



**Addis Ababa University**

**Addis Ababa Institute of Technology**

**School of Electrical and Computer Engineering**

**Telecommunication Engineering Graduate Program**

**Quality of Experience Evaluation for Addis Ababa UMTS**

**Enterprise Data Customers**

**By**

**Abera Reesom Bisrat**

**Advisor**

**Beneyam Berehanu Haile (PhD)**

A Thesis Submitted to School of Electrical and Computer Engineering, in Partial  
Fulfillment of the Requirements for the Degree of Masters of Science in  
Telecommunications Engineering

**October 2018**

**Addis Ababa, Ethiopia**

## Abstract

Penetration of high-speed mobile data services including social media and video services has been significantly increased across the globe due to fast development of mobile network and smartphone technologies. A similar trend has also been seen in Ethiopia mainly due to large mobile network expansion projects of the sole incumbent operator ethio telecom, particularly for Universal Mobile Telecommunications System (UMTS) network. To achieve a successful business, mobile operators need to continuously monitor satisfaction of their customers and the quality of their networks to take timely marketing, network optimization and other relevant decisions. While traditionally the focus has been towards network Quality of Service (QoS), operators recently also provide attention to the aggregate user quality perception – Quality of Experience (QoE). Yet, a combined quality analysis for mobile networks in Ethiopia, particularly for the popular UMTS data service, has not been performed. In this thesis work, the detailed QoS and QoE evaluation for Addis Ababa UMTS data service including both network quality perspectives and user side perception focused on selected enterprise customers are presented.

Assessment of quality monitoring process in ethio telecom has been done before conducting the evaluation on QoS and QoE. The evaluation is made based on download throughput, upload throughput and latency quality metrics collected from network management system (NMS), indoor walk test, crowdsourcing test using RTR-NetTest tool and contextually formulated survey questionnaire. In general, achieved throughput and latency results show that both QoS and QoE are not good and there is dissatisfaction of customers. For instance, the average download throughput results are 0.57 Mbps from NMS, 0.86 Mbps from indoor walk test and 2.53 Mbps from RTR-NetTest. These quantitative results are reflected in the perception result of the participants where a Mean



Opinion Score value of 2.65 for the satisfaction of downloading files or video/music is achieved.

**Keywords**—*Quality of Experience; Quality of Service; Throughput; Latency; UMTS; Mobile Operators; Enterprise Customers; Data service; Customer Satisfaction; Mean Opinion Score*



**Addis Ababa University**  
**Addis Ababa Institute of Technology**  
**School of Electrical and Computer Engineering**

This is to certify that the thesis prepared by Abera Reesom Bisrat, entitled: *Quality of Experience Evaluation for Addis Ababa UMTS Enterprise Data Customers* and submitted in partial fulfillment of the requirements for the degree of Master of Science (Telecommunications Engineering – Telecommunication Information Systems Track) complies with the regulation of the University and meets the accepted standards with respect to originality and quality.

**Signed by the Examining Committee:**

_____	_____	_____
Chair or School Dean	Signature	Date
<u>Beneyam Berehanu Haile (PhD)</u>	_____	_____
Advisor	Signature	Date
_____	_____	_____
Internal Examiner	Signature	Date
_____	_____	_____
External Examiner	Signature	Date
_____	_____	_____
Director of Postgraduate Program	Signature	Date



## Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

Abera Reesom Bisrat

Name

\_\_\_\_\_

Signature

Place: Addis Ababa

Date of Submission: \_\_\_\_\_

This thesis has been submitted for examination with my approval as a university advisor.

Beneyam Berehanu Haile (PhD)

Advisor

\_\_\_\_\_

Signature



## Dedication

To my lovely parents – Haleka Reesom Bisrat (ሃለቃ ርእሶም ብሰራት) and Rakib Gebretekle (ራኽብ ገብረተክለ).

## Acknowledgment

I would like to thank God for giving me the wisdom and skill to carry out my thesis work. My special thanks goes to my advisor Beneyam Berehanu Haile (PhD) for his continuous support and advice during the research period. I am also very grateful to thank employees of ethio telecom (Departments of Service Management Center, Engineering and Customer Service Front Office) who have supported me in collecting data and providing necessary information for the successful delivery of this thesis work. Especially, my gratitude goes to Bezuyayehu Zerihun, Hadgu Belay, Kelem Birhane and Yemane Techane for their vital support.

I would like to thank the thesis progress report examiners Yalemzewd Negash (PhD) and Yihenew Wondie (PhD) for their valuable comments and suggestions. I am also glad to thank ethio telecom for giving me the opportunity to study my postgraduate program at Addis Ababa University, Addis Ababa Institute of Technology (AAiT). Last but not least, I am pleased to thank my twin brother, my wife and daughters for their priceless cares throughout my postgraduate program.



# Table of Contents

Abstract.....	i
Declaration .....	iv
Acknowledgment.....	vi
Table of Contents .....	vii
List of Figures .....	x
List of Tables.....	xi
Abbreviations and Acronyms .....	xii
Chapter 1 .....	1
1. Introduction .....	1
1.1. Background.....	1
1.2. Statement of the Problem.....	3
1.3. Objective of the Thesis.....	5
1.3.1. General Objective .....	5
1.3.2. Specific Objectives.....	5
1.4. Methodology.....	6
1.5. Selected Related Literature Review.....	8
1.6. Scope of the Thesis.....	11
1.7. Contribution.....	11
1.8. Thesis Organization.....	12
Chapter 2 .....	13
2. UMTS Network and Data Service .....	13
Quality of Experience Evaluation for Addis Ababa UMTS Enterprise Data Customers	vii



---

2.1. Background.....	13
2.2. Architecture of UMTS .....	13
2.3. UMTS QoS Classes.....	15
Chapter 3.....	18
3. Quality of Experience in UMTS Network .....	18
3.1. Comparison of QoS and QoE .....	19
3.2. Description of QoS Metrics.....	21
3.3. QoE Measurement Techniques .....	22
Chapter 4.....	24
4. Quality of Experience Measurement in Addis Ababa.....	24
4.1. Quality Handling Process in ethio telecom.....	24
4.2. Plan for Taking Measurements .....	27
Chapter 5.....	29
5. Data Collection Mechanisms.....	29
5.1. Network Management System.....	30
5.2. Indoor Walk Test.....	30
5.3. RTR-NetTest .....	32
5.4. Subjective Metrics .....	35
Chapter 6.....	38
6. Analysis, Results and Interpretations .....	38
6.1. Nastar.....	38
6.2. Indoor Walk Test.....	42



---

6.3. RTR-NetTest .....	48
6.4. Subjective Metrics .....	52
6.4.1. Quality Related Metrics .....	53
6.4.2. Spatiotemporal Metrics .....	55
6.4.3. Other Metrics .....	56
6.4.4. Feedback from Participants .....	57
Chapter 7 .....	58
7. Conclusion and Future Work.....	58
7.1. Conclusion .....	58
7.2. Future Work.....	60
References .....	61
Appendix A.....	66
Appendix B .....	67
Appendix C.....	68

## List of Figures

Figure 1-1: Mobile Data Demand Forecast in Addis Ababa .....	2
Figure 1-2: Mobile Internet Call Records.....	4
Figure 1-3: RTR-NetTest Technical Setup.....	7
Figure 1-4: Methodology Used.....	7
Figure 1-5: Major Functions of the E2E QoE Assurance System .....	8
Figure 2-1: Network Elements in a PLMN .....	14
Figure 2-2: UMTS QoS Classes.....	16
Figure 3-1: Hierarchy of Quality Assessment Indicators .....	18
Figure 3-2: Ratio of QoE/QoS from 2002 - 2016 .....	21
Figure 4-1: Information Flow to Support Performance Management .....	25
Figure 4-2: Quality Management Network Architecture .....	27
Figure 5-1: Data Collection Mechanisms .....	29
Figure 6-1: Download Throughput from Nastar.....	39
Figure 6-2: Addis Ababa Spatial Distribution - Download Throughput (Kbps) .....	40
Figure 6-3: Geographical Locations of the Buildings.....	42
Figure 6-4: Download Throughput from Indoor Test .....	43
Figure 6-5: Ethio's HQ - Download Throughput Spatial Distribution .....	44
Figure 6-6: CBE AA - Download Throughput Spatial Distribution .....	45
Figure 6-7: Latency from Indoor Walk Test .....	47
Figure 6-8: RTR-NetTest Average Result.....	49
Figure 6-9: RTR-NetTest Optimum Result .....	51
Figure 6-10: Download Throughput Temporal Distribution.....	52
Figure 6-11: Quality Related Metrics 1.....	54
Figure 6-12: Quality Related Metrics 2.....	54
Figure 6-13: Why Wi-Fi?.....	56
Figure 6-14: Feedback from Participants .....	57



## List of Tables

Table 2-1: Fundamental characteristics of the UMTS QoS classes .....	17
Table 3-1: Examples of QoS and QoE.....	20
Table 3-2: 5-Point ACR .....	23
Table 5-1: List of Buildings for Indoor Walk Test.....	31
Table 5-2: Device Summary for RTR-NetTest.....	33
Table 5-3: Fields from RTR-NetTest Data.....	34
Table 5-4: Summary of Subjective Metrics .....	36
Table 5-5: Demography of Participants .....	37
Table 6-1: Maximum Upload Speed.....	41
Table 6-2: Upload Throughput from Indoor Walk Test.....	46
Table 6-3: RTR-NetTest Total Tests .....	48
Table 6-4: Category of Subjective Metrics.....	53
Table 6-5: Best and Worst Performing Locations .....	55
Table 6-6: Best and Worst Time Periods .....	56

## Abbreviations and Acronyms

2G	Second Generation
3G	Third Generation
4G	Fourth Generation
AA	Addis Ababa
ACE	Advancing Customer Experience
ACR	Absolute Category Rating
CBE	Commercial Bank of Ethiopia
CEI	Customer Experience Indicator
CICRA	Channel Islands Competition and Regulatory Authorities
CN	Core Network
CS	Circuit Switched
CSV	Comma Separated Values
DBW	Downlink Bandwidth
E2E	End to End
ETSI	European Telecommunications Standards Institute
FAN	Fixed Access Network
GGSN	Gateway GPRS Support Node
GMSC	Gateway MSC
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HD	High-definition
HLR	Home Location Register
HQ	Headquarter
HSDPA	High Speed Downlink Packet Access

---

HSPA	High Speed Packet Access
HSPA+	Evolved HSPA
HSUPA	High Speed Uplink Packet Access
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ISP	Internet Service Provider
IT	Information Technology
ITU	International Telecommunication Union
ITU-T	ITU Telecommunication Standardization Sector
Kbps	Kilobits Per Second
KPI	Key Performance Indicators
KQI	Key Quality Indicators
LTE	Long Term Evolution
MB	Megabyte
Mbps	Megabits per second
ME	Mobile Equipment
MFT	Maximum Flow Throughput
MOS	Mean Opinion Score
ms	Millisecond
MSC	Mobile Switching Center
NGN	Next Generation Networks
NMS	Network Management System
NNOC	National Network Operation Center
O & M	Operation and Maintenance
PB	Petabyte (10 <sup>15</sup> )

---

PLMN	Public Land Mobile Network
PS	Packet Switched
QoE	Quality of Experience
QoP	Quality of Protection
QoS	Quality of Service
RAN	Radio Access Network
RNC	Radio Network Controller
SGSN	Serving GPRS Support Node
SMC	Service Management Center
SMS	Short Message Service
SOHO	Small Office Home Office
TE	Terminal Equipment
TEP	Telecom Expansion Project
TPO	Transformation Program Office
UE	User Equipment
UK	United Kingdom
UMTS	Universal Mobile Telecommunications System
USIM	UMTS Subscriber Identity Module
UTRAN	UMTS Terrestrial RAN
VLR	Visitor Location Register
VoIP	Voice over IP

---

# Chapter 1

## 1. Introduction

### 1.1. Background

Because of advancement of mobile network and device technologies and innovative data services, in recent years, it has been observed that the number and expectation of mobile data subscribers are dramatically increasing in emerging markets. To successfully serve the increasing mobile data users with satisfactory service quality, mobile operators should continuously expand and optimize their mobile networks.

In the case of Ethiopia, the latest expansion project called Telecom Expansion Project (TEP) has been initiated and implemented since 2013 to improve network capacity, coverage and quality for improved accessibility of various mobile data services by ethio telecom. Mainly, Second Generation (2G) and Third Generation (3G) mobile networks have been deployed to cover most parts of the country. Furthermore, the Fourth Generation (4G) network has been partially deployed in Addis Ababa. These and previous mobile networks are currently accommodating more than 65 million mobile subscribers in the country [1].

As described in [2], improving network coverage to support data services including email, social media, video streaming and music downloads requires managing network complexity while ensuring Quality of Service (QoS) for the network and Quality of Experience (QoE) for the user. Understanding QoE means understanding perception of mobile customers and evaluating their satisfaction in a continuous manner by considering the growing traffic demand and smartphone usage for various day-to-day activities.

Globally, there is an increased trend of monthly traffic demands and most of the traffic share is using smartphones as reported by Cisco Visual Networking Index [3]. A survey conducted by Hot Telecom also shows that most mobile subscribers use their mobile devices related to using the Internet [4]. Both the forecast and the survey are know-how for mobile operators to focus on perception of their customers on top of network quality.

Authors in [5] note in the introductory part of their book that one frustrated customer (on the service being provided) can tell 13 people about the bad experience. To avoid a high number of complaints in order to satisfy customers, dealing with QoE is worthwhile. For evaluating QoE for UMTS data users, the case study has been conducted in Addis Ababa. The population in the city is expected to grow to 6.6 million [6]. With this forecasted high number of population, the mobile traffic demand is predicted to be more than 20 PB per month in 2021 [7] as shown in Figure 1-1.

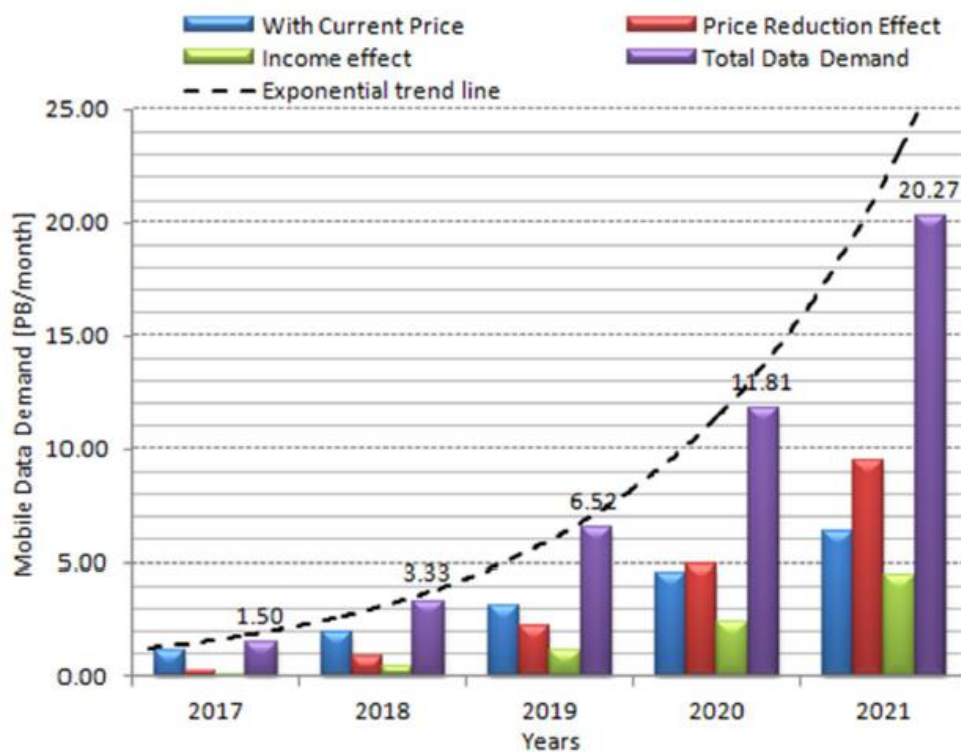


Figure 1-1: Mobile Data Demand Forecast in Addis Ababa [7]

## 1.2. Statement of the Problem

As described in [3], the traffic demand forecast is increasing every year. This by itself is a challenge for mobile operators to accommodate high traffic and satisfy their cellular network users. A survey conducted by Hot Telecom shows that in 2015 the level of mobile users' dissatisfaction was 9%, 9%, 10% and 25% in Europe, Asia, North America and South America, respectively [4]. The survey states that 86% of mobile users in South America suffered from low quality or poor coverage.

Ofcom [8] which is the regulator and competition authority for the United Kingdom (UK) communications industries has reported that a study conducted in the UK shows that the proportion of mobile consumers with a reason to complain about their mobile provider has continued to fall in 2016. However, most complaints to mobile providers are related to the service not performing as it should. Customer satisfaction surveys were also done by Channel Islands Competition and Regulatory Authorities (CICRA) [9] in Guernsey and Jersey with three telecom operators JT, Sure and Airtel. Participants were asked about the overall satisfaction with the quality of the mobile service they receive from their telecom service providers. The surveys were done in May 2014, Nov 2014, May 2015 and Nov 2015. On both islands (Guernsey and Jersey), the maximum percentage of very satisfied or satisfied participants is around 90 and the minimum is around 40.

In Ethiopia where the case study is conducted, there have been projects to enhance the coverage and capacity of the network which can improve the quality of services and customer satisfaction. However, within almost less than two years after deployment of new sites particularly for the UMTS network, second-hand information shows that customers of 3G network have not been satisfied. A recent study [10] conducted in Addis Ababa for the evaluation of quality of UMTS voice service states that there are customer complaints in the capital, Addis Ababa, which has arisen after the TEP.

Data was collected on mobile Internet-related call records from ethio telecom Customer Service division (Front Office Department). The call records were handled in the months of September through December 2017. From the total number of mobile Internet-related call records handled by contact centers of ethio telecom, 57% of them are related to mobile Internet quality problems. Figure 1-2 shows the ratio of mobile Internet related call records in the abovementioned months.

