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

Quality of Experience Model for Addis Ababa Voice Service Using Adaptive Neuro Fuzzy Inference Approach

By

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Mentor

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Abstract

This thesis deals with the development of a Comprehensive Quality of Experience (CQoE) which is the combination of objective Quality of Experience (OQoE) and the Subjective Perception of Quality (SPQ) in the ratio of 80% and 20% respectively. QoE (Quality of experience) is the perceived quality of a service by the user. CQoE is a model that measures and predicts the users' perceived quality. It uses the real Global System for Mobile Communication (GSM) and Universal Mobile Telecommunications System (UMTS) data, for this purpose, to channel it according to the need of the user.

The ethio telecom has to be needed a model for QoE that is capable of assessing, measuring, predicting and anticipating the needs and expectations of customers. In a competitive environment, a service provider (SP) with no QoE model would easily lose its business to the others who have and use QoE models and strive sustainably to enhance the quality of the voice call service they provide.

The user perceived quality is measured by Mean Opinion Score (MOS) scale, by evaluating Quality of Service (QoS) metrics. Service monitoring tool data and calculated MOS measurements are then used as reference data, in order to produce a new QoE prediction model, using Adaptive Neuro Fuzzy Inference System (ANFIS). The concept of the SPQ has been introduced with the intent of getting first hand feedback from customers, by using Questionnaire. Voice call Service is given to customers, who are human beings having two main aspects: the rational, objective and the emotional, subjective. OQoE deals with the rational, objective aspect of voice call service quality given by a SP, while the SPQ deals with the undeniable emotional, subjective aspect of voice service quality given by a SP. By combining these two aspects, one gets the full picture of voice quality level given by a SP.

The 3G and 2G voice calls QoE models perform the perceived quality by these QoS metrics: PCSR (Perceived call success rate), E2ED (End to End delay) and PCDR(Perceived call drop rate). These models estimate the QoE with a Root Mean Squared Error (RMSE) and Pearson Correlations in the following order respectively: for OQoE (3G & 2G), CQoE (3G& 2G) : 0.47% & 95.05%, 0.35% & 93.82%, 0.06% & 97.88%, 0.023% & 99.24%.to the measured QoE.

Key words: QoE, QoS, OQoE, SPQ, CQoE, GSM, UMTS, Voice service.

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.

Menbere Asfaw Feleke ________________

Name **Signature**

Place: Addis Ababa

Date of Submission: **December 2019**

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

Dr. Eng. Yihenew Wondie ________________

Advisor **Signature**

Dedication

- To all my instructors
- To all my family
- Specially my parents Ato Asfaw Feleke, W/oTewabech Hailegebriel and my brother Dr.Hailegiorgis Feleke Asfaw.

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First, I want to express my deepest gratitude to the ALMIGHTY GOD who has given me the strength, power, wisdom and time to do this thesis.

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Menbere Asfaw

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List of Acronyms

2D	Two dimensional
2G	2nd Generation
3D	Three dimensional
3G	3rd Generation
4G	4th Generation
AMR	Adaptive Multi-Rate
ANFIS	Adaptive Neuro Fuzzy Inference System
AUC	Authentication Unit Centre
BSC	Basic System Controller
BTS	Basic Trans receiver System
CM	Codec mode
CMOS	Calculated mean opinion score
CN	Core Network
COQoE	Comprehensive Objective QoE
CQoE	Comprehensive Quality of Experience
CS	Circuit Switched
DBN	Deep Belief Network
E2E	End to End
E2ED	End to End Delay
Ec/N0	Carrier Energy on Spectral Noise Density
EIR	Equipment Identity Register
ESQoS	E2E Service Quality of Service
FDD	Frequency Division Duplex
GGSN	Gateway General Packet Radio Service Support Node
GMSC	Gateway Mobile-Station Switching Centre
GPRS	General Radio Packet Service
GSM	Global System for Mobile Communication
HLR	Home Location Register
HSPA	High Speed Packet Access
ITU	International Telecommunications Union
ISDN	Integrated Services Digital Network
KPI	Key performance indicator
KQI	Key Quality indicator
ME	Mobile Equipment
MLR	Multi Linear Regression
MMOS	Measured Mean Opinion Score

MOS(MOS_c)	Mean Opinion Score
MS	Mobile Station
MSC	Mobile-Station Switching Centre
MT	Mobile Termination
NSS	Network and Switching Subsystem
OMC	Operation Maintenance Centre
OSS	Operation Support Subsystem
PCDR	Perceived call drop rate
PCSR	Perceived call success rate
PLMN	public Land Mobile Network
PLR	packet loss rates
PCA	Principal Component Analysis
PS	Packet Switched
PSTN	Public Switched Telephone Network
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research and development
RLC	Radio Link Control
RMSE	Root Mean Squared Error
RNC	Radio Network Controller
ROI	Return On Investment
RF	Radio Frequency
RSCP	Received Signal Code Power
SGSN	Serving General Packet Radio Service Support Node
SIR	Signaling interference ratio
SP	Service provider
SPQ	Subjective Perception of Quality
SPSS	Statistical Package for Social Sciences
SQoS	System QoS
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
USIM	UMTS Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register

Chapter 1

Introduction

All telecom Service Providers (SP) give National and International communication services on wired and wireless technologies. Cellular Network is one of them. There are different types of cellular network services. One of them is voice call service. Most of the customers use voice service. This service generates the main source of income and profit for them.

All the above-mentioned considerations make it mandatory that, the Service providers, as a thriving company should assess the Quality of service and Quality of Experience (QoE) and thus measure it by objective scientific parameters as well as by subjective parameters such as the SPQ.

Beyond QoS measurement and assessment ethio telecom has to be needed QoE model for assessing, measuring and predicting QoE for voice service. This research paper is aimed at providing a model that measures QoE in terms of objective and subjective parameters thus giving crucial feedback that would be used to improve quality of voice service sustainably and as a consequence improve customer satisfaction.

Research results clearly show that for every customer that complains about a certain provided service there are 29 others who will not complain, On the average 26 customers out of the 29 will simply leave the service once they become dissatisfied [1]. This fact has many implications. In a competitive environment where several SP compete a SP which does not give due attention to quality of service would lose its users at an exponential rate to the one that gives due attention to QoE and adjusts its service according to the users' quality needs.

This makes it mandatory for the operators to assess, measure, predict, and anticipate user satisfaction of a service, in order to adjust the service quality according to the user's needs. The user experience depends on many factors, such as network, end device features and user expectation.

This thesis deals with the development of the concept and computation of Comprehensive Quality of Experience (CQoE) which is the combination of objective Quality of Experience (QoE) and the Subjective Perception of Quality (SPQ) in the ratio of 80% and 20% respectively.

The rationale behind the 80 % allocation for OQoE and 20 % for the SPQ is:

The OQoE is measured and computed by the experimental scientific method, which is rational, objective, clearly definable, reproducible, and accurately measurable. All of these considerations make the OQoE a reliable, objective way of measuring the voice call quality of service. That is why 80 % has been allotted to it.

The SPQ is a subjective perception of voice quality variable from person to person, from time to time, from place to place. It is dependent on the emotion of the person at the moment of filling the Questionnaire. Yet it is necessary to be known and quantified, because the voice call service is given to human beings who have the emotional aspect. Their decision-making is the result of rational and emotional considerations. That is why 20 % has allotted to it.

OQoE addresses the objective, rational aspect of voice call quality of service by using strict scientific ways and algorithms to measure, predict and anticipate voice quality level. The QoE is measured in terms of Mean Opinion Score (MOS) [1] , that represents the user's opinion about a service using a scale from 1 to 5, 1 (bad quality) to 5 (excellent quality). This makes it mandatory for the operators to assess, measure, predict, and anticipate user satisfaction of a service, in order to adjust the service quality. All of these activities are aimed at getting data regarding user need, satisfaction level, and predicting needs and anticipating voice call problems and solving them so that customers would have a high standard quality service complying to International voice call quality standards.

1.1 Motivation

The inexistence of a QoE model that evaluates the quality of the voice call service at the ethio telecom, that is capable of assessing, predicting and anticipating voice call quality needs and problems, have motivated me to develop the concept and computation of the CQoE .

The voice call service is given to customers who are human beings. The latter have a mind that is a value driven decision system. The main factors that determine their values and principles are reason, emotion, socio-cultural context of their upbringing… first hand assessment of the human value system is required in order to give a service that is satisfactory to the customers.

The main lesson that has been learnt from the literature review is that all of the papers compute QoE using rational, scientific ways to determine it. The more subtle, emotional side of the customers' values have been neglected.

To address such a challenge the concept of the CQoE has been introduced. It is called comprehensive, evidently, because it encompasses the analysis of the two main aspects of the human psyche' i.e. the rational and the emotional aspect.

1.2 Statement of the problem

Ethio telecom has to be needed QoE model, which is capable of assessing, predicting, anticipating the quality of the voice call service. In a context where there would be many competitive Service Providers who have QoE models and give far better high standard and high quality services the ethio telecom would easily lose its business and customers to them.

Additionally, there are plenty of voice and data complaints from end users in Addis Ababa. Network Analysis report by ethio telecom [2], July 2018 indicates the presence of Longer call setup delay, call drop, mute call, radio network resource congested sites, coverage and quality problems.

Table 1.1 Sample UMTS end to end QoS assessment report [3].

Type/service	Test case	Target	Result
Voice short Call	#of call attempt		153
	#of call completed successfully		148
	Call setup success rate (%)	>=98%	96.7%
	Coverage: RSCP (received signal code power)	>-95dBm >95%	>-95dBm,(99.0%)
	Coverage :Ec/No	>-13dB >95%	>-13dB,(82.6%)

Furthermore, the network performance data indicates [3] UMTS E2E (End-to-End) QoS assessment using Drive Test (DT) on Aug 16, 2018 shows there are areas (around 19%) with poor signal quality for which their Ec/No less than -13dB (~ 19% -- <-13 dB). Poor signal quality results in poor speech quality and prolonged call setup time in some areas of the city. Drive test areas having better coverage performance but signal quality degradation (Ec/No) is observed mainly caused by pilot signal pollutant & overshooting cells. The presence of quality problem on those services. Coverage and voice quality problems are a common daily occurrence.

If the SP is capable of developing a CQoE model that can measure, assess, predict and anticipate quality of experience it can easily use these data to identify the obstacles of quality voice call service and generate short term, medium term and long term technical solutions through research and development (R&D).

Research and development (R&D) is very important in making a Service Provider competent, sustainable, leading the market and having and keeping a main share of the market and the business.

1.3 Objective

1.3.1 General Objective

The main objective of this thesis is to develop or determine a CQoE model that is capable of assessing, predicting and anticipating the quality of voice call service provided by the ethio telecom, by combining the objective, scientific approach that is OQoE computation and the subjective, emotional approach using the Questionnaire SPQ.

1.3.2 Specific Objectives

- Performing literature review on QoE.
- Preprocess/analysis of the smart care collected data gotten from the ethio telecom.
- Mapping QoS parameters with QoE feature.
- Feature extracting of available QoS parameters using correlation analysis.
- To propose OQoE model using Machine learning approach, ANFIS.

- Preparing, distributing Questionnaire to customers to assess Subjective Perception Quality.
- Computing CQoE by combining the OQoE and the SPQ, and making inferences on results.
- Assessing the temporal aspect of OQoE and making inferences on CQoE.
- Assessing the spatio-temporal aspect of the SPQ and Temporal aspect of OQoE making inferences.
- Giving Recommendation.

1.4 Methodology

The system model analyzes the selected QoS and user perception parameters such as QoS parameters, which take from service monitoring tool and subjective questioner. The methodology is showed in Figure 1. In the literature review there are different model done to solve the problem and to predict an output MOS through the mathematical expression that takes as input a parameter. The output achieved through a learning algorithm and use the features obtained from service monitoring tool data, which is an active end-to-end testing solution.

To achieve this the research applies different methods:

- Literature review
- Data collection
- Preprocessing /Analyze the data
- Selection of preferred QoS metrics
- Applying machine learning algorithm

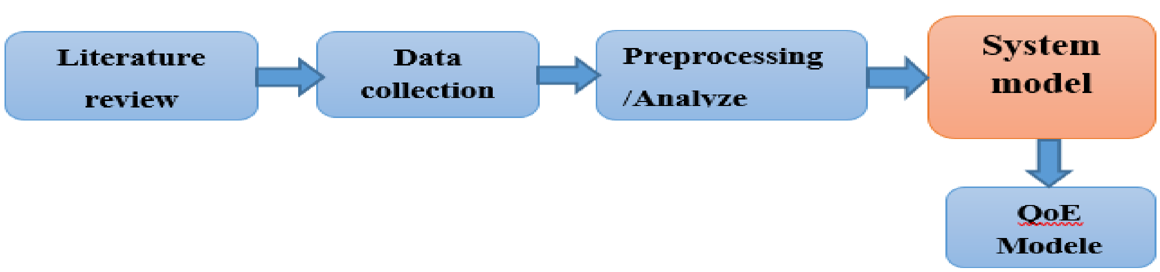


Figure 1.1 Methodology Used

1.5 Selected Literature Review

A literature review of selected QoE model researches have been made and the lessons learnt from them have been stated. The latter have been used as a feedback to develop this paper.

According to [1] QoE is the perceived quality of a service by the user. It is computed to plan telecom networks with the aim of satisfying customers' needs and expectations. The paper proposes two novel QoE models for 3rd Generation (3G) voice calls and web browsing in 4th Generation (4G). Support Vectors Regression (SVR) algorithm has been used to develop both models. The input data are gotten from drive tests. The models map these metrics in a single metric of QoE, the Mean Opinion Score (MOS). The 3G voice calls QoE model performs an estimation of the perceived quality through the following Radio Frequency (RF) metrics: RSCP, Ec=N0, SIR and SIR Target. This model estimates the QoE with a Root Mean Squared Error (RMSE) and Pearson correlation of to the measured QoE.

The aims [4] proposing a general model capable of predicting QoE for mobile networks. Particularly, based on data mining for Adaptive Multi-Rate (AMR) codec voice, and proposed a novel QoE assessment methodology. The proposed algorithm consists of two parts. The first part is regards speech quality of fixed rate codec mode (CM) of AMR while in the other one adaptive rate CM is designed. Basic network measured parameters which taken from real mobile network, that have much impact on speech quality, QoE can be monitored in real time for operators. In general, the numerical results recommend that the correlation coefficient between predicted values and true values is greater than 90% and root mean squared error is less than 0.5 for fixed and adaptive rate CM.

According to [5] based on radio link parameters with low complexity to proposes a speech quality assessment algorithm for GSM network that predicts and controls QoE of voice service for operators. In order to get the mapping model from radio link parameters to speech quality the two algorithms are used that is Multiple Linear Regression (MLR) and Principal Component Analysis (PCA) .The Data set for model training and testing is obtained from real commercial network of China Mobile. According to the test results if there is enough training data, this algorithm can predict radio speech quality with high accuracy and could be used to control speech quality of mobile network in real time.

This paper [6] presents quality prediction models for voice, based on Adaptive Neuro-Fuzzy Inference Systems, for AMR telephony service provided by GSM and UMTS rollout public land mobile networks. It uses drive test data in order to evaluate objectively the End-to-End service QoS as well as radio System QoS (SQoS) parameters. Then, the collected measurement data are used to train ANFIS empirical models. Then assessment of the prediction performance by showing 2D/3D FIS surfaces and the impacts of SQoS to ESQoS is done. The prediction methodology can be applied in Quality of Experience centric radio network planning, fine-tuning and optimization processes by mobile operators.

According to [7] the Voice over Internet Protocol (VoIP) communication service, which is amply used, and it counts with many users across the world. Since the voice signal quality can be affected by several degradations that happen in the network infrastructure the QoE cannot be fully achieved. As a consequence a global speech quality assessment method is used. Several networks that consider different packet loss rates (PLR) have been used and wireless channel models are implemented; Based on the ITU-T Recommendation P.862 algorithm the reduced signals are evaluated and in Preliminary results showed a relationship between both fading and PLR parameters and the global speech quality index. The ITU-T Recommendation P.563 describes a non-intrusive assessment method for speech nevertheless; its results are not assured. In this context, the main objective of work is to propose a non-intrusive classification model for speech quality based on Deep Belief Network (DBN) that considers the wired and wireless impairments on the speech signal. To get a high correlation between the proposed model based on DBN and P.862 algorithm from experimental results, additionally, subjective tests were carried out.

This paper [8] states that QoE parameters describe the end-to-end (E2E) quality as experienced by the mobile users. These are hard to measure and quantify. System Quality of Service (SQoS) parameters are metrics that are related to the network status. It is defined from the viewpoint of the service provider rather than the service user. Also, E2E Service Quality of Service (ESQoS) parameters define the QoS of the services and they are gotten directly from the QoE parameters.

