JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING

UMTS/HSPA and LTE-A Radio Network Performance Analysis and Evaluation, Case of Jimma Town

By

Abalegn Dagnachew Wubie

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Submission Date: March, 2022

Declaration

I, Abalegn Dagnachew declare that this thesis entitled "UMTS/HSPA and LTE-A Radio Network Performance Analysis and Evaluation, Case of Jimma Town" is a presentation of my own work. All material and contents referred from other sources has been clearly acknowledged based on the compliance of accepted practices. I also proclaim that this thesis has not been previously submitted by any researcher in this and other institutions.

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Abstract

Cellular communication technology have established a remarkable successes & introduced felicitous solutions to alleviate exasperating quality of service (QoS) challenges. It is mightily envisaged that cellular networks have often been deployed ensuring seamless accommodation of users growing demand with deep insight of usability and feasibly. In this regard, several mobile network operators (MNOs) in low income countries often failed to serve with unabated mobile network & imperiled the business due to limitations while evaluating socio-economic status, information communication technology (ICT) literacy status, device eco system, traffic usage trend & other essential technical preempts that are needed to be addressed during pre-deployment stages. Moreover, users' quality of experience (QoE) would essentially be maintained as key part of initial planning and aftermath optimization.

Field reliant drive testing and operations support system (OSS) based key performance index (KPI) measurements were carried out for both third generation (3G) and fourth generation (4G) cellular networks of Jimma town. Actix and SAP business object tools are used to analyze both test measurements respectively. In this thesis, aforementioned multiple rendering test scenarios and techniques are implemented for both data and voice assessment tests respectively. On the top of this, viability and impact assessment of LTE-A layering and post layering performance of UMTS/HSPA network is analyzed.

Following analysis & evaluation of both test scenarios, the result depicts that poor coverage, quality and throughput distributions that are observed in numerous parts of the town. These problems are mainly associated with to capacity limitations & RF optimization setbacks. This work makes a far-reaching use of live network KPI measurement & analysis in purpose of improving coverage, capacity and quality performance of Jimma town 3G and 4G networks using radio parameter tuning and network upgrading. With a best practice exploration, the throughput performance of a proposed HSPA+ release 9 is simulated.

Keyword: HSPA, KPI, LTE-A, Mobile broadband, QoE, QoS, Radio network UMTS

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Abbreviations

BER	Bit Error Rate
BLER	Block Error Rate
CAPEX	Capital Expenditures
CINR	Carrier to Interference plus Noise Ratio
CN	Core Network
CPICH	Common Pilot Channel
CSFB	Circuit Switched Fallback
EPC	Evolved Packet Core
FDD	Frequency Division Duplex
F-DPCH	Fractional Dedicated Physical Channel
GSM	Global System for Mobile
HSPA	High Speed Packet Access
LTE	Long Term Evolution
MIMO	Multiple-Input and Multiple-Output
OFDM	Orthogonal Frequency Division Multiplexing OFDM
OPEX	Operational Expenditure
OSS	Operations Support system
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RNC	Radio Network Controller

RSCP	Received Signal Code Power
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
SINR	Signal Interference Noise Ratio
UMTS	Universal Mobile Telecommunications System
WCDMA	Wideband Code-Division Multiple Access

Chapter 1

Introduction

1.1 Background

Cellular communication technology has been one of the most important element of today's society and it has progressively developed since the first systems were introduced in the 1980s [1]. to fulfill sophisticated social necessity. Cellular network adoption has shown rapid growth in recent years due to demand driven technological advancements along with the development of internet of things (IoT) and explosive rise of digital ecosystem. The sector has introduced several streamlined features and solutions in the course of it's technological evolution. Initially, the first generation was commercially introduced in early 1980s and began cellular network revolution with limited analog services. The second generation cellular network also introduced after a decade with incorporation of enhanced voice and introduction of limited data service.

Higher speed cellular standard has appeared in mid-2001 with the introduction of third generation universal mobile telecommunication system (UMTS) network. It still held largest market share globally providing faster speed, diversified compatibility and multimedia services which are relevant in meeting users emerging demand for high speed connections. The introduction of UMTS has eased limitation of preceding 2G network with initial throughput up to 2 Mbps. The newer 3G standards High Speed Packet Access (HSPA) & evolved HSPA allows bitrates theoretically reach as high as 672 Mbps [2] [3]. This abundant throughput and compromised features make UMTS to become most adopted wireless radio network worldwide. The UMTS-HSPA+ system has provided well-suited and varied services to subscribers in addition to high speed data services with flexible rate matching. The HSPA platform continues evolving towards a greater level of upgraded versions of HSPA+ that are specified by third generation partnership project (3GPP) of Release 7, Release 8, Release 9 and HSPA release 10 and beyond.

Likewise, the industry has launched the first fourth generation cellular technology called long term evolution (LTE) in 2008. It is an IP based technology initially developed providing data rate of 100 Mbps a speed. And the succeeding development named LTE advanced (LTE-A) provides a download speed up to 1 Gbps. LTE advanced pro (LTE-A PRO) is also designed aiming to deliver a data speed three times faster than LTE-A [4][5]. The fifth generation (5G), an ambitious & striding technology has been widely adopted globally in early 2020s. 5G promises an array of enhancements, providing extremely higher data rates, ultra-low latency, and increased network capacity. Initial 5G deployments was twice faster than LTE-A PRO but it gradually set to deliver a speed up to 10 Gbps [6]. Beside aforementioned 3GPP continuous and fast changing scenery of cellular technologies, several standards have been developed by contrary standardization group called 3GGP-2 though it had displayed least market influence and gradually kept silent since 2013.

Ethio telecom, a state-run telecommunication operator started commercial mobile service in 1999 and has massively upgraded and expanded with various vendors that allow to further improvement on capacity, quality and coverage of its 2G/3G network in late 2014 [7][8][9]. Moreover, the operator has heavily financed in the LTE-A network expansion in Addis Ababa and layering rollouts in major cities of the country.

In the furtherance of these deployments, UMTS-HSPA+ radio network of release 7 has been launched in Jimma town over 900 MHz and 2100 MHz bands on March 2015. The service has been provided aiming to meet the future demand for mobile user capacity and providing mobile data and multimedia communication services as a part of nationwide telecommunication expansion project (TEP). Likewise, LTE-A service is also deployed in the town in June 2021 [10] so as to address growing demand of subscribers for mobile data services. Despite remarkable deployments and commitment for faster internet service provisioning activities, there has still been observed both data and voice quality of service (QoS) concerns all over the town. Thus, demand oriented, situational and forward-looking capacity dimensioning, coverage planning and optimization is crucial.

1.2 Statement of the Problem

Exasperating coverage, capacity, quality and data service problems has still been a subject of Jimma town cellular network nevertheless the sole operator has launched UMTS-HSPA+ broadband network five years ago and also rolled-out gigabyte 4G LTE-A network in June 2021. With these efforts, the operator have established a remarkable development though the counter-intuitive outcome has still revealed setbacks in QoS & QoE aspects. Moreover, the deployed network has not alleviated an enduring quality, capacity & coverage problems that users often perceived. In this regard, various reasons are furnished to the necessity of implementing well-suited, cost-effective, situational network re-dimensioning, optimization and upgrading of existing network in the town. Lower smartphone penetration rate and lack of LTE enabled devices in the region [11][12], limitations on legacy reliant voice service solution (CSFB) [13], very poor consumer profile & data usage trend of the region [14], device and service affordability [15][16], low economic profile residents [17][18] (where 51.96% the house hold income falls between birr 200-500. Similarly, recent survey referred in [19][20][21] shows majority of the population earn less than 1450 birr in a month), digital illiteracy [22], poor traffic usage of high speed internet demanding applications and internet gateway limitations [23]. Furthermore, hysterical inflation and foreign exchange scarcity has slumped mobile broadband service utilization celerity along with setbacks alluded.

Generally, it is never easy to justify with conviction that the recent LTE-A migration is non-rewarding by only considering unpromising current situation and poor RF performance. It needs end-to-end assessment in both test cases. Thus, this thesis is set to address the aforementioned problems by implementing both drive test and OSS data test scenarios. Integration of both test items aimed to provide comprehensive assessment on both UMTS -HSPA & LTE-A networks of the town.

1.3 Objectives of the Research

1.3.1 General Objective

The general objective of this thesis is to analyze and evaluate the performance of UMTS/HSPA and LTE-A mobile radio network of south western Ethiopia's largest town, Jimma.

1.3.2 Specific Objectives

Specific objectives of this thesis are:

- To evaluate existing network quality, coverage, data throughput and traffic performance.
- To examine viability and traffic impact of recently layered LTE-A network.
- To tip-off optimization and upgrading solutions for the existing network.

- To show post upgrading and optimization coverage and capacity predictions.

1.4 Methodology

In this thesis, two essential field & OSS based data collection and analysis methods are employed. Following review of related literature(s), RF audit, requirements and KPI definitions are performed as shown in figure 1.1.

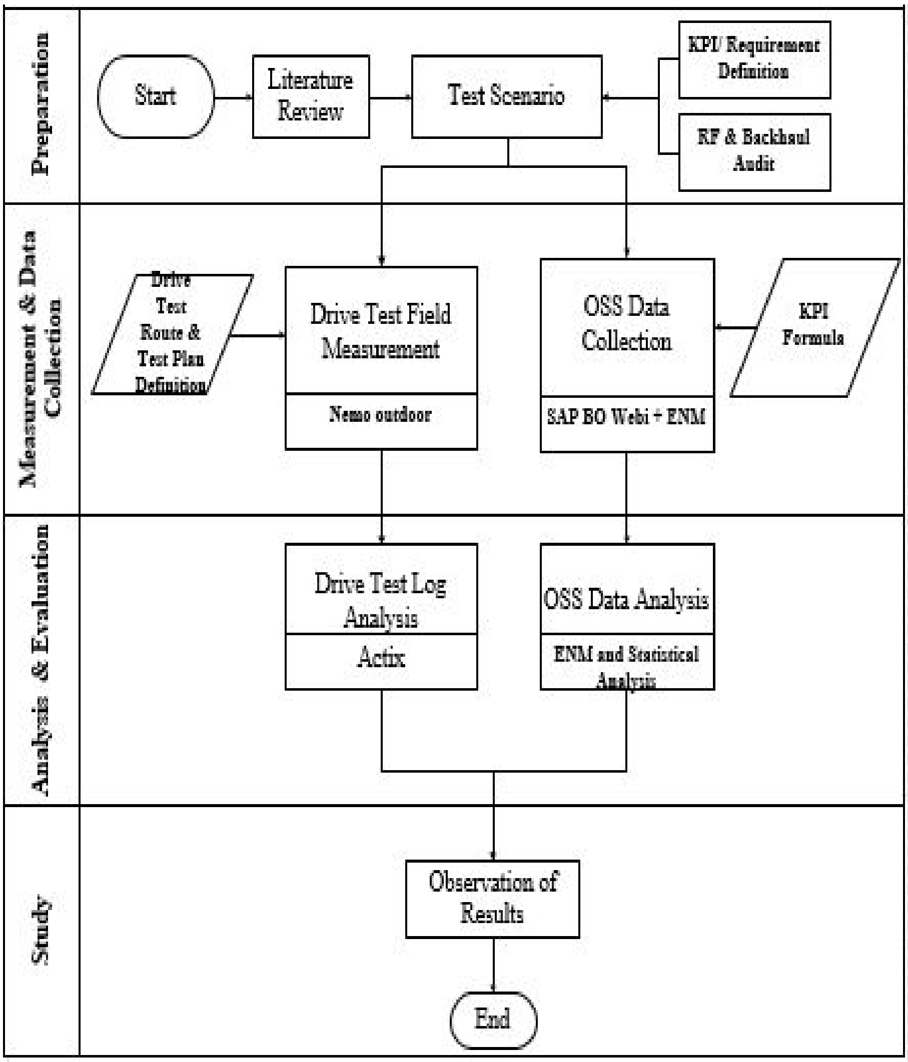

Figure 1.1: Methodology

For the first test item, drive test route is defined using Google earth considering demographic settlement, nodes placement and terrain distributions of Jimma town. Drive test data collection is carried out for both UMTS/HSPA and LTE-A networks using a Nemo outdoor. For the second test, OSS data collection is conducted using Ericsson performance management systems called ENIQ & SAP Business Objects Web Intelligence. In this regard, data is exploited for a specified test period & metrics. Marking LTE-A deployment as a verge, the collected data is organized temporally for analysis. The next part of this study encompasses assessment of drive test result using Actix and OSS data analysis. Lastly, suitable solutions and recommendations will be provided based on the result of analysis.

1.5 Significance of Research

This thesis is intended to identify an enduring coverage, quality and capacity problems of Jimma town. Sufficient mobile data and voice service solutions that are explored considering cost effectiveness and essential RF requirements. These ensure not only service excellence but also guarantee revenues & capitalize existing resource.

Generally, the findings of this thesis will contribute to the benefit of the community as well as the operator as it helps to establish pertinent radio network that adequately address service requirement.

1.6 Scope and Limitation of Research

This thesis is projected to assess the performance & identify an outstanding QoS problems of Jimma town broadband mobile network by analyzing drive test and OSS data measurements. In this regard, Nemo outdoor and Actix are used for drive test measurement collection and analysis respectively whereas OSS data collection is carried out using and SAP business objects web intelligence client.

The drive test has an irrefutable setback regarding coverage hole detection and indoor measurement scenes though the shielding effect of test vehicle is bound to take the impact comparable. Furthermore, service interruption during drive testing and poor road conditions are the major limitations of this thesis.

1.7 Contributions of Research

In an unremunerative investment and vulnerable radio network operation, this thesis will be used as an allusive and attestation document for mobile network service operators in the course of implementing upgrading, layering and migration. In addition, the thesis tips-off economical RF solutions & pragmatically justified its applicability in addressing existing network problem. The integration of drive test and OSS data test scenarios has helped-out to understand enduring problems and RF condition explicitly.

1.8 Thesis Outline

The thesis is organized in six chapters. The first chapter presents introduction, objective, methodology , scope, limitation and significance of the thesis. The second chapter discusses review of related works. The third chapter explains basics of UMTS and LTE cellular communication technologies. The key element of this thesis, the radio network traffic evaluation and performance analysis with KPI definition, RF requirement & data collection are presented in chapter four. The fifth chapter covered the result and discussion. The last chapter contains conclusion and recommendation of the thesis.

Chapter 2

Literature Review

There has been many studies carried out into performance analysis of cellular network. In study [24], imperative assessment for selected KPIs of 4G LTE network were carried out aiming to improve coverage and capacity of existing network in Smart city, Legos, Nigeria. KPIs are derived from experimental drive-test measurements performed in specified route of the cluster and presented post processing measurements comprehensibly. However, the test was conducted in optimal RF condition for limited coverage metrics. In addition, the test device was an enhanced highly capable modem that might not characterize real subscriber perspective experience as test phones are much more favorable in depiction.

Analytic approaches of solving capacity and data throughput problems where statistics of traffic consumption and develop predictions to establish effective expansion and migration. Authors in the research [25] had also described several technologies and features to address problems associated with data rate. Sectoring, node re-positioning, carrier aggregation, modulation order, frequency reframing, VAMOS technology & multiple-input and multiple-output (MIMO) technology are among the possible solutions that are described. In addition, prerequisites for implementation network migration along with device and subscriber penetration and trend are also addressed too. However, most of the solutions are not cost-effective and could not easily incorporated in to existing network.

In literature [26], Optimal methods of traffic directioning are presented over different RF conditions with analysis and comparisons of results at different scenarios. Results are also illustrated in simulation and analytical methods. Gain through load-based, throughput-based and traffic flow method algorithms are also assessed in correlation with both static and dynamic directing methods and optimal conditions are revealed in each cases. Nevertheless, worst traffic situation when both 3G and 4G are at higher traffic loads is not considered in any aspect.

According to [27], a certain 4G network parameters of quality indicators are evaluated using NetSim, namely channel quality indicator (CQI), signal interference noise ratio (SINR) and transport block (TB) are analyzed to illustrate the performance of exiting LTE network. Particularly, CQI performance is clarified as a function of different modulation levels from QPSK to 64 QAM where best CQI results higher order modulation schemes are illustrated over lower orders. The paper demonstrated these QoS indicator parameters over a range of 1 Km. Although, the study did not consider vital service level QoS parameters and limited to conduct field measurements of wider range.

The research published in [28] adopted both capacity and coverage system models aiming to dimension the network considering site selection, environmental factors, frequency interference, coverage prediction and capacity analysis practices. The clarified system models include coverage and antenna band width and side lobe power modeling. Antenna radiation pattern, coverage and throughput performances are evaluated and simulated with respect to various MIMO antenna configurations.

A study in [29] encompasses planning of 3G UMTS RF network with the help of atoll planning software tool. Various parameters like location of base stations, number of antennas to be connected to each base station, EIRP, altitude, azimuth & down tilt of each antenna are defined in the course of developing a radio network that fulfil coverage, quality and capacity requirements. In addition, performance analysis and RF tuning optimization activities are covered. But propagation model and obstructions are not put in to conjecture though the load capacity of the network is considered from marketing survey data & network is planned considering the Cell breathing process present in 3G networks.

According to [30], capacity and QoS analysis are explained based on CINR and throughput in LTE planning for the case of Sudanese capital city, Khartoum. Assessment of essential RF parameters is established to examine quality and coverage performance of the network. Graphs and maps are used to elaborate dimensioning, coverage analysis. and also system level simulator threshold level capacity analysis was performed. Meanwhile, demographic projections and traffic requirement assessment are not considered in the process of this thesis. Finally, the authors suggested to analyses the effect of obstruction in received signal level as well.

Brief overview of cellular network evolutionally overviewed in [31] & [32] with extensive elaboration of respective features, applications and limitations. The study considered both 3GPP and 2GPP standards through performance comparisons. But the paper only dealt in depth on 1G-3G and refrained to provide sufficient details for 4G and 5G. Evolutionary developed wireless techniques are discussed, beside this performance of HSPA is also assessed in association with different feature, and advantage of deploying UMTS with HSPA technology was studied as well as the cost benefit analysis is performed both for operator and subscriber ownership of HSPA radio access network. Lastly, the authors remarked deploying HSPA is cost-effective scheme as it's a simple software upgrade on existing WCDMA network.

According to [33] throughput and spectral efficiency performance of UMTS and EDGE networks are examined through different scenarios over both in uplink and downlink. The data is contributed by different operators and these very large amount of information about an existing or proposed system, including the different services and different subscriber types so as to allow the system resources to be allocated with great flexibility. The paper mainly investigated the performance of UMTS and provide guidance in the design of the wireless networks though it mainly covered capacity related parameter.

In [34] drive test based 2G network performance analysis executed. The paper revealed that drive test provides eloquent subscribers perspective measurements. The analysis is carried out in terms of KPI parameters and focused only in 2G CS service. Optimization and RF tuning recommendations are given based on CS and it may impact the performance of PS service. In addition, it's performed without comprehensive cell reference data lack to run the overall RF schemes.

