Addis Ababa University
Addis Ababa Institute of Technology
School of Electrical and Computer Engineering
Telecommunication Engineering Graduate Program

Evaluation of QoE for Fixed wire-line Broadband Data Service in the case of Addis Ababa Enterprise Customers Ethiopia

Advisor Dr Mesfin Kifle

By Wallelign Asfaw

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By: Wallelign Asfaw

Dr.Mesfin Kifle _____

Advisor

Signature

Dr.Yalemzewd Negash _____

Examiner

Signature

Dr. Surafel Lemma _____

Examiner

Declaration

I, the undersigned, declare that the thesis comprises my work in compliance with internationally accepted practices; I have fully acknowledged and referred to all materials used in this thesis work.

Wallelign Asfaw Mammo _____

Name Signature

Place: Addis Ababa

Date of Submission: _____

Dean, School of Electrical and Computer Engineering

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Abstract

Telecom operators should monitor the satisfaction level of their customers and the quality of their networks to take on-time network optimization, redesign and marketing, in general effective resource allocation decisions. Therefore, it is necessary to evaluate the impact of fixed wire-line broadband performances on the customers' experience. QoE is an emerging technology, it has become an increasing research area. In this thesis, QoE is evaluated with objective and subjective methods. Most of earlier studies used subjective method to evaluate QoE, but the evaluation we used a combination of objective and subjective methods which give more realistic results. Moreover, the nobility of this thesis to the best of my knowledge is a unique combination of network quality metrics. It is based on download, upload speed and latency of QoE objective metrics which are collected from the customers' end devices, using Testmy.net, ping-test.net tools. Furthermore, we formulate a survey questionnaire to evaluate user MOS.

The evaluation result indicates user perception is not satisfactory during on-peak hours with MOS value of 2.88. Whereas the satisfaction of customers during off-peak hours is good with MOS value of 3.90. On the other hand, the objective fuzzy logic QoE output indicates 4.0 at off-peak hours and 2.67 on-peak hours. To summarize, off-peak hour's satisfaction result is good (greater than 3.5) and on-peak hour's satisfaction needs attention to improve the experience since our result shows less than the benchmark value of quality of experience 3.5.

According to our analysis, the main problem is latency which does not fulfil ITU benchmark, but the upload and download speed fulfil Ofcom recommendation. The recommended solution to reduce latency especially during on-peak period is to implement a proxy cache server. This solution leads to reduce traffic volume more than 50% of inter-domain link, saves bandwidth of inter-domain link and handles more traffic without upgrading uplink capacity.

Keywords: quality of service, quality of experience, fixed broadband, enterprise customer, download speed, upload speed, latency, mean opinion score fuzzy logic, quality metrics, subjective, objective.

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Acronyms

3G----------Third Generation

4G----------Fourth Generation

BB----------Broadband

BO----------Back Office

BoA----------Bisector of Area

CMTS ----------Cable Modem Termination System

CoA----------Centroid of Area

CSV----------Comma Separated Value

D----------Download

DPI----------Deep Packet Inspection

DSL----------Digital Subscriber Line

DSLAM---------Digital Subscriber Line Access Multiplexer

ECSM----------Enterprise Customer Service Management

FAN----------Fixed Access Network

FBM----------Functional Benchmarking

FIS----------Fuzzy Inference System

ICT----------Information Communication Technology

IETT----------International Engineering Task Force

IPDV----------IP packet Delay Variation

IP----------Internet Protocol

IPLR----------IP Packet Loss Rate

ISP----------Internet Service Provider

IPTD----------IP Packet Transfer Delay

ISDN----------Integrated Service Digital Network

ITU----------International Telecommunication Union

KPI----------Key Performance Indicator

LoM----------Largest of Maximum

MBPS----------Mega Bite Per Second

MDI----------Media Delay Index

MLR----------Media Loss Rate

CP----------Content Provider

CSM----------Customer Service Management

MSAG----------Multi-Service Access Gateway

MSAN----------Multi-Service Access Node

GBPS----------Giga Bite Per Second

NNI----------Network to Network Interface

O&M----------Operation and Maintenance

JPEG----------Joint Photographic Experts Group

KBPS----------kilo Bite per Second

HTML----------HyperText Markup Language

MoM----------Mean of Maximum

MOS----------Mean Opinion Score

MS----------Mille Second

NGNP----------New Generation Network Project

NMS----------Network Management System

NNOC----------National Network Operating Center

PRTG----------Paessler Router Traffic Grapher

QoE----------Quality of Experience

QoS----------Quality of Service

RTT----------Round Tripe Time

SMC----------Service Management Center

SOHO----------Small Office Home Office

SOM----------Smallest of Maximum

TCP----------Transmission Control Protocol

TT----------Travel Ticket

U----------Uninterrupted

UP----------Upload

UK----------United Kingdom

US----------United States

USO----------Universal Service Obligation

VOIP----------Voice Over IP

WLAN----------Wide Local Area Network

Chapter 1 Introduction

1.1 Background

Communication sector has changed rapidly as we enter to the globalization which leads to convergence between the broadband Internet and the content sector. The importance of ICT is visible as it has been applied in various fields for the purpose of service improvement. It has been known that resources can be managed efficiently through ICT. Broadband plays a vital role to improve the competitiveness of an economy and sustainability of economic growth of the society. Many governments around the world are increasingly committed to extending broadband networks to their citizens [1]. In Ethiopia, the usage of Internet and multimedia by government, corporate, and public sectors is increasingly changing. Broadband will contribute to economic growth and social interaction development by increasing productivity and introducing new services in the long term. Furthermore, broadband is an inclusive term to mention high-speed networking services, which is a set of digital communication technologies with the capacity to transmit significant amounts of data at a high data rate. As a pivotal point to enabling technology in the networked society, can help to boost the economy of Ethiopia at the national level as well as help to improve the lives of its citizens by facilitating many services to a wider population.

Even if a number of broadband technologies are available, the speeds for these technologies differ from one to the other based on the medium the technology used. Most of the time ISPs owner advertise broadband service by download and upload speeds in terms of kbps, Mbps and Gbps. Therefore, understanding the actual technology to match the user proposed purpose when purchasing broadband data service is vital.

Broadband technologies can be divided into two categories, wired and wireless broadband technologies, in this paper our focus on wired broadband network data service.

Wired broadband essentially there is a physical connection to a physical location of a business center with a wire, relatively deliver better speed than wireless because it encounters less interference from the surrounding. There are three main types of wired broadband connection types. DSL relatively low-speed connection, coaxial cable, and fiber which is high capacity transmission speeds vary depending on the type of modem, cable network, and how many people in the neighbourhood are using a cable connection to share the bandwidth that gets from ISP. ISP is a company that supplies Internet connectivity to business customers. ISPs operate

networks that connect end-users to the Tier 1 Internet as shown in Figure 1-1, service provider allowing them to access resources worldwide. ISPs used to allow users access to networks that fulfil the required equipment [2]. ISPs are responsible for making sure you can access the Internet, routing Internet traffic, resolving domain names, and keeping the network infrastructure that makes Internet access possible.

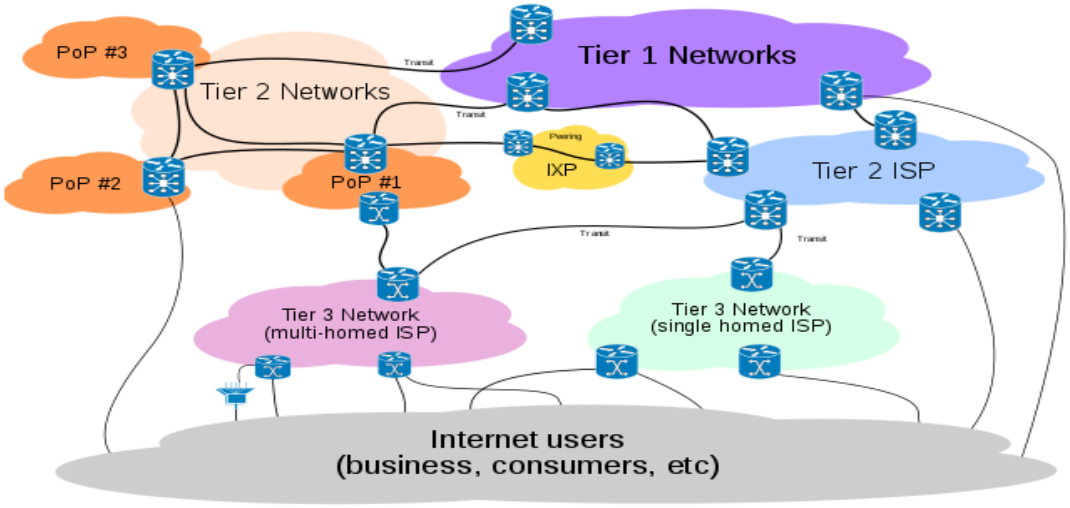


Figure 1-1. ISP Three tier model [2]

ISP provides speeds which have a significant impact on the QoS Internet users receive and the range of activities they can carry out. Therefore, speed is often a key consideration when customers choose their broadband service and it is important that customers know what speed they are likely to receive at the user end (actual speed) rather than advertising speed, which is *the speed of Internet at ISP station and* controlled by ISP owner. Broadband speed has come out as the single dominantly cited metric for characterizing the quality of broadband service. There are now a number of sites and organizations that measure the speed of a user's broadband service in terms of upload speed and download speed [3].

Actual speed is the speed of user-received at the work station, it is a percentage of advertised speed as shown in *Table 1-1* page 3, actual speed always less than advertised speed due to various real reasons such as distance from ISP, traffic, technology etc. technology factor, such as ADSL, cable and fiber are the most common type, each of them has different data rate and hence the actual speed also differed from one to the other, xDSL significantly lowest from the mentioned technology. When we compare the actual download and upload speed on the average of the three technology, the upload is a better speed at the user end as shown in Table 1-1 page 3, this is due to traffic load of download speed than upload speed since most of the user download some content than upload [4].

Table 1-1. Sample ISP average Actual speed vs. Advertising speed in terms of technology [4]

	Download speed over 24hrs			Upload speed over24hrs		
Technology	XDSL	Cable	FTTX	XDSL	Cable	FTTX
Actual/Advertising speed	On the average 76%			On the average 88%		

1.1.1 Broadband service

Broadband usually concerns with high-speed Internet access that is always connected and faster than the traditional dial-up access. Broadband includes several high-speed transmission technologies such as DSL, Cable, and fiber. Broadband Internet is a key driver of economic growth and national competitiveness, it has a deep and widespread social impact, and it is just a network delivering high-speed connectivity. Broadband is better defined as an ecosystem comprising of Network, Services and Users as shown in *Figure 1-2* in the form of system cycling.

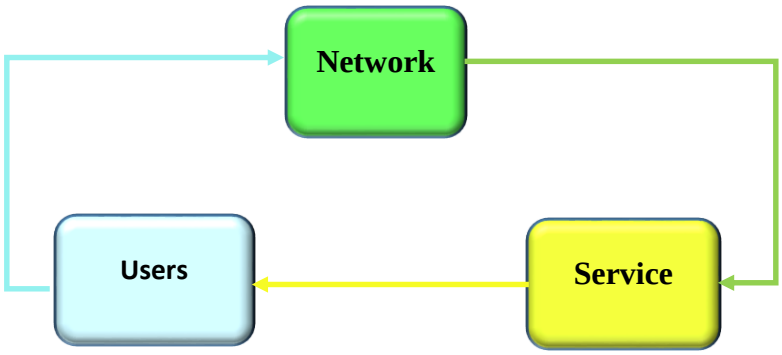


Figure 1-2 broadband service block diagram

ethio telecom is the sole operator of providing communication infrastructure for different services, one of the services is fixed wire-line broadband data service. Addis Ababa Enterprise customers as a case study to evaluate their satisfaction level for the service. The case study result is used for various purpose such as optimizing the existing system, further expansion, and in general, helps efficient resource allocation to improve customers satisfaction by taking action according to the analysis results recommendation.