Quality estimation models have been used for network planning and optimization for mobile voice and video telephony service. The research aim is developing arithmetical estimation models for UMTS multimedia network based on drive-test measurement campaign. Regression result estimates, there is a weaker dependence between the SQoS and ESQoS parameters and join the strength of the dependence with the accuracy of the measurements used to compute the estimates.

According to [9] it presents a unified QoS prediction methodology based on neuro-fuzzy inference systems that can be used in modern rollout mobile communication networks. The research is focused on speech and video quality of wireless multimedia communications affected by radio key performance indicators of mobile radio access networks, and on how to estimate QoE using fuzzy-based techniques. The research propose a methodology that is based on modern experimental drive-test equipment with which a measurement campaign is configured and conducted in various environments. Afterwards, the models are developed based on real network measurements and numerical results are presented.

LESSONS LEARNT: from the literature review, it is easily noticeable that all the researches address the rational that is objective needs of the users. They mostly uses drive test data as an input. But there is another human dimension the emotional, the subjective which should be gotten from customers first hand perception through Questionnaire. The voice call service is given to human beings who have the rational, objective aspect needs, and the emotional, subjective needs and expectations. So this should be included in the computation of the QoE.

1.6 Scope and Limitation

The scope of this thesis is to provide a model of CQoE based on real GSM and UMTS, limited to voice call service only, that is capable of assessing, predicting, anticipating the voice call quality needs and problems of customers and giving guidelines on how to address them.

1.7 Contribution

Development a CQoE model (the combination of OQoE and SPQ) for GSM and UMTS voice call service for ethio telecom.

- To develop OQoE using the objective scientific approach for UMTS.
- To develop OQoE using the objective scientific approach for GSM
- To assess SPQ by preparing a Questionnaire and evaluating it.
- To compute and propose CQoE model by combining OQoE and SPQ.
- To make inferences on the results and give Recommendation.

1.8 Thesis organization

This thesis is organized in the following manner.

Chapter 1 deals with the need of the CQoE, basic concepts of CQoE, its computation in the introduction part. Then follows the motivation part and the statement of the problem. The general and specific objectives are discussed successively. Next, a review of selected pertaining literature has been analyzed. The scope and limitation have then been set. Finally, the contributions of this thesis have been stated.

In Chapter 2 the basic concepts of GSM, UMTS, QoS and QoE have been discussed together with their architecture.

Chapter 3 deals with the methodology used to develop the QoE model.

Chapter 4 deals with the concept of the CQoE, its computation and inferences are made based on the results.

Chapter 5 Addresses the Conclusion, recommendation and future issues.

Chapter 2

Overview of Cellular Networks with QoS and QoE

This chapter has the background information of GSM and UMTS wireless technology. The architecture of each technology, detail description of the architecture, the technology difference and importance of QoS and QoE are considered. The ethiotelecom is at present giving both these services for voice call. The customers use both 2G and 3G voice call services indiscriminately. That is exactly why both services have been dealt with in this research.

2.1 Global System for Mobile Communication (GSM)

One of the most standard digital cellular telecommunications systems used all over the world is Global System for Mobile Communication (GSM) that is a Second Generation (2G) wireless access technology. It is the first cellular system to recognize digital modulation, network level architectures and services, Radio Frequency (RF) for GSM standard started at 1900 MHz It was first used in Europe in 1991 and at present is one of the most popular digital cellular telecommunications systems amply used all over the world [10,22,32]. It is a broadly spread, consistent and P2P (Pearson to Pearson) channel through all over the world. These features make GSM a channel appropriate for a diversity of applications in different domains specially security applications such as secure voice communication [24].

Voice service is the main and basic service given by GSM. In addition, GSM can send and receive several types of data services at bit rates up to 9600 bps. GSM wireless access technology gives several services. The GSM services are a subset of Integrated Services Digital Network (ISDN) services. GSM uses two bands of 25 MHz, 890-915 MHz and 935-960 MHz for transmitting and receiving, respectively and it uses Frequency Division Duplex (FDD) and Time Division Multiple Access (TDMA). The receive band is divided into 128 channels each with 200 KHz bandwidth, each channel is shared between as many as eight users. The GSM system has three parts: Network and Switching Subsystem (NSS), Basic Station Subsystem (BSS) and Operation Support Subsystem (OSS) [10,22,23] .

The NSS contains the equipment and functions linked to end-to-end calls, management of subscribers, switching and communicating with other networks such as ISDN and Public Switched Telephone Network (PSTN). As shown in Figure.2.1 the NSS consist of the following units: Mobile-Station Switching Centre (MSC), Home Location Register (HLR), Visitor Location Register (VLR), Authentication Unit Centre (AUC) and Equipment Identity Register (EIR).

The HLR is a central database that holds subscriber information and location information of all the users exist in in the area of MSC. The VLR is a database of all roaming mobiles in the area of MSC but not residing there. The AUC is a database that provides HLR and VLR with authentication parameters and for security purposes encryption keys. The EIR is a database that includes numbers of all registered mobile units. The BSS is built up of Basic System Controller (BSC), Basic Transceiver System (BTS) and Mobile Station (MS), also the BSS consists of many of BSCs each of which controls many BTSs and it is associated with the channel management, transmission functions and radio link control.

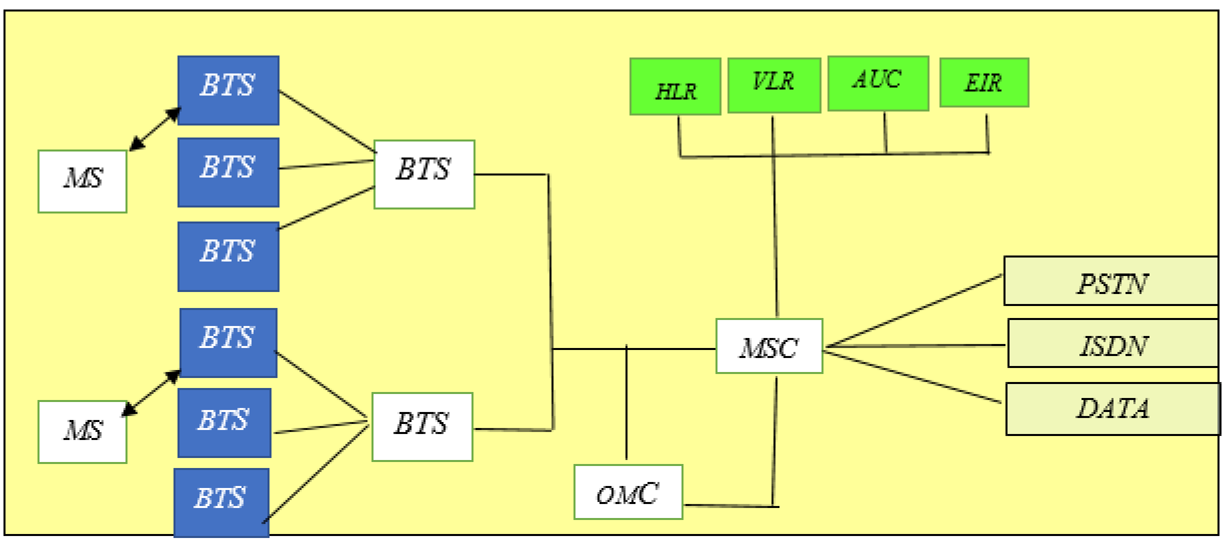


Figure 2.1 Global System for Mobile (GSM) Structure [10].

The BSS provides and manages radio transmission paths between MSs and MSC, which is the heart of NSS, and it provides call setup, routing, switching, handover and other functions. The BSS also manages the radio interface between MSs and all other subsystems of GSM while OOS is built up of Operation Maintenance Centre (OMC) and system software, which manages and monitors whole GSM system.

The disadvantage in the GSM technology occurs when a radiation noise is generated from an antenna propagation signal of a Smartphone[10] .This leads the voice quality of the Smartphone to be degraded.

2.2 Universal Mobile Telecommunications System (UMTS)

UMTS is the result of GSM system and General Radio Packet Service (GPRS) developed by Third Generation Partnership Project (3GPP) to enhance some features such as data rate in radio interface and the compatibility for the two services domains: Packet Switched (PS) and Circuit Switched (CS) data transmission [10,11,34].

The starting aims of UMTS access technology were:

- Growth in the market for fixed networked multimedia services.
- Increasing demand for rapid and remote access to information.
- E-Commerce and transaction based applications.

The key enablers of UMTS:

- Appropriate regulatory framework.
- Advances in spectrum efficient radio technologies and data compression techniques.
- Development of open UMTS standards.
- Improvements in user interface design and display technologies.
- Reduced size, power and cost of mobile devices.
- Early exploitation of GPRS and GSM2 and services.

The UMTS provides different types of services some of them are:

- Mobile services such as voice, email, fax and Short Message Service (SMS).
- Mobile multimedia services

In the Figure 2.2, the architecture of UMTS network consists of three different blocks [10, 34]. The first one, User Equipment (UE) which is composed of Mobile Equipment (ME) and UMTS Subscriber Identity Module (USIM) card. The ME is the radio terminal used for radio communication over Uu interface while USIM is a smartcard that includes the subscriber identity, performs authentication algorithms and stores authentication and encryption keys and some subscription information that are needed at the terminal. The second one, UMTS Terrestrial Radio Access Network (UTRAN) comprises sets of Node B and Radio Network Controller (RNC). The Node B converts the data flow between Iub and Uu interfaces, it also participates in radio resource management. The RNC owns and controls the radio resources in its domain as it is the service access point for all services UTRAN which provides the core network; for example, management of connections to UE. The third one, UMTS core network. The elements of GSM/UMTS are described below:

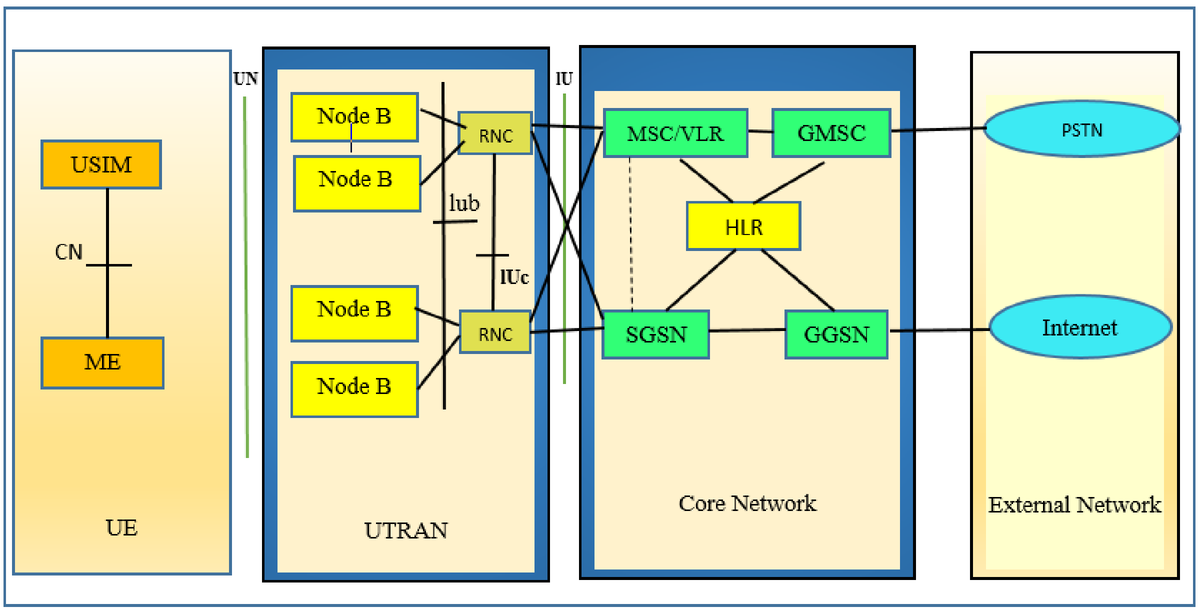


Figure 2.2 Universal Mobile Telecommunications System (UMTS) Architecture [10].

The second one, UTRAN comprises sets of Node B and RNC. The Node B converts the data flow between Iub and Uu interfaces, it also participates in radio resource management. The RNC owns and controls the radio resources in its domain as it is the service access point for all services UTRAN which provides the core network; for example, management of connections to UE. The third one, GSM/UMTS core network [10]. A brief description of the elements of GSM/UMTS core network is provided as follows:

- HLR:as stated on GSM the HLR is a centralized database located in the user's home system that stores the master copy of the user's service profile. The service profile consists of important things such as Information on allowed services, forbidden roaming areas and supplementary service information (e.g., status of call forwarding and call forwarding number). It is created when any new user subscribes to the system and it remains stored as long as the subscription is active. In order to routing incoming transactions to UE (e.g., calls or short messages), the HLR also stores the UE's location on the level of MSC/VLR and/or SGSN.

- MSC/VLR: is the switch MSC and database VLR that serves the UE in its current location for CS services. The MSC function is used to switch the CS transactions while VLR.
- Function includes a copy of the visiting user's service profile and more precise information on UE's location within the serving system. The part of the network that is accessed via MSC/VLR is often referred to as CS domain. The MSC also has a role in the early UE handling.
- Gateway Mobile-Station Switching Centre (GMSC): is the switch at the point where UMTS public Land Mobile Network (PLMN) is connected to the external CS networks. All incoming and outgoing CS connections go through GMSC.
- Serving General Packet Radio Service Support Node (SGSN) functionality: the SGSN is similar to that of MSC/VLR but it is usually used for PS services. The support is also required for early UE handling operation like SGSN and MSC.
- Gateway General Packet Radio Service Support Node (GGSN) functionality: the GGSN is close to that of GMSC but is in relation to PS services.

The external networks consist of CS and PS networks. The CS support connections like the existing telephony service (e.g., ISDN and PSTN). The PS supports connections for packet data services [10,34]

- In UMTS system there are number of interfaces between the logical networks elements which have been defined as follows [34]:
- Cu interface: it is the communication interface between USIM smartcard and ME. It matches a standard format for smartcards.
- Uu interface: this is the WCDMA radio interface. The Uu is the interface through which UE accesses the fixed part of the system and is therefore probably the most important open interface in UMTS.
- Iu interface: this is the communication interface between UTRAN and the core network. Similarly to the corresponding interfaces in GSM. It supports different protocol stacks for

interfacing with CS or PS. The open Iu interface gives UMTS operators the possibility of acquiring UTRAN and core network from different manufacturers.

- Iur interface: the open Iur interface allows the communication interface between adjacent RNCs from different manufacturers and therefore complements the open Iu interface.
- Iub interface: the Iub is the physical communication interface between Node B and RNC.

2.3 QoS and QoE

On this section try to define and explains the differences between QoS and QoE [26]. This helps us to understand the requirements of the operator and the end-user:

QoS is defined as the ability of the network to deliver a service at an assured service level. QoS includes all functions, mechanisms and procedures in the cellular network and terminal that ensure the provision of the negotiated service quality between the user equipment (UE) and the core network (CN).

QoE is defined by the International Telecommunication Union (ITU) as "the overall acceptability of an application or service as perceived by the end user" [27].

In [26] QoE is how a user perceives the usability of a service when in use and how satisfied he or she is with a service in terms of, for example, usability, accessibility, retainability and integrity of the service. Service integrity concerns throughput, delay, delay variation (or jitter) and data loss during user data transmission; service accessibility relates to unavailability, security, activation, access, coverage, blocking, and setup time of the related bearer service; service retain ability, in general, characterizes connection losses. Generally QoS and QoE it has different overview [30].

2.3.1 Quality of Experience Vs Quality of Service

QoS is closely related to the quality of experience, both of them describe service quality but from different views. Table 2.1 illustrates the differences between QoE and QoS.

Table 2.1Comparison between QoE and QoS [40].

QoS	QoE
Describes service quality from network perspective	Describes service quality from user perspective
Represented by metrics such as packet loss, delay and delay variation (jitter)	Represented by metrics such as Mean Opinion Score
QoS metrics may be difficult to understand by the user and does not represent importance information for them	QoE metrics can clearly reflect users experience and users can understand such information

2.4 UMTS QoS Architecture

Network Services are considered end-to-end, this means from one Terminal Equipment (TE) to another TE. An E2E service may have a certain QoS level, which is provided for the user of a network service. It is the user that decides whether the customer satisfied with the provided QoS or not [12,24]. To realize a certain network QoS a bearer service with clearly defined characteristics and functionality is to be set up from the source to the destination of a service. A bearer service includes all aspects to enable the provision of a contracted QoS. These aspects are among others the control signaling, user plane transport and QoS management functionality. A UMTS bearer service layered architecture is illustrated in Figure 2.3, each bearer service on a specific layer offers its individual services using services provided by the layers below.

