voice (VoIP) call while at the same time performing web browsing or FTP download. A VoIP bearer would provide the necessary QoS for the voice call, while a best-effort bearer would be suitable for the web browsing or FTP session.

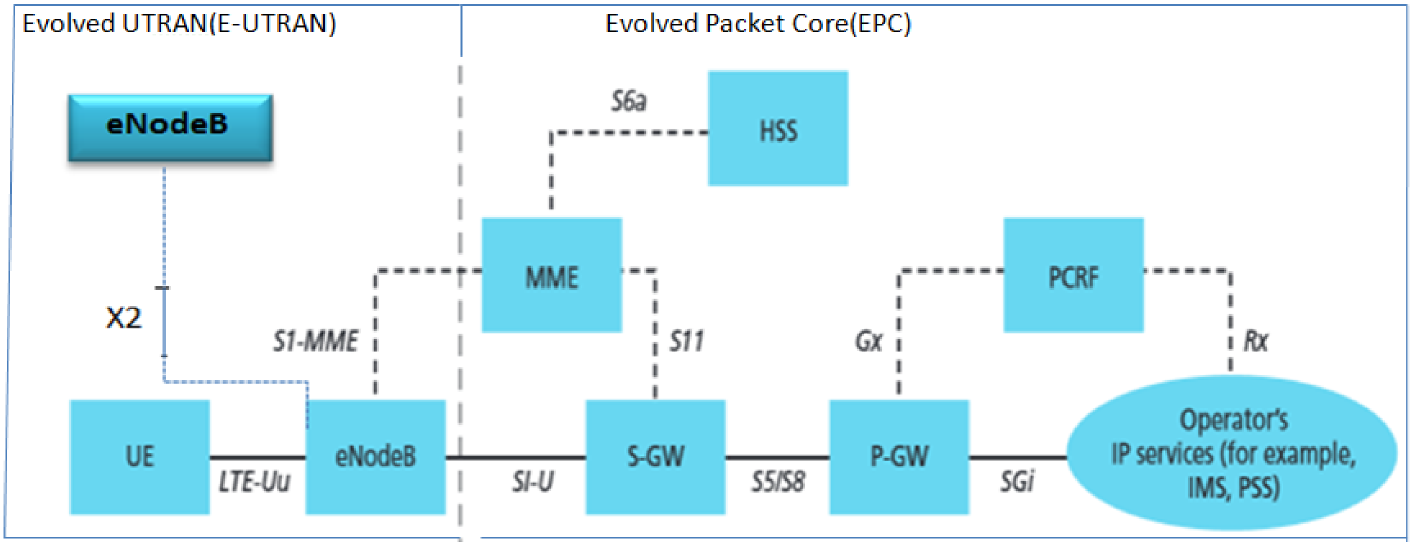


Figure 2.8 The 4G LTE (EPS) networks

The network must also provide sufficient security and privacy for the user and protection for the network against fraudulent use. This is achieved by means of several EPS network elements that have different roles. Figure 2.8 shows the overall network architecture, including the network elements and the standardized interfaces. At a high level, the network is comprised of the CN (EPC) and the access network E-UTRAN. While the CN consists of many logical nodes, the access network is made up of essentially just one node, the evolved NodeB (eNodeB), which connects to the UEs. Each of these network elements is interconnected by means of interfaces that are standardized in order to allow multi-vendor interoperability. This gives network operators the possibility to source different network elements from different vendors. In fact, network operators may choose in their physical implementations to split or merge these logical network elements depending on commercial considerations. The functional split between the EPC and E-UTRAN is shown in Figure 2.8. The EPC and E-UTRAN network elements are described in more detail below.

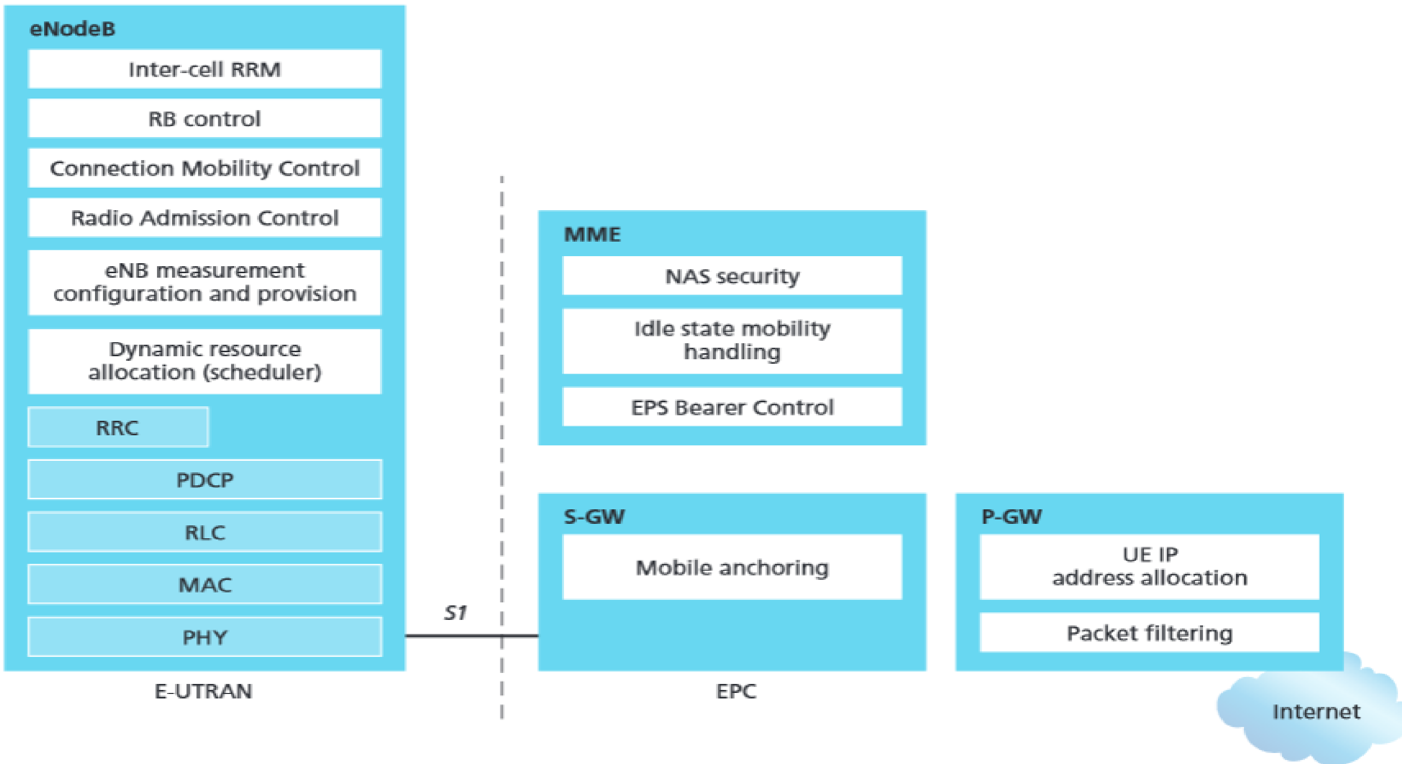


Figure 2.9 Functional split between E-UTRAN and EPC

2.3.1 The core networks

The core network (called EPC in SAE) is responsible for the overall control of the UE and establishment of the bearers. The main logical nodes of the EPC are list as the following [7][8]:

• PDN Gateway (P-GW)

• Serving Gateway (S-GW)

• Mobility Management Entity (MME)

In addition to these nodes, EPC also includes other logical nodes and functions such as the Home Subscriber Server (HSS) and the Policy Control and Charging Rules Function (PCRF). Since the EPS only provides a bearer path of a certain QoS, control of multimedia applications such as VoIP is provided by the IP Multimedia Subsystem (IMS), which is considered to be outside the EPS itself.

The logical CN nodes are shown in Figure 2.9 and discussed in more detail below:

• *PCRF* – The Policy Control and Charging Rules Function 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 PCRF provides the QoS authorization (QoS class identifier [QCI] and bit rates) that decides how a certain data flow will be treated in the PCEF and ensures that this is in accordance with the user's subscription profile.

• *HSS* – The Home Subscriber Server contains users' SAE subscription data such as the EPS-subscribed QoS profile and any access restrictions for roaming. It also holds information about the PDNs to which the user can connect. This could be in the form of an access point name (APN) (which is a label according to DNS naming conventions describing the access point to the PDN) or a PDN address (indicating subscribed IP address(es)). In addition the HSS holds dynamic information such as the identity of the MME to which the user is currently attached or registered. The HSS may also integrate the authentication center (AUC), which generates the vectors for authentication and security keys.

• *P-GW* – The PDN Gateway is responsible for IP address allocation for the UE, as well as QoS enforcement and flow-based charging according to rules from the PCRF. It is responsible for the filtering of downlink user IP packets into the different QoS-based bearers. This is performed based on Traffic Flow Templates (TFTs). The P-GW performs QoS enforcement for guaranteed bit rate (GBR) bearers. It also serves as the mobility anchor for interworking with non-3GPP technologies such as CDMA2000 and WiMAX® networks.

• *S-GW* – All user IP packets are transferred through the Serving Gateway, which serves as the local mobility anchor for the data bearers when the UE moves between eNodeBs. It also retains the information about the bearers when the UE is in the idle state (known as "EPS Connection Management — IDLE" [ECM-IDLE]) and temporarily buffers downlink data while the MME initiates paging of the UE to reestablish the bearers. In addition, the S-GW performs some administrative functions in the visited network such as collecting information for charging (for example, the volume of data sent to or received from the user) and lawful interception. It also serves as the mobility anchor for interworking with other 3GPP technologies such as general packet radio service (GPRS) and UMTS.

• *MME* – The Mobility Management Entity (MME) is the control node that processes the signaling between the UE and the CN. The protocols running between the UE and the CN are known as the Non Access Stratum (NAS) protocols.

The main functions supported by the MME can be classified as:

• *Functions related to bearer management* – This includes the establishment, maintenance and release of the bearers and is handled by the session management layer in the NAS protocol.

• *Functions related to connection management* – This includes the establishment of the connection and security between the network and UE and is handled by the connection or mobility management layer in the NAS protocol layer.

NAS control procedures are specified and discussed in more detail in the following section.

Non Access Stratum procedures

The Non Access Stratum procedures, especially the connection management procedures, are fundamentally similar to UMTS. The main change from UMTS is that EPS allows concatenation of some procedures to allow faster establishment of the connection and the bearers [8] [9].

The MME creates a UE context when a UE is turned on and attaches to the network. It assigns a unique short temporary identity termed the SAE Temporary Mobile Subscriber Identity (S-TMSI) to the UE that identifies the UE context in the MME. This UE context holds user subscription information downloaded from the HSS. The local storage of subscription data in the MME allows faster execution of procedures such as bearer establishment since it removes the need to consult the HSS every time. In addition, the UE context also holds dynamic information such as the list of bearers that are established and the terminal capabilities.

To reduce the overhead in the E-UTRAN and processing in the UE, all UE-related information in the access network, including the radio bearers, can be released during long periods of data inactivity. This is the ECM-IDLE state. The MME retains the UE context and the information about the established bearers during these idle periods. To allow the network to contact an ECM-IDLE UE, the UE updates the network as to its new location whenever it moves out of its current tracking area (TA); this procedure is called a tracking area update. The MME is responsible for keeping track of the user location while the UE is in ECM-IDLE.

When there is a need to deliver downlink data to an ECM-IDLE UE, the MME sends a paging message to all the eNodeBs in its current TA, and the eNodeBs page the UE over the radio interface. On receipt of a paging message, the UE performs a Service Request procedure, which results in moving the UE to the ECM-CONNECTED state. UE-related information is thereby created in the E-UTRAN, and the radio bearers are reestablished. The MME is responsible for the reestablishment of the radio bearers and updating the UE context in the eNodeB. This transition between the UE states is called an idle-to-active transition. To speed up the idle-to-active transition and bearer establishment, PS supports concatenation of the NAS and Access Stratum (AS) procedures for bearer activation.

Some interrelationship between the NAS and AS protocols is intentionally used to allow procedures to run simultaneously rather than sequentially, as in UMTS. For example, the bearer establishment procedure can be executed by the network without waiting for the completion of the security procedure.

Security functions are the responsibility of the MME for both signaling and user data. When a UE attaches with the network, a mutual authentication of the UE and the network is performed between the UE and the MME/HSS. This authentication function also establishes the security keys that are used for encryption of the bearers.

2.3.2 The access network

The access network of LTE, E-UTRAN, simply consists of a network of eNodeBs,as illustrated in Figure 2.9 [8][9]. For normal user traffic (as opposed to broadcast), there is no centralized controller in E-UTRAN; hence the E-UTRAN architecture is said to be flat.The eNodeBs are normally interconnected with each other by means of an interface known as “X2” and to the EPC by means of the S1 interface — more specifically, to the MME by means of the S1-MME interface and to the S-GW by means of the S1-U interface.

The protocols that run between the eNodeBs and the UE are known as the “AS protocols.”

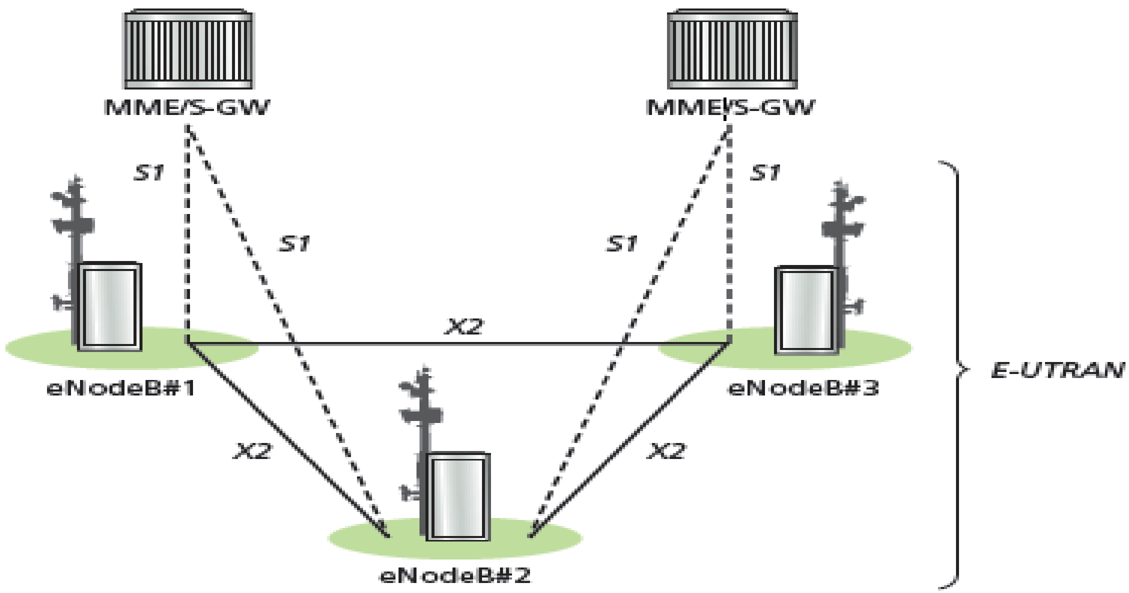


Figure 2.10 Overall E-UTRAN architecture

The E-UTRAN is responsible for all radio-related functions, which can be summarized briefly as:

• *Radio resource management (RRM)* – This covers all functions related to the radio bearers, such as radio bearer control, radio admission control, radio mobility control, scheduling and dynamic allocation of resources to UEs in both uplink and downlink.

• *Header Compression* – This helps to ensure efficient use of the radio interface by compressing the IP packet headers that could otherwise represent a significant overhead, especially for small Packets such as VoIP.

• *Security* – All data sent over the radio interface is encrypted.

• *Connectivity to the EPC* – This consists of the signaling toward MME and the bearer path toward the S-GW.On the network side, all of these functions reside in the eNodeBs, each of which can be responsible for managing multiple cells. Unlike some of the previous second- and third-generation technologies, LTE integrates the radio controller function into the eNodeB. This allows tight interaction between the different protocol layers of the radio access network (RAN), thus reducing latency and improving efficiency. Such distributed control eliminates the need for a high-availability, processing-intensive controller, which in turn has the potential to reduce costs and avoid "single points of failure." Furthermore, as LTE does not support soft handover there is no need for a centralized data-combining function in the network.

One consequence of the lack of a centralized controller node is that, as the UE moves, the network must transfer all information related to a UE, that is, the UE context, together with any buffered data, from one eNodeB to another. Mechanisms are therefore needed to avoid data loss during handover.

An important feature of the S1 interface linking the access network to the CN is known as "S1-flex."

This is a concept whereby multiple CN nodes (MME/S-GWs) can serve a common geographical area, being connected by a mesh network to the set of eNodeBs in that area. An eNodeB may thus be served by multiple MME/S-GWs, as is the case for eNodeB #2 in Figure 2.10.

The set of MME/S-GW nodes that serves a common area is called an MME/S-GW pool, and the area covered by such a pool of MME/S-GWs is called a pool area. This concept allows UEs in the cell or cells controlled by one eNodeB to be shared between multiple CN nodes, thereby providing a possibility for load sharing and also eliminating single points of failure for the CN nodes. The UE context normally remains with the same MME as long as the UE is located within the pool area.

2.3.3 Roaming architecture

A network run by one operator in one country is known as a "public land mobile network (PLMN)."

Roaming, where users are allowed to connect to PLMNs other than those to which they are directly subscribed, is a powerful feature for mobile networks, and LTE/SAE is no exception. A roaming user is connected to the E-UTRAN, MME and S-GW of the visited LTE network. However, LTE/SAE allows the P-GW of either the visited or the home network to be used, as shown in Figure 2.11. Using the home network's P-GW allows the user to access the home operator's services even while in a visited network. A P-GW in the visited network allows a "local breakout" to the Internet in the visited network.

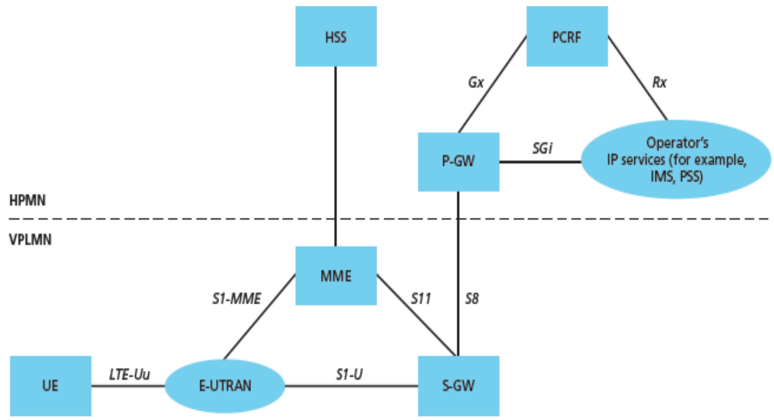


Figure 2.11 Roaming architecture for 3GPP accesses with P-GW in home network

2.3.4 General protocol model for E-UTRAN interfaces

The general protocol model for E-UTRAN interfaces is depicted in figure 2.12 and described in detail in the following sub clauses. The structure is based on the principle that the layers and planes are logically independent of each other. Therefore, as and when required, the standardization body can easily alter protocol stacks and planes to fit future requirements.

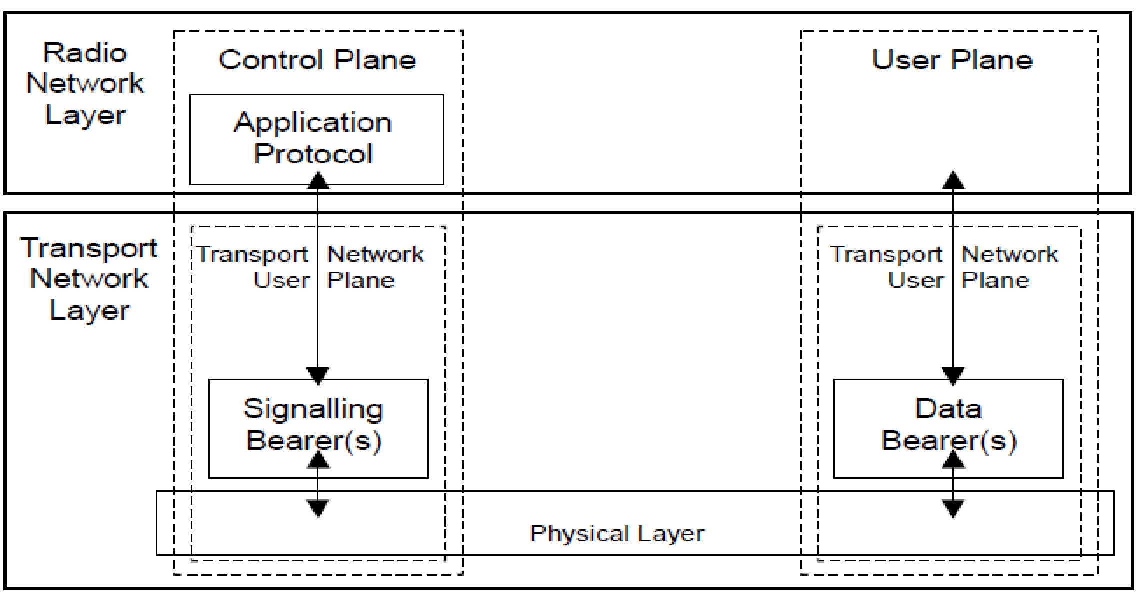


Figure 2.12 The general protocol model for E-UTRAN interfaces

2.3.5 Control plane

The control plane includes the Application Protocol, i.e. S1AP and X2AP and the Signaling Bearer for transporting the Application Protocol messages.

The Application Protocol is used e.g. for setting up bearers (i.e. E-RAB) in the Radio Network Layer. The bearer parameters in the Application Protocol are not directly tied to the User Plane technology but are rather general bearer parameters.

The protocol stack for the control plane between the UE and MME is shown in Figure 2.13. The blue region of the stack indicates the 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.

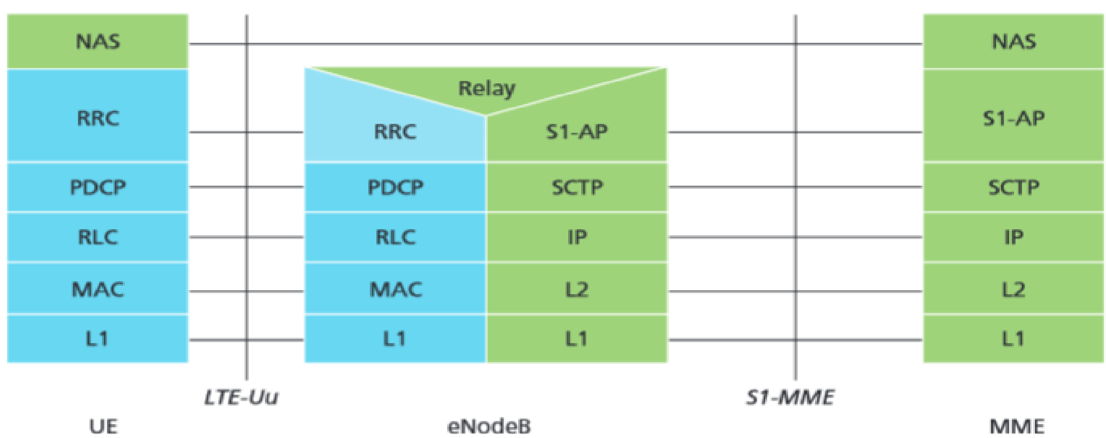


Figure 2.13 Control plane protocol stack

The Radio Resource Control (RRC) protocol is known as "layer 3" in the AS protocol stack. It is the main controlling function in the AS, being responsible for establishing the radio bearers and configuring all the lower layers using RRC signaling between the eNodeB and the UE.

2.3.6 User plane

The user plane includes the data bearer(s) for the data stream(s). The data stream(s) is characterized by a tunneling protocol in the Transport Network Layer. An IP packet for a UE is encapsulated in an EPC-specific protocol and tunneled between the P-GW and the eNodeB for transmission to the UE. Different tunneling protocols are used across different interfaces. A

3GPP-specific tunneling protocol called the GPRS Tunneling Protocol (GTP) is used over the CN interfaces, S1 and S5/S8.

The E-UTRAN user plane protocol stack is shown in blue in Figure 2.14, consisting of the Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC) and Medium Access Control (MAC) sublayers that are terminated in the eNodeB on the network side.

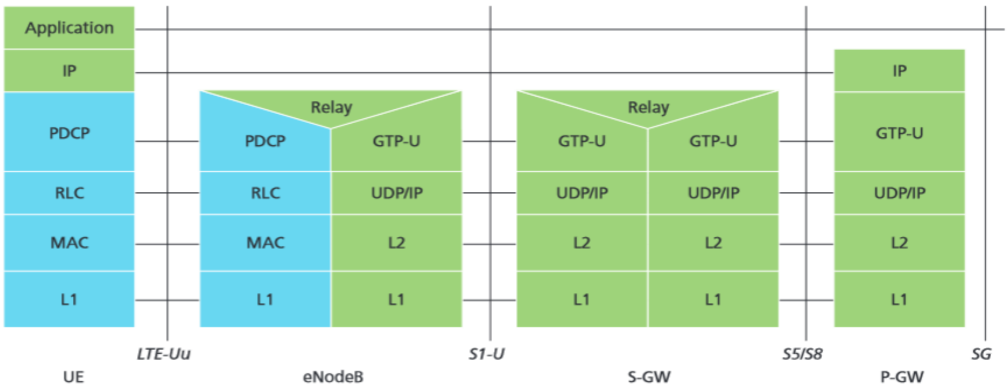


Figure 2.14 The E-UTRAN user plane protocol stack

Data handling during handover

In the absence of any centralized controller node, data buffering during handover due to user mobility in the E-UTRAN must be performed in the eNodeB itself. Data protection during handover is a responsibility of the PDCP layer. The RLC and MAC layers both start afresh in a new cell after handover.

2.4 Review of Related Works

2.4.1 QoS solutions proposed Based on the Layer

QoS solutions proposed for 4G network can be classified based on the layer in which the mechanism works. Although research to provide QoS in 4G network has happened in data-link, physical, transport and application layer, predominant architectures are available in network layer. A different approach is cross layer design for providing QoS in 4G networks where it tries to optimize architecture across adjacent layers. Traditional approach has been to treat the layers as different entities. A higher layer protocol only makes use of services at lower layers and is not concerned about the implementation of service.

Table 2.2: LAYER WISE APPROACHES [13]

S.No	Layer	Author	Approach
1	Application, Transportation, Presentation	Perumalraja, Chung-Horng Lung, Anand Srinivasan.2013	QoS –aware security architecture based on Ellipitical curve Diffiew Hellman (ECDH)
2	Transport, Network	Pedor Fetunal et al	Header compression to save the bandwidth
3	Network	Rui et al	End-to –End QoS based on Diffsery
4		V.Marques et al.2003	IP based QoS approach with with AAAC
5		Joachim Hillebrand	QoS signal architecture
6		Koch	Adaptive resource control
7		Martin et al	Smart scheduler in LTE
8		Fumio Ishizaki et al, Mohsin Iftkhar et al.	Packet scheduling algorithms
9		Mohsin Iftkhar et al.2012	Translation matrix to maintain QoS
10		P. Pengaraju, Chung-Horng Lung, Srinivasan.2013	XOR network coding for node protection

11		Perumalraja et al.2012	QoE monitoring and E2E service assurance
12	Data Link	D.Wu and R.Negi.2003	Effective capacity
13		Chen at al	Cross layer algorithms and QoS engine
14	Cross Layer design (CLD)	FIshizaki G.U. Hwang	An effective band width function (physical & Data-link layer)
15		J. Tang and X.hang	Physical-Data-link cross layer resource allocation scheme

In CLD approach, protocols can be designed by allowing direct communication between entities in nonadjacent layers for resource optimization. CLD in wireless is different mechanism than CLD in wireline. Layer wise classification and the approaches followed by various researchers is listed in TABLE 2.2.