The customer of fixed broadband data service users can have a classification with a profile named Enterprise key account customers and Small Office Home Office (SOHO) customers, they are Enterprise customers with certain criteria to differentiate them. There are around 42,000 Enterprise customers, among these, there are grouped as Key account enterprise customers. Our target mostly on the Key Accounts enterprise customers because of as high-profile customers in terms of revenue generation, can represent all the Enterprise customer who can reflect the image

of the company is included in this group. There are around 3,000 Key Account enterprise customers in Ethio Telecom. Most of the customers are registered as headquarter which can have a number of staffs and branch offices under their supervision. To incorporate the enterprise customers, we assessed the enterprise shops of Ethio Telecom in Addis Ababa. Ethio Telecom has six zonal office and eight enterprise shops, however, we focused on the main office of the shops which is located around black lion school church road where the enterprise customers are managed in this office and is almost in the center of the city which handles high traffic due to size of customers around this area. After selecting certain customers buildings for our case study, some buildings were identified which are near to the selected Enterprise shop (central Addis Ababa zone) for conducting the test, the reason of site and building selection is the density of enterprise customers and hence to get the real load of traffic. The next plan is to use an alternate tool for collecting quality indicator metrics. We have found Testmy.net and Ping-test.net tool, the reason to select this tools is that it can generate the necessary data format of minimum, average and maximum at once with better accuracy, the objective method (Fuzzy logic) require this format of inputs, the detail of the tools is demonstrated in chapter 4 page 27.

1.1.2 Quality metrics

The main parameters of measuring QoS of broadband Internet are

A) Download Speed is a data transmission speed that takes time for an amount of data to be transferred successfully from Internet to user which are both connected to the Internet.

B) Upload Speed is a data transmission speed that takes time for an amount of data to be transferred successfully from point A (user) to point B (Internet) which are both connected to the Internet. It is the speed of data transfer in the reverse direction of download speed.

C**)** Latency is the time interval between the instances that a packet of data is launched from an IP based machine located at Point A to the moment it is received by a machine located at Point B. Latency should be less than 350ms [5]. Latency is the most common metrics that affect user perception [6]. The more common way of measuring latency is called RTT, which calculates the time it takes for a data packet to travel from one point to another on the network and for a response to be sent back to the source. There are a number of factors that affect the speed and quality of your Internet connection such as transfer technology, your location, the number of people you share the connection with and the device you use are only some of these factors [6]. Network overload also can be a source of latency, when the network is overloaded processing delay increase and hence latency will increase due to queue, this usually happens

within about 5-10% of the total capacity of the given broadband link [7], [8]. A completely unloaded network will show latency close to the lowest physical time. You can never avoid the effects of network load but how well it is managed is critical for a quality connection and is the main differentiator between a lower-quality service and a higher quality service. If the frequently requested database is located relatively nearby to the user, the latency will be reduced. The following points can help to reduce latency:

1. Optimize the network devices and route path: This is a very widely accepted practice but requires a device in the source and destination to be effective [8].

2. There are proxying techniques it is the Storing of Internet or private data on a server closer to the end-user [8]. There is a cache server that is closer to the users than the origin server, hence the length of the path in terms of a number of hops the data travel be reduced and hence latency is reduced. Use of cache is the propagation delay and the total processing time of the routers is reduced, and thus the latency experienced at each user request is reduced, the total bandwidth consumed per each transmission, computed as the sum of the bandwidth used at each link is saved. As a consequence, we can transmit more data in the network with no need to increase the link capacity. This also reduces the probability of link congestion. The load on the origin servers is reduced [9]. Cache reduces the number of inter-cache protocol messages by a factor of 25 to 60, saving the bandwidth consumption by over 50%, eliminates 30% to 95% of the protocol CPU overhead [10].

The benefit of the cache server for the key players (user, ISP and CP).

For users used to consume more content and at a better quality, reduced latency and increased amount of content available can even make new services possible, leveraging fast access to remote information, they can move more and more data and processing from the client to the server, allowing thinner clients on local machines, able to run with less resources and at low power [9].

For local ISPs: can improve the quality of experience perceived by the subscribed users, since a part of traffic is directly served from caches inside the ISP network, the inter-domain traffic is reduced, which results in operational expenditure saving, more and higher quality content can be served without updating the capacity of links, which brings capital expenditure saving [9].

For the content providers (CPS**)** e.g. Google, Netflix etc. Being able to serve more content at a higher quality to users, CPs can attract more views and increase revenue consequently, CPS can

increase the amount of content served without updating the server infrastructure, which brings a capital expenditure saving [9].

3. Fusion Broadband Bonding: Helps with Latency reduction Fusion Broadband is the most cost-effective and simple way to increase your bandwidth. We merge broadband connections in spite of ISP into one single Internet connection [8].

Fusion Broadband Bonding is a way to build a very fast business broadband connection by aggregating multiple connections together. We can bond any number of connections and any type of connection as long as they are fundamentally stable in their speed profile; meaning that they can sustain a relatively consistent speed over a period of around 10 seconds. More importantly, we are able to bond together connections not only of different speeds and technologies but also from different ISPs. This gives the customer a true broadband connection built on multi-carrier, multi-technology redundancy.

Fusion Broadband offers three bonding platforms: Bonded Premium (bond as many lines as you like), Nano Bonder (bond up to two lines) and Mini Bonder (bond two or three lines)

Each Fusion Bonding system has a few additional features that you can select via the Fusion Bonding Admin Portal except with Nano Bonder, such as QoS used for service priority, Compression is used download and upload speed improvement and TCP Acceleration used a performance-enhancer [11]. Example of QoS as shown in Figure 1-3 which adds bandwidth to the more sensitive service of voice over Ip (VOIP).

Figure 1-3. bandwidth allocation for sensitive service [11].

As a summary, Slow Internet can be caused by low bandwidth, high latency, high traffic, the high distance between source and destination, by your device performance by types of application you use etc. There can also be slowdowns caused by over-loaded routers. Bandwidth is a measure of how much data can be sent and received at a time as shown in Figure 1-4. The higher the bandwidth a network has, the more data it can send back and forth. Bandwidth isn't

used to measure speed but rather an indicator of capacity. How fast information is transferred is measured by Internet speed, while bandwidth refers to the capacity of an individual Internet connection. So if your Internet connection has a bandwidth of 5 Mbps, your speed would only be that fast if it's operating at full capacity [6].

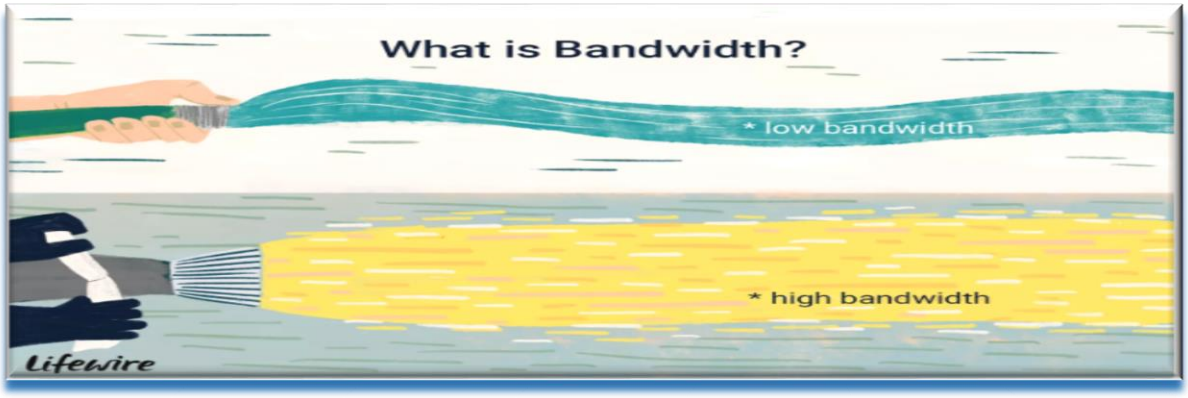


Figure 1-4. Bandwidth impact on data flow

High bandwidth can transfer more data as shown in Figure 1-4, but it doesn't give guarantee necessary high network performance because bandwidth performance is affected by a number of other quality metrics such as latency, packet loss, jitter etc. If throughput in the network is being affected by latency, packet loss, and jitter then your service will see delays or maybe annoying even if you have a substantial amount of bandwidth available [12].

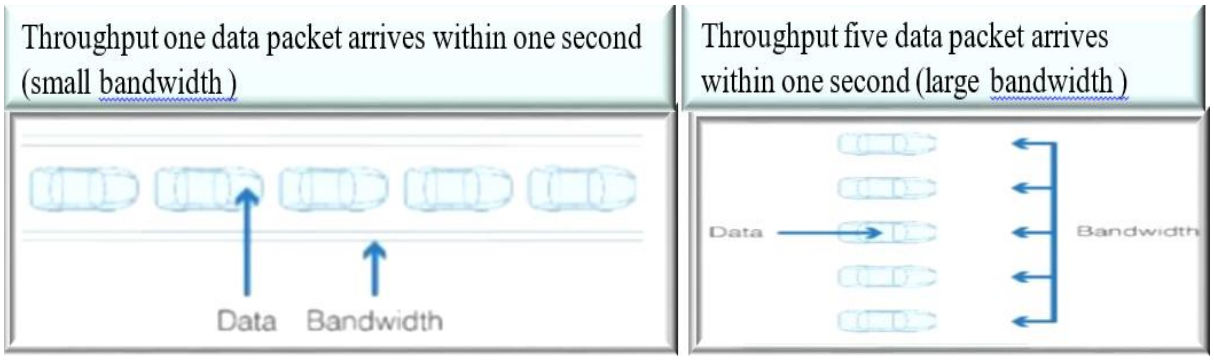


Figure 1-5. Throughput vs. bandwidth [13]

Bandwidth is the maximum amount of data that can go through a given medium and throughput is the amount of data that actually goes through that medium. If you're purchasing Internet service, take consideration you pay your ISP for bandwidth and get throughput. Throughput will always be less than your bandwidth. One of the most helpful ways to conceptualize bandwidth and throughput is highway analogy that is bandwidth is the width of the road if width increases the number of car pass through the road increase with faster speed as shown in Figure 1-5, the

car travel through the road is an analogy to data. Bandwidth is the number of lanes on a highway while throughput is the cars travelling on that highway. Adding lanes (bandwidth) could improve traffic speeds, but it would not solve all your speed problems. On a highway, collisions and slow-moving vehicles can slow things down. Similarly, on a network, collisions, latency, and overhead can cause delays that aren't necessarily solved by adding bandwidth.

Effect of latency on throughput: latency can have a big impact on throughput as shown in Figure 1-6. If we think back to our highway analogy, the amount of time it takes to travel across the highway is latency. TCP relies heavily on acknowledgements, which means a receiver must acknowledge a sender for the transmissions to proceed. If it takes a long time for the packets to get back to the sender, there will be a lot of wasted time and lower throughput. With current technology, latency, and packet overhead are you won't get speeds that Mach the bandwidth you purchase from your ISP.