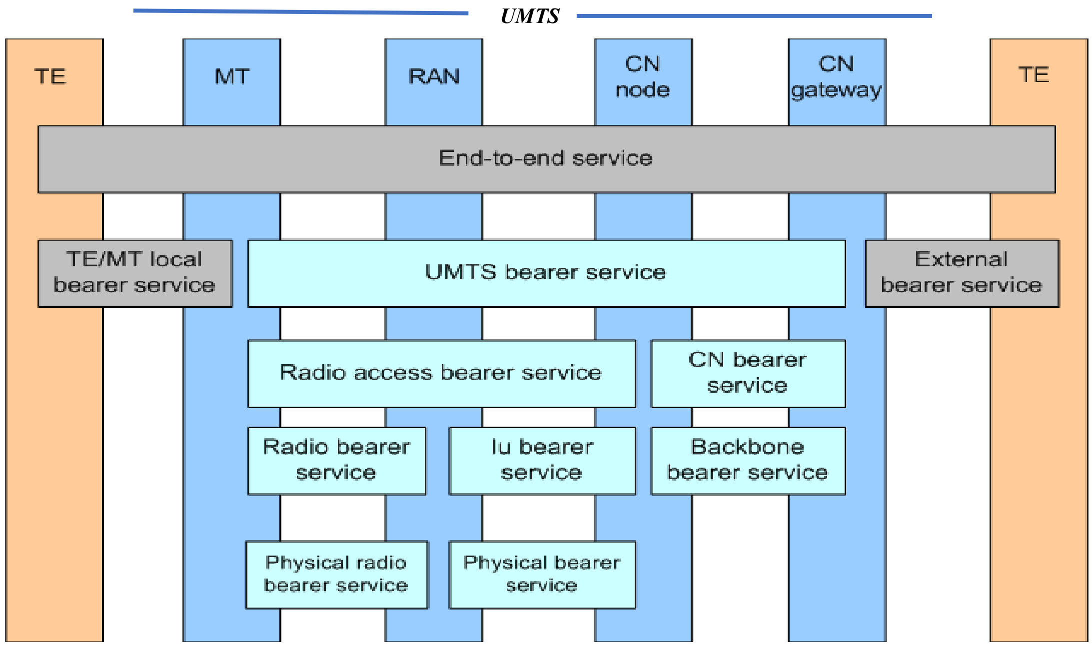


Figure 2.3 UMTS QoS Architecture [33].

On its way from one TE to another TE the traffic has to pass different bearer services of the network. A TE is connected to the UMTS network by use of a Mobile Termination (MT). The E2E Service on the application level uses the bearer services of the underlying network(s). The E2E-service used by the TE will be realized using a TE/MT local bearer service, a UMTS Bearer service, and an external bearer service. It provides the various services offered by the UMTS bearer service that the UMTS operator offers. This bearer service provides the UMTS QoS.

In [25] the QoS architecture shown in Figure 2.3 have the following layers:

- **UMTS Bearer Service:** A Mobile Termination (MT) is used to connect a Terminal Equipment (TE) to the UMTS network. The traffic has to pass from one TE to another TE through different bearer services of the network. The UMTS bearer service delivers the UMTS QoS as the UMTS operator offers services provided by UMTS bearer service.

- **End-to-End Service:** It uses the bearer services of the network on the application level. It is used by the TE and realization of this is done using a TE/MT Local Bearer Service, a UMTS Bearer Service, and an External Bearer Service.
- **Radio Bearer Service:** It makes use of UMTS Bearer Service possible over the cellular network topology taking into account various aspects such as mobility and mobile subscriber profiles.
- **Radio Access Bearer Service:** It deals with signaling flow along with the user data. It depends on the radio interface and mobility of mobile station.
- **Core Network Bearer Services:** It connects the UMTS Core Network (CN) lu Edge with the CN gateway to external network. It effectively controls and utilizes backbone network.
- **Lu Bearer Service:** It together with the physical bearer service provides the transport between UTRAN and CN. It also provides various bearer services for variety of QoS.
- **Backbone Network Service:** It covers layer1/layer2 functionality and is selected as per operator choice to fulfil basic QoS requirements of the core network bearer service .It is not specific to UMTS as it can also use existing standards.

2.5 UMTS Services and applications

Any communication network service is reflected end-to-end, which is from one Terminal Equipment (TE) to another TE [39]. Each service has a certain QoS, which is delivered to the user though the user decides whether the customers is satisfied with the service being provided.

From a UMTS network perspective, 3GPP defines different QoS classes: conversational class, streaming class, interactive and background class. Table.2.1 shows the different traffic type and their QoS constraints [10,13].These QoS constraints can be used as a basis for decision making (e.g., priorities video streaming over web browsing traffic)[36]. The QoS classes are discussed in [37, 38]:

- Conversational class: the conversational class services are mainly for conversational real time applications such as voice, video telephony and video gaming. This class services can be supported by fixed resource allocation in the network. This class is the most sensitive to delay and the most well known use of this system is telephony speech.
- Streaming class: the streaming class services are meant for streaming media applications such as multimedia, Video on Demand (VoD) and webcast. In this class a certain amount of delay Variation is tolerable due to application level buffering. Besides, this class service is a variant of the constant bit rate and real time variable bit rate services.
- Interactive class: the interactive class is applicable for services requiring assured throughput. To ensure better response times for this class a higher scheduling priority compared with the background class may be required such as web browsing, network gaming and database access. Traffic flow prioritization is taken into account within the service class.
- Background class: the background class services are for traditional best effort services such as e-mail, SMS and downloading. This is traffic has the lowest priority among all the classes. This class is class insensitive to delay.

Table 2.2 UMTS Traffic type and QoS Requirements for different traffic type [10].

Traffic Type	Application	Service Data Unit (SDU) Loss Rate	End to End Delay
Conversation	Voice		< 150 ms.
Streaming	Streaming	< 10-1	< 250 ms.
Interactive	Web	< 10-3	< 4 s.
Background	FTP	< 10-3	-

2.6 QoE dependencies

QoE is a multi-factor concept, depending on a plethora of multiple and diverse parameters. The main properties of QoE are User-, Application-, Terminal, and Time-dependency [14].

- **User dependency** means that users may perceive QoE in different ways even when receiving the same service, they may show different preferences regarding their sessions, or they may prioritize different factors as important. Moreover, due to their variations in emotions, expectations or experiences, they may evaluate services that offer the same QoS much differently.

- **Application dependency** describes the different impact of different applications on QoE. This is a main property of QoE. Different applications have different technical requirements, influence factors and constraints. For instance, VoIP applications are delay-sensitive, whereas video applications are bandwidth-sensitive. This implies that QoE should be evaluated in a completely different way per application and that different QoE management objectives should be devised per application type.
- **Terminal dependency** is the impact of diverse devices on QoE in terms of their technical characteristics, capabilities and limitations. For instance, characteristics such as resolution, color or screen size seem to play a key role in the perceived QoE of the user. However, potential device limitations may be sometimes falsely attributed to network or service deficiencies. Moreover, powerful devices may increase user expectations in terms of achieved QoE.
- **Time dependency**, lastly, stems from the fact that many of the QoE influence factors are time-variant and thus, difficult to control. These factors may range from fluctuating user subjectivity to unstable wireless channel conditions.

  The authors realize that, based on the above dependencies; QoE must be managed on a per-user, per-application, and per-terminal basis in a real-time method.

2.7 Interdependence between QoS and QoE

QoS is the ability of the network to provide a service at an assured service level. In order to provide the best QoE to users in a cost-effective, competitive and efficient manner, network and service providers must manage network QoS and service provisioning efficiently and effectively. QoE is the term used to describe user perceptions of the performance of a service. Service integrity concerns throughput, delay, delay variation (or jitter) and data loss during user data transmission; service accessibility relates to unavailability, security (authentication, authorization and accounting), activation, access, coverage, blocking, and setup time of the related bearer service; service retain ability , in general, characterizes connection losses [15].

QoS and QoE are so interdependent, that they have to be studied and managed with a common understanding. The aim of the network and services should be to achieve the maximum user rating, while network quality is the main building block for reaching that goal effectively. QoE, however, is not just limited to the technical performance of the network, there are also non-technical aspects, which influence the overall user perception[15].

- QoS encompasses all functions, mechanisms and procedures in the cellular network and terminal that ensure the provision of the negotiated service quality between the UE and the CN.
- QoE is how a user perceives the usability of a service when in use – how satisfied they are with a service in terms of, for example, usability, accessibility, retain ability and integrity of the service. Service accessibility relates to unavailability, security, activation, access, coverage, blocking, and setup time of the related bearer service; service retain ability, in general, characterizes connection losses.

Based on the QoE definitions [15] it is clear that QoE depends on both human and technical factors which include the following:

- Application factors: Application type, e.g. VoIP, streaming video, Web access,
- Content, such as type of video or videoconference.
- Device features such as screen resolution, interface, battery, and power consumption.
- Network-level QoS such as throughput, packet loss, delay, and jitter.
- Service characteristics such as reliability, availability, coverage, cost, etc.
- User factors such as expectations, requirements (including security), perception, demographics, etc.
- Context**,** which can include access type (wireless/wired), movement (mobile/stationary), location, social/task, etc.

QoE can be estimated using a subjective or objective approach. Subjective QoE estimation requires user involvement and quantifies the QoE in terms of a MOS. On the other hand, objective QoE assessment estimates the QoE using a parametric model, without requiring the involvement of users. The parametric model can depend on the application, context, etc, and is a function of the network-level QoS which is typically estimated from measurements [16].

Different types of relations between the QoS and QoE include the following:

- Linear: Such a dependence suggests that an additive change of the QoS has a linear influence on the QoE.
- Logarithmic: Such a dependence suggests that a multiplicative change of the QoS has a linear influence on the QoE.
- Exponential: Such a dependence suggests that an additive change of the QoS has a multiplicative influence on the QoE.
- Power: Such a dependence suggests that a multiplicative change of the QoS has an exponential influence on the QoE

2.8 Assessment of KPIs and KQIs for QoE

The quality of service challenges for operators are maximizing the utilization of offered services, increasing their own revenues[17] , competition among themselves, developing and experience new scalable services, optimizing the network performance, ensure and improve the Return On Investment (ROI). Focusing on the traditional QoS management will not ensure these challenges. Because, the traditional QoS management is limited to the network centric operations such as radio KPI analysis and control, coverage and interference analysis, mobility and intersystem interoperability analysis, network integrity and capacity auditing, pilot pollution control, layer 3 analysis for failed events (set-up, drop…) network or UE based, cluster optimization and re-planning, low throughputs causes analysis, functions upgrade & follow-up. There should be a paradigm shift from network centric KPI analysis to user centric KQI analysis to coup with these challenges[17]. Figure 2.4 shows this hierarchical relationship between KPI, KQI and QoE.

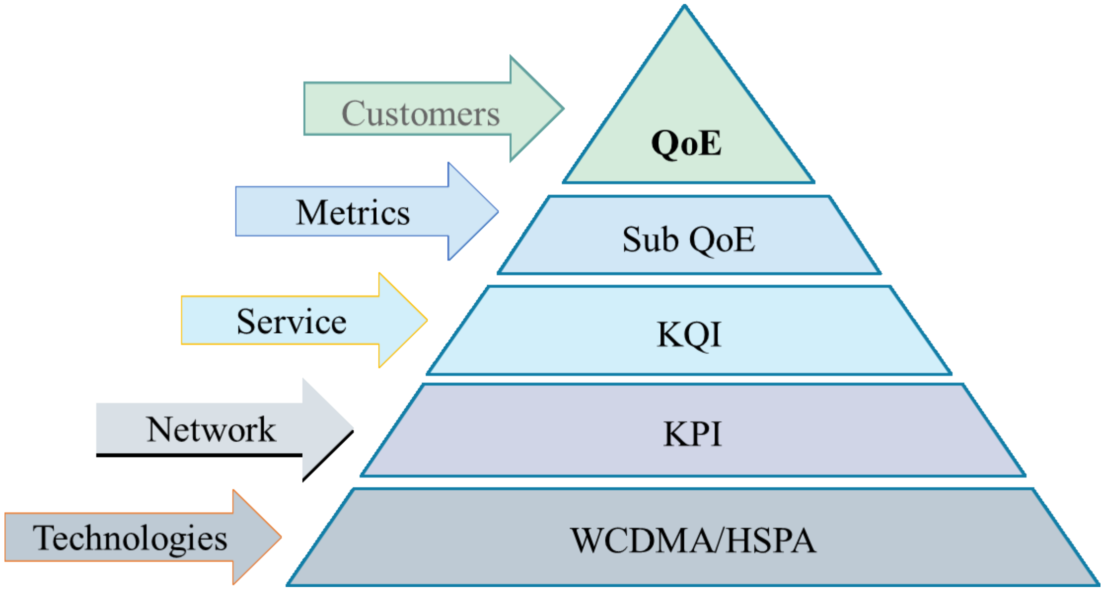


Figure 2.4Hierarchical relationship between KPI, KQI and QoE(adopted from[17]).

Transformation from objective KPIs to subjective QoE needs mapping between each service QoE with one or more influential QoS parameters. Similarly, each service quality is related to one or more of KPIs. For example [17]:

- Voice quality: accessibility, call drop, speech quality
- WEB quality: accessibility, web delay, download speed
- SMS quality: accessibility, access delay …

Therefore,

KQI_n=f (KP I_1, KPI_2 ... KPI_n)

QoE_n=g (KP I_1, KQI_2 ... KQI_n) =g (f (KP I_1, KQI_2... KPI_n))

The Network KPI includes radio KPIs, bearer network KPIs, and CN KPIs.

Service quality KQI includes voice and data service KQIs and QoE includes the user perception.

Chapter 3
System Modeling

The methodology used to develop a model for the CQoE consists of a combination of OQoE computation using the ANFIS algorithm and Questionnaire evaluation. These two are added in the ratio of 80% and 20 % respectively.

For this study used as input data to get from ethiotelecom service monitoring tool. It has perceived call success rate, End-to-End delay and perceived call drop rate. It needs "ground truth" of MOS values to input it in the ANFIS algorithm to get the required estimated model; an existent objective model was used [18]. A ground truth of MOS formula is non-linear regression model for voice quality prediction in the form of a polynomial has been used to get the calculated MOS.

$$MOS_C=3.91-0.17p+1.5*10^{-3}d+6.51*10^{-3}p^2-2.4*10^{-5}pd^2-7.53*10^{-6}pd-10^{-4}p^3+2.62*10^{-8}\ d^3+1.38*10^{-7}pd^2-5.51*10^{-8}dp^2 \quad (3.1)$$

Where p is adapted as the perceived call drop rate and d is the End-to-End delay.

Now all the necessary data set is ready, i.e. perceived call success rate, End-to-End delay, call drop rate and the calculated MOS by the above-mentioned polynomial equation. Then all these four parameters data are correlated using a tool SPSS and the results would be analyzed. The detail system model is illustrated in Figure 3.1.