Rui et al proposes an end-to-end QoS solution for 4G IP based networks capable of supporting all types of services, from legacy to adaptive multimedia. It also supports user mobility, both intra- and inter-domain across different access technologies [13]. It is a scalable solution, based on DiffServ to provide layered resource control. Resource management is performed on a per-aggregate basis in the core. Several access networks (AN), which are capable of supporting different access technologies, are present in each Administrative Domain (AD). A core subdomain is also present inside each AD to provide interconnection between the access networks through Subdomain Routers (SR). Connection to other administrative domains is provided via Edge Routers (ER). To provide QoS to variety of services, novel functionalities are added to the Access Routers (AR). ARs mark and recognize individual flows. ARs also translate other QoS reservation mechanisms, such as the IntServ, Resource Reservation Protocol (RSVP) into Differentiated

Service Code Point (DSCP) markings and QoS Broker requests. Collection of all these functions is called Advanced Router Mechanisms (ARM). In each domain, an Authentication, Authorization, Accounting, Auditing and Charging (A4C) server is available.

Pedro Fortuna1 et al presents a solution for including header compression mechanisms in 4G networks to provide QoS to the real time flows. Robust Header Compression (RoHC) scheme used to compress the headers of IP based protocols such as Real Time Protocol (RTP), User Datagram Protocol (UDP) and Transmission Control Protocol (TCP). RoHC is particularly adequate for wireless links as they are bandwidth constrained and have high bit error rate. The header compression technique is saving resources when packets have a header/payload size ratio is around 1. In the 4th generation of mobile communications (4G), audio and video flows are transported as IP packets and hence need QoS guarantees. RoHC is based on the suppression of header fields because many of the header fields are static in a flow. To build the context information, all the header fields have to be sent uncompressed. After the initialization of the context, the static and inferable fields are skipped in subsequent RoHC packets. From here on, they carry out only the dynamic fields.

Chen et al proposes cross layer QoS architecture for 4G heterogeneous network services. QoS engine and cross layer algorithms are the main components. QoS engine is composed of QoS daemon, QoS agent and control module. Cross Layer Architecture monitors and adjusts resources periodically. In the absence of CLA, average latency and average packet loss are reduced by 2% and 8.5% respectively [13].

Significant research is done by P. Rengaraju, ChungHorng Lung, and Anand Srinivasan in the field of QoS in 4G. Some of their works are described below.

P.Rengaraju et al have researched on measuring the QoS performance for node protection in 4G wireless networks using network coding. Exclusive OR (XOR) network coding is used to explain the node protection for multihope 4G wireless networks. It is followed by measurement of the QoS performance, such as packet delivery ratio (PDR), latency and jitter, for different scenarios. Failure of a single and two relay node with and without proposed protection scheme is tested along with user's mobility. The simulation results compare the QoS performance with protection against failure of relay nodes to that of no failure scenario. They are almost same. Due to their protection mechanism, network reliability is increased [13].

Hussain Mohammed and P.J.Radcliffe propose packet scheduling scheme for 4G wireless to improve QoS in wireless networks. The new packet algorithm modifies IP and radio layers to support Broadband Wireless Access (BWAS) QoS. Concept of fairness is added. Their results provide low handoff packet drop rate, low packet forwarding rate, low packet delay, ensures fairness among the users of different services and generate higher revenue. "Satisfaction Factor" is used to measure the efficiency of various scheduling schemes. A downlink packet scheduler is located at the NodeB's of BWAS. It regulates the distribution of the downlink shared channels to the mobile users by deciding which packet should be transmitted during a given time frame. Major control of the performance attributes of these systems is done by the scheduler. It gives carriers an opportunity to maximize revenue. Algorithm includes a step to eliminate the contention between users whenever they have the same fairness measure value [13].

Jaume Ramis et al discuss traffic scheduling algorithms for wireless systems. Scheduling algorithms of wireline cannot be applied in wireless due to hostile nature of medium. Scheduling algorithms for wireless can be 1). Centralized or 2). Distributed. Distributed scheduling is mainly applied in adhoc or uplink operation where users contend for channel access. Due to greedy behaviors of nodes, there is no efficiency, fairness and QoS fulfillment that can be done with centralized approach. Paper gives exhaustive survey of centralized wireless scheduling techniques. They are evaluated with relevant performance criteria suitable for next generation networks.

Idea of translation matrix to maintain QoS for a roaming user is novel and described by Mohsin Iftikhar et al. The parsimonious traffic model is used where only few parameters are used to match measurements. The model is similar to an on/off process. Matrices are maintained by each network to keep track of the traffic behavior of the various traffic classes. As the terminal changes network access, existing flow parameters are compared to possible new reservation classes with the help of matrices. Mechanism to build the matrices and implementation scenario of QoS mapping between two different kinds of access network is explained. Universal Mobile Telecommunication System (UMTS)-to-IP QoS mapping is performed by a translation function in the Gateway GPRS Serving

Node (GGSN) router as suggested by 3rd Generation Partnership Project (3GPP). GGSN router should classify each UMTS packet flow to map it to a suitable IP QoS class.

QoE aware vertical handover is proposed by Kandaraj P. et al. One of the Multi-Criteria Decision Making (MCDM) techniques is Technique of Order Preference by Similarity to Ideal Solution (TOPSIS). It is deployed by the authors. Too artificial alternatives are hypothesized in this method, namely ideal alternative and negative ideal alternative. Ideal alternative that has the best level for all attributes considered and negative ideal alternative have the worst attribute values. Among two alternatives, TOPSIS chooses one that is closest to the ideal solution and farthest from negative ideal alternative [13].

2.4.2 Analytical Evaluation of QoS in the Downlink of OFDMA Wireless Cellular Networks

The problem of power allocation in Code-Division Multiple Access (CDMA) networks is addressed in many papers such as the power allocation problem is studied jointly with beamforming. More recently, an extensive literature addresses resource (power and bandwidth) allocation in OFDMA networks. Here are some examples [15]. In generality is however difficult to evaluate the QoS offered by the network with these methods implemented. Some studies consider the case of a single cell. The multi-cell case is studied in [17] different frequency reuse schemes are compared. The present work adopts the approach proposed with a background in [16]) that is implemented in the dimensioning tool of Orange. It consists in proposing some network control mechanism that is simple enough and can be studied by the classical tools of queueing theory. Moreover, we follow the ideas presented for queueing models suitable for streaming and elastic traffics respectively. The present paper relies on and continues the work in [44]. Besides presenting in more detail, the results there, we study the performance of a network serving elastic traffic, as well as a network serving simultaneously streaming and elastic traffic. Moreover, we illustrate the proposed approach by solving the dimensioning problem.

2.4.3 Path Loss evaluation for 4G LTE network

The network performance of LTE networks have been studied extensively in Literature. The authors in [18] presented a computation of path loss using different propagation models for LTE

Advance networks in different terrains; rural, dense urban and suburban. The paper analyzed path loss for broadband channels at 2300MHz, 2600MHz and 3500 MHz using MATLAB. The paper performed this study using the following prediction models; Stanford University Interim model, COST 231 Walfisch-Ikegami model, ECC-33/Hata Okumura e

xtended model and COST 231 Hata model. The comparison of the various propagation models showed that the least path loss was obtained by using COST-231 Hata prediction method. It was concluded that the prediction errors for SUI and ECC models are significantly more than COST 231 Hata and COST Walfisch-Ikegami models. The research work published in [19] investigates three empirical propagation models for 4G LTE networks in the 2-3 GHz band. This was undertaken in urban and rural areas in Erbil city in Iraq. The results were compared with field measurements and tuning methods were suggested to fit the measured path loss results of the Standford University Interim (SUI) model and Okumura Hata, extended COST 231 Hata model. It was seen that the optimum model which was closer to the measured path loss data was the extended COST 231 Hata model. COST 231 Hata model had the mean error value lowered to a zero value, the mean standard deviation value lowered to 7.8dB and root mean square error being 7.85dB. Thus, the COST 231 Hata model was the propagation prediction model predicted for the city. The research work published in [20] makes a comparison for the diverse suggested propagation models to be implemented for 4G wireless at various antenna heights. The path loss for the various models; Stanford University Interim model, COST 231 Hata model and COST Walfisch-Ikegami model were computed in different environmental scenarios; Urban, suburban and rural areas. MATLAB simulation was used for the computation for frequencies in the 2300 MHz, 2600 MHz and 3500MHz band. It was concluded that path loss was least using COST 231 Hata model for all environmental scenarios and the different frequencies than the other models. The advantages of this approach were in its adaptability to dissimilar environments by infusing the appropriate correction factors for diverse environments. It was concluded that path loss was least in urban areas for 1900

MHz and 2100 MHz frequencies using SUI model. COST231 gave the highest path loss for 1900 MHz and Ericsson 9999 predicted the highest path loss for 2100 MHz band.

2.4.4 Throughput and Round-Trip Time Performance evaluation for 4G LTE network

Several publications analyze the cellular performance based on samples collected at the mobile backbone. Gerber et al. [21] describe an approach to measure the maximum mobile throughput based on packet traces. This approach is extended by Huang et al. [22], evaluating the throughput of a 4G network and individual flows in a similar manner. Both studies observe the traffic generated by a large number of devices over the area of several base stations. This allows deriving data rates for single devices as well as the overall throughput from within the network. In contrast, this paper analyzes the RTT with focus on long-term variations.

Wylie-Green et al. [23] analyze the throughput and RTT performance of an unloaded and loaded LTE network from different distances using multiple devices. The described measurements were conducted on newly built hardware and hence analyze the optimum network performance. The purposely generated traffic does not affect the system performance, as it is below the system capacity.

A detailed analysis of the one-way delay of different parts of the network can be found in [24]. The authors measured the timing between a local machine connected to a LTE and HSPA network, a time synchronized server, and additional vantage points within the mobile network. In this work, end-to-end measurements from the mobile device are used to evaluate the performance based on network management decisions.

A different approach, based on measuring the network performance from handsets only, is published by Sonntag et al. [25]. They developed an application measuring a number of network parameters like throughput and RTT and collect the data on their server. The analysis of the collected data is limited to a few general metrics and the creation of bandwidth maps. Contrary, this paper analyzes the measured RTT in detail to derive the performance based on the path taken through the cellular network.

The prediction of the availability of WiFi networks is used to improve mobile connectivity by Nicholson et al. [26]. This approach is extended by Buietal ,who propose as stochastic mobile bandwidth prediction model. A different approach is used by Wac, applying machine learning techniques to predict mobile QoS. In this paper, this approach is extended to forecast the RTT based on the time of the connection.

Contrary to [22] [27] this paper focuses on the root cause analysis of performance variations in the cellular network. Two different data sets were collected, complementing each other. The crowd sourcing-based data set is similar to the data collected by Sonntag et al. [25], but additionally includes fine granular location and cell information. The complementary data set extends the first one by RTT measurements to the DNS server and trace-routes between the mobile device and measurement server. Based on the combination of both, a detailed analysis of the cellular network performance becomes possible. No such data set or analysis is available to the best of the author's knowledge.

2.4.5 A Comparison of 3G and 4G network

A comparison of 3G and 4G network in order to list out the drawback and merits of the two evolution of wireless Technology was done by Kumar and Suman [49]. The research focuses on their Architecture, speed, supporting technology, bandwidth and QoS. They gave full description of LTE and 3G Architecture stating that LTE Architecture is flat IP based architecture and made it a better choice than 3G. LTE because it reduces latency and cost and its infrastructures consist of a set of various networks using IP (Internet protocol) as a common protocol so that users are in control. They suggested that 3G should be integrated with the IP based technology so that it can have tremendous data transmission and support VoIP as well.

2.4.6 Studies on efficient resource block allocation in LTE system

Kaur and Kuma [50] carried out studies on efficient resource block allocation in LTE system. They aimed at using different scheduling algorithm in order to get the best throughput. They proposed algorithm that will first of all judge the scheduling block required by each user and after that assign scheduling block to each user according to their priority while allowing fair distribution of available resources among the users. Simulation results drawn from their study showed that there is an improvement in the overall system throughput.

2.4.7 Main principles of the LTE network architecture

A research was conducted on the main principles of the LTE network architecture by [51] They explained that LTE was designed to support only packet-switched services and aims to provide seamless Internet Protocol (IP) connectivity between user equipment (UE) and the packet data network (PDN), without any disruption to the end users' applications during mobility. They proposed that LTE is a better choice for next generation wireless mobile networks due to its simple architecture. They gave an overview of LTE and its architecture and the functions of both the core and access network. They also explained the Functional details and layout of the associated protocols. The objective of their research was to provide wireless mobile network with simple architecture and to give five categories of LTE interfaces namely Air interface, E-UTRAN interfaces, Core network interfaces, Mobility and interworking interfaces, and service interfaces. According to them, LTE Architecture is simple, flat IP based, reduces latency and cost, and it is compatible with 3GPP and non 3GPP Technologies. They emphasized LTE network element and Interface which is made up of UE, E-UTRAN and EPC.

2.4.8 Study on cross layer scheduling algorithm.

Tantawy et al . [52] gave a study on cross layer scheduling algorithm. He explained that LTE came as a result of an increasing need of next generation mobile networks to offer high performance, mobile broadband services. The objective of the work is to develop a cross-layer scheduling algorithm in LTE that will offer high performance, mobile broadband services, along with a combination of high bit-rates and system throughput in both the uplink and downlink along with low latency. A novel QoS guaranteed cross-layer scheduling algorithm for LTE system was proposed which allocates resources to the users as resource blocks. Ayyazian [53] carried out a project on making 4G OFDM small-cell solutions smarter, scalable, cost effective and future proof. The thesis aimed at managing Interference in order to make 4G OFDM smaller, scalable, cost effective and future proof. The work uses an extensive portfolio of outdoor or indoor LTE small-cell solutions. Airspan invested in technologies for interference management in aggressive frequency reuse scenarios and offers a unique small cell with integrated non-line-of-sight and line-of-sight backhaul. They also developed a high performance, low cost solution for 3.5 GHz operators that wants to deploy LTE Advanced Services using carrier aggregation.

2.4.9 Adaptive proportional fair scheduling algorithm for LTE

In [54], the authors propose an adaptive proportional fair scheduling algorithm for LTE which adjusts the scheduling
priority according to individual user's channel condition. This method gives more scheduling probability to the users who are under poor channel condition for a long period of time and avoids the users whose channel conditions are favorable occupying too much resource. It enhances the fairness with a limited degradation of whole system throughput.

2.4.10 Analyzing network capacity performance by using MATLAB for real-time simulations.

In [55], the network capacity performance of 2x2, 4x4, 8x8 and 12x12 systems was analyzed by the authors using MATLAB for real-time simulations. The authors simulated the channel capacity of the different MIMO schemes against probability error at different signal to noise ratio; 0dB, 10dB, 20dB, 40dB and 60dB. It was concluded that the maximum channel capacity is achieved at 60dB and 0dB for 12x12 and 2x2 MIMO configurations respectively.

Chapter Three

Quality of Service in 4G LTE network

Quality of Service (QoS) in cellular networks is defined as the capability of the cellular service providers to provide a satisfactory service which includes voice quality, signal strength, low call blocking and dropping probability, high data rates for multimedia and data applications etc.
4G/LTE as an important technology which is mainly used for handling fast growing data rate traffic. Quality of Service in LTE has become a significant part of network planning and designing when deploying fixed broadband for different data and voice services. [13] Many of the subscribers make use of LTE services for various critical operations (e.g. voice calls, bank transactions, hospital operations), and many other subscribers who just only want to enjoy Internet & applications experiences (e.g. game playing, searching, web browsing). All such types of services or applications may require different quality of service. For example, a VOIP is less sensitive to delay to meet QoS; file transfer is more sensitive to delay this mean long delay. LTE was designed to meet the increased data rate and application demands with reliable and trustworthy connections and at a low cost of deployment. In order to with stand with these future challenges, a highly flexible QoS framework must be designed.

3.1 Quality of Service and Quality of Experience

Fundamentally, 4G LTE is designed to provide real-time, delay-sensitive multimedia to support a different type of Experience (QoE). QoE is a measurement of how well a system or an degradation in voice or video quality or it is user perception to the network, whereas QoS focuses on standard quantitative performance from a network perspective. QoE is directly related to QoS. Therefore, one can map the objective QoS measurements (e.g.delay, packet loss and jitter) into the user's perception QoE, through an appropriate set of tools and processes. QoS is defined as the capability of the communication network to provide a service at an assured service level. QoE is basically depends on customer satisfaction in terms of usability, accessibility, and integrity of the service. QoE, however, is not limited to the technical performance of the network; there are also non-technical aspects, which influence the user perception and satisfaction.

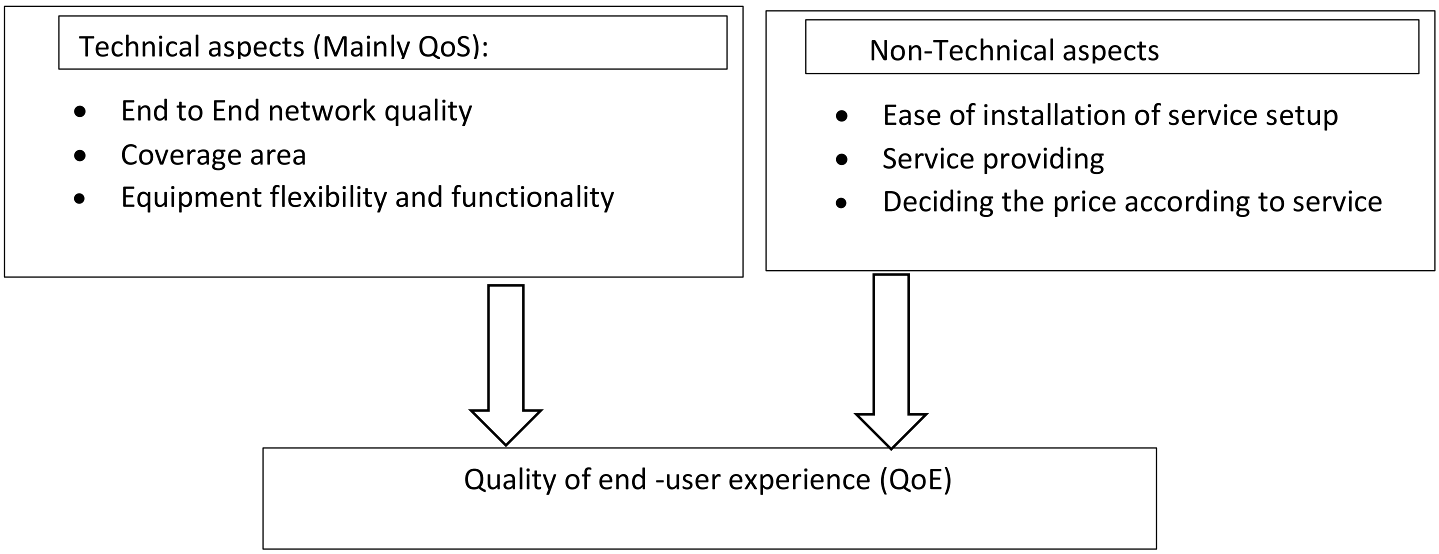


Figure 3.1 Relation between QoS and QoE [14]

Figure 3.1 QoE is affected by technical (QoS) and non-technical aspects of service. QoE is expressed in "feelings" such as Poor,Fair,Good ,very Good and Excellent rather than metrics. QoS relates to all mechanisms, functions and procedures in the network and terminal that implement the quality attributes (bearer service) negotiated between the UE and the CN.

3.2 4G LTE QoS Architecture

In LTE based Network QoS is implemented between UE and PDN Gateway [11] [12]. This QoS is applied through a set of bearers. These set of bearers may include radio bearer, S1 bearer and S5/S8 bearer and collectively called as Evolved Packet System (EPS).A bearer simply acts as a traffic separation element that enables differential treatment of traffic with different QoS requirements. Bearer provides a virtual path between a UE and PDN Gateway.

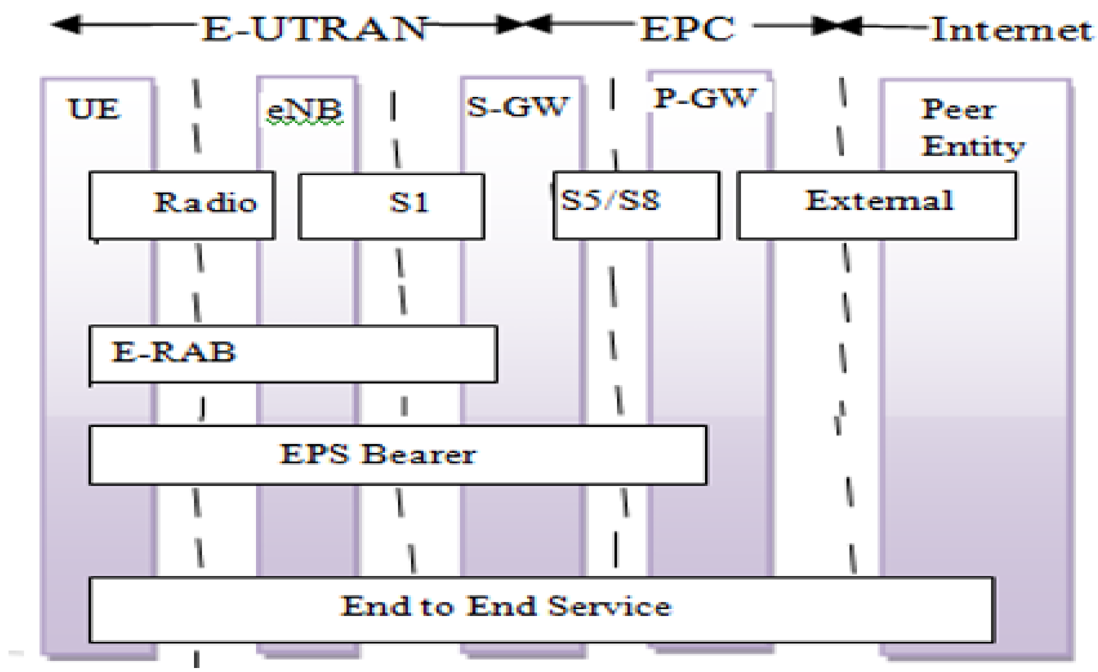


Figure 3.2: QoS Bearer/Architecture in 4G network.

3GPP has defined the QoS framework for 4G network, In the QoS concept the 4G Bearer or Bearer is a logical entity that includes all the packet flows that receive a common QoS treatment between UE and EPC Gateway and it present the basic level of granularity for QoS control.

The end-to-end service consists of the local bearer service, LTE bearer service, and external bearer service. These services ensure the QoS of the end-to-end service. They are described as follows:

- The external bearer service is coordinated by the telecom operator with the connected networks. Between the LTE bearer service and the external bearer service, QoS mapping is required. Through the QoS mapping, the QoS requirement is sent to the next network element (NE).

- The coordination and QoS mapping between LTE bearer services is very important for implementing the end-to-end QoS of LTE.

The 4G LTE bearer service consists of the evolved radio access bearer (E-RAB) service and the core network bearer (CNB) service.

The E-RAB service is implemented through the radio bearer (RB) service and S1 bearer service. The RB service covers all the aspects of the transmission on the radio interface, and the S1 bearer service provides the transmission between the E-UTRAN and the CN. For PS services, the S1 bearer service can provide different QoS classes.

The role of the core network bearer (CNB) service is to provide a negotiated 4G LTE bearer service. The CN provides different QoS classes for different backbone bearer services. A specific backbone bearer service can be selected to meet the QoS requirement of the CN bearer service. The E-RAB service involves the Uu, S1,and S5/S8 interfaces.

Each bearer uses a set of QoS parameters to describe the properties of the transporting channel, such as bit rates, packet delay, packet loss, bit error rate and scheduling policy.

3.3 4G Bearer and QoS classes

4G bearer is classified into two;

Default Bearer and Dedicated Bearer

- **Default Bearer**

When a mobile device or User Equipment (UE) initiates the connection to the LTE network for first time. Mobile device or UE will be assigned the default bearer based on its service requirement and remain connected until the UE disconnect from the network. Default bearer doesn't support any guaranteed bit rate service, it only offer best effort service. Each default bearer comes with a separate IP address. Quality of Service Class Identifier (QCI) 5 to 9 (Non- Guaranteed Bit Rate) can be assigned to default bearer.

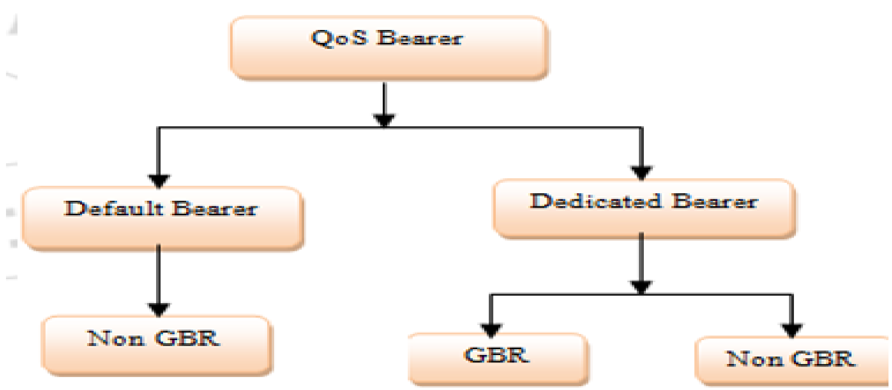


Figure 3.3 QoS Bearer

- Dedicated Bearer

Dedicated bearer is another important bearer on the top of default bearer. This bearer acts as a dedicate tunnel to give suitable treatment to specific services (i.e. VoIP, video). It doesn't require additional IP address but it shares the address assigned by the default bearer. Dedicated bearer offers both Guaranteed Bit Rate (GBR) and Non-Guaranteed Bit Rate Service (Non-GBR). Dedicated bearer uses a TFT (Traffic Flow Templates) to give special treatment to specific services. Dedicated Bearer further classified as [2] 3] [4] [5]:

- **Guaranteed Bit Rate Bearer (GBR):**

Minimum guaranteed bit rate (GBR) bearers are mainly used for applications such as VoIP and other real time voice calling applications. GBR has dedicated network resources and is needed for real-time voice and video applications. Each bearer associated with a predetermined GBR QoS parameter value. If the traffic carried by the GBR bearer conforms to the value associated with the GBR bearer, then there is no chance of congestion related packet loss on the service which utilizing the GBR bearer. A Guaranteed Bit Rate (GBR) bearer usually is established "on demand basis" because it blocks all transmission resources by reserving them during an admission control function.