In [35], a comprehensive practical performance analysis and comparison of the LTE and HSPA+ (3GPP Release 8) network is carried out based on field test measurements. Key performance metrics, including RSRP, RSRQ, BLER, CQI, SINR, RSCP, handover, throughput and spectral efficiency are measured for both technologies. Additionally, the result demonstrated that LTE system offers a greater spectral efficiency and reduced interruption time during handover compared with that of the HSPA+ system. However, the drive tests conducted at a speed of 80 km/h that is incapable condition to contend Doppler frequency shift. Additionally, the test device used in the study is not commercially available and insufficient to resemble depict real user experiences.

The research [36] covers comparison between HSPA+ and LTE focusing on coverage and capacity aspects. Both single and multiple users' model is developed in purpose of cell radius calculation on a certain requested throughput and employing all available system resources in a random fading channel. The trade-off between Cell radii, throughput and bandwidth was elaborated long with performance comparison between the two technologies. The test was conducted in indoor, vehicular and pedestrian RF environment for different services. The result presented that LTE provided a better access and throughput performance over UMTS/HSPA+

in both test cases. However, the study missed out to to examine other radio parameters that perhaps impact the network radius and throughput

Following a review on the aforementioned literature, conducive approaches and methodologies are scientifically organized and carried out in this thesis.

Chapter 3

Cellular Wireless Communication Technologies

3.1 Introduction to Cellular Wireless Technologies

Cellular telecommunications technology allows wireless connectivity of untethered as well as wired devices distributed over inhabited terrestrial area called cell. The technology has been extensively deployed all over the world and has essentially become the most popular platform for modern telecommunication access industry. Because of continuous connectivity, cost effectiveness, immense service provisioning, scalability, flexibility, accessibility, secured network management system and other magnificent features wireless mobile communication have eased life and saved time. Over the last four decades, impressive cellular network adoption has been implemented in all country regardless of religious, cultural and socio-economic aspects. Moreover, progressive advancements, adaptability and compatibility over the mobile services provided by various mobile generation technologies revolutionized the extent popularity and significance [37]. Figure 3.1 illustrates evolutionary development of cellular technology.

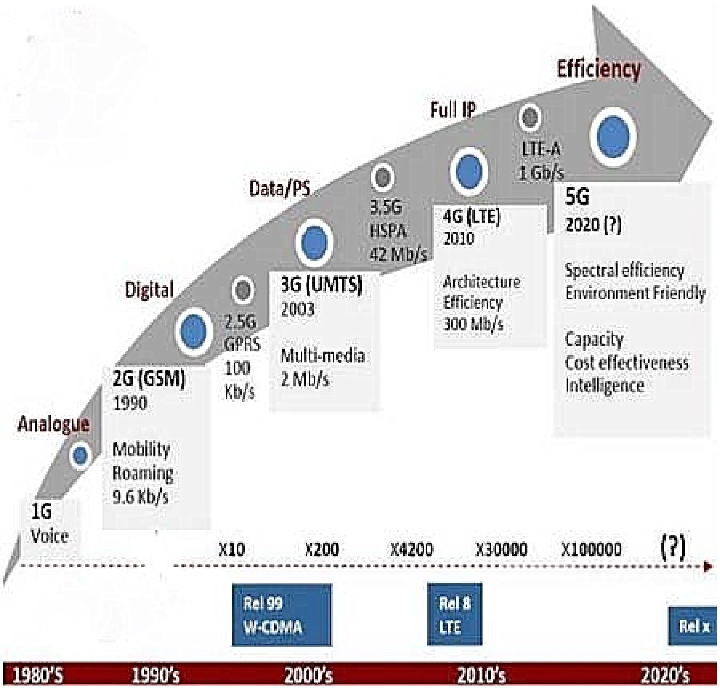

FIGURE 3.1: Evolution of Cellular Technology [37]

Radio frequency (RF) spectrum allocation and frequency reuse techniques are the fundamental element of all generations of cellular communication technologies. Basically, mobile radio systems that use prevalent multiple access techniques rely upon frequency reuse where users in geographically separated cells simultaneously use the same carrier frequency [1]. This ascertain the provision large traffic handling capability as well as spectral efficiency.

3.2 Introduction to UMTS

UMTS is a third generation wireless network technology that functions based on the wideband code division multiple access (WCDMA) technology. UMTS systems operate at a channel bandwidth of 5 MHz and each data streams are uniquely recognized by a specific code and are spread to the interval of available spectrum. It's an IP based technology that offer enhanced spectral efficiency than it's predecessors thereby standards are developed by 3GPP. UMTS networks operates either in a frequency division duplex (FDD) or time division duplex (TDD) modes. In FDD, uplink and downlink transmit simultaneously use different frequencies. Whereas in TDD scheme, same frequency is used for both uplink and downlink directions but they use different time slots for transmissions [38]. Particularly, FDD is suitable for symmetric connectivity while TDD is adaptable to any frequency band & suitable for both symmetric and asymmetric services.

3.2.1 Overview of UMTS System Architecture, Functional Units and Interfaces

A typical UMTS network architecture is outlined based on existing global system for mobile (GSM) network elements with classic integration of new 3G network elements and interfaces. Figure 3.2 shows UMTS network architecture is fundamentally classified on its three interacting sub-systems; these are called user equipment (UE), access network (AN) and core network (CN). All elements in the layout are designed and standardized in a way to ensure inter-operability, software upgrading & modular renovations flexibility. Moreover, evolutionary developments can be adapted to the network without causing interruption to prevailing network elements and services.

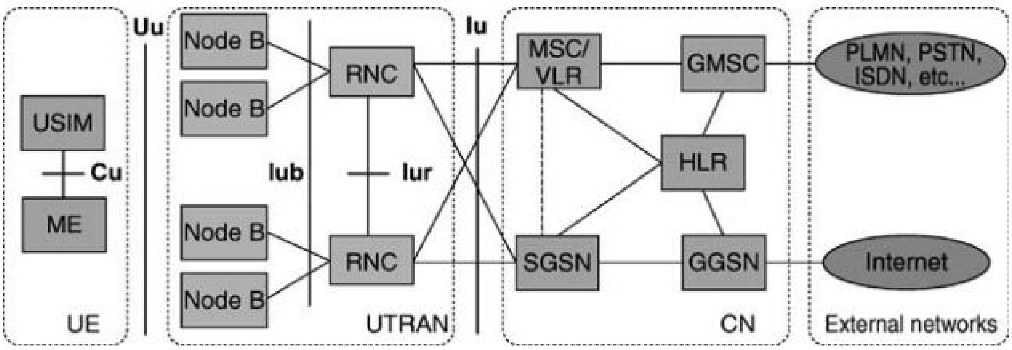

FIGURE 3.2: UMTS Network Architecture [39]

The entire network architecture is categorized based on the nature of traffic, functional elements and protocol structure. From the nature traffic point of view, the architecture contains two domains, namely packet-switched (PS) and circuit-switched (CS) domains. While protocol structure is considered, the UMTS network is classified in to access stratum and non-access stratum. Hence, the access stratum contains the protocols handling activities between user equipment (UE) and radio access network. The non-access stratum contains protocols handling activities between the UE and core network domains [40].

User Equipment (UE)

UE is a device that is designed to operate in specified UMTS frequency band so as to interconnect the user and the radio access network. It's divided into two units called mobile equipment (ME) and UMTS subscriber identity module (USIM). ME is a terminal used in for radio communication in a defined frequency and technology and USIM is used to access a network that functions subscriber authentication, identity, storage and subscription by inter-operating with ME.

Radio Access Network

In UMTS system architecture, radio access network (RAN) is a subsystem that perform all radio functionalities where WCDMA is an exquisite standard in a purview. It is also called UMTS terrestrial RAN (UTRAN) and contains two distinctive elements. The radio element is called NodeB and controlling element is radio network controller (RNC). NodeB mainly provide radio resource management, radio coverage and convert data flow between Iub and Uu interfaces [39] however RNC is a vendor dependent a switching and controlling element of UTRAN. RNC manage and controls the radio resources in its domain. Handover control, power control, admission control, code management and packet scheduling are notable functions of RNC [40].

Core Network

UMTS core network is basic unit that consists of a CS entity for providing voice and CS data services and a PS entity for providing packet-based services along with mobility management and call control functions. The UMTS core network contains several functional units. In particular, mobile switching center (MSC) and visitor location register (VLR) are integrated for CS services, serving GPRS support node (SGSN) and gateway GPRS support node (GGSN) support PS services. There are numerous units that are specified to perform different functions such as billing, service management, element management, session management, switching routing, authentication, routing and service management [41][42].

UMTS Radio Interfaces

The UMTS interface are defined aiming to interconnect internal functionality of different network elements as well as layers and planes that are logically independent. Interfaces are categorized in to two structural groups. Namely, user plane protocols which provide radio access bearer services through access stratum and control plane protocols that are responsible for controlling the radio access bearers and the connection between the UE and the network from different aspects. Common UMTS radio interfaces that are:

- **Iu Interface**: Iu interface is an open logical interface that interconnects RNC of UTRAN to the U-MSC of CN. On the UTRAN side the Iu interface is terminated at the RNC, and at the UCN side it is terminated at U-MSC. It mainly carries call control information[42].
- **Iur Interface**: Iur is an interface between two RNCs serving RNC (SRNC) and drift RNC (DRNC). It's used in soft handoff where communication between one RNC and one Node B of two different RNCs are realized through the Iur interface [42].
- **lub Interface**: Iub provide logical connection between the RNC and Node B. The Iub interface is used for all of the communications between Node B and the RNC of the same RNS [42].
- **Uu Interface**: Uu is the radio interface between a Node B and UE. The Uu is the interface through which UE accesses the fixed part of the system [42].

3.2.2 Key Technologies in UMTS/HSPA

Several UMTS & WCDMA associated standards and technologies are developed over the journey towards enhanced mobile broadband services. These technologies & features have been integrated wireless systems in order to improve capacity, coverage, quality and data throughput performance. Among these technologies; magnificent solutions in antenna arrays systems, inter-frequency handover scheme, advanced modulation techniques, intelligent base station operations are most notably introduced in 3G era.

3.2.2.1 Wideband Code Division Multiple Access

Wideband code division multiple access system (WCDMA) is a fundamental standard for UMTS technology that offered higher data speed than predecessor cellular technologies. It operates with chip rate of 3.84 Mcps and bandwidth of 5 MHz. In this circumstance, bits streams are spread over a wide bandwidth by multiplying the user information with quasi-random bits originated from CDMA spreading codes. In order to support very high bit rates, the use of a variable spreading factor and multi-code connections are incorporated. Basic contextual piece and benefits of WCDMA standard specifications include high data rate, multi-mode operation, coherent detection, multiuser detection and smart adaptive antennas and compatibility and conjunction operation with predecessor network [39].

3.2.2.2 Spreading and Modulation

Distribution of the data which is going to be communicated through a chip rate of 3.84 Mcps has employed channelization codes to separate channels in downlink transmission. It's used in the physical channel and specifically operate data symbol transformation in to a number of chips (channelization) and cell identification application to as spreading signal (scrambling), where the number of chips per data symbol is called the spreading factor (SF). During de-spreading the received user data per chip streams are multiplied with the same code chips used while spreading of user data bits. Thus, the original user bit sequence has been recuperated properly with aligning organization between the user data and spreading code. Furthermore, modulation schemes are defined to establish high spectral efficiency and avoid interference during transmission as its necessary to guarantee data is transmission efficiency over the available spectrum and also boost system capacity. Spectrum efficiency, signal to noise ratio and error correction are among the factors considered in modulation formats used in UMTS. Phase Shift Keying (PSK) modulation types are widely used in UMTS providing advantages in many requirements.

3.2.2.3 Rake Receiver

Rake receiver is radio receiver typically designed to receive multiple channel signals through several detector and mixers of received signals. It improves the S/N and reduce the effect of multipath fading of the received signals by combining multipath signals. The rake receiver contains several correlators where the detected signals are multiplied by time-shifted versions of a locally generated code sequence. The intention is to separate signals such that each finger only sees signals coming in over a single resolvable path.

3.2.2.4 Softer and Soft Handover

Handovers are a significant entity that ensure mobility in cellular architectures. Several handovers are implemented in UMTS for different purposes including seamless service provisioning and load control. In this regard, options for more consistent systems of handover effected & various handover types are available in which decisions are made upon pre-defined RF situation. In this aspect, soft and softer handover are the two commonly adopted types in UMTS systems. Soft handover is a situation where a cell phone is simultaneously connected to two or more cells during a call. where us, In softer handover the cell phone is simultaneously connected to cells of same NodeB.

3.2.2.5 Code Resource Generation and Allocation

In UMTS, codes are generated and applied so as to isolate users & cells from shared bandwidth & cellular system respectively. These codes are mainly employed to minimize interference and boost spectral efficiency. Therefore, code resources are classified in to channelization code, scrambling code and synchronization code. Table 3.1 illustrated principles, specification and usages for each codes.

	Synchronization codes	**Channelization codes**	**Scrambling codes, uplink**	**Scrambling codes, Downlink**
Type	Gold codes, primary synchronization codes (PSC), secondary synchronization codes (SSC),	OVSF , sometimes called Walsh code	Complex-valued gold code segment (long) or complex valued S(2) codes (short)	Complex-valued gold code segment, Pseudo noise (PN)codes
Length	256 chips	4-512 chips	38,400 chips/256 chips	38,400 chips
Duration	66.67 μs	1.04μs-133.34μs	10 ms/66.67 μs	10ms
Number of codes	1 primary code/ 16 secondary code	Spreading factor :UL 4-256, DL 4-512	16,777,216	512 primary/15 secondary for each primary code
Spreading	No, does not change bandwidth	Yes, increases bandwidth	No, does not change bandwidth	No, does not change bandwidth
Usage	To enable terminal to locate and synchronize to the cells' main control channels	UL: To separate physical data from same terminal, DL: To separate connection to different terminals in a cell	Separation of terminals	Separation of cells

TABLE 3.1: Code resource in WCDMA [39]

3.2.2.6 Power Control

Power control is one of the key technologies in UMTS system that ensure QoS provisioning as its algorithm are subjected to minimize the effect of interference and attenuation. In addition, conventional call quality is maintained when both the BTS and the MS are involved to adjust power. Power control in UMTS are classified based on link type and effect. These include inner loop power control, outer loop power control, open loop power control and closed loop power control [43].

- Inner loop power control: In this case, both sender and receiver are communicated based on SIR and targets of received information and makes adjustment accordingly.
- Outer loop power control: This scheme is an enhancement on closed loop power control where QoS target is maintained by tuning SIR.
- Open loop power control: It's a technique implemented at the establishment of connection where the average downlink path loss is used to control the link power.

3.2.2.7 Admission Control

The admission control (AC) in WCDMA network determines whether a new user will be allowed to establish a call or not. It is used to limit interference and better QoS to a service provide at particular instant. Decisions are made both in UL and DL based requirements embedded in admission control algorithms.

3.2.2.8 Load Control/Congestion Control

Load and congestion control processes ensure the QoS by establishing system load level in required range. Implementations are carried out in UMTS by continually measuring of system load, defining load control thresholds and specifying operating mode. Both load and congestion control parameter often used handover triggering and load offloading options that are executed without call drops.

3.2.2.9 Multipoint Transmission

Multipoint transmission is an advanced piece of evolved HSPA that is developed by 3GPP aiming to alleviate cell edge and capacity limitations overlaying on existing radio & UE resources. It has featured in two common forms. The first one, which is often envisaged as a renovation to DC HSPA is called single frequency multipoint transmission & the second called dual frequency multipoint transmission. It's mainly improve cell edge performance and dynamic load balancing both in single and dual carrier scheme.

3.2.3 HSPA and Evolved HSPA

An enhanced 3GPP standard for 3G over a prevailing WCDMA based system has been developed with the incorporation of intelligent features that are designed aiming to boost the performance of existing UMTS network called HSPA technology. The specifications and features have introduced MIMO systems, multi-carrier operation and multi-point transmission in the course of advancement and these features has enormously improve throughput and system capacity compared with preceding footprint. HSPA provide higher data rate performance with the combination of high speed downlink packet access (HSDPA)that was introduced in release 5 with fast link adaptation and scheduling capability. The uplink counter part, high speed uplink packet access (HSUPA) is also launched later in release 6. Both HSDPA and HSUPA are separate entities with different specification, properties and function. HSDPA is packet based UMTS standard that provides enhanced capacity, reduced delays, and high throughput in downlink. QPSK, 16 QAM and 64 QAM modulation solutions are used. Whereas HSUPA is also packet based UMTS standard that provides enhanced capacity, reduced delays, and throughput in uplink data transmission. BPSK and QPSK are a modulation techniques are adopted in HSUPA.

Similarly, an upgraded version of HSPA technology called Evolved HSPA (HSPA+) is released in 2005 offering enormous throughput & capacity. It is an easy overlay of existing HSPA and designed to provide data throughput up to 672 Mbps by integrating carrier aggregation, layer-2 enhancements, advanced modulation and MIMO. It has been widely deployed by several operators worldwide to enhance mobile broadband services and used as a key transitional element for towards 4G migration. HSPA+ has practically deliveded hundereds of megabytes per second that are more comparable to the initially available speeds of newer LTE networks without deploying a new radio network [44][3].

3GPP Release (Freeze date)	**Peak rates (DL)**	**Description of Spectrum and Technology**
Rel 5-6 (Jun 02 – Mar 05)	14 Mbps	5 MHz, 2100 MHz, single antenna
Rel 7 (Dec 07)	28 Mbps	5 MHz, 2600, 2100, 1800 or 900 MHz, 64 QAM or 2 layer MIMO
Rel 8 (Dec 08)	42 Mbps	2 x 5 MHz, 2100, 2600, 1800 or 900 MHz., Dual carrier or 2 layer MIMO
Rel 9 (Dec 09)	84 Mbps	2 x 5 MHz, 2100, 2600, 1800, 900 or 800 MHz, 2 layer MIMO
Rel 10 (Mar 11)	169 Mbps	4x5 MHz, 3500, 2100, 2600, 1800, 900, 800 (including 1 x 5 MHz @ 900 & 3 x 5 MHz in2100 MHz),2 layer MIMO
Rel 11+ (Aug 13)	336-672 Mbps	40 MHz 2x2 / 4x4 MIMO

Table 3.2: HSPA/HSPA+ spectrum and technical specification [3].

These technologies have been deployed gradually over the decade. Table 3.2 illustrates peak theoretical data rate and incorporated feature of various HSPA versions.