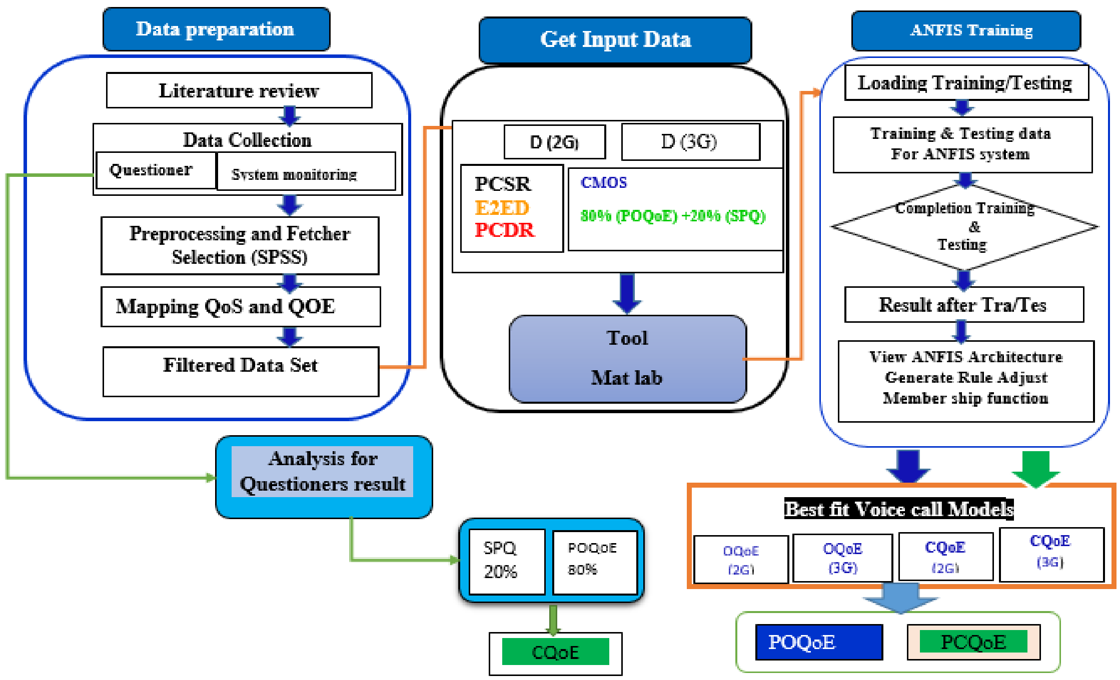


Figure 3.1 System Model

3.1 Correlation Analysis

Correlation analysis is used to analyze the linear correlation between two variables. In case of this research to measure, the correlation between two variables and measure predicted values and the original ones using Pearson correlation coefficient. A Pearson correlation coefficient $(\boldsymbol{r_{xy}})\boldsymbol{i}$ between two variables $\boldsymbol{x_i}$ and $\boldsymbol{y_j}$ as follows

$$\boldsymbol{R_{Pearson}} = (\boldsymbol{r_{xy}})\boldsymbol{ij} = \frac{\sum_{t=1}^{T}(x_{ti}-\bar{x}_i)(y_{tj}-\bar{y}_{tj})}{\sqrt{\sum_{t=1}^{T}(x_{tj}-\bar{x}_j)^2}\sqrt{\sum_{t=1}^{T}(y_{tj}-\bar{y}_j)^2}} \qquad \textbf{(3.2)}$$

Where T is the sample size, $x = \{x_{t1}, x_{t2},..., x_{tm},\}$ and $y = \{(y_{t1}, y_{t2}, ..., y_{tn}\}$ represent two feature sets with the same sample size $\bar{x}_i = \sum_{t=1}^{T} x_{ti/T}$ and $\bar{y}_i = \sum_{t=1}^{T} y_{ti/T}$.The value of Pearson correlation coefficient $(\boldsymbol{r_{xy}})\boldsymbol{ij}$ is in a range of [−1, 1] as shown in Fig.3.2 A value of 1 is the maximum positive −1 is the maximum negative and 0 means no linear correlation. When the result of $(r_{xy})ij$ is near to close to 0, it may probably lead to the confused positive and negative relevance as presented in [31]. In this situation, it needs some interventions on choosing indicators.

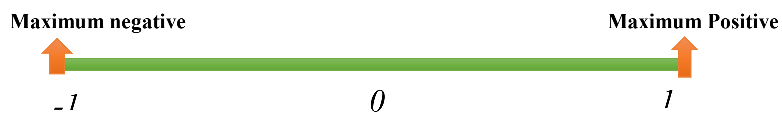


Figure 3.2 Correlation Result [31].

3.2 Machine Learning Algorithms

Machine Learning (ML) is a means use a set of observations, imitating the network state and the user's perception. In order to extract inference rules to predict automatically the QoE value IT is applied to the QoE-QoS relationship modelling, To deal with this modelling problem, it is necessary to select the appropriate learning type [1, 20].The main learning types focusing on the ones that suit the QoE-QoS relationship modelling.

The learning algorithms have the scope of predicting an output y through a mathematical expression that takes n parameters as input, called features. These algorithms take as input a training set. The development process for each learning algorithm follows the same methodology. To train and evaluate the data set is divided in three different subgroups, as follows:

- 60% - Training set
- 20% - Test set;
- 20% - Validation set

The machine-learning algorithm called Adaptive Neuro Fuzzy Inference System has been used to get OQoE and CQoE, In this case it has been chosen as the preferred algorithm, because it has the following comparative advantages over other main algorithms.

Jang first proposed it in 1993 [20]. ANFIS is a simple data learning technique and to get the desired output that uses Fuzzy Logic to transform given inputs into a through highly interconnected Neural Network processing elements and information connections, which are weighted to map the numerical inputs into an output.

ANFIS synergizes the advantages of the two machine learning techniques (Fuzzy Logic and Neural Network) into a single technique. It works by applying Neural Network learning methods to tune the parameters of a Fuzzy Inference System (FIS). The synergistic advantages of ANFIS are stated below:

- It refines fuzzy IF-THEN rules to describe the behavior of a complex system;
- It does not require prior human expertise;
- It is easy to use;
- It is capable of fast and accurate learning;
- It offers desired data set; greater choice of membership functions to use; strong generalization abilities; excellent explanation facilities through fuzzy rules; and
- It is easy to incorporate in both linguistic and numeric knowledge for problem solving.

3.3 ANFIS Architecture

ANFIS architecture is an adaptive network that uses managed learning on machine learning algorithm that is a function like to the model of Takagi–Sugeno fuzzy inference system. Figure 3.3 shows the scheme fuzzy reasoning mechanism for Takagi–Sugeno model and ANFIS architecture[19,20,28,29].For easiness, assume that there are two inputs x and y, and one output f. Two rules were used in the method of "If-Then" for Takagi–Sugeno model, as follows

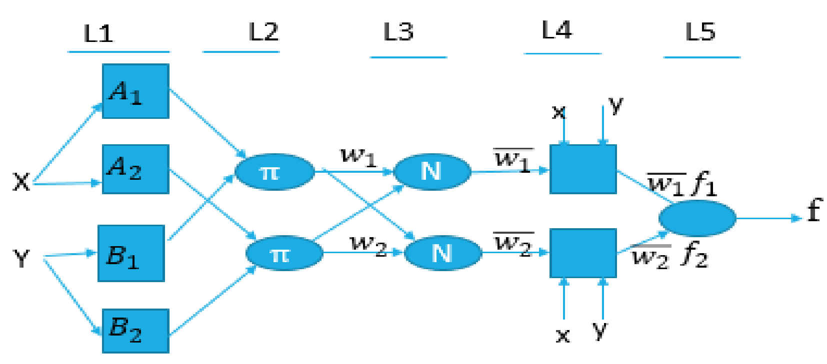


Figure 3.3 ANFIS architecture, Sugeno model [20].

Different rules cannot share the same output membership function [20,28]. The number of membership functions must be equal to the number of rules. To present the ANFIS architecture, two fuzzy IF-THEN rules based on a first order Sugeno model are considered:

Rule (1) If x is A_1 And y is B_1 ,Then f_1=p_1 x+ q_1 y+r_1

Rule (2) If x is A_2 And y is B_2 ,Then f_2 =p_2 x+ q_2 y+r_2

where x and y are the inputs, A_i and B_i are the fuzzy sets, f_i are the outputs within the fuzzy region specified by the fuzzy rule, and p_i, q_i, and $r_i$are the design parameters that are determined during the training process. Figure 3.3 illustrates the reasoning mechanism for this Sugeno model, which is the basis of the ANFIS model. The ANFIS architecture used to implement these two rules, a circle indicates a fixed node, whereas a square indicates an adaptive node. ANFIS has a five-layer architecture. Each layer is explained in detail below.

In Layer (1), all the nodes are adaptive. The outputs of Layer 1 are the fuzzy membership grade of the inputs, which are given by the following equations:

$$O_{1,i} = \mu A_i(x),\ i=1 \qquad (3.3)$$

$$O_{1,i} = \mu B_{i-2}(y),\ i=3 \qquad (3.4)$$

where x and y are the inputs to node i, and A_i and B_i are the linguistic labels (high, low, etc.) associated with this node function. **μ A_i (x)** and **μ B_{i-2}(y)** can adopt any fuzzy membership function. For example, if the bell-shaped membership function is working, **μ A_i (x)** is given by

$$\mu A_i(x) = \frac{1}{1+\ [(\frac{x-c_i}{a_i})^2]b_i},\ i = 1, 2, \qquad (3.5)$$

or the Gaussian membership function by

$$\mu A_i(x) = exp\ [-(\frac{x-c_i}{a_i})^2] \qquad (3.6)$$

Wherea_i,b_i, and c_i are the parameters of the membership function

In Layer (2), this layer contains fuzzy operators that the nodes are fixed nodes; it uses the AND operator to fuzzify the inputs. They are labeled with, indicating that they perform as a simple multiplier. The output of this layer denoted as follows:

$$O_{2,i} = w_i = \mu A_i(x) * \mu B_i(y), i=1,2 \quad (3.7)$$

In Layer (3), the nodes are fixed nodes labeled by N. It is the normalized layer, and its function is to normalize the weight function in the following process

$$O_{3,i} = \overline{w_i} = \frac{w_i}{w_1+w_2}. i=1,2, \quad (3.8)$$

Outputs of this layer are called normalized firing strengths.

In Layer (4), the nodes are adaptive. The output of each node in this layer is simply the product of the normalized firing strength and a first order polynomial (for a first order Sugeno model). The output of this layer is given by

$$O_{4,i} = \overline{w_i} * f_i = \overline{w_i}(p_i x + q_i y + r_i) \quad (3.9)$$

Where w is the output of Layer 4, and p_i, q_i and $r_i$are the consequent parameters.

In Layer (5), there is only one single fixed node labeled with Σ. This node performs the summation of all incoming signals. The overall output of the model is given by

$$O_{5,i} = \sum_i (\overline{w_i} f_i) = \frac{\sum_i (w_i f_i)}{\sum_i w_i} \quad (3.10)$$

3.4 Training Process for ANFIS System

The process starts by gaining a training data set and checking data sets. A set of input and output vectors is the training data [20] .Two vectors are used to train the ANFIS system the input vector and the output vector. The training data set is used to find the premise parameters for the membership functions. A threshold value of the error between the real and desired output is determined.

Based on the least squares method to get the consequent parameters. If the error is larger than the threshold value, then the premise parameters are updated by gradient decent method. The process is ended when the error becomes less than the threshold value. To compare the model with the real system use the checking data set. The general training process of ANFIS model shown on Figure 3.4.

ANFIS training learning rules use hybrid learning, joining the least squares and the gradient descent method. The goal of using ANFIS for model learning is to accomplish the best performance possible. ANFIS training starts by generating a set of appropriate training data in order to be capable to train the Neuro-Fuzzy system.

ANFIS training uses the anfis function. The system of evaluation compared to the preferred output is conducted using the evalfis function. The first step is to make the training data to work with ANFIS in MATLAB. For ANFIS function the data set that is the input data must be prepare as matrix form, where the last column in the matrix is the output, and the matrix contains as many columns as needed to signify the inputs to the system. The rows represent all the existing data conditions. Formation of the membership functions is dependent on the system designer. The designer may create the parameters of the membership functions if they have knowledge of the expected shapes, or they can use the command genfis1 from MATLAB to help in the creation of the initial set of membership functions [20, 28]. The genfis1 command helps to create the membership functions.

The system training begins when created the preliminary membership functions. The anfis is the command provided by MATLAB to train an ANFIS system. To input the training data it must defined the membership functions and created using the fismat command, and some training options in order to produce the most acceptable output. When the training process is finished (trn-fismat) to produce the training error and the final membership functions see Figure 3.4.

The checking data set can be used in combining with the training data set for improved accuracy. It is possible for ANFIS to function with only one training data set, however input of checking data increases the possibilities to be understood by the system, and hence the system's effectiveness. After the training process is complete, ANFIS provides evaluate the system performance by using the evalfis function. The fuzzy system that was established based on the completed training (trn-fismat) is used. The process of evaluating system performance starts by entering input data sets into the fuzzy system. These data sets do not include output values. The output of the evalfis function denotes the final output of the ANFIS system. This response output can be evaluate by means of correlations between the desired learner situations and the learning.

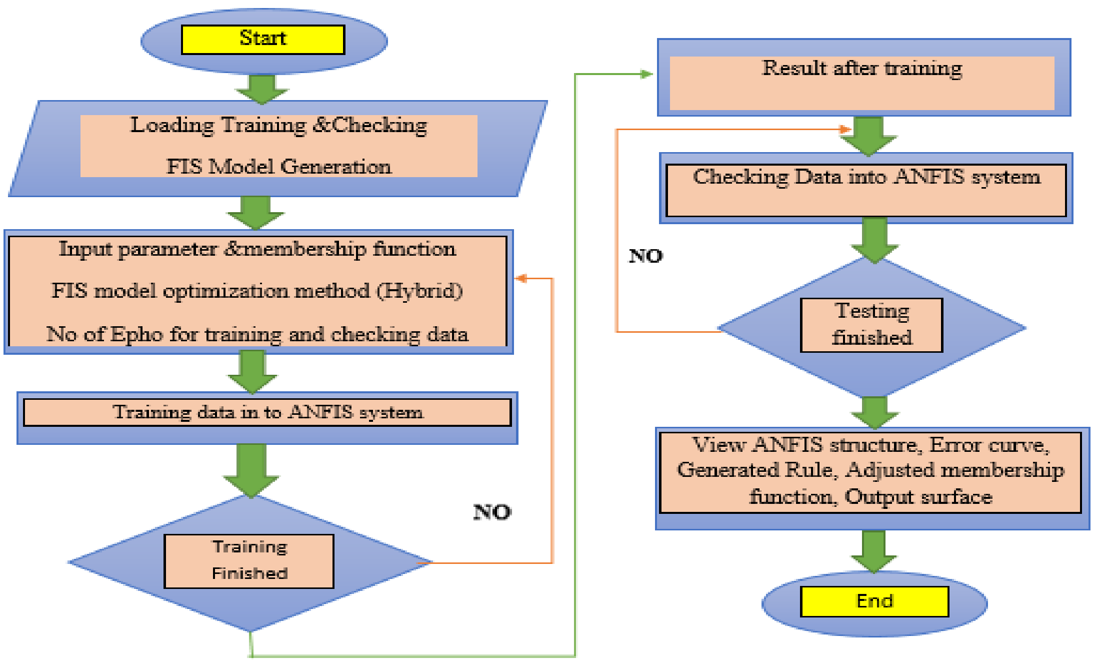


Figure 3.4 General training system on ANFIS Algorithm [20].

3.5 Hybrid Learning Algorithm

ANFIS is a hybrid learning algorithm that a combination of gradient descent and least squares methods. In the forward pass of the hybrid-learning algorithm, node outputs go forward until Layer 4 and the consequent parameters are determined by the least squares. Using gradient descendent, the premise parameters are updated and in case of backward pass, the error signals propagate backward .The converges of hybrid learning approach is much faster by decreasing search space dimensions of the original back propagation method [20].

$$f = \frac{w_1}{w_1+w_2} f_1 + \frac{w_2}{w_1+w_2} f_2 \quad (3.11)$$

$$f = \overline{w}(p_1 x + q_1 y + r_1) + \overline{w}(p_2 x + q_2 y + r_2) \quad (3.12)$$

$$f = (\overline{w_1} x)\, p_1 + (\overline{w_1} y)\, q_1 + (\overline{w_1})\, r_1 + (\overline{w_2} x)\, p_2 + (\overline{w_2} y)\, q_2 + (\overline{w_2} y)\, r_2 \quad (3.13)$$

Where p_1 ,q_1, r_1, p_2 , q_2, and r_2 are the linear consequent parameters. The least squares method is used to identify the optimal values of these parameters. The least squares and gradient descent method is used to optimize the consequent and the premise parameters respectively. The output of the ANFIS is calculated by using the consequent parameters found in the forward pass. The output error is used to adapt the premise parameters by means of a standard backpropagation algorithm. It has been proven that this hybrid algorithm is highly efficient in training the ANFIS systems.

3.6 Selection of Inputs for ANFIS model

In order to creating learning system input selection is critical thing [20]. An unnecessary number of inputs will increase the computation time necessary for building the model using ANFIS. As a result, it is essential to order all system inputs and create the learning model. To build an accurate model for prediction, significant inputs must be selected.

In [20], the author listed some practical considerations for inputs selection:

- Remove irrelevant inputs.
- Remove inputs that are dependent on other inputs.
- Make the underlying model more concise and transparent.
- Reduce the time for model construction.

The method presented in [20] takes advantage of the ANFIS structure. It is based on the assumption that the ANFIS model with the smallest Root Mean Square Error (RMSE) after a small number of epochs has a greater potential of achieving a lower RMSE when given more epochs of

3.7 Mechanism to evaluate the Result

The ANFIS training process starts by determining fuzzy sets and the number of sets of each input variable and shape of their membership function. All the training data passes through the Neural Network, to adjust the input parameters to find the relationships between input/output, and to minimize the errors. RMES is the function used to monitor the training errors. RMSE is defined as where N is the total number of prediction, $\boldsymbol{y}^{(i)}$ is the predicted time series, and $\hat{y}^{(i)}$ is the original series.