- **Non-Guaranteed Bit Rate Bearer (Non-GBR)**

Non-GBR bearer doesn't guarantee any particular bit rate service. This bearer is mainly used for applications such as web browsing and FTP transfer. A service which utilizing Non-GBR bearer is highly prone to congestion related packet losses. It does not block any specific transmission resources. A non-GBR bearer is established in the default or dedicated bearer and get remain established for a longer period of time. A non-GBR bearer does not have dedicated bandwidth and is used for best effort traffic such as file downloads, www, IMS signaling and email.

For 4G network, each bearer assigned only one QoS class and each class is identified with a single scalar called QCI(QoS Class Identifier).

QCI specifies the forwarding treatment that the user-plane traffic gets between UE and gateway such as resource type, packet delay budget and packet error lost rate.

3GPP has standardized nine QCI values from 1 to 9 , QCI specification parameters and common applications as presented in Table 3.1.The QCI characteristics ensures that services using the same QCI class will receive a minimum level of QoS[11].

The bearer parameters associated with a QCI are:

- Packet Delay Budget (PDB)
- Packet Loss Rate (PLR)
- Priority
- Resource Type (GBR or Non-GBR)

Table 3.2 E-UTRAN Radio Interface characteristics/ QoS classes[12].

QCI	Resource Type	Priority Level	Packet Delay Budget	Packet Loss Rate	Examples Services
1	GRB	2	100ms	10-2	Conversational Voice
2		4	150ms	10-3	Conversational Video(Live Streaming)
3		3	50ms	10-3	Real Time Gaming
4		5	300ms	10-6	Non-Conversational Video(Buffered Streaming)
5		1	100ms	10-6	IMS Signaling
6	Non-GBR	6	300ms	10-6	Video(Buffer Streaming)
7		7	100ms	10-3	Voice,Vidio(Live Streaming)Interactive Gaming
8		8	300ms	10-6	TCP-based(eg.www,e-mail,chat,ftp,p2p file)
9		9			Sharing, Progressive Video

3.4 QoS Performance Indicator Parameters

QoS indicator parameters are widely used by 4G LTE systems with the aim of evaluating the QoS delivered to end-users; which can be given with a planned structure: 1) the first plane represents network availability as the QoS from the network's point of view; 2) the second plane represents network access as the basic requirement from the user's point of view. In our case to evaluate QoS of data transmission over 4G network, we consider the following parameters [29]:

- Network geographic observation parameters;
- Network coverage and quality analysis parameters;
- Network Performance analysis parameters;
- Drive test service quality analysis parameters

3.4.1 Network Geographic Observation Parameters

Network geographic observation uses radio link measurement reports (MRs) of subscribers on the live network to locate exceptions. This function combines data based on the call times in call history records (CHRs) and MRs to achieve location positioning and then displays the distribution of coverage, traffic, and exceptions of wireless networks on the geographic information system (GIS) at the grid level. This helps network optimization engineers evaluate network performance, identify hot spots, and quickly locate problematic areas in a straightforward way [29].

It replaces traditional drive tests (DTs) and addresses the problem that DTs fail to cover all areas, thereby providing telecom operators with cost-effective network evaluation and problem identification means. And also it replaces traditional simulation means to display the coverage of each serving cell on the live network, helping telecom operators identify problematic areas such as those with a poor coverage. Network coverage geographic observation supports the geographic rendering for RSRQ, soft
handover area, pilot pollution area, LAC stability, primary serving cell, etc [29].

3.4.2 Network Coverage and Quality Analysis Parameters

The SEQ analyzes the measurement reports (MRs) sent by UEs to display the coverage, quality, and subscriber distribution of the test cell. The analysis result helps users to determine whether problems such as weak cell coverage, cross coverage, and poor service quality occurs on the live network. An MR reported by a UE contains downlink received

signal received power (RSRP) and Refence signal received (RSRQ) [30].

3.4.3 Network Performance Analysis Parameters

The SEQ Performance Analysis System is an intelligent and integrated tool developed by Huawei Technologies Co., Ltd. It allows locating and analyzing wireless network quality problems and it is applicable to GSM, GPRS, EDGE, UMTS, CDMA and LTE networks. It supports the operations of multiple users; various wireless performance analysis and it is a basic support platform for further analyzing and locating wireless networks problems.

The Nastar stands on a server-client architecture and includes a set of functions as Service Geographic Observation, Cell and Terminal Performance analysis as well as Coverage, Neighboring and Pilot Pollution analysis. It uses the following types of data:

_ Network performance data to analyze coverage, neighboring cells and pilot pollution.

_ Uplink frequency interference data for uplink interference analysis.

_ Call history record to terminal and cell performance analysis.

The Service Geographic analysis is obtained by the aggregation of both network performance and call history data, [31] [32].

The SEQ provides the LTE cell performance analysis function to help quickly identify abnormal cells and obtain data of abnormal calls in these cells.

The obtained data helps network optimization engineers detect the causes of abnormal cells, facilitating in-depth problem analysis. The SEQ locates and analyzes network problems by monitoring performance counters, and then analyzes the counters of the entire network or for a specific E-NodeB. These counters are: RAB setup failure, abnormal release, QoS problem, delay

problem, etc [30].The performance surveillance (PRS) is a platform for analyzing performance data of mobile networks, customizing reports, and displaying reports (i.e., Packet loss, Voice quality indicator, KPIs, Counters, etc). The PRS is applicable to routine maintenance of mobile network. It can monitor and analyze the performance of the entire network [33].

3.4.4 **Drive Test Service Quality Analysis Parameters**

Drive testing is a method of measuring and assessing the coverage, capacity and Quality of ... record a wide variety of the physical and virtual parameters of mobile cellular service in a given geographical area.

4G LTE – Drive test and Coverage Analysis Radio Parameter @ GENEX Probe PCI (Physical Cell Identifier) Value range[34] : 0 – 839, cross-check any cross feeder problem when conducting moving test. RSRP (Reference Signal Receive Power) ⎫ -70 dBm to -90 dBm → Good ⎫ -91 dBm to -110 dBm → Normal ⎫ -110 dBm to -130 dBm → Bad SINR (Signal to Interference Noise Ratio) 16 dB to 30 dB → Good ⎫ 1 dB to 15 dB → Normal ⎫ -10 dB to 0 dB → Bad [34].

Among various measurements, the three most important ones are [35]:

RSRP, RSRQ, RSSI.

All these are derived from Reference signals.

Reference signals are equivalent to what Pilot signals do in UMTS.

- RSRP – Reference Signal Received Power

  RSRP is the water and wine for a UE, from the moment a UE is powered-on to the point it goes into idle mode. RSRP measurements will always be used by the UE.If analogy helps RSRP is the equivalent of the UMTS CPICH Received Signal Code Power (RSCP).
  RSRP measurements are used for

  - Cell selection
  - Cell reselection
  - Handover
  - Mobility measurements
  - Estimate the Path Loss for power control calculations

RSRP is the average power received from a single cell specific Reference Signal Resource Element

1. The average RSRP is taken in linear units
2. Power measurement is based upon the energy received during the useful part of the OFDMA symbol and excludes the energy of the cyclic prefix.
3. Reference point for RSRP measurement is the antenna connector of the UE

Please note, that RSRP can be based upon the cell specific Reference signal transmitted by only the first antenna port or RSRP can be based upon the cell specific reference signal transmitted by first and second antenna ports.

- RSRP Measurement Reporting:

When RSRP value is reported back, its not that UE send the actual measurement right away. In fact, a mapping is applied to RSRP measurements prior to including them within RRC messages. The range of RSRP measurements is defined from -140 dBm to -44 dBm with one dB resolution.

- RSSI – Reference Signal Strength Indicator

The RSSI is calculated as a linear average of the total power measured across OFDMA symbols which contain Reference Symbols transmitted from the first antenna port (if MIMO is not used). E.g., OFDM symbols 0 and 4 in a slot, in the measurement bandwidth over N resource blocks.

The total received power of the carrier RSSI includes the power from: co-channel serving cells, on-serving cells, adjacent channel interference, thermal noise and from total measured over 12 sub-carriers including reference signals from serving cell and traffic in the serving cell.

RSSI provides information about total received wideband power including all interference and thermal noise. Simply we can write it as:

RSSI = wideband power = noise + serving cell power + interference power

RSSI is a more traditional metric which has been used in other technologies such as GSM and CDMA1X etc.

- RSRQ – Reference Signal Received Quality

In order to get more details about Channel quality and whole bandwidth. A better metric to measure is Reference signal received quality. RSRQ is a C/I type of measurement and it indicates the quality of the received reference signal. The RSRQ measurement provides additional information when RSRP is not sufficient to make a reliable handover or cell reselection decision.RSRQ is the equivalent of UMTS CPICH E_c/I_o.

RSRQ measurements are also used for: Cell selection, Cell reselection, Handover and Mobility measurements.

Mathematically RSRP is defined as:

RSRQ = RSRP / (RSSI/N)

Where: N = # of resource Blocks over which the Received Signal Strength Indicator (RSSI) is measured.

Table 3.3 LTE Metrics including RSRP, RSRQ and SINR [36]

RF Conditions Grade	RSRP (dBm)	RSRQ (dB)	SINR (dB)
Excellent	>=-80	>=-10	>=20
Good	-80 to -90	-10 to -15	13 to 20
Fair/Mid Cell	-90 to -100	-15 to -20	0 to13
Cell Edge/Bad	<=-100	< -20	<=0

In this particular example, three measurement quantities are used

- RSRP (Reference Signal Received Power)
- RSRQ (Reference Signal Received Quality)
- SINR (Signal to Interference & Noise Ratio)

It is common sense that the performance of any wireless system has a direct relationship with the RF conditions at the time. To aid with performance analysis then, we typically define some ranges of RF measurements that correspond to some typical RF conditions one might find themselves in.

When it comes to LTE, I came across the above table that presents a good classification. The source of this table is a EUTRAN vendor and has been complied during the RF tuning process for a major US operator. Of course, there are no rules as to how various RF conditions are classified, so different tables will exist but to a great extent you can expect them to align. Here is bellow description for the above parameters measurements.

RSRP is a measure of signal strength. It is of most importance as it used by the UE for the cell selection and reselection process and is reported to the network to aid in the handover procedure. For those used to working in UMTS WCDMA it is equivalent to CPICH RSCP. The 3GPP spec description is "The RSRP (Reference Signal Received Power) is determined for a considered cell as the linear average over the power contributions (Watts) of the resource elements that carry cell specific Reference Signals within the considered measurement frequency bandwidth."

RSRQ is a measure of signal quality. It is measured by the UE and reported back to the network to aid in the handover procedure. For those used to working in UMTS WCDMA is it equivalent to CPICH Ec/N0. Unlike UTMS WCDMA though it is not used for the process of cell selection and reselection.

The 3GPP spec description is "RSRQ (Reference Signal Received Quality) is defined as the ratio: N×RSRP/(E -UTRA carrier RSSI) where N is the number of Resource Blocks of the E-UTRA carrier RSSI measurement bandwidth.

The new term that appears here is RSSI (Received Signal Strength Indicator). RSSI is effectively a measurement of all of the power contained in the applicable spectrum (1.4, 3, 5, 10, 15 or 20MHz). This could be signals, control channels, data channels, adjacent cell power, background noise, everything. As RSSI applies to the whole spectrum we need to multiple the RSRP measurement by N (the number of resource blocks) which effectively applies the RSRP measurement across the whole spectrum and allows us to compare the two.

Finally SINR is a measure of signal quality as well. Unlike RSRQ, it is not defined in the 3GPP specs but defined by the UE vendor. It is not reported to the network. SINR is used a lot by operators, and the LTE industry in general, as it better quantifies the relationship between RF conditions and throughput. UEs typically use SINR to calculate the CQI (Channel Quality Indicator) they report to the the network. The components of the SINR calculation can be defined as:S: indicates the power of measured usable signals. Reference signals (RS) and physical downlink shared channels (PDSCHs) are mainly involved. I: indicates the power of measured signals or channel interference signals from other cells in the current system. N: indicates background noise, which is related to measurement bandwidths and receiver noise coefficients.

Received Power and Network Capacity Simulation Methodology. As part of the coverage analysis, an estimation of the Reference Signal Received Power (RSRP) was made. RSRP for usable reference signals typically varies [48]. Table I gives a description of the different ranges of RSRP which is used for our coverage analysis.

TABLE 3.4. RSRP Reference Range [48].

RSRP Power (dBm)	**Description**
< -90	*Excellent/Near cel*l
-90 to -105	Good/Mid-cell
-106 to -110	Fair/Cell edge
-110 to -120	Poor

Chapter Four

Control and User Plane Management Tools

4.1 Introduction of Control Plane Management Tools

Control Plane management tools are the system those carry the signaling information of the networks. Performance management system, which is called in this thesis “control plane management tools” is a protocol model defined by ITU-T for managing open systems in a communications network. It provides a framework for achieving interconnectivity and communication across heterogeneous operations system and telecommunication networks and also it provides the method of efficiently monitoring network performance and facilitates network optimization and troubleshooting. It includes element management system and operating support system. An element management system consists of systems and applications for managing network elements (NE) on the network element management layer of the performance management system. As recommended by ITU-T, the element management system's key functionality is divided into five key areas: fault, configuration, accounting, performance and security. An operational support system (OSS) is a group of computer programs or an IT system used by communications service providers for monitoring, controlling, analyzing and managing a computer or telephone network system. Generally speaking, performance management system is applicable to the data reported by the NEs and the operations performed on the operating support system (OSS) [57,60]. Figure 4.1 shows the performance management architecture. The performance management system architecture includes: performance surveillance (PRS), Unified management systems (i.e. U2000) and network elements (NEs). NEs communicate with each other based on the TCP/IP protocol [63]. It includes:

- Base Station Controller (BSC) and eGBTS on the GSM network; Evolved Gateway BTS(eGBTS) are being introduced to share sites with UMTS and LTE
- Radio Network Controller(RNC) and NodeB on the UMTS network;
- Evolved NodeBs(e NodeBs), including macro, micro, and pico eNodeBs on the LTE network;

- MBSC and multimode base station on the single RAN network. It is software part that connect BSCs and RANs for monitoring[64].
- eRelay,Single DAS,Core networks:CS,PS,IMS,Wireline and SingleSDB
- Site Power: Genenetor, Battery, Solar, Solar Panel, Wind Turbine
- Mobile Broadband Backhaul (MBBH Backhaul) [63]: It manages MBB backhaul devices used on a mobile network. such as : Router, lan swich,ferewall,microw wave, TN and …

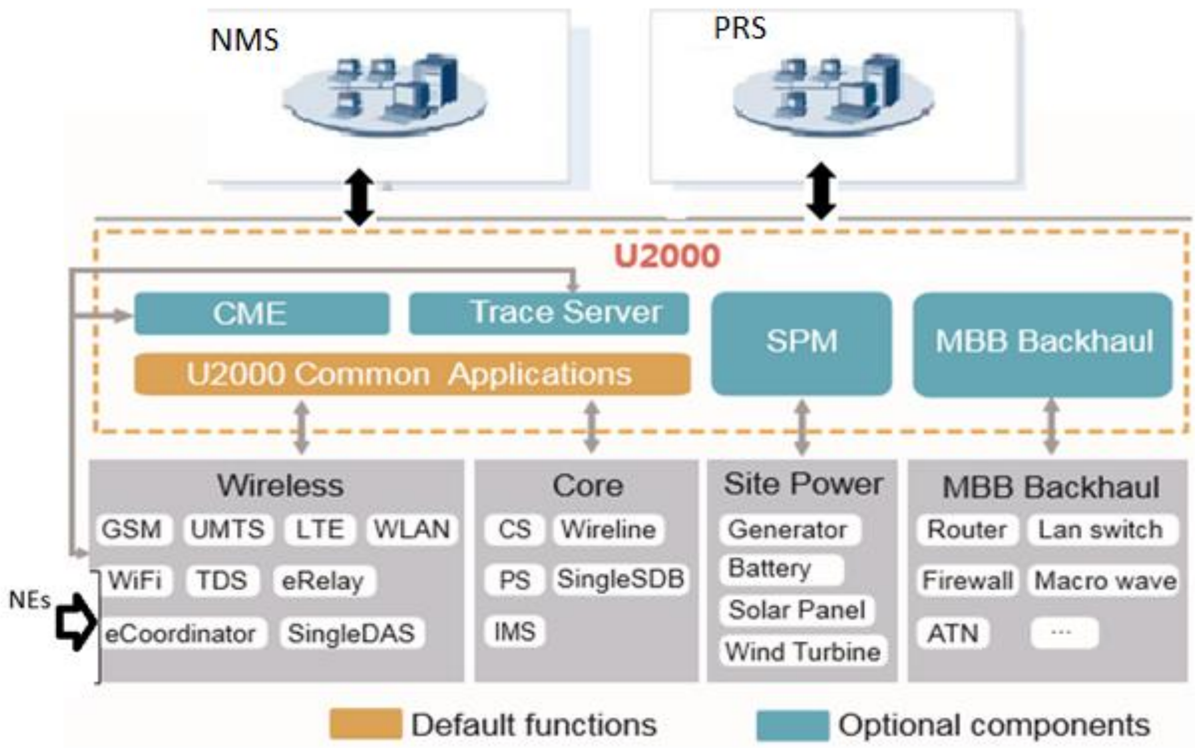


Figure 4.1 Shows the performance management architecture [37].

4.1.1 Introduction to U2000

iManager U2000 Unified Network Management System (U2000 for short) was designed to efficiently and uniformly manage transport, access, and IP equipment at both the network element (NE) layer and the network layer [38]. The U2000 provides unified management and visual O&M to help operators reduce operation and maintenance (O&M) costs and transform networks to All-IP networks.

U2000 Common Applications: Manages Huawei RAN devices and CN devices by default and provides various functions, such as configuration and performance management.

The following are applications and features of the U2000.

- E2E Service Provisioning
- Quick and Accurate Fault Locating
- Visual IP Network Management
- Quick OSS Interconnection

Currently, the U2000 series of products are serving more than 200 operators worldwide. Huawei now leads both the bearer NMS market (25% market share) and the broadband access NMS market (29% market share). By cooperating with global mainstream OSS vendors, Huawei will continue to lead the advancements in NMS technology for next generation networks [38].

4.1.2 Introduction of the Performance Surveillance (PRS)

The performance surveillance (PRS) in figure 4.1 is a platform for analyzing performance data of mobile networks, customizing reports, and displaying reports. The PRS is applicable to routine maintenance of mobile network. It can monitor and analyze the performance of the entire network. The PRS provides open performance interfaces, centrally managing the performance data collected from multiple operation support systems (OSSs). It also aggregates multi-dimension performance data, provides specific data storage policies, and stores key data for a long period of time. Huawei PRS is an end-to-end visibility solution for mobile broadband (MBB) networks that makes the O&M process far simpler, both in terms of the steps involved and the relative skill needed to carry them out [39].

Huawei PRS can visualize and simplify the performance analysis process. Based on predefined KPI monitoring and analysis parameters for the GSM, UMTS, and LTE technologies, PRS detects network performance faults, generates KPI alarms automatically, and facilitates troubleshooting through KPI trend, high-priority cell, and fault cause analyses; all help operators to enhance network performance [39].

4.1.3 Service Experience Quality (SEQ) analyst solution.

SEQ analyst is used for testing and simulating network performance, measuring quality services for different network generation from 2G to 4G cellular networks. In thesis I used this system for 4G LTE QoS measurement. The measurement will be done on side of control plane side PS and user plan side of PS interfaces such as Gn, Gn-DT, Gi,S1-U, S1_MME,S11, S6a,Gb, Iu-PS,Gr,Gp.The following main activities will be performed.

- end-to-end per service and per user data collection and in-depth analysis a correlated manner.
- service models adaptation and data visualization to depict actual customer experience.
- Enables multidimensional drilldown from KQIs or KPIs and analyzes the root causes of service failures based on the per-user signaling message flows, thereby ensuring fast fault location.
- Monitors the KQIs and KPIs of VIP customers in real time, helping carriers identify VIP customers who are having poor service experience and identify the causes, ensuring the service experience of VIP customers.

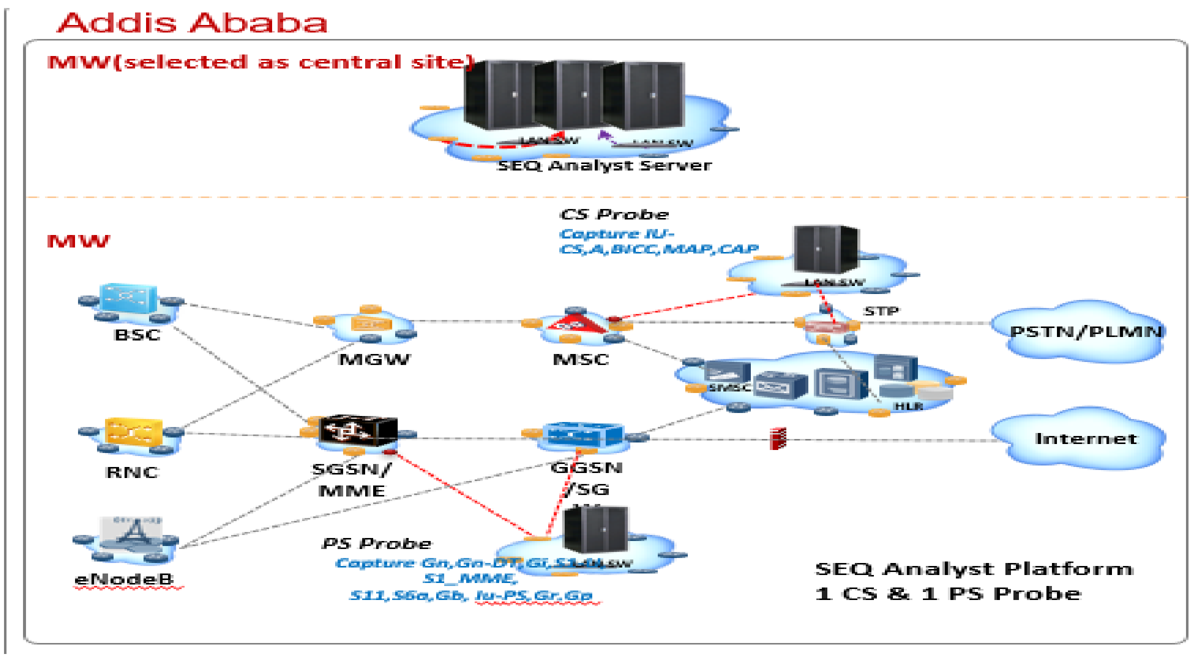


Figure 4.2 SEQ platform, PS and CS Probes Deployment [40]

4.1.3.1 *SUI Model*

Stanford University Interim (SUI) model is developed for IEEE 802.16 by Stanford University [41]. It is used for frequencies above 1900MHz. In this propagation model, three different types of terrains or areas are considered (Table 4.1). These are called as terrain A, B and C. Terrain A represents an area with highest path loss, a very densely populated region while Terrain B represents an area with moderate path loss, a suburban environment. Terrain C has least path loss which represents a rural or flat area. These different terrains and their factors used in SUI model are described in following table.

TABLE 4.1: Different Terrains & Their Parameters [41]

Parameters	Terrain A	Terrain B	Terrain C
A	4.6	4	3.6
B(1/m)	0.0075	0.0065	0.005
C(m)	12.6	20	20

The path loss in SUI model can be given as: $PL = A + 10(^{d}/d_0) + X_f + X_h + S$ … (1)

Where PL is path loss in dBs, d is the distance between the transmitter and receiver, d_0 is the reference distance (Here its value is 100), X_f is the frequency correction factor, X_h is correction factor for Base station height, A is free space path loss measurement in dBs, S is shadowing factor and γ is the path loss component.

The path loss component is given as $\gamma = a - bh_b + {}^{c}/h$ … (2)

Where hb is the height of the base station and a, b and c represent the terrain factors for which the values are selected from the above table.

The free space path loss is given as: $A = 20\log({}^{4\pi d}{}_{0/\lambda})$ ….(3)

Where d_0 is the distance between transmitter and receiver and λ is the wavelength.

The correction factor for frequency is $X_f = 6\log(^{f}/_{2000})$ …(4)

Where f is frequency in MHz.

The correction factor for base station height is $X_h = -10.8log\ (^{hr}/_{2000})$ (5)

Where hr is height of receiver antenna. The above expression is used for terrains A and B and for terrain C the expression is as given below: $X_h = -20log\ (^{hr}/_{2000})$ … (6)

The shadowing factor S is given as following:

$S = 0.65(logf)^2 - 1.3\log(f) + \alpha$ … (7)

Here, α=5.2 dB for rural and suburban environments (Terrain A and Terrain B) and 6.6 dB for urban environment (Terrain C).

4.1.3.2 *Okumura Model*

Okumura's model [41] is one of the most widely used models for signal prediction. It can be used for frequencies in the range 150–1920 MHz (it can be expanded up to 3000 MHz) and distances between transmitter and receiver of 1–100 km. It can be used for base-station antenna heights ranging from 30–1000 m. while the receiver height can be 3 m to 10 m. This model is basic model for development of almost all other models. To determine path loss using Okumura's model, the free space path loss is first calculated. Median attenuation relative to free space (Amu) is added to it. Later correction factors according to the type of terrain are added to it. The path loss in model can be calculated as:

$(db) = Lf + (m,)(f,d) - G(hc) - G(hr) - GAREA$ ----(8)

Here Lf is the free space path loss. Free-space path loss is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal. Free space path loss is calculated by

$Lf = -20\log(\lambda/_{4\pi d0})$ ----(9)

Here G(hc) and G(hr) gives the Base Station antenna gain factor and receiver gain factors respectively. They are calculated as follows:

$(hb) = 20\log(h_b\ /_{200}\ )$ ----(10)

$(hr) = 10\log(^{h_r}/_3)$ ----(11)

Where h_b and h_r are the heights of base station and receiver respectively. The area gain $GAREA$ depends on the area being used. Okumura developed a set of curves giving the median attenuation relative to free space, $A(m,n)(f,d)$ is median attenuation relative to free space[41].

4.1.3.3 Standard Propagation Model

Keenan-Motley model used in 900 to 1800MHz indoor environment prediction and the SPM propagation model from Atoll software which is more suitable for LTE systems under dense urban areas of communication environment [41].

Here is the SPM standard propagation model:

P_R=P_{TX}-[K_1+k_2×Log(d)+K_3×Log(H_{TXeff})+K_4×Diffraction
Loss+K_5×Log(d)×Log(H_{TXeff})+K_6×H_{RXeff}+K_7×Log(H_{RXeff})+$K_{clutter}$ ×f$_{(clutter)}$)+$K_{hill\ loss}$]---(12)

Where P_R is received power (dBm), P_{TX} is Transmit power (EIRP) (d Bm), K_1 is Offset constant (d B), K_2 is Product factor of log(d),D is Distance between the receiver and the transmitter (m), K_3 is Product factor of log(HTxeff),K_4 is Product factor of diffraction calculation, K_4 must be positive, Diffraction Loss is Loss caused by obstruction diffraction (d B), K_5 is Product factor of log(HTxeff)log(d) , K_6 is Product factor of HRxeff, K_7 is Product factor of log(RTxeff), H_{RXeff} is Effective phone antenna height (m), $K_{clutter}$ is Effective phone antenna height (m), $f_{(clutter)}$ is The weighted average loss caused by landforms, $K_{hill,\ LOS\ is}$ Correction factor for mountain area (0 for non-line-of-sight).