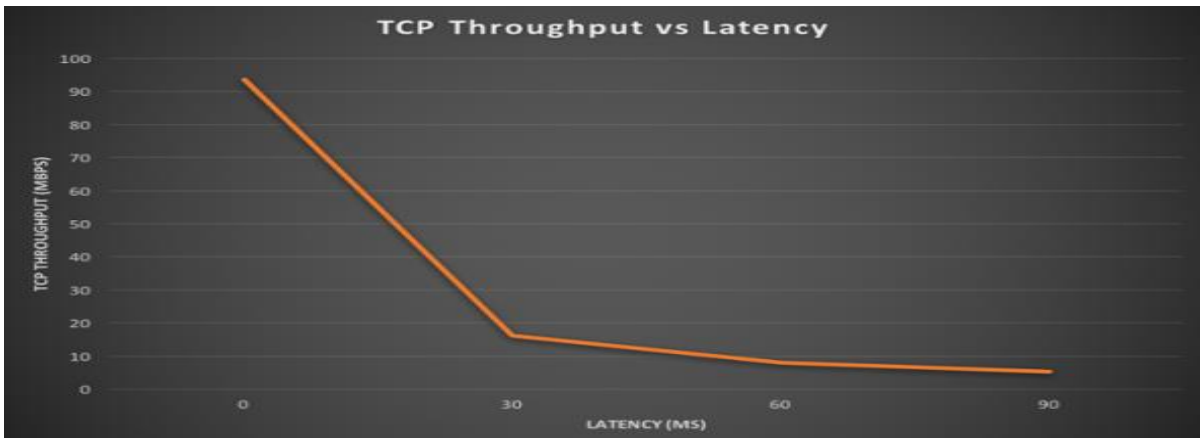


Figure 1-6. Latency and throughput relationship [14]

Download speed: Some online activities require you to download data from a server in the form of image, videos, text and more, all require you to download data. You need fast download speeds, which is how many megabits of data per second that you can download from the Internet.

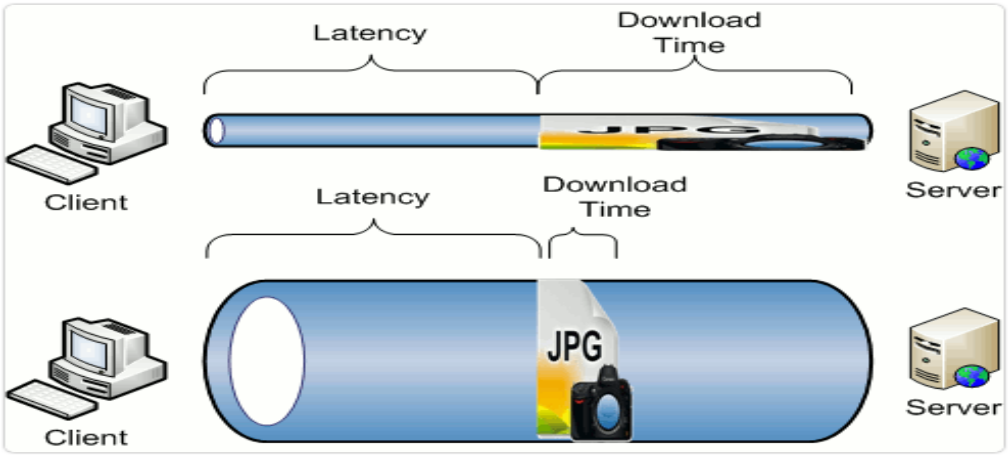


Figure 1-7. Latency vs. bandwidth [15]

In Figure 1-7 one is low bandwidth and the other one high bandwidth. When sending a JPEG across both connections the latency for the first byte of data to travel from the source to the destination is the same. The low bandwidth connection downloads the file slower than the high bandwidth connection because fewer data can travel in a queue than parallel transmission. But in both cases, latency is still there [15].

Upload speed: Some online activities need data to travel in the opposite direction. Activities such as sending emails, playing live tournament-style games and video calling a friend require you to send data to someone else's server. To send the data quickly, you need fast upload speeds which is how many megabits of data per second that you can upload information to the internet.

Many providers offer Internet plans with far faster download Internet speeds than upload speeds as shown in Table 1-2 with the assumption of download traffic is larger than the upload traffic. For example, AT&T US telecom operator download and upload Internet speeds can have as much as an 80 Mbps margin difference between top download and upload rates. Provider Internet download and an upload speed ratio of US operator [16].

Table 1-2. Sample ISP download and upload speed ratio [17].

The provider (operators)	Download speed/upload speed ratio in Mbps
AT&T	25/5,75/10,100/20
Spectrum	100/10,400/20,940/35
XFINITY	15/2,150/5,250/10

Most providers give customers' slow upload speeds because the majority of online activities need more download speed than upload speed as shown in Table 1-2 because of traffic volume and content property. Some common online activities that need fast download speed than upload speed are:

- Watching a Netflix movie or show
- Shopping online
- Scrolling through social media
- Showing video with you Tube
- Reading on line articles
- Streaming music services

Quality metrics affect different application with a different degree as shown in Table 1-3.

Table 1-3. Quality parameters and degree of impact on different service [18].

Application	Quality metrics of Data transmission speed and latency		
	Download	Upload	Latency
Browse(text)	More Relevant (++)	Less relevant(-)	More Relevant (++)
Browse (media)	Very relevant (+++)	Less relevant (-)	More Relevant (++)
Download file	Very relevant (+++)	Less relevant (-)	Relevant (+)
Streaming media	very relevant (+++)	less relevant (-)	Relevant (+)
VOIP	Relevant (+)	Relevant (+)	Very relevant (+++)
Gaming	Relevant (+)	Relevant (+)	Very relevant (+++)
Transaction	Less relevant (-)	Less Relevant (-)	More relevant (++)

The broadband connection should provide to home or business at list connection capable of delivering a download speed of 10Mbit/s and an upload speed of 1Mbit/s. This is the specification for the Government's proposed broadband Universal Service Obligation (USO) [19] in the UK.

The inclusion of a minimum upload speed reflects the growing importance to people and businesses of services such as videoconferencing and video sharing, which need good upload, as well as download, speeds. Figure 1-8 shows the increasing trends of average download and upload speed of different year in the UK [20].

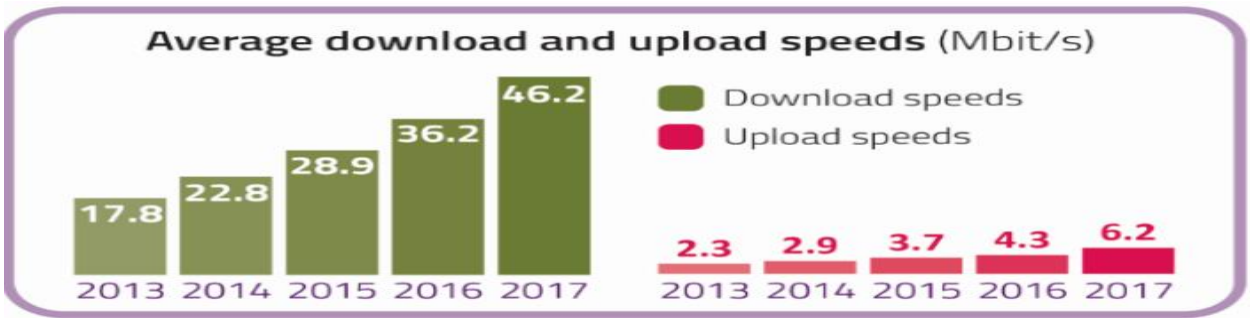


Figure 1-8. Average download and upload speed change trend in the UK [20]

Upload speeds are important to users who use real-time video communication services, or who need to upload or share files. The UK average upload speed increased by 21% in the year to November 2017.

1.1.3 Fuzzy logic

Intelligent machine learning algorithms automatically learn from past observations in order to make more accurate predictions in the future. They have been the prime focus of researchers developing objective QOE evaluation and prediction models [21]. One of the most popular machines learning algorithms is a fuzzy logic inference system (FIS). According to [22], the FIS outperforms other estimation techniques in terms of modelling capabilities and making decisions with imprecise information. In this thesis, the proposed model used to evaluate fixed broadband data service QoE. Evaluation framework used FIS to analyze and map the correlation between QoS parameters and measured QoE. The learning process involves feeding data as a linguistic value of the data range in terms of minimum, average and maximum from the measured QoS dataset. Once the system calculated the degree of membership vale by using membership function, it can generate QoE, based on any combination of input QoS parameters. The proposed work provides two novel and efficient reference-free models for the prediction of quality of experience in terms of different quality metrics.

Fuzzy means has no clear demarcation, the value of the fuzzy system donated by a range of value, its membership to a certain system determined by the degree of membership rather than exact matching. Fuzzy inference is the actual process of reflecting from a given input to an output using fuzzy logic as shown in Figure 1-9. Fuzzy inference systems have been effectively implemented in fields such as automatic control, decision analysis, data classification, expert systems, and computer vision. Because of its multidisciplinary behaviour, it has many names such as fuzzy rule-based system, fuzzy expert system, fuzzy model, fuzzy associative memory, fuzzy logic control or simply fuzzy system. The fuzzy system has the following structure.

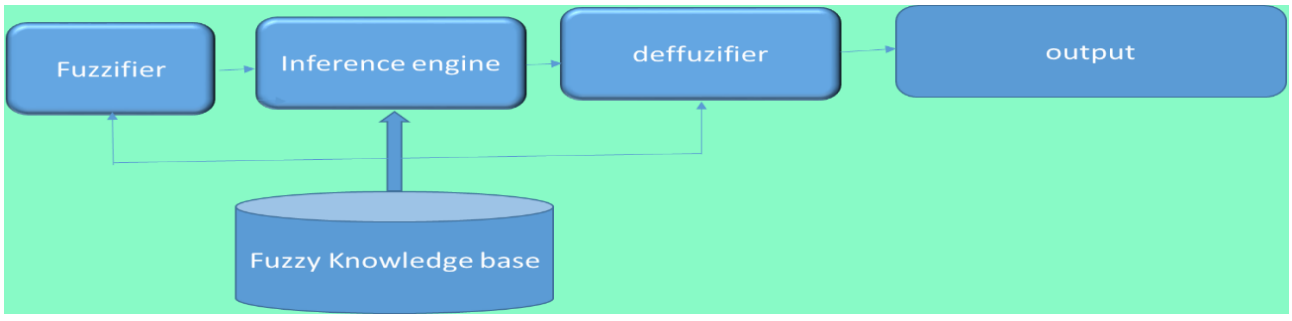


Figure 1-9. Fuzzy logic model [23]

Input can be a crisp value but, the crisp value can be fuzzified, that is a change to a range of value of linguistic terms such as minimum, average and maximum, this process is called fuzzification. Inference engine used to determine the degree of membership of the input value all the fuzzified variable e.g. minimum has a minimum contribution and the average has a maximum contribution to the underlined output. The average value of a certain data can represent lass or more the system rather than the minimum or maximum because it's value may occur a limited time or maybe once during the test period, so not representative but must be calculated its own contribution to the output of a certain system. Implication used to analyze the correlation of the range of input whether the relation is negatively or positively correlated with the output based on a certain rule. Aggregation used to aggregate the fuzzified input degree of membership value. Defuzzification is the reverse process of fuzzification that is converting a range of value of linguistic terms and map to the output of crisp value. The fuzzy knowledge base is creating a certain rule based on experience, logic and benchmark data. The knowledgebase is a combination of knowledge and database. A rule base containing a number of fuzzy IF-THEN rules [24],[25].

1. 2 Motivation and goal

QoE is not analyzed as research of fixed wire-line broadband data service in the case of Ethio-telecom for the purpose of customer satisfaction improvement. Enterprise customers' complain about the service, however; the root cause of the problem is not identified and now well accepted by many researchers' objective and subjective combined analysis of the user QoE evaluation are a far better representation and an indication of network performance as well as experienced by the end-user than the raw quality of service. The combined results could lead to a specific problem [23] are some of my motivation. The customer satisfaction level can improve if action is taken based on the result of the research.