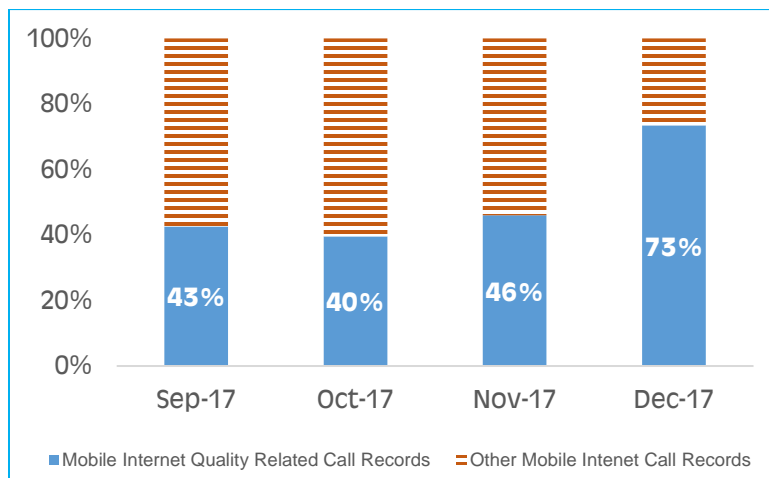


Figure 1-2: Mobile Internet Call Records

For a better understanding of user-side QoS that influences customer satisfaction, drive test which has been traditionally used by mobile operators is one of the most important methods. In the case of ethio telecom, drive test is done based on customer complaints, which is not actually a formal communication and is a location-based drive test which is not user-centric. For QoS analysis, data is collected from Network Management System (NMS) which is vendor dependent tool for handling the user complaints and further analysis. In addition to this, a combined QoS and QoE evaluation has not also been formed in Ethiopia particularly for UMTS data service.

This thesis work is formulated to answer the following research questions:

1. Does ethio telecom as a mobile operator methodologically differentiate QoS from QoE?

2. Does ethio telecom consider what the perception of its subscribers is?
3. How does ethio telecom evaluate the satisfaction of UMTS data service users?
4. What do users perceive about the UMTS data service in Addis Ababa?
5. Does ethio telecom take the perception of its customers as an input to improve the quality of UMTS data service?
6. Is there a variation with the throughput of UMTS data service in Addis Ababa?
7. When a user complains about the service being provided, is the analysis user-centric or location-based?

## 1.3. Objective of the Thesis

### 1.3.1. General Objective

In general, objective of this thesis is to thoroughly investigate quality experience of UMTS enterprise data customers for selected Addis Ababa scenario.

### 1.3.2. Specific Objectives

To achieve the aforementioned ultimate objective, the following specific objectives are set:

- To identify and formulate relevant subjective and objective quality measuring metrics for UMTS data service from enterprise perspective
- To evaluate ethio telecom's quality monitoring process
- To identify alternative platforms for quantitatively measuring selected quality metrics
- To undertake measurements using identified platforms in selected enterprise venues
- To analyze collected data from QoS and QoE perspectives
- To compare QoS and QoE results obtained from NMS/drive test data and selected alternative methods

## 1.4. Methodology

This study, QoE for Addis Ababa UMTS enterprise data service subscribers, focuses on experience of mobile users when customers use 3G network and access data services. Four methods are identified for collecting the required data after identifying and selecting quality metrics for both objective and subjective measurements.

For the objective measurements, data is collected from NMS, Indoor walk test and RTR NetTest. The NMS data is gathered from Nastar System which is vendor dependent management system. A study in [10] used Nastar as one of the methods to evaluate voice quality of service in Addis Ababa. In this work, quality metrics downlink throughput and uplink throughput for each geographic point are taken on a weekly basis.

Indoor walk test is performed using Nemo Handy tool which is a commercialized tool commonly used by mobile operators. Researchers in [10-14] used the tool in their studies. The indoor test is done near Addis Ababa National Theatre, which is one of the locations with a high number of enterprise customers. 20 buildings are part of the test, and one floor in each building is considered based on the distribution of customers, which is identified with the help of building managers and guards. Applied quality metrics, in this case, are download throughput, upload throughput, local latency and international latency.

The other tool used is a crowdsourcing test using RTR-NetTest app which is a free tool downloaded from Google Play or Apple Store. Employees of ethio telecom were able to download the tool and make a test based on the procedures in Appendix A by locking their mobile devices to 3G only. The owner of the tool is the Austrian Regulatory Authority for Broadcasting and Telecommunications. The description of the tools is

available in [15] and was used as a measurement tool in [16-18]. The technical setup for the RTR-NetTest is illustrated in Figure 1-3.

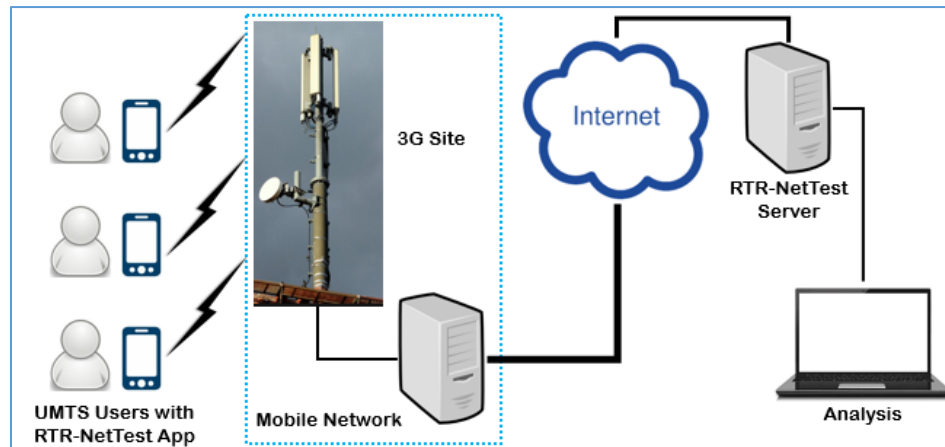


Figure 1-3: RTR-NetTest Technical Setup

For the subjective test, a survey questionnaire has been prepared by filtering current issues and referring to [4, 8, 9, 19-22]. The questionnaire consists of 18 questions related to quality metrics and one question for receiving feedback from the participants. Distribution of the questionnaire is by preparing hard copies and sharing using Google Form to enterprise customers in Addis Ababa. The questionnaire which has been applied for this thesis work is included in Appendix C.

These four ways of data collection have helped us to evaluate and assess the overall satisfaction of the UMTS data users. Additional tools like MATLAB, Microsoft Excel, Actix Analyzer and MapInfo have been used as part of this thesis work. A summary of the methodology used is shown in Figure 1-4.

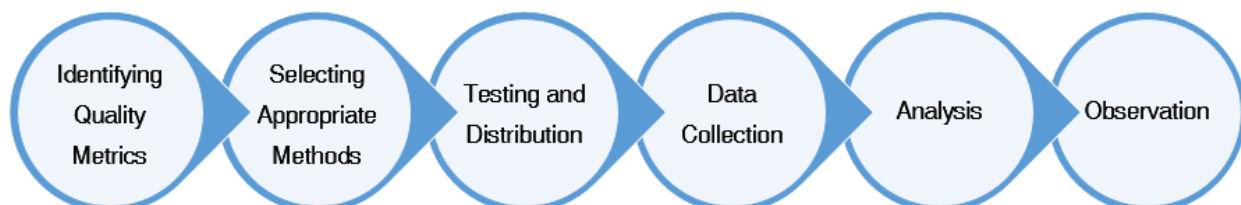


Figure 1-4: Methodology Used

## 1.5. Selected Related Literature Review

A method for the evaluation of QoE for Information Technology (IT) services is presented in [23]. The authors note that new methods and adaptations are needed for better user satisfaction. For measuring QoE of IT services, a model with three steps is proposed – IT system definition, user and service configuration and QoE evaluation. Authors in [24] also present a framework for measuring QoE for mobile in a living lab environment by considering the shift towards user-centric measurements. Under this proposed framework and architecture, it is suggested that the proposed tool has to comply with basic requirements for long-term measurement.

A study in [25] describes that there is a shift from QoS to QoE. For satisfaction of customers, service providers must have management and control decision mechanisms based on user QoE. QoE comprises End to End (E2E) system effects including users themselves, their terminals and core and access networks including infrastructures. A framework is proposed for E2E QoE assurance system which can be implemented in Next Generation Networks (NGN) to assure QoE. Figure 1-5 depicts the major functions of E2E QoE assurance system.

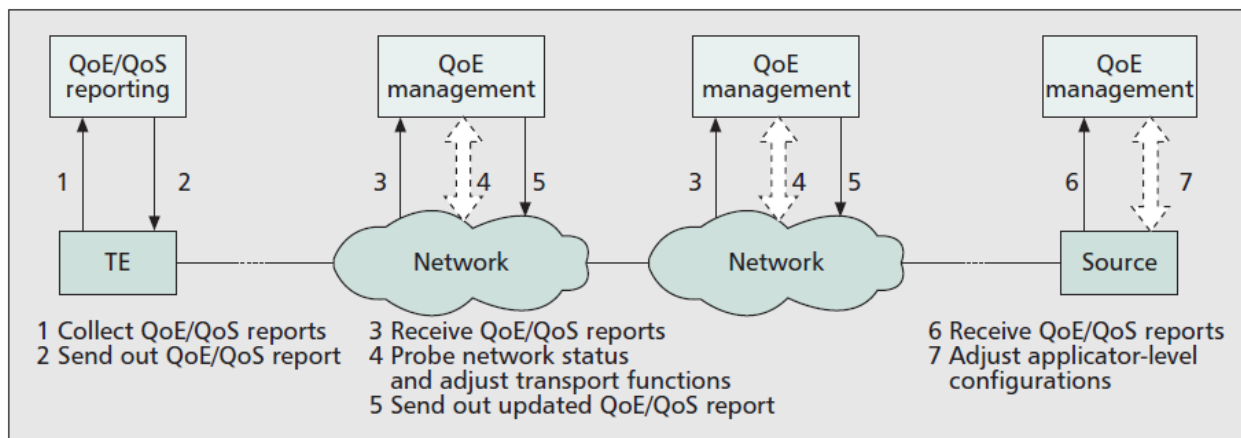


Figure 1-5: Major Functions of the E2E QoE Assurance System [25]

Quality of Protection (QoP) and QoE in multimedia communications are presented in [26]. Multimedia streaming over mobile devices is one of the most promising communication services that includes a huge number of applications. Different applications contain different types of media like video and audio. As the applications are different, service providers have to focus on QoE rather than QoS for a better satisfaction of customers. Influencing factors for QoE like human, system and context are also explained briefly.

Do we really know what quality mobile subscribers expect when a service is delivered to them? A study was conducted in [27] to deal with what the expectation of mobile subscribers is with regard to the quality of the provided service. The paper is introduced by stating the network evolution from Circuit Switched (CS) to Packet Switched (PS) technologies. This trend has helped the emergence of new services like Voice over IP (VoIP) telephony and multimedia streaming. Subscribers expect their mobile devices to provide high-quality connectivity and performance all the time. By differentiating the QoS and QoE, factors which can affect subscriber QoE like mobile application responsiveness, time required to download a webpage, stalling in a video and video content resolution are listed out.

A study in [19] introduces a research project called Advancing Customer Experience (ACE) which provides the context for the QoE trials. Web surfing and file downloads are parts of the test and the download bandwidth limits vary from 64 and 2048 Kbps. Participants were instructed to rate the quality of the connection using an electronic rating tool. In addition to this, the network traffic of users was also captured with tracing probe. After collecting the experience of the participants, the Mean Opinion Score (MOS) ratings are compared with the lab tests. For the web browsing, the lab and field test have minor

difference whereas, for the file downloading, the field tests show a better result compared to the lab test.

Authors in [20] study QoE by using lab and field tests. The tests were conducted on three smartphone popular applications – YouTube, Facebook and Gmaps. In the lab test, the downlink Bandwidth (DBW) was considered. Whereas in the field test, only the Maximum Flow Throughput (MFT) was taken. The study was conducted by getting feedback from customers by rating their overall experiences as MOS. In the case of YouTube, for MFT greater than 5 Mbps is similar to the lab results of DBW greater than 4 Mbps. For the case of Gmaps, good QoE can be expected for an MFT greater than 2 Mbps which is similar to the result obtained from the lab test. In the case of Facebook, MFT of greater than or equal to 1 Mbps results in a good QoE.

In [28], it is stated that it is important to evaluate QoE with respect to different types of mobile devices in order for service providers and device vendors to increase revenue and avoid churn. The authors study the impact of mobile device size, resolution and device make and model on QoE for video services. Mobile devices with similar display size and resolution but from different manufacturers are used in the experiment. The authors conclude that mobile device preference has an impact on QoE for video services.

To the best of our knowledge so far, there is no research that has been done in Addis Ababa for evaluating the satisfaction of UMTS data users using four mechanisms listed in the Methodology Subsection. This thesis work focuses on evaluation of QoE of enterprise UMTS data subscribers in Addis Ababa by focusing on network side results from NMS, Indoor drive test and crowdsourcing RTR-NetTest. In addition to this, perception of enterprise customers using survey questionnaire is also considered.

## 1.6. Scope of the Thesis

The study investigates QoE for UMTS enterprise data customers in Addis Ababa where the case study is conducted.

## 1.7. Contribution

In this research, the evaluation is based on network side perspectives and perception of users for UMTS data service. QoS assessment for UMTS voice service in Addis was done in [10]. The evaluation of user side QoS measurement techniques for Addis Ababa LTE data service was also done in [22]. However, our work focuses on QoE evaluation for Addis Ababa UMTS data service subscribers by focusing on four ways of evaluation methods which are functions of QoE. These methods are network side evaluation which is obtained from NMS, Indoor walk test and a crowdsourcing dataset using RTR-NetTest. In addition to this, user side perception using survey questionnaire is considered.

This study focuses on QoE which is currently an emerging discipline. This helps mobile operators to deal with the services provided to their customers and consider the perception of their customers as an input for optimizing and enhancing their networks. In general, the author believes the following points are the main contributions to mobile operators, particularly to ethio telecom.

- Addressing quality handling process.
- Understanding QoE and deal with user perception.
- Methodology for evaluating QoE.
- Usage of crowdsourcing test tools for measuring QoE.
- Consideration of user perception as an input for future enhancements and better customer satisfaction.

## 1.8. Thesis Organization

The remaining parts of the thesis are organized as follows. Chapter two presents a background on UMTS networks and data services. Chapter three presents a discussion on quality of experience in UMTS. Chapter four discusses quality of experience measurement practice in ethio telecom. Then data collection mechanisms that are applied in this thesis are discussed in Chapter five which is followed by data analysis, results and interpretations in Chapter 6. Finally, Chapter seven presents conclusion of the work and future work.

## Chapter 2

### 2. UMTS Network and Data Service

#### 2.1. Background

The evolution from an analog system to a digital system has brought accessing high-speed data for day-to-day communication. As stated in [29], second generation telecommunication systems like Global Systems for Mobile Communications (GSM) have a high number of subscribers compared to landline subscribers. Because of the limitation of supporting high-speed data in GSM, third generation systems have emerged with high data rate and image or video quality. In this thesis, we refer to the third generation network as Universal Mobile Telecommunication System (UMTS). In the essence of UMTS, we refer to two technologies: High Speed Packet Access (HSPA) and evolved HSPA (HSPA+) which are available technologies in Addis Ababa.

GSMA, which represents the interests of mobile operators worldwide, defines HSPA in [30] as a technology which enables operators to upgrade their networks to run at the speed of broadband networks. HSPA includes High Speed Downlink Packet Access (HSDPA), High Speed Uplink Packet Access (HSUPA) and HSPA+. HSPA can support a maximum of 14.4 Mbps downlink speed and 5.7 Mbps of peak uplink speed. HSPA+ supports up to 42 Mbps theoretical peak data rate.

#### 2.2. Architecture of UMTS

Before discussing QoS and QoE, it is worthwhile to understand the architecture of UMTS network. UMTS network has network elements with unique identities in its Public Land Mobile Network (PLMN) [29]. A detailed description of UMTS PLMN is shown in Figure 2-1. Elements of UMTS are User Equipment (UE), UMTS Terrestrial Radio Access

Network (RAN) which is abbreviated as UTRAN and Core Network (CN). Apart from its elements, UMTS is connected to external networks for accessing other PLMNs.

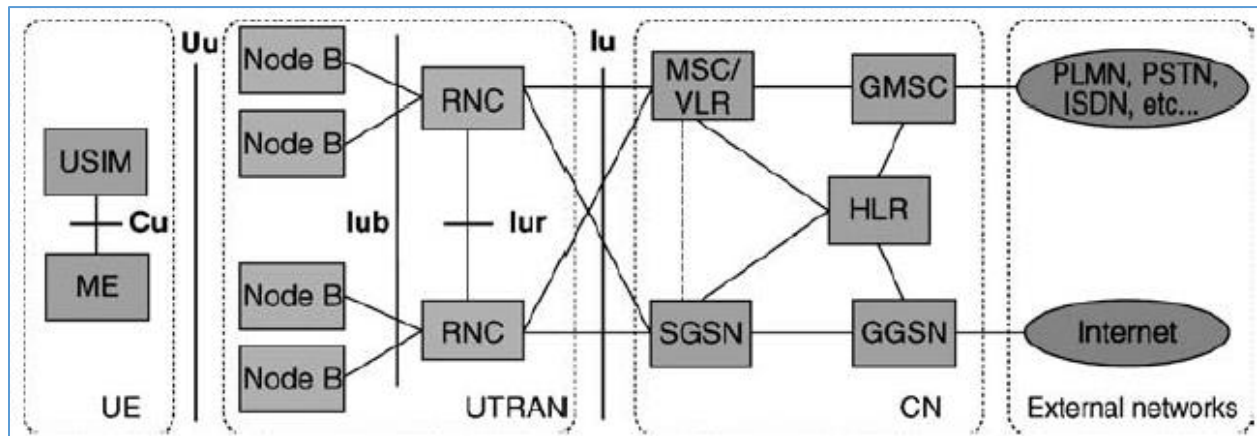


Figure 2-1: Network Elements in a PLMN [29]

By referring to [29], a description of UMTS elements and its external networks is stated below.

**User Equipment (UE)** consists of two parts – Mobile Equipment (ME) and UMTS Subscriber Identity Module (USIM). ME is used for radio communication with UTRAN whereas the USIM is a smartcard which holds subscriber information and authentication information.

**UMTS Terrestrial RAN (UTRAN)** includes two elements named as Node B and Radio Network Controller (RNC). The Node B is also called a base station which converts the data flow between the Uu and Iub interfaces. These interfaces enable the Node B to communicate with UE and RNC. The RNC owns and controls radio resources in its domain.

**Core Network (CN)** consists of Home Location Register (HLR), Mobile Switching Center (MSC), Gateway MSC (GSMC), Visitor Location Register (VLR), Serving General Packet Radio Service (GPRS) Support Node (SGSN) and Gateway GPRS Support Node (GGSN).

HLR is a database which consists of a permanent profile of subscribers including information on permitted and forbidden services. MSC/VLR is a switch and a temporary database for a copy of UE's location for services in Circuit Switched (CS) services. When the UE is in need to connect to external CS networks, the functionality is handled by GMSC. SGSN is similar in functionality to MSC/VLR of CS but is dedicated for Packet Switched (PS) services. The functionality of the GGSN is in line with GMSC though it is applicable only for the PS service.

The external networks are divided into two parts - CS network and PS network. Connections like telephony or voice services to external networks are routed across the external CS network while PS services like the Internet are forwarded through the external PS network.