In this formula, the distance between the receiver and the transmitter can be calculated as d, and then through which the cell radius can be calculated to carry out the coverage area. It is generally assumed that the coverage area of cells of the omnidirectional site is 2.6 times of its radius and is 1.95 times for the one of the three-sector base site. By comparing the area of the needed coverage area and the cell's area, the number of sites of the coverage area in the region can be finally obtained [42].

4.1.3.4 Interference Model

The calculation of interference is an essential process of the network simulator. The better the interference modeling is, the more accurate results can be obtained. On the other hand, the interference calculation is very computer time consuming: the received interference has to be calculated every time when the interference situation changes due to the fast power control.

For LTE, the basic Radio Link Budget (RLB) equation between UE,EnodeBs and neighbor EnodeBs can be written as follows (in units of dB):

$PathLos_{dB} = TxPower_{dB} + TxGains_{dB} - TxLosses_{dB} - RequiredSINR_{dB} + RxGains_{dB} - RxLosses_{dB} - RxNoise_{dB}$ … (13)

Where,Path Loss = Total path loss encountered by the signal from transmitter to receiver (W), TxPowerdB = Power transmitted by the transmitter antenna (dBm),TxGainsdB = Gain of transmitter antenna (dB),TxLossesdB = Transmitter losses (dB),RequiredSINRdB = Minimum required SINR for the signal to be received at the receiver with the required quality or strength (dB),RxGainsdB = Gain of receiver antenna (dB),RxLossesdB = Receiver losses (dB),RxNoisedB = Receiver Noise (dBm).

Equation 1 is shown in units of decibel for the sake of clarity. However, all the derivation will

be done with terms in absolute units. Equation 1 can be written in absolute terms as follows:

$$PathLoss = \frac{TxPower * TxGains * RxGains}{TxLosses * RequiredSINR * RxLosses * RxNoise} \quad \ldots(14)$$

Where,Path Loss = Total path loss encountered by the signal from transmitter to receiver (W),TxPower = Power transmitted by the transmitter antenna (W),TxGains = Gain of transmitter antenna,TxLosses = Transmitter losses (W),RequiredSINR = Minimum required SINR for the signal to be received at the receiver with the required quality or strength,RxGains = Gain of receiver antenna,RxLosses = Receiver losses (W),RxNoise = Receiver Noise (W).

In LTE, the basic performance indicator is 'Required SINR'. Maximum allowed path loss is calculated according to the condition:

$$SINR=\frac{AveRxPower}{Interference+RxNoise}=\frac{AveRxPower}{OwnCellInterference+OtherCellInterference+RxNoise}\ldots(15)$$

Where,

SINR = Signal to interference and noise ratio,AveRxPower = Average received power (W), Interference = Interference power (W),OwnCellInterference = Power due to own cell interference (W),OtherCellInterference = Power received for neighboring cells (W).

In downlink, assuming the maximum available transmission power is equally divided over the cell bandwidth, the average received power (AveRxPowerDL) in the bandwidth allocated to the user is derived as follows:

$$AveRxPowerDL=\frac{AveTxPowerr}{linkLossDL}=\frac{MaxENodeBTxPower}{CellBandwidth}\times\frac{AllocatedBandwidth}{LinkLossDL}\ldots..(16)$$

Where, SINR = Signal to interference and noise ratio,AveRxPower = Average transmitted power (W),LinkLossDL = Total link loss in downlink (W),MaxNodeBTxPower = Maximum Power transmitted from NodeB (W),CellBandwidth = Allocated bandwidth of LTE network cell (MHz), AllocatedBandwidth = Bandwidth of channel over which the signal is transmitted
(MHz).

The MaxNodeBTxPower in LTE depends on the cell bandwidth, which can range from 1.25 to
20
MHz. Specifically, MaxNodeTxPower is 20 Watt (43 dBm) up to 5 MHz and 40 Watt (46dBm) above this limit [43].

In uplink, assuming no power control, the average received power (AveRxPowerUL) is:

AveRxPowerUL=$\frac{MaxUETxPower}{LinkLossUL}$ … (17)

Where, MaxUETxPower= Max transmission power of user equipment (W),LinkLossUL = Total link loss in uplink (W).

The MaxUETxPower can be either 0.125 W or 0.25 W (21 or 24 dBm) [43]. The LinklossUL includes the distance-dependent Pathloss and all other gains and losses at the transmitter and the receiver. The gains include antenna gains and amplification gains (e.g. Mast Head Amplifier (MHA) in the UL direction). The above gain does not need to be considered explicitly, in case antenna configuration is taken into account in link level simulations (i.e., the effect is included in the RequiredSINR value). The losses include body loss at the terminal side, cable losses and Mast

Head Amplifier noise figure at the eNodeB and finally some margins (OtherLosses) needed to take into account shadow fading and indoor penetration loss. Therefore, link loss (LinkLoss)

can be written as:

Linkloss=$\frac{RxGains*TxGains}{Pathloss*\ RxLosses*TxLosses*OtherLosses}$------(18)

Where, OtherLosses= Includes all losses not covered by the mentioned RLB terms (W)

The received noise power (RxNoise) in Watts:

RxNoise =Thermal Noise ReceiverNoiseFigure=(ThermalNoiseDensity Allocated Bandwidth) ReceiverNoiseFigure.

Where,ThermalNoise = Thermal Noise (W),ReceiverNoiseFigure = Receiver Noise Figure,Thermal Noise Density = -174 dBm.

In the DL direction, due to the OFDM access technology and assuming the appropriate length of cyclic prefix, we can assume there’s no own cell interference (OwnCellInterference is zero). OtherCellInterference is the total average power received from other cells in the allocated bandwidth. Similarly, in the UL direction the Interference (also called Noise Rise) is the power received from terminals transmitting on the same frequency in the neighboring cells

(OtherCellInterference).

4.1.3.5 Mobility Model

In SEQ simulator the users' mobility data from MR, CHR and property matrices related to users are located and displayed on the simulation map according to the mobility model. The real handover generation and completion processes are collected from mobility data and used by this simulator.

4.1.3.6 Traffic Model

The construction of an adequate traffic model is an important task in the performance evaluation of wireless communication networks. The study of traffic models not only helps us to understand network behavior for traffic but also help in optimization and plan the network for the bandwidth and other requirements so that the users can enjoy the better quality of service. The behavior of the developed traffic model is the mimic behavior of the real

. SEQ radio network simulator, simulates the real network traffic behavior by using the users' traffic data from MR, CHR and property matrices related to users to locate and display the distribution of traffic on map according to the traffic model. The real data generation and completion processes are collected from traffic data and used by this simulator, this is made according to a Poisson process [44].

4.2 Introduction of User Plane Management Tools

Drive testing (DT) system is a method of measuring and assessing the coverage, capacity and QoS of a mobile radio network from user perspective point of views, which is called in this thesis "user plane systems tools". It can detect and record a wide variety of the physical and virtual parameters of mobile communication service in a given geographical area.

The technique consists of Nemo handy, global positioning system (GPS), DT route, MapInfo, Google earth, engineering parameters, scanner and laptop. By measuring what a wireless network subscriber would experience in any specific area, operators can make directed changes to their networks that provide better coverage and service to their customers [45].

The DT Analysis is a post-processing optimization platform that analyzes cellular interface data that was collected using the drive test wireless network optimization software.

- The analyzed data streams are combined in the collection system and come from two sources. Air interface data fields that relate to the user's specific radio technology.
- Navigation position (or geodetic reference) and time stamp for each data reading.

This combined data lets you evaluate the characteristics of the cellular system to determine problem areas and plan improvements based on time of day and the physical location of the data readings [45].

Nemo handy is a state of the art handled tool for testing mobile real time applications QoS/QoE and measuring the performance of wireless networks.

Its extensive application testing features are complete with voice quality testing, full application level metrics on voice and video calls, UL/DL data transfers, Web browsing, SMS/MMS messaging and ping. It provides a complete and detailed picture of the QoS performance of the end users. Nemo Outdoor is a laptop-based drive test tool for wireless network testing which supports over 300 terminals and scanning receivers from various vendors and all major network technologies. It is one of the DT tools, which is used to collect the DT data of the network, which can show the users' QoS. Through the Nemo out door, the network performance can be evaluated, the network optimization can be guided and the fault can be rectified. The collected DT data of the network on the radio network can be saved as the logfile. This facilitates the data analysis after the logfile is imported to other post processing software (such as Actix analyzer).

The Actix is DT logfiles analysis software, which is used to analyze and process test data of networks. The Actix can also generate network test reports to meet network analysis requirements of customers. The generated test reports effectively reflect the operation status of radio networks and provide guidelines for network verification, network evaluation, network optimization, and fault location. Therefore, the test reports help operators learn about network performance, quickly locate network problems and improve work efficiency. A scanner is a radio receiver that can automatically tune or scan, two or more separate frequencies, stopping when it finds a signal on one of them and then continuing to scan other frequencies when the initial transmission stop.

Chapter Five

Data Collection and Analysis Results

5.1. Control Plane System Data Collection and Analysis Results

The Service Experience Quality (SEQ) analyst tool is deployed on the Element Management System (EMS) side of an operator's network. The SEQ analyst tool collects required analysis data from NEs through the EMS data center and provides them analysis for network optimization. The SEQ mainly uses the following activities for 4G LTE network analysis: such as S1-MME attach delay Analysis, S6a Insert Subscriber Data Delay, MME paging delay and success, E2E delay, Handover Resource Allocation Delay, S11 Default Bearer Creation Delay analysis and for many other control plane displaying the analysis data visitations.

5.1.1 Addis Ababa 4G LTE S1-MME attach delay Analysis

The LTE S1-MME interface is responsible for delivering signaling protocols between the eNodeB and the MME. S1-MME interface consists of a Stream Control Transmission Protocol (SCTP) over IP and supports multiple UEs through a single SCTP association. It also provides guaranteed data delivery. The application signaling protocol is an S1-AP (Application Protocol). The LTE S1-MME is responsible for Evolved Packet System (EPS) bearer setup/release procedures, the handover signaling procedure, the paging procedure and the NAS transport procedure. LTE Transport network layer is built on IP transport, similar to the user plane but for the reliable transport of signaling messages SCTP is added on top of the Internet Protocol.

Control messages between the eNB and the MME are sent over S1-MME interface as embedded in S1AP messages. S1AP messages are delivered through S1 signaling connections dedicatedly established for each user. The S1 signaling connections are defined by an ID pair (eNB UE S1AP ID, MME UE S1AP ID) allocated by the eNB and the MME for identifying UEs.

According to Ethiotelecom the connection setup or attach success threshold/target or benchmark is >= 98% in each 24Hr [66].However from bellow network Analysis snapshot most of site are below target.

LTE is well positioned to meet the requirements of next-generation mobile networks. The latency in the user plane is less than 5 ms and, in the control plane, is 50 ms[59].Figure 5.1 Snapshot Shows S1-MME Attach Delay(ms) for AA LTE sites.

The total delay increases as the UEs travel with increasing speed due to the degradation in the received SINR level. The total packet delay becomes less with higher bandwidths.

The strength of radio signals degrades as the distance between the transmitter and receiver increases due to the propagation losses they face from buildings and terrain along the way.

The system throughput is reducing with the increased number of UEs in the LTE network. The reason for this is the congestion in the network, since the system bandwidth has to be shared by the UEs located in the area. We have observed that as the number of UEs increase, the network only serves a limited number of UEs (carried traffic) by dropping some of the UEs.

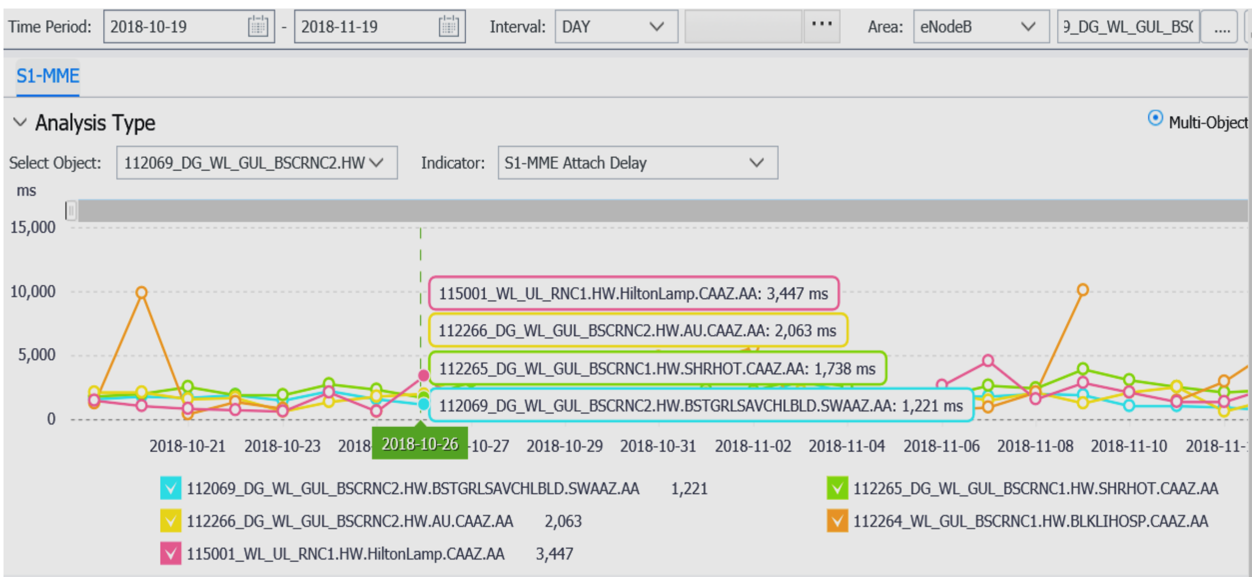


Figure 5.1 Addis Ababa 4G LTE sites S1-MME High Attach Delay (ms) simulation snapshot. The figure is represent specific eNodeBs because it hide the rest of eNodeBs sites.Table 5.1 Shows S1-MME Attach Delay(ms) vs S1-MME Attach Success Rate(%) for AA LTE sites .

eNodeB	S1-MME Attach Delay(ms)	Success Rate(%)
112264_WL_GUL_BSCRNC1.HW.BLKLIHOSP.CAAZ.AA	10077	14.28
112264_WL_GUL_BSCRNC1.HW.BLKLIHOSP.CAAZ.AA	9898	1.14
112264_WL_GUL_BSCRNC1.HW.BLKLIHOSP.CAAZ.AA	5677	27.77
112264_WL_GUL_BSCRNC1.HW.BLKLIHOSP.CAAZ.AA	5378	28.57
112264_WL_GUL_BSCRNC1.HW.BLKLIHOSP.CAAZ.AA	4898	33.33

5.1.2 Handover Resource Allocation Delay Analysis

Many works have been done comparing the S1 and X2 handover in terms of the EPC signaling load and the results proofs that X2 handover can reduce EPC signaling load more than six times compared with S1 handover[60]. In this thesis we will see snapshots the handover between EnodeBs. X2 interface can be established between one eNB and its neighbors in order to exchange the intended information. From our observation Handover Resource Allocation Success Rate and Handover Resource Allocation delay at EnodeB in Ethiotelecom show below the target. The target set by Ethiotelecom is >=98 %[67].But some site show 94% successes.

Average handover failure=$\frac{The\ Amount\ of\ failure\ handover}{Total\ amount\ triggered\ handover}$-------(19)

In a typical case, multiple applications may be running in a UE at any time, each one having different quality of service requirements [12] from table of QCI.

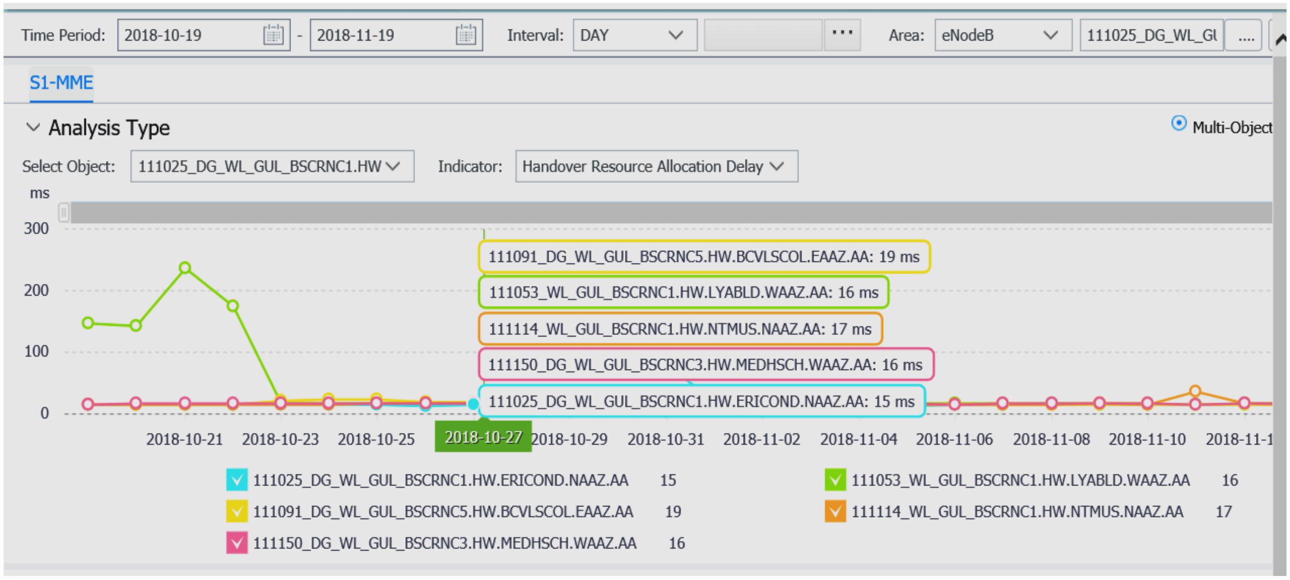


Figure 5.2 Addis Ababa 4G LTE sites S1-MME High Handover Resource Allocation Delay(ms) simulation snapshot

The table below shows High Handover Resource Allocation Delay(ms) for Selected 4G LTE AA sites[October 2018].

Table 5.2 Shows High Handover Resource Allocation Delay(ms) vs Handover Resource Allocation Success Rate(%).

eNodeB	Handover Resource Allocation Delay(ms)	Handover Resource Allocation Success Rate(%)
112264_WL_GUL_BSCRNC1.HW.BLKLIHOSP.CAAZ.AA	29	100
111395_WL_GUL_BSCRNC1.HW.SUMALTERA.NAAZ.AA	27	97.77
111197_DG_WL_GUL_BSCRNC3.HW.KUMEDA.WAAZ.AA	32	97.73
111150_DG_WL_GUL_BSCRNC3.HW.MEDHSCH.WAAZ.AA	28	97.4
111279_WL_GUL_BSCRNC5.HW.SMTMDCHU.EAAZ.AA	58	94.61
111395_WL_GUL_BSCRNC1.HW.SUMALTERA.NAAZ.AA	25	98.26
111053_WL_GUL_BSCRNC1.HW.LYABLD.WAAZ.AA	142	86.2

5.1.3 S11 Default Bearer Creation Delay analysis.

This measurement provides the number of attempted default bearer creation. Receipt of "Create Session Request" message by S-GW from MME on the S11 interface, this message may contains multiple default bearer IDs, each default bearer shall be cumulated to the counter.From our observation S11 Default Bearer Creation Success Rate(%) analysis show below target of Ethiotelecom(>=95%).Here is below snapshot shows default bearer creation delay. Control plane latency should bellow 50ms. However our LTE network not meet the threshold.

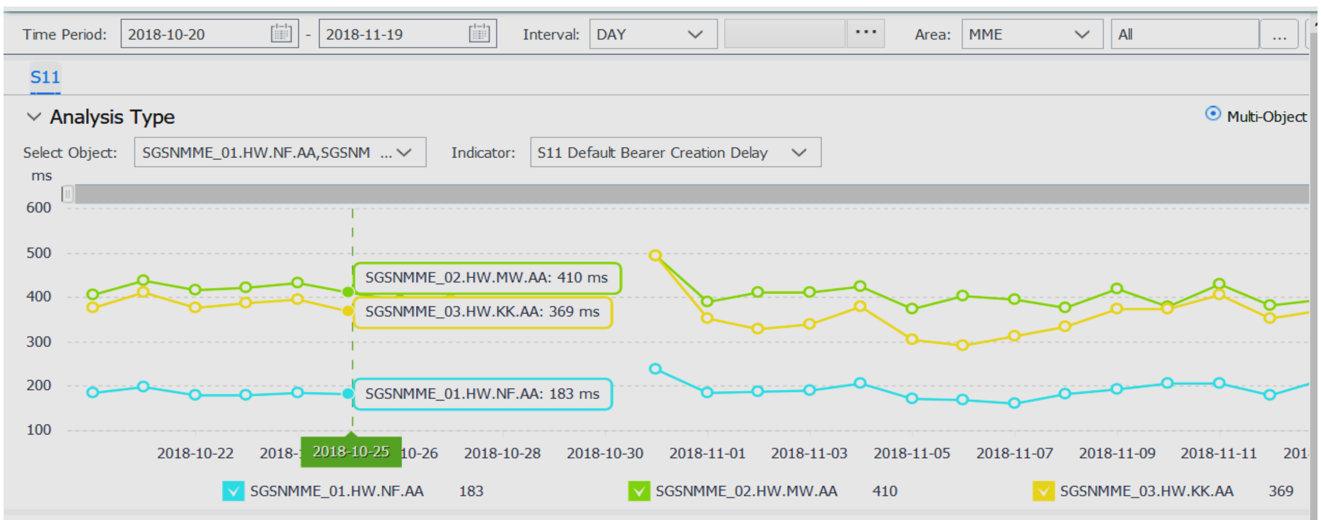


Figure 5.3 S11 Default Bearer Creation Delay analysis snapshot

Let us see table 5.3 below the comparative of S11 Default Bearer Creation Delay(ms) vs S11 Default Bearer Creation Success Rate (%) [October 2018].As we see from this table there is high delay and S11 Default Bearer Creation Success Rate(%) is bellow the company threshold.

Table 5.3 Comparative of S11 Default Bearer Creation Delay(ms) vs S11 Default Bearer Creation Success Rate(%).

MME	S11 Default Bearer Creation Delay(ms)	S11 Default Bearer Creation Success Rate(%)
SGSNMME_03.HW.KK.AA	410	88.67
SGSNMME_02.HW.MW.AA	438	88.94

SGSNMME_02.HW.MW.AA	417	89.46
SGSNMME_02.HW.MW.AA	423	89.12
SGSNMME_02.HW.MW.AA	432	87.01
SGSNMME_02.HW.MW.AA	410	89.43
SGSNMME_03.HW.KK.AA	494	88.82

5.1.4 S6a Insert Subscriber Data Delay Analysis

Insert Subscriber Data is a Subscriber Data Handling procedure in LTE services. This procedure is used to manage the subscription data of subscriber in MME and SGSN over S6a/S6d interface. IDR (insert subscription data request) is invoked by Home Subscriber Server for subscription data handling. IDR is MAP subscriber management service utilized in GSM/UMTS networks, standardized by 3GPP, and defined in the MAP specification, TS 29.002.[56] This service is used to provide specific subscriber data in the following environments: by an HLR to update a VLR, by an HLR to update a SGSN, and by an HSS to update a MME via IWF in an EPS.[56] This service is primarily used by the home subscriber management entity to update the serving subscriber management entity when there is either a change in a subscriber parameter, or upon a location updating of the subscriber. Figure 5.3 shows Ethiotelecom HSS S6a Insert Subscriber Data Delay Analysis result that is vary in different days. However, it is almost good.

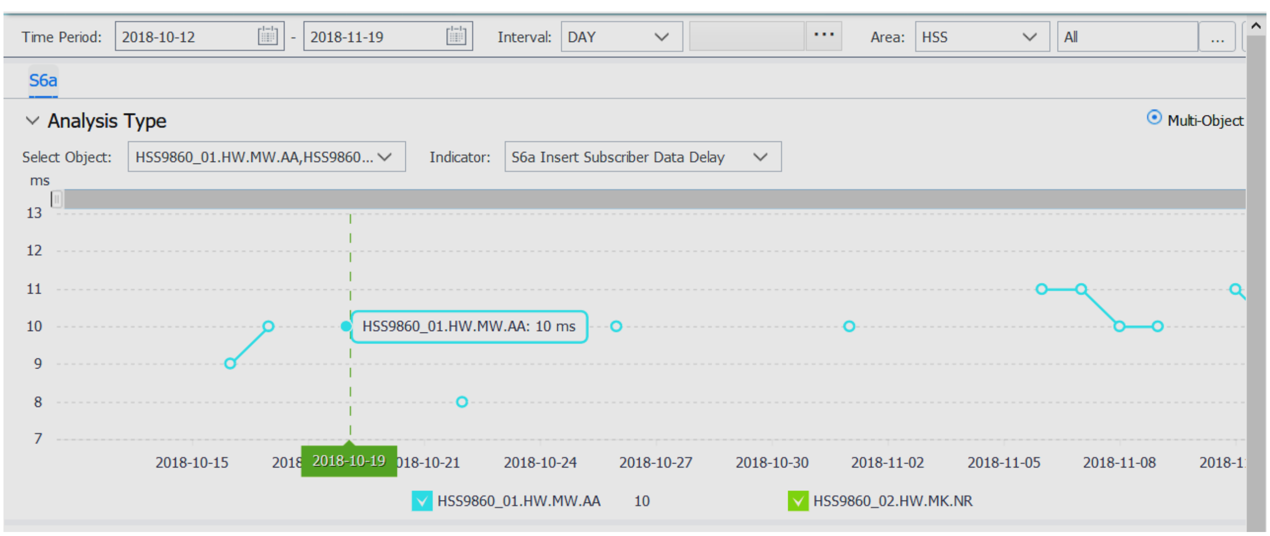


Figure 5.4 S6a Insert Subscriber Data Delay Analysis snapshot

Table 5.4 S6a Insert Subscriber Data Delay

DAY	HSS	S6a Insert Subscriber Data Delay(ms)	S6a Insert Subscriber Data Success Rate(%)
10/3/2018	HSS9860_01.HW.MW.AA	8	100
10/16/2018	HSS9860_01.HW.MW.AA	9	100
10/17/2018	HSS9860_01.HW.MW.AA	10	100
10/19/2018	HSS9860_01.HW.MW.AA	10	100
10/22/2018	HSS9860_01.HW.MW.AA	8	100
10/26/2018	HSS9860_01.HW.MW.AA	10	100
11/1/2018	HSS9860_01.HW.MW.AA	10	100
11/6/2018	HSS9860_01.HW.MW.AA	11	100
11/7/2018	HSS9860_01.HW.MW.AA	11	100
11/8/2018	HSS9860_01.HW.MW.AA	10	100
11/9/2018	HSS9860_01.HW.MW.AA	10	100

5.1.5 MME Paging Success Rate Analysis

The MME paging for EPS (Evolved Packet System) services is defined in the 3GPP specifications [57] as a part of the connection establishment procedure for the downlink data service requests. The SGs interface connects the databases in the VLR and the MME. Evolved LTE systems apply MME paging in parallel with the MSC (Mobile Switching Center) and SGSN (Serving GPRS support node) paging mechanisms that are defined for service requests of other types.