The result or the ANFIS output would then be evaluated by the Root Mean Squared Error (RMSE).The RMSE measures the square root of the average of the square of the differences between the predicted and the original values. Expression (3.14) gives this metric, where $y^{(i)}$ and $\hat{y}^{(i)}$ are the original and predicted values of the i^{th}set of parameters, respectively.

$$\textbf{RMSE}=\sqrt{\frac{1}{m}\sum_{i=1}^{m}(\boldsymbol{y}^{(i)}-\hat{\boldsymbol{y}}^{(i)})^{2}} \qquad \textbf{(3.14)}$$

To simplify the results interpretation, the RMSE is converted to percentage. This conversion is done by equation (3.12), where $\boldsymbol{y}_{max}$ and $\boldsymbol{y}_{min}$are 5 and 1 respectively, since y is a value of MOS and its scale ranges from 1 to 5.

$$\textbf{RMSE[\%]}=\frac{rmse}{y_{max-}y_{min}} \qquad \textbf{(3.15)}$$

Chapter 4
Analysis and Result

4.1 Concept of the Comprehensive Quality of Experience

This thesis starts with the consideration of a basic reality, i.e. Voice call service is given to human beings. The latter have a rational, objective side and an emotional, subjective side. A business should know customers', physical and psychological needs, expectations and anticipate them. In order to satisfy them as much as possible sustainably to be competitive, stay in the market and lead it. The research deals with the development of a Comprehensive Quality of Experience, which is the sum, total of Objective Quality of Experience and the Subjective Perception of Quality in the ratio of 80% and 20% respectively. It is computed by this general formula:

$$CQoE=OQoE+SPQ \tag{4.1}$$

The relation more expressed in the following way this mathematical relation coming on from the general concept, as we know OQoE is scientific and mathematical where as SPQ is emotional, user opinions past experiences, expectations, user perception and judgement so the weight is determined based on this logic.

$$\mathbf{CQoE=w*OQoE+(1-w)*SPQ} \tag{4.2}$$

$$\mathbf{CQoE=0.80*OQoE+0.20*SPQ} \tag{4.3}$$

4.2 Computation of the Objective Quality of Experience for 3G

The ANFIS algorithm has computed the OQoE. The input data is gotten from ethio telecom service monitoring tool. The data consists of nine months 5,538 inputs, i.e. Perceived Call Success Rate (PSSR), End-to-End delay (E2ED) and Perceived Call Drop Rate (PCDR). These are defined below and the sample real raw data put on Table 4.1.

- Perceived Call Success Rate (PCSR) is the voice call success rate perceived by the calling subscriber.
- End to End delay (E2ED) is the amount of time the calling subscriber waits before hearing the ring back tone.
- Perceived call drop rate (PCDR) is the call drop rate perceived by subscribers.
- MOS(MOS_c) is mean opinion score that estimate user satisfaction.

Table 4.1 Sample input raw data.

Current period	Perceived Call Success Rate(%)	E2E Call Connection Delay(ms)	Perceived Call Drop Rate(%)
2019-01-01 01:00	NA	NA	NA
2019-01-01 11:00	97.11	4425	0.16
2019-01-01 12:00	97.17	4523	0.19
2019-01-01 19:00	96.83	4641	0.19
2019-01-01 20:00	96.26	4707	0.25
2019-01-01 21:00	95.56	4930	0.42

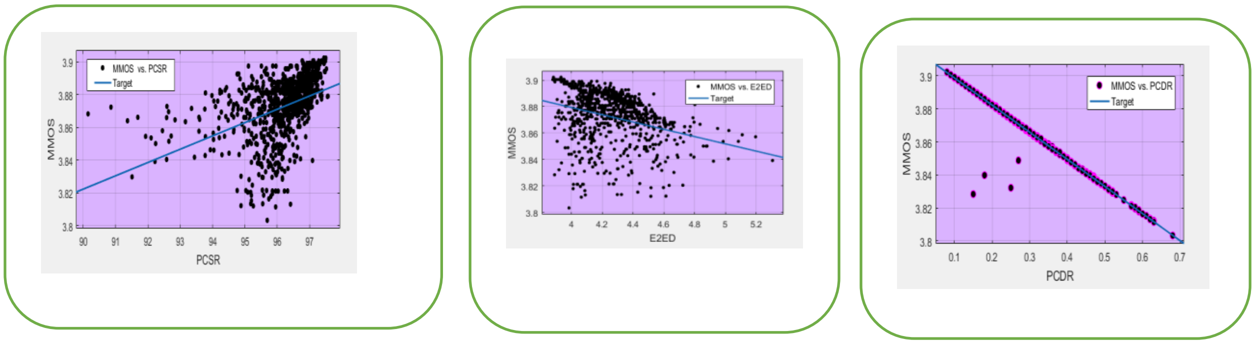
The non-linear regression model for voice quality prediction is in the form of a polynomial. It has been used to get the calculated MOS (MOS_c), that is the initial target value of this research. After the computation of MOS, the data set is now ready for further analysis, to see the correlation result of each parameter with other parameters. The sample filtered data and correlation result is shown on Table 4.2 and 4.3 respectively.

$$MOS_c = 3.91 - 0.17PCDR + 1.5*10^{-3}E2ED + 6.51*10^{-3}PCDR^2 - 2.4*10^{-5}PCDR*E2ED^2 - 7.53*10^{-6}PCDR*E2ED - 10^{-4}PCDR^3 + 2.62*10^{-8}E2ED^3 + 1.38*10^{-7}PCDR*E2ED^2 - 5.51*10^{-8}E2ED*PCDR^2 \quad (4.4)$$

Table 4.2 Processed Data.

Perceived Call Success Rate(%)	E2E Call Connection Delay(s)	Perceived Call Drop Rate(%)	MMOS
96.97	4.132	0.19	3.842589
97.29	4.067	0.18	3.836729
96.75	4.022	0.18	3.854542
97.12	4.025	0.1	3.870119

Each parameter and MOS values have been correlated, prior to Training and Validation of the Proposed Models, to observe their graphical relationship. The correlation results are shown in Figure 4.1. The relations graph clearly shows that PCDR is highly correlated to measured MOS.



a. PCSR Vs ***MMOS*** b. E2ED Vs ***MMOS*** c. PCDR Vs ***MMOS***

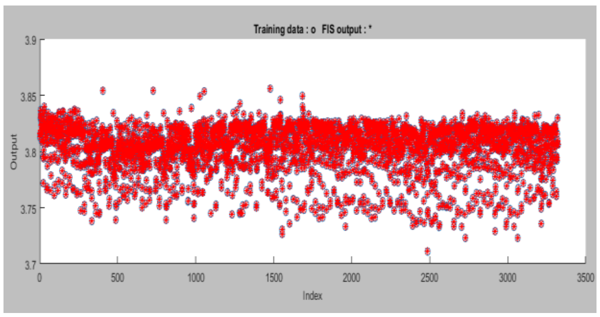
Figure 4.1 Relationship between the three selected inputs and MMOS (a-c) on 3G

Table 4.3 Features Correlation result for the voice model.

Pearson correlation	PCSR	E2ED	PCDR	$MMOS(MOS_c)$
PCSR	1	-0.251	-0.152	0.139
ETED	-0.251	1	0.281	-0.475
PCDR	-0.152	0.281	1	-0.978
$MMOS(MOS_c)$	0.139	-0.475	-0.978	1

ANFIS training is began by inputting training data aimed at training the Neuro-Fuzzy system. Then the initial membership functions are chosen, EPHO number assigned to start the ANFIS training. The command provided by MATLAB to train an ANFIS system is anfisedit. Once the training process is done, the final membership functions and training error from the training data set are produced; estimate of the system compared to the desired output is showed using the evalfis function.

The data has been divided into three sets: the training data set, the testing data set and the validation data set. The training data set has been used to train the ANFIS, while the validation data set has been used to check the accuracy and the effectiveness of the trained ANFIS model to get the final result of the learning. Sample Load training Data and error graphs are shown in Figure 4.2.



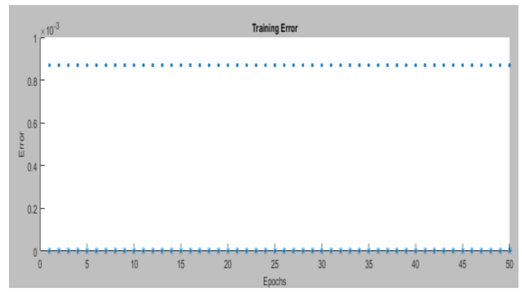


Figure 4.2 Load training and testing data and error result for 3G 3*3*3.

The best ANFIS model is chosen based by comparing the RMSE and Pearson Correlation values for different epoch numbers and the number of membership functions assigned to ANFIS structure.

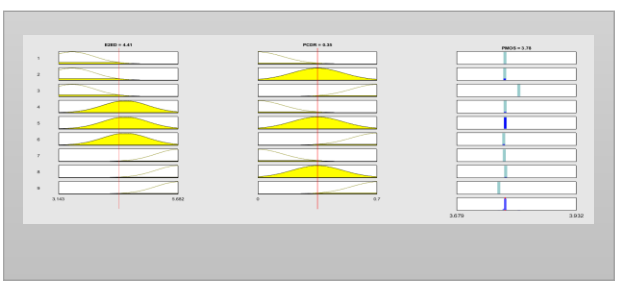
Table 4.4 The Structure of ANFIS Analysis Information for 3G services using three parameters.

ANFIS Parameter Type	ANFIS 1			ANFIS 2			ANFIS 3		
Member ship function type	**Gaussian curve**			**Generalized bell shape**			**Triangular-shaped**		
Number of membership function	(4*4*4) 64			(4*4*4) 64			(4*4*4) 64		
Training data set	3323	1933	1139	3323	1933	1139	3323	1933	1139
Testing data set	1107	643	573	1107	643	573	1107	643	573
Checking(validation data set	1108	635	673	1108	635	673	1108	635	673
Epoch number	50	25	15	50	25	15	50	25	15
number of nodes	158			158			158		
Number of Linier parameters	256			256			256		
Number of non Linier parameters	36			36			36		
Total number of parameters	292			292			292		
Number of fuzzy rules	64			64			64		
Input combinations				PCSR,E2ED,PCDR					
RMSE	**0.005047**	**0.4323**	**0.00762**	**0.0070**	**0.02659**	**0.01513**	**0.004706**	**0.005192**	**0.009515**
R-square (Pearson Correlation)	**0.9466**	**0.4912**	**0.8589**	**0.9086**	**0.3597**	**0.5804**	**0.9505**	**0.9397**	**0.8411**

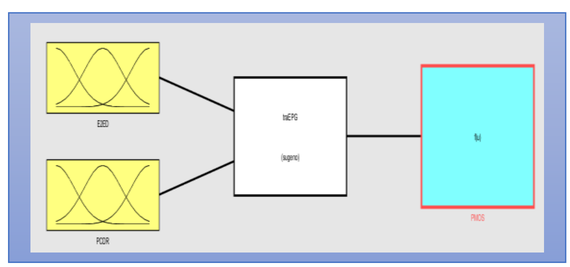
Table 4.5 The Structure of ANFIS Analysis Information for 3G services using two parameters.

ANFIS Parameter Type	ANFIS1	ANFIS2	ANFIS3
Member ship function type	Gaussian curve	Generalized bell- shape	Triangular-shaped
No.of Membership function	9	9	9
Training data set	3323	3323	3323
Testing data set	1107	1107	1107
Validation data set	1108	1108	1108
Epoch number	50	50	50
Number of nodes	35	35	35
Number of Linier para.	27	27	27
Number of non Linier parameters	18	18	18
Total No of Par.	45	45	45
Input combinations	E2ED,PCDR		
RMSE	0.004707	0.004711	0.0047
R-square	0.9505	0.9507	0.9503

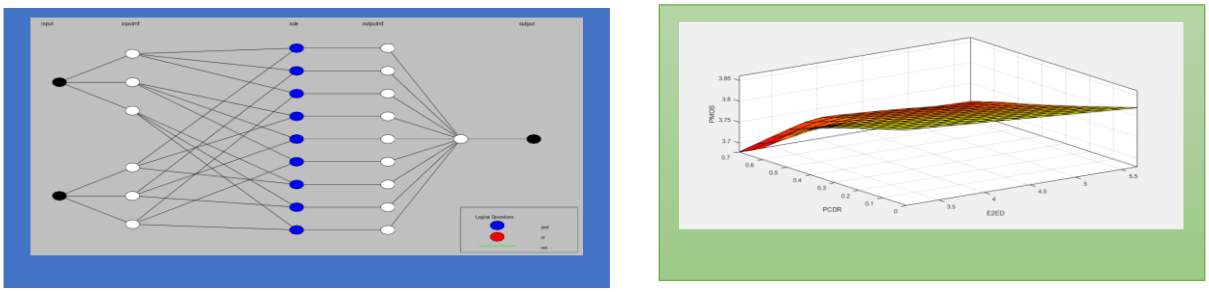
After a thorough analysis of membership functions, the membership function number 4*4*4 and 3*3*3 have been chosen to train the model. The membership function types are Gaussian, Triangular-shaped and Generalized bell shaped are used. The generated fuzzy inference system structure contains 64 and 9 fuzzy rules respectively. The detail description is illustrated in Table 4.4. and 4.5.



a Rule viewer



b. Fuzzy logic Design

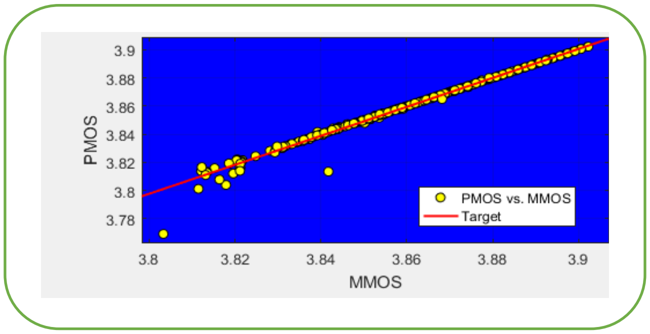


c.Anfis model structure d.PCDR,E2ED Vs PMOS

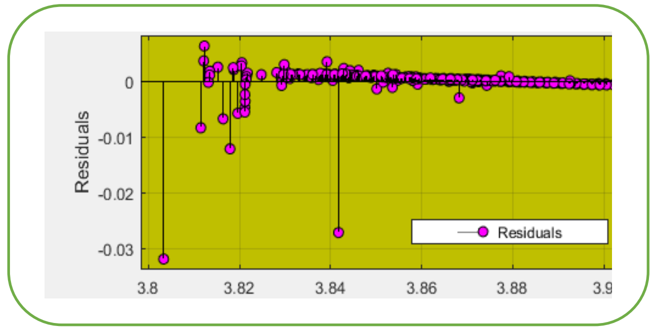
Figure 4.3 Sample outputs of ANFIS Structure for membership function of “3*3”.

As per the Table 4.4 and 4.5, it can be easily inferred that the Triangular membership function having the minimum RMSE upon validation, with the epoch numbers 50, is the best result. Based on that RMSE values are 0.004706, 0.0047 and Pearson Correlation values are 0.9505, 0.9503 respectively best other than. One third of the data has been used for validation, and input to the ANFIS model to get the PMOS. Then it is compared to the measured MOS.

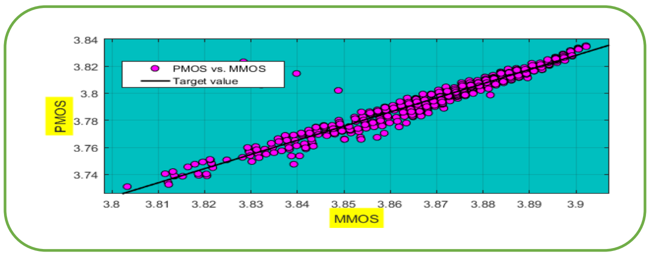
The first estimation model is tested by plotting the relations between the Measured and predicted MOS and the predicted MOS and the residuals. The residuals are the differences between the calculated MOS values and the Predicted values, and one of the method to checking model validation method [1]. Figure 4.4 (a) and (b) shows each one of these plots for the test set, respectively. The plot with the calculated and predicted MOS should be symmetrically distributed around a diagonal line and the plot with the predicted MOS and the residual should be symmetrically distributed around a horizontal line. The graph of Figure 4.4 (a) and b it is verify the desired condition, which could mean that the selected features have a linear dependency with the measured MOS.