### **2.3. UMTS QoS Classes**

Network service is considered end-to-end which is from one Terminal Equipment (TE) to another TE [31]. Each service has a certain QoS which is provided to the user though the user decides whether he/she is satisfied with the service being provided. To clearly understand UMTS QoS classes also called traffic classes, the European Telecommunications Standards Institute (ETSI) describes four UMTS QoS classes [31]. These classes are conversational class, streaming class, interactive class and background class. The UMTS classes are highlighted in Figure 2-2.

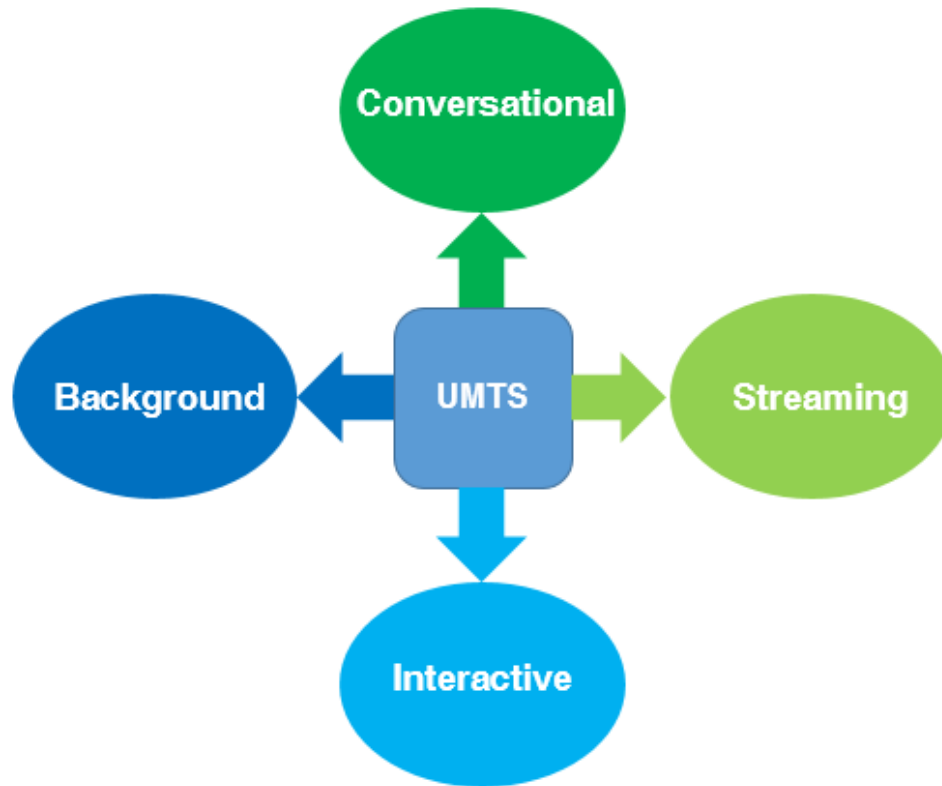


Figure 2-2: UMTS QoS Classes

**Conversational Class:** comprises real-time symmetric services like voice or video telephone. Human perception of the maximum transfer delay defines the characteristics of this traffic class.

**Streaming Class:** comprises typically one-way real-time services such as video downloading and news streaming.

**Interactive Class:** provides an asymmetric non-real-time services with more capacity for the downlink than for the uplink. Interactive Web and database retrieval are examples of interactive services.

**Background Class:** in this class, services are characterized by the fact that the destination is not expecting the data to arrive within a certain time. Examples of these services include the background delivery of emails, files and Short Message Service (SMS).

Conversational class is most sensitive to delay, followed by streaming class, interactive class, and then background class. Fundamental characteristics of the UMTS QoS classes are shown in Table 2-1.

Table 2-1: Fundamental characteristics of the UMTS QoS classes [31]

Traffic class	Fundamental Characteristics	Examples
Conversational	Preserve time relation (variation) between information entities of the stream conversational pattern (stringent and low delay).	Voice
Streaming	Preserve time relation (variation) between information entities of the stream	Streaming video
Interactive	Request response pattern and preserve payload content	Web browsing
Background	Destination does not expect the data within a certain time	Background download of emails

## Chapter 3

### 3. Quality of Experience in UMTS Network

Telecom operators can assess and evaluate the performance of their networks and services, which help them to at least know what their customers feel about their networks. They can measure the performance by listing out some Key Performance Indicators (KPIs) or Key Quality Indicators (KQIs). These measurements are not sufficient to address or evaluate the overall feeling of their customers. Figure 3-1 shows a hierarchy of quality assessment indicators [32].

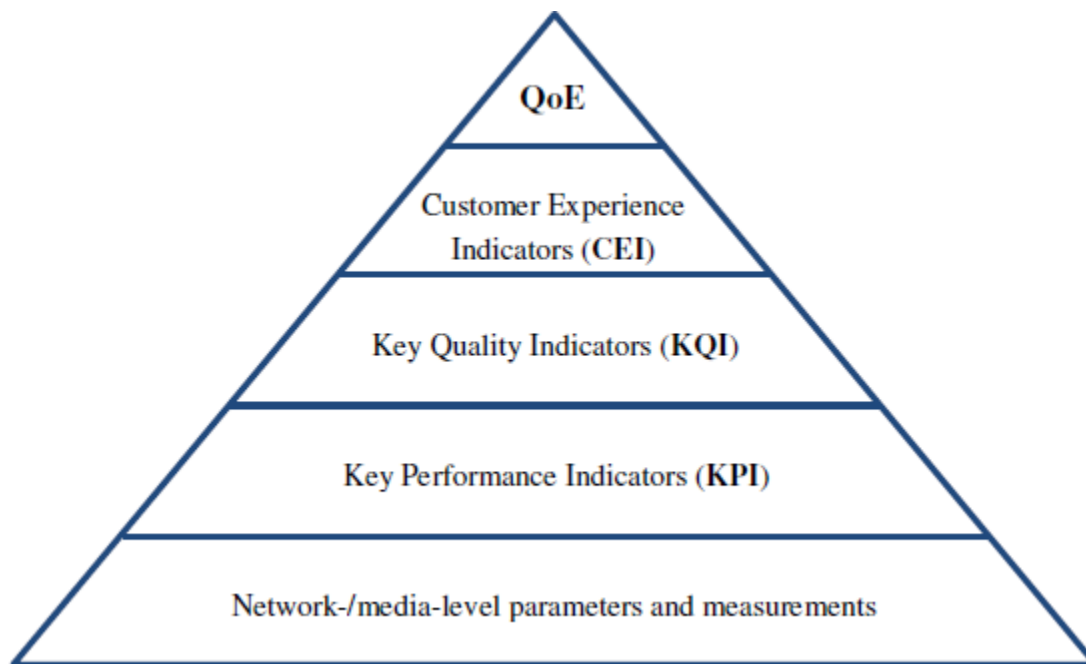


Figure 3-1: Hierarchy of Quality Assessment Indicators [32]

It is mentioned in [33] that Internet Service Providers (ISPs) and their customers have a gap when they talk about the performance of network services. The authors address the way ISPs measure about network services and customers measure the service being provided is different. Service providers focus on network level quality of service like download throughput, upload throughput, latency, jitter and delay. These metrics help

to see the overall performance on network level or between network nodes. We can put some reference values to see the performance but it does not help them what really the customers feel. The subjective perception of users which is called quality of experience plays a key role in understanding what customers really feel about the services they get from ISPs.

### 3.1. Comparison of QoS and QoE

In order to evaluate the satisfaction of the customers, it is important to differentiate the two terminologies: Quality of Service and Quality of Experience. The International Telecommunication Union Telecommunication Standardization Sector (ITU-T) [34] has defined both terms with two different perspectives. QoE is defined as the degree of delight or annoyance of the user of an application or service. Whereas, QoS is defined as the totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service.

In a similar way, authors of Broadband Forum [35] also define both terms with different viewpoints. QoE is the overall performance of a system from the point of view of the users. QoE is a measure of end-to-end performance at the services level from the user perspective and an indication of how well the system meets the users' needs while QoS is defined as a measure of performance at the packet level from the network perspective. QoS also refers to a set of technologies (QoS mechanisms) that enable the network operator to manage the effects of congestion on application performance as well as providing differentiated service to selected network traffic flows or to selected users.

ETSI has defined QoE in [36] as a measure of user performance based on both objective and subjective psychological measures of using an Information and Communications

Technology (ICT) service or product. To differentiate the two terminologies, QoE is based on end-user behavior which is user-centered while QoS is technology-centered.

As described in [34-36], QoS is with respect to the network which could be helpful for service providers or mobile operators. On the other hand, QoE is related to the satisfaction of service users. To correlate these two terms, the authors in [37] describe that QoE is an extension of the traditional QoS. To make clear about QoS and QoE, some examples are depicted in Table 3-1.

Table 3-1: Examples of QoS and QoE

Examples of QoS	Examples of QoE
<ul style="list-style-type: none"> <li>• The download throughput is 4 Mbps</li> <li>• The upload throughput is 1 Mbps</li> <li>• The jitter is 200 ms</li> <li>• The latency is 50 ms</li> <li>• The call setup success rate is 94%</li> <li>• The call drop is 0.5%</li> <li>• Call center average answer duration is 20 seconds</li> </ul>	<ul style="list-style-type: none"> <li>• I am feeling very happy about the network</li> <li>• We cannot upload files</li> <li>• I am very satisfied with Internet browsing</li> <li>• The quality of the video is poor</li> <li>• I feel bad about the network</li> <li>• We are unable to end our conversations</li> <li>• Call center response and approach is Excellent</li> </ul>

QoE is an emerging field of study as stated in [38]. It is a multidisciplinary field that focuses on different research areas, though it is the most important disciplinary in telecommunications services. Authors in [38] note that the research on QoE is growing compared to QoS. They put a summary of the ratio of QoE to QoS on abstract papers registered in Institute of Electrical and Electronics Engineers (IEEE) starting from 2002 to June 2016. The ratio of QoE to QoS has an increasing trend as shown in Figure 3-2.

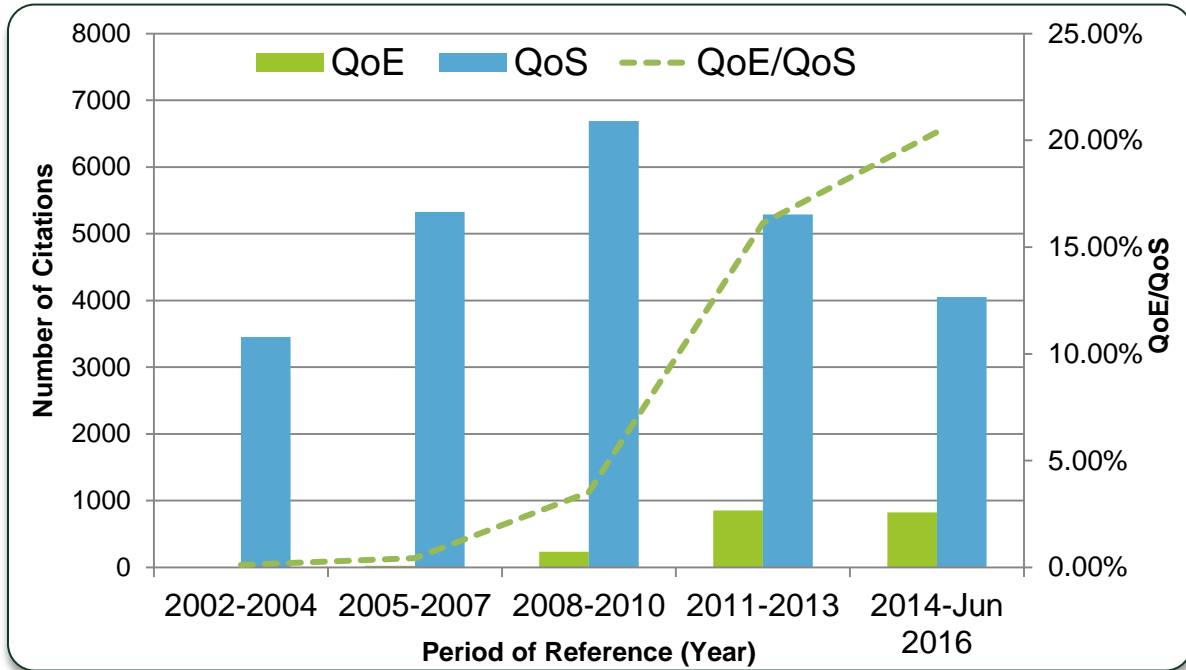


Figure 3-2: Ratio of QoE/QoS from 2002 - 2016 [38]

### 3.2. Description of QoS Metrics

Quality of service metrics which are considered for evaluating experience of UMTS data subscribers in this thesis work are:

- Download throughput or data rate,
- Upload throughput or data rate, and
- Latency or ping

ETSI describes all the above metrics in [39]. The download and upload throughputs are described as download and upload mean data rates and the latency is defined as a ping which has the same meaning. The download and upload mean data rates indicate the average data transferred during a certain period of time. Latency or ping is also defined as the time required for a packet to travel from a source to a destination and back. The formulas for the throughputs and ping are shown in Equations (1) and (2).

$$\text{Download | Upload Mean Data Rate [kbps]} = \frac{\text{User data transferred [Kbit]}}{(t_{\text{data transferred complete}} - t_{\text{data transfer start}}) [s]} \quad (1)$$

Where:

$t_{data\ transfer\ start}$  is time of successfully started data transfer and

$t_{data\ transferred\ complete}$  is time when data transfer complete

$$Ping [ms] = (t_{packet\ received} - t_{packet\ sent})[ms] \quad (2)$$

Where:

$t_{packet\ sent}$  is time when packet is sent

$t_{packet\ received}$  is time when packet is received

### 3.3. QoE Measurement Techniques

Like QoS metrics, metrics for QoE are also identified. Objective metrics are metrics which are helpful for measuring and understanding QoS. On the other hand, there are subjective metrics for measuring the perception of service users or QoE. During the evaluation of QoS, the metrics are extracted in their corresponding units which help telecom service providers to see the performance of their networks and satisfaction of their users by setting different thresholds. For the perception of customers for a given service, apart from QoS indicator metrics, a set of subjective metrics can be prepared and ask users about their feelings regarding the services being provided. We can use Likert Scale as stated in [40] for measuring the subjective metrics based on the responses of participants by conducting a survey.

Likert Scale is defined in [40] as “5 or 7 point scale that offers a range of answer options – from one extreme attitude to another, like ‘extremely likely’ to ‘not at all likely.’ Typically, they include a moderate or neutral midpoint.” One sample of the answers, for example, for the subjective question – “How satisfied or dissatisfied are you with our services?” is listed below based on 5-point Likert Scale.

### 5-point Likert Scale:

- Very satisfied
- Somewhat satisfied
- Neither satisfied nor dissatisfied
- Somewhat dissatisfied
- Very dissatisfied

The subjective metrics that are collected based on the Likert Scale have to be converted to MOS value so that there will be manipulation of the perception of subscribers of a service numerically. ITU-T describes in [41] the most commonly used scale for converting subjective questions to numerical values. The commonly used scale is a 5-point scale called Absolute Category Rating (ACR). Table 3-2 shows responses of subjective questions with their respective scales.

Table 3-2: 5-Point ACR [41]

Response	Scale
Excellent	5
Good	4
Fair	3
Poor	2
Bad	1

The recommended value for MOS is greater than 3.5 as mentioned in [42]. If the average MOS value is greater than 3.5, the participants are assumed to have good experience or perception of the service they get from service providers.

## Chapter 4

### 4. Quality of Experience Measurement in Addis Ababa

#### 4.1. Quality Handling Process in ethio telecom

Before collecting data for analysis purposes, investigation has been done on quality handling process in ethio telecom, which is the sole telecom service provider in Ethiopia. Ethio telecom has its own organizational structure for its day-to-day operations though our focus is on quality handling process. There are divisions, departments, sections and groups in the company for its business activities. From all the divisions, we have investigated Customer Service and Network division which are responsible for quality handling and customer complaints related to UMTS data service.

The evaluation has started by assessing whether ethio telecom has a unique process for handling UMTS data service complaints or not. For example, if a customer complains about low downlink throughput when accessing UMTS data service, how is the complaint handled? There is no clear process for handling such complaints. The same response is given from Network division in specific departments of Engineering and SMC.

A summary of the gaps identified during the investigation is listed below:

- Internet quality complaints are handled for fixed wired broadband network rather than cellular network like UMTS data service.
- There is no clear process for handling and following UMTS data service quality related complaints, though the complaints are recorded.
- Sometimes, quality related complaints are handled through public meetings, management meetings and quality circle meetings.
- UMTS data service quality complaints are sometimes handled in an informal way.

By observing the problems, assessment was done to see if there can be a process for handling quality complaints. ETSI in [43] recommends that there has to be a quality manager for complaints and performance degradations coming from customers. A detailed description of the information flow to support performance management is shown in Figure 4-1.