The goal of this thesis research is to study QoE by using the objective and subjective methods for QoE evaluation of the fixed wire-line broadband data service. The methods involved identifying the right toolset to be able to effectively conduct the research, identifying fuzzy logic to convert the QoS metrics as an input and produce an output of QoE, conduct appropriate questionnaire assessment. The aim was to evaluate QoE in depth by considering common network scenarios. This would involve users' opinion based on the service quality they experience as a result of a network problem. Meaningful results collected from this realistic user-involved research used to highlight the factors that affect network performance, which helps to

network service providers to solve the problem that could provide a better service to their customers.

1.3. Statement of the problem

The research used to evaluate customer satisfaction level towards fixed wire-line Broadband data Services for Enterprise customers. It is because nowadays the customers increasingly changed by time. Ethio Telecom had begun to launch broadband services before, but the speed of broadband diffusion is gradually growing, as a result broadband services have been receiving many negative feedbacks in terms of download speed, upload speed and latency of response time from the users. Therefore evaluate QoE in terms of the subjective and objective methods are necessary, hence, in this thesis, it is very crucial to identify the customer's satisfaction level and feedback on the usage of broadband data services to point out the reasons of the complaint, which helps for network optimizations, upgrade or generally allocate the resource effectively according to the key finding to improve the service.

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

1. What do Enterprise users perceive (satisfaction level) about fixed wire-line broadband data service in the case of Addis Ababa?
2. What is the main problem of the perceived level of QoE?
3. What is the recommended solution to minimize the problem or improve QoE?

1.4 Objective

1.4.1 General objective

The thesis evaluates the quality of experience with a combination of subjective (MOS) and objective with quality of service metrics using Fuzzy logic of fixed wire-line broadband data service to identify Enterprise customers' perception level, point out the main problem for the recorded results and suggest the solution of the problem.

1.4.2 Specific objective

- Collect relevant data of the Enterprise customers
- Assess relevant metrics for the objective quality measure
- Find out appropriate tools for an objective method
- Collect data from the live system of the end-user device.
- Prepare questionnaire for the selected group of users

- Make analysis the collected data of QoS metrics and MOS from user response
- Generate quality of experience from QoS metrics by using Fuzzy logic system.
- Recapitulate the satisfaction level of the Enterprise customers
- Point out the problem from the evaluated point of view
- Propose a solution to the problem.

1.5 Methodology

This research concerns, QoE evaluation for fixed wire-line broadband Enterprise data service subscribers. Four methods are identified for collecting the required data after identifying and selecting quality metrics for both objective and subjective measure.

For the case of objective measurements, data is collected from NMS (to get Enterprise customer-related data), Testmy.net (to get upload and download speed), and Ping-test.net is used to get latency. Quality metrics are download speed, upload speed and latency for each of the selected Enterprise customers measured a weekly base from the customer's network end device. ping-test.net tool is a commonly used for international as well as local latency, the concern is International latency because of the user highly affected by International latency, the detail of the tools is covered in chapter 4, the other tools for data collecting is Google form for questioner purpose which is also very common data collecting mechanism to collect user opinion or feeling. The test was done in central Addis Ababa zone around Leghar, which is one of the locations with a high number of Enterprise Customers office located. 25 buildings are part of the test, the reason for selection are high traffic demand, high distribution of customers in this area. The measurement is performed with the help of building IT representative and another concerned person of the broadband data service customers.

These four ways of data collection have helped us to evaluate and assess the overall satisfaction of the fixed wire-line broadband data users. Additional tools like MATLAB, Microsoft Excel, Mendeley and Grammarly have been used as part of this thesis work. A summary of the methodology used as shown in Figure 1-10

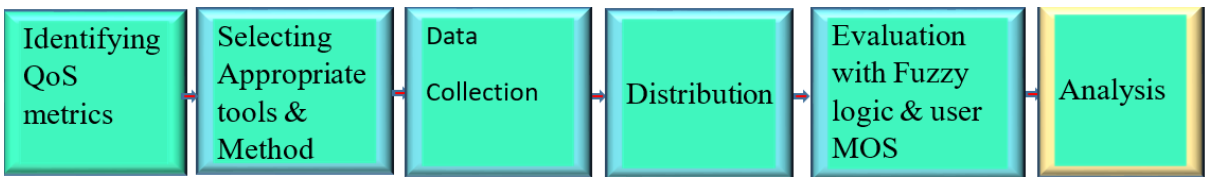


Figure 1-10. Methodology

1.6 Related Work

The estimation of the QoE provides valuable input in order to measure the user satisfaction of a particular service [26]. All the Network analysis models can be divided into two major groups qualitative and quantitative. Many quantitative models have been developed in terms of numbers from 1 to 5 to represent user perception MOS (subjective method). Parameters of the integrity of service; throughput, delay, packet loss and jitter as parameters of network QoS as an inputs (Objective method). A literature survey is done on qualitative performance by use of a variety of variables, input and output linguistic terms. The paper [26] proposes a fuzzy logic model for the analysis of computer network QoE. Moreover, by using the fuzzy logic concept, the output linguistic terms show the user perception about a product or a service (QoE) by use of membership functions, in this case, triangular membership function which shows the mapping of each linguistic term to a certain range of values rather being precise to a particular value. The concern is to advance the analysis and evaluation of the quality of experience in computer networks by the use of fuzzy logic [26].

The use of ICT [27] to bridge the gap that exists in the area of customer service satisfaction between an internet service provider (ISP) and the subscribing customer in the process of providing internet services cannot be overemphasized. Fuzzy logic has emerged as a tool to deal with qualitative decision-making problems in order to achieve robustness, tractability, and low cost. This paper proposes a fuzzy logic model for the evaluation of the quality of service (QoS) in multimedia transmission. In order to achieve our objectives, we develop a prototype of a computer-aided system for an intelligent quality of service using a fuzzy logic model. The study designs a decision support system for the quality of service intelligence system. We design a fuzzy logic evaluator for the quality of service computing system using MATLAB toolbox [27].

QoS involves tracking of jitter, latency and other measurable parameters [28]. It is a series of objective measurements of performance. If the QoS score isn't good enough, operators can search for the problem and fix it. QoE is a far more subjective measure of how the viewer is judging the audio and video that is being viewed. It is less straight-forward. The closest comparison is the mean opinion score (MOS). The challenge of calculating (evaluating) QoE is made even greater by the increasing complexity of the cable environment. What the Federal Communications Commission and perhaps the courts finally determine on Net Neutrality may influence QoE in two ways: The rules will control how spectrum is divided up between tenants of the network and how deeply operators are allowed to examine the packets flowing through

those networks. A third issue that makes QOE a difficult challenge is the limitation of CMTS technology that is in place [28].

The impact of network performance on user experience is important [29], as it determines the success or failure of a service. Monitoring of network-level performance criteria is easier and more usual. But the problem is then to correlate this network-level Quality of Service (QoS) to the Quality of Experience (QoE) perceived by the users. Efforts have been done in the previous years to map user behaviour to traffic characteristics on the network to QoS. The work, try to associate on one side the correlations between various traffic characteristics measured on an operational network and on the other side the user experience tested on an experimental platform. Our aim is to observe some pronounced trends regarding relationships between both types of results. More precisely, we want to validate how and to what extent the volumes of user sessions represent the level of user satisfaction. Along this way, we need to revise classical relationships between some of the network performance indicators such as loss, download time and throughput in order to strengthen the understanding of this impact on each other and on user [29].

The paper [30] presents a comparison between Mamdani and Sugeno Fuzzy inference system models for evaluating the QoE of a multimodal virtual environment. The models were built and simulated in MATLAB and hypothetical results were generated using an identical environment for both models. The results show that there are advantages and disadvantages to using either model. Mamdani fuzzy inference system displays consistency in the results and expressive power. Both models, show high correlation value and thus reflect fairly reliable results and can be utilized to come up with a crisp QoE value [30].

MOS is a wide-spread and popular measure of media quality [31]. Large numbers of subjective MOS data and objective quality metrics have been made available. Choices made in the design of subjective experiments on media quality have an important influence on MOS values and need to be taken into consideration when analyzing and using MOS data. Objective media quality metrics rely on data from those subjective experiments for tuning and validation and therefore affected by the same choices and factors. The paper presented a number of important methods and practical applications of MOS. Alternative subjective and objective quality indicators that are able to address some of the shortcomings of MOS can put a more versatile set of quality measurement tools at the users' end [31].

1.7 Scope and limitation

The study investigates the quality of experience evaluation for fixed wire-line broadband data service for ethio telecom enterprise customers in the case of Addis Ababa with the subjective and objective method. Limitation analysis is not considered in terms of technology rather overall perception since most of the Enterprise customers are fiber user and time limitation to analyze each technology type of ADSL, Cable and Fiber connection type separately.

1.8 Thesis contribution

Evaluation for Addis Ababa fixed broadband data service subscribers by focusing on two ways of evaluation methods which are functions of QoE. These methods are accessed side evaluation which is the data obtained from NMS, Testmy.net and pingtest.net dataset. In addition to this, user side perception using a survey questionnaire is considered.

This study focuses on QoE which is currently an emerging discipline. This helps the ISP owner (operators) to deal with the services provided to their customers and consider the perception of their customers as input for optimizing, redesigning, allocating the resource to upgrade the performance of their networks. In general, the author believes the following points are the main contributions to ISP owners, particularly to Ethio telecom.

- Addressing quality handling process.
- Understanding QoE and deal with user perception.
- System model for evaluating QoE.
- Usage of crowdsourcing test tools for measuring QoE.
- Inclusion of user perception as input for service improvements and maintain customers satisfaction

1.9 Significance of the research

- The result of this study is expected to provide the benefit for resource allocation, network optimization and hence improve Broadband Services
- This study aimed to determine the relative importance of Broadband Services because it has social and economic benefits
- Broadband Services quality and the stability of Broadband Services from the perspective of business customers group in Addis Ababa

- Provide suggestions and recommendations from the respondent, in order to understand the way to improve and develop Broadband Services
- it is essential for a better understanding of what user really need to make them satisfy on service offering by Broadband Services

  From the network point of view
- used for network optimization
- used for network redesign
- used for network upgrade

1.10 Thesis organization

The next parts of the thesis are organized as follows

Chapter two presents broadband network and data service. Chapter 3 Quality of Experience (QoE) in fixed broadband Network data service. In chapter four Tools and Data collection mechanism that are applied in this thesis are discussed. Chapter Five data analysis, results and interpretation of subjective and objective method quality of experience evaluation. Finally, chapter six presents conclusion, future work and recommendation are presented.

Chapter 2 Broadband network and data service

Broadband network transmission capacity is faster than primary rate Integrated Services Digital Network (ISDN) at 1.5 or 2.0 Megabits per second (Mbps) [32] for statistical purposes: Minimum download speed of 256 Kb/s. Importance of breakdown by technology gives additional information on infrastructure, that are XDSL, Cable modem and Fiber

2.1 Background

Broadband communication networks are regarded as aggregated networks (providing voice, video and data) over the wired network including Ethernet and fiber. The multiservice support of these networks not only opened a new era in telecommunications but rather also has challenged the network operator's abilities and capacities [33]. The evolution of broadband communication networks can be seen as a competition between two technological domains, namely WLAN and cellular [33]. The international standardization organizations have been working hard to progress each of these technological domains that are taking over the broadband communication era. However, fixed wireline network provided relatively better speed service than another medium of communication, since Latency in broadband network is better than the mobile n etwork as shown in Figure 2-1. Mobile data services provide consumers with the convenience of having data transfer but often lack the high speeds and low latency than fixed networks. Many users are aware of this limitation, particularly in the use of applications that require high bandwidth or low latency, including file downloads (or uploads), online video games, and video streaming [34].