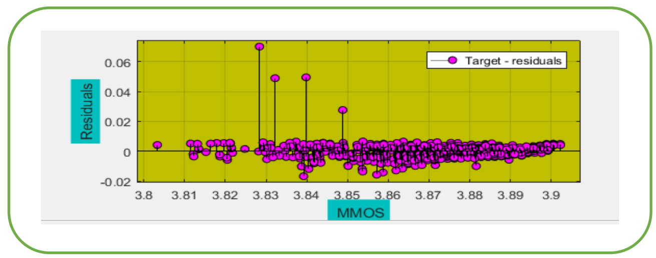
a. MMOS vs PMOS



b. MMOS vs. Residuals



c. MMOS vs PMOS



d. MMOS vs. Residuals

Figure 4.4 Relation between the predicted MOS Vs Measured MOS and residual values by4*4*4 and 3*3

This demonstrates that the ANFIS model works well for voice quality prediction for real 3G voice service data. The Predicted Mean opinion score is computed using the ANFIS algorithm. The average OQoE is 3.803069. Refer to Annex two see the results.

4.3 Computation of the Objective Quality of Experience for GSM

The input data is gotten from ethio telecom service monitoring tool. The data consists of one month 's 896 inputs, i.e. PCSR, E2ED and PCDR. These are defined below; the sample real raw data put on Table 4.6. After having filtered the data, Pearson correlation has been used, to see the relations of parameters and select the parameters for training.

Table 4.6 Sample raw data for 2G.

Current period	Perceived Call Success Rate(%)	E2E Call Connection Delay(ms)	Perceived Call Drop Rate(%)
2019-08-20 16:00	96.96	6342	0.22
2019-08-20 20:00	96.19	6911	0.41
2019-08-20 21:00	96.19	6961	0.51
2019-08-06 00:00	NA	NA	NA
2019-08-06 01:00	NA	NA	NA
2019-09-05 02:00	96.79	5603	0.15

The non-linear regression model for voice quality prediction is in the form of a polynomial, which is identical to the 3G. It has been used to get the calculated MOS (MOS_c), that is the initial target value of this research. After the computation of MOS, the data set is now ready for further analysis, to see the correlation result of each parameter with other parameters. The sample filtered data and correlation result is shown in Table 4.7 and 4.8 respectively. The polynomial formula to compute the Measured MOS (MOS_c) is identical to that of the 3G. Refer to the mathematical expression (4.4).

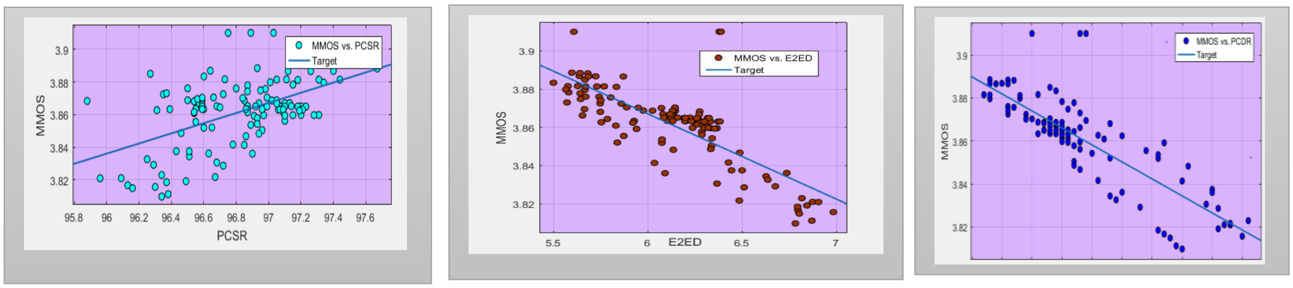
Table 4.7 Processed Data.

Perceived Call Success Rate(%)	E2E Call Connection Delay(s)	Perceived Call Drop Rate(%)	MOS_c
96.69	5.808	0.33	3.848343
96.40	5.61	0.31	3.865079
96.32	5.573	0.21	3.873611
96.77	5.491	0.16	3.885143

Table 4.8 Correlation analysis result for 2G.

Pearson correlation	PCSR	E2ED	PCDR	MMOS
PCSR	1	-0.133	-0.251	0.229
E2ED	-0.133	1	0.711	-0.876
PCDR	-0.251	0.711	1	-0.890
MMOS	0.229	-0.876	-0.890	1

Each parameter and MOS values have been correlated, prior to training and validation of the Proposed Models, to observe their graphical relationship. The correlation results are shown in Figure 4.5. The relations graph clearly shows that PCDR is highly correlated to MOS.



a. PCSR Vs MMOS b.E2ED Vs MMOS c. PCDR Vs MMOS

Figure 4.5 Relationship between the three selected inputs and MMOS on 2G.

ANFIS training is began by inputting training data aimed at training the Neuro-Fuzzy system. Then the initial membership functions are chosen, EPHO number assigned to start the ANFIS training. The command provided by MATLAB to train an ANFIS system is anfisedit. Once the training process is done, the final membership functions and training error from the training data set are produced; estimate of the system compared to the desired output is showed using the evalfis function.

The data has been divided into three sets: the training data set, the testing data set and the validation data set. The training data set has been used to train the ANFIS, while the validation data set has been used to check the accuracy and the effectiveness of the trained ANFIS model to get the final result of the learning. Sample Load Training Data and error graphs are shown in Figure 4.6

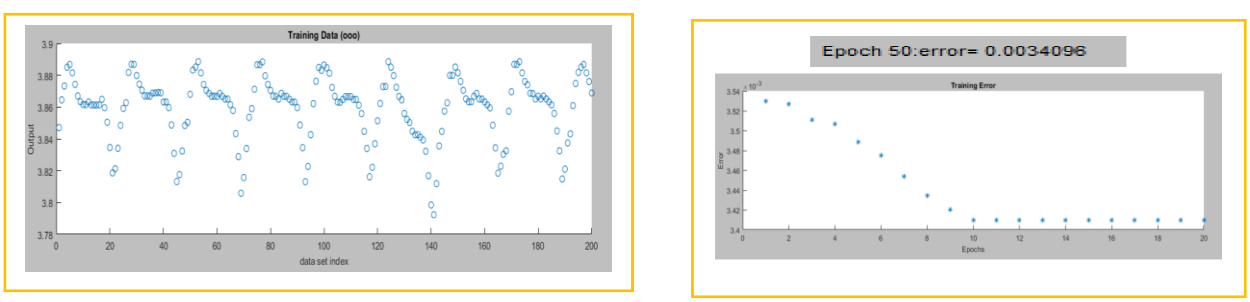


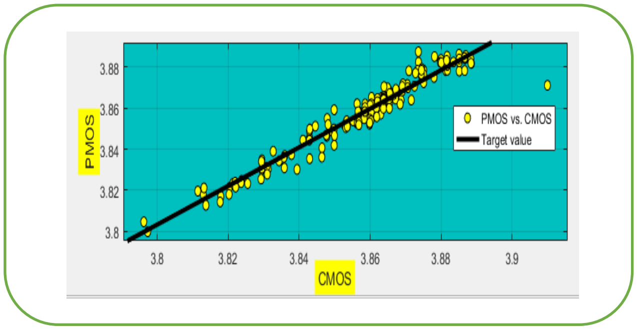
Figure 4.6 load training data and training error result for 2G.

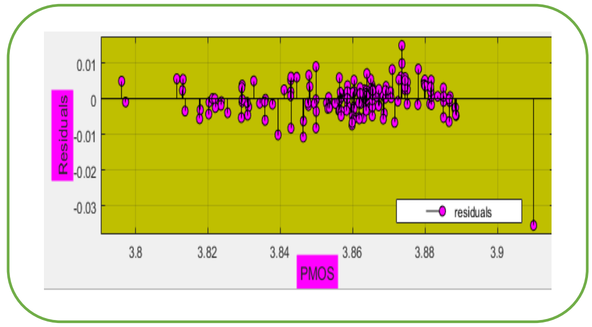
The best ANFIS model is chosen based by comparing the RMSE and Pearson Correlation values for different dataset, epoch numbers and the number of membership functions assigned to ANFIS structure. After a thorough analysis of membership functions, the membership function number (3*3*3) has been chosen to train the model. The generated fuzzy inference system structure contains 27 fuzzy rules. The detail description is illustrated in Table 4.9.

Table 4.9 The Structure of ANFIS Analysis Information for OQoE of 2G services.

ANFIS Parameter Type	ANFIS1			ANFIS2			ANFIS3		
Member ship function type	Gaussian curve			Generalized bell- shape			Triangular-shaped		
No.of Membership fun.	27			27			27		
Training data set	543	200	130	200	130	101	200	130	101
Testing data set	179	130	100	130	100	100	130	100	100
Checking data set	179	100	100	100	100	100	100	100	100
Epoch number	50	20	15	20	15	10	20	15	10
Number of nodes	78			78			78		
Number of Linier parameters	108			108			108		
Number of non Linier parameters	18			135			135		
Total No of Par.	126			243			243		
No.of fuzzy rules	27			27			27		
Input combinations	PCSR,E2ED,PCDR								
RMSE	0.004791	0.0064	0.0088	0.0086	0.0087	0.0109	0.017	0.02	0.0109
R-square	0.9382	0.8802	0.82	0.66	0.78	0.631	0.54	0.25	0.48

One third of the data has been used for validation, and input to the ANFIS model to get the PMOS. Then it is compared to the calculated MOS. The model is tested by plotting the relations between the measured and predicted MOS and the predicted MOS and the residuals. Figure 4.7 (a) and (b) shows each one of these plots for the test set, respectively. The plot with the calculated and predicted MOS should be symmetrically distributed around a diagonal line and the plot with the predicted MOS and the residual should be symmetrically distributed around a horizontal line. The graph of Figure 4.7 (a) it is verify the desired condition, which could mean that the selected features have a linear dependency with the measured MOS.





a. MMOS vs PMOS b. Predicted MOS vs. Residuals

Figure 4.7 Relation between measured MOS Vs predicted MOS and Residual for 2G.

As per the Table 4.9, it can be easily inferred that the Gaussian membership function having the minimum RMSE upon validation, with the epoch numbers 50, is the best result, i.e. low RMSE is 0.004791 and highest Pearson Correlation is 0.9382. This demonstrates that the ANFIS model works well for voice quality prediction for real 2G voice data. The Predicted Mean opinion score is computed using the ANFIS algorithm. The average OQoE is 3.858627. Refer to annex two.

4.4 Concept of the Subjective Perception and its computation

The concept of SPQ accommodates the emotional, subjective needs and expectations of customers. It gives us first hand feedback from customers, by using Questionnaire. A meticulous and standard Questionnaire prepared in the English Language, translated also in the Amharic Language and given to around 400 sample customers to fill. The number of samples has been set to 400 by a standard formula[21].

$$n = N / [1 + N(e)2] \quad (4.5)$$

where N=Number of population (Addis Ababa) = 4,691,182

n=number of sample

e=level of precision (in this case use 5%)

n= 4,691,182 / (1+ (4,691,182)*(0.05*0.05)) =399.96

Therefore, the number of samples is set at 400.

The Questionnaire inquires: Demography of participants, success rate, delay, drop rate, network quality, overall voice call service quality level that is quality related metrics and spatio-temporal aspects of voice call service quality. There are twelve questions, of which ten are marked and two are used as a general feedback. All of the ten questions are graded as follows: 10- Excellent, 8-Very Good, 6-Good, 4-Poor, 2-Very poor.

Table 4.10 Evaluation Marking

MARKING 100% ⟶ 2 0%					
	a	b	c	d	e
1	10	8	6	4	2
2	To be used for feed back				
3	To be used for feed back				
4	10	8	6	4	2
5	10	8	6	4	2
6	10	8	6	4	2
7	4	10	8	6	2
8	8	2	4	6	10
9	10	8	6	4	2
10	2	4	6	8	10
11	10	8	6	4	2
12	10	8	6	4	2

Around 400 participants have filled and submitted the questionnaire, on the months of July and August 2019. A demography of the participants is shown in Table 4-11. The participants are a cross section of the Addis Ababa society.

Table 4.11Demography Analysis.

Demography of Participants		
Sex	Male	234
	Female	179
Age	Under 18	14
	18-34	211
	35-54	171
	Above 55	17
Education	Master's degree &above	56
	Degree	220
	Diploma	77
	12 complete	55
	Below 12	5

The overall evaluation of the four hundred has been shown in the Figure 4.8 below.

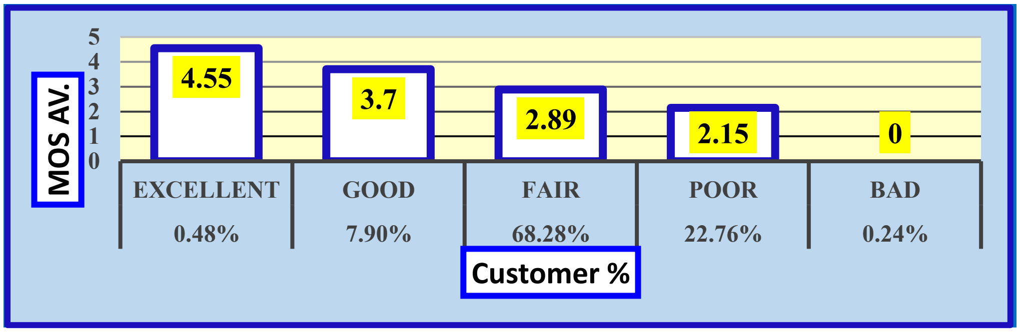


Figure 4.8 Overall SPQ result in % of Customer vs MOS AV.

The subjective perception of quality related metrics is shown below in Figure 4.9 and 10. Quality related metrics: Call success rate, Call Drop, Delay and call interruption.

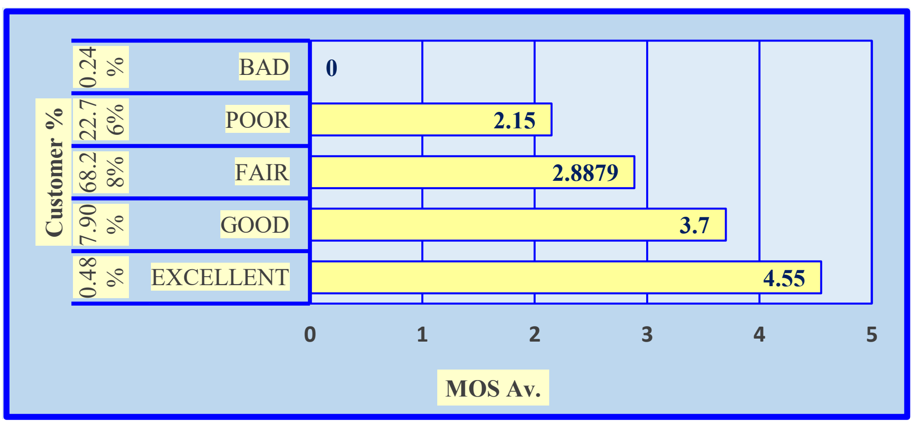


Figure 4.9 SPQ quality related metrics in average MOS format.

Inference: as the graph shows on Figure 4.10, 23 % of sample customers give a very low perception of quality. 68.28 % of sample customers give an average perception of quality and 7.97 % of sample customers give a high perception of quality evaluation**.** The detailed Quality related SPQ metrics Vs MOS average are shown in Figure 4.9.

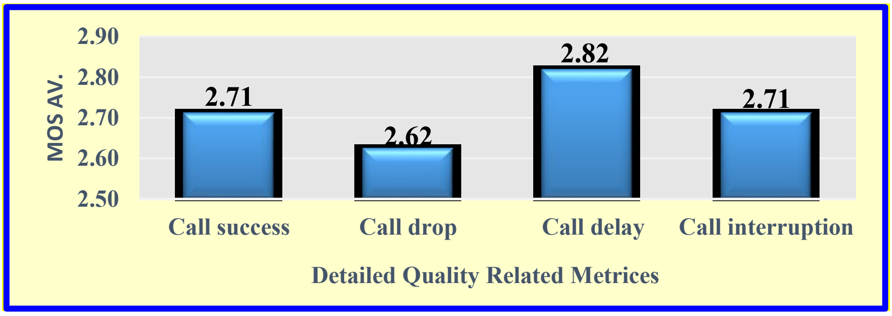


Figure 4.10 SPQ of detail Quality related metrics Vs MOS.AV.

The detail Questionnaire are shown on the Annex. The SPQ for each Questionnaire has been carefully marked and the Average SPQ computed. The average SPQ is = 55.56 %, put in the QoE standard format 2.50. Refer to Annex two, for the results.

4.5 Computation of the Compressive Quality of Experience

4.5.1 Compressive Quality of Experience with Mathematical Equation

CQoE=w*OQoE+ (w-1)*SPQ **(4 .6)**

CQoE= 0.80*OQoE+ 0.20*SPQ **(4.7)**

Table 4.12 Results of CQoE using mathematical relation.