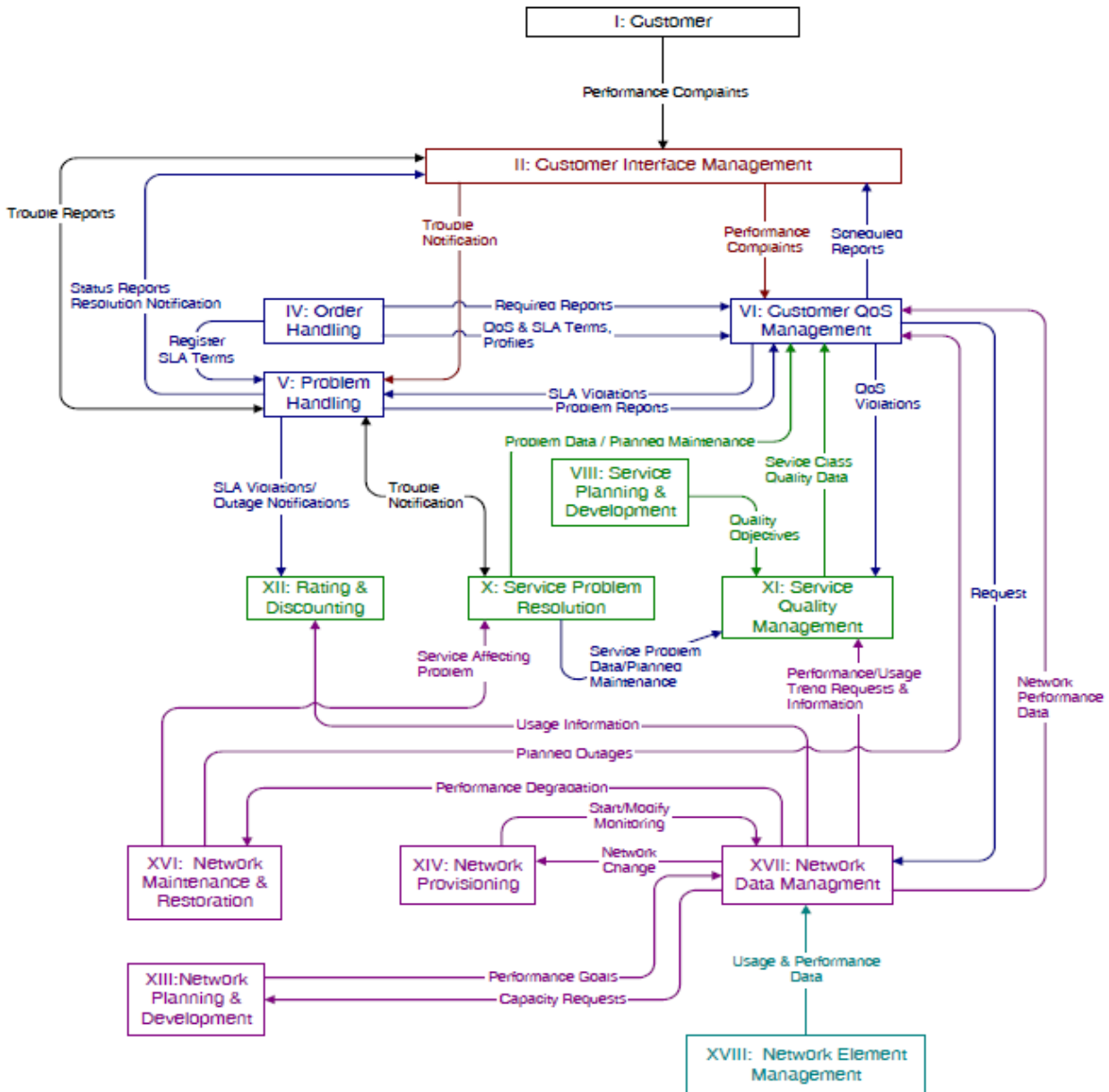


Figure 4-1: Information Flow to Support Performance Management [43]

As shown in Figure 4-1, there has to be a quality manager for the proper handling of customer complaints. In the figure, number VI (Customer QoS Management) is a focal point for the communication between II (Customer Interface Management) which is Customer Service in ethio telecom case and other departments. Some of the departments linked with Customer QoS Management are XI (Service Quality Management) and XIII (Network Planning and Development) which are SMC and Engineering in ethio telecom context, respectively. Therefore, missing the main responsible team for quality handling process can cost to customer dissatisfaction and revenue loss.

However, within the existing structure of ethio telecom, quality management network architecture for ethio telecom is proposed as depicted in Figure 4-2. If formal communication with customers is established, complaints like UMTS data service speed variation, low-speed throughput and delay in accessing websites and social media networks can be properly managed.

As shown in Figure 4-2, there has to be a communication with customers when there is UMTS data service problem or complaint. Customer Service is the interface for the customers and issues which cannot be resolved by Customer Service will be communicated to Service Management Center if they are related to UMTS data service complaints. Service Management Center can also communicate with other departments of the Network division for resolving the complaints received from Customer Service. In addition to this, if there are problems which cannot be resolved by the departments under Network division, there will be communication with vendors for further support and investigation. Finally, as the communication is bi-directional, customers have to be notified through Customer Service for a better customer satisfaction by addressing the received complaints.

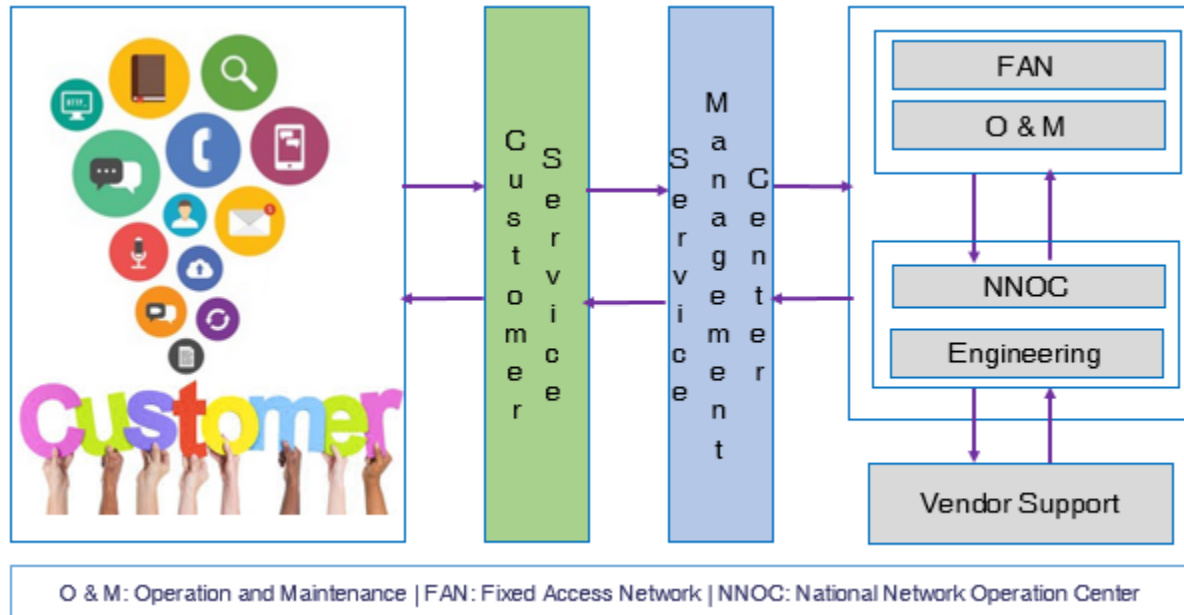


Figure 4-2: Quality Management Network Architecture

## 4.2. Plan for Taking Measurements

After assessing the quality handling process, the plan was to conduct the research in Addis Ababa. For QoS related metrics, the assessment has been arranged using data from NMS (collected from Nastar), Indoor walk test using Nemo Handy tool and using an alternate tool by considering crowdsourcing dataset.

In addition to quality metrics, data collection which shows the perception of the users has been planned. Covering all locations and all groups of the society cannot be accomplished within a limited period of time. Therefore, we have planned to focus on a specific society and location for a brief analysis of our results and observation. The assessment has been started from investigating customer segmentation in UMTS data service. As there is no clear customer segmentation for UMTS data service in ethio telecom, we have dealt with the segmentation of other products like broadband Internet and found two groups – Enterprise and residential customers.

This customer segmentation was first applied for fixed broadband services but UMTS data service users can have a profile named as Enterprise customer. Enterprise customers are also grouped as Key Accounts and Small Office Home Office (SOHO). Our target is on the Key Accounts enterprise customers as high-profile customers who can reflect the image of the company are included in this group.

There are around 3,000 Key Account enterprise customers in ethio telecom. Some of the customers are registered as headquarter which can have a huge number of staffs and branch offices under their supervision. To incorporate the enterprise customers, we assessed the enterprise shops of ethio telecom in Addis Ababa. Ethio telecom has eight Enterprise shops, however, we focused on the main office of the shops which is located near Churchill road and is almost in the center of the city.

After selecting the shop for our case study, some buildings were identified which are near to the selected Enterprise shop for conducting the Indoor walk test. The next plan is to use an alternate tool for collecting quality indicator metrics. We have found RTR-NetTest tool which is a crowdsourcing tool and can be downloaded from Google Play or Apple Store. Employees of ethio telecom whose offices near the identified shop were selected to conduct the tests. Ethio telecom employees have been selected as candidates for conducting the test since they have a free Internet UMTS package which can make the test easier for data collection.

## Chapter 5

### 5. Data Collection Mechanisms

The main objective of the thesis work is to evaluate the overall quality of experience for UMTS enterprise data customers in Addis Ababa. In order to understand the perception of the customers, it is important first to see what really the customers get from the service provider by identifying certain objective quality metrics. In addition to objective quality metrics, a set of subjective quality metrics has been prepared and distributed to enterprise customers to assess their perceptions regarding the UMTS data service they get from ethio telecom. The data collection includes four ways of data gathering for further analysis and evaluation as shown in Figure 5-1.

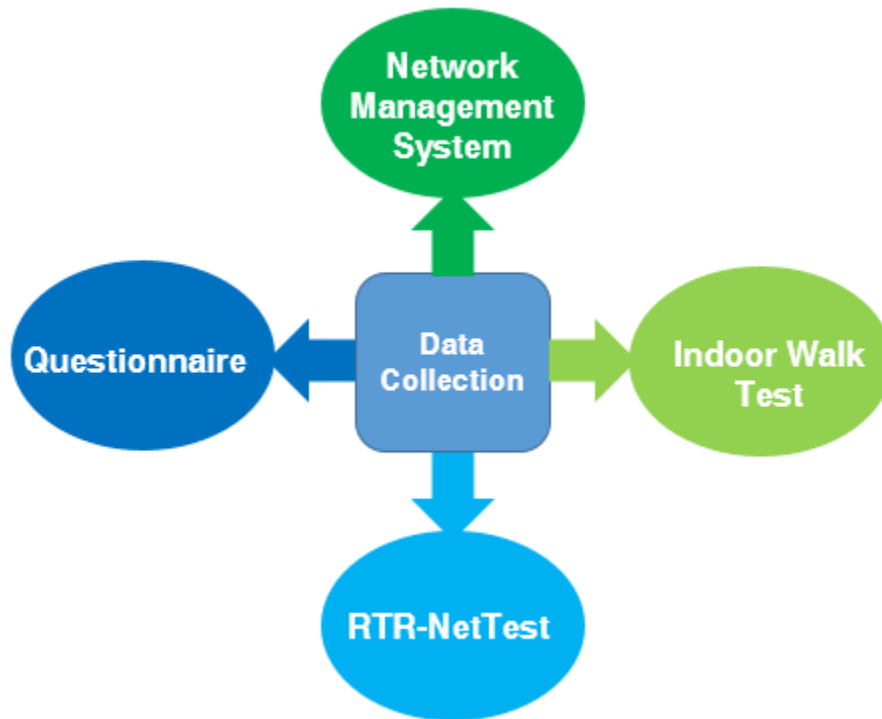


Figure 5-1: Data Collection Mechanisms

The upcoming clauses illustrate each mechanism of data collection – NMS, indoor walk test, RTR-NetTest and survey questionnaire.

## 5.1. Network Management System

Objective quality metrics have been collected from NMS with the help of Nastar tool which is vendor dependent tool. The Nastar tool is integrated with sites located in Addis Ababa. In this case, throughput metrics of UNMS network are collected based on the location of the users in Addis Ababa when they access UMTS data service. A study in [10] mentions Nastar as one of the tools in evaluating a thesis work on voice quality of service in Addis Ababa. The quality metrics considered in our study are downlink throughput and uplink throughput for each geographic point on an average weekly basis.

A task has been created to collect data from Nastar. The data was collected from April 29 through July 1, 2018, for eight weeks. The 3G technologies considered during data collection are HSPA and HSPA+ by taking both downlink and uplink throughput metrics. The values are averagely put based on the geographic location of the users.

After completion of each task, the data has been extracted in Comma Separated Values (CSV) format file. The data is then manipulated using Microsoft Excel and we get a plot to see the spatial distribution of the metrics in the city using MapInfo.

## 5.2. Indoor Walk Test

Indoor walk test or in-building walk test has been conducted using Nemo Handy tool version 2.71.391 installed in Samsung Galaxy S5 G900F mobile. Nemo Handy is one of the commercialized tools and is at least used by [10-14] for their studies. The indoor walk test in our study covers buildings near the National Theatre in Addis Ababa. This location is one of the places with a high number of enterprise customers during working hours. 20 buildings are part of the test and we have considered one floor in each building for a test based on the distribution of customers. The distribution was identified by requesting

building managers and guards. The collected metrics are download throughput, upload throughput, local latency and international latency. Table 5-1 shows list of the buildings including floor number for each test and abbreviation of each building which is applied throughout this document.

Table 5-1: List of Buildings for Indoor Walk Test

S.N.	Building name	Abbreviation	Floor Test
1	Abyssinia Bank Head Quarter	Abyssinia	3 <sup>rd</sup>
2	Awash Bank Head Quarter	Awash	Ground
3	Commercial Bank of Ethiopia Addis Ababa Branch	CBE AA	1 <sup>st</sup>
4	Debrewerk Tower	Debrewerk	2 <sup>nd</sup>
5	Dil Betigil Tower	Dilbetigil	7 <sup>th</sup>
6	Ethiopia Hotel	Ethio Hotel	2 <sup>nd</sup>
7	Ethio telecom’s Head Quarter	Ethio's HQ	4 <sup>th</sup>
8	Fana Broadcasting Corporate	Fana	1 <sup>st</sup>
9	K Kare Center	K Kare	1 <sup>st</sup>
10	Ethio telecom - Legehar	Legehar	2 <sup>nd</sup>
11	Mezid Plaza	Mezid	1 <sup>st</sup>
12	Microwave – ethio telecom	Microwave	3 <sup>rd</sup>
13	National Tower	National	3 <sup>rd</sup>
14	Ras Hetel	Ras Hotel	Ground
15	Sengatera Axion	Sengatera	1 <sup>st</sup>
16	Wabe Shebelle Hotel	Shebelle	2 <sup>nd</sup>
17	Tewelde and Sons Building	Tewelde	2 <sup>nd</sup>
18	Transformation Program Office – Enterprise	TPO	Ground
19	Yeha City Center	Yeha	Ground
20	Yobek Commercial Center	Yobek	Ground

The metrics have been collected by writing a script which is one of the features of Nemo Handy tool. The throughput measurements are taken by downloading 100 MB file from a local server for download throughput and uploading 50 MB file to a local server to get the upload throughput. For measurement of the latency, a ping has been made to a local server to get the local latency whilst a ping to Facebook has been made to get the international latency. A map which shows the route of each test has been uploaded to the test tool. After completion of each test, the results have been extracted from the test tool and manipulated using Actix Analyzer.

The in-building test was made from June 28 to July 13, 2018 during working hours. The latest test was conducted at 10:00 in the morning and the last test was made at 16:00 in the afternoon. The results are extracted using Actix Analyzer. We get the raw data using Microsoft Excel format including statistics like average, maximum and minimum values. To see the spatial distribution of each test, we get a plot of the detail spatial distribution of each metric using Actix Analyzer by showing different ranges.

### 5.3. RTR-NetTest

The other tool applied for data collection is a crowdsourcing tool called RTR-NetTest. The tool is free and can be downloaded from Google Play or Apple Store. Employees of ethio telecom were able to download the tool and make a test based on procedures depicted in Appendix A by locking their mobile devices to 3G only. The owner of the tool is the Austrian Regulatory Authority for Broadcasting and Telecommunications. The description of the tool is available in [15] and stated in [16-18] as a measurement tool. The metrics for this specific test are downlink throughput, uplink throughput and international latency. The latency has been considered as international latency since the ping was made to a server outside Ethiopia.

Table 5-2: Device Summary for RTR-NetTest

S.N.	Device Name	Max Download (Mbps)	Reference
1	Che2-UL00	42.2	[44]
2	Galaxy Grand DuoS	21	[45]
3	Galaxy Note 3	21	[45]
4	Galaxy S4 LTE-A	42.2	[44]
5	Galaxy S5	42.2	[46]
6	HTC One (HTC One_M8)	42.2	[44]
7	HTC One E9PLUS dual sim	42.2	[44]
8	Huawei G620-L72	42.2	[44]
9	HUAWEI P8max	42.2	[44]
10	HUAWEI TIT-AL00	21	[46]
11	iPhone 4s	14.4	[45]
12	iPhone 6 Plus	42.2	[46]
13	Lenovo PB2-650M	42.2	[47]
14	MI NOTE LTE	42.2	[46]
15	SM-C710F	21	[46]
16	SM-G530H	21	[45]
17	SM-G965F	42.2	[44]
18	SM-J320W8	42.2	[44]
19	SM-J510F	21.1	[44]
20	T1-701u	21	[48]
21	TECNO-W5	42.2	[49]

The technical setup for the RTR-NetTest is illustrated in Figure 1-3 under the Methodologies Subsection 1.4 and sample of the results collected from the participants are included in Appendix B.

Ethio telecom employees have been selected to perform the test as they have a free Internet package which doesn't hinder them from making the tests because of the charge made for each test. Around 140 ethio telecom employees were requested through email and in person in the months of June and July 2018. Only 31 participants have made tests and finally, which leads to 32 participants including the researcher. Of the 32 participants, 21 unique devices have been identified from the tests. All the devices have the capability of supporting up to 5.76 Mbps upload speed. The list of devices, including their capability of supporting download speed, is shown in Table 5-2 and the detailed information for each device is available in the allotted reference column.

After following the procedures in Appendix A, the participants have sent details of the test and the raw data has been extracted in CSV format from RTR-NetTest crowdsourced dataset. Table 5-3 shows a summary of collected fields from RTR-NetTest data within their descriptions.

Table 5-3: Fields from RTR-NetTest Data

S.N.	Field Name	Description
1	time_utc	This field helps us to identify the time in which the test is conducted. We can extract day and hour of measurements conducted from this field by converting the time into Ethiopian time zone. The time zone had three hours difference during the test period.

S.N.	Field Name	Description
2	model	This field is important for knowing and identifying which device is used during the test period.
3	cat_technology	The technology used during the measurement period is identified using this field. The researcher is able to identify and sort out tests which are conducted by selecting 3G network only.
4	network_type	We choose this field to know the technology of 3G network selected by the user during the test period. For example, HSPA and HSPA+ technologies are identified using this field.
5	download_kbit	This field shows the result of the downlink throughput in Kilobits Per Second (Kbps) though we convert the figure into Mbps for our final analysis.
6	upload_kbit	The result of the upload throughput in Kbps is extracted from this field. The result is converted into Mbps during analysis.
7	ping_ms	This field helps us to extract the international latency in ms.

## 5.4. Subjective Metrics

The aim of identifying subjective metrics is to correlate the QoS results with the perception of enterprise customers about the services being provided. To evaluate the perception of the users, a questionnaire which consists of subjective questions or metrics has been prepared. Some of the questions are prepared by referring to [4, 8, 9, 19-22]. We have tried to make the questionnaire clear and readable with the help of [50] which illustrates the questionnaire preparation.

The questionnaire consists of 15 questions related to quality metrics, 3 questions about demography of the participants and one question for receiving comments or feedback from the participants. A summary of the subjective metrics is displayed in Table 5-4. Each subjective metric is given identification starting from Q01 to Q19. Appendix C displays details of the subjective metrics.