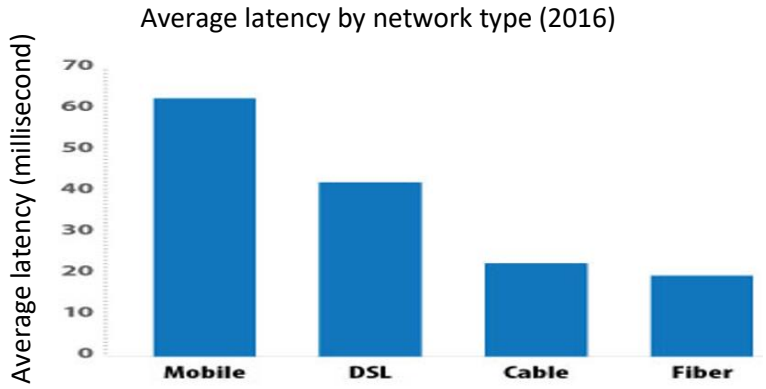


Figure 2-1. Latency with different technology [31]

2.2 Architecture of ethio telecom Broadband Service

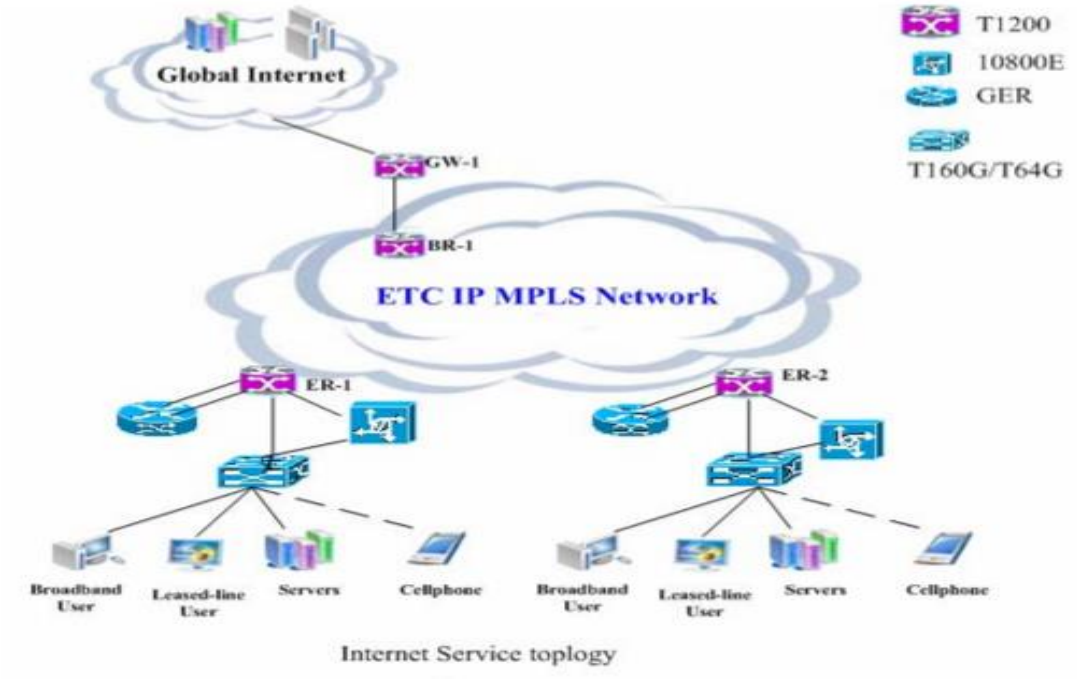


Figure 2-2. Architecture of broadband service of ethiotelecom (NGNP)

Figure 2-2 shows the architecture of ethio telecom broadband data service that describes inter-domain link (Global Internet) that connected to Getaway and connected to two edge router (ER).

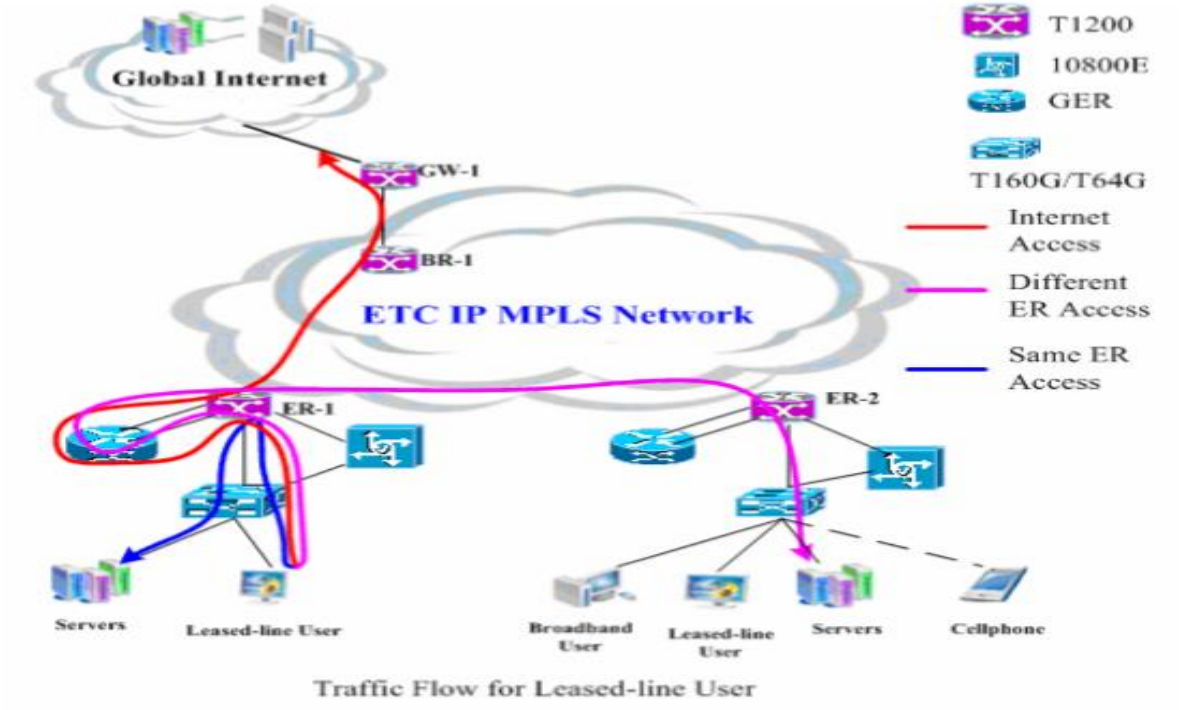


Figure 2-3. Broadband service traffic flow route (NGNP)

Figure 2-3 shows the traffic flow of broadband data service from the end-user to the global Internet with internal hardware components.

2.3 Broadband QoS Classes

Table 2-1 shows the quality of service measurements for fixed broadband internet network from the regulatory point of view ITU-[32]

Table 2-1. Broadband quality classes

Service/Application	**Network Performance Parameters**		
	IP TD	IPDV	IPLR
Voice over IP (VoIP) Video Teleconference (VTC) Note 1**:** PSTN Voice quality	≤100 ms	≤50 ms	≤10–3
oice over IP (VoIP) eleconference (VTC) atellite Voice quality	≤400 ms	≤50 ms	≤ 10–3
Transaction data Note 3**:** Highly Interactive data (Signalling)	≤100 ms	U	≤10–3
Transaction data Note 4**:** Interactive data (Business data)	≤400 ms	U	≤10–3
Video streaming	≤1 s	U	≤10–3
Traditional applications of Default IP networks	U	U	U

Chapter Summary: the chapter demonstrates broadband technology, latency difference from one network type with other, ethiotelecom broadband service architecture and data flow route with reference of ethiotelecom new generation network project (NGNP) network diagram and finally broadband quality of service class based on network latency which shows different service have different latency tolerance value in (ms).

Chapter 3 Quality of Experience (QoE) in fixed broadband Network

In this Internet revolution era, technology became an essential part of our daily life. Most of us possess a technological device that helps to access different Internet services like voice, video, emails. Service provider fulfils customers' demands and QoE requirements. In return, the customer's expense for the service they get, QoE is an emerging technology and becomes increasingly a research area[35], and it refers to the overall acceptability of an application or service, as perceived subjectively by the end-user. QoE as the degree of feeling of the user of an application or service (ITU). It comes from the fulfilment of his or her expectations with respect to the utility situation of the application or service in the light of the user's personality and current state. And hence, QoE is a subjective measure and vary according to user expectation and context. It requires tests with actual users in a controlled environment to properly estimate the QoE; which requires high cost and is time-consuming. In the Internet, services and applications have become an important source of income for the network operators. For this, they should fulfil the user's QoE requirements. To fulfil these requirements they require an efficient QoE monitoring and estimation tool. Therefore, there is a need for tools that can objectively measure the QoE with reasonable accuracy.

3.1 Quality of experience from quality of service metrics (objective method)

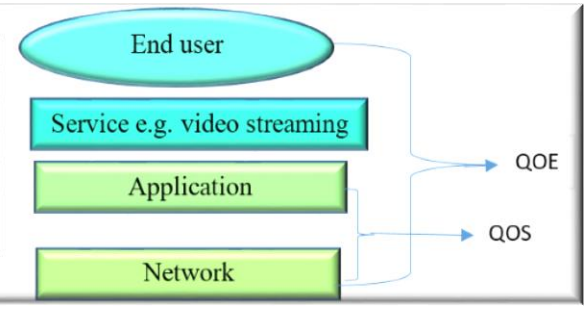
Other approaches for measuring user satisfaction rely on objective QOS parameters collected from the network. In this case, the QoS parameters are monitored and controlled in order to provide a satisfactory level of service quality. Different QoS parameters like download speed, upload speed, latency, packet loss, jitter etc. are essential metrics for determining the service quality from a technical point of view [18]. However, QoS parameters do not necessarily reflect the users' satisfaction and feelings towards a particular service. In this thesis work, to overcome these shortcomings, The methods were used different hybrid approaches that combine both subjective and objective metrics to objectively predict QOE [18].

QoE monitoring or supervision and estimation is a multi-disciplinary approach which involves user psychology, engineering science, economics, etc. The QoE depends on different elements (i.e., content, network, application, business model, etc.) that directly or indirectly affect the user's perception towards the service.

3.2 Comparison of quality of service and quality of experience

Table 3-1 QOS vs. QOE [24].

QOS	QOE
Technology centric	User centric
Network level	End user level
Application level	Overall performance
Controlled by provider	Exercised by end user
Affected by network performance only	Affected by end user performance also.



QoE is a subjective metric as it reflects the perception of the users to a particular service as shown in Table 3-1. User attitude and expectation towards broadband services play a vital role in determining the QoE. Moreover, the QoE can depend on different user profiles like age, gender, interest, skills, the frame of mind, Experience, etc.

Figure 3-1. QOE ecosystem [23]

Also, different environmental conditions can impact how users perceive the service content as shown in Figure 3-1. Fixed broadband QOE can vary according to when, where, and with whom the service is used. QOE ecosystem incorporates all the possible components that directly or indirectly affect user's perception towards the broadband service. The diversity of these components makes the QoE estimation complex. Maintaining the Enterprise customer quality of experience has many advantages economically for the operator as well for the country and also for the creation of employment opportunity.