The mobility management entity (MME) of the evolved packet system interfaces to the MSC server via the SGs interface. The CSFB mechanism is implemented using this SGs interface. Paging success rate is defined as a ratio of the total number of the paging messages responded by user terminals of the total number of S1AP paging messages generated by the MME. Measuring the Paging success rate is used to estimate the coverage and capacity of the network. Typical values of paging success rate are above 96%. In well-managed networks the paging success rate is in a range from 98.00% to 98.80%. Such performance is achieved by a complex optimization of radio access network that includes numerous KPIs not directly related to the paging procedure. It is not possible in practice to reach 100% paging success rate as there are inevitably UEs that drop out of coverage with no notification to the network. Bellow Figure 5.5 shows Ethiotelecom MME Paging Success Rate Analysis result that shows bellow the target settled by company.

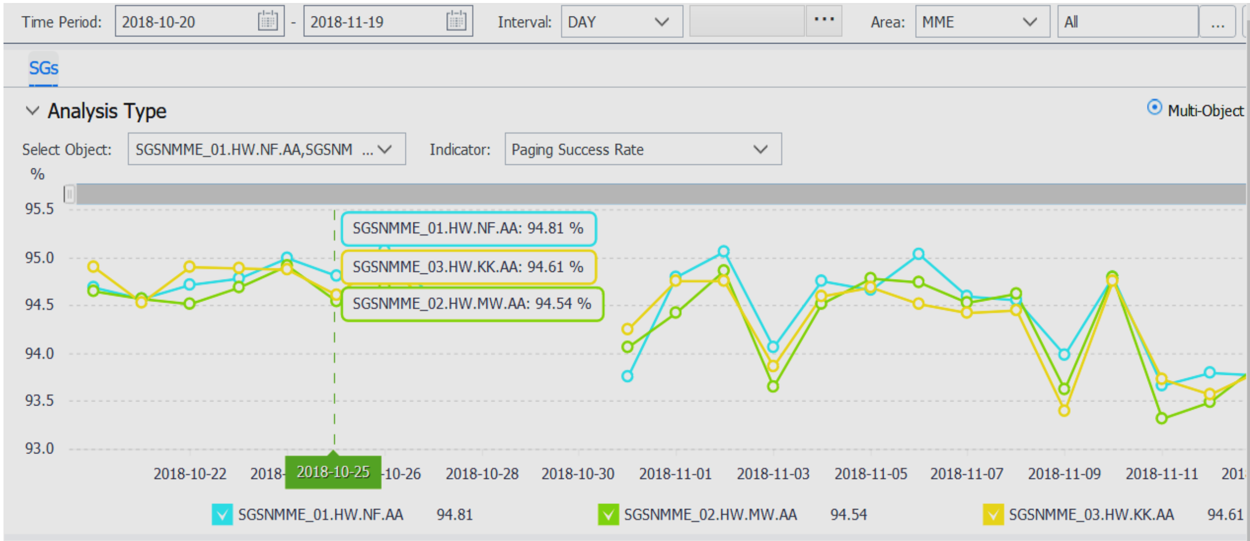


Figure 5.5 MME Paging Success Rate Analysis snapshot

Table 5.5 below shows the most low paging LTE sites in AA. Delay budget for TCP based service the thresholds is 300ms, hover Addis Ababa's 4G LTE SGSNMME network entity is below threshold.

Table 5.5 MME Paging Success Rate Analysis description

DAY	MME	Paging Success Rate(%)	Average Paging Delay(ms)
11/12/2018	SGSNMME_03.HW.KK.AA	93.57	637
11/18/2018	SGSNMME_01.HW.NF.AA	93.55	636
11/13/2018	SGSNMME_03.HW.KK.AA	93.81	631
11/17/2018	SGSNMME_01.HW.NF.AA	94.26	631
11/12/2018	SGSNMME_01.HW.NF.AA	93.8	630
11/17/2018	SGSNMME_03.HW.KK.AA	94.16	630
11/18/2018	SGSNMME_03.HW.KK.AA	93.87	630
11/11/2018	SGSNMME_03.HW.KK.AA	93.73	628

11/12/2018	SGSNMME_02.HW.MW.AA	93.49	628
11/15/2018	SGSNMME_03.HW.KK.AA	93.97	626
11/13/2018	SGSNMME_01.HW.NF.AA	93.77	625

5.1.6 E2E Delay Analysis

For mobile operators, in order to ensure that data provides the same high-level service the total end-to-end delay of less than 300 ms[58].From our data collection Figure 5.6 E2E delay Analysis snapshot result show specific Addis Ababa LTE end to end high delay .

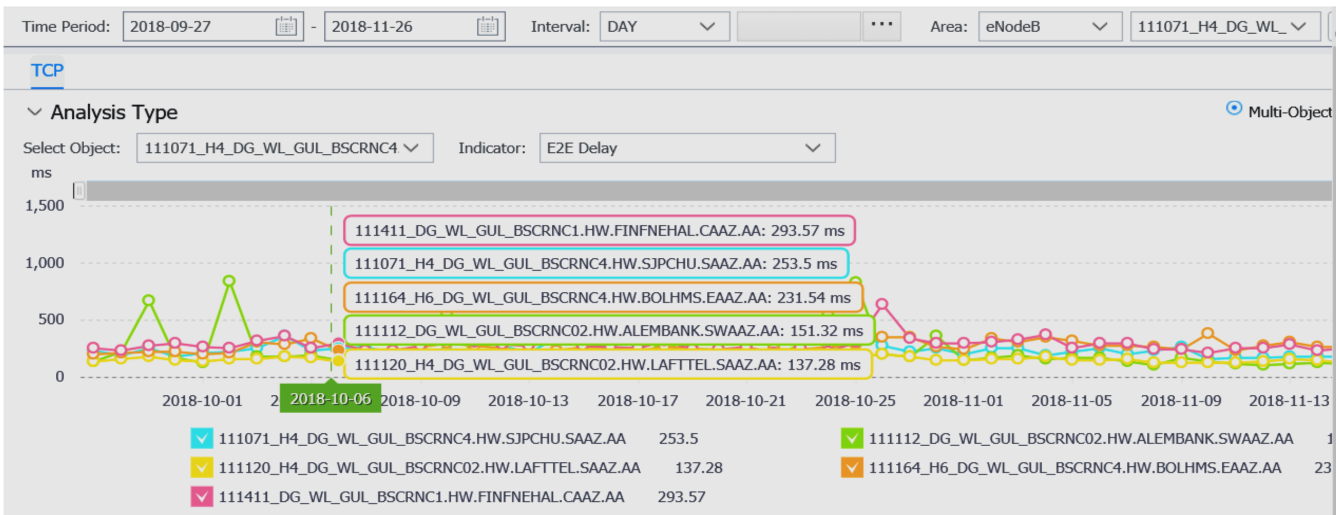


Figure 5.6 E2E delay Analysis snapshot

Let us see the worst or high end to end delay 4G LTE sites from all over Addis Ababa LTE network.

Table 5.6 E2E delay Analysis snapshot.

Day	eNodeB	E2E Delay(ms)_KPI Value
11/17/2018	112266_DG_WL_GUL_BSCRNC2.HW.AU.CAAZ.AA	1764.76
11/14/2018	112266_DG_WL_GUL_BSCRNC2.HW.AU.CAAZ.AA	1386.22
11/24/2018	111071_H4_DG_WL_GUL_BSCRNC4.HW.SJPCHU.SAAZ.AA	1015.99
11/15/2018	112266_DG_WL_GUL_BSCRNC2.HW.AU.CAAZ.AA	846.91
10/2/2018	111112_DG_WL_GUL_BSCRNC02.HW.ALEMBANK.SWAAZ.AA	836.35
10/25/2018	111112_DG_WL_GUL_BSCRNC02.HW.ALEMBANK.SWAAZ.AA	832.34
10/7/2018	115001_WL_UL_RNC1.HW.HiltonLamp.CAAZ.AA	680.07
9/29/2018	111112_DG_WL_GUL_BSCRNC02.HW.ALEMBANK.SWAAZ.AA	666.46
10/22/2018	115001_WL_UL_RNC1.HW.HiltonLamp.CAAZ.AA	649.64
11/24/2018	111120_H4_DG_WL_GUL_BSCRNC02.HW.LAFTTEL.SAAZ.AA	649.03
11/18/2018	112266_DG_WL_GUL_BSCRNC2.HW.AU.CAAZ.AA	643.57

From above Table summary observation there is high end to end delay in Ethiotelecom LTE network.so optimization is further need for this network. In all over control plane QoS evaluation analysis result there is disparities between the Ethiotelecom targets and analysis results.

5.2. **User Plane System Data Collection and Analysis Results**

The main objective of the drive test was to investigate data performance of Addis Ababa LTE network. Drive test is normally conducted to investigate network problem associated to poor coverage, downlink throughput, uplink throughput and quality. Accordingly drive test has been done for evaluating poor coverage, downlink throughput, uplink throughput and quality of data service in Addis Ababa 4G LTE network, December 2018.

The DT was done by using test tools called Nemo handy, laptop, GPS, engineering parameters and DT routes to gathers data, which are later, analyzed using standard tool actix software to give a picture of the coverage footprint and data service of the Addis Ababa LTE network. Typically, coverage is identified by the coverage performance indicator (RSRP) and quality is identified by the quality performance indicator (RSRQ), which will show the signal strength.

5.2.1 Data DT Testing Information

The drive test is performed according to the need and the types of test data services, which are the same that the network supports. Everything depends on the LTE technology. The mobile configured in the collecting software (nemo handy), performing downlink and uplink for a specific number. Short uplink and downlink should last the average of a user data service: a good reference Ethiotelecom data service value is 40Mbps and 20Mbps for downlink and uplink respectively. Server to check whether the data are being established and successfully completed (being a good way to also check the network setup time).

And the Nemo handy is used for data to measure changes or degradation in the quality of the data connection.

Table 5.2: Shows the data DT test information.

Data Test Details	Specifications
ERAN System	LTE
Data Test Algorithm	
DT type	LTE DL and UL
Data Quality Measurement	FTP DL and UL throughput
Test Procedure	
LTE_UE_RSRP	Coverage performance of the service areas are checked
LTE_UE_RSRQ	Quality performance of the service areas are checked

5.2.2 Addis Ababa LTE Network Information

Addis Ababa 4G LTE network has 3 MMEs, 328 eNodeB or sites. From those sites in my thesis I did the indoor coverage test in Four buildings areas.

Reasons of Selecting these Areas are as the following:

1. **Black Lion Hospital(BLH):** This area is covered with many students and researchers these have high smart phone and Tablets those need high internet access.
2. **Ethiotelecom Microwave Office (EMWO):** This area is Backbone of for all of Ethiotelecom network connectivity, so it is mandatory visual ling the status of LTE network around the Operators environment side.
3. **Ethiotelecom Head office (EHO):** This area is surrounded with many business centers and many governmental and non-governmental head offices, so to see the data usage of Critical Customers of this area, so we conducted data collection and simulation for this area.
4. **Getu Commercial center:** This area is covered with many business centers nearest to Bole area, so to see the data usage of Key Customers or Enterprise Customers we conducted data collection and simulation for this area.

5.2.2.1 Black Lion Hospital(BLH) Coverage Analysis

To find out the maximum and minimum cell range, Simulation was performed for users in urban areas within the Addis Ababa Central Business Area. The RSRP levels were randomly distributed ranging between -75 to -105dBm for the 4G LTE configurations.

In the definition of network coverage, the requirements of effective coverage for a certain sampling point is that its LTE_UE_RSRP should be better than the specified threshold (RSRP> -105dBm). Figure 5.2.2.1 shows Black Lion Hospital LTE network DT coverage performance analysis [December 11, 2018]. From DT Indoor analysis result, in general 76% and 23% of the hospital indoor coverage was good and poor respectively, where expected good coverage threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the BLH coverage is not meet the threshold. This is due to the blockage of the building. So, this building need the installation of new Indoor Base Station (IBS).

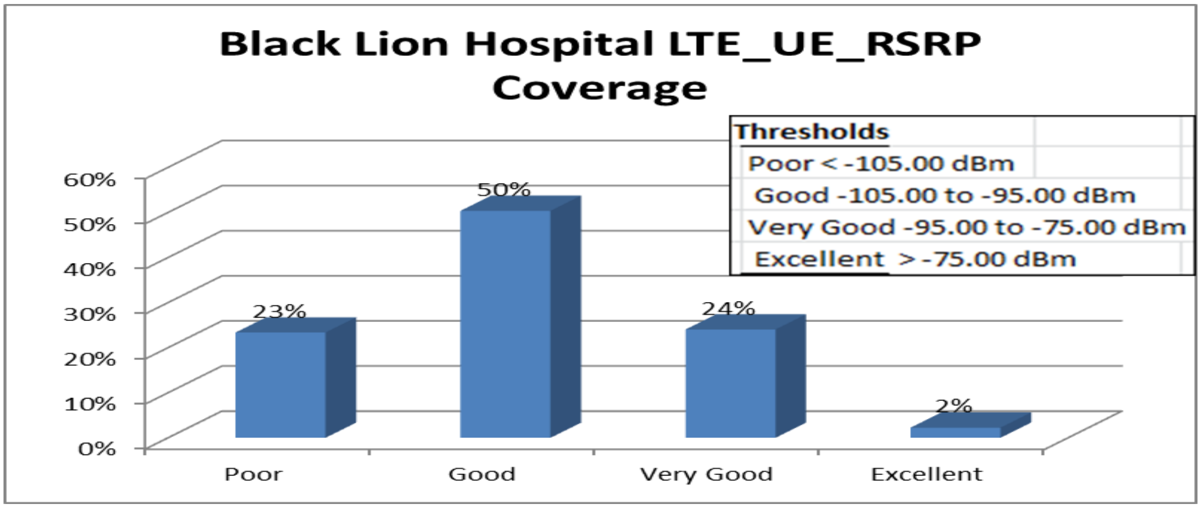


Figure 5.2.2.1 Black Lion Hospital LTE network DT coverage performance analysis

5.2.2.2 Black Lion Hospital LTE_UE_RSSI Strength

To know the strength of signal, Simulation was performed for users in urban areas within the Addis Ababa Central Business. The RSSI levels were randomly distributed ranging between -85 to -65dBm for the 4G LTE configurations. In the definition of network signal strength, the requirements of effective signal strength for a certain sampling point is that its LTE_UE_RSSI should be better than the specified threshold (RSRP> -85dBm). Figure 5.2.2.2 shows Black Lion Hospital LTE network DT signal strength performance analysis [December 2018]. From DT Indoor analysis result, in general 100% and 0% of the hospital indoor signal strength was good and poor respectively, where expected good signal strength threshold is greater than or equal to 95%. The DT indoor analysis result shows that the BLH signal strength is meet the threshold. So, for this reason it is not advisable to do coverage analysis by using RSSI.

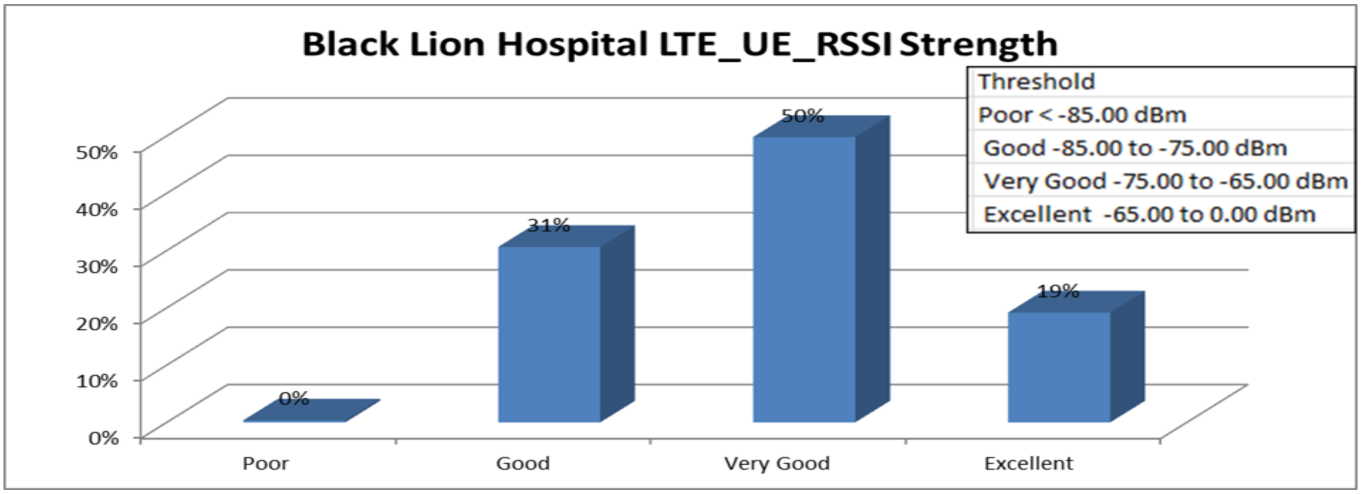


Figure 5.2.2.2 Black Lion Hospital LTE network DT signal strength performance analysis snapshot.

5.2.2.3 Black Lion Hospital LTE_UE_RSRQ

To know the signal quality, the RSRQ levels were randomly distributed ranging between -19 to -2dB for the 4G LTE configurations. In the definition of network signal quality , the requirements of effective signal quality for a certain sampling point is that its LTE_UE_RSRQ should be better than the specified threshold (RSRQ > -19dB). Figure 5.2.2.3 shows Black Lion Hospital LTE network DT signal quality performance analysis [December 2018]. From DT Indoor analysis result, in general 100% and 0% of the hospital indoor signal quality was good and poor respectively, where expected good signal strength threshold is greater than or equal to 95%. The DT indoor analysis result shows that the BLH signal strength is meet the threshold. Since there are limited number of LTE users in the building, the quality signal strength seems meet the threshold.

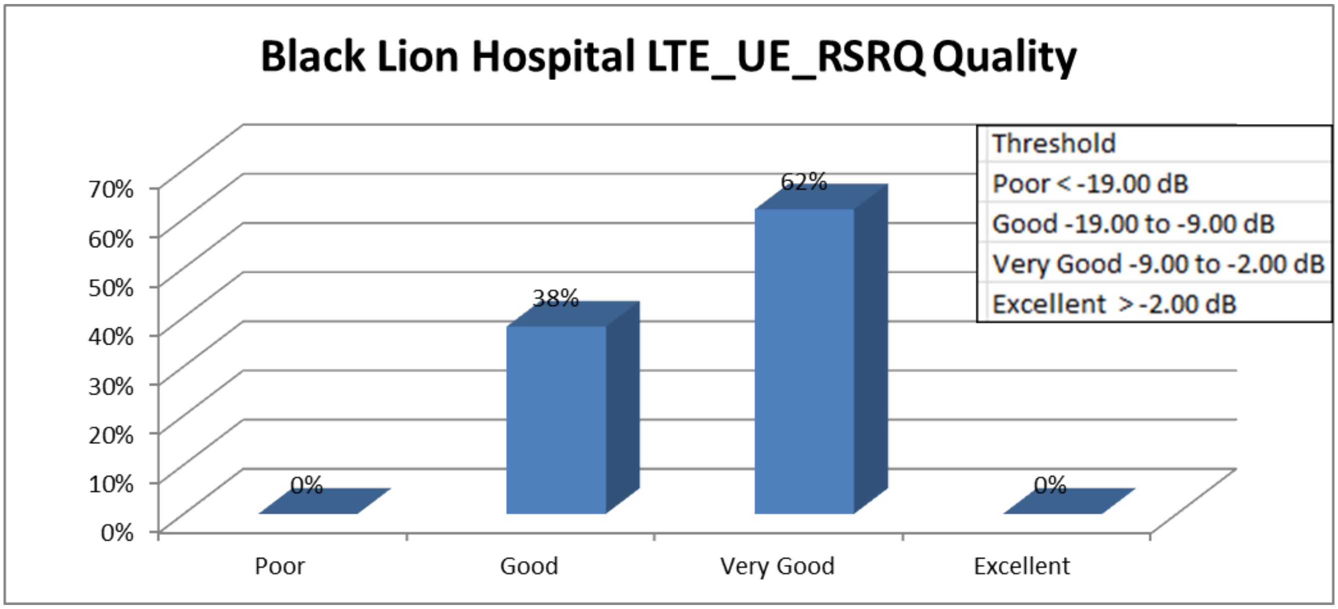


Figure 5.2.2.3 Black Lion Hospital LTE network DT signal quality performance analysis snapshot.

5.2.2.4 Black Lion Hospital LTE_UE_SINR

The SINR levels were randomly distributed ranging between -3 to 20dB for the 4G LTE configurations. In the definition of network signal to interference noisy ration, the requirements of effective useful internal UE internal UE signal quality for a certain sampling point is that LTE_UE_SINR should be better than the specified threshold (SINR > -3dB). Figure 5.2.2..4 shows Black Lion Hospital LTE network DT SINR signal quality performance analysis. From DT Indoor analysis result, in general 96% and 4% of the hospital indoor SINR signal quality was very good and good respectively, where expected good signal strength threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the BLH useful signal quality is meet the threshold. Since there are limited numbers LTE users in the building, the SINR seem meet the threshold.

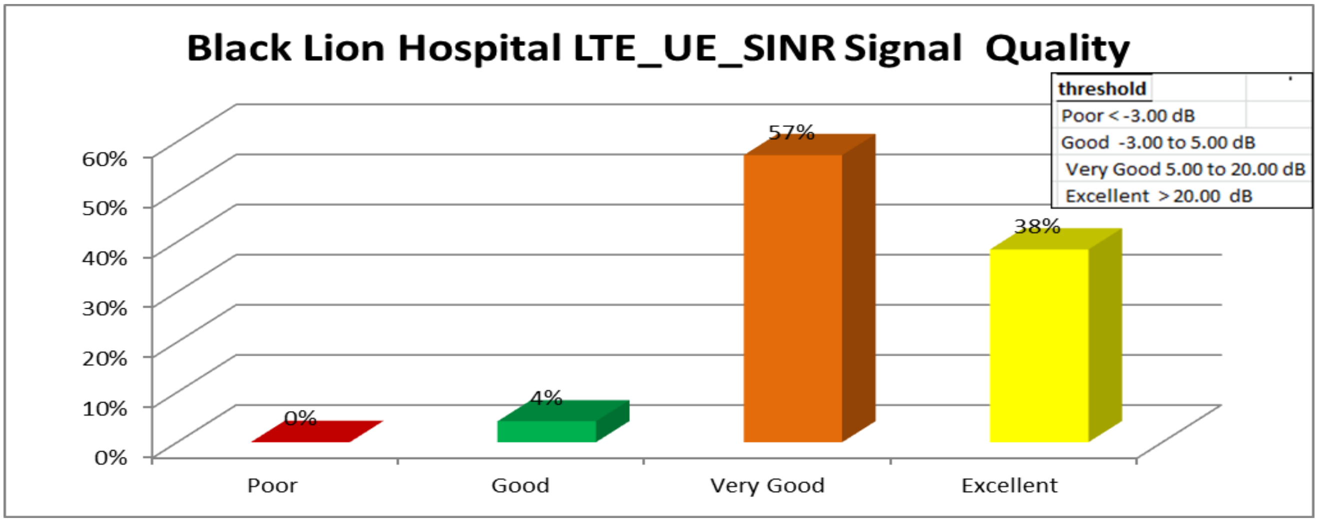


Figure 5.2.2.4 Black Lion Hospital LTE network DT SINR signal quality performance analysis snapshot.

5.2.2.5 Black Lion Hospital LTE_UE_Throughput_DL

Downlink throughput values were randomly distributed ranging between 32kbps (0.03125'

Mbps) to 36000kbps(35.16Mbps) from 4G LTE data services according to Ethiotelecom.. In the definition of network downlink throughput, the requirements of effective downlink throughput for a certain sampling point are that LTE_UE_Throughput_UL should be better than the specified threshold (DL > 32kbps). Figure 5.2.2.5 shows Black Lion Hospital LTE network DT downlink performance analysis. From log file Actix analyzer analysis result, in general 93% and 8% of the hospital indoor downlink was good and poor respectively, where expected good downlink throughput threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the BLH downlink throughput is not meet the threshold. So, optimization need for DL.

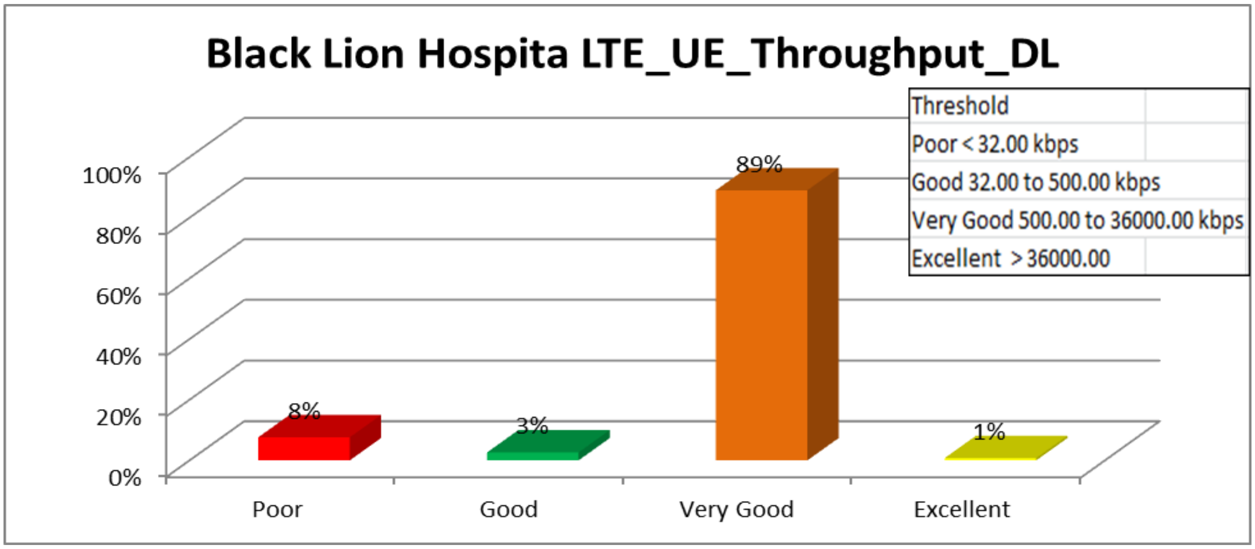


Figure 5.2.2.5 Black Lion Hospital LTE network DT downlink performance analysis snapshot.

5.2.2.6 Black Lion Hospita LTE_UE_Throughput_UL

Uplink throughput values were randomly distributed ranging between 4kbps (0.004Mbps) to 20000kbps(19.53Mbps) from 4G LTE data services according to ethiotelecom.. In the definition of network uplink throughput, the requirements of effective uplink throughput for a certain sampling point are that LTE_UE_Throughput_UL should be better than the specified threshold (UL > 4kbps). Figure 5.2.6 shows BLH LTE network DT uplink performance analysis. From log file Actix analyzer analysis result, in general 99% and 1% of the hospital indoor uplink was good and poor respectively, where expected good uplink throughput threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the BLH uplink throughput is meet the threshold. So, this indicate there is limited number of UL user for LTE in this building.