3.3 Introduction to LTE

The rapid evolution of the technology remarkably transformed the telecommunication industry in the last 20 years. In other word, it has also been noted as an revolution in wireless broadband communication along with promising penetration rated of the device ecosystem and mobile network technology advancement. Competition between mobile network operators and vendors outstanding inventions has taken the technology significant steps forward. 3GPP, cellular technology enabler groups are in place to go hand-in-hand with advancement in mobile communications technology. Thus, the development of LTE & LTE-A has maintained promising performance in-terms of data throughput, latency and spectral efficiency [45].

LTE is all IP based cellular architecture technology for high speed broadband mobile data. LTE have reformed the wireless communication industry and become one of the most deployed high speed cellular system in many part of the world. In LTE, low latency and high speed ensure seamless provisioning for high speed demanding interactive service like streaming, gaming, IoT and M2M applications. Basically, LTE uses orthogonal frequency division multiplexing (OFDM) and operate in a channel bandwidths interval from 1.4 MHz to 20 MHz and supports both FDD and TDD as aiming to address the future generation cellular technology requirements and growing mobile communication services requirements.

3.3.1 LTE Architecture

LTE architecture standardization are developed to establish promising throughput and delay improvement. The architecture contains interfaces, principles of operational for each constituent elements. The LTE architecture supports only the packet switched (PS) domain that enable the LTE network elements to communicate with each other over the underlying IP transport network. As shown in figure 3.3 below, serving LTE architecture consists of an evolved UMTS terrestrial radio access network more commonly known as E-UTRAN, and the system architecture evolution, also known as SAE. SAEs' main component is the evolved packet core, also known as an EPC.

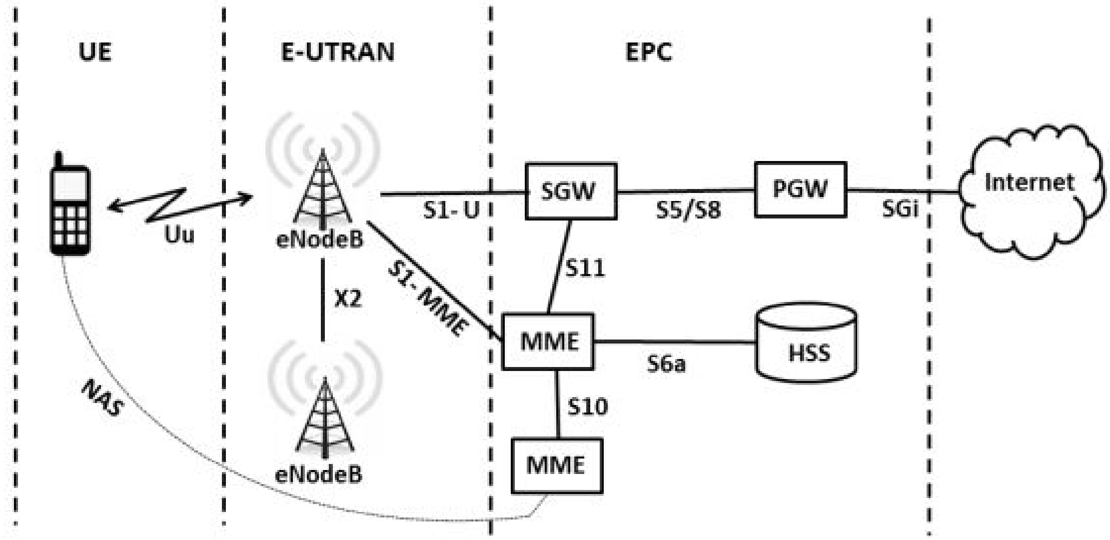

FIGURE 3.3: LTE Network Architecture [46]

E-UTRAN

Mainly made up with base station called as eNodeB /eNB. It performs radio resource management, scheduling and admission control and User packer header compression/decompression.

SAE

Its simplified IP based format that is standardized with suitable and less complex platform compared to systems of earlier analogues network architectures. It defines access gateway and connectivity standards with other wireless communications.

EPC

In LTE, the core network contained a number of functional elements such as mobility management entity (MME, serving gateway (SGW), packet data network gateway (PGW) and home subscriber server (HSS) that mainly handle mobility management, authentication, routing upload and download IP packets, IP address allocation.

3.3.2 Key LTE Feature and Technologies

Several technologies and protocol stacks are developed aiming to offer unprecedented service provisioning regarding throughput and latency. New advanced technological developments in LTE has transformed economic growth and enabled industries to operate in digital platform and also put a remarkable milestone for the next generation networks. Most notable technologies of LTE are OFDM, multi-carrier technology, advanced MIMO, radio access technology, dynamic spectrum sharing (DSS), and incorporation of higher order modulations might also be mentioned as well.

3.3.2.1 Orthogonal Frequency Division Multiplexing

OFDM is an essential element LTE that provide higher spectral efficiency, greater multipath propagation and interference mitigation and enormous bandwidth capabilities. The principle of operation of OFDM relies up on bandwidth splitting to multiple sub-carriers of 1KHz. And the orthogonality property crammed sub-carriers tightly without employing guard bands. As shown on figure 3.4, these sub-carriers are allocated to users at different times and the sub-carriers are separated with limited overlapping sections, as the peak of each sub-carrier intersects the zero crossing of the neighboring sub-carrier [47]. The main carrier of the OFDM modulation signal is mathematical presented in equation 3.1[1] as:

$$S(t) = \sum_{n} b(t - nT, X_n) \tag{3.1}$$

Where, A represents the block, N is block length, $1/T$ Hz is sub-carriers are spacing, T_s is symbol duration, $T = NT_s$ is duration for a block of N symbols, n is a block index and X_n is the data symbol block at epoch n. $[b(t, X_n]$ and the offset is given by:

$$b(t, X_n) = h_\alpha(t) \sum_{k=0}^{N-1} {x_{n_k}}^{j} 2 \left(\frac{\pi(k - (N-1)/2)t}{T} \right) \tag{3.2}$$

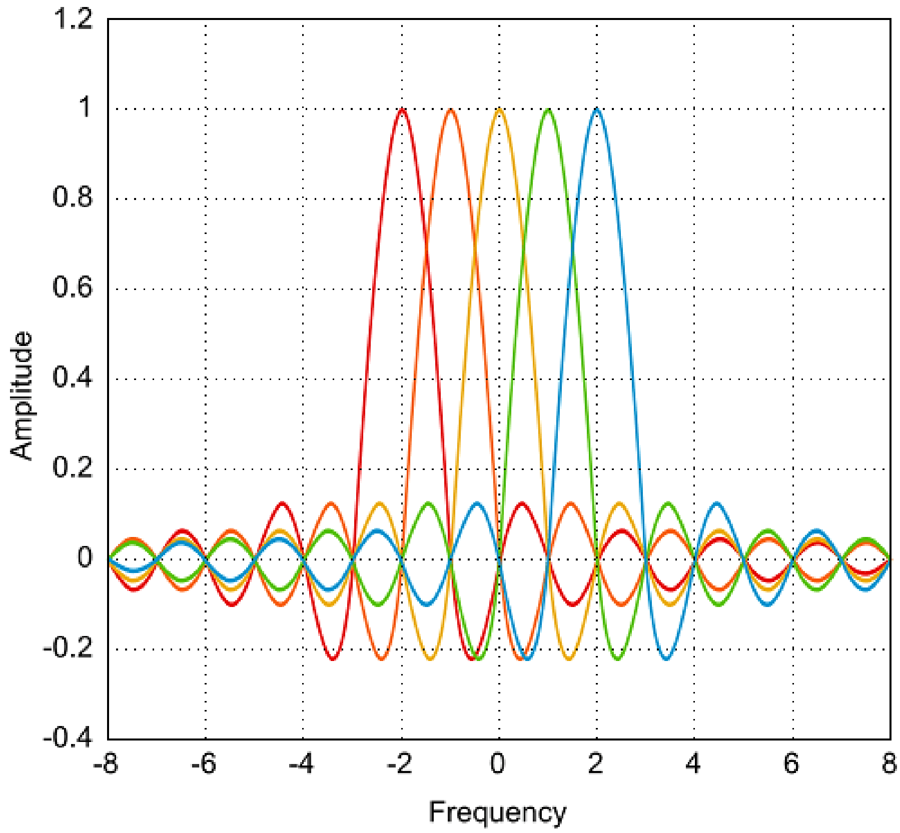

FIGURE 3.4: Frequency domain of an OFDM signal[47]

3.3.2.2 Multicarrier Technology

In LTE, a single user entertained an immense data rate with the combination of multiple carrier assignment. Up to five carrier component of 20 MHz bandwidth are aggregated together to serve same user with a maximum bandwidth of 100 MHz. This technology boosts peak speed and improve link reliability. There are three types of carrier aggregation. The first one called intra-band non-contiguous, where multiple adjacent carriers are combined in a single operating band. The second one is inter-band non-contiguous carrier aggregation; this is little complex technique in which multiple carriers are aggregated in different band. The last one named intra-band contiguous aggregates are combination of separate carriers in a single operating band.

3.3.2.3 Advanced MIMO

The use of multiple antennas at both the transmitter and the receiver can simply be considers as a scheme to further improve the signal-to-noise interference ratio and achieve additional diversity gain while comparing with the implementation of only multiple receive antennas or multiple transmit antennas. Hence, MIMO is applied to enhance the total transmission speed and quality by incorporating different spatially separated antennas of same operating frequency and time so as to offer efficiency in SINR improvement and higher data rates over the radio interface. LTE adopted various MIMO technologies including transmit diversity, single user (SU)-MIMO, multiuser (MU)-MIMO, closed-loop rank-1 precoding, and dedicated beamforming. Moreover, adoption of MIMO technology increases data rate, consistency, spectral and energy efficiency. Equation 3.3 shows that a MIMO based systems perpetuate higher data rate with incormpration of multiple antennas [45].

$$C \approx B \log_2(1 + M_T N_T {}^* \text{ SNR}) \tag{3.3}$$

In this case, the channel capacity (C) is given by Shannon theorem is boosted by maintaining a $M_T N_T$ fold progression in SNR. Where B is the channel bandwidth, M_T is the number of transmitting antennas and N_R is the number of receiving antennas.

3.3.2.4 Higher Order Modulations

An OFDM based modulation scheme in LTE provides very high data rates within a certain transmission bandwidth. In this regard, the modulation format added a remarkable advantage in efficient bandwidth utilization so as to carry more data per radio wave. LTE introduced 256 QAM for down link communication with much better data rate performance than 64 QAM. And more recently 3GPP developed 1024 QAM standard.

3.3.2.5 Dynamic Spectrum Sharing (DSS)

DSS is an exceptional and innovative technological milestone in modern cellular technology as it alleviates limitations over radio frequency spectrum assignments and frequency re-farming. The technology enabled two network service provisioning with one antenna that me enables the simultaneous operation of LTE and 5G in the same frequency band. With this solution, an operator can share the frequency band between different radio services. This enable new radio service implementation without new antenna units and frequency assignments.

3.3.2.6 Beamforming

Beamforming is implemented to enhance spatial throughput performance by concentration the beam towards a particular user using position prediction at the node. It is commonly employed at cell edge. Both single and multi-layer beam forming techniques are used in LTE & operates upon user defined symbols.

3.3.2.7 Self Organizing Networks (SON)

SON is an advanced mobile network system that manage radio network resources in purpose of enhancing networks. It is intended to make the planning, configuration, management, optimization and RF tuning as simple as possible. It is an economical solution that has been developed to ease complexity in running the network as well as improve operational adaptability and effectiveness.

3.3.3 LTE advanced and LTE Pro

Considering rapidly growing mobile broadband service drivers and capacity requirements 3GPP has made multiple enhancements on LTE standard. In consequence, LTE-A and LTE Advanced Pro (LTE-A Pro) were developed in the course of providing gigabit internet and ease the road for succeeding radio technology. It took-up the scope of cellular technology with implementation of advanced techniques. It's widely employed to serve contemporary broadband users such as vehicle to everything (V2X), device to device (D2D), internet of things (IoT), machine to machine (M2M), gaming and video streaming. Enhancements are mainly achieved by integrating evolved carrier aggregation and MIMO. In this case, LTE-A Pro exploits resources efficiently to provide much improved connectivity. Eventually, 5G enabler solution called Massive MIMO antenna configuration introduced in LTE-A pro. And it's widely renowned for three vital features namely 4X4 MIMO, 256 QAM and enhanced carrier aggregation. In addition, it has revealed to entertain gigabit LTE without utilizing new spectrum or employing one of the traditional cell splitting or cell sectoring methods [5][45].

Chapter 4

Radio Network Performance Analysis

Traffic evaluation and performance analysis provides a wide-ranging prospect to understand a radio network and identify problems. In practice, it is a key platform for cellular network service providers mainly used to assess and control a network coverage, capacity & quality of service. It's realized through continuous performance evaluation and analysis of a network KPI that is often carried out from initial roll-out to operation as well as it is conducted when new hardware/software package is integrated in to a network.

Furthermore, it's widely employed to characterize customers profile, service demands and potential areas. In this regard, operators often analyze the network performance and evaluate service quality indicators either to identify problems or tune RF parameters in the course of optimizing their network. The objective of network optimization scoped out from enhancing network performance to improving QoS and quality of experience (QoE). Therefore, assessing and optimizing QoE is the trend for optimizing today mobile networks. The overall network elements are standardized considering QoS requirements and performance objectives. Noting that QoS in cellular networks is mainly related to the capability of the network to provide a satisfactory service that assure acceptable service quality, accessibility, retainability and integrity for both CS and PS applications [38][48].

Generally, RF data collection, traffic evaluation and performance analysis often managed through capturing and assessing real-world data of the RF network called the drive test and analysis of traffic statistics from a radio network. Both mechanisms are effectively used by several operators to address coverage, capacity and QoS of a mobile radio network. The performance of the radio network is measured in terms of KPIs that are specified based on the condition & statistics generated from the radio network. Thus, both drive test and OSS data test scenarios are key steps in finding paramount solutions.

4.1 Drive Test Based Performance Analysis

Drive testing is a method of measuring and assessing the coverage, capacity and QoS of a mobile radio network [48]. It's often carried out in order to verify the coverage and quality of a network using drive test tools and analyzers. It's conducted in a defined cluster and drive test route that are demarcated considering subscriber settlement, terrain and RF obstructions. It is often needed to conduct drive testing in purpose of RF tuning, network optimization and exploration of other RF issues in the network.

Drive testing consists of a mobile vehicle equipped with radio network measurement equipment that can measure RF parameters of mobile cellular service. Log files, the recorded data are examined to evaluated the result and service performance based on test purpose. Generally, drive test network assessment scheme is the preeminent methods establishing performance figures aiming to understand RF conditions that are related to signal quality, strength, interference, PS/CS call statistics, handover, neighboring cell patterns.

4.2 OSS-Data Oriented Performance Analysis & Evaluation

In cellular communication, the performance counters and mobile network KPIs collected at the OSS establishes extremely valuable information about the radio access network performance with detailed granularity and also provides cost effective, time/spot independent and users real time experience [49]. Hence, RF records of mobile users & the network can provide valuable information for understanding the behavior & traffic trend of networks for mobile network operators (MNOs). This can help MNOs to invest intelligently in locations where they operate with inferior performance and offers a reliable and convenient traffic analysis solution as well [50]. OSS based data analytic contains an architecture for data collection and network automation in cellular network systems. These contemporary and powerful big data analytic can be manipulated to provide appropriate and efficient solutions to address problems related to QoS.

Moreover, several OSS integrated mobile network traffic statistic analyzing tool can be used to analyze different parameters of services that are adopted based on operator's engagement and interest. The statistics can be evaluated in carrier, cell, node or cluster level and poor KPIs can be improved with appropriate RF solution considering the effect of other KPIs and network elements. Thus, it's compulsory to initially confirm operation status of the network for a specified test period before data collection and analysis so as to establish strong statistical significance and avoid incorrect results and generalizations.

An OSS based measurement and analysis are executed by a centralized powerful analytic and reporting third party tool called SAP business object (BO) web intelligence and Ericsson network performance management system named ENIQ. As shown in figure 4.1, SAP BO uses internally incorporated business intelligence (BI) tools to collect data from system database through an integrated SAP BO universe. The universe contains classes and objects of required test domain [51]. In this thesis the universe is developed for all test cases by integrating relevant

KPI counters in respective objects and classes where objects are described by parameters for analysis and measurements. And also analysis and reporting templates are created using interactive and flexible web based user interface called web intelligence (Webi). In this case, performance management includes network

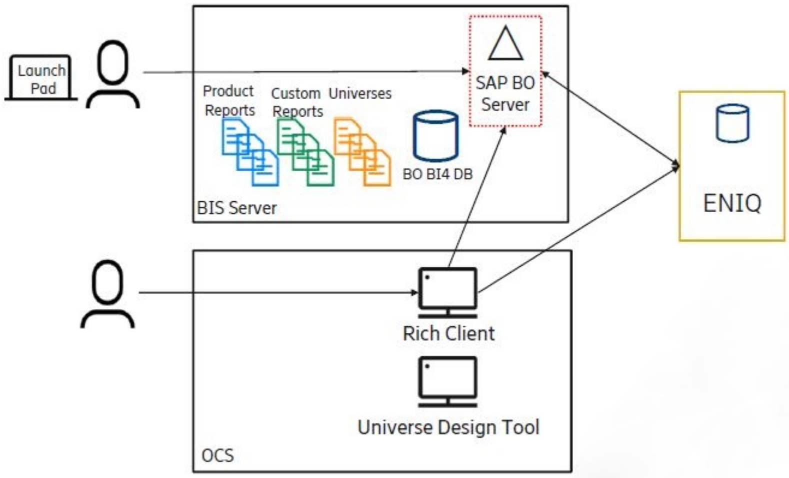

FIGURE 4.1: General Overview of SAP BO Web intelligence & ENIQ performance management system [52]

data set, counter data set, network elements, data storage, data processing and clients providing end users. ENIQ product delivery comprises a generic ENIQ system platform including Operations Support System Radio Core (OSS-RC), data transfer, load control, data warehouse, a set of technology packages and web portal [52].