Table 5-4: Summary of Subjective Metrics

Q01	Overall quality of 3G data service satisfaction
Q02	Downloading files or video/music satisfaction
Q03	Uploading files or video/music satisfaction
Q04	Web browsing delay
Q05	Accessing social media networks
Q06	Quality of video
Q07	Choosing best locations for Data connection
Q08	Choosing worst locations for Data connection
Q09	Choosing best time periods for Data connection
Q10	Choosing worst time periods for Data connection
Q11	Preference of Wi-Fi network
Q12	Why Wi-Fi?
Q13	Contact center satisfaction
Q14	Switching to a new service provider
Q15	Devices for accessing 3G data service
Q16	Gender
Q17	Age range
Q18	Educational background
Q19	Any other comments

To make it understandable for the participants, detailed instructions have been included as a cover page in the questionnaire. We distributed the questionnaire in hard copies to one of the enterprise shops near the location where the indoor walk has been conducted. Some enterprise customers have also been invited to fill the questionnaire using Google Form. A total of 129 participants have responded to the questionnaire during the months of June and July 2018. A demography of the participants is shown in Table 5-5 though the response from each participant is not complete.

Table 5-5: Demography of Participants

<b>Sex</b>	Male	88
	Female	33
<b>Age Range</b>	Under 18	2
	18 – 24	17
	25 – 34	65
	35 – 54	37
	Above 55	5
<b>Educational Background</b>	Master’s degree and above	31
	Bachelor’s degree	66
	University or college student	8
	Diploma or certificate	12
	Grade 11 – 12	7
	Grade 10 and below	5

## Chapter 6

### 6. Analysis, Results and Interpretations

As stated in Chapter 5, data has been collected using four mechanisms – Nastar (from NMS), Indoor Walk Test (using Nemo Handy), crowdsourcing RTR-NetTest and Subjective metrics. The output of the results and their interpretations are described in Subsections 6.1, 6.2, 6.3 and 6.4.

#### 6.1. Nastar

As described in Subsection 5.1, Nastar data was collected from April 29 through July 1, 2018, for eight weeks. The weeks have been labeled from Week 1 to 8 (W01 – W08). Metrics considered are downlink throughput and uplink throughput, which are average for HSPA and HSPA+ for all subscribers in Addis Ababa when they access UMTS data service. The results are extracted on an average weekly basis based on the geographical location of the subscribers. The extracted data consists of average values for each unique location.

The raw data is extracted in CSV file format and analysis is done using Microsoft Excel and MapInfo. We have considered the average and maximum values of the data on a weekly summary to assess satisfaction of the participants. The average and maximum values of the downlink throughput in Mbps are shown in Figure 6-1 for each week.

As shown in Figure 6-1, the average download throughput is in the range of 0.53 and 0.63 Mbps, though the maximum download throughput goes up to 16 Mbps and the obtained minimum result is 0 Mbps. The network has a capability of supporting high data speed which is enough for mobile broadband users. However, the overall download throughput can result in customer dissatisfaction for some specific services.

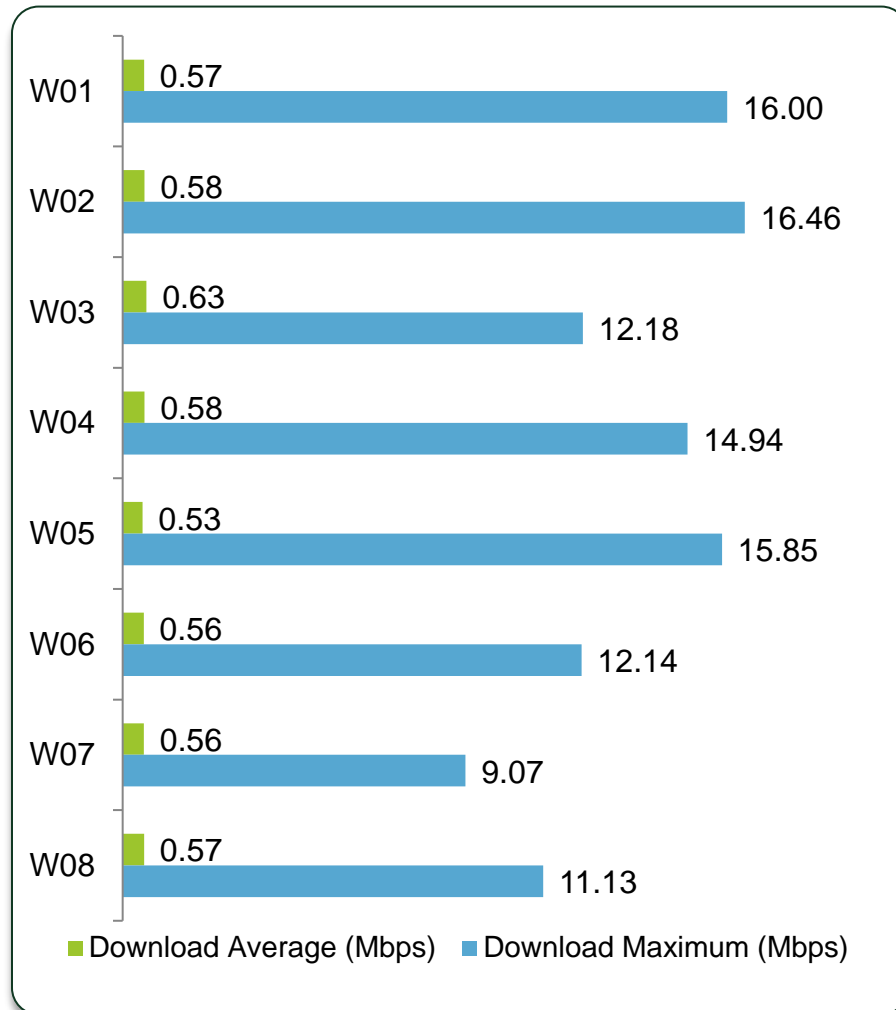


Figure 6-1: Download Throughput from Nastar

Ken's Tech Tips [51] which is one of the UK's longest-running independent mobile technology websites states that for browsing the web a download speed of 0.3 Mbps is enough. For watching YouTube videos and making Skype calls, a speed of 0.5 Mbps is required. However, for making a High-definition (HD) Skype video call and watching HD iPlayer need a minimum download speed of 1.5 and 3.2 Mbps, respectively. The author in [52] states that a download speed of 4 Mbps is needed to download and stream videos. The overall average download throughput during the test period for our case is 0.57 Mbps, which we can conclude that for a better user experience, the average

download speeds are not enough for UMTS data service subscribers for video calling and streaming videos.

A spatial distribution of download speed is depicted in Figure 6-2 from June 8 to 14, 2018. From the plot, we can see that more than 80% of the area has below 1 Mbps of download data rate. Only 2% of the area has a download speed of more than 2 Mbps.

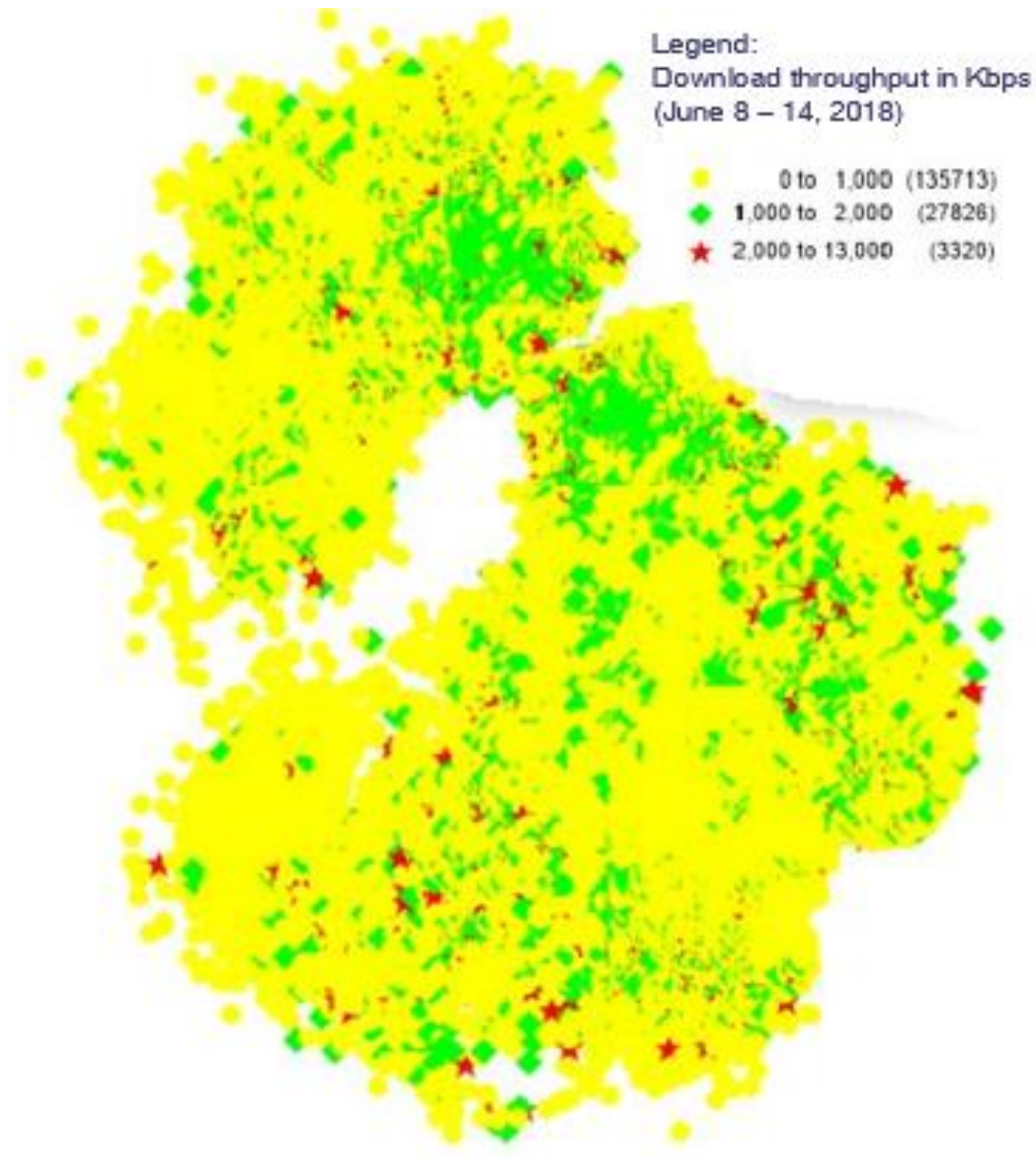


Figure 6-2: Addis Ababa Spatial Distribution - Download Throughput (Kbps)

From Nastar, the average and maximum upload speeds in Mbps are extracted. Though the result of the average upload speed in each week is 0.04 Mbps, the maximum upload throughput for each week is shown in Table 6-1.

Table 6-1: Maximum Upload Speed

Week	Maximum Upload Speed (Mbps)
W01	2.32
W02	2.22
W03	2.22
W04	2.12
W05	2.28
W06	1.78
W07	2.17
W08	2.15

The results in Table 6-1 show that the maximum upload speed is in the range of 1.78 and 2.32 Mbps during the test period and the minimum upload throughput is 0 Mbps in each week. As the maximum and minimum upload speeds do not represent all UMTS data service users, our focus is on the average values. Using an online speed test, a result in [52] shows that the upload speed is 21 times slower than the download speed. However, Nastar result shows that the average upload speed is almost 14 times slower than the average download speed though the results are very less for satisfying customers.

A report in [53] shows that the average upload speed of 3G mobile Internet in the UK was 1.6 Mbps in June 2014. The result extracted from Nastar shows that the value is 40 times slower than the result found in [53]. From Table 6-1, we can estimate there will not be a

better user satisfaction with a very low upload speed which makes difficult for UMTS data subscribers to upload files.

## 6.2. Indoor Walk Test

The indoor walk test has been conducted using Nemo Handy tool. Our focus is evaluating what the real figure of the customers' experiences during daytime is. The test was performed during the daytime from 10:00 to 16:00. The buildings are expected to accommodate a high number of enterprise customers during the selected period. We preferred the indoor walk test to the outdoor or drive test as most customers are expected to be in a stationary place when they access the data service. It is also mentioned in [54] that most of the mobile traffic generated is from indoor. 70% - 80% of the traffic generated is inside buildings and in some cities, 50% of the traffic generated is from 10% of the buildings.

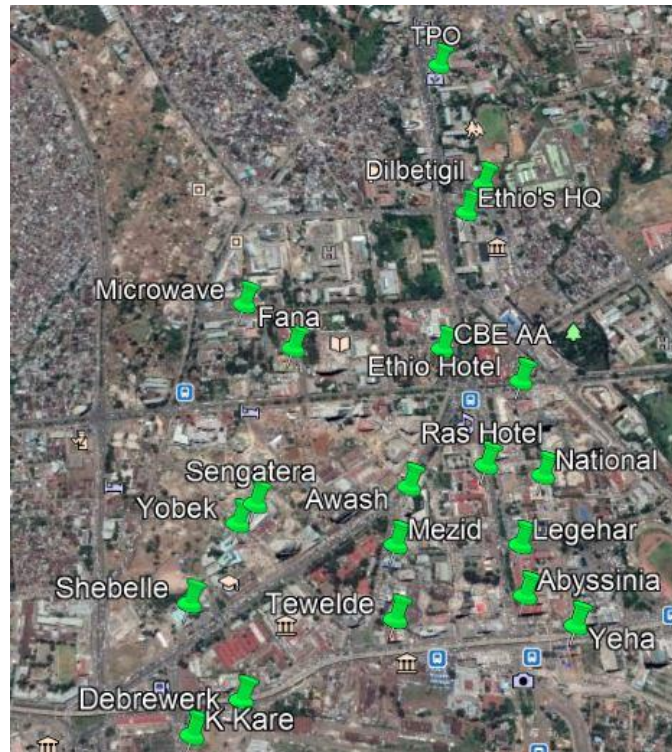


Figure 6-3: Geographical Locations of the Buildings

The Indoor walk test has been done in selected 20 buildings near Addis Ababa National Theatre. List of the buildings has been mentioned in Subsection 5.2 in Table 5-1. Geographical location of the buildings is shown in Figure 6-3.

The metrics for the indoor test considered in this work are downlink throughput, uplink throughput, local latency and international latency. Figure 6-4 shows a result of the average and maximum download throughput for each building. A maximum of 13.34 Mbps download speed has been achieved at ethio telecom’s headquarter whereas the average download throughput for all the buildings is 0.86 Mbps though a minimum download throughput of 0.53 Kbps is achieved in Legehar.

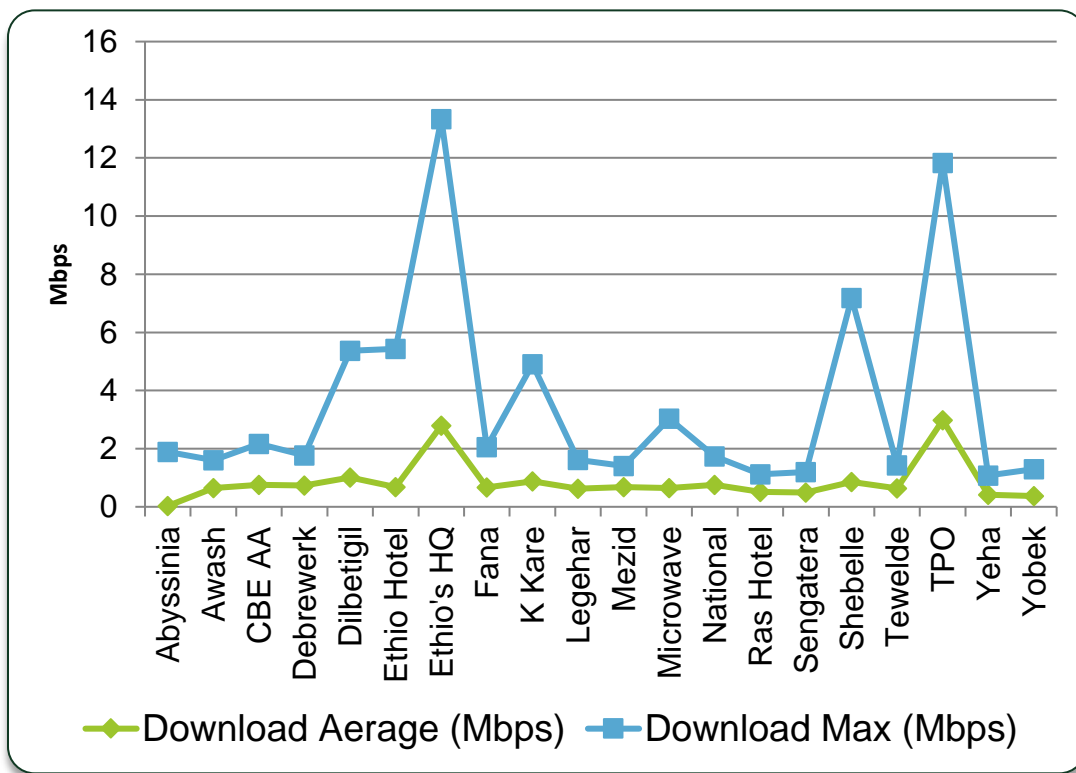


Figure 6-4: Download Throughput from Indoor Test

From a total of 20 buildings, 9 of the buildings have a maximum download throughput more than 2 Mbps. If we observe the average throughput in each building, only three buildings have a download speed of more than 1 Mbps. 85% of the buildings have less

than 1 Mbps download speed which makes it difficult to satisfy customers. According to [20], for good customer satisfaction, customers have to get 1 Mbps to access Facebook, 2 Mbps to access Google Maps and a download speed of 4 Mbps for accessing YouTube. As mentioned in [51], less than the abovementioned download speeds, for example for accessing YouTube, can be enough for accessing websites and watching videos. However, for better customer satisfaction, high download speed is advisable.

In order to see further analysis, two buildings within the same test periods are taken with different average throughputs - CBE AA and Ethio's HQ. We want to see the spatial distribution of the download throughput in the buildings with an average download speed of 0.76 Mbps and 2.79 Mbps for CBE AA and Ethio's HQ, respectively. A spatial distribution of the download data rate for the two buildings is shown in Figure 6-5 and Figure 6-6.



Figure 6-5: Ethio's HQ - Download Throughput Spatial Distribution



Figure 6-6: CBE AA - Download Throughput Spatial Distribution

The upload speed result, including both average and maximum values, is shown in Table 6-2. For the maximum upload speed, only 25% of the buildings have an upload speed of more than 1 Mbps with a maximum upload speed of 2.58 Mbps in TPO. The overall average upload throughput is 0.17 Mbps though a minimum upload throughput of 0.49 Kbps is achieved in Microwave.

The average upload throughput is almost similar to the result found from Nistar for 75% of the buildings. TPO has a better average upload speed which is 0.93 Mbps compared to the other buildings. As illustrated in Subsection 6.1, the upload throughput is not good and can result in customer dissatisfaction.