System type	Av. result of OQoE	Av. SPQ	CQoE=((0.8*OQoE)+ (0.2*2.5))	CQoE=((0.9*OQoE)+ (0.1*2.5))	CQoE=((0.6*OQoE)+ (0.4*2.5))
UMTS(3G)	3.803069	2.5	3.542455	3.672762	3.281841
GSM(2G)	3.858627	2.5	3.586902	3.722764	3.315176

4.5.2 Result interpretation, inference using 80% -20% relation

To try to show on table 4.12 by different percent of OQoE and SPQ results but the interpretation is given by 80% and 20% mathematical relationship.

4.5.2.1 UMTS (3G)

The OQoE is 3.803069, mean while the CQoE is 3.542455. The percentage variation is given below:

%variation = (3.542455-3.803069)/ 3.803069*100%=-6.853%

INFERENCE:

A drop of 6.853% has been observed. This is a considerable drop, regarding quality. The introduction of the SPQ, and its integration in the QoE has resulted in the decrease of the OQoE by this number. Thus, much has to be done on voice quality of service to get higher and higher OQoE, SPQ and CQoE values, which imply higher customer physical, rational, psychological, emotional satisfaction.

4.5.2.2 GSM (2G)

The OQoE is 3.858627, mean while the CQoE is 3.586902. The percentage variation is given below:

%variation = (3.586902-3.858627)/ 3.858627*100%=-7.042%

INFERENCE:

A drop of 7.042% has been observed. This is a considerable drop, regarding quality. The introduction of the SPQ, and its integration in the QoE has resulted in the decrease of the OQoE by this number. Thus much has to be done on voice quality of service to get higher and higher OQoE, SPQ and CQoE values, which imply higher customer physical, rational, psychological, emotional satisfaction.

OVER ALL INFERENCE:

The drop in percentage is worse in the 2G voice call service, as compared to the 3G. Therefore, much has to be done, with more emphasis, to the 2G regarding the improvement of voice call quality of service, to match the needs and expectations of customers.

4.6 CQoE by Using ANFIS

4.6.1 CQoE by applying ANFIS for 3G

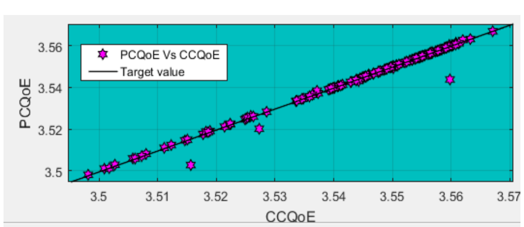
As usual, the best ANFIS model is chosen by comparing the RMSE and Pearson Correlation values for different number of membership functions assigned to the ANFIS structure. After a thorough analysis of membership functions, the membership function number (3*3*3) has been chosen to test the model. The detail result is illustrated in Table 4.13.

Table 4.13 The Structure of ANFIS Analysis Information for CQoE of 3G services.

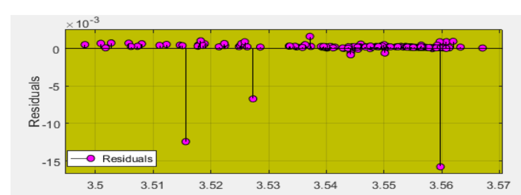
ANFIS Parameter Type	ANFIS1	ANFIS2	ANFIS3
Member ship function type	Gaussian curve	Generalized bell- shape	Triangular-shaped
No.of Membership fun	27	27	27
Training data set	438	438	438
Testing data set	146	146	146
Validation data set	146	146	146
Epoch number	50	50	50
Number of nodes	78	78	78
Number of Linier parameters	108	108	108
Number of non Linier parameters	27	27	27
Total No of Par.	135	135	135
Input combinations	PCSR, E2ED, PCDR		
RMSE	0.0018	0.01303	0.00023
R-square	0.9876	0.6487	0.9998

One third of the data has been used for validation, and input to the ANFIS model to get the PCQoE. Then it is compared to the calculated CQoE. The model is tested by plotting the relations between the calculated CQoE and predicted CQoE MOS and the predicted CQoE and the residuals. Figure 4.11 (a) and (b) shows each one of these plots for the test set, respectively.

As per the Table 4.13, it can be easily inferred that the Triangular membership function having the minimum RMSE upon validation, with the epoch numbers 50, is the best result, i.e. RMSE is 0.00023 and Pearson Correlation 0.9998.



a. CMOS vs PMOS



b. Predicted MOS vs. Residuals

Figure 4.11Relation between calculated CQoE MOS Vs predicted CQoE MOS and residual for 3G.

4.6.2 CQoE by applying ANFIS for GSM (2G)

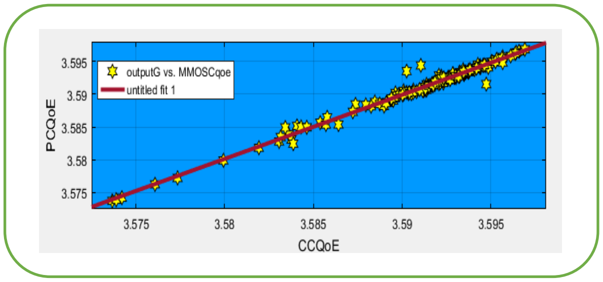
Based on one-month service monitoring tool data and the same data use for 3G around 400 Questionnaire average results have been input to the ANFIS algorithm and to get CQoE estimation model as follows

Table 4.14 The Structure of ANFIS Analysis Information for CQoE of 2G services

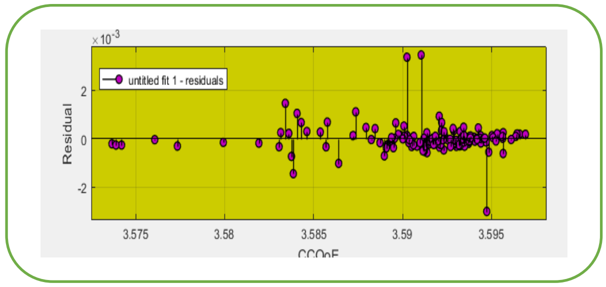
ANFIS Parameter Type	ANFIS1	ANFIS2	ANFIS3
Member ship function type	Gaussian curve	Generalized bell- shape	Triangular-shaped
No.of Membership fun	27	27	27
Training data set	538	538	538
Testing data set	179	179	179
Validation data set	179	179	179
Epoch number	50	50	50
Number of nodes	78	78	78
Number of Linier para.	108	108	108
Number of non Linier parameters	27	27	27
Total No of Par.	135	135	135
Input combinations	PCSR,E2ED,PCDR		
RMSE	0.00061	0.00144	0.00094
R-square	0.9788	0.9056	0.9452

The model is tested by plotting the relations between the calculated CQoE and predicted CQoE MOS and the predicted CQoE and the residuals. Figure 4.12 (a) and (b) shows each one of these plots for the test set, respectively.

As per the Table 4.14, it can be easily inferred that the Gaussian membership function having the minimum RMSE upon validation, with the epoch numbers 50, is the best result, i.e. RMSE is 0.00061 and Pearson Correlation 0.9788.



a. CMOS vs PMOS



b. Predicted MOS vs. Residuals

Figure 4.12 Relation between calculated CQoE MOS Vs predicted CQoE MOS and residual for 2G.

Percentage variation between predictive objective QoE and predictive compressive Quality of experience. The result is shown in table 4.15.

Table 4.15 Percentage variation results.

Services	Av.POQoE	Av.PCQoE	%variation
3G	3.802943	3.542352	6.854%
2G	3.858627	3.586855	7.0432%

INFERENCE:

A drop of 7.0432% and 6.854% on the result of 2G and 3G respectively has been observed. This is a considerable drop, regarding quality. The introduction of the SPQ, and its integration in the QoE has resulted in the decrease of the OQoE by these numbers.

4.7 Computation of the CQoE by Using ANFIS for both OQoE and SPQ

Another, pragmatic approach of the computation of the CQoE, by using the ANFIS algorithm both for the OQoE and for the SPQ has been proposed here. This proposal is based on the notion, that a software application for the SPQ would be developed, made available to all customers and a sustainable number of data could be collected, by incentivizing customers.

Based on this assumption, just to show the viability of using machine learning to compute CQoE by using one-month input data from the service monitoring tool and around 400 Questionnaire results have been input to the ANFIS algorithm and the CQoE computed on the above section 4.6, both for 2G and 3G.

4.8 Spatial & Temporal Analysis for OQoE, SPQ and CQoE

The Spatial-temporal analysis is aimed at determining where and when best or worst perception of quality have been observed. The graph below shows the OQoE, SPQ value at different locations of Addis Ababa. On Table 4.16 also showed that Best and Worst quality of voice service, Outside &Inside home, Walking &Transport.

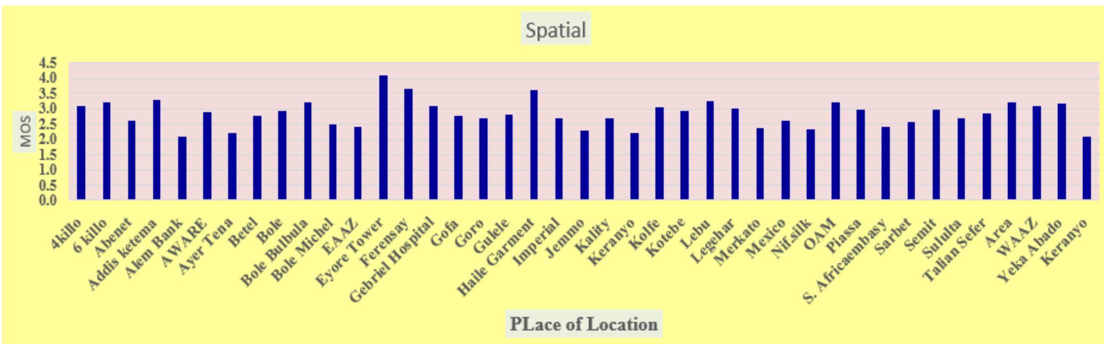


Figure 4.13 Different locations of Addis Ababa where the survey conducted Vs SPQ MOS.

Table 4.16 Best and Worst quality of voice service Outside &Inside home, Walking &Transport.

Location	Best Quality of voice service	Worst Quality of voice service
Outside Home/Office	284	25
Inside Home/Office	47	210
Walking	53	52
On transportation	29	126

The Perceptions of the customers for the best and worst time for their voice call quality of service shown on Table 4.16. The best period of time in which participants get good voice quality of service is during the night from 9:00 pm to 4:00 am. This is logical because the number of customers using the service decreases drastically at this time, as most customers go to bed by that time interval. The time that the subscribers get the worst voice service is during the afternoon from 12:00pm.to 6:00 pm. This is because most customers use voice call at this time interval so there is high congestion. The survey result is illustrated on Table 4.17 below:

Table 4.17 Best and Worst SPQ time wise.

Time Period	Best Quality of voice service (Q7)	Worst Quality of voice service (Q8)
Early Morning (4:00 a.m.-8:00 a.m.)	97	35
Morning (8:00 a.m.-12:00 p.m.)	47	96
Afternoon (12:00 p.m.-6:00 p.m)	20	205
Evening (6:00 p.m.-9:00 p.m)	46	59
Night (9:00 p.m.-4:00 a.m.)	203	18

4.8.1 OQoE Temporal analysis

Based on OQoE data try to see the analysis of time with PCDR and time with PMOS. The analysis result shown in Figure 4.14 and Figure 4.15.as the graph shows there is high call drops at nighttime and low perception registered.

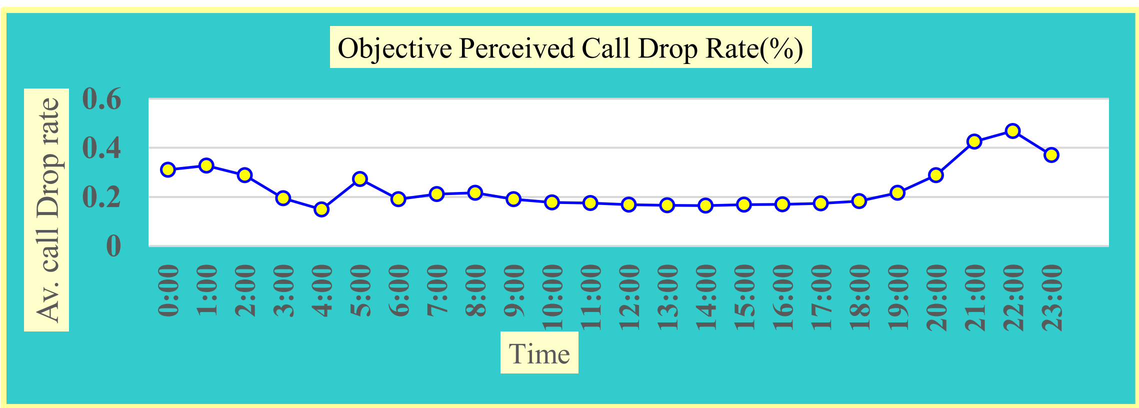


Figure 4.14 Temporal distribution of PCDR Vs time.

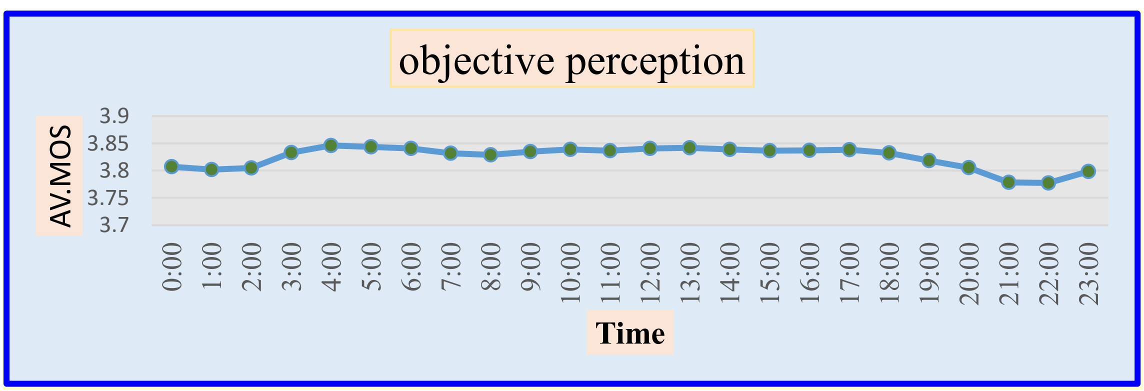


Figure 4.15 Temporal distribution of PMOS vs time for 3G.

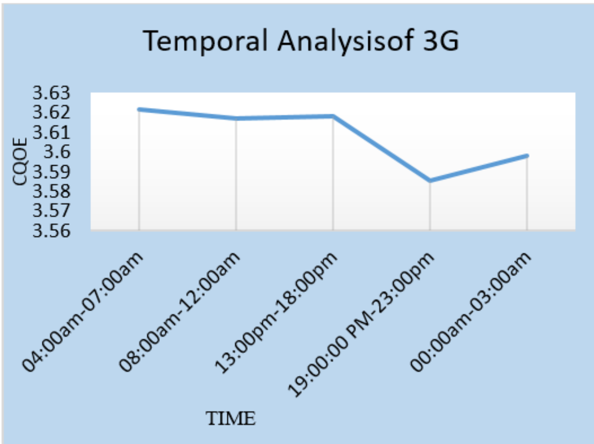
4.8.2 CQoE Temporal analysis

CQoE is not the same everywhere and at any time. It varies from place to place and from time to time. Here is the chart that shows the temporal aspect of the CQoE. The 5,538 data set has been subdivided into five time periods within a day or 24 hours. The OQoE and CQoE have been computed by the same token discussed in previous sections.

Table 4.18 Temporal analysis result based different gap of time using CQoE.

3G/2G	Time	Time Gap	No.of Event	OQoE	SPQ	CQoE
GSM	**Night**	00:00am-03:00am	152	3.8717	2.5	3.59736
	Early Morning	04:00am-07:00am	152	3.87848	2.5	3.60279
	Morning	08:00am-12:00am	185	3.86326	2.5	3.59061
	Afternoon	13:00pm-18:00pm	222	3.85633	2.5	3.58507
	Evening	19:00 pm-23:00pm	185	3.8297	2.5	3.56376
UMTS	**Night**	00:00am-03:59am	888	3.82296	2.5	3.5583
	Early morning	04:00am-07:59am	927	3.84026	2.5	3.5722
	Morning	08:00am-12:59am	1189	3.83469	2.5	3.5677
	Afternoon	13:00pm-18:59pm	1394	3.83482	2.5	3.5678
	Evening	19:00pm -23:59pm	1121	3.79998	2.5	3.5399

The CQoE temporal analysis is aimed at determining when best or worst perception of quality have been observed. The analysis result shown in Figure 4.16.