The impact of network QOS on QoE reflects on the ability to identify the perceived degree of impairment due to network malfunction is a key point in the QoE estimation. Moreover, the effect of network malfunctions on traffic can range from distortion-less to intolerable

distortion. Also, the selection of network-related key performance indicators (KPIs) or QoS parameters that can impact QOE is difficult because of the quality of experience affected by many factors such as latency, download speed, upload speed, jitter, packet loss etc.

3.3 Description of Quality of Service Metrics

The main parameters of QoS of broadband Internet on the basis of ITU-2015 [36] are:

a) Data download speed: data transmission speed defined as the time taken for an amount of data to be transferred successfully from source to user which are both connected to the internet.

b) Data upload speed: data transmission speed defined as the time taken for an amount of data to be transferred successfully from user to destination or to the Internet.

c) Latency is the time interval between the instances that a packet of data is launched from an IP based machine located at Point A to the moment it received by a machine located at Point B, which should be less than 350ms in case of International ping [5].

3.4 QOE measurement techniques

Quality of experience technique can be classified objective and subjective type, the objective type is quality of service with the network perspective to analyze QoS based on network parameters, on the other hand, quality of experience used to measure user perception by means of the subjective method. In this paper QoE determined by objective using network metrics as input and evaluate the quality of experience by means of Fuzzy logic, as well as a subjective method using questionnaires, the subjective method has metrics to measure the perception of the user. The user feeling expressed in terms of the Likert scale as ITU [25] . This is conducted based on the responses of the participant's survey. Likert scale defined in [37] as "5" scale response from one extreme to other that means from "Excellent" to "bad" as shown in Table 3-2 by providing a range of answer option which gives the possibility of expressing user feeling. The collected opinion is converted to Mean opinion score (MOS) [25].

Table 3-2 Standard mean opinion score value with perception [25]

Score	Quality	Impairment
5	Excellent	Imperceptible
4	Good	perceptible, but not annoying
3	Fair	slightly annoying
2	Poor	Annoying
1	Bad	very annoying

3.5 Quality of Experience Measurement in Addis Ababa Fixed Broadband Service

Before collecting data for analysis purposes, the investigation has been done on the quality handling process in Ethio telecom, which is the sole telecom service provider in Ethiopia. Ethio telecom has its own organizational structure for its day-to-day operations though our focus is on quality handling process. There are divisions, departments, sections and groups in the company for its business activities. From all the divisions, they are Responsible for quality handling and customer complaints related to fixed broadband data service. The evaluation has started by assessing whether Ethio telecom has a unique process for handling broadband data service complaints or not Investigated Customer Service and Network division which have the following format in Table 3-3

Table 3-3 ethio telecom quality monitoring process

Dep.	Section	Activity	CSM Weekly KPIs Detail		Remarks
BO	CSM	Key Account Customers Visit	Planned Visit	9	
			Actual Visit	4	
		TT Follow Up	Total Number of TTs Handled	102	
			Total Solved TTs	56	
			TTs Solved With Escalation	5	
			TTs Solved In Coordination With Handlers	51	
			On Progress TTs	46	

PAESSLER PRTG Network Monitor

GW Report: **(041) AFNET-STM1-DJI-ETHIO-CMC001 (ETHIOTELECOM-CMC-NNI-Connection)**

Report Time Span:	18.04.2019 00:00:00 - 25.04.2019 00:00:00					
Report Hours:	24 / 7					
Sensor Type:	SNMP Traffic (30 s Interval)					
Probe, Group, Device:	Local Probe > INTERNET GATEWAY > 2/26/2019 (ETC-Bole-MPLS-ASBR) [Cisco IOS Cisco Switch]10.0.2.209					
Uptime Stats:	Up:	100 %	[6d23h36m5s]	Down:	0 %	[0s]
Request Stats:	Good:	100 %	[20106]	Failed:	0 %	[0]
Average (Sum):	8 mbit/s					
Total (Sum):	545,056 MByte					

For example, if a customer complains about low speed when accessing fixed broadband data service, how is the Complaint handled? There is a process for handling such complaints. The same response is given from Network division in specific departments of Engineering and SMC (service management center). In general Quality of experience is not practice in broadband service unless controlling the quality of service in the getaway level of controlling total traffic in and traffic out by using PRTG (Paessler Router Traffic Grapher) tool and observe it with a certain benchmark traffic flow without differentiation of the service like 3G, 4G and broadband data service traffic but in the section level of Enterprise customer's quality of service controlled by

selecting a certain KPI parameter's like number of faults occurs within a week, time taken to clear the fault, is the fault need to escalate to other section, types of fault, number of TT, Is the TT cleared or post ponded, there is a template to report such kind of controlling mechanism? Reports are prepared weekly to immediate supervisor. As shown in Table 3-3 formats.

3.6 Problem handling process of ethio telecom Enterprise customer of Fixed Broadband data service

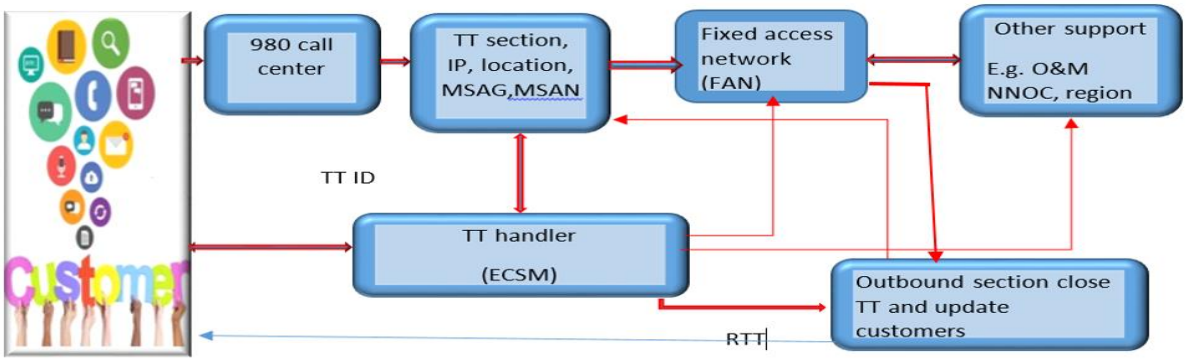


Figure 3-2. Problem handling process of ethiotelecom fixed wire-line BB service

980 call center register the problem with necessary information from the user.TT section creates travel ticket with necessary information about the problem and network-related information and if possible solve the problem and close the ticket, otherwise forward to FAN.

FAN section solves the problem by own or with the collaboration of other section such as NNOC, O&M and another concerned body, and the final output sends to outbound section. Outbound section confirms the user if the problem solved properly or not and close the TT otherwise if the user isn't satisfied send to TT section to reassign the TT to the concerned section again to keep the quality.TT handler (ECSM)-communicate all the participants concerning the fault including the user and negotiate to speed up the process of fault clearing and monitor the required quality with communicating the user if not back the TT to outbound section reassign the TT until the required quality achieved as shown in Figure 3-2.

Chapter Summary: the chapter demonstrates the quality of experience from quality of service metrics. Comparison of quality of service with quality of experience, quality of experience ecosystem which shows the quality of experience affected by many factors, explain about quality metrics of network and user mean opinion score value with its degree of impact towards user filling and process of ethiotelecom quality of experience monitoring system with handling user complain.

Chapter 4 Tools and Data collection mechanism

The main objective of the thesis work is to evaluate the overall quality of experience for fixed broadband enterprise data customers in Addis Ababa. In order to understand the perception of the customers, it is important first to see what really the customers get from the service provider by identifying certain objective quality metrics. In addition to objective quality metrics, a set of subjective quality metrics have been prepared and distributed to enterprise customers to assess their perceptions regarding the fixed broadband data service they get from Ethio telecom. The data collection includes four ways as shown in Figure 4-1 of data gathering for further analysis and evaluation.

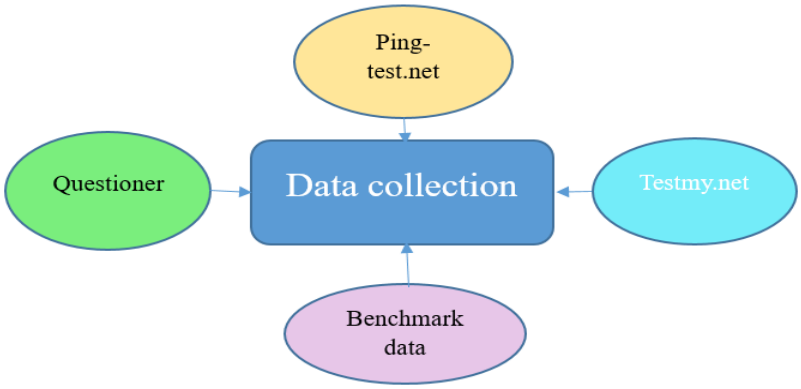


Figure 4-1. Data collection system

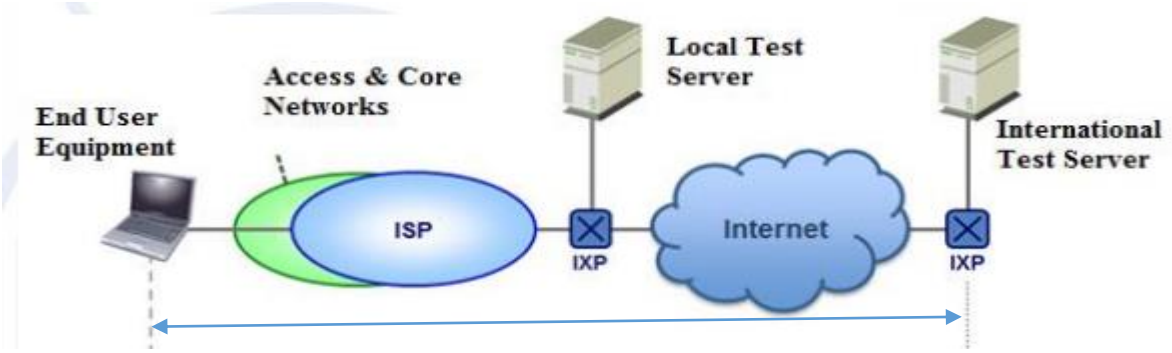


Figure 4-2. Tools setup system [38]

Figure 4-2 shows a setup of measurement of Internet quality metrics of latency, download and upload speed at the national level test server.

4.1 Objective Data Collecting Tools

4.1.1 TestMy.net

It is an Internet speed test website that's been offering free. The website is easy to use, works in all web browsers without the need for plugins and offers stats about your bandwidth that you may not find in other speed tests. The results of TestMy.net tool are displayed in a clear and understandable formate [39].

Test Internet Speed with TestMy.net have the following advantage

- It used both desktop and mobile web browsers.
- It can collects the results of individual's speed tests at their database page
- It can run an upload or download test separately or combine the two.
- The Servers are located in different area, it is possible to test all at the same time with Multithread Speed Test.
- The size of the file used to test the download and upload bandwidth is customizable
- Results can exported to a CSV file.

TestMy.net providers aren't related with any particular service provider. All the statistics provided by TestMy.net are 100% human-readable.TestMy.Net is one of the experienced and reliable websites to test internet speed. To measure speed Testmy.net use HTML5 while other sites are using Java and flash to check internet speed. No need any third-party plugin since the website provides direct browser checking, so TestMy.Net avoids the buffering time between the browser and the third-party plugin. This would provide with accurate results. It provides real-time browsing conditions through graphical representation.TestMy.Net has 88 servers available that would be selected to provide the best results. It uses one of its most trusted servers instead of detecting IP location to offer nearest server. It uses an advanced algorithm to measure the performance of the Internet service. It uses a simple design with a user-friendly interface. Multithread testing can achieve by TestMy.Net to check speed and also TestMy.Net has the option of the single test as well which means if you want to test uploading speed or download speed separately mode [36].