4.3 Initial Deployment

The essence of mobile network planning is to provide the utmost coverage and capacity of radio network. It is a key element that comprised RF requirement and dimensioning widely implemented in purpose of ensuring sufficiency & resilience while designing network. In a nominal planning for Jimma city UMTS-HSPA network, 35 sites are dimensioned and settlement is carried-out based on planning inputs. Figure 4.2 illustrates coverage prediction for initial network design of

Jimma town. This simulation & propagation analysis is prepared based on initial design, RF parameters and site locations. The predicted coverage performance is

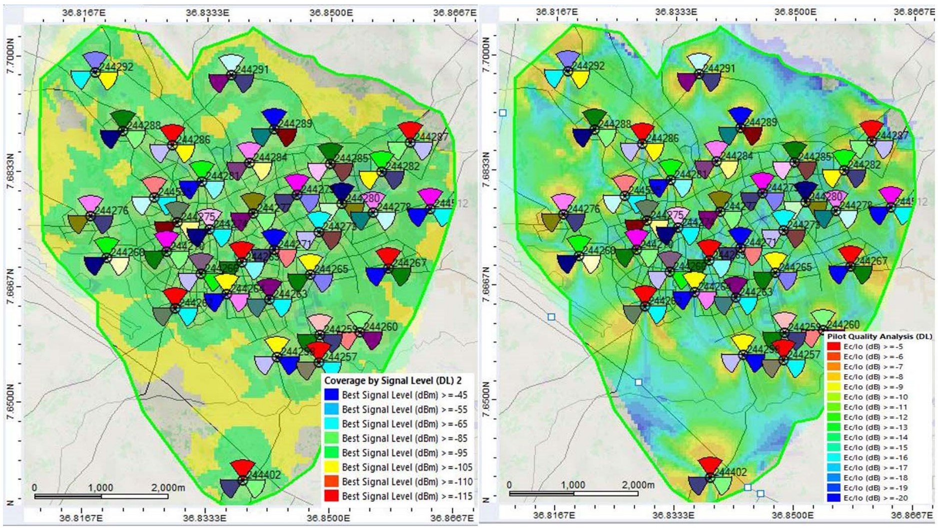

FIGURE 4.2: Coverage prediction of initial deployment

evaluated using COST 231 propagation model. In addition, essential configuration and parameter are defined considering HSPA+ release 7 specification & planning figures that are calculated on preceding modeling stages.

4.4 KPI Metrics & Parameters

In cellular network, a drive test is conducted to validate quality, coverage, capacity and data service performance in a specified test route. The following drive test parameters are commonly used to evaluate and improve aforementioned RF requirements.

Received Signal Code Power

Received signal code power (RSCP) is the power on one code measured by the receiver on the primary common pilot channel (CPICH). It's denoted by equation 4.1 [39]:

$$RSCP(dbm) = RSSI(dbm) + E_c/N_o(dbm) \tag{4.1}$$

In WCDMA, received signal strength indicator (RSSI) represents received power level before de-scrambling, E_c is scrambling code energy per chip and No represents total energy per chip measured by a user.

Energy per Chip to Noise Power Density

Energy per chip over the noise spectral density is the measure of the quality of the signal. It's given by equation 4.2 [39] as shown below.

$$E_c/N_o(dBm) = 10\log_{10}(\text{CPICH Power/Total Transmit Power}) \tag{4.2}$$

Pilot Pollution

Pilot pollution is a condition where a mobile station does not have enough RAKE fingers for processing all the received pilot signals or there is no dominant pilot signal at all. This would create pilot pollution interference and overload the mobile station's RAKE receiver. Therefore, the mobile station's RAKE receiver attempts to separate paths from three or more dominant pilot signals in the time domain to utilize path diversity. In each diversity (path/branch/finger), a large interference component exists due to the finger's own signal and others' signals [53].

Reference Signal Received Quality

Reference Signal Received Quality (RSRQ) is a measurement in LTE network employed to attest the quality of the received reference signal[54]. Equation 4.3 presented $RSRQ$ in a relation with $RSRP$ & $RSRI$.

$$RSRQ = (N * RSRP)/RSSI \tag{4.3}$$

Reference Symbol Received Power

Reference Symbol Received Power (RSRP) is received signal power level in an LTE cell network[54].

$$RSRP(dBm) = RSSI(dBm) - 10\log_{10}(12\text{N}) \tag{4.4}$$

In this regard, N denotes number of resource blocks across the RSSI.

Signal to Interference and Noise Ratio

Signal to interference & noise ratio ($SINR$) indicates the quality of signal quality, it determines strength of the information signal compared to the undesired interference and noise. The general $SINR$ expression is given by equation 4.5 as follows.

$$SINR = \frac{P_{r,i}}{I_{in} + I_{out} + N_o} \tag{4.5}$$

Here, $P_{r,i}$ represents the received power of the desired user, I_{in} represents the total interference coming from the inner region due to using the same center frequency and the same frequency band. I_{out} represents the total interference coming from the outer region due to using the same center frequency and the same frequency band. N_o represents the thermal noise power [55].

4.4.1 Main OSS and Drive test QoS KPI

Service Accessibility

Data accessibility measures the degree of service availability when the subscriber demanded. It is often measured by PS attach success rate, RRC setup success rate, radio access bearer (RAB) setup success rate, call setup success Rate, CSFB call setup success rate and attached time metrics.

Service Retainability

Data retainability deals about network to seamlessly provide uninterrupted resource for a specified user's possession. In this regard, PS call drop rate, CS call drop rate and call setup failure rate are commonly used indicators.

Service Utilization

Service utilization is used to characterize the overall network services by examining subscribers profile, traffic usage trend and service pattern. It's widely described by the amount of data traffic, the number of CS subscribers and the number of CS users in a specified time and network cluster.

Data Integrity

Both speed and amount of packets delivered and transmitted are also used to measure the reliability of cellular network. UL/DL data throughput and latency are the two widely indicator used to measure data service integrity.

Mobility Management

A cellular network is necessary needed to maintain active call connections while the PS/CS user is moving or while encountering bad RF condition by transferring form cell to cell of same technology or between different technologies. Both inter radio access technologies (IRAT) and intra technology handover performance metrics are employed to assess mobility setbacks.

4.5 Measurement and Definition of Requirements

Multiple data collection and measurement platforms are adopted in cellular communication industry to assess quality of experience (QoE) and monitor a certain mobile network. Measuring and evaluating coverage, quality and capacity of service are used to determine the existent RF situation and cognize network aptness. Data collection is a key element in this activity where data type, accuracy, factors and analysis techniques cautiously conducted to ensure QoE & service excellence. Thus, measurement tools need to be versatile to align with the different measurement needs throughout the life span of a network in different context [56]. In this thesis drive test and OSS statistic measurement are used for data collection and measurement.

4.5.1 Data Collection using Drive Testing

In this thesis, RF drive testing is evocatively implemented to collect and assess RF coverage, capacity and quality of both 3G and 4G radio network of the town. The test setup contains licensed Nemo-Outdoor, laptop and handset & global positioning system (GPS) unit that can detect and record several parameters of both data and voice service in a defined test route. In order to ensure the flawless and relevance of the test, data collection has been carried out considering pre-test site health status of all network elements of town with recommended driving speed. Data collection is composed of four essential task units that are sequential conducted aiming to ease post analysis tuning actions. These activities include terrain examination, drive test routes definition, test plan organization and measurement

Target Area Terrain Examination

It's needed to address topographical constraints and potential black spots so as to guarantee RF coverage and quality efficacy. Thus, it's examined and illustrated using google earth satellite image that offer strong visual description, terrain profile, distance and LOS characteristics across a target area with high-resolution feature. Therefore, every spots of a defined target area are technically classified, organized and examined in detail in a relation with its terrain profile and RF performance characteristics. In this thesis, the target area is categorized in to three parts namely hills, lowlands and plains. Figure 4.1 shows classification of target area that would further used in fingering possible obstructions and coverage hole. These detection is examined so as to setup effective drive test route. As shown in figure below 10 km^2 of hilly and 11.5 km^2 lowland spots are studied cautiously among 45.4 km^2 of the totally targeted cluster area.

Radio Base Station Distribution

Serving node patterns for 35 UMTS and 23 LTE nodes of Jimma town radio networks are shown in figure 4.3. Node placement are usually made considering basic RF requirements namely capacity and coverage planning, economic and traffic factors.

Drive Test Routes Definition

Drive test routes are plotted initially aiming to specify spots where test measurements are taken place. The route comprised vindicating most attainable possibilities in the aspect of coverage, capacity and quality assessment.

In addition, test routes are defined considering several factors including nodes settlement, traffic condition, access road, compliant records and aforementioned geographical obstructions to meet the target of the test. Here again google earth is a tool that is adopted to spot out the path. The figure 4.4 shows routes for 3G

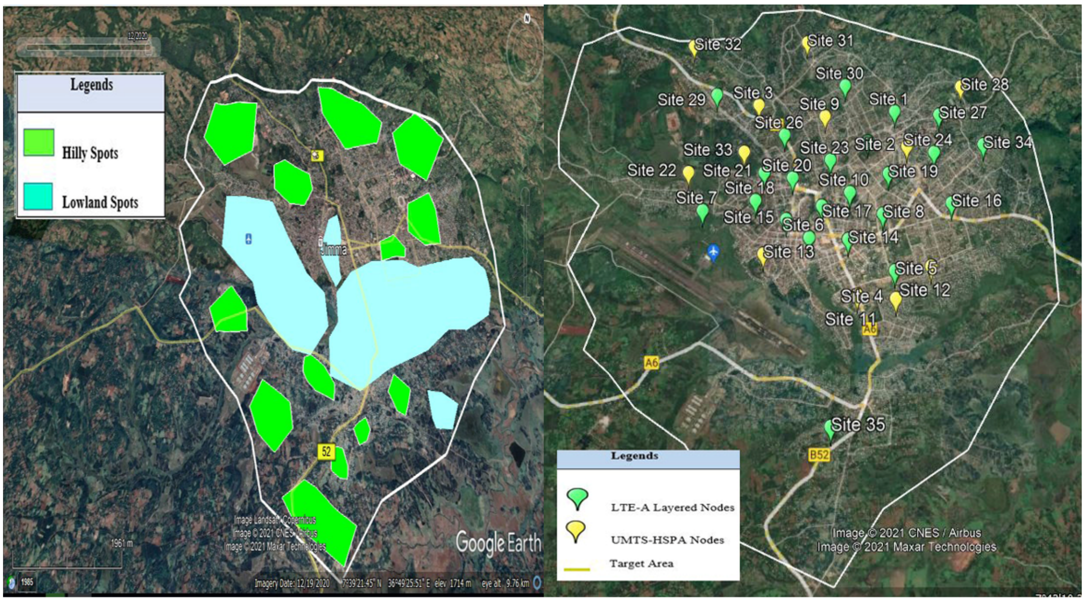

FIGURE 4.3: Terrian Profile & Nodes Distributions of Target Area

and 4G test tests. The test route for 4G covers 78.8 km route distance and in 30 km^2 of target area. Whereas 3G have had a greater amount radio element. It contains a test route of approximately 125 km and enclosed by 45.4 km^2 coverage area. Finally, both routes are successfully driven with minor access road challenge and effectively addressed the required target spots

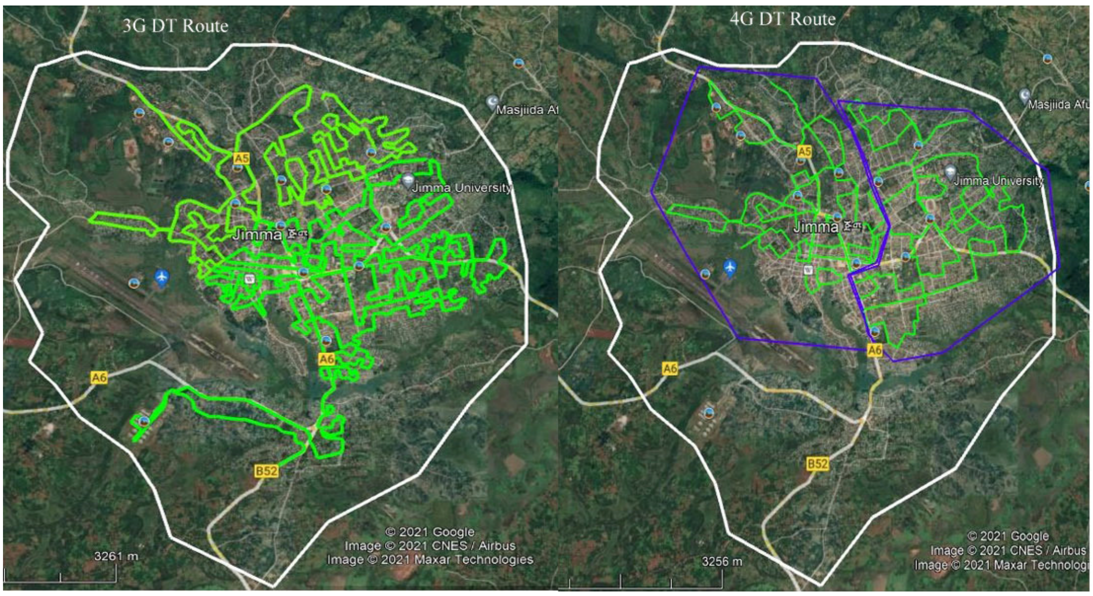

FIGURE 4.4: 3G and 4G Drive Test route

Test plan and KPI Definition

The test plan describes two basic elements namely test type and technical specification of the service to test and how the test is conducted. Test plans are itemized in voice and data test categories for both 3G and 4G tests. Test plans are organized to address coverage, quality and capacity problems since this thesis is intended to evaluate the performance of existing network. Thus, test types are specified according to table 4.1 in a relation with associated KPIs. Lastly,

Test Category	**Test Items**	**KPI**
Voice	Short call for UMTS	RSCP/SIR/EcNo/Pilot Pollution
Data	HSDPA HSUPA FTP throughput DL for LTE-A FTP throughput UL for LTE-A HTTP throughput DL LTE-A	Throughput Throughput RSRP/RSRQ/SNIR/Throughput Throughput Throughput

Table 4.1: Test plan

measurement and data collection has been carried out using a vehicle equipped with all drive test tools. confirming the pre-conditions, such as site health status, engineering parameters, device functionality and server reachability are verified before starting the test using OSS KPI statistic, RF audit and on-site inspections test. In this study the measurement accompanied to record signal strength, signal quality, interference, call statistics, session statistics, handover and throughput information.

4.5.2 Data Collection using OSS-based Network Statistics

Besides the dive test measurement, OSS-KPI statistic is also used in this thesis to evaluate the data throughput and traffic trend over the last one year. The analysis is illustrated in two sections that are tabulated in six months of data assessment that are arranged before and after deployment of LTE network. The development of temporal KPI statistics of the Jimma town 3G and 4G network contains two comparable terms. Twelve months for UMTS-HSPA and six months for LTE-A network performance is examined to meet specific objectives of this thesis. Noting that OSS data provides un-remitted measurements over a specified periods for both technologies, a unified analysis of both measurement scenarios constitutes a comprehensive detail of town's radio network performance. The analysis is also organized so as to come up with technical justifications regarding the feasibility and the impact of recently deployed LTE-A network as well as the overall end user experience of radio network of Jimma town. Figure 4.1 presents general overview of Ericsson performance management system that is integrated on Ericsson network management (ENM) platform.

4.5.3 RF Audit

Engineering parameters recorded as a precondition to verify existing RF resource and identify limitations. Post drive test tuning activities ad corrective adjustments are recommended based on registered parameters. RF audit and site solution are itemized both for UMTS and LTE nodes of the town.

4.5.3.1 Hardware and Channel Element Evaluation

All radio stations are equipped by Ericsson radio base station RBS6000 series designed for outdoor and indoor solutions. The RBS basically contains power distribution units, cooling units, control unit, cable trays and 19" rack to house baseband and backhaul elements. Every RBS is configured with three remote radio units (RRUs) per node based on the scheme, RRUS 01 (B1) for 3G and R2219 (B3) for LTE- A. There are two variants of baseband processing & traffic management units in the network namely digital unit for WCDMA (DUW 3101) and baseband 6630(BB6630).

Baseband 6630 (BB-6630)

BB6630 is a mixed mode baseband unit that supports multi radio operation. It provides the tremendous expansion and upgrading capability for GSM, WCDMA, LTE and future services. Currently BB-6630 is integrated in 23 radio stations in Jimma.

Description	**LTE/WCDMA/GSM**
Voice	480 MHz
Capacity	4000 connected users + 600 VoIP users/384/576 CE UL/DL +180 HSDPA Code/24 TRX
Pick DL throughput	600 Mbps
Pick UL throughput	300 Mbps
Cell capacity	12 cells/12 cell carriers
Operation	FDD/TDD /LTE-FDD /LTE-FDD and mixed
CPRI Interface	15 CPRI Port

TABLE 4.2: BB6630 Specification [57]

BB-6630 offer flexible configurations that is adapted based on the demand or license. Table **??** shows technical specification for Ericsson BB-6630.

Digital Unit for WCDMA (DUW 3101)

The Digital Unit WCDMA (DUW) is a baseband processing unit that mainly provides traffic and transport management functionalities as well as interfaces to other radio units. In Jimma, DUW 3101 is integrated in 12 nodes of network of the town. An essential resource named channel element (CE) are parts nodeB hardware resources that are described & run by software license. The number of CE specifies processing capability of a DUW. CE are often optimized and expanded to meet high speed data and service requirements. Table 4.3 presents technical data for currently installed DUW 3101 and upgraded variant. Moreover, existing Ericsson CE is capacity distribution of the town is also thought-out in this thesis. In this case, we found that 95% of nodes have CE capability of less that 512.

Description	Configuration	DUW 30	2*DUW 31	DUW 40
Cell carriers	Max number of carrier	6	12	12
Capacity Data Maximum DCH capacity	Channel Elements, (Downlink/Uplink)	768/512	1536/1024	1152/768
Ethernet Interface	100/1000 BaseT Ethernet	1	1	3
Optical Interface	STM-1	1	1	1
Radio Interface	Radio Interface Connections CPRI	1.25 Gbps, 2.5 Gbps, 5 Gbps (4), 10 Gbps	1.25 Gbps, 2.5 Gbps, 5 Gbps(4), 10 Gbps	1.25 Gbps, 2.5 Gbps, 5 Gbps(4), 10 Gbps
Throughput (Mbps)	DL Peak Throughput (Mbps) UL Peak Throughput (Mbps)	252 48	504 94	336 138

Table 4.3: Technical specification of DUW [58]

4.5.3.2 Backhaul Evaluation

The link capacity and bandwidth utilization is key index & determining factor of mobile broadband network both at dimensioning and operational stages. A number of throughput and quality limitations are associated with packet link capacity of backhaul. Both backhaul and local backbone network capacity are audited so as to ascertain whether the network establish seamless connectivity or subjected to packet drops, interruptions and poor QoS due to capacity limitations that would not be capable of accommodating gigabit requirements. Here, 11 nodes are integrated with 1 Gbps,12 to 369 Mbps and the remaining 12 sites are connected with 179 Mbps backhaul links. Ericsson mini link Compact node (CN510), traffic node (TN-6P) and SP420 routers are deployed for existing mobile backhaul and metro aggregation in Jimma though all elements are not capable of carrying a gigabit traffic.

4.5.4 Definition of Requirements

The definition of requirements presented based on the existing and projected demands of subscribers served in target area of the network. Hence, its fundamental to define and have a picture of a radio network to be implemented & RF KPI requirements are described based on acceptable global practices.In purpose of achieving acceptable QoS and resource optimization; KPI requirement for both 3G and 4G test plans are defined based on vendor recommendation, reviewing related works and 3GPP specifications [59][60] [61]. The analysis is carried out considering targets presented in table 4.4. The objective of KPI setting is to measure the performance and recommend relevant improvement ideas with exiting resource and also investigate alternative solution that are economical & viable.