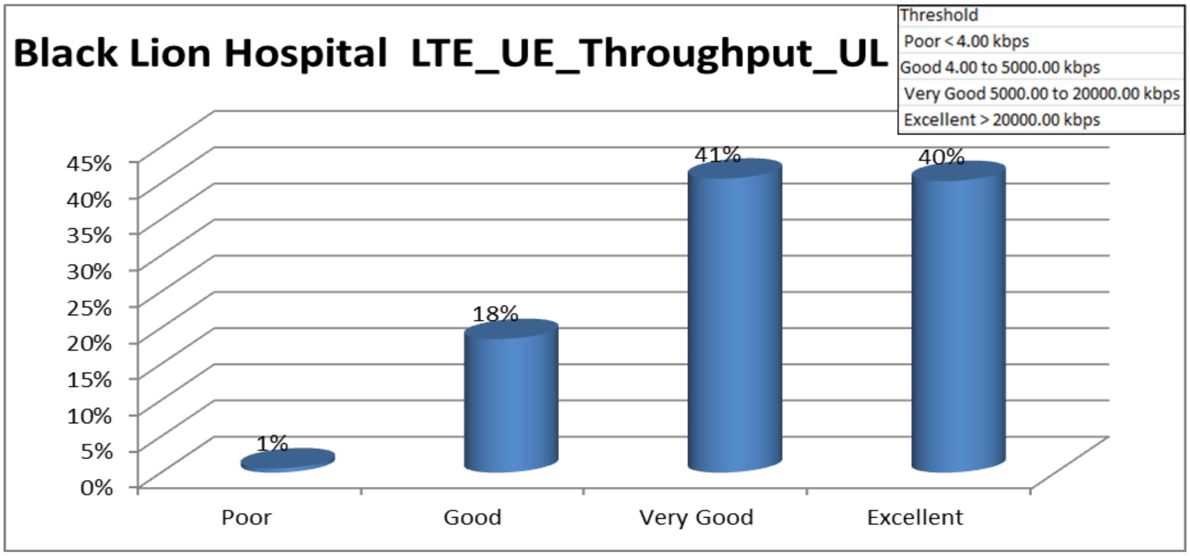
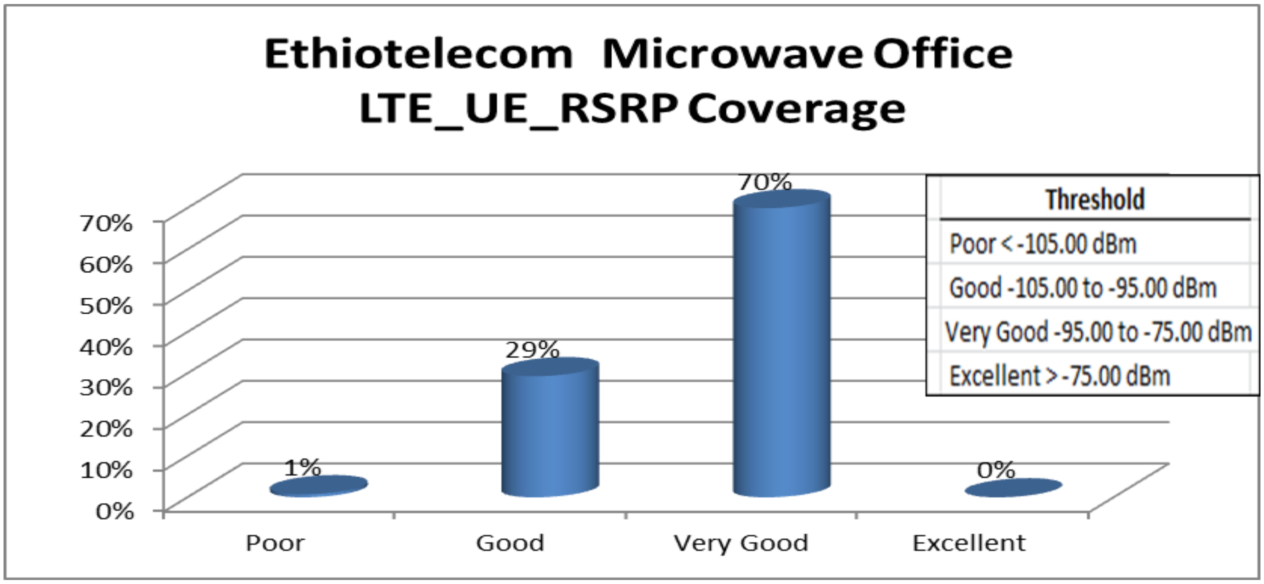


Figure 5.2.2.6 Black Lion Hospital LTE network DT uplink performance analysis snapshot.

5.2.2.7 Ethiotelecom Microwave Office (EMWO) LTE_UE_RSRP Coverage Analysis

To find out the maximum and minimum cell range, Simulation was performed for users in urban areas within the Addis Ababa Central Business Area. The RSRP levels were randomly distributed ranging between -75 to -105dBm for the 4G LTE configurations.

In the definition of network coverage, the requirements of effective coverage for a certain sampling point is that its LTE_UE_RSRP should be better than the specified threshold (RSRP> -105dBm). Figure 5.2.2.7 shows EMWO LTE network DT coverage performance analysis [December 10, 2018]. From File Log Indoor analysis result, in general 99% and 1% of the Microwave Office indoor coverage was good and poor respectively, where expected good coverage threshold is greater than or equal to 95% [66]. The DT indoor analysis result shows that the EMWO coverage is meet the threshold. So, no need of optimization in this area.



5.2.2.7 Ethiotelecom Microwave Office (EMWO) LTE_UE_RSRP Coverage Analysis snapshot

5.2.2.8 Ethiotelecom Microwave Office LTE_UE_RSSI Strength Analysis

In the definition of network signal strength, the requirements of effective signal strength for a certain sampling point is that its LTE_UE_RSSI should be better than the specified threshold (RSRP> -85dBm). Figure 5.2.2.8 shows EMWO LTE network DT signal strength performance analysis [December 10,2018]. From DT Indoor analysis result, in general 100% and 0% of the EMWO indoor signal strength was good and poor respectively, where expected good signal strength threshold is greater than or equal to 95%. The DT indoor analysis result shows that the EMWO signal strength is meet the threshold. So, no need of optimization for RSSI.

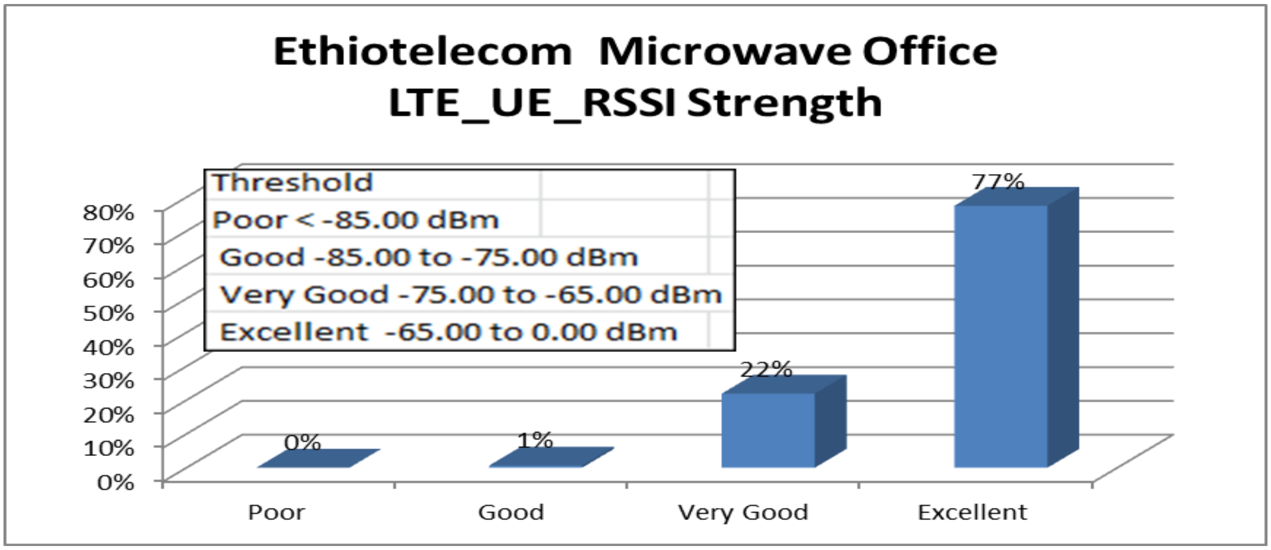
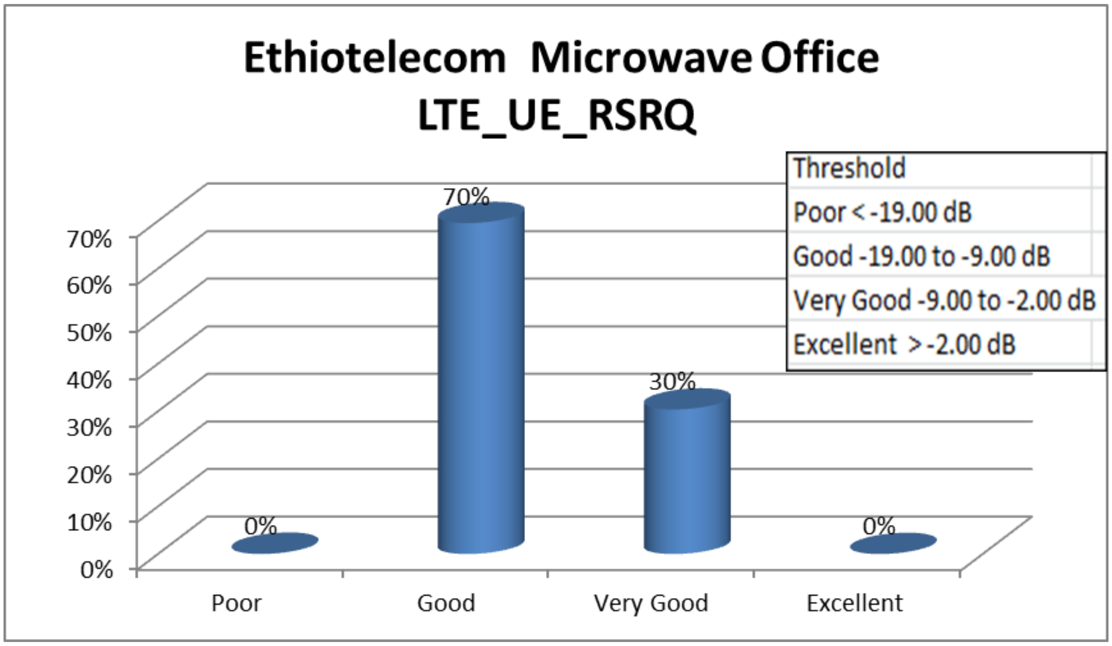


Figure 5.2.2.8 EMWO LTE network DT signal strength performance analysis snapshot

5.2.2.9 Ethiotelecom Microwave Office LTE_UE_RSRQ

In the definition of network signal quality, the requirements of effective signal quality for a certain sampling point is that LTE_UE_RSRQ should be better than the specified threshold (RSRQ > -19dB). Figure 5.2.2.9 shows EMWO LTE network DT signal quality performance analysis. From DT Indoor analysis result, in general 100% and 0% of the hospital indoor signal quality was good and poor respectively, where expected good signal strength threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the EMWO signal strength is meet the threshold. So, no need of optimization for RSRQ.



5.2.2.9 EMWO LTE network DT signal quality performance analysis snapshot

5.2.2.10 Ethiotelecom Microwave Office LTE_UE_SINR

The requirements of effective useful internal UE internal UE signal quality for a certain sampling point is that LTE_UE_SINR should be better than the specified threshold (SINR > -3dB). Figure 5.2.10 shows EMWO LTE network DT SINR signal quality performance analysis. From DT Indoor analysis result, in general 100% and 0% of the Microwave office indoor SINR signal quality was good and poor respectively, where expected good signal strength threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the Microwave useful signal quality is meet the threshold. So, no need of optimization for SINR.

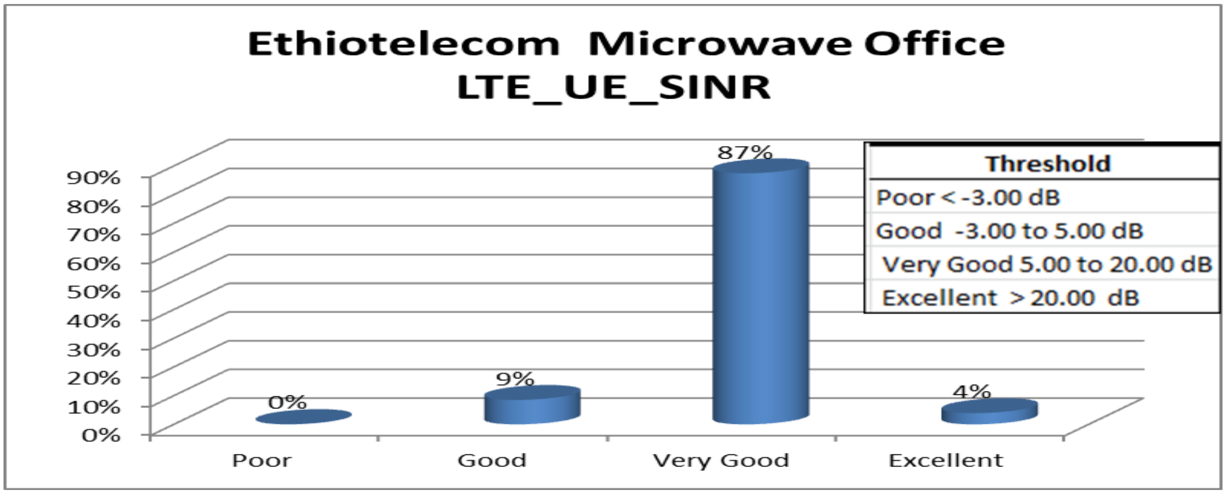


Figure 5.2.2.10 Shows EMWO LTE network DT SINR signal quality performance analysis snapshot

5.2.2.11 Ethiotelecom Microwave Office LTE_UE_Throughput_DL Analysis

. In the definition of network downlink throughput, the requirements of effective downlink throughput for a certain sampling point are that LTE_UE_Throughput_UL should be better than the specified threshold (DL > 32kbps =0.03125Mbps). Figure 5.2.2.11 shows EMWO LTE network DT downlink performance analysis. From log file Actix analyzer analysis result, in general 93% and 7% of the EMWO indoor downlink was good and poor respectively, where expected good downlink throughput threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the EMWO downlink throughput is not meet the threshold. Since there are many users in building resource optimization advisable.

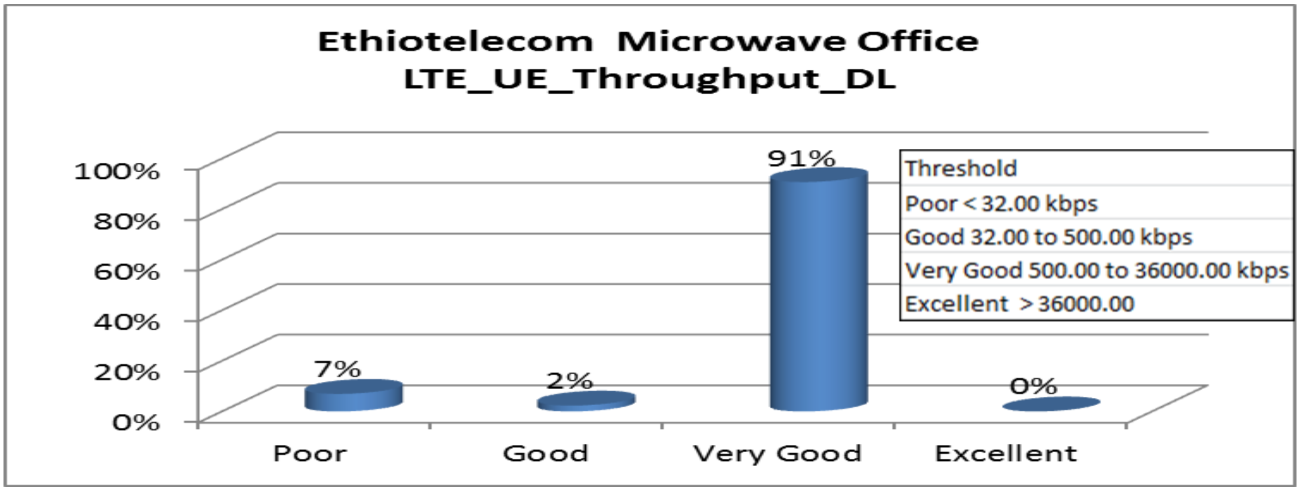


Figure 5.2.2.11 EMWO LTE network DT downlink performance analysis snapshot

5.2.2.12 Ethiotelecom Microwave Office LTE_UE_Throughput_UL

The requirements of effective uplink throughput for a certain sampling point are that LTE_UE_Throughput_UL should be better than the specified threshold (UL > 4kbps=0.004Mbps). Figure 5.2.2.12 shows EMWO LTE network DT uplink performance analysis. From log file Actix analyzer analysis result, in general 93% and 7% of the EMWO indoor uplink was good and poor respectively, where expected good uplink throughput threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the EMWO uplink throughput is not meet the threshold. Since there are many users in building resource optimization advisable.

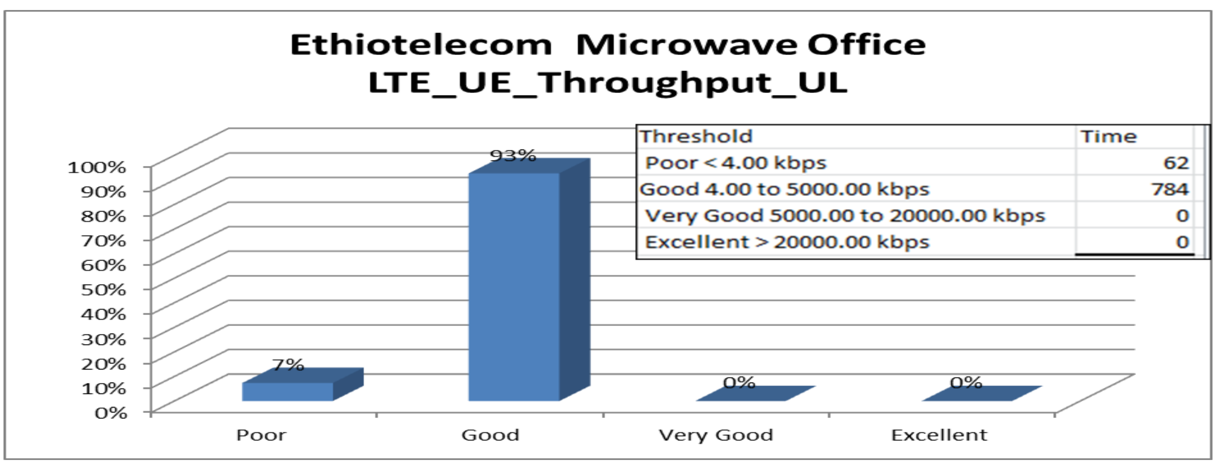


Figure 5.2.2.12 EMWO LTE network DT uplink performance analysis snapshot

5.2.2.13 Ethiotelecom Head office (EHO)LTE_UE_RSRP Coverage Analysis

The RSRP levels were randomly distributed ranging between -75 to -105dBm for the 4G LTE configurations. In the definition of network coverage, the requirements of effective coverage for a certain sampling point is that its LTE_UE_RSRP should be better than the specified threshold (RSRP> -105dBm). Figure 5.2.2.13 shows EHO LTE network DT coverage performance analysis[December 12, 2018]. From File Log Indoor analysis result, in general 100% and 0% of the EHO indoor coverage was good and poor respectively, where expected good coverage threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the EHO coverage is meet the threshold. So, no need of optimization in this area for coverage.

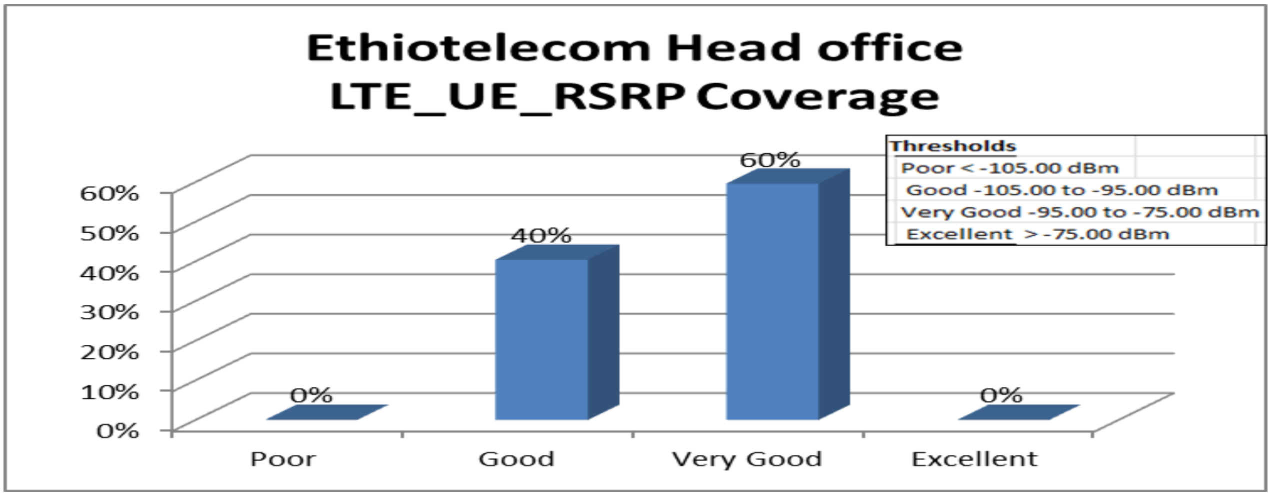


Figure 5.2.2.13 EHO LTE network DT coverage performance analysis snapshot

5.2.2.14 Ethiotelecom Head office LTE_UE_RSSI Signal Strength Analysis

In the definition of network signal strength, the requirements of effective signal strength for a certain sampling point is that its LTE_UE_RSSI should be better than the specified threshold (RSSI> -85dBm). Figure 5.2.14 shows EHO LTE network DT signal strength performance analysis. From DT Indoor analysis result, in general 100% and 0% of the EHO indoor signal strength was good and poor respectively, where expected good signal strength threshold is greater than or equal to 95%. The DT indoor analysis result shows that the EHO signal strength is meet the threshold. So, no need of optimization for RSSI.

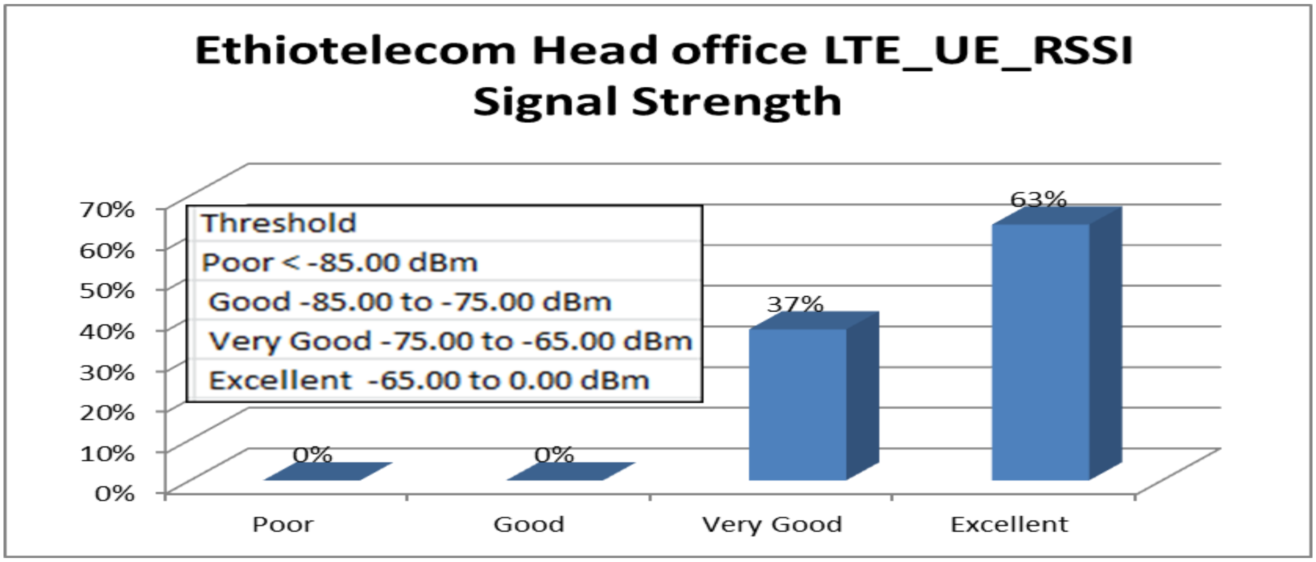


Figure 5.2.2.14 EHO LTE network DT signal strength performance analysis snapshot

5.2.2.15 Ethiotelecom Head office LTE_UE_RSRQ Quality Analysis

In the definition of network signal quality, the requirements of effective signal quality for a certain sampling point is that LTE_UE_RSRQ should be better than the specified threshold (RSRQ > -19dB). Figure 5.2.2.15 shows EHO LTE network DT signal quality performance analysis. From DT Indoor analysis result, in general 100% and 0% of the Head Office indoor signal quality was good and poor respectively, where expected good signal strength threshold is greater than or equal to 95%. The DT indoor analysis result shows that the Head Office signal quality is meet the threshold. So, no need of optimization for quality.

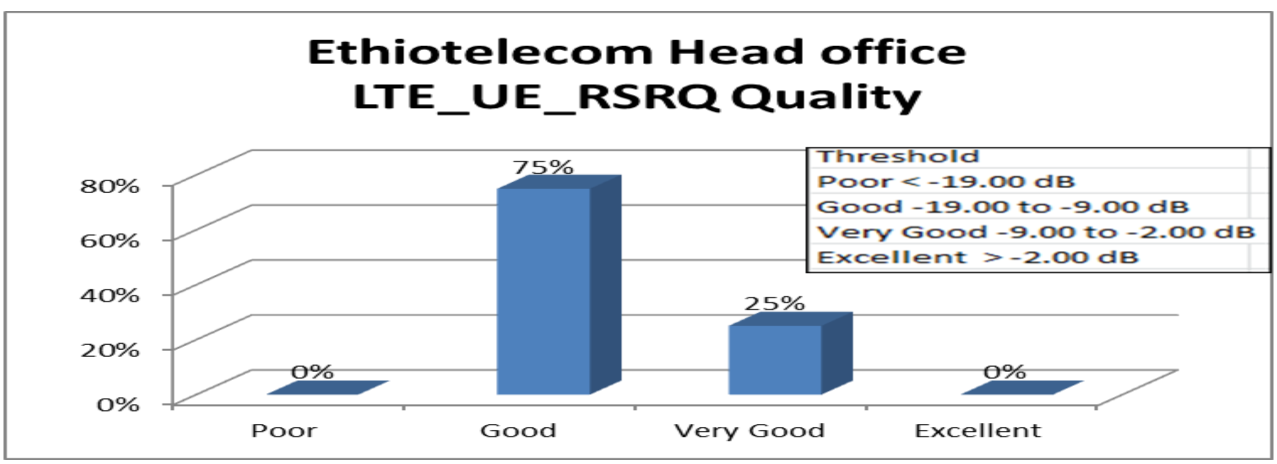


Figure 5.2.2.15 EHO LTE network DT signal quality performance analysis snapshot

5.2.2.16 Ethiotelecom Head office LTE_UE_SINR Signal Quality Analysis

The requirements of effective useful internal signal quality for a certain sampling point is that LTE_UE_SINR should be better than the specified threshold (SINR > -3dB). Figure 5.2.2.16 shows EHO LTE network DT SINR signal quality performance analysis. From DT Indoor analysis result, in general 100% and 0% of the Microwave office indoor SINR signal quality was good and poor respectively, where expected good signal strength threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the EHO useful signal quality is meet the threshold. So, no need of optimization for SINR.