Table 6-2: Upload Throughput from Indoor Walk Test

Building	Upload Average (Mbps)	Upload Max (Mbps)
Abyssinia	0.04	0.10
Awash	0.04	0.09
CBE AA	0.48	1.81
Debrewerk	0.05	0.23
Dilbetigil	0.79	2.53
Ethio Hotel	0.04	0.08
Ethio's HQ	0.36	1.89
Fana	0.04	0.14
K Kare	0.20	1.50
Legehar	0.04	0.3
Mezid	0.04	0.11
Microwave	0.03	0.08
National	0.03	0.10
Ras Hotel	0.03	0.07
Sengatera	0.04	0.08
Shebelle	0.04	0.08
Tewelde	0.04	0.09
TPO	0.93	2.58
Yeha	0.04	0.09
Yobek	0.03	0.08

Latency or ping is one of the metrics collected from the Indoor walk test. This metric is measured in ms and was collected by making a ping to a local server and Facebook during the test period. The two metrics extracted here are local latency and international latency based on the testing servers which are local server and Facebook, respectively. Figure 6-7 displays both local and international latencies. The average and minimum values for each building are considered.

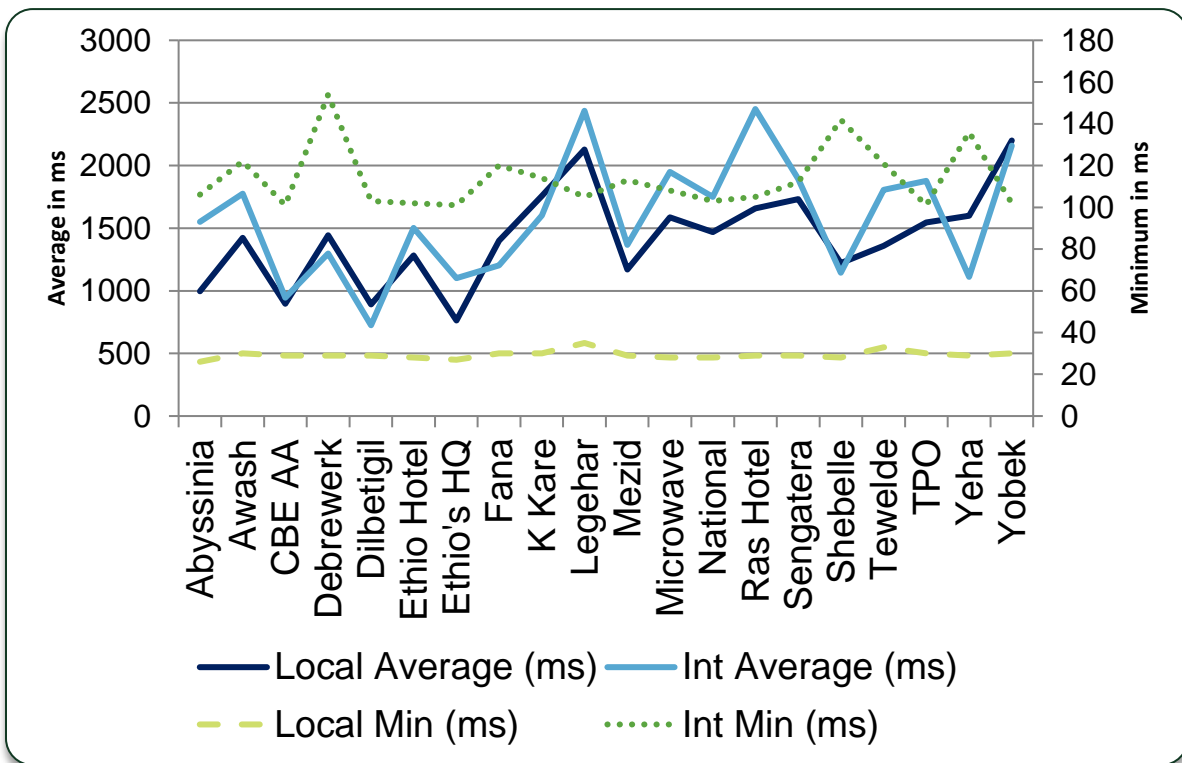


Figure 6-7: Latency from Indoor Walk Test

Serious gaming, including entertainment and applications with content of education, training and simulation, can degrade the quality and experience of ratings if the network latency is more than 30 - 50 ms [56]. With a similar concept, authors in [55] describe that humans can have a good experience with a latency of 50 ms though a latency of 1 – 10 ms is acceptable for healthcare applications as stated in [56]. As indicated in Figure 6-7, the minimum local latency for all the buildings is around 30 ms which is acceptable for

human experience. However, the other three metrics average local latency, minimum international latency and average international latency for all the building are very high and the maximum latency goes up to nearly 10 seconds in some buildings. These can result in quality degradation and bad user experience.

### 6.3. RTR-NetTest

Ethio telecom employees have performed the crowdsourcing RTR-NetTest around the areas where the Indoor walk test was conducted while the participants were also informed to make a test in locations away from their offices. A total of 805 tests using 21 unique devices are conducted by 32 participants as depicted in Table 6-3. On average, 38 tests are performed by each participant.

Table 6-3: RTR-NetTest Total Tests

Device Name	Total Tests
Che2-UL00	21
Galaxy Grand DuoS	22
Galaxy Note 3	23
Galaxy S4 LTE-A	20
Galaxy S5	38
HTC One (HTC One_M8)	17
HTC One E9PLUS dual sim	22
Huawei G620-L72	15
HUAWEI P8max	51
HUAWEI TIT-AL00	11
iPhone 4s	16
iPhone 6 Plus	21
Lenovo PB2-650M	20

Device Name	Total Tests
MI NOTE LTE	16
SM-C710F	15
SM-G530H	321
SM-G965F	15
SM-J320W8	84
SM-J510F	24
T1-701u	18
TECNO-W5	15
<b>Total:</b>	<b><u>805</u></b>

Detailed instruction for the test is displayed in Appendix A. The participants were informed to conduct an indoor test, for example, inside their offices, homes, cafés and restaurants. Metrics collected in this case are download throughput, upload throughput and international latency. The average values of the metrics are shown in Figure 6-8.

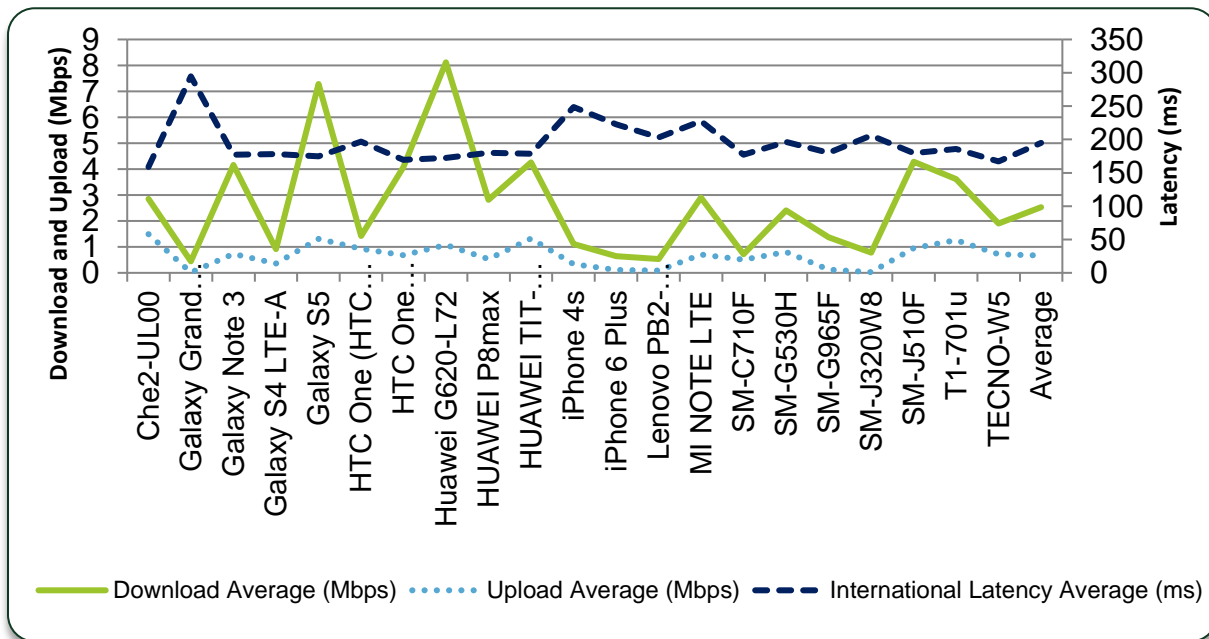


Figure 6-8: RTR-NetTest Average Result

It is noted in [28] that the perception of users can be affected by the devices they use as different devices have different models. As shown in Figure 6-8, the average download and upload throughputs are not uniform for all the devices because of the nature of the devices and the spatiotemporal distribution of the tests. An average download speed of more than 4 Mbps has been acquired from 29% of the devices. The same ratio of devices, 29%, also has an average download speed of less than 1 Mbps. The average download speed for all the devices is 2.53 Mbps. On the other hand, a minimum download throughput of 4 Kbps is collected from Lenovo PB2-650M device. A report which is generated by OpenSignal [57] shows that in May 2018, a download speed of 10.49 Mbps has been achieved by Telekom in Germany. This indicates that the average result obtained here is almost 4 times less than the result obtained from Telekom.

The average result of the upload speed is less than 1.5 Mbps for all the devices. 76% of the devices have an average upload speed of less than 1 Mbps which can result in delays when we upload files or videos. The overall average upload speed is 0.67 Mbps though the minimum is 3 Kbps (for iPhone 6 Plus device) which results a delay in uploading files or videos and leads to a dissatisfaction with service users.

Figure 6-8 shows that the average result of international latency for each device is higher than 150 ms. As stated in [55, 56], a latency of higher than 50 ms can result in bad user experiences. The average result for all the devices is 195 ms with a maximum latency of 1,892 ms collected from SM-G530H. When the result is compared with Vodafone of Germany in May 2018 [57], it is 3.5 times higher which can result a high delay during communication.

The optimum result obtained from RTR-NetTest, which is maximum for download and upload speed and minimum for the international latency, is shown in Figure 6-9.

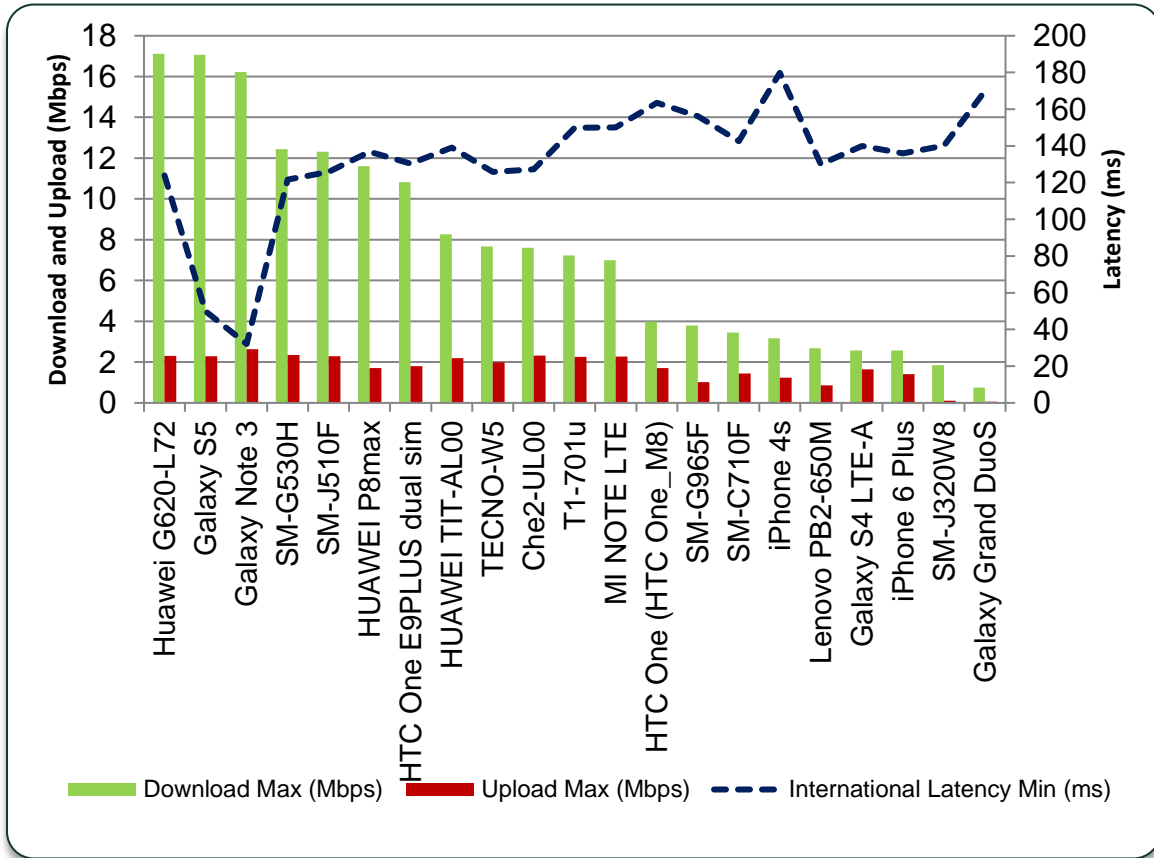


Figure 6-9: RTR-NetTest Optimum Result

The maximum download data rate for each device is between 0.76 and 17.11 Mbps with a range of 16.35 Mbps. 43% of the devices have a maximum download speed of less than 4 Mbps. The maximum upload speed varies from 0.07 Mbps to 2.30 Mbps. The optimum latency is observed in two devices with a latency of 32 and 50 ms. All the other devices have a minimum international latency of higher than 120 ms. It can be concluded from the obtained results that the network and the devices have a capability of supporting a high data rate with acceptable latency.

Form the collected data, the result of the tests using the same handset in the same location is not constant because of the time in which the test was conducted. As shown in Figure 6-10, temporal distribution of download throughput varies in different time periods.

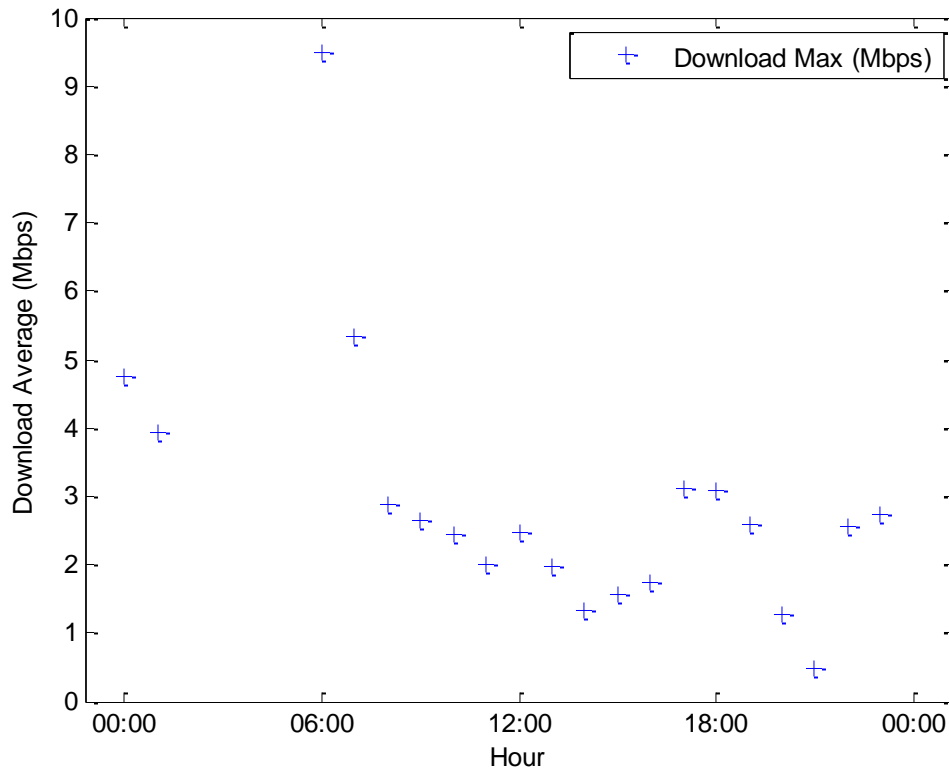


Figure 6-10: Download Throughput Temporal Distribution

The temporal distribution in Figure 6-10 shows the average result of the download throughput of all the devices on an hourly basis. The maximum throughput is obtained at 6:00 in the morning whilst the least throughput is achieved at 21:00 which is a busy hour for 3G network in ethio telecom context. From this result, we can conclude that subscribers who access UMTS data service in different time periods have different perceptions about the service because of variation of the download throughput.

## 6.4. Subjective Metrics

Subjective metrics are a result of responses from enterprise customers. As described in Chapter 5, a telecom survey consisting of 18 questions including one comment has been conducted on selected enterprise customers in Addis Ababa.

For analysis purpose, the telecom survey has been grouped into four categories as follows:

- Quality related metrics
- Spatiotemporal metrics
- Other metrics and
- Feedback from participants

Detail description of the questions is available in Appendix C, and a summary of the questions is depicted in Table 5-4 under Subsection 5.4. A group of each metric with a list of question numbers is shown in Table 6-4.

Table 6-4: Category of Subjective Metrics

Category	Subjective Metrics
Quality related metrics	Q01-Q06
Spatiotemporal metrics	Q07-Q10
Other metrics	Q11-Q15
Feedback from participants	Q19

#### 6.4.1. Quality Related Metrics

Q01-Q06 are categorized as quality-related metrics. The results of quality-related metrics collected based on 5-point Likert Scale are shown in Figure 6-11 and Figure 6-12.