Indicator	KPI	Target
Coverage	Measured $RSRP$	-95 dBm over 97 % of area
Quality	Measured $RSRQ$	> -15 dB over 95 % of area
Quality	Measured $RSRQ$	> -15 dB over 95 % of area
Interference	Measured $SINR$	> 9 dB over 95 % of are
Coverage	Measured $RSCP$	> -88 dBm over 97 % of area
Interference	Measured E_c/N_o	> -12 dB over 95 % of area
Pilot Pollution	Pilot Pollution Location percentage	5%

Table 4.4: KPI Target definition

Following a growing high speed application in the town, it is needed to provide 20 Mbps consistently [3][62].

4.6 RF Planning

In this thesis, the radio network planning is performed with assumption of an initial RF configuration and ideal specifications of HSPA+ release 9 standard

Parameter	**Value**	**Remark**
Number of 3-sector sites	35	
Tx power Bandwidth	20 W 10 MHz	 With CA
Indoor penetration loss	10 dB	
Carrier frequency	2100 MHz	
MIMO Configuration	2X2	
Code Rate	2/3	
Carrier Configuration	U333	
Propagation Model	COST 231	
Access Technology	CDMA	
Coding	CTC	
Modulation	16 QAM (UL)/ 64 QAM (DL)	
Inter-site distance	1000m	
Target Load	0.75	
BS antenna height	35 m	
TX cable loss	2 dB	
Antenna gain	18 dBi	
Electrical down tilt (RET)	0-12 Degrees	
Mechanical down tilt	0-5 Degree	
Required Eb/No	7 dB	
Noise figure	5 dB	
Interference Margin	6 dB	
Shadow fading margin	7.5	
Path loss constant	129.4 dB	
Required signal power	110 dBm	
Coverage Probability (Cell edge)	0.9	
Cell range	3 km	

Table 4.5: RF Parameter

are considered to simulate high data rate & good coverage areas in the town capitalizing existing radio resources. Thus, we have not performed the radio link budget calculation for sake of re-dimension whilst basic link budget parameters are taken in to consideration to acquire the utmost path loss performance.

Moreover, employing COST 231 propagation model coverage and capacity estimations are made considering both transmitter and receiver radio parameters in [56][59][63]. Latest digital map is also employed to overcome clutter and terrain changes that have been built after initial deployment. Table 4.5 presents essential RF parameter that are used in this thesis.

4.7 Viability of LTE-A Layering

I. Traffic Impact

LTE-A data traffic has been growing promisingly and it is estimated to account more than one-third of 750.5 TB that was utilized in consecutive quarters after launch. The celerity could still indicates possibilities of market growth. Due to a rise in subscription and service utilization, the average throughput per user has also been abridged through time.

Data-devouring applications and new mobile broadband services has accelerated LTE-A utilization in the town and the layering has addressed these growing demand to a certain extent despite throughput and coverage issues. Figure 5.14 illustrates that the adoption has been potentially alleviating several problems in providing fast data rate broadband services. Moreover, LTE-A bolster town's mobile network triggering digital platform employment that concurrently maintain ecosystem development and boost commercial interaction as well.

II. Profitability Analysis

Following a massive deployment of 3G and 4G networks, mobile broadband market becomes one of the promisingly growing business sector in Ethiopia and it has abundantly maintained the economic benefits besides. This section assessed the profitability of recently deployed LTE-A network layering in major towns of south & south western Ethiopia. This include all 185 eNBs and 1 core station that are settled by Ericsson as a part of operators' three year strategic plan. The analysis is accomplished using a widely accepted financial metrics called return on investment (ROI) and internal rate of return (IRR). In order to calculate both metrics, revenue is estimated based on the first 6 months' PS traffic utilization of L1800 and predictions are made for the remaining 6 months of the year using least squares regression (LSR) model. An average tariff rate for mobile internet is used to calculate the revenue as well. In this regard, both investment costs and revenue are estimated considering all valuable taxes upon the operational regulation and declaration of Ethiopian revenues and customs authority. In table 4.6 revenue estimation of LTE-A layering is presented in which loan interest, backhaul upgrading and internet gateway costs are not considered in this computation.

Month (2021/22)	**Sum of Data Volume (MB)**	**Revenue After Tax (Birr)**	**Operation and Maintenance Estimation (Birr)**	**Utility Cost Estimation (Birr)**	**Miscellaneous Operational expense Estimation (Birr)**
Jun	25653271.9	1250597.007	301030.1867	599705.25	1202500
Jul	225482034	10992249.17	404370.5833	599705.25	1202500
Aug	349459092	17036130.71	305878.3167	599705.25	1202500
Sep	429311590	20928940.01	351321.1	599705.25	1202500
Oct	486494340	23716599.07	439091.28	599705.25	1202500
Nov	518293949	25266830	331314.52	599705.25	1202500
Dec	567015652	27642013.01	478454.5667	599705.25	1202500
Jan	611506831	29810958.01	432681	599705.25	1202500
Feb	655998010	31979903	366800	599705.25	1202500
Mar	700489190	34148848	302680.2233	599705.25	1202500
Apr	744980369	36317792.99	473529	599705.25	1202500
May	789471548	38486737.99	470545.29	599705.25	1202500
Total		**297577599**	**4657696.077**	**7196463**	**14430000**

TABLE 4.6: Revenue and Cost Estimation of LTE-A Layering

While computing total investment cost estimation, both an onshore 110895287.083 birr and offshore 606714959.13 birr project rollout expenses are taken in to account with 6780000 birr operation and 66288990 birr cluster and optimization expenses. Moreover, the average broadband revenue growth rate reported by the operator in 2019/20 and 2020/21 fiscal year over the last two years is also used to predict 2022/23 and 2023/24 revenues. Thus, the predicted revenue for each term after 4% of dividend will be 284724034.4 and 311070364.7 birr respectively. And the overall operational cost is 26284159.08 birr. Official requests to the Ethio Telecom regarding information related to revenue, subscription rate, device penetration has been rejected twice, thereby aforementioned estimations are made cautiously. In this regard, few costs are not thought in the analysis of both metrics whereas the itemized expenses and revenue reveals approximate financial circumstances nonetheless.

Return On Invested Capital (ROIC)

ROIC is a key indicator widely used to evaluate the profitability of an investment that measures the effectiveness from an investment in relation to the initial investment [64]. It shows financial performance and also attests viability of the investment with simple and flexible assessment of generated profit and its capital. According to [67] $ROIC$ is mathematically expressed as shown in equation 4.6.

$$ROIC = \frac{NOPAT}{Invested \quad Capital} \tag{4.6}$$

Where, $NOPAT$ stands for net operating profit after tax and Invested Capital is the sum of all capital expenditure. Thus, based on the computations of cost items mentioned above table:

$$\begin{aligned} NOPAT &= (260441702.3 + 284724034.4 + 311070364.7 - 26284159.08) \\ &= 12988546.96 \quad birr \end{aligned}$$

Thus, the return On invested capital will be:

$$\begin{aligned} ROIC &= \tfrac{12988546.96}{818004020.3} * 100\% \\ &= 1.59\% \end{aligned}$$

From the result, the ROIC did not exceeded the recommended value 2%. Therefore, the investment is thought to be not promisingly profitable in this metrics although the positive value indicates is still creating a value to a certain extent. In the other word, the figured ratio depicts presence of non-negligible profit generation in a return for the of capital tied up into an investment.

Internal Rate of Return (IRR)

Internal rate of return (IRR) is a most implemented investment assessment tool used in capital planning to measure profitability of investments. It indicates the financial efficiency and quality of an investment. Its widely used techno economic analysis criteria adopted by several telecom operators so as to ascertain the value accomplished with respect to the capital [65][67]. It determines the discount rate of an investment in which the net present value (NPV) matches investment cost. According to [67] IRR is mathematically given by equation 4.7. where NPV is zero.

$$NRV = \sum_{n=0}^{N} \left(\frac{C_n}{(1 + IRR)^n} \right) \tag{4.7}$$

Where, n is a period, C_n is cash and IRR is internal rate of return. Thus, substituting three years of forecasted cash flow values into equation 4.7 results :

$$\sum_{n=0}^{N} \left(\frac{C_n}{(1+IRR)^n} \right) = 0$$

$$-816963395.3 + \left(\frac{260441702.3}{(1+IRR)^1} \right) + \left(\frac{284724034.4}{(1+IRR)^2} \right) + \left(\frac{311070364.7}{(1+IRR)^3} \right) = 0$$

Hence,

$$IRR = 2.32\%$$

From the result, the value of IRR is less than a recommended minimum discount rate for telecom operator, which is 10%. Hence, the profitability of an investment in a projected three year would be regarded as a long shot though lowest suggested IRR value depends on investment strategy and financial status of a business.

Chapter 5

Result and Discussion

This section provides analysis and discussions of radio network performance evaluated both in real time assessment and network performance statistic scenarios. All measurement and data collection has been recorded from December 2020 to November 2021.

5.1 Jimma Town UMTS-HSPA and LTE-A Network Coverage and Throughput Distribution Analysis

Coverage and throughput distribution analysis of Jimma town UMTS-HSPA and LTE-A mobile broadband network is carried out by examining a drive test records that is conducted based on a pre-defined test plan and route.

5.1.1 Jimma Town UMTS-HSPA Network Coverage Distribution

The coverage distribution both 3G and 4G networks of the town is evaluated with analysis of signal strength, quality and interference metrics named RSCP, Ec/No, RSRP, SINR, RSRQ along with pilot pollution event analysis. In this regard, drive test route is defined considering fundamental factors like NodeB settlement, obstructions, propagation pattern and radio wave losses.

The figure 5.1 shows RSCP of 3G existing network in Jimma town. Most test detection revealed the town is in good form regarding signal strength where the larger portion of target area is covered with good signal level. Nearly 1.5 % of test spots exhibited poor signal strength level (< -88 dBm). As shown in same plot, most poor signal spots are associated with obstructions and terrain at the edge of the target area.

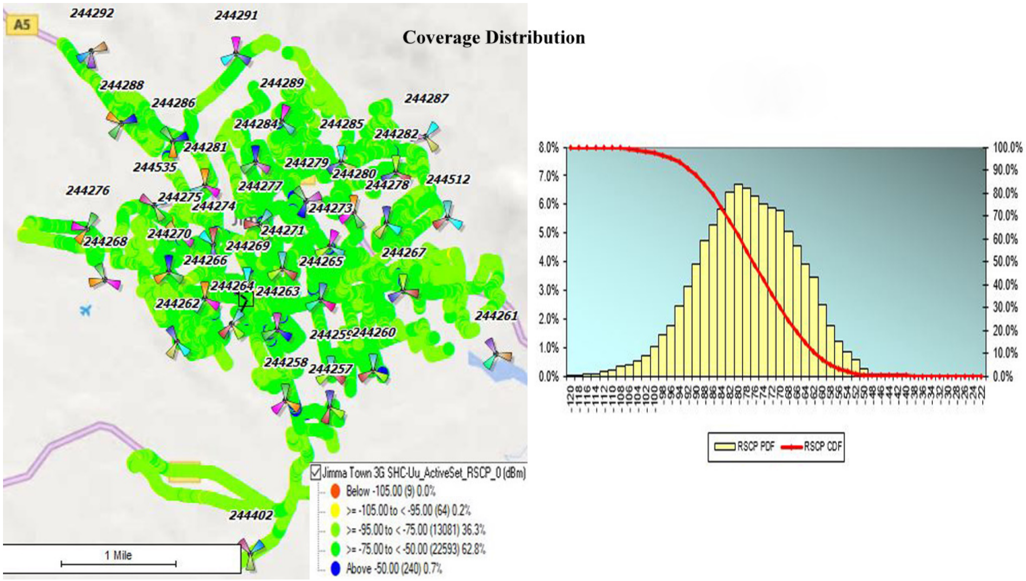

FIGURE 5.1: 3G Coverage Distribution

In the same plot, PDF & CDF statistics of the coverage distribution is also shown in histogram where more than 98% of measurement records of tested routes in the town are a very good signal level. Based on the drive test analysis report the interference and noise level of the town is monitored to further assess bad coverage spot in the town. As presented in figures 5.23 the impact of noise and interference in the test route is illustrated with E_c/N_o and SIR parameter metrics. Among the overall target patch notable portion of samples are observed with bad E_c/N_o and most samples are alluded with in the good SIR range.

According to the analysis, majority of the illustrated bad EC/No regions are related to bad coverage (discussed above) and pilot pollutions. Figure 5.3 shows

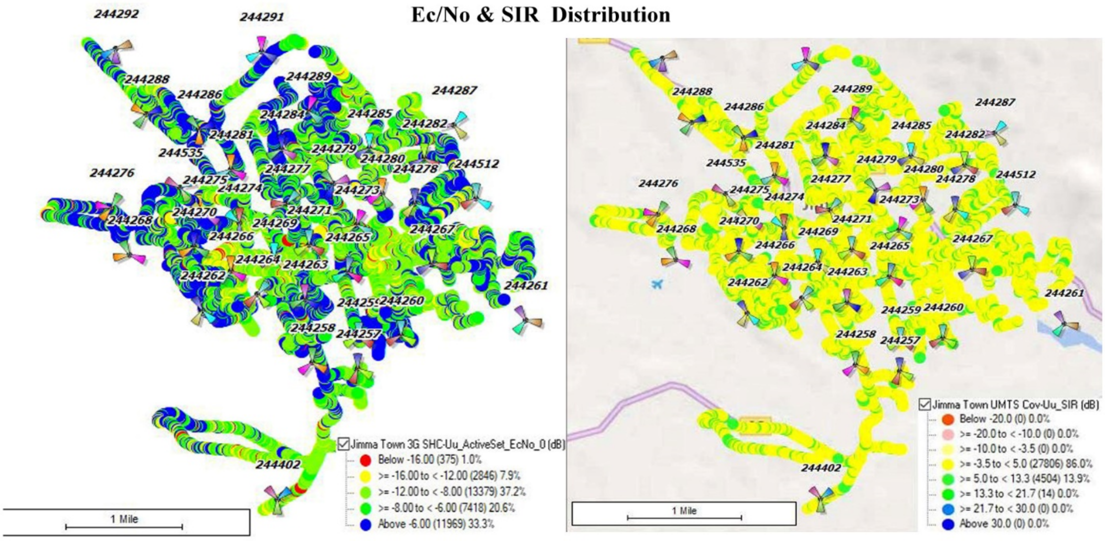

FIGURE 5.2: 3G E_c/N_o and SIR Distribution

several unexpected pilots are detected in these spots serving from distance. From the total 4275 recorded events, 342 overshooting or mis-aligned pilots are detected passing the nearby tier. Most impacted areas in the town are illustrated in black box below in which 10 cells are distinguished with relatively larger occurrence.

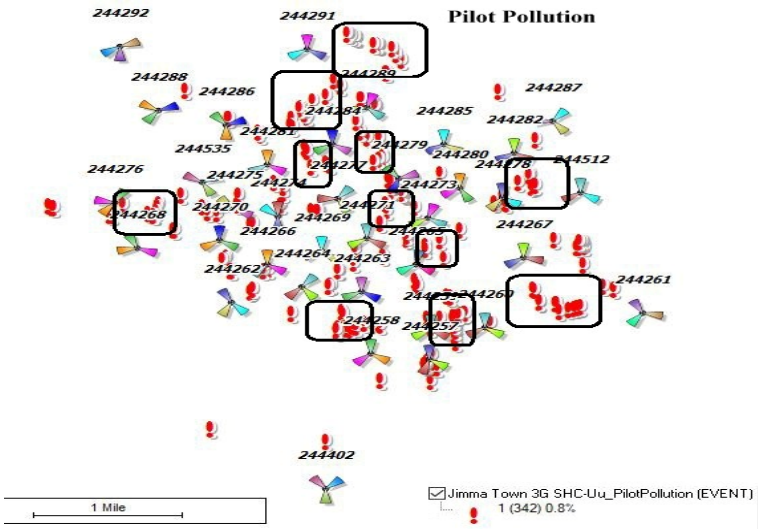

FIGURE 5.3: 3G Pilot Pollution

5.1.2 Jimma Town UMTS-HSPA Network Throughput Distribution

Both downlink and uplink data throughput distribution of Jimma town 3G HSPA technology is reviewed through both the drive test measurements and OSS network statistic. Figure 5.4 depicts application and physical data throughput result of HSDPA drive test measurement taken from test trajectory across the town. When examining the values HSDPA samples we found average throughput of 8663.39 Kbps and maximum throughput reached is 25270 Kbps. Greater number of samples are realized having a lower throughput in both test cases. Higher throughput values are also checked out in few spots that have had good radio conditions. From the result, a far-ranging poor HSDPA throughput performance of the town need significant improvement so as to alleviate an illustrated data integrity and QoS problems.

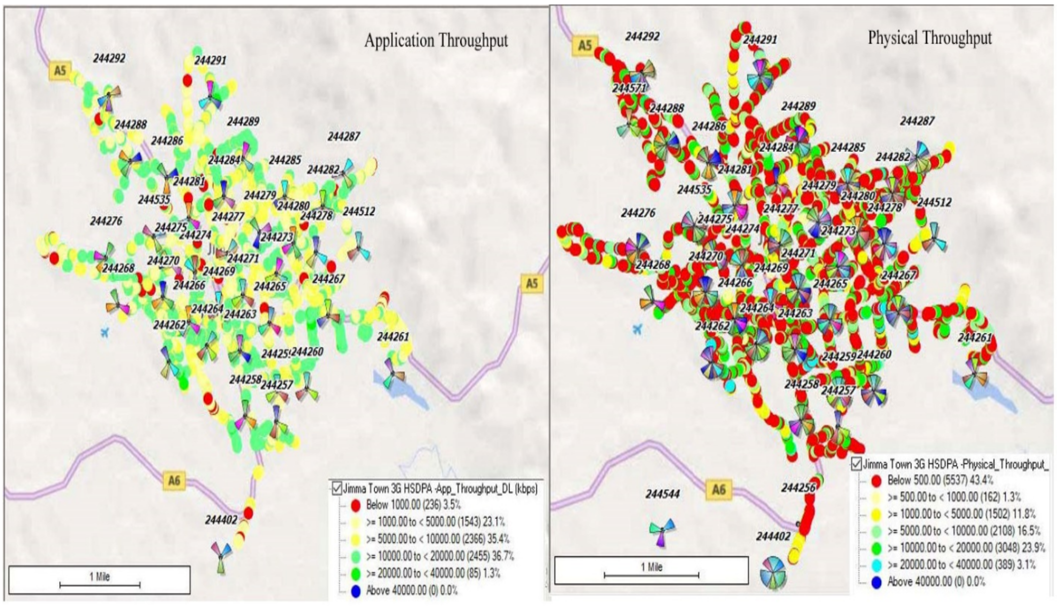

FIGURE 5.4: HSDPA Throughput Distribution

The downlink application throughput performance of HSPDA is analyzed in different radio conditions. Figure 5.5 presents HSDPA performance over conditional $EcNo$, $RSCP$, BLER & power levels. Higher downlink throughput samples are associated with good radio conditions, whereas lower throughput samples are allied to poor coverage and quality spots.