4.1.2 Ping Test.net

Ping Test.net is an easy tool which can measures Internet connection latency. The latency result is similar to the ping command result. In the practice, it shows the round trip time a packet needs to pass the route from your computer to the server. Regardless of, ping-test.net tool is better than standard ping command since ping-test.net measures the latency for small and large packets. In this case, the latency for small packets will be less than for the higher ones. This change is not shown by Regular ping command [40].

The result of the ping test largely affected by the number of terminals on the path between your computer and the server. These terminal are called routers and they are responsible for packet transmitting from the source IP address to the target IP address. Every packet has to be managed by the router and this operation takes some time. Also, the introduced physical link between two routers can create to the ping delay. So, the large latency is available in case of intercontinental connections where very long fiber links are used. Large ping values may be also seen in case of overloaded routers, links or servers.

4.2 subjective quality metrics

The subjective data collected from fixed wire-line service end-user of the Enterprise Customer. The collected data used for subjective analysis to get customer satisfaction level. The question is formulated 21 questions. Among the question selected the appropriate quality metrics for analysis purpose and grouped into three groups:

1. Quality-related metrics

   Q01 About overall quality

   Q02 About download speed

   Q03 About upload speed

   Q04 about browsing delay

2. Spatiotemporal metrics

   Q07 best time network performance

   Q08 worst time network performance

3 Other Metrics

   Q09 access preference (Wi-Fi or fixed BB

   Q10 Reason of preference

   Q11 contact center response

   Q12 Fault clearing

   Q13 Maintenance quality

   Q14 need more upload or download speed

   Q17 Shift to other operator if exist

The detail of the subjective metrics is found in appendix B.

Chapter 5 Data Analysis, Result and discussion

5.1 Objective of data analysis

The following data signal is collected by Testmy.net and ping-test.net tools which concern the objective quality metrics of download, upload speed and latency regarding minimum, average, and maximum signal that is measured by tools. It is used to input for fuzzy logic (objective method) and to visualize the network stability status. The graph shows the y-axis represents either speed or latency, and the x-axis represents the test data size or time of the test taken.

5.1.1 Fixed Wire Line Broadband Service Down Speed in terms of signal and digit

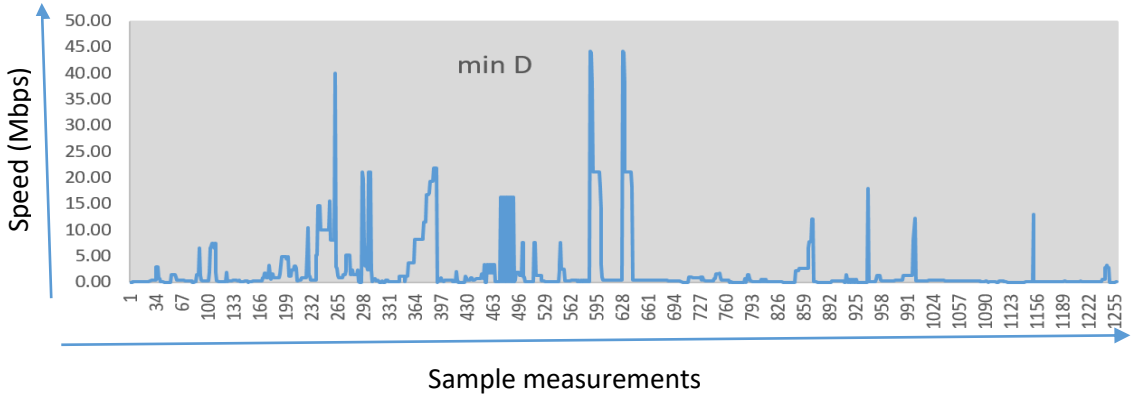


Figure 5-1. Minimum download speed signal

Figure 5-1 shows the minimum download speed collected with different time from the user end device, when we compare with the average value as shown Figure 5-2 the minimum speed variation is better, some of the peak value is idle time speed, one of the advantages of fixed wire-line broadband is always connected not interrupted, then the minimum speed is less or more stable.

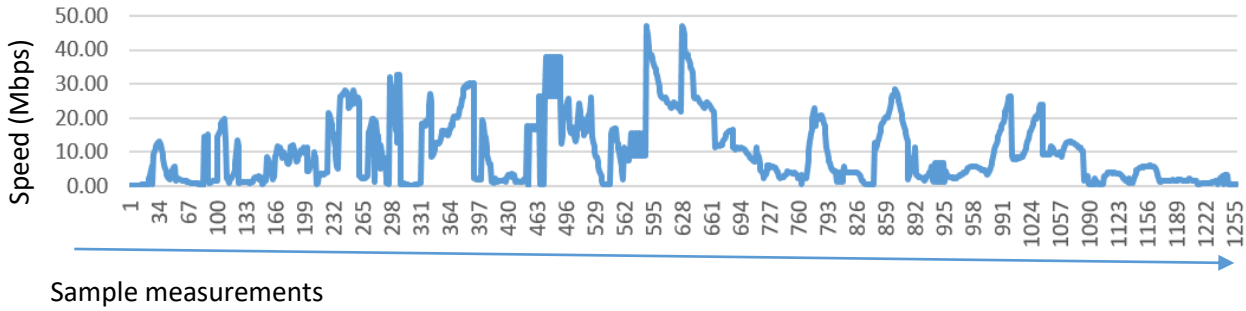


Figure 5-2. Average download speed signal

The average value of a certain signal is very important to determine the behaviour of a certain signal or user satisfaction level; however, as shown in Figure 5-2 which is less stable. Download

speed contributes more for user satisfaction as shown in the correlation *Table 5-4*, page 48 download speed contributes 83.88%, therefore the operator work on average speed stability.

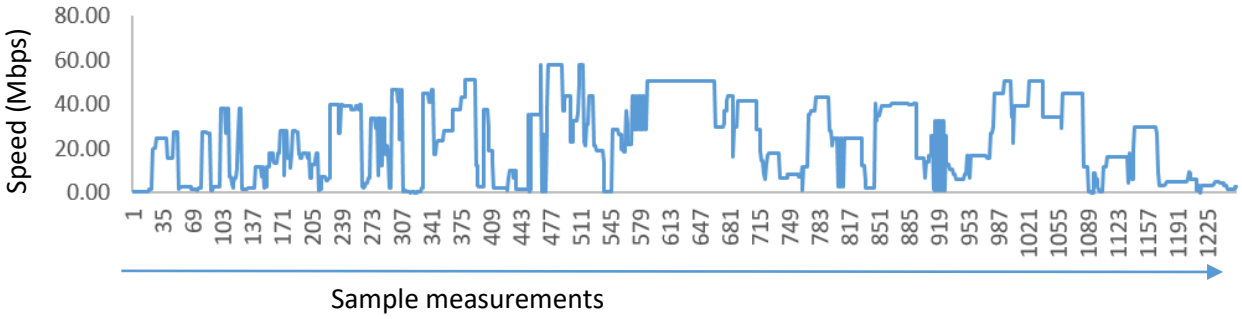


Figure 5-3. Maximum download speed signal

The maximum value of the download speed is less stable as shown in Figure 5-3, this indicates download speed user demand is high.

Download speed variation of the collected data in terms of digit:

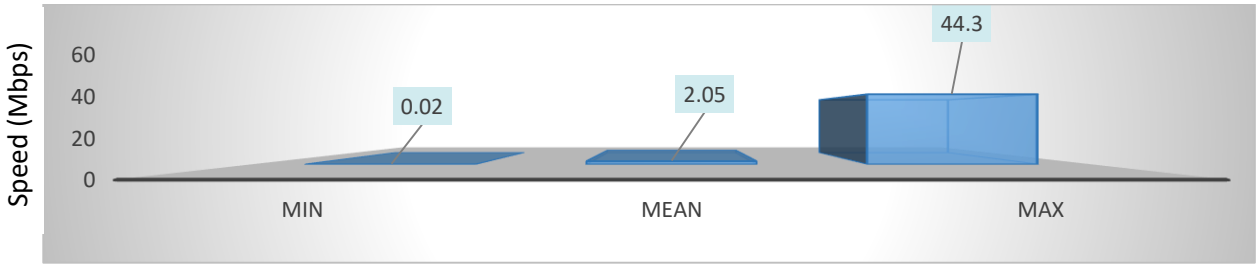


Figure 5-4. Minimum download speed variation with time in Mbps

The above Figure 5-4 shows how much variation with different time's measurement.

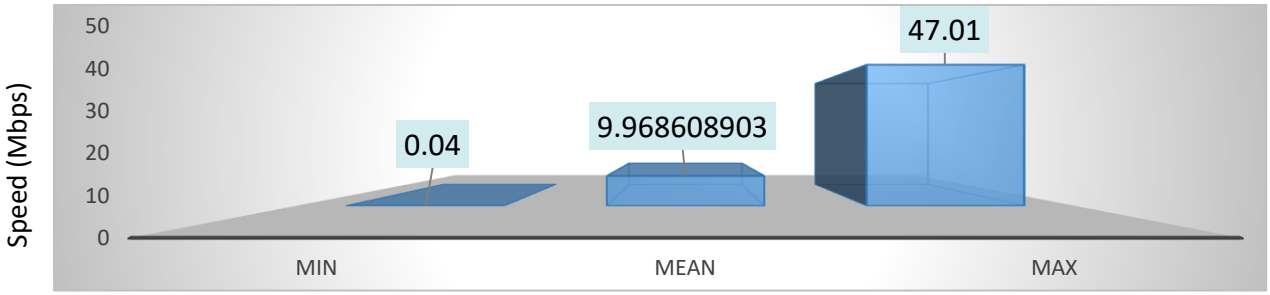


Figure 5-5. Average download speed variation with time in Mbps

The above Figure 5-5 shows how much variation of the average value with the time change of the test period, the graph used to visualize how much of the average value of download speed fluctuates with different traffic time, it indicates how much the network is stable. According to Ofcom [19], the average value of download speed to satisfy the user 10 Mbps and according to

our analysis the value we achieved 9.97Mbps, this shows the download speed fulfil Ofcom recommendation.

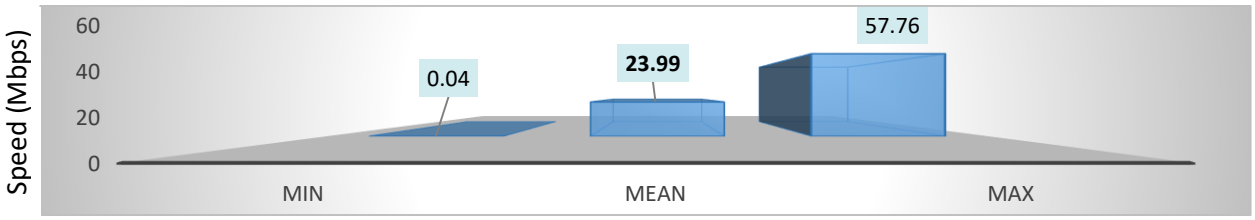


Figure 5-6. Maximum download speed variation with time in Mbps

The above Figure 5-6 shows how much variation of the maximum download speed value that means the tools generate minimum, average and maximum at one time. The above shows the maximum value variation when testing with different traffic time. It shows too much variation that is from 0.04Mbps to 57.76Mbps. Too much variation can cause decreasing of user satisfaction, so maintain stability is crucial to satisfy the user.