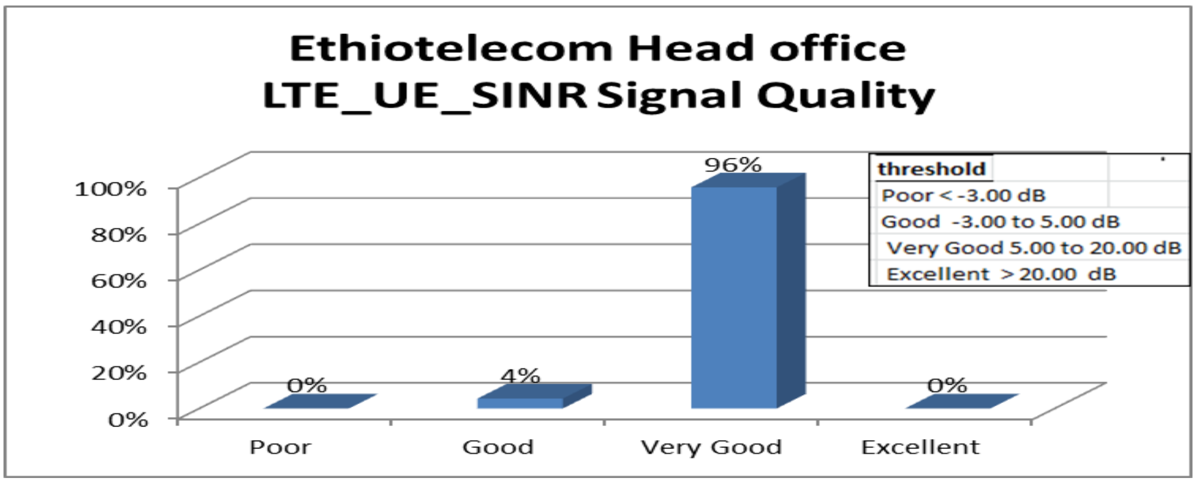


Figure 5.2.16 EHO LTE network DT SINR signal quality performance analysis snapshot

5.2.2.17 Ethiotelecom Head office LTE_UE_Throughput_DL Analysis

In the definition of network downlink throughput, the requirements of effective downlink throughput for a certain sampling point are that LTE_UE_Throughput_DL should be better than the specified threshold (DL > 32kbps =0.03125Mbps). Figure 5.2.2.17 shows EHO LTE network DT downlink performance analysis. From log file Actix analyzer analysis result, in general 94% and 6% of the EHO indoor downlink was good and poor respectively, where expected good downlink throughput threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the EHO downlink throughput is not meet the threshold. Since there are many users in building resource optimization advisable.

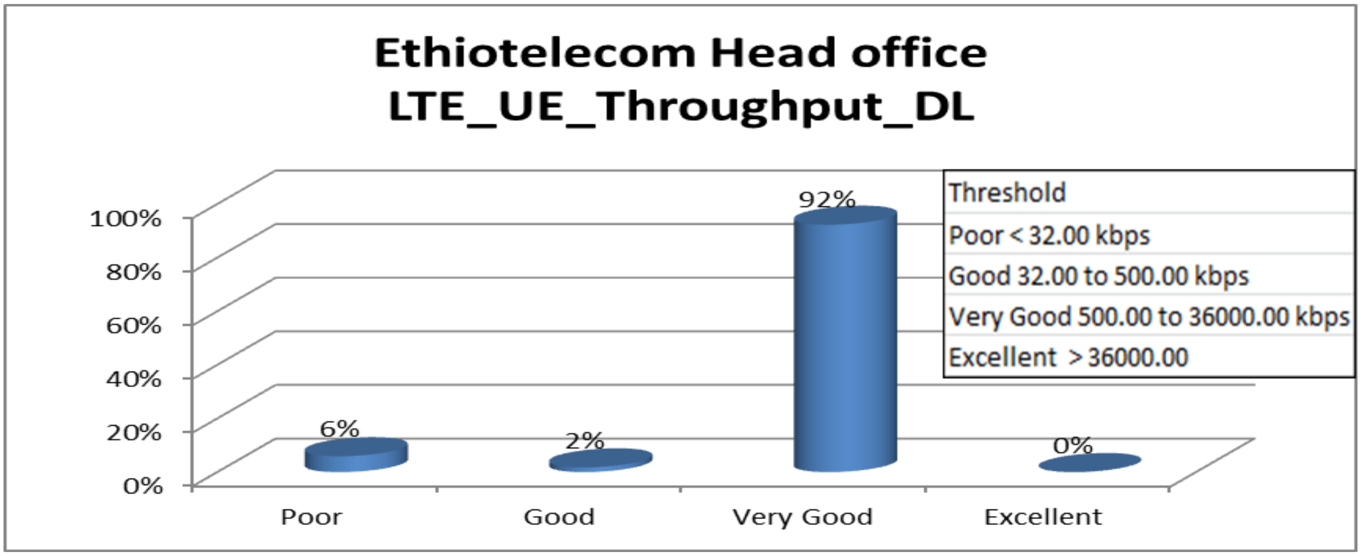


Figure 5.2.2.17 EHO LTE network DT downlink performance analysis snapshot

5.2.2.18 Ethiotelecom Head office LTE _UE_Throughput_UL Analysis

The requirements of effective uplink throughput for a certain sampling point are that LTE_UE_Throughput_UL should be better than the specified threshold (UL > 4kbps=0.004Mbps). Figure 5.2.2.18 shows EHO LTE network DT uplink performance analysis. From log file Actix analyzer analysis result, in general 99% and 1% of the EHO indoor uplink was good and poor respectively, where expected good uplink throughput threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the EHO uplink throughput is meet the threshold. So, no need of optimization for UL. Since there are limited numbers users for UL, the threshold seems fit the target.

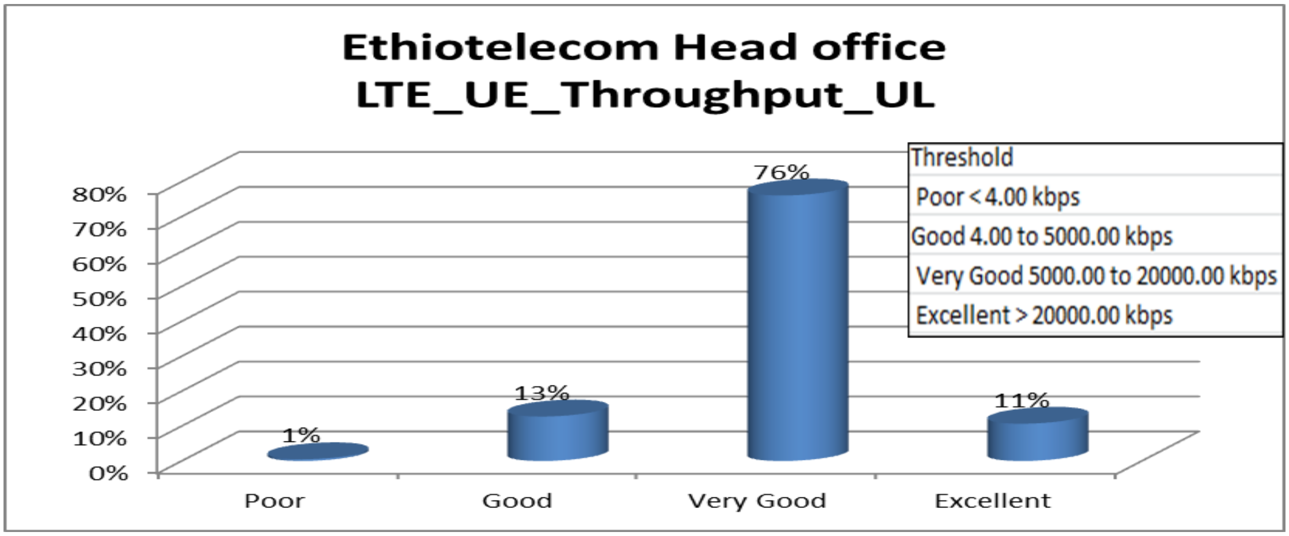


Figure 5.2.2.18 EHO LTE network DT uplink performance analysis snapshot

5.2.2.19 Getu Commercial center LTE_UE_RSRP Coverage Analysis

LTE_UE_RSRP should be better than the specified threshold coverage is (RSRP> -105dBm). Figure 5.2.2.19 shows EHO LTE network DT coverage performance analysis[December 13, 2018]. From File Log Indoor analysis result, in general 83% and 17% of the Getu Commercial Center indoor coverage was good and poor respectively, where expected good coverage threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the Getu Commercial Center coverage is not meet the threshold. This is due to the blockage of the building. So, this building need the installation of new Indoor Base Station(IBS).

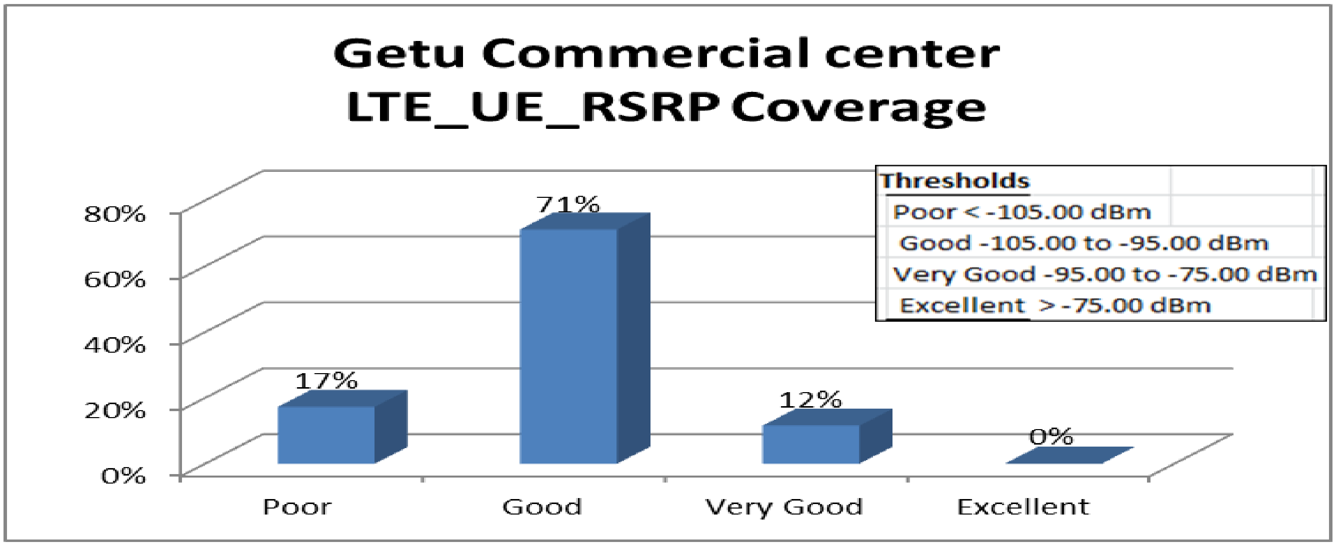


Figure 5.2.2.19 EHO LTE network DT coverage performance analysis snapshot

5.2.2.20 Getu Commercial center(GCC) LTE_UE_RSSI Signal Strength Analysis

LTE_UE_RSSI should be better than the specified threshold (RSSI > -85dBm). Figure 5.2.2.20 shows GCC LTE network DT signal strength performance analysis. From DT Indoor analysis result, in general 100% and 0% of the GCC indoor signal strength was good and poor respectively, where expected good signal strength threshold is greater than or equal to 95%. The DT indoor analysis result shows that the GCC signal strength is meet the threshold. So, for this reason it is not advisable to do coverage analysis by using RSSI.

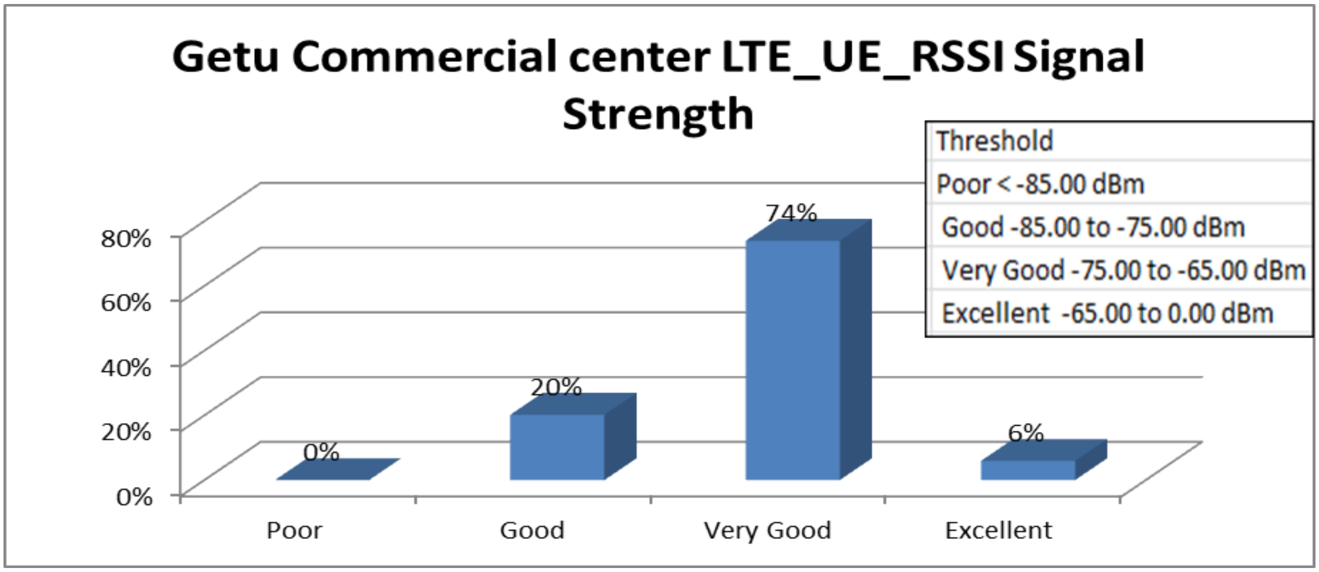


Figure 5.2.2.20 GCC LTE network DT signal strength performance analysis snapshot

5.2.2.21 Getu Commercial center LTE_UE_RSRQ Quality Analysis

LTE_UE_RSRQ should be better than the specified threshold (RSRQ > -19dB). Figure 5.2.21 shows GCC LTE network DT signal quality performance analysis. From DT Indoor analysis result, in general 100% and 0% of the Getu Commercial indoor signal quality was good and poor respectively, where expected good signal strength threshold is greater than or equal to 95%. The DT indoor analysis result shows that the Getu Commercial signal quality is meet the threshold. Since there are limited numbers LTE users in the building, the quality signal strength seems meet the threshold.

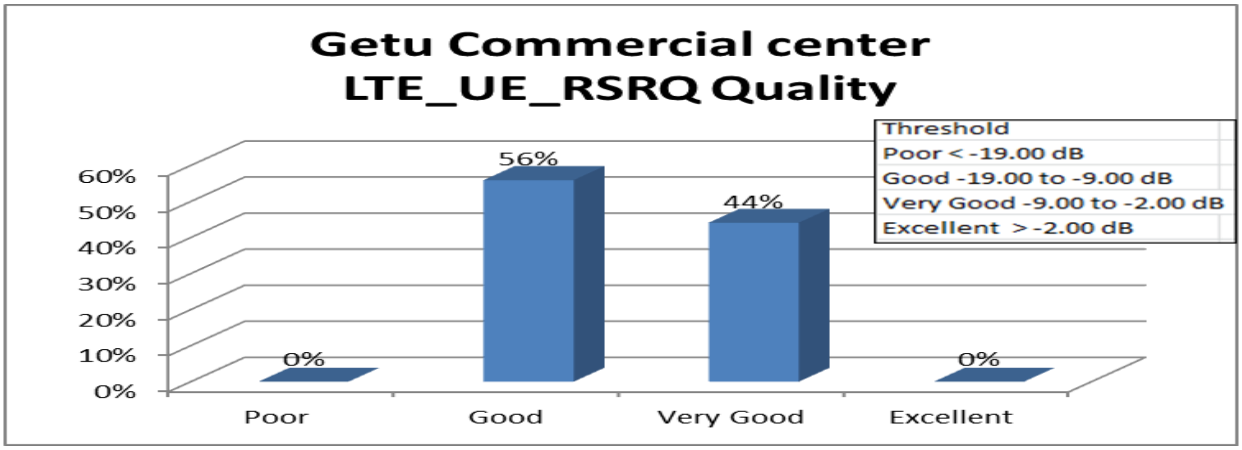


Figure 5.2.2.21 GCC LTE network DT signal quality performance analysis snapshot

5.2.2.22 Getu Commercial center LTE_UE_SINR Signal Strength Analysis

LTE_UE_SINR should be better than the specified threshold (SINR > -3dB). Figure 5.2.2.22 shows GCC LTE network DT SINR signal quality performance analysis. From DT Indoor analysis result, in general 100% and 0% of the GCC indoor SINR signal quality was good and poor respectively, where expected good signal strength threshold is greater than or equal to 95%. The DT indoor analysis result shows that the GCC useful signal quality is meet the threshold. Since there are limited number of LTE users in the building, the SINR seems meet the threshold.

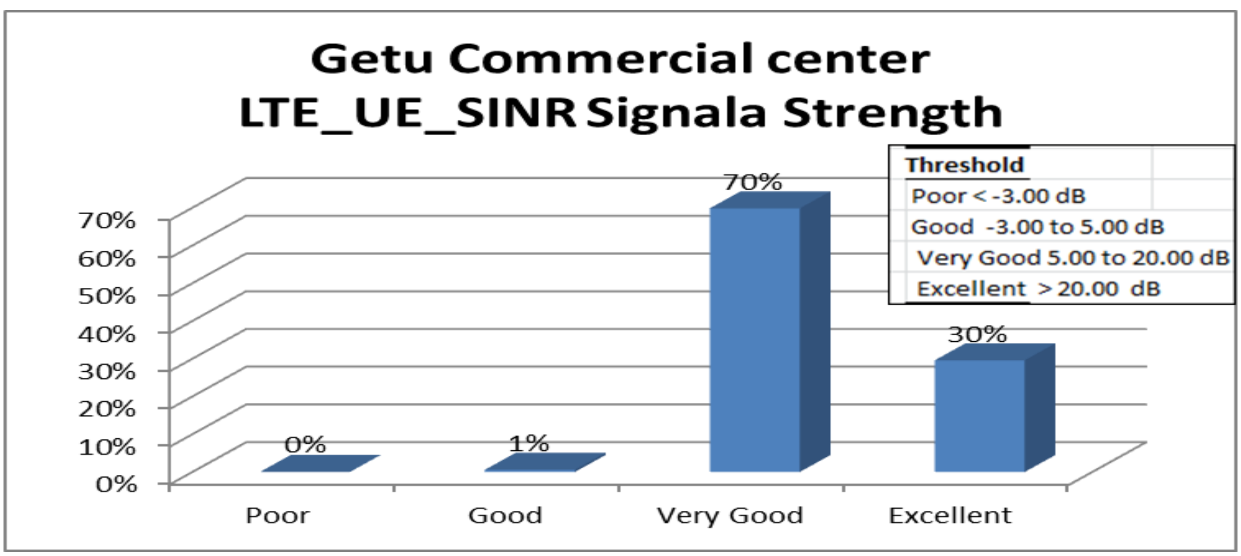


Figure 5.2.2.22 GCC LTE network DT SINR signal quality performance analysis snapshot

5.2.2.23 Getu Commercial center LTE_UE_Throughput_DL Analysis

Requirement for LTE_UE_Throughput_DL should be better than the specified threshold (DL > 32kbps =0.03125Mbps). Figure 5.2.2.23 shows Getu Commercial LTE network DT downlink performance analysis. From log file Actix analyzer analysis result, in general 94% and 6% of the Getu Commercial indoor downlink was good and poor respectively, where expected good downlink throughput threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the GCC downlink throughput is no meet the threshold. Since there are limited number of LTE users in the building, the DL seems meet the threshold.

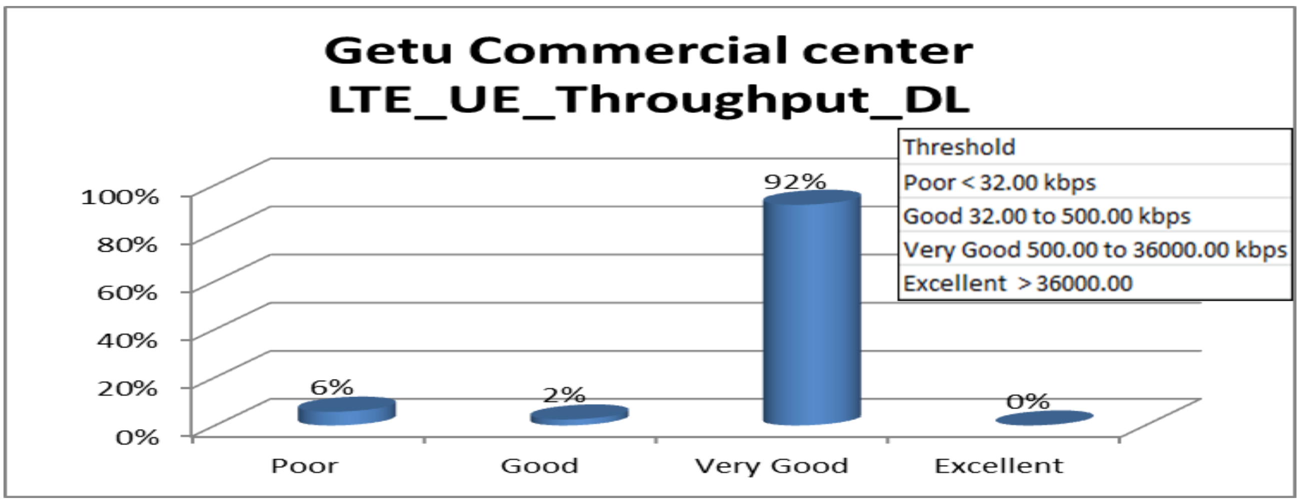


Figure 5.2.2.23 Getu Commercial LTE network DT downlink performance analysis snapshot

5.2.2.24 Getu Commercial center LTE_UE_Throughput_UL Analysis

The requirements of effective LTE_UE_Throughput_DL should be better than the specified threshold (UL > 4kbps=0.004Mbps). Figure 5.2.2.24 shows GCC LTE network DT uplink performance analysis. From log file Actix analyzer analysis result, in general 97% and 3% of the GCC indoor uplink was good and poor respectively, where expected good uplink throughput threshold is greater than or equal to 95%[66]. The DT indoor analysis result shows that the GCC uplink throughput is meet the threshold. Since there are limited number of LTE users in the building, the DL seems meet the threshold.

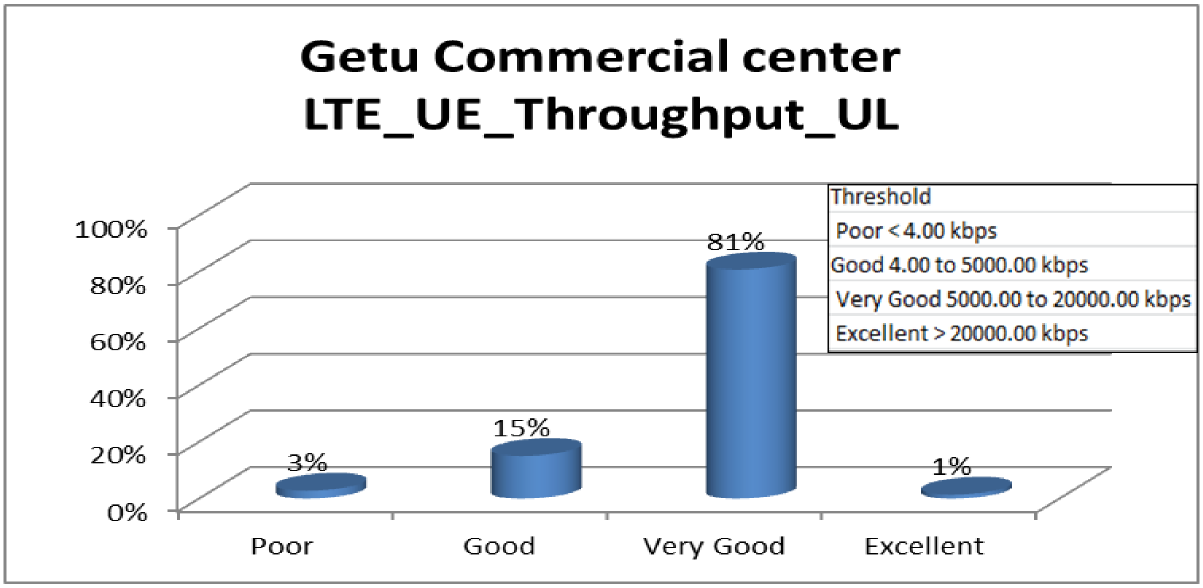


Figure 5.2.2.24 GCC LTE network DT uplink performance analysis snapshot

5.2.2.25 Black Lion Hospital LTE_UE_Path Loss Analysis

The path loss is defined reduction in power density or ratio of the transmit power to the receive power [68]. This is loss of power between UE and ENodeB. As the path loss increase the packet loss also increase. Channel parameter measurements of indoor Long Term Evolution (LTE) systems for the deployment of base stations to have good coverage and service reliability (SR) target is 90% [68]. The acceptable path loss is range is 6dB [71].

The DL starts to reach the targeted DL rate of 4.0 Mb/s (typical setting of the expected DL data rate at the cell edge) with the path loss of 130 dB [70]. As the path loss decrease or less the better the quality of signal received, the better the performance and throughput achieved by the subscriber. This lead to meet the best QoS.

Using the ITU-R indoor path loss model [69], the path loss between a femtocell eNB and an UE separated by a distance d(m) in a given cell is:

$PL(d) = 20\log_{10}(f) + 10N\log_{10}(d) + L_f(n) - 28$ (dB)……………. (19) whereas:

Lf(n) is the penetration loss between the floors, where n is the number of floors. In Ethiotelecom the Penetration Loss (dB) and path loss(Db) benchmark range is 15 to 130 dB for urban area [66] and good coverage target is 95%.