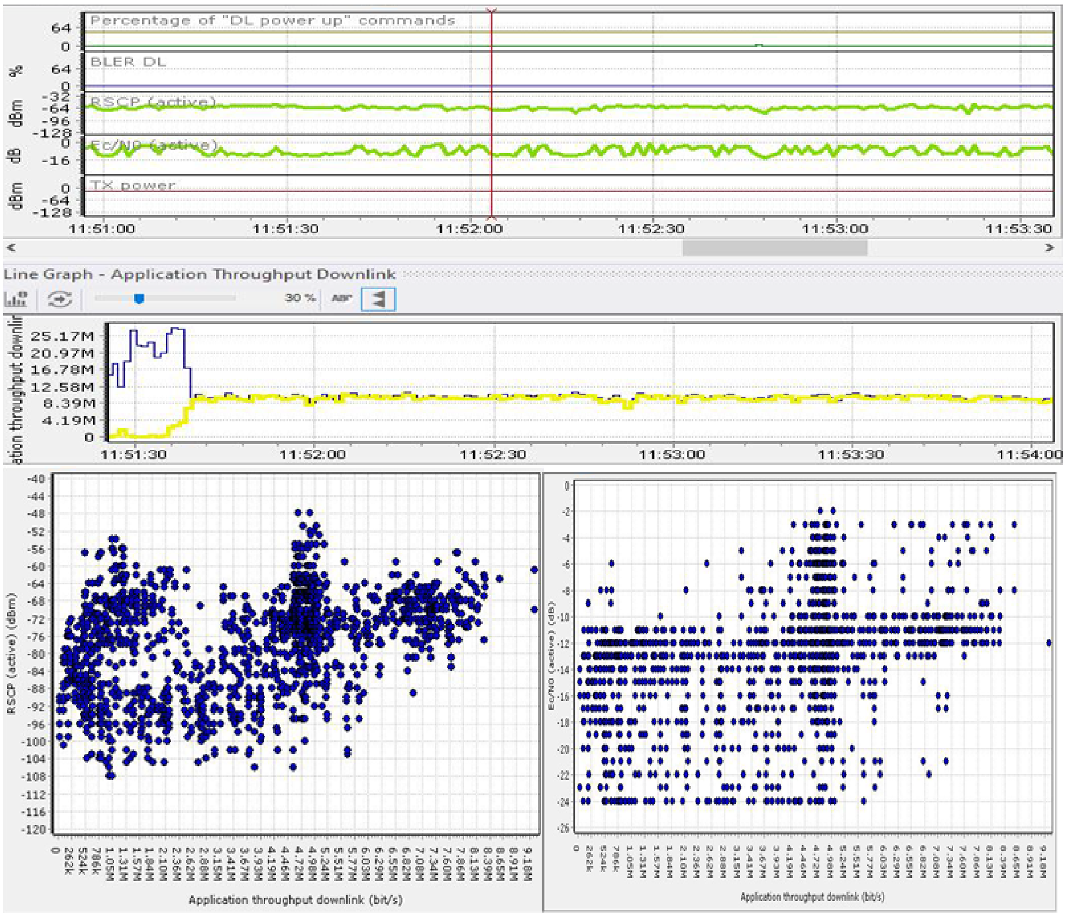

FIGURE 5.5: HSDPA Throughput Vs Radio condition

Figure 5.6 presents the physical and application data throughput of HSUPA drive test records. The result shows that almost all samples are allied below 5000 Kbps of data throughput. Samples related poor uplink throughput of the town is collected in the areas of dense residential and marketing settlement. Based on statistical computation of samples the average throughput is 1844.95 Kbps and the maximum is 8320 Kbps.

In purpose of assessing causes of poor throughput performance further, we have evaluated other essential throughput correlated KPI as well. In this regard, CQI and BER distribution of Jimma town is presented in figure 5.7. From the plot, large number of samples are seen in an acceptable level of CQI and BER. Hence, throughput setback is clearly associated with capacity of the network.

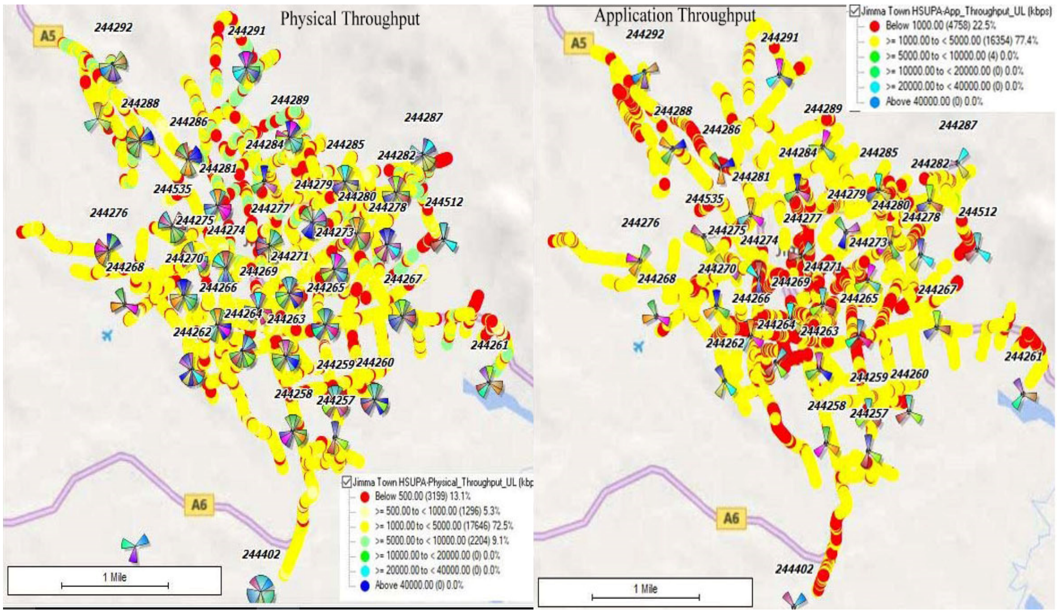

FIGURE 5.6: HSUPA Throughput Distribution

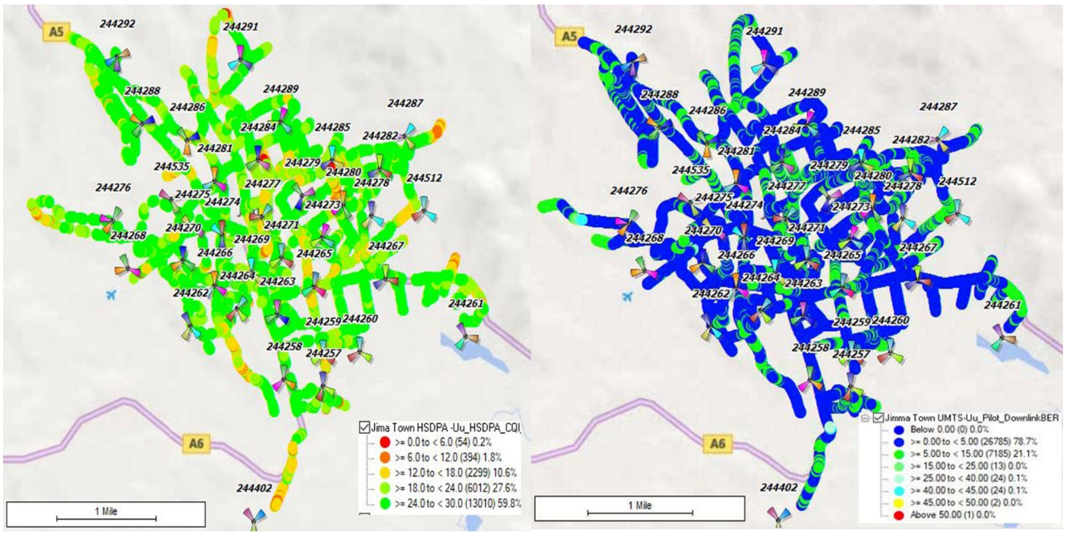

FIGURE 5.7: 3G CQI and BER Distribution

5.1.3 Jimma Town LTE-A Network Coverage Distribution

In Jimma town, the coverage and quality distribution of a recently deployed LTE-A is an imperative subject that substantiate the qualm in the viability and traffic impact of cellular network. The coverage performance for LTE-A cellular network is evaluated using a drive test logs that are taken from a predefined LTE-A test route of the town. Figure 5.8 attests that poor $RSRP$ is detected in a large part of test routes where more than 15% of the samples are associated with bad level of signal strength. It is also shown in a result that a very bad coverage spots are realized around the north western edge of the town whereas a certain coverage holes have been noticed in central parts as well.

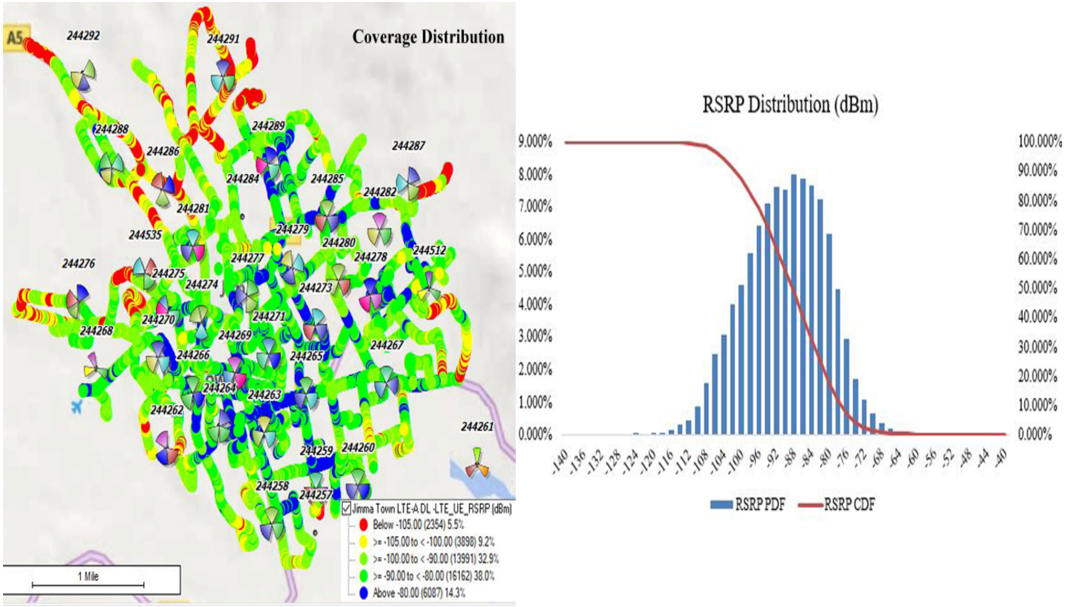

FIGURE 5.8: Coverage Distribution of LTE-A network in Jimma town

Correspondingly, the quality and interference distribution pattern of the town also clearly illustrates poor coverage profile. From the analysis result shown in figure 5.9, both $RSRQ$ and $SINR$ distribution of the town is poor. These bad distri-

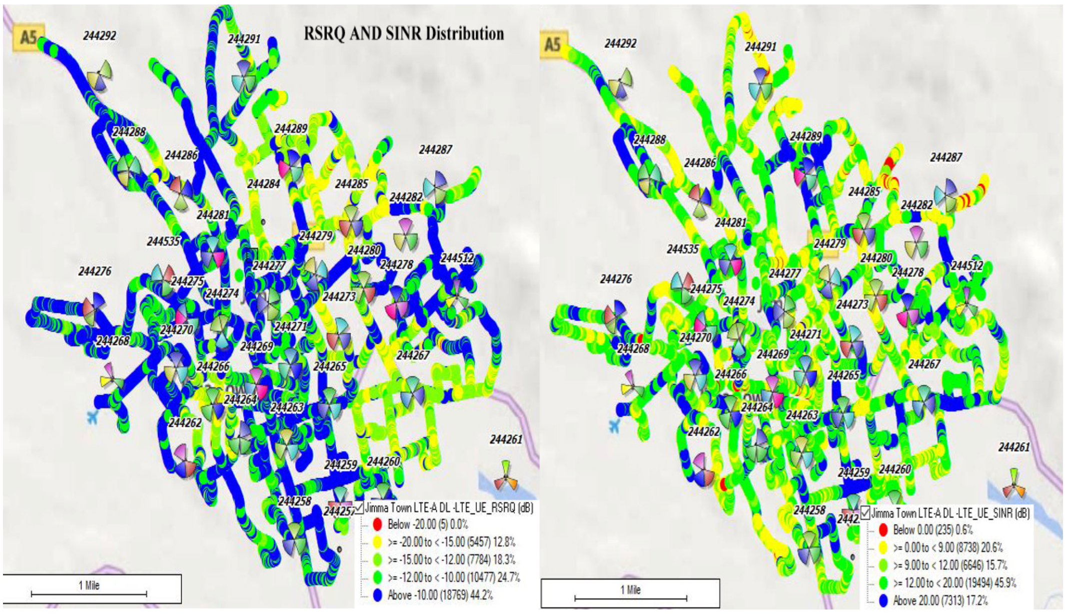

FIGURE 5.9: $RSRQ$ and $SINR$ Distribution of LTE-A Network

butions are detected typically at the edges of the town. The coverage austerity in terms of signal strength and quality of the town is very critical. When analyzing the results illustrated above, it could be easily associated with the lack of eNBs as only 23 nodes are layered to serve the whole part of the town.

5.1.4 Jimma Town LTE-A Throughput Distribution

The download and upload throughput performance of LTE-A network of the town is analyzed using a drive test sampled records and OSS KPI statistics. Figure 5.10 presents application and physical throughputs of FTP and HTTP download tests that are evaluated through drive test measurement collected from DT route where unevenly distributed poor throughput trajectory sections are observed across the town. Relatively, central part of the town has shown better throughput performance; however, the north-western segment test samples acquired lower data rate. From the analysis result, the average physical and application throughput for FTP test are 64347.61 Kbps and 57384.21 Kbps respectively. For HTTP, 18973.27 Kbps application and 19682.8 Kbps physical DL throughput are figured from test log as well. Likewise, nearly all test samples of both ftp and http drive test down-

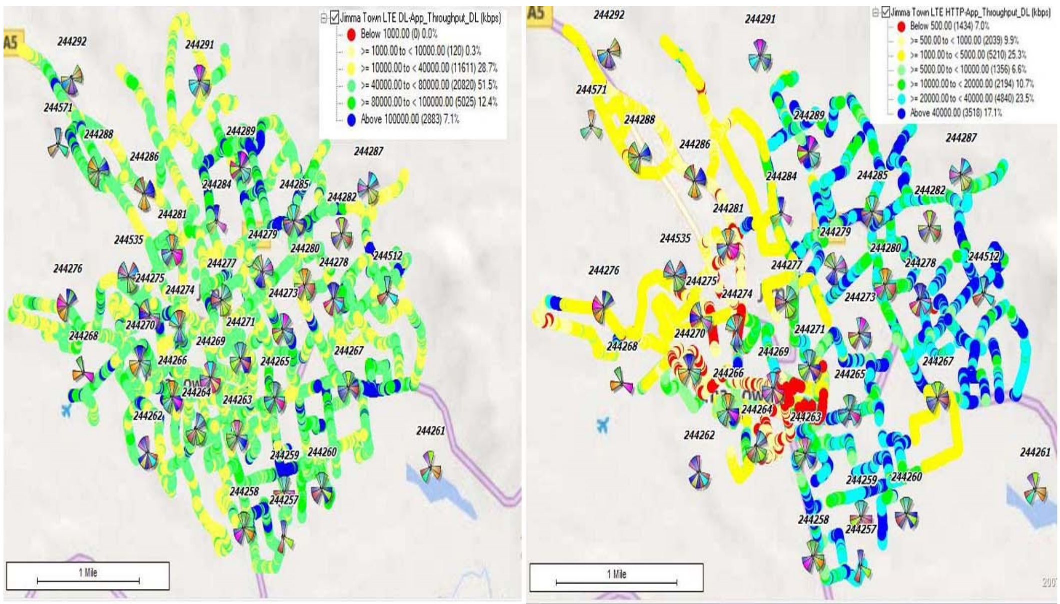

FIGURE 5.10: LTE-A download throughput distribution of Jimma Town

link throughput measurements are failed to secure a gigabit internet speed offer by LTE-A. Considering technological prospects, these figures depicted doubts in high-speed broadband internet provisioning & viability of recently layered LTE-A network by a larger extent.

Similarly, the upload data throughput performance of LTE-A network attested in figure 5.11. The plot represents the distribution of upload throughput measurements over the test routes. Relatively several poor download data rate detection areas are observed in in the southern part of the town and good data rate samples are recorded on the north-western of the town. From drive test analysis, the average application throughput is 32119 Kbps though 24.6% of the measurement has carried a data rate below 20000 Kbps.

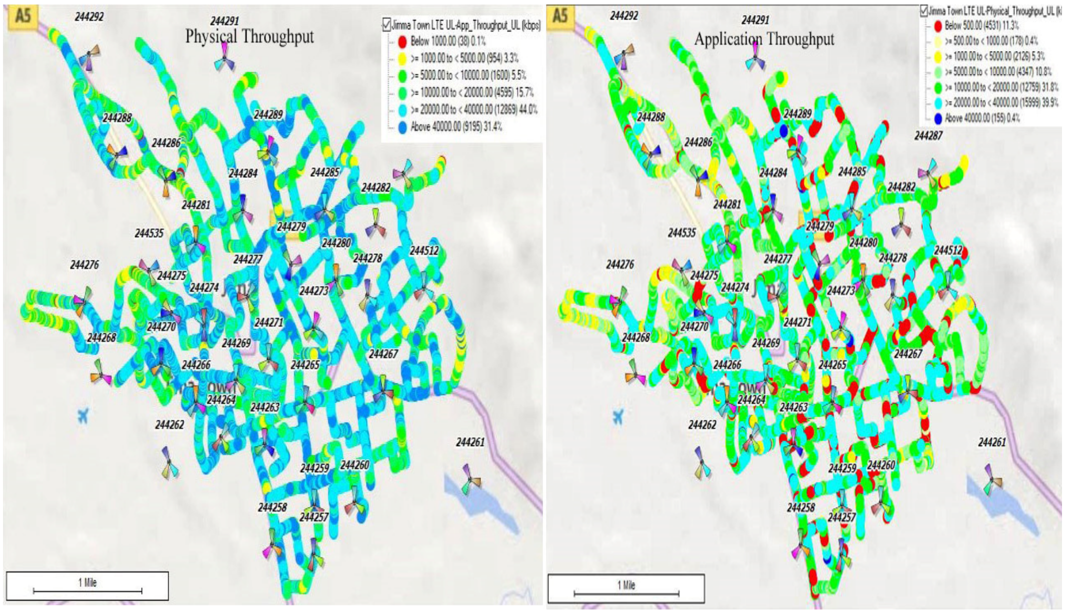

Figure 5.11: LTE-A Upload Throughput Distribution

Downlink throughput performance of LTE-A network is also evaluated over different radio conditions. As shown in figure 5.12 a higher downlink throughput spots are associated with good radio conditions. Though majority of measurement samples are allied to poor RSRP levels where more than 65% of sample are below -95 dBm.