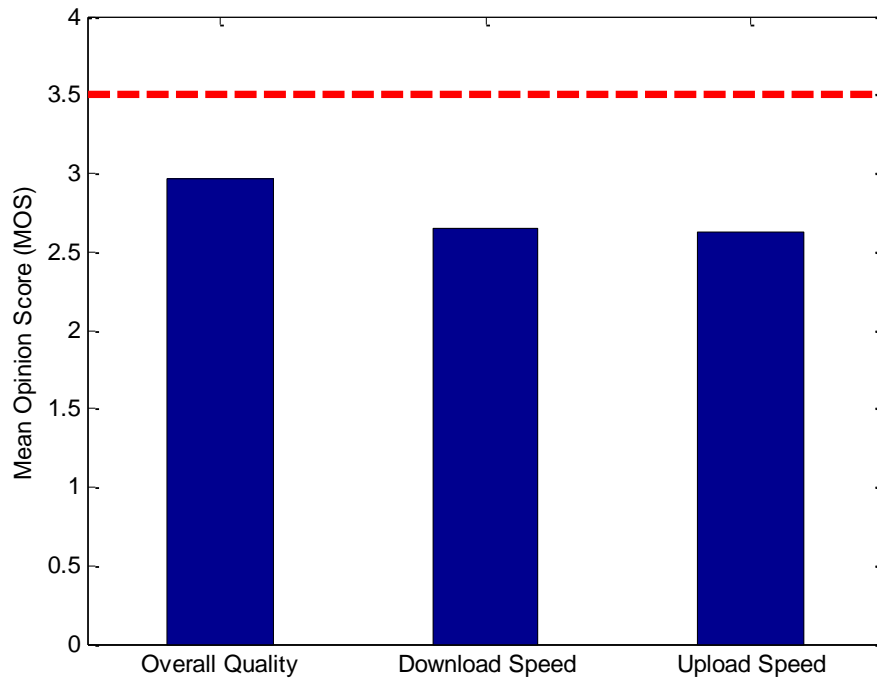


Figure 6-11: Quality Related Metrics 1

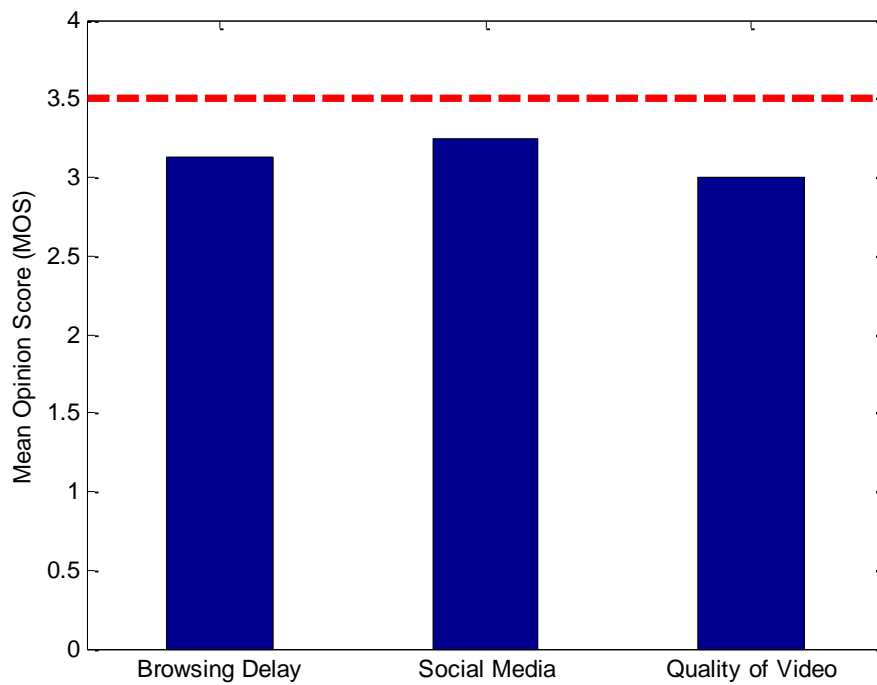


Figure 6-12: Quality Related Metrics 2

As stated in [42], the average MOS value has to be greater than 3.5 for a better customer satisfaction. However, the results in Figure 6-11 and Figure 6-12 show that the MOS value for all the quality-related metrics is less than 3.5. When we correlate the results with Subsections 6.1, 6.2 and 6.3, the achieved data rate and latency have a direct relation with the response of the participants. The results obtained from Nastar, Indoor Test and RTR-NetTest are not satisfactory. These bring customer dissatisfaction and responses from the participants prove that customers are not happy with the current 3G data service as our survey shows an overall MOS value of 2.96 for the satisfaction of UMTS data service.

#### 6.4.2. Spatiotemporal Metrics

Spatiotemporal metrics are included in this study to see where and when enterprise customers perceive the worst and best performance of the 3G data service. As shown in Table 6-5, the participants get the best data connection outside their homes. On the other hand, the participants get the worst 3G data connection inside their homes. We can conclude that high attention must be given to indoor coverage as most traffic generated is indoor [54].

Table 6-5: Best and Worst Performing Locations

Location	Best Performing Responses	Worst Performing Responses
Inside taxi/bus/car	9	29
When walking	27	15
Outside office	26	19
Inside office	45	39
Outside home	52	16
Inside home	23	60

Perceptions of the enterprise customers for the best and worst time periods for their data connections are illustrated in Table 6-6. The best time period in which participants get the best data connection is during the night from 9:00 PM to 10:00 PM. This time period is

considered as a busy hour for 3G service in ethio telecom context, which contradicts the response of the customers. However, the result from RTR-NetTest shows the least download throughput during the busy hour in ethio telecom context. The time period the subscribers get the worst 3G data service is during the afternoon from 1:30 PM to 6:00 PM as per the survey result shown in Table 6-6.

Table 6-6: Best and Worst Time Periods

Time Period	Best Performing Responses	Worst Performing Responses
Night (9:00 PM to 10:00 PM)	73	18
Evening (6:00 PM to 9:00 PM)	29	26
Afternoon (1:30 PM to 6:00 PM)	4	52
Lunchtime (12:00 PM to 1:30 PM)	10	48
Morning (8:30 AM to 12:00 PM)	21	35
Early morning (5:00 AM to 8:30 AM)	50	6

### 6.4.3. Other Metrics

Most of the participants (60%) access the 3G data service using their cell phones, though there are subscribers who access the 3G data service using 3G Wi-Fi modem and 3G dongle. The participant preference of 3G to Wi-Fi is very high. 77% of the participants reply that they prefer Wi-Fi to 3G data service and the reasons are to save money and get faster downloads for videos and files as shown in Figure 6-13.

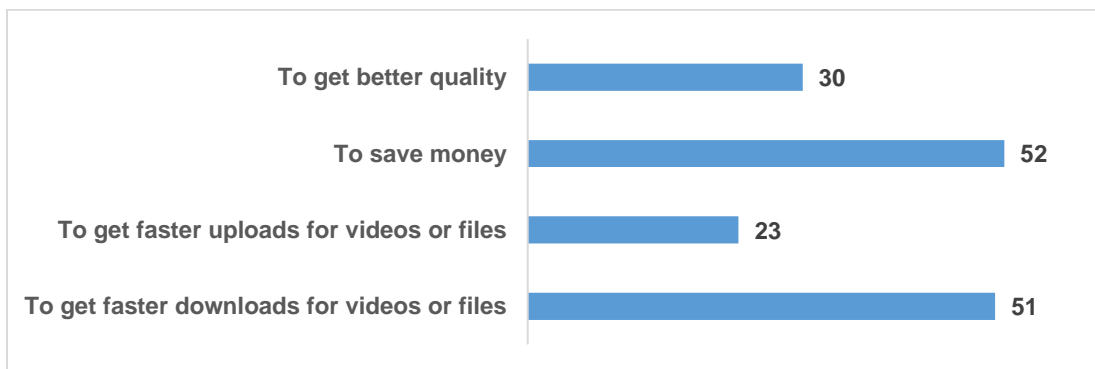


Figure 6-13: Why Wi-Fi?

The participants' satisfaction regarding contact center of ethio telecom has a MOS value of 3.24 which is less than 3.5. The trust of the participants for the current telecom service provider in Ethiopia is not satisfactory. The percentage of very likely and likely switching to a new service provider, if launched, is 75% which is a high figure and shows a know-how with the dissatisfaction of the customers.

#### 6.4.4. Feedback from Participants

The last question of the questionnaire focuses on the feedback of the participants. A summary of their response is shown in Figure 6-14. The maximum feedback given is on the expensiveness of 3G tariffs. However, a reduction of 43% mobile Internet tariff has been implemented since August 22, 2018 [58], which is declared after our survey. Meanwhile, high attention must be given to the comments provided by the enterprise customers like accessibility and speed issues.

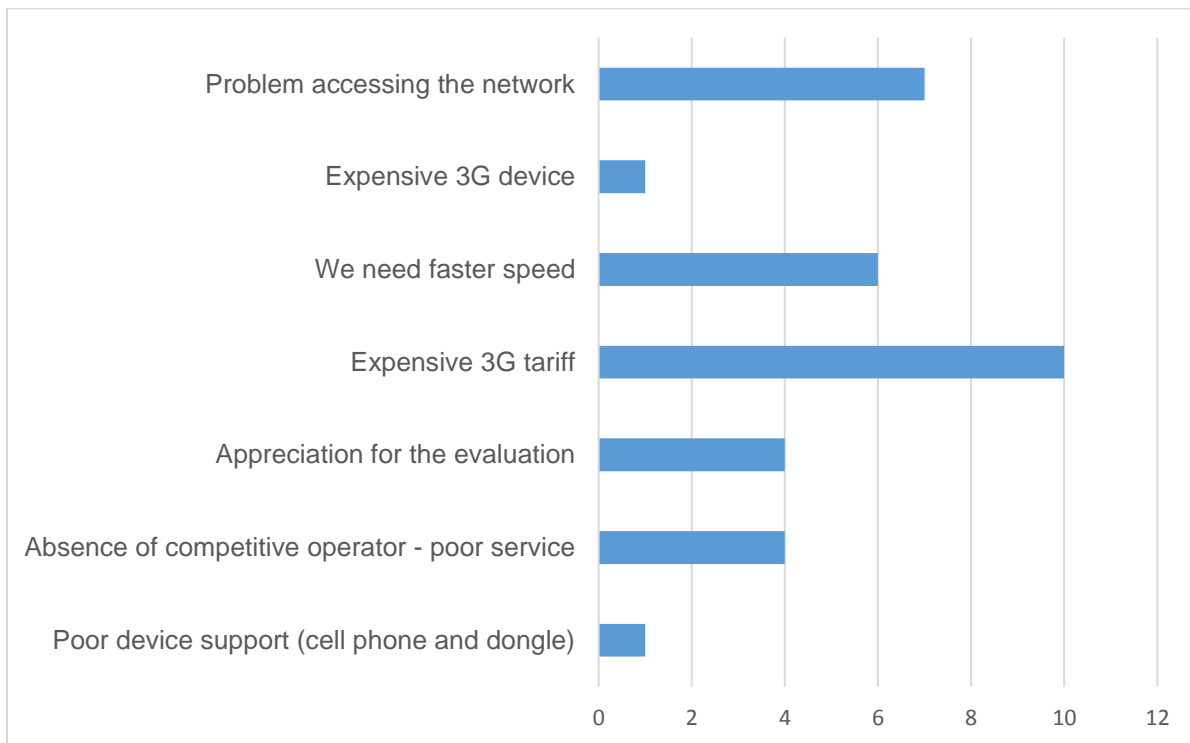


Figure 6-14: Feedback from Participants

## Chapter 7

### 7. Conclusion and Future Work

#### 7.1. Conclusion

The introduction of capable modern technologies and smartphones with innovative data services has brought business opportunities for telecom operators. Yet, for exploiting the opportunity, mobile operators are expected to monitor and evaluate the satisfaction of their customers by taking relevant optimization and other decisions. Operators can assess and monitor the performance of their networks using QoS metrics that contribute to user QoE, which is also a function of user capability and opinion.

In the case of Ethiopia, there have been important projects to improve mobile services provided by the sole incumbent operator of the country, ethio telecom. UMTS data service is one popular service being delivered across the country. Yet, a considerable number of customers are not satisfied with UMTS data service regardless of implementation of the projects. In this thesis work, we have analyzed both user side QoE and QoS towards the network to thoroughly understand user perception, user side network quality and their correlation, focusing on selected enterprise customers of Addis Ababa.

After dealing with the quality monitoring process in ethio telecom, three quality metrics have been identified – download throughput, upload throughput and latency for network side assessment. In addition to the quality metrics, subjective metrics have been collected and identified which can show us the perception of the users. Data has been collected for quality evaluation from NMS, Indoor walk test and using a crowdsourced approach RTR-NetTest in Addis Ababa. The subjective quality indicator metrics have also been collected by preparing a questionnaire for enterprise customers of ethio telecom in Addis Ababa.

From the collected data, the average download throughput from NMS is 0.57 Mbps, 0.86 from Indoor walk test and 2.53 Mbps from crowdsourcing RTR-NetTest. For better customer satisfaction, the recommended download throughput has to be above 4 Mbps. However, the results obtained here are less than the recommended value and can bring to customer dissatisfaction which has been reflected in the responses of the enterprise customers with a MOS value of 2.65 for downloading files or video/music.

The average upload data rate is 0.04 Mbps from NMS and the result from Indoor walk test is 0.17 Mbps. The upload throughput result from crowdsourcing RTR-NetTest is 0.67 Mbps. The results are not good and have a direct relation in the response of the customers with less MOS value of 2.62 for uploading files. In addition to the download and upload data rates, the latency obtained from Indoor walk test and RTR-NetTest are not satisfactory. The average value of the local latency is 1,426 ms from the Indoor walk test. On the other hand, the result of the international latency is 1,582 ms and 195 ms from Indoor walk test and RTR-NetTest, respectively. The quality metrics have a direct effect on satisfaction of the participants which resulted a MOS value of 3.13 for delay browsing the Web and 3.25 for accessing social media networks.

From the subjective metrics, the overall satisfaction of the participants for accessing UMTS data service in Addis Ababa is 2.96 MOS value. The result shows that there is dissatisfaction of customers for the service being provided. 75% of the participants are very likely or likely switching to a new service provider from the question regarding their perception of the current UMTS data service provider. From both the objective and subjective metrics, the satisfaction of UMTS data service subscribers must be a crucial task for ethio telecom as continues evaluation of customer satisfaction which can bring customer satisfaction, attract new customers and finally increase revenue.

## 7.2. Future Work

The following areas are recommended for future work.

- To fully understand the perception of the users in Ethiopia, a research has to be also done in other major cities of the nation.
- We can follow the same methodology for evaluation of the perception of UMTS and GSM voice users. Researches can also be done for the overall satisfaction of fixed broadband users.
- QoE evaluation using other alternate tools like SpeedTest and OpenSignal to address the perception of the customers.
- Developing an alternate crowdsourcing tool for collecting both objective and subjective quality metrics.
- We have observed that the national latency is higher than the international latency. This has to be conducted as a separate research for addressing and resolving the problem.
- QoE evaluation has to be done for other customer segmentation like University lecturers, Students, Governmental Employees, Merchants and other groups of the society for a broad understanding of users' perceptions.
- A QoE evaluation has to be also done by letting customers rate on a current service being provided to them by varying, for example, the download throughput of UMTS data service.

## References

- [1] Ethio telecom, “Ethio Telecom Home Page,” 2018. Available: <http://www.ethio-telecom.et/>. [Accessed Sep. 17, 2018].
- [2] K. I. Lakhtaria, “Enhancing QoS and QoE in IMS Enabled Next Generation Networks,” *International journal on applications of graph theory in wireless ad hoc networks and sensor networks (GRAPH-HOC)*, vol. 2, no. 2, pp. 61-71, June 2010.
- [3] Cisco, *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016-2021*, Cisco White Paper, 2017.
- [4] HOTE TELECOM, *4 Keys to Shaping Quality of Experience*, June 2015.
- [5] D. Soldani, M. Li, and R. Cuny, *QoS and QoE Management in UMTS Cellular Systems*, John Wiley & Sons, Ltd., 2006.
- [6] World Population Review, “Addis Ababa Population 2018,” 2018. Available: <http://worldpopulationreview.com/world-cities/addis-ababa-population/>. [Accessed Jan. 24, 2018].
- [7] B. B. Haile, D. A. Bulti, and B. M. Zerihun, “On the Relevance of Capacity Enhancing 5G Technologies for Ethiopia,” in *The 10<sup>th</sup> Ethiopian ICT Annual Conference (EICTC-2017)*, Addis Ababa, 2017.
- [8] Ofcom, *Reason to Complain Research*, Ofcom Fieldwork, Dec. 2016.
- [9] CICRA, *Customer Satisfaction Survey – Mobile Results*, CICRA 16/10, Mar. 2016.
- [10] A. Jiso, “Quality of Service Evaluation of Voice over UMTS Network: The case of Addis Ababa,” MSc. dissertation, Dept. Elect. and Comp. Eng, Addis Ababa Univ., Addis Ababa, 2017.
- [11] S. Gupta, and R. Garg, “Taxonomy of Tools and Techniques for Network Monitoring and Quality Assurance in 3G Networks,” *International Journal of Computer Applications*, vol. 120, no. 21, pp. 34-41, June 2015.
- [12] F. Afroz, R. Subramanian, R. Heidary, K. Sandrasegaran, and S. Ahmed, “SINR, RSRP, RSSI and RSRQ Measurements in Long Term Evolution Networks,” *International Journal of Wireless & Mobile Networks (IJWMN)*, vol. 7, no. 4, pp. 113-123, Aug. 2015.

- [13] J. A. Palazon, M. Sepulcre, J. Gozalvez, J. Orozco, and O. Lopez, "Heterogeneous Wireless Connectivity for Fixed and Mobile Sensing Applications in Industrial Environments," in *Proceedings of the 16<sup>th</sup> IEEE International Conference on Emerging Technologies and Factory Automation*, Toulouse, 2011, pp. 1-8.
- [14] F. J. Rivas-Tocado, M. Sepulcre, and J. Gozalvez, "Innovative Tools and Processes for Mobile Communications Research and Education," *International Journal of Online Engineering*, vol. 12, no. 9, pp. 40-46, Sep. 2016.
- [15] BEREC, *BEREC Preliminary report in view of a common position on monitoring mobile coverage*, BEREC BoR (17) 186, Oct. 2017.
- [16] E. Lipenbergs, V. Bobrovs, and G. Ivanovs, "Investigation of Service Quality of Measurement Reference Points for the Internet Services on Mobile Networks," *Latvian Journal of Physics and Technical Sciences*, no. 5, pp. 64-73, Oct. 2016.
- [17] K. Kousias, A. Lutu, C. Midoglu, A. Argyriou, O. Alay, and M. Riegler, "The Same, Only Different: Contrasting Mobile Operator Behavior from Crowdsourced Dataset," in *2017 IEEE 28<sup>th</sup> Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, Montreal, 2017, pp. 1-6.
- [18] A. S. Khatouni, M. Mellia, M. A. Marsan, S. Alfredsson, J. Karlsson, A. Brunstrom, O. Alay, A. Lutu, C. Midoglu, and V. Mancuso, "Speedtest-like Measurements in 3G/4G Networks: the MONROE Experience," in *IEEE 2017 29<sup>th</sup> International Teletraffic Congress (ITC 29)*, Genoa, 2017, pp. 169-177.
- [19] R. Schatz, and S. Egger, "Vienna Surfing – Assessing Mobile Broadband Quality in the Field," in *Proceedings of the first ACM SIGCOMM workshop on Measurements up the stack*, Toronto, 2011, pp. 19-24.
- [20] P. Casas, B. Gardlo, M. Seufert, F. Wamser, and R. Schatz, "Taming QoE in Cellular Networks: from Subjective Lab Studies to Measurements in the Field," in *2015 11<sup>th</sup> International Conference on Network and Service Management (CNSM)*, Barcelona, 2015, pp. 237-245.
- [21] H. Y. Lin, S. H. Hsieh, K. H. Chen, and T. C. Wu, "Large-scale Mobile Internet Performance Measurement in Taiwan," in *2014 6<sup>th</sup> International Conference on Ubiquitous and Future Networks (ICUFN)*, Shanghai, 2014, pp. 516-519.
- [22] B. Alemayehu, "Evaluation of User Side Quality of Service Measurement Techniques for Addis Ababa LTE Data Service," MSc. dissertation, Dept. Elect. and Comp. Eng, Addis Ababa Univ., Addis Ababa, 2018.