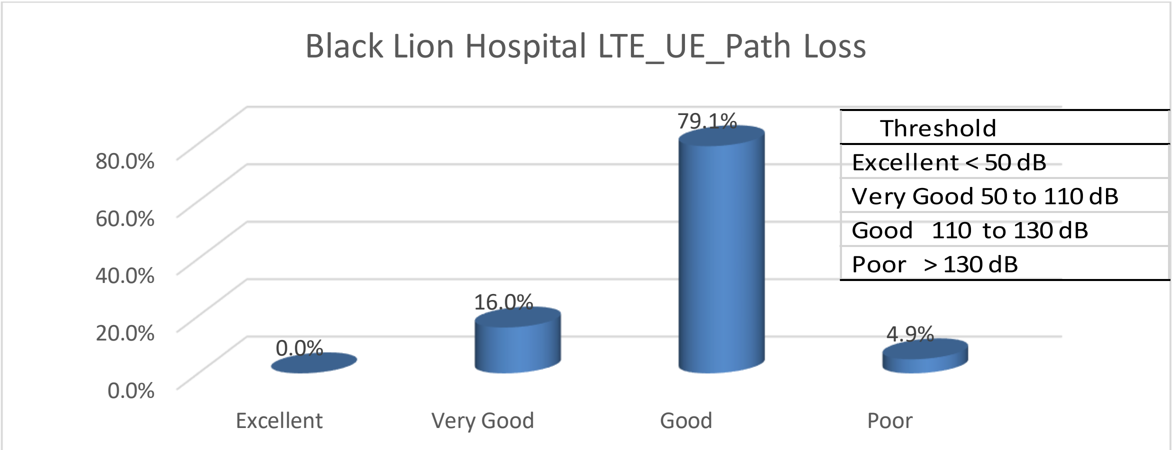


Figure 5.2.2.25 Black Lion Hospital LTE_UE_Path Loss Analysis snapshot

As Figure 5.2.2.25 shown the DT analysis result shows that the Black Lion Hospital LTE_UE_Path Loss analysis result 16% and 79.1% is Very Good and Good respectively , this area shows low path loss acceptable by Ethiotelecom[66]. The company target is 95% taken as a good range[66]. However,this target not meet excellent grade which is bellow 50dB path losss,so it need further resource adjustment and optimazation.

5.2.2.26 Ethiotelecom Microwave Office LTE_UE_Path Loss Analysis

In Ethiotelecom the Penetration Loss (dB) and path loss(dB) benchmark range is 15 to 130 dB for urban area [66] and good coverage target is 95%.

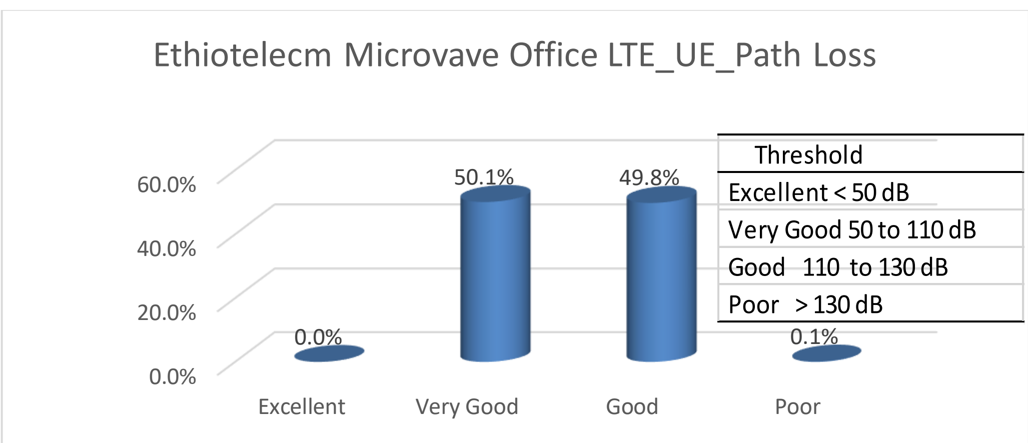


Figure 5.2.2.26 Ethiotelecom Microwave Office LTE_UE_Path Loss Analysis Snapshot

As Figure 5.2.2.26 shown the DT analysis result shows that Ethiotelecom Microwave Office LTE_UE_Path Loss Analysis result 50.1% is Very Good ,So this area shows low path loss acceptable by Ethiotelecom[66]. However, this target not meet excellent grade which is bellow 50dB path losss,so it need further resource adjustment and optimazation.

5.2.2.27 Ethiotelecom Head Office LTE_UE_Path Loss Analysis

In Ethiotelecom the Penetration Loss (dB) and path loss(dB) benchmark range is 15 to 130 dB for urban area [66] and good coverage target is 95%.

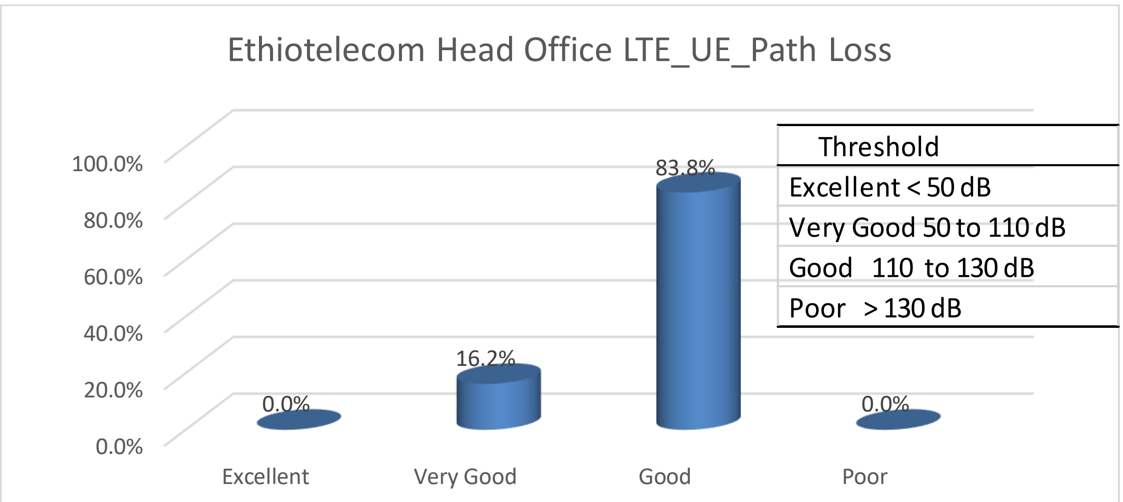


Figure 5.2. 2.27 Ethiotelecom Head Office LTE_UE_Path Loss Analysis Snapshot

As Figure 5.2.2.27 shown the DT analysis result shows that Ethiotelecom Head Office LTE_UE_Path Loss analysis result is 16.2% and 83.8% is Very Good and Good respectively,So by taking the sum of both grade or range is 100% is Good so, this area shows low path loss acceptable by Ethiotelecom[66]. However,this target not meet excellent grade which is bellow 50dB path losss,so it need further resource adjustment and optimazation.

5.2.2.28 Getu Commercial Center LTE_UE_Path Loss Analysis

In Ethiotelecom the Penetration Loss (dB) and path loss(dB) benchmark range is 15 to 130 dB for urban area [66] and good coverage target is 95%.

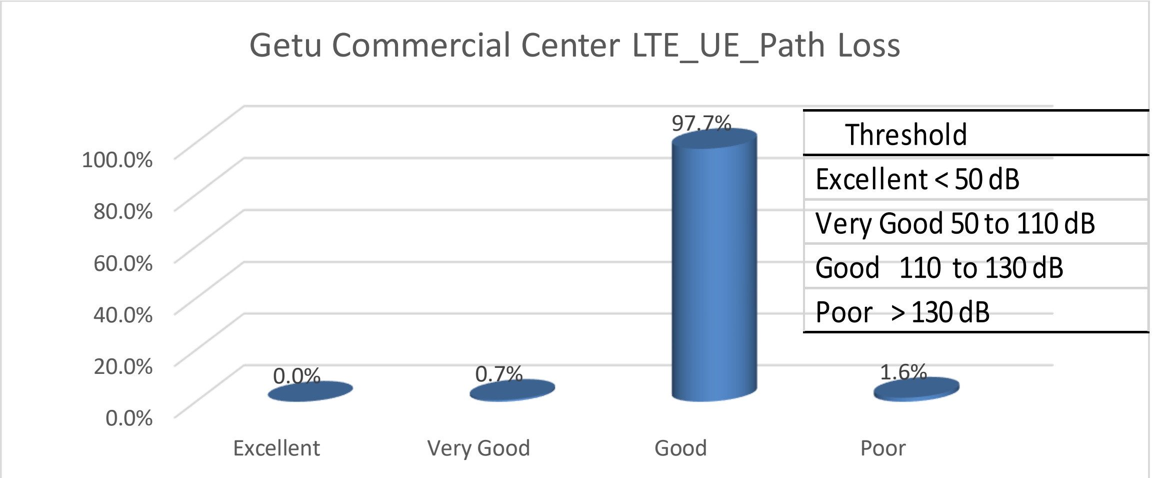


Figure 5.2.2.28 Getu Commercial Center LTE_UE_Path Loss Analysis snapshot.

As Figure 5.2.2.28 shown the DT analysis result shows that Getu Commercial Center LTE_UE_Path Loss analysis result is 0.7% and 97.7% is Very Good and Good respectively,So by taking the sum of both grade or range is 98.4% is Good so, this area shows low path loss acceptable by Ethiotelecom[66].However,this target not meet excellent grade which is bellow 50dB path losss,so it need further resource adjustment and optimazation.

5.2.2.29 Black Lion Hospital LTE_UE_Block Error Rate(BLER) Analysis

In the radio network, the eNB takes care of assigning the radio resources, also called Physical Resource Blocks(PRBs) to the users in the network. While scheduling the PRBs, the eNB estimates the wireless channel quality for each user and adapts the transmission parameters (including the selected Modulation and Coding Scheme (MCS) and the transmit mode, e.g. transmit diversity of MIMO/SM) to meet the target Block Error Rate (BLER) which is typically 10% [5]. In LTE, the requirement for the received signal is to achieve the target BLER of 10%. BLER is ratio of the bits wrongly received to all data bits sent [72]. In Ethiotelecom web browsing acceptable BLER parameter target is 1% [66]. Figure 5.2.2.29 shows Black Lion Hospital LTE_UE_Block Error Rate(BLER) Analysis.

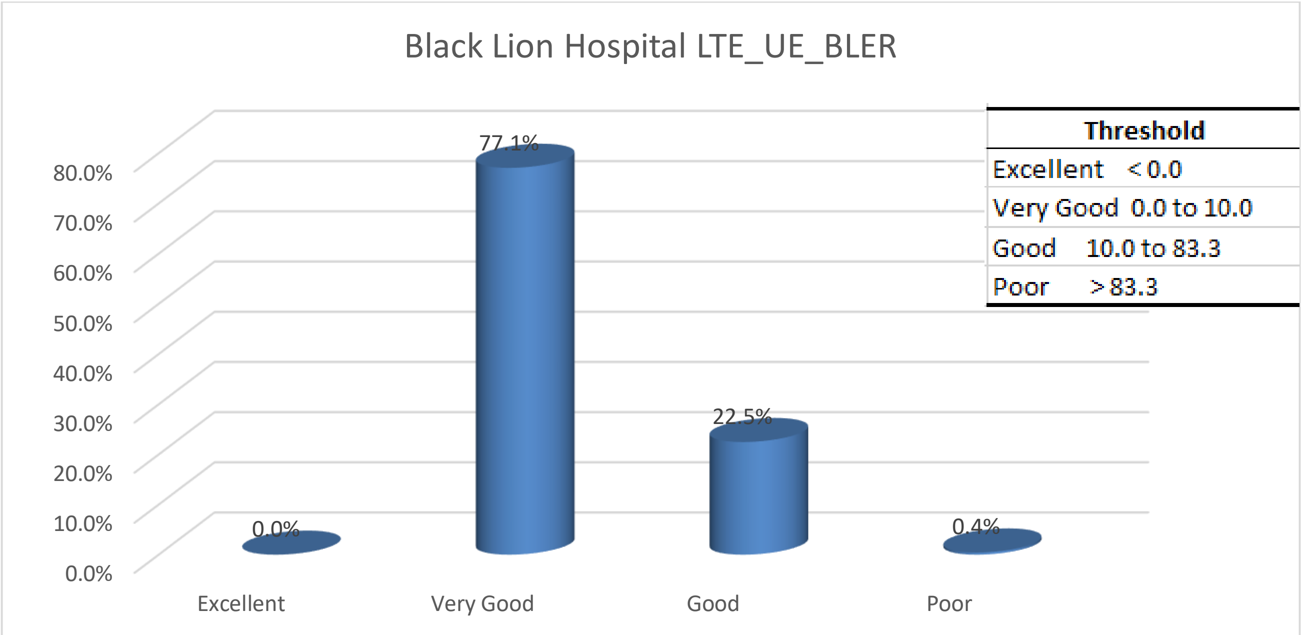


Figure 5.2.2.29 Black Lion Hospital LTE_UE_Block Error Rate(BLER) Analysis Snapshot.

The Black Lion Hostpital BLER DT analysis result is 77.1% and 22.5 are Very Good and Good respectively.However the result doesn't meet the Excellent Target,so this area need further reource optimazation.

5.2.2.30 Ethiotelecom Microwave Office LTE_UE_Block Error Rate(BLER) Analysis

In Ethiotelecom web browsing acceptable BLER parameter target is 1% [66]. Figure 5.2.2.30 shows Ethiotelecom Microwave Office LTE_UE_Block Error Rate(BLER) Analysis.From the DT analysis result is 82% and 17.6% is Very Good and Good respectively. However the result doesn't meet the Excellent Target,so this area need further reource optimazation.

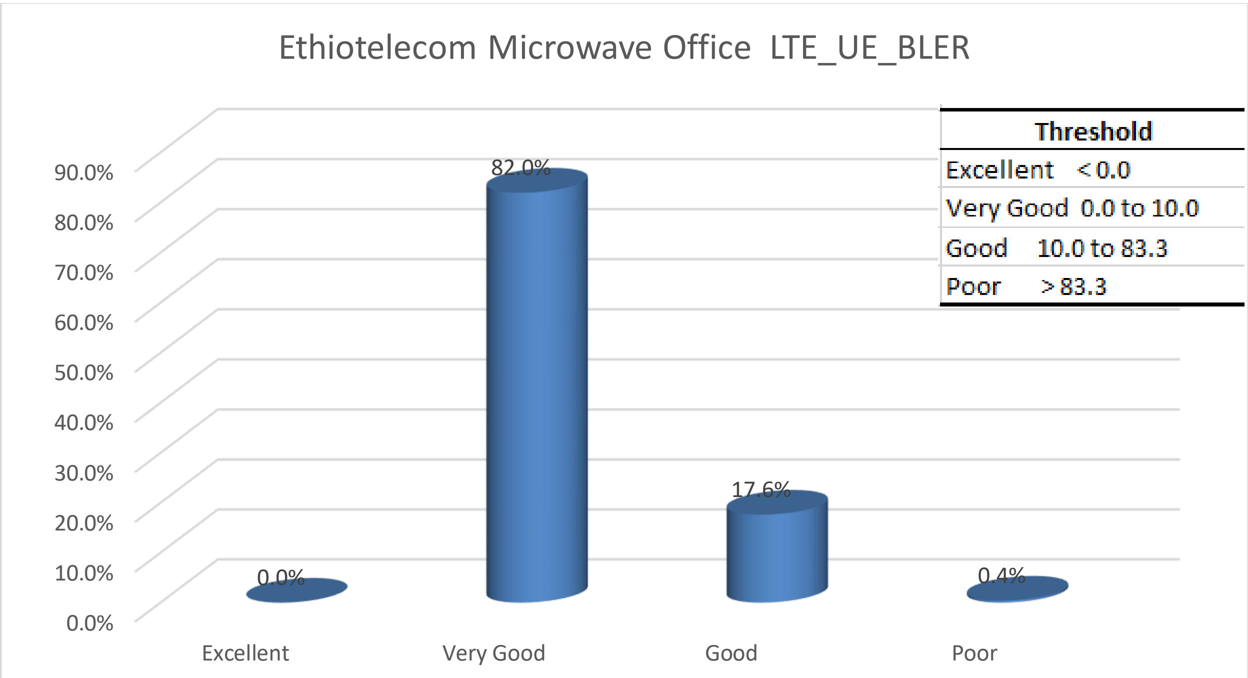


Figure 5.2.2.30 Ethiotelecom Microwave Office LTE_UE_Block Error Rate(BLER) Analysis Snapshot.

5.2.2.31 Ethiotelecom Head Office LTE_UE_Block Error Rate(BLER) Analysis

In Ethiotelecom web browsing acceptable BLER parameter target is 1% [66]. Figure 5.2.2.31 shows Ethiotelecom Head Office LTE_UE_Block Error Rate(BLER) Analysis.From the DT analysis result is 72% and 28% is Very Good and Good respectively. However the result doesn't meet the Excellent Target,so this area need further reource optimazation.

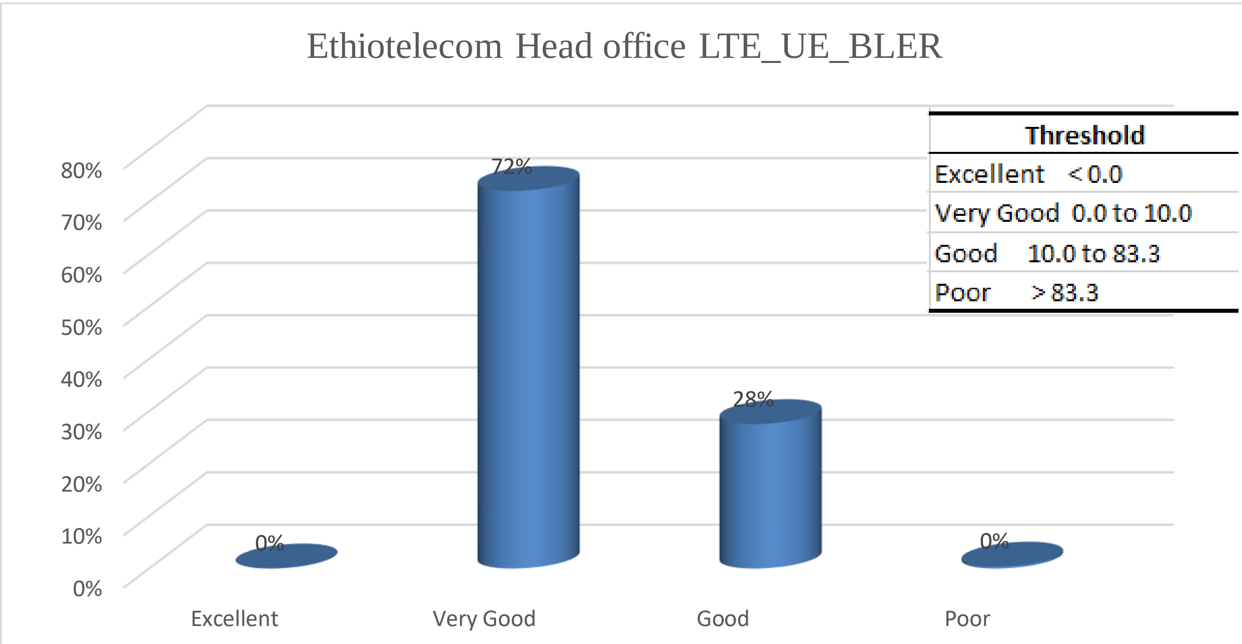


Figure 5.2.2.31 Ethiotelecom Head Office LTE_UE_Block Error Rate(BLER) Analysis Snapshot.

5.2.2.32 Getu Commercial Center LTE_UE_Block Error Rate(BLER) Analysis.

In Ethiotelecom web browsing acceptable BLER parameter target is 1% [66]. Figure 5.2..2.32 shows Getu Commercial Center LTE_UE_Block Error Rate(BLER) Analysis.From the DT analysis result is 71% and 29% is Very Good and Good respectively. However the result doesn't meet the Excellent Target,so this area need further reource optimazation.

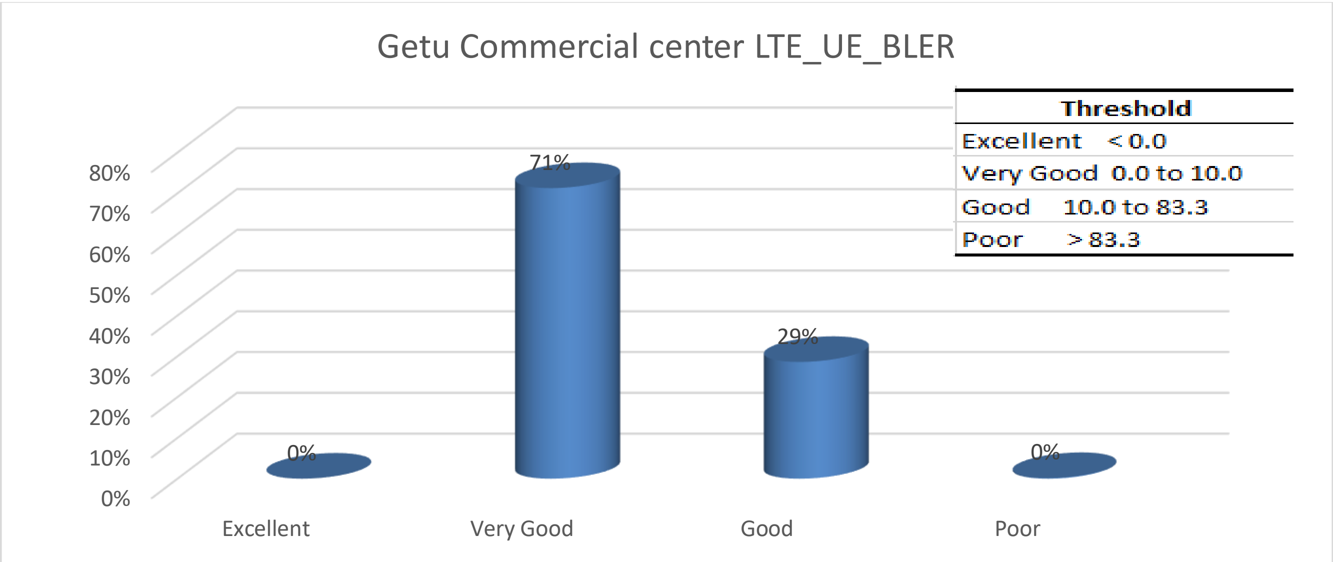


Figure 5.2.2.32 Getu Commercial Center LTE_UE_Block Error Rate(BLER) Analysis Snapshot.

From all DT simulation analysis result there is no sites meet the Excellent Grade Range (<1%) of target. So it is advisable conducting resource optimization for all area. It is also important implementation of Self-organizing network.

5.3 **Discussion**

In all QoS parameters analysis result observation of the service of Ethiotelecom 4G LTE is not good because there is problem poor coverage in all most area. As well as the downlink and uplink throughput also limited or poor. The target coverage 4G LTE of ethio is 95%, but from simulation result is 89.5% in average. So this indicate problem of coverage. The target of Ethiotelecom maximum downlink and uplink 4G LTE is 40Mbps and 20Mbps respectively. But the simulation results from Actix Analyzer in all of site 93.5% and 97% of downlink and uplink respectively is good, however this result is below the company target. There is no end user obtain the maximum service from this network.

. In all over data collection and analysis on control plane and user plane side of Ethiotelecom LTE network there is gab between threshold settled by company and the actual real data performance. From my observation it is difficult to compare LTE ethio with other network and with ITU and 3GPP standard LTE network because ethio LTE operate with limited performance. Especially Maximum DL and UL ethio LTE is 40Mbps and 20Mbps respectively. This is also show bellow LTE requirement specification. As we seen from simulation result the network performance around Ethiotelecom Offices almost better than from other Companies and Commercial center of Addis Ababa. This also show unequal distribution of LTE network resource in the city.

Chapter Six

Conclusion and Recommendation

6.1 Conclusion

A few a years ago ethio telecom introduce the new technologies 4G LTE network. A total of 329 eNodeBs are available on the whole network of ethio telecom, All LTE sites are deployed in AA area and 1 site In Awassa. According to the specification of eNodeB, one site support 500paging/s. there are 400000 LTE users in Addis Ababa wireless network.

ethio telecom is vested with the responsibility of realizing the telecommunication sub sector expansion plan of the successive Ethiopian Government's Growth and Transformation Plans (GTPs). It has carried out intensive expansion work mainly on mobile network to extend the coverage to 85% and scale up the capacity to more than 60 million subscribers as part of the country GTP II and introduce the new technologies including 4G network.

For Addis Ababa city's case, it has carried out intensive expansion work to extend the coverage of LTE network to 100% and scale up the capacity to more than 1.5 million subscribers. The current LTE network infrastructure deployed in the Addis Ababa city, which is solely managed by ethio telecom, is undergoing major expansions in the last 4 years and resulted in a tangible improvement of coverage and quality performance. However, there are complaints from subscribers (end users) from various parts of the city.

The main motivation of this thesis work is to evaluate the existing QoS performance of Data transmission in LTE network in case of Addis Ababa. The evaluation is made by analyzing collected real data from control plane and user plane systems.

The analysis results show that, in general, there is some disparities between the ethio telecom targets and analysis results, which indicating the need to further improve the network's QoS.

Based on the analysis result and literature review, integration means is proposed to improve the QoS of Data in LTE network.

6.2 Recommendation

To improve the quality of Data transmission in LTE network, here are the lists of the recommended possible solutions of the works of this thesis research:

- Implementation of QoS manager in different levels of network;
- Appropriate resource allocation in the network;
- In urban area like Addis Ababa city the inter EnodeB distance or inter system distance (ISD) must be less than or equal 500 meters (micro Site);
- In area where, there are no high buildings, the coverage and quality are bad and also the traffic is high, installing the new site will be the solution;
- In area where, there are no high buildings, the coverage is good, the quality is bad and also the traffic is high, the RF optimization (i.e. CE license addition, power license addition, site expansion, parameters adjustment, etc) will be the solution;
- In area where, there are high buildings, the coverage is good, the quality is bad and also the traffic is high, adding the boosters or repeaters and installing indoor BTS will be the solution;
- Installing distributed antenna in each of building can solve problem poor coverage;
- Finally, organize the Addis Ababa LTE network in a hierarchical way (i.e. femto cells, pico cells, microcells, macro cells and global cells served by satellites) is recommended.

6.3 Future Works

In this thesis we have conducted the evaluation of Quality of service in 4G LTE data services on control plane and user plane sides. I recommend the future researchers on the following area:

- It is open area to do research on Quality of Service evaluation between different network environments with other wireless data networks and fixed networks. Such as with in different mobile generation and fixed wireless networks such as Wi-Fi.
- It is open area to do research on Quality of Service evaluation on circuit switch fall back services (CSFB) over 4G LTE in Ethiotelecom company.

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