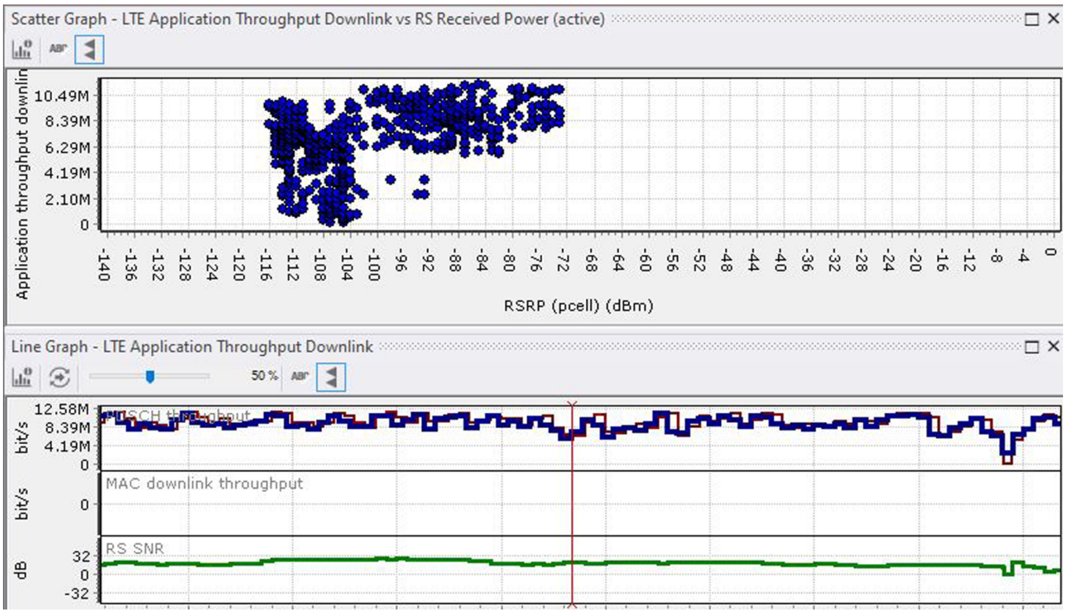

FIGURE 5.12: LTE-A Downlink Throughput Distribution Vs Radio Condition

5.1.5 Jimma Town UMTS/HSPA and LTE-A Handover Performance Analysis

The evaluation of of drivetest field measurements depicts that there is no outstanding mobility issue in both UMTS and LTE-A networks.

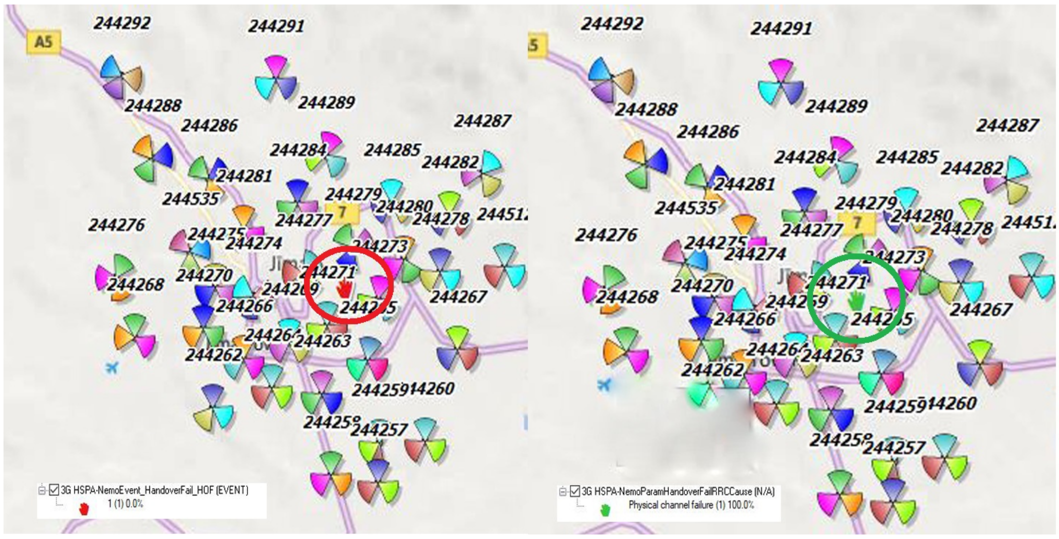

FIGURE 5.13: Jimma Town UMTS/HSPA Handover Performance

Figure 5.13 illustrates mobility perfoormance of UMTS/HSPA network where there is only a single handpver event is detected due to physical channel resource unavailability. Similarly, no handover failure event is detected in LTE-A.

5.2 OSS KPI Traffic Evaluation

Valuable performance metrics of service integrity & usability are examined to realize traffic volume and data throughput.

5.2.1 OSS Data Traffic Volume Analysis

The PS traffic volume data is collected in a specific period from aforementioned nodes of 3G and 4G network in the town. Figure 5.14 presents the data traffic volume intensity of both UMTS-HSPA & LTE-A. From the total 750.5 TB of traffic, about 65.83% of PS traffic is carried through dominant 3G network over the last six months; however, 2G, fixed access network and all CS traffics are exclude in this computation. From the result analysis, traffic volume for LTE-A is progressively rising since the launch in early June 2021. This growing tide of LTE-A traffic in the town is basically triggered by globally prophesied mobile users' migration trend for emerging mobile broadband connections and also operator's motivational rewards and bundles in purpose of embracing new technology in spite of minor turndown observed in November 2021. The traffic volumes and data utilization trend of last six months revealed that a gigabyte LTE-A has flourished a remarkable despite this hysterical solution plagued by throughput & late celerity depletion. Whereas, the plot above shows UMTS-HSPA PS service of Jimma town has maintained the linear utilization trend over a specified period.

5.2.2 HSPA & LTE-A User Throughput Evaluation

Statistical analysis of user data rate attests that user throughput of HSDPA & HSUPA is immensely lower than globally accepted verge of mobile broadband services. From the result, the average DL user throughput of HSDPA in the last one year is 584.45 Kbps. As illustrated in figure 5.15 user throughputs is between 600 Kbps and 700 Kbps whereas HSUPA is less than 100 Kbps in both assessment terms. In both PS and CS case, predicted traffic celerity has not been accomplished

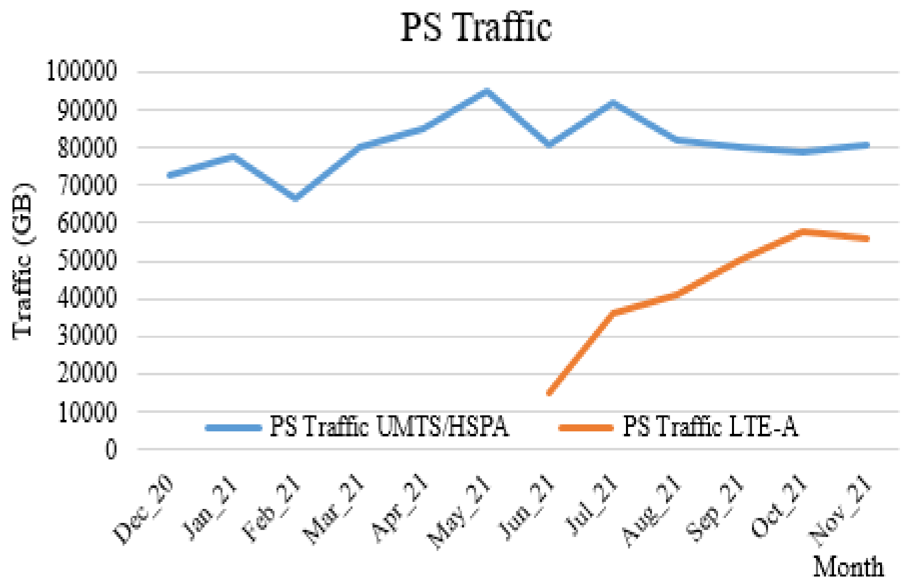

FIGURE 5.14: Jimma Town UMTS-HSPA & LTE-A Data Traffic Volume

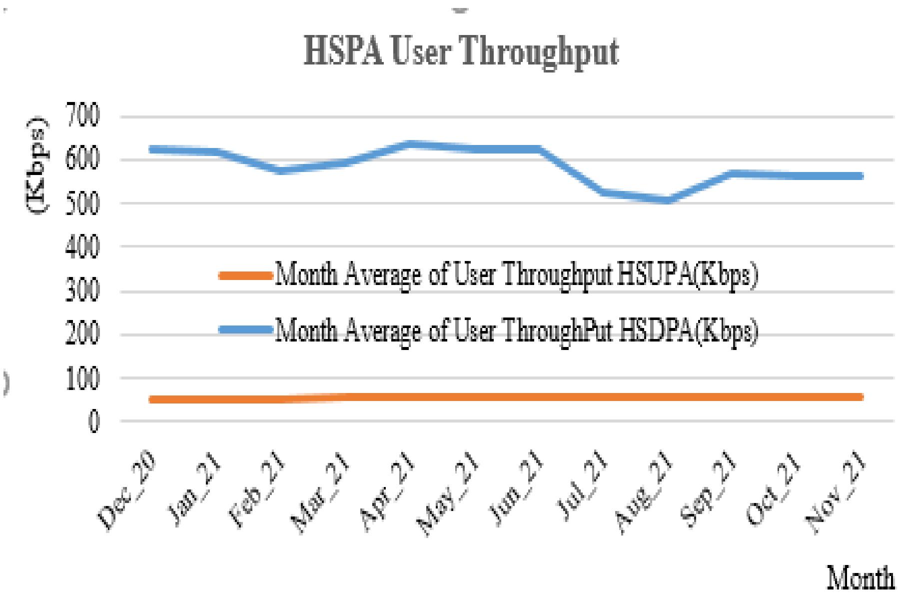

FIGURE 5.15: HSPA User Throughput

after a high traffic load assuaging LTE-A layering has been launched. In addition, slight CS traffic growth and RRC/RAB congestion that are presented in figure 5.16 has illustrated negligible impact of 4G layering on predecessor 3G network. In addition, HSDPA and HSUPA inaccessibility rate is poor and has not been significantly improved after LTE-A layering as well. Figure 5.17 presents both uplink and downlink PS call setup success rates (CSSR) of HSPA network.

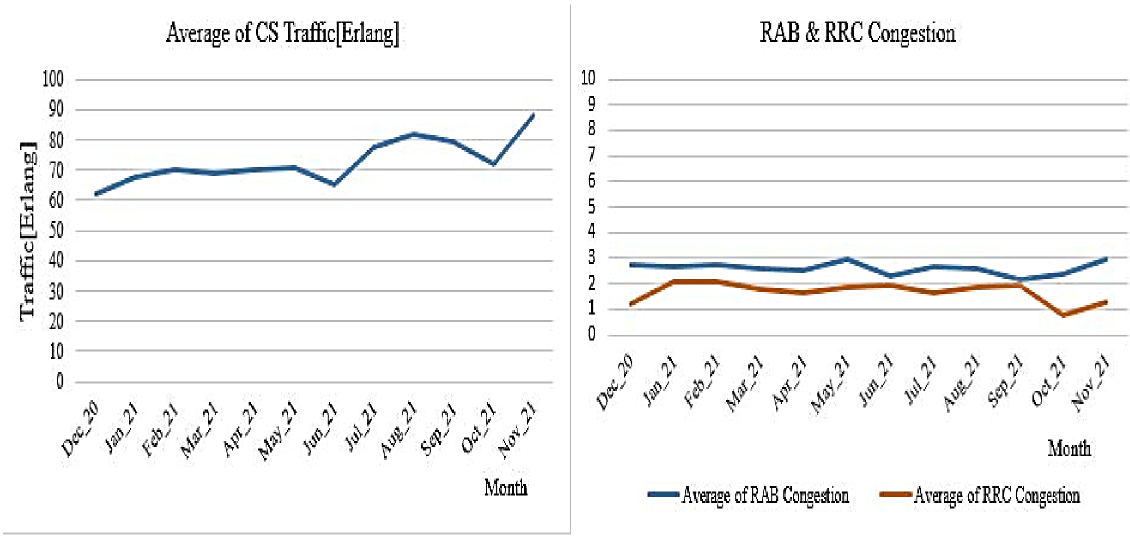

FIGURE 5.16: UMTS-HSPA CS Traffic and RAB/RRC congestion

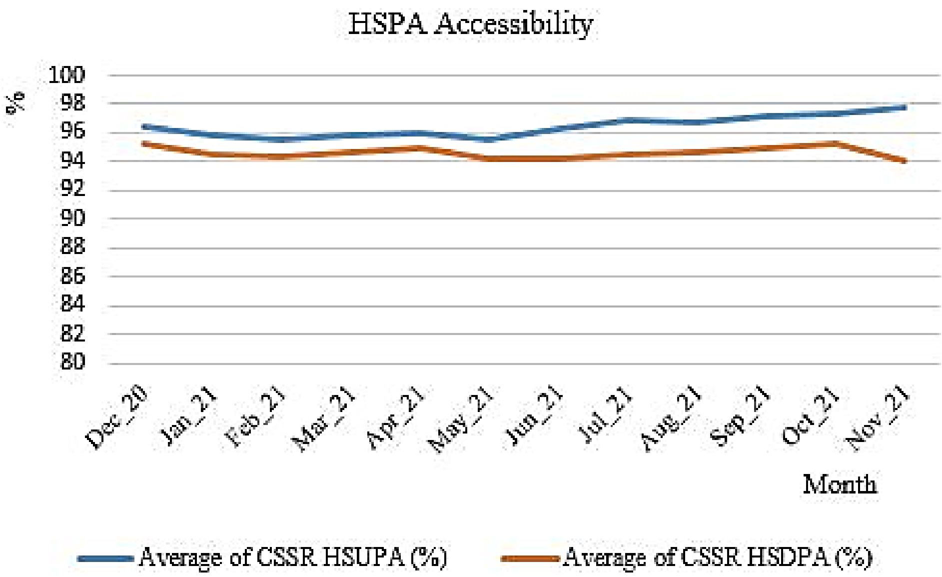

FIGURE 5.17: HSPA Accessibility

Data analysis of LTE-A cell and user throughput items of Jimma town has shown smaller figures likewise. From statistical analysis the result, the average user and cell throughputs are 33.25 Mbps and 16.24 Mbps respectively which is extremely smaller speed than anticipated rate of LTE-A standard. Figure 5.18 presents average cell and user throughputs of UL and DL traffic. Due to smaller data load, the average cell throughput is lower than user throughput in all interval.

In this regard, LTE-A network has not experienced accessibility problem over the last six months. From result and analysis shown in Figure 5.19, the accessibility

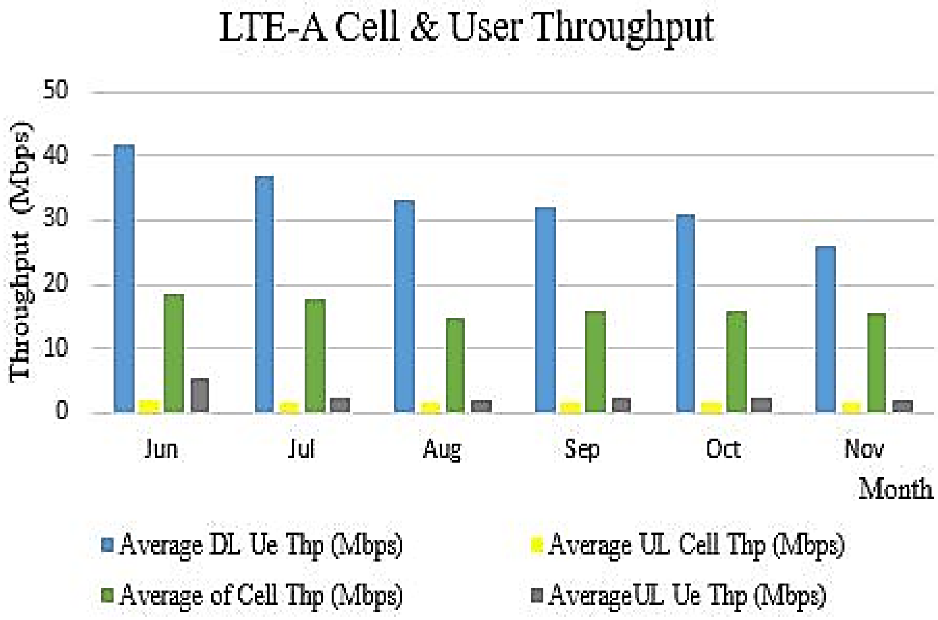

FIGURE 5.18: Cell and User Throughput of LTE-A Network

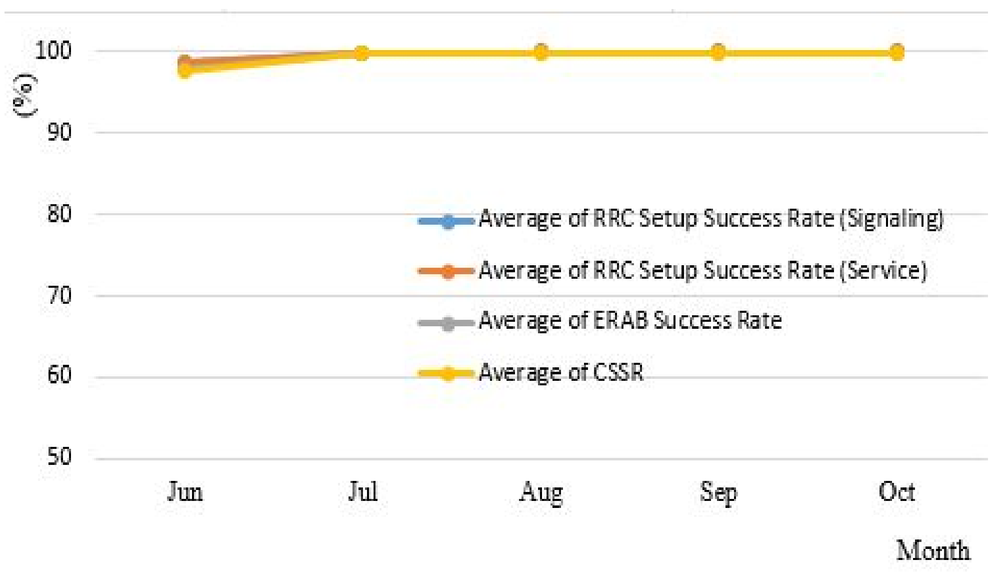

FIGURE 5.19: LTE-A Accessibility

performance of LTE-A network in the town did not encountered notable problem in accessing the network over the last six month and users are likely served sufficiently in LTE-A coverage area of the town.