- [23] M. Morkas, and B. Ksiezopolski, "The Method for Quality of Experience Evaluation of IT Services," *Studia Informatica*, vol. 37, no. 2, pp. 73-84, 2016.
- [24] K. D. Moor, I. Ketyko, W. Joseph, T. Deryckere, L. D. Mare, L. Martens, and G. Verleye, "Proposed Framework for Evaluating Quality of Experience in a Mobile, Testbed-oriented Living Lab Setting," *Mobile Networks and Applications*, vol. 15, issue 3, pp. 378-391, 2010.
- [25] J. Zhang, and N. Ansari, "On Assuring End-to-End QoE in Next Generation Networks: Challenges and a Possible Solution," *IEEE Communications Magazine*, vol. 49, issue 7, pp. 185-191, 2011.
- [26] N. Adam, N. Osman, and I. Mkwawa, "Quality of Protection and Quality of Experience in Multimedia Communications," *International Journal of Computing and Information Sciences*, vol. 12, no. 1, pp. 95-104, Sep. 2016.
- [27] P. Gilski, and J. Stefanski, "Quality Expectations of Mobile Subscribers," *Journal of Telecommunications and Information Technology*, vol. 1, pp. 15-19, Jan. 2015.
- [28] A. Elmnsi, N. Osman, and I. Mkwawa, "The Impact of Mobile Device Preference on the Quality of Experience," *International Journal of Computing and Information Sciences*, vol. 12, no. 1, pp. 89-94, Sep. 2016.
- [29] H. Holma, and A. Toskala, *WCDMA FOR UMTS – HSPA EVOLUTION AND LTE*, 5<sup>th</sup> ed. John Wiley & Sons, Ltd., 2010.
- [30] GSMA, "HSPA," 2018. Available: <https://www.gsma.com/aboutus/gsm-technology/hspa>. [Accessed Aug 30, 2018].
- [31] European Telecommunications Standards Institute, *Quality of Service (QoS) concept and architecture*, ETSI TS 123 107 V15.0.0, 2018.
- [32] R. C. Streijl, S. Winkler, and D. S. Hands, "Mean Opinion Score (MOS) revisited: methods and applications, limitations and alternatives," *Multimedia Systems*, vol. 22, pp. 213-227, Mar. 2016.
- [33] J. Shaikh, M. Fiedler, and D. Collange, "Quality of Experience from user and network perspectives," *Annales des Telecommunications*, vol. 65, pp. 47-57, Feb. 2010.
- [34] International Telecommunication Union, *Vocabulary for performance, quality of service and quality of experience*, ITU-T P.10/G.100, 2017.


- [35] T. Rahrer et al., “Triple-play Services Quality of Experience (QoE) Requirements,” Architecture & Transport Working Group, Technical Report TR-126, Dec. 13, 2006.
- [36] European Telecommunications Standards Institute, *Human Factors (HF); Quality of Experience (QoE) requirements for real-time communication services*, ETSI TR 102 643 V1.0.2, 2010.
- [37] A. J. Verdej, K.D. Moor, I. Ketyko, K. T. Nielsen, J. Vanattenhoven, T. D. Pessemier, W. Joseph, L. Martens, and L. D. Marez, “QoE Estimation of a Location-Based Mobile Game using on-body sensors and QoS-related data,” in *2010 IFIP Wireless Days*, Venice, 2010, pp. 1-5.
- [38] D. Z. Rodriguez, R. Rosa, R. D. Nunes, and E. T. Affonso, “Assessment of Quality-of-Experience in Telecommunication Services,” *International Journal of Digital Information and Wireless Communications (IJDIWC)*, vol. 6, no. 4, pp. 241-259, Oct. 2016.
- [39] European Telecommunications Standards Institute, *Definition of Quality of Service parameters and their computation*, ETSI TS 102 250-2 V2.6.1, 2017.
- [40] SurveyMonkey, “What is a Likert scale?,” 2018. Available: <https://www.surveymonkey.com/mp/likert-scale/>. [Accessed Mar. 26, 2018].
- [41] International Telecommunication Union, *Mean opinion score interpretation and reporting*, ITU-T P.800.2, 2013.
- [42] C. Pedro and S. Raimund, “Quality of Experience in Cloud Services: Survey and Measurements,” *Computer Networks*, vol. 68, Aug. 2014.
- [43] European Telecommunications Standards Institute, *Universal Mobile Telecommunications System (UMTS); 3G Telecom Management: Principles and high level requirements*, ETSI TS 132 101 V3.4.0, 2001.
- [44] GSMarena, “Mobile phone reviews, specifications and more,” 2018. Available: <https://www.gsmarena.com/>. [Accessed Aug. 1, 2018].
- [45] PhoneMore, “Much More about Phones,” 2018. Available: <https://www.phonemore.com/>. [Accessed Aug. 1, 2018].
- [46] PDevice, “APS Products Archive,” 2018. Available: <https://www.pdevice.com/product/>. [Accessed Aug. 1, 2018].

- [47] Technology World, "TECHNOLOGY WORLD (PHONES / TABLETS)," 2018. Available: <http://www.gadgetgurubn.com/>, [Accessed Aug. 1, 2018].
- [48] Huawei, *Huawei Product Description*, MediaPad T1 7.0, 2015.
- [49] BestMobs, "Phone Specs, News and Reviews," 2018. Available: <https://bestmobs.co/>. [Accessed Aug. 1, 2018].
- [50] E. Fanning, "Formatting a Paper-based Survey Questionnaire: Best Practices," *Practical Assessment, Research & Evaluation*, vol. 10, no. 12, pp. 1-14, Aug. 2005.
- [51] Ken's Tech Tips, "Download Speeds: What do 2G, 3G and 4G actually mean for you?," 2012. Available: <https://kenstechtips.com/index.php/download-speeds-2g-3g-and-4g-actual-meaning>. [Accessed Aug. 1, 2018].
- [52] Steve's Internet Guide, "Internet Speeds Explained," Dec. 2017. Available: <http://www.steves-internet-guide.com/internet-speeds/>, [Accessed Aug. 27, 2018].
- [53] The Statistics Portal, "Average 3G and 4G HTTP upload speeds in the United Kingdom (UK) as of June 2014, by provider (in Mbit/second)," 2014. Accessed: <https://www.statista.com/statistics/398655/average-3g-and-4g-http-upload-speed-by-provider-in-the-uk/>. [Accessed Aug. 27, 2018].
- [54] M. Tolstrup, *Indoor Radio Planning - A Practical Guide for GSM, DCS, UMTS, HSPA and LTE*, 2<sup>nd</sup> ed. John Wiley & Sons, Ltd., 2011.
- [55] B. Briscoe et al., "Reducing Internet Latency: A Survey of Techniques and their Merits," *IEEE Communications Surveys & Tutorials*, vol. 18, issue 3, pp. 2149-2196, Nov. 2014.
- [56] I. Parvez, A. Rahmati, I. Guvenc, A. I. Sarwat, and A. Dai, "A Survey on Low Latency Towards 5G: RAN, Core Network and Caching Solutions," Aug. 2018.
- [57] OpenSignal, "OpenSignal Reports," 2018. Available: <https://opensignal.com/reports/>, [Accessed June 11, 2018].
- [58] Ezega, "Ethio Telecom Announces Major Reduction on Internet, Voice Call, SMS Rates," 2018. Available: <https://www.ezega.com/News/NewsDetails/6533/Ethio-Telecom-Announces-Major-Reduction-on-Internet-Voice-Call-SMS-Rates>. [Accessed Sep 25, 2018].

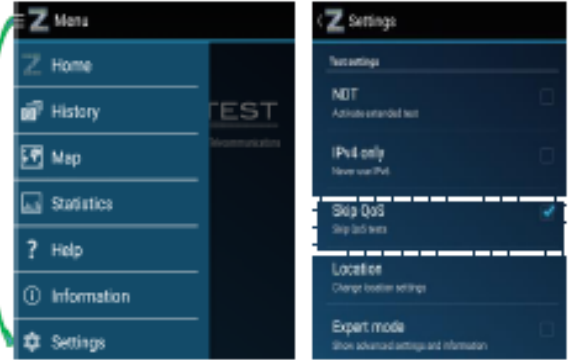
# Appendix A

## RTR-NetTest Instructions


**1** Download and install RTR-NetTest from Google Play or Apple Store.



**2** Run the application and go to Menu → Settings and enable 'Skip QoS'.



**3** Make your network selection 3G (WCDMA or UMTS) only and enable your cellular network data connection. After running the application, select START for Indoor tests (home, office, cafe or restaurant).



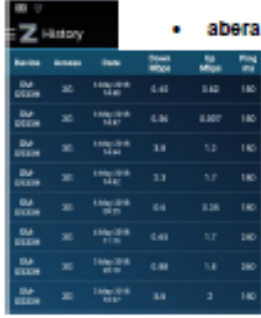
**4** Perform indoor tests for at least two consecutive days. (A minimum of eight tests in each day in different time periods). After completing the tests, follow instructions 5 and 6.

**5** Select Menu → History from RTR-NetTest.



**6** Take screenshot of the history data and send to one of the following contacts:

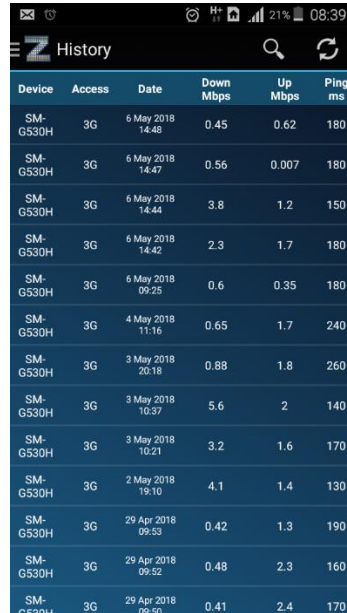
- +251-911-508713 (Using Viber)
- aberabile@gmail.com (Email)
- abera.reesom@ethiotelecom.et (Email)



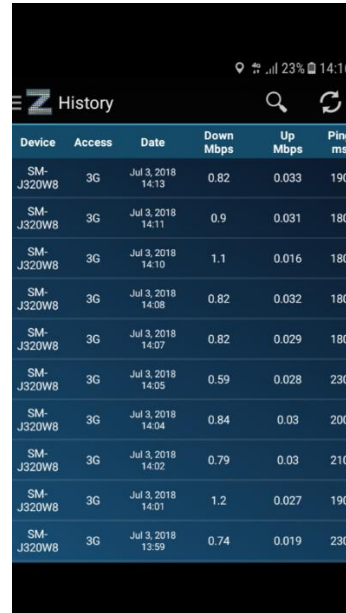
*Thank You!*

# Appendix B

## RTR-NetTest Sample Results



Device	Access	Date	Down Mbps	Up Mbps	Ping ms
SM-G530H	3G	6 May 2018 14:48	0.45	0.62	180
SM-G530H	3G	6 May 2018 14:47	0.56	0.007	180
SM-G530H	3G	6 May 2018 14:44	3.8	1.2	150
SM-G530H	3G	6 May 2018 14:42	2.3	1.7	180
SM-G530H	3G	6 May 2018 09:25	0.6	0.35	180
SM-G530H	3G	4 May 2018 11:16	0.65	1.7	240
SM-G530H	3G	3 May 2018 20:18	0.88	1.8	260
SM-G530H	3G	3 May 2018 10:37	5.6	2	140
SM-G530H	3G	3 May 2018 10:21	3.2	1.6	170
SM-G530H	3G	2 May 2018 19:10	4.1	1.4	130
SM-G530H	3G	29 Apr 2018 09:53	0.42	1.3	190
SM-G530H	3G	29 Apr 2018 09:52	0.48	2.3	160
SM-G530H	3G	29 Apr 2018 09:50	0.41	2.4	170



Device	Access	Date	Down Mbps	Up Mbps	Ping ms
SM-J320W8	3G	Jul 3, 2018 14:13	0.82	0.033	190
SM-J320W8	3G	Jul 3, 2018 14:11	0.9	0.031	180
SM-J320W8	3G	Jul 3, 2018 14:10	1.1	0.016	180
SM-J320W8	3G	Jul 3, 2018 14:08	0.82	0.032	180
SM-J320W8	3G	Jul 3, 2018 14:07	0.82	0.029	180
SM-J320W8	3G	Jul 3, 2018 14:05	0.59	0.028	230
SM-J320W8	3G	Jul 3, 2018 14:04	0.84	0.03	200
SM-J320W8	3G	Jul 3, 2018 14:02	0.79	0.03	210
SM-J320W8	3G	Jul 3, 2018 14:01	1.2	0.027	190
SM-J320W8	3G	Jul 3, 2018 13:59	0.74	0.019	230



Device	Access	Date	Down Mbps	Up Mbps	Ping ms
Che2-UL00	3G	Jul 12, 2018 7:39 AM	3.3	2.3	130
Che2-UL00	3G	Jul 12, 2018 7:38 AM	3.1	1.9	140
Che2-UL00	3G	Jul 12, 2018 7:38 AM	5.3	2.1	130
Che2-UL00	3G	Jul 9, 2018 6:29 PM	5.6	2.2	130
Che2-UL00	3G	Jul 9, 2018 6:28 PM	1.6	1.8	130
Che2-UL00	3G	Jul 9, 2018 6:27 PM	2.5	1.6	150
Che2-UL00	3G	Jul 9, 2018 6:26 PM	2.3	1.5	140
Che2-UL00	3G	Jul 9, 2018 4:58 PM	2.4	2	200
Che2-UL00	3G	Jul 9, 2018 4:57 PM	5.8	1.9	200
Che2-UL00	3G	Jul 9, 2018 4:57 PM	0.4	1.3	190
Che2-UL00	3G	Jul 9, 2018 4:56 PM	5.6	1.3	200
Che2-UL00	3G	Jul 9, 2018 4:55 PM	1.4	0.1	200
Che2-UL00	3G	Jul 9, 2018 4:53 PM	7.6	0.85	200



Device	Access	Date	Down Mbps	Up Mbps	Ping ms
SM-J510F	3G	Jul 13, 2018 12:55 PM	8.5	0.9	170
SM-J510F	3G	Jul 13, 2018 12:48 PM	8.5	0.54	150
SM-J510F	3G	Jul 12, 2018 8:56 PM	0.65	0.032	230
SM-J510F	3G	Jul 12, 2018 8:54 PM	0.74	0.058	220
SM-J510F	3G	Jul 12, 2018 1:39 PM	1.6	0.007	170
SM-J510F	3G	Jul 12, 2018 1:30 PM	3.6	0.16	170
SM-J510F	3G	Jul 12, 2018 1:27 PM	1.1	0.15	150
SM-J510F	3G	Jul 11, 2018 9:06 PM	0.1	0.028	220
SM-J510F	3G	Jul 11, 2018 9:04 PM	0.25	0.02	210
SM-J510F	3G	Jul 11, 2018 9:02 PM	1	0.025	210
SM-J510F	3G	Jul 11, 2018 9:30 AM	11	2.3	150
SM-J510F	3G	Jul 11, 2018 9:28 AM	3.7	2	150
SM-J510F	3G	Jul 11, 2018 9:26 AM	5.2	2.3	130

## Appendix C

### Subjective Metrics

Q1. How satisfied or dissatisfied are you with the overall quality of 3G data service?

- Very satisfied    Somewhat satisfied    Neither satisfied nor dissatisfied    Somewhat dissatisfied    Very dissatisfied

Q2. How satisfied or dissatisfied are you when you download files or video/music?

- Very satisfied    Somewhat satisfied    Neither satisfied nor dissatisfied    Somewhat dissatisfied    Very dissatisfied

Q3. How satisfied or dissatisfied are you when you upload files or video/music?

- Very satisfied    Somewhat satisfied    Neither satisfied nor dissatisfied    Somewhat dissatisfied    Very dissatisfied

Q4. The browsing delay when you access websites is:

- Very low    Low    Moderate    High    Very high

Q5. How satisfied or dissatisfied are you when you access social media networks?

- Very satisfied    Somewhat satisfied    Neither satisfied nor dissatisfied    Somewhat dissatisfied    Very dissatisfied

Q6. How satisfied or dissatisfied are you with the quality of videos (in YouTube or video chatting)?

- Very satisfied    Somewhat satisfied    Neither satisfied nor dissatisfied    Somewhat dissatisfied    Very dissatisfied

Q7. Choose two locations where you can get the best 3G data connection speed.

- Inside home    Outside home    Inside office    Outside office    When walking    Inside taxi/bus/car

Q8. Choose two locations where you can get the worst 3G data connection speed.

- Inside home    Outside home    Inside office    Outside office    When walking    Inside taxi/bus/car

Q9. Choose two time periods in which you get the best speed of 3G data connection.

- Early morning (5:00 AM to 8:30 AM)    Morning (8:30 AM to 12:00 PM)    Lunchtime (12:00 PM to 1:30 PM)  
 Afternoon (1:30 PM to 6:00 PM)    Evening (6:00 PM to 9:00 PM)    Night (9:00 PM to 10:00 PM)

Q10. Choose two time periods in which you get the worst speed of 3G data connection.

- Early morning (5:00 AM to 8:30 AM)    Morning (8:30 AM to 12:00 PM)    Lunchtime (12:00 PM to 1:30 PM)  
 Afternoon (1:30 PM to 6:00 PM)    Evening (6:00 PM to 9:00 PM)    Night (9:00 PM to 10:00 PM)

Q11. If there is Wi-Fi network available in your surroundings, do you prefer Wi-Fi network or 3G cellular network?

- Wi-Fi network       3G cellular network

Q12. If your answer for Q11 is 'Wi-Fi network', why do you choose it? (You can choose one or more options)

- To get faster downloads for videos or files       To get faster uploads for videos or files  
 To save money       To get better quality

Q13. If you have ever called ethio telecom contact center regarding 3G data quality problem, how do you rate the response?

- Excellent     Good     Fair     Poor     Bad

Q14. If a new service provider or operator launches 3G data service network in Addis Ababa, will you switch to the new service provider?

- Very likely     Likely     Indifferent     Unlikely     Very unlikely

Q15. How do you access 3G data service? (You can choose one or more options)

- Using 3G cell phone     Using 3G dongle     Using 3G Wi-Fi Modem     Other: \_\_\_\_\_

Q16. Your gender is:

- Male     Female

Q17. Your age range is:

- Under 18     18 - 24     25 - 34     35 - 54     55+

Q18. Your educational background is:

- Master's degree and above     Bachelor's degree     University or college student  
 Diploma or certificate     Grade 11 - 12     Grade 10 and below

Q19. Any other comments:

**Thank you for your response!**