5.1.2 Fixed Wire Line Broadband service Upload speed in terms of signal and digit.

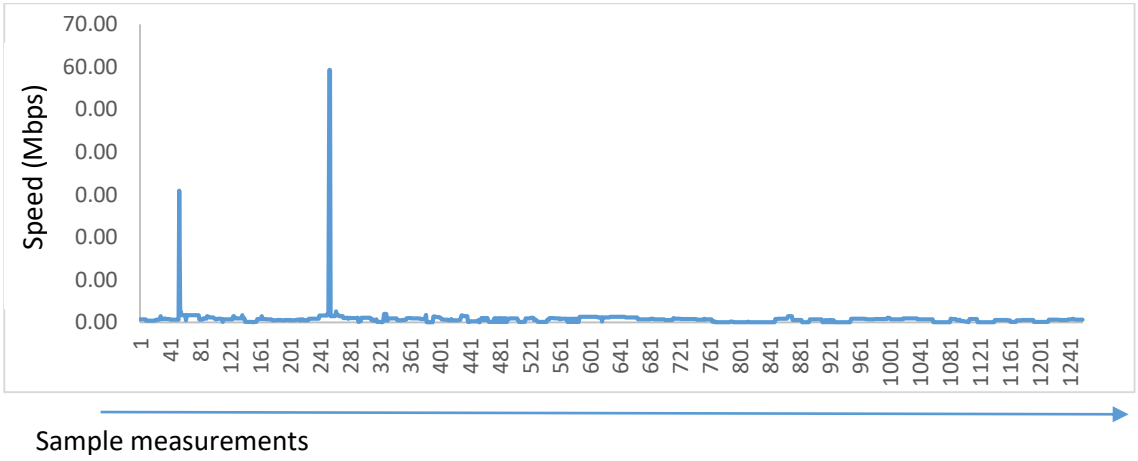


Figure 5-7. Minimum upload speed signal

The minimum value of upload speed during the test period of time show stability as shown in Figure 5-7 relatively. In the minimum download speed variation, the peak signal shows less traffic during the test period.

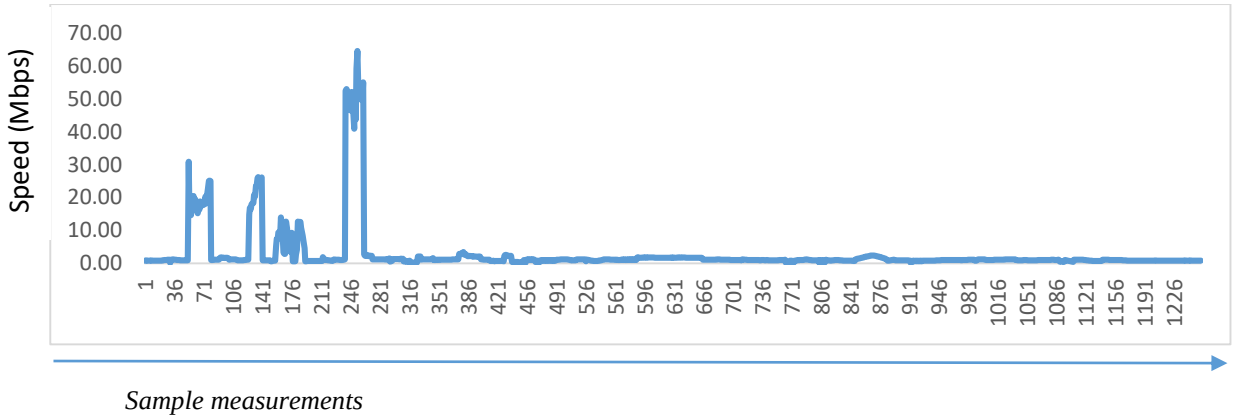


Figure 5-8. Average upload speed signal

The average value of upload speed as shown Figure 5-8, which is the most important data for the contribution of users satisfaction according to Ofcom and also our real data correlation result, about 45.70% contribute to user satisfaction, as observed from the correlation of quality metrics to user MOS, the result is shown in *Table 5-4* , page 48.The signal is less stable during the initial test period, the peak value (better speed) is the service speed during less traffic time.

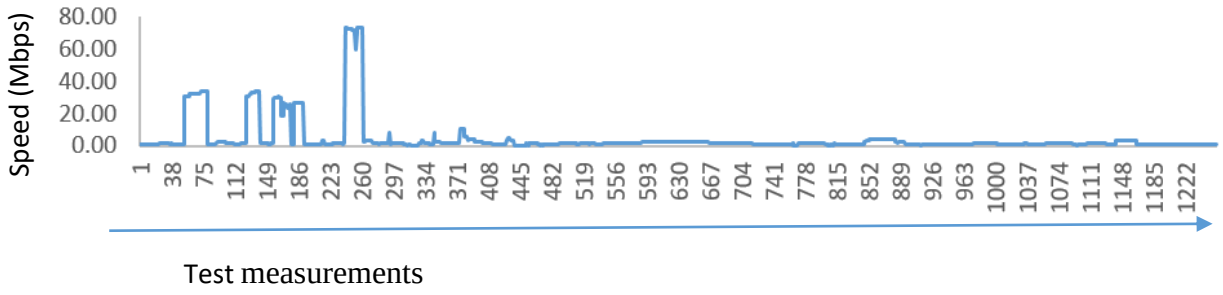


Figure 5-9. Maximum upload speed signal

The above Figure 5-9 shows maximum upload speed variation with time and traffic change, it is relatively stable except during the initial test period ,indicates users of uploader change with time relaivly steady.

Upload speed variation of the collected data in terms of digit.

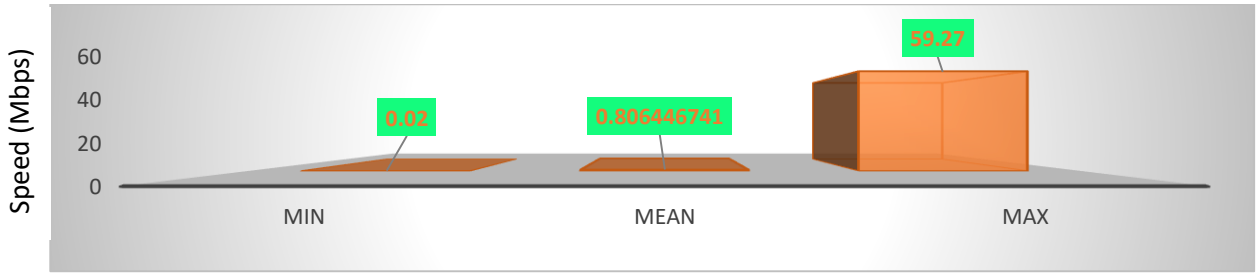


Figure 5-10. Minimum upload speed variation with time in Mbps.

The above *Figure 5-10* shows the minimum upload speed variation in terms of number in Mbps generated by Testmy.net tool with the time change, it shows too much gap between the minimum (0.02Mbps) and maximum (59.27 Mbps), which indicates the degree of network stability.

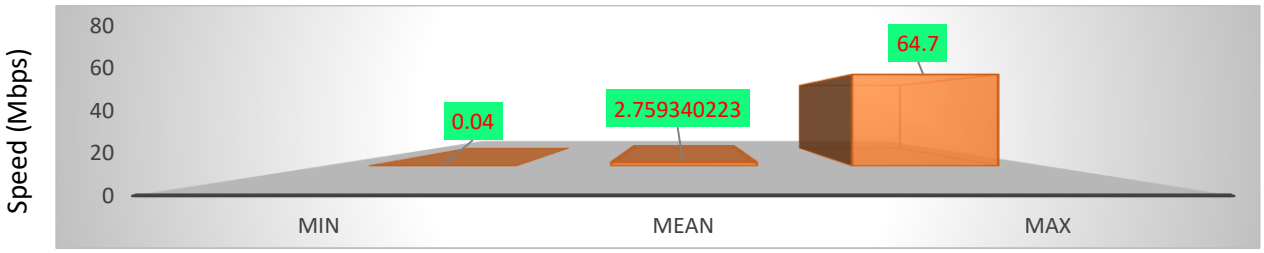


Figure 5-11. Average upload speed variation with time in Mbps

Figure 5-11 the average value of upload speed, it shows too much gap between the minimum (0.04Mbps) and maximum (64.7 Mbps), which also indicates the degree of network stability. The average value of upload speed affects more than the minimum and maximum for user satisfaction, the average value should be less or more stable. But in general, the overall average value is 2.76 Mbps, it fulfils Ofcom recommendation of at least 1Mbps to satisfy the user e Ofcom [19].

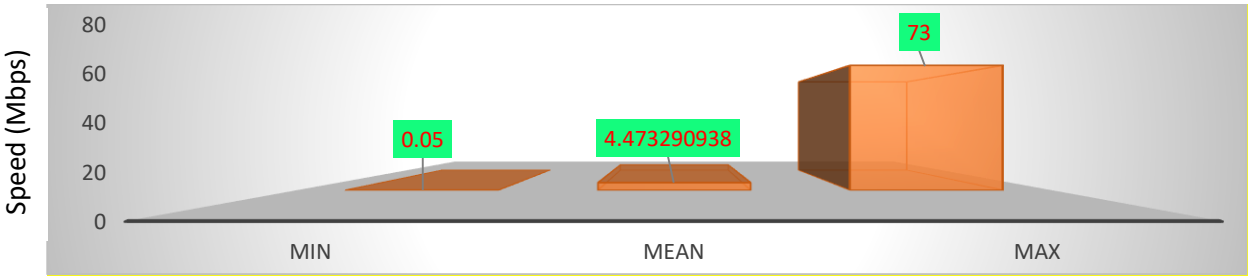


Figure 5-12. Maximum upload speed variation with time in Mbps

Figure 5-12 shows the maximum upload speed value generated by Testmy.net tools with time variation during the test period, it shows minimum (0.05Mbps) and maximum (73 Mbps) which indicates the degree of network stability.

5.1.3 Fixed Wire Line Broadband Service Latency in term of signal and digit

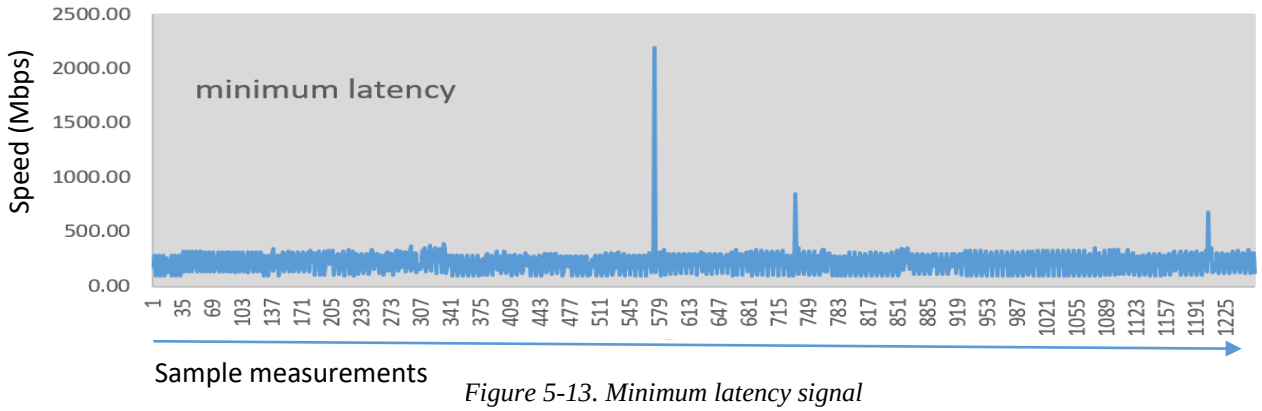


Figure 5-13. Minimum latency signal

The minimum latency shown in Figure 5-13 is stable except for some unexpected condition, but the average latency as shown

Figure 5-14 less stable or high variation relatively, but the average value has more impact on user satisfaction than minimum.