Following afore-presented performance analysis and traffic evaluation of both UMTS-HSAPA & LTE-A network of the town, a comprehensive summary has been cited in purpose of providing a comprehensible RF picture in-terms of coverage and quality and throughput metrics.

5.2.3 Comparison of Theoretical and Measured Throughput Performance

Theoretical and measured performance of LTE-A and HSPA+ network is illustrated in figure 5.20. Due to poor radio condition and load offering capability of the network, the measure data rates of UL & DL of both technologies are very poor. This smaller throughput explicitly show the extent of real time experience compared to typical throughput that would be envisaged in a good radio condition.

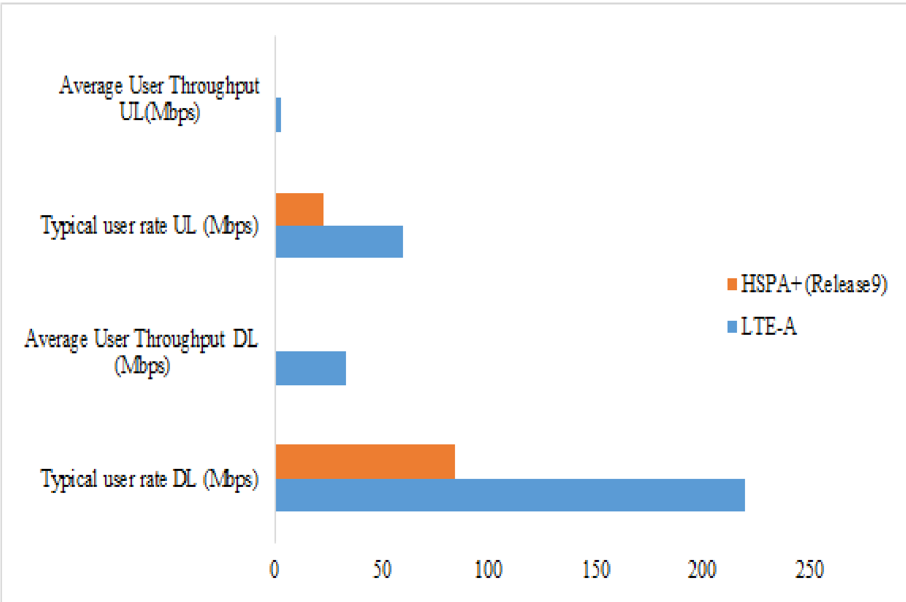

FIGURE 5.20: Theoretical vs Measured Throughput

5.3 Summary of Result and Analysis

The overall analysis results provide sufficient reason and certainty that explicitly figured a rationale behind LTE-A layering and its impact on existing UMTS-HSPA network. In addition, the comprehensive RF performance of the town mobile broadband network besides. Following results on both driver test and OSS data analysis scenarios, we have generalized the following overviews:

- Optimal coverage requirements for UMTS-HSPA are fairly fulfilled though there are remarkable parts the target area possessed by bad quality and interference. In addition, very small number of pilot pollution events are recorded that would perhaps be solved by RF adjustment and tuning. Table 5.1 and 5.2 shows the general coverage distribution picture of the network employing essential metrics.
- For LTE-A, severe coverage problem is depicted at various parts of the town to a large degree. It's below the recommended level and also failed to meet company's coverage standard by far. This weak coverage and blackspots problems would be associated with lack of eNBs. Results in table 5.1 and 5.2 illustrates the extent of bad coverage distribution along with quality and interference levels.

Similarly, The PS service is also characterized by poor data throughput performance and traffic utilization trend. Considering enhanced profile and high speed capability of deployed HSPA and LTE-A technologies, the data rate performance is beyond comparison. As shown in table5.3 very low data speed UMTS-HSPA and LTE-A user throughput has been entertained both scenarios. Though the problem has spread out all over the town, much poor spread spots are observed at the edges of the town. Moreover, aforementioned Radio network, backhaul and backbone capacity limitations are renowned reasons that are basically associated with data rate and PS service problems.
Note that OSS data is gathered for LTE-A from 01 June 2021 to 30 November 2021 and from 01 December 2020 to 30 November 2021 for UMTS-HSPA.

Tec.	**Indicator**	**KPI**	**Target**	**Test Result**	**Frequency (Count/Total Sample)**
LTE-A	Coverage	Measured $RSRP$	> -95 dBm over 97% of area	71.00%	30185/42492
	Quality	Measured $RSRQ$	> -15 dB over 95 % of area	87.10%	37030/42492
	Interference	Measured $SINR$	>9 dB over 95 % of area	74.50%	26252/36185
UMTS-HSPA	Coverage	Measured $RSCP$	> -88 dBm over 97 % of area	98.60%	35468/36185
	Interference	Measured E_c/N_o	> -12 dB over 95 % of area	91.00%	32766/36185
	Pilot Pollution	Pollution Events	< 5%	0.80%	342/36185

TABLE 5.1: Coverage Performance of LTE-A & UMTS-HSPA

Indication	$RSRQ$ **(dB) (Result)**	$RSRP$ **(dB) (Result)**	$SINR$ **(dB) (Result)**	(E_c/N_o) **(dB) (Result))**	$RSCP$ **(dB) (Result))**
Excellent	44.20%	14.30%	17.20%	33.30%	0.70%
Very good	24.70%	38%	45.90%	20.60%	62.80%
Good	18.30%	32.90%	15.70%	37.20%	36.30%
Fair	12.80%	9.20%	20.60%	7.90%	0.20%
Bad	0%	5.50%	0.60%	1.00%	0%

TABLE 5.2: Coverage Performance Indicators of LTE-A & UMTS-HSPA

5.4 Coverage and Throughput Prediction following RF Optimization and Upgrading

Solutions for extremely rising PS and CS service of mobile network is necessarily needed to thrive in QoS, viability and sweeping adaptation circumstances. With the deep insight of users profile, traffic trend, financial constraints and network performance we have recommended two commercially available and vendor specific relevant solutions for Jimma town mobile broadband service problems. Moreover,

Tec.	Service	Average Application Throughput(Mbps) by drive test measurement	Average Physical Throughput(Mbps)by drive test measurement	User Throughput(Mbps) obtained by OSS Data Analysis
LTE-A	Downlink	56.04	62.84	32.67
	Uplink	31.37	16.14	2.31
	HTTP (DL)	18.53	19.22	
UMTS-HSPA	HSDPA	8.46	5.82	0.54
	HSUPA	1.80	2.44	0.06
	HTTP (DL)	18.53	19.22	

Table 5.3: Data Throughput Performance

these remarks are delivered based on valuation of existing resource audit and best practices and effective practices of other operators.

I. RF Optimization

Certainly, tremendous capacity would be attained with implementation of hardware and software capacity upgrading of existing radio resources. In this case, adoptions of enhanced variants of baseband unit DUW40, dual integration of DUW31 and CE capacity expansion ultimately improve the performance of existing network. A promising technical specifications presented in table 4.3 ensures a wide room for massive enhancement with incorporation these and other essential software and hardware products that are commercially provided by a vendor.

The coverage analysis shows that existing network is substantially impacted by settlements and structural developments that has been built aftermath of implementation. Here the initial design was prepared by considering RF planning and digital terrain inputs of the time. Moreover, fast demographic & architectural change has eventually deteriorated RF performance of the town. We've examined that few changes on selected parameters that are presented in figure 5.21 would tremendously enhance the coverage and quality of the network. In this case, Figure 5.22 evocatively revealed that remarkable quality and coverage improvements

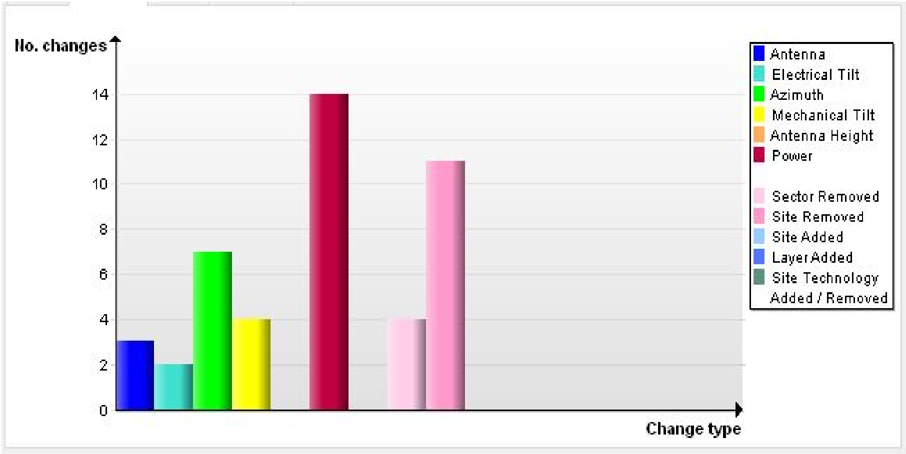

FIGURE 5.21: Required RF parameter changes

could be achieved with calibration of these engineering parameters and physical changes.

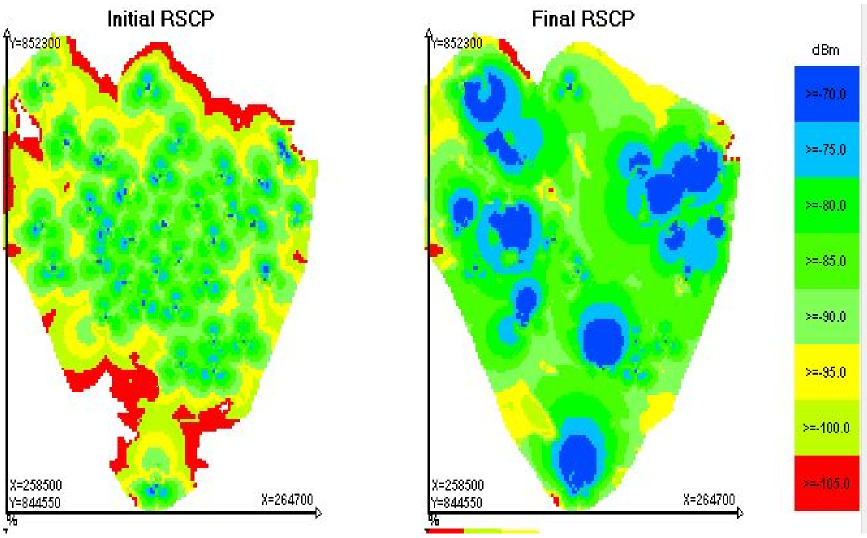

FIGURE 5.22: Post optimization coverage prediction

Here, most poor coverage and quality spots could extensively be tuned without additional resource utilization. Optimization would also occasionally rely on vendor specific solutions. Within the era of competitive market, vendors has progressively developed different quality, coverage and capacity boosting features to address limitations that are practically encountered in the respective eras of the technology.

similarly, $EcNo$ of existing network would magnificently be improved using parameter adjustment as shown in figure 5.23.

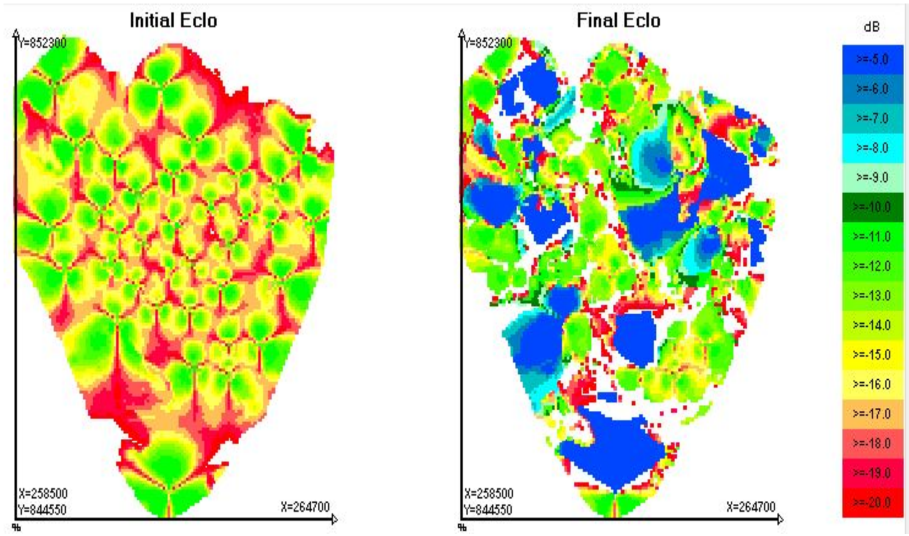

FIGURE 5.23: Post optimization $EcNo$ prediction

II. Network Upgrading

An improved version of HSPA+ network have been deployed successfully with remarkable capacity and considerable throughput feats worldwide. According to [4] [63] [66], several operators across the world have implemented evolved versions such as 84 Mbps and 168 Mbps HSPA+ aiming to realize phenomenal benefits and features presented in [3][42][44]. These operators have rationalized the following four vital technical and economic advantages:

1. It is a cost effective software upgrade. No new hardware component and infrastructure investment is required.

2. With a vast WCDMA/HSPA device ecosystem, it provides high speed mobile broadband service seamlessly. operators to offer mobile broadband services at a lower cost, while the increased voice capacity allows them to free up resources to support more data.

3. It is an ultimate solution to leverage the existing HSPA network until a rich device ecosystem and PS traffic is established for 4G network. In this regard, high LTE enabled device penetration and broadband service utilization trend are a key triggering elements of LTE migration.

4. It utilizes existing frequency spectrum.

In a purpose of verifying pertinence of a recommended HSPA+ 84 Mbps network, we've validated an envisaged performance achieving maximum of 61.44 Mbps data throughput in widely held coverage spots of target area. Figure 5.24 illustrated maximum download throughput prediction of Jimma town HSPA+ 84 Mbps network using WINPROP. The prediction is made considering of HSPA+ release 9 RF specifications for all 35 nodes of existing network.

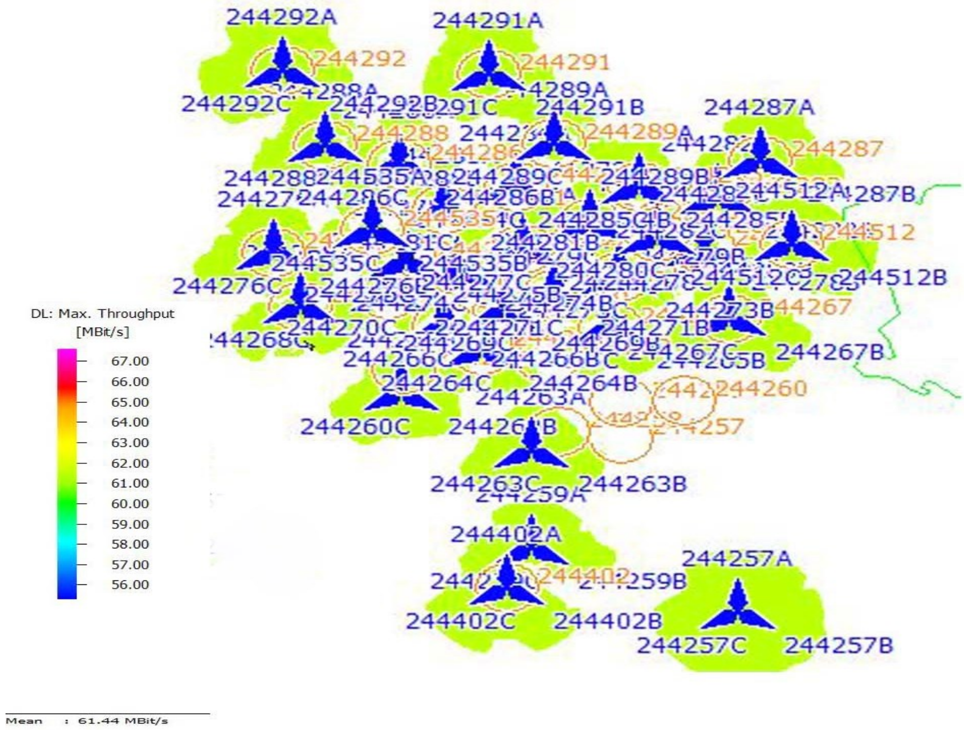

FIGURE 5.24: Jimma Town HSPA+ Release 9 Throughput Prediction

In addition, the prediction depicts that a widely-held spots of a target area has been served with incredible throughput.

Chapter 6

Conclusion and Recommendation

6.1 Conclusions

As a part of national development plan, the implementation of a continued 3G and 4G mobile network expansion and layering activities in Jimma town have enhanced coverage and quality access and device proliferation of mobile broadband services. In 2021, the operator has launched 4G LTE-A service in the town to address aforementioned crucial concerns although a propitiously anticipated gigabyte LTE-A has not delivered acute breakthrough in its debut. I this context, service integrity, traffic pattern and financial feasibility are needed to be perused so as to ensure return on investment and avoid wagering.

Hence, performance analysis & evaluation of selected test metrics is conducted aiming to disclose hindering components of existing network and also render an evocative picture of existing radio network service and RF ecosystem of Jimma Town. Both OSS data and drive test measurements are evaluated to mightily realistically discern service limitations users experience and traffic profile of the network. on this matter, radio nodes settlement oriented drive test routes are defined for both 3G and 4G test items. According to regional trend analysis depicts that device penetration, literacy and economic factors have influenced the progress besides. Following the results, we conclude that the town is still underserved in the aspect of PS services and a recently layered LTE-A radios have not been deployed in capability to accommodate the current & imminent demands of the town. In addition, poor coverage, quality and throughput distributions that are observed in numerous parts of the town is associated with RF adjustment and tuning gaps that that is not optimized to best meet the coverage and capacity requirements with available resources. The bottleneck effect of local backhauls, national backbone networks and international gateways shall better be optimized or expanded so as to ensure resilient and on-demand broadband connections.

Generally, the main purpose of this thesis is to identify mobile broadband service problem using practical approaches and provide suggestions that would excel on effective resource utilization and developing far-reaching economical upgrading solutions.

6.2 Recommendation

Establishing an ultimate and apt solutions require authentic approaches. Hence, this work could be extended to address problems in realizing coverage hole and indoor measurement limitations using algorithms and novel approaches as well as examine bandwidth hog of the network. Additionally, we acclaim future works that revitalize the network QoS & capacity with advanced data mining and traffic projection techniques so as to address drawback comprehensively.

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