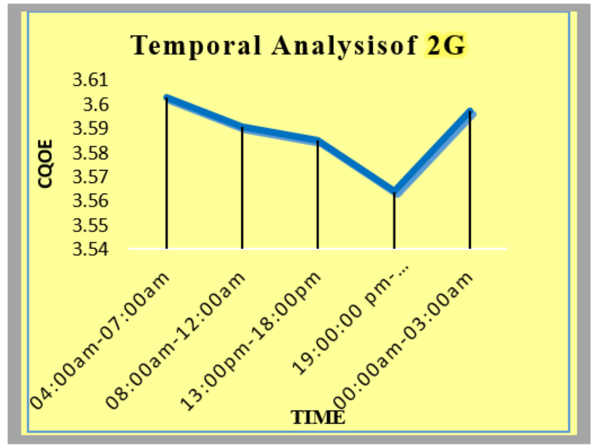


Figure 4.16 The relation between Time Vs CQoE for 3G and 2G.

4.8.3 Result interpretation of Temporal Analysis of COQoE, inference

The highest CQoE is noticed at the first time interval, in the early morning from 4:00 a.m.-7:59 a.m. This is expectable since the number of calls is not so many, the network would not be so jammed. From 8:00 a.m.-12:59 p.m. it is has a minimum decrease in the CQoE value, as the number of calls increases. Then 13:00 p.m.-18.59p.m. The CQoE decreases considerably and sharply, this means that the peak of calls is in this time interval. The ethiotelecom should take steps to enhance CQoE in this time interval, as low quality voice call service is noticed in this time interval. From 19:00 p.m. - 23:59 p.m. the value of the CQoE starts to gain momentum and increase sharply as the voice calls start to decrease and the number of Addis Ababa residents who get to sleep increases sharply.

Chapter 5

Recommendation, Conclusion and Future works

5.1. Recommendations

To get a sustainable data from Questionnaire the following idea has been proposed as a recommendation:

- To develop a software application for the Questionnaire which can easily be downloaded from the ethio-telecom website and distributed by X-ender from client to client or free SMS. An incentive in the form of a mobile service packet would be awarded to clients filling and sending the Questionnaire to the ethio-telecom. The advantages of the software application include:
  - Simplicity
  - Easy accessibility
  - Effortlessness
  - First hand customer impression of voice quality service
  - Scalability
  - Sustainability
  - Instantaneous accessibility
  - Easy upgradability, enhance ability, edit ability as per change of customer needs and expectations.
- The radio receivers and transmitters of voice call service should strictly comply to International norms and Standards.
- Standard and quality cellphones are needed to get high quality voice call experience. The ethiotelecom should establish a quality & standard authority department having rules, regulations, principles and practices complying to International Telecom Standards (ITU Standards). The quality & standard authority department of the ethiotelecom that would be established would enforce the rules and regulations to sell acceptable quality cellphones. This would highly enhance the CQoE.

- To establish a research and development (R&D) department to cope with sustainable competition and change of needs and expectations of customers.

5.2. Conclusion

As it has been seen, this thesis is all about the development of a Comprehensive Quality of Experience (CQoE), which is the combination of objective Quality of Experience (OQoE) and the Subjective Perception of Quality (SPQ) in the ratio of 80% and 20%. CQoE is a model that measures and predicts the users' perceived quality. It uses the real Global System for Mobile Communication (GSM) and Universal Mobile Telecommunications System (UMTS) data, for this purpose, to adapt to the need of the user.

The thesis has been motivated by the fact that, the ethio telecom has no model for QoE that is capable of assessing, measuring, predicting and anticipating the needs and expectations of customers. A SP having no QoE model, would easily lose its business to the others who have QoE models and strive sustainably to enhance the quality of the voice call service they provide, assuming many competitive SP exist in Ethiopia.

The user perceived quality is measured by Mean Opinion Score (MOS) scale, by evaluating Quality of Service (QoS) metrics. Service monitoring tool data and calculated MOS measurements are then used as reference data, in order to produce a new QoE prediction model, using machine learning techniques by using the Adaptive Neuro Fuzzy Inference System (ANFIS). The concept of the SPQ has been introduced with the intent of getting first hand feedback from customers, by using Questionnaire. Voice call Service is given to customers, who are human beings having two main aspects: the rational, objective and the emotional, subjective. OQoE deals with the rational, objective aspect of voice call service quality given by a SP, while the SPQ deals with the undeniable emotional, subjective aspect of voice service quality given by a SP. By combining these two aspects, one gets the full picture of voice quality level given by a SP.

The CQoE has been computed in various ways. The CQoE and the OQoE have been compared, and inferences made based on the percentage variations. The major finding is that the CQoE is more than 6% less than the OQoE, both for the 2G and 3G. This is a considerable drop in voice service quality assessment. The drop is caused by the introduction of the SPQ in the QoE equation, i.e. the evaluation of the emotional aspect of voice call service given to customers. This is a very indicative clue of the importance of incorporating SPQ in the CQOE computation.

The proposed 3G & 2G voice calls QoE models perform the perceived quality by these QOS metrics: PCSR, E2ED and PCDR. These models estimate the QoE with a Root Mean Squared Error (RMSE) and Pearson Correlations in the following order respectively: for OQoE (3G & 2G), CQoE (3G& 2G) : 0.47% & 95.05%, 0.35% & 93.82%, 0.06% & 97.88%, 0.023% & 99.24%.to the measured QoE. Furthermore, the recommendations on section 5.1: that helps to enhance voice call quality.

5.3. Future works

As for the future works a detailed analysis and study should be done on the recommendation stated above, comprehensive plans and actions plans should be developed accordingly to sustainably address voice quality issues and make ethiotelecom live up to its ideal of giving excellent quality of service in all its endeavors of different services.

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Annex I

Around 400 Answered Questionnaires (English &Amharic language)

English language Questionnaire

Present Location: Sub city ___________ Woreda----------Age________ Gender_____ Date________

Educational background:

○ Below grade four ○ Below grade eight ○ Twelve complete ○ Diploma ○ Degree ○ MSc & above

1. How do you evaluate the quality of mobile network voice service?
   ○ Excellent ○ very good ○ good ○ poor ○ bad
2. Where do you get the best quality voice services?(it possible choose 2)

   ☐ Outside home ☐ In the house ☐ When walking ☐ on transportation

3. Where do you get the worst quality of voice services? (it possible choose 2)

☐ Outside home ☐ In the home ☐ When walking ☐ on transportation

4. How do you evaluate the call success in mobile network?

○ Excellent ○ very good ○ good ○ poor ○ bad

5. How do you evaluate the call drop rate in your calls?

○ Negligible ○ rare ○ sensible ○ frequent ○ very frequent

6. How do you evaluate the call delay? ○ Negligible ○ very short ○ short ○ long ○ very long

7. When do you get good voice service?

○ Early Morning (4:00 a.m.-8:00 a.m.) ○ Morning (8:00 a.m.-12:00 p.m.)

○ Afternoon (12:00 p.m.-6:00 p.m). ○ Evening (6:00 p.m.-9:00 p.m) ○ Night (9:00pm-4:00am)

8. When do you get bad voice service?

○ Early Morning (4:00 a.m.-8:00 a.m.) ○ Morning (8:00 a.m.-12:00 p.m.)

○ Afternoon (12:00 p.m.-6:00 p.m.) ○ Evening (6:00 p.m.-9:00 p.m.) ○ Night (9:00pm-4:00am)

9. How do you evaluate the overall mobile voice service of ethio-telecom?

○ Excellent ○ very good ○ good ○ poor ○ bad

10. If a new mobile service provider will been introduced, do you want to switch to the new operator?

○ Surely ○ very likely ○ likely ○ unlikely ○ never

11. Do you think ethio-telecom is sensitive and sensible to customers' voice service quality?
   ○ Sure ○ mostly ○ often ○ rarely ○ never
12. Does the already setup voice call has interruption ○ Sure ○ mostly ○ often ○ rarely ○ never

Amharic language Questionnaire

አገልግሎቱን የሚጠቀሙበት ቦታ(ክ/ከተማ)--------------------------- እድሜ---------- ጾታ----------ቀን------------

የትምህርት ደረጃ

○ ከአራተኛ ክፍል በታች ○ ከስምንተኛ ክፍል በታች ○ አስራሁለተኛ ክፍል ○ ዲፕሎማ ○ ዲግሪ ○ ማስተርስ ና ከዚያ በላይ

1. የሞባይል የድምጽ ጥሪ አገልግሎት ኔትዎርክ እንዴት ነው?

○ እጅግ በጣም ጥሩ ○ በጣም ጥሩ ○ ጥሩ ○ ጥሩ አይደለም ○ በጣም ጥሩ አይደለም

2.ጥሩ የሞባይል ድምጽ አገልግሎት የሚያገኙት የት ቦታ ሆነው ሲጠቀሙ ነው?(ሁለት መልስ ይምረጡ)

☐ ከቤት ውጭ ☐ ቤት ውስጥ ☐ በጉዞ ላይ ☐ በትራንስፖርት ላይ

3.ጥሩ ያልሆነ የሞባይል ድምጽ አገልግሎት የሚያገኙት የት ቦታ ሆነው ሲጠቀሙ ነው?(ሁለት መልስ ይምረጡ)

☐ ከቤት ውጭ ☐ ቤት ውስጥ ☐ በጉዞ ላይ ☐ በትራንስፖርት ላይ

4. የሞባይል የድምጽ የጥሪ ስኬት ደረጃ እንዴት ይመዝኑታል?

○ እጅግ በጣም ጥሩ ○ በጣም ጥሩ ○ ጥሩ ○ ጥሩ አይደለም ○ በጣም ጥሩ አይደለም

5. የሞባይል የድምጽ ጥሪ ሙከራ መውደቅ(መቋረጥ) እንዴት ነው?

○ ከግምት የማይገባ ○ ትንሽ ○ ትንሽ ተደጋጋሚ ○ ተደጋጋሚ ○ በጣም ተደጋጋሚ

6. የድምጽ ጥሪ ሙከራ መዘግየቱን ደረጃ እንዴት ይመዝኑታል?

○ ከግምት የማይገባ ○ ትንሽ ይዘገያል ○ ይዘገያል ○ በጣም ይዘገያል ○ እጅግ በጣም ይዘገያል

7. ጥራት ያለው የሞባይል የስልክ ጥሪ በአብዛኛው በየትኛው ሰአት ይገጥሞታል?

○ በጣም ጠዋት(ከ10፡00-2፡00 ሰዐት) ○ ጠዋት(ከ2፡00-6፡00 ሰዐት) ○ ከሰአት(ከ6፡00-12፡00 ሰዐት)

○ ማታ(ከ12፡00-3፡00 ሰዐት) ○ ሌሊት(ከ3፡00-10፡00)

8. ጥራት የሌለው የሞባይል የስልክ ጥሪበየትኛው ሰአት ይገጥሞታል?

○ በጣም ጠዋት(ከ10፡00-2፡00 ሰዐት) ○ ጠዋት(ከ2፡00-6፡00 ሰዐት) ○ ከሰአት(ከ6፡00-12፡00 ሰዐት)

○ ማታ(ከ12፡00-3፡00 ሰዐት) ○ ሌሊት(ከ3፡00-10፡00)

9. የኢትዮ ቴሌኮምን አጠቃላይ የሞባይል የስልክ ጥሪ አገልግሎት እንዴት ይገል**ጹታል** ?

○ እጅግ በጣም ጥሩ ○ በጣም ጥሩ ○ ጥሩ ○ ጥሩ አይደለም ○ በጣም ጥሩ አይደለም

10. ሌላ የስልክ አገልግሎት ሰጪ ድርጅት ቢመጣ ደንበኝነቶን ይቀይራሉ ?

○ አዎ ○ ልቀይር እችላለሁ ○ አስብበታለሁ ○ ላልቀይር እችላለሁ ○ በፍፁም አልቀይርም

11. ኢትዮ ቴሌኮም ለደንበኞቹ የድምጽ ጥሪ አገልግሎት ኔትዎርክ ጥራት ችግሮችን ለመስማትና ለመፍታት ፈጣን መልስ ይመልስሎታል?

○ አዎ በደንብ በአብዛኛው ጊዜ ○ አንዳንዴ ○ አልፎ አልፎ ○ በጭራሽ

12.ጥሪ አድርገው በንግግር ላይ እያሉ መቆራረጥ ያጋጥሞታል ?

○ አዎ ○ በአብዛኛው ○ በተደጋጋሚ ○ አልፎአልፎ ○ በጭራሽ

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Annex II

I. 5538 nine-month data OQoE computation for 3G

II. 896 one-month data OQoE Computation for 2G

III. 400 data +Av SPQ(400) data for (2G&3G) to show sample CQoE

IV. 400 Questioners marking result and average.

I Sample 3G data

PCSR	E2ED	PCDR	MMOS	PMOS
96.97	4.132	0.19	3.884017	3.884064
97.29	4.067	0.18	3.885603	3.885744
96.75	4.022	0.18	3.885541	3.885576
97.12	4.025	0.1	3.898997	3.898554
97.77	4.095	0.05	3.907543	3.906207
98	4.136	0.07	3.904215	3.902241
97.74	4.229	0.07	3.904342	3.90348
97.83	4.362	0.08	3.902834	3.902696
97.68	4.398	0.1	3.899507	3.899457
97.45	4.434	0.1	3.899556	3.899635
97.22	4.491	0.12	3.896262	3.896357
96.72	4.684	0.16	3.889797	3.889693
96.83	4.706	0.15	3.891506	3.891391
97.09	4.638	0.13	3.894777	3.894773
97.22	4.519	0.11	3.897985	3.898066
			.........AV=	**3.803069**

II. Sample 2G data

PCSR	E2ED	PCDR	MMOS	PMOS
96.22	5.753	0.27	3.861617	3.8641
96.37	5.767	0.29	3.861567	3.860745
96.56	5.665	0.24	3.869931	3.871428
96.29	5.796	0.26	3.871605	3.863967
96.31	5.754	0.26	3.863279	3.865336
96.70	5.786	0.22	3.864948	3.869869
96.29	5.723	0.26	3.866649	3.866582
96.42	5.696	0.30	3.86847	3.86195
96.33	5.717	0.31	3.861737	3.860208
96.04	5.674	0.24	3.875086	3.872382
			.......Av=	***3.858627***

III. Sample 3G Data used for CQoE

Perceived Call Success Rate(%)	E2E Call Connection Delay(s)	Perceived Call Drop Rate(%)	MMOS	PMOS	Av.SPQ	CQoE
96.40	5.61	0.31	3.864505	3.861875	2.5	3.5895
96.32	5.573	0.21	3.873278	3.877996	2.5	3.602397
96.77	5.491	0.16	3.885037	3.884688	2.5	3.60775
97.02	5.631	0.09	3.886793	3.883102	2.5	3.606481
96.95	5.607	0.08	3.881518	3.884647	2.5	3.607718
96.71	5.681	0.11	3.874234	3.87848	2.5	3.602784
96.51	5.905	0.15	3.866981	3.869639	2.5	3.595711
96.56	6.1	0.19	3.863385	3.865443	2.5	3.592354
96.47	6.176	0.21	3.861595	3.861708	2.5	3.589367

IV.Sample 2G Data use for CQoE

Perceived Call Success Rate(%)	E2E Call Connection Delay(s)	Perceived Call Drop Rate(%)	MMOS	PMOS	Av.SPQ	CQoE
96.30	4.017	0.34	3.858884	3.858785	2.5	3.587028
96.51	4.006	0.19	3.883844	3.883824	2.5	3.607059
97.00	4.129	0.10	3.89914	3.899182	2.5	3.619346
96.97	4.122	0.14	3.892394	3.892425	2.5	3.61394
96.80	4.15	0.20	3.882367	3.882511	2.5	3.606009
96.98	4.223	0.21	3.880794	3.880916	2.5	3.604733

Sample Subjective marking result and average

Place	%value	MOS	Place	%value	MOS	
24 Kebele	64	3.2	6KIlo	68	3.4	
4 killo	62	3.1	A,A	56	2.8	
4 kilo	40	2	A.A	28	1.4	
6 killo	54	2.7	A.A	32	1.6	
6 killo	56	2.8	A.A	32	1.6	
6 killo	60	3	Piassa	46	2.3	
A.A	60	3	Bole	46	2.3	
A.A	60	3	Merkato	46	2.3	
A.A	60	3	A.A	46	2.3	
.	.	.	.	.	.	
					……..Av=	**2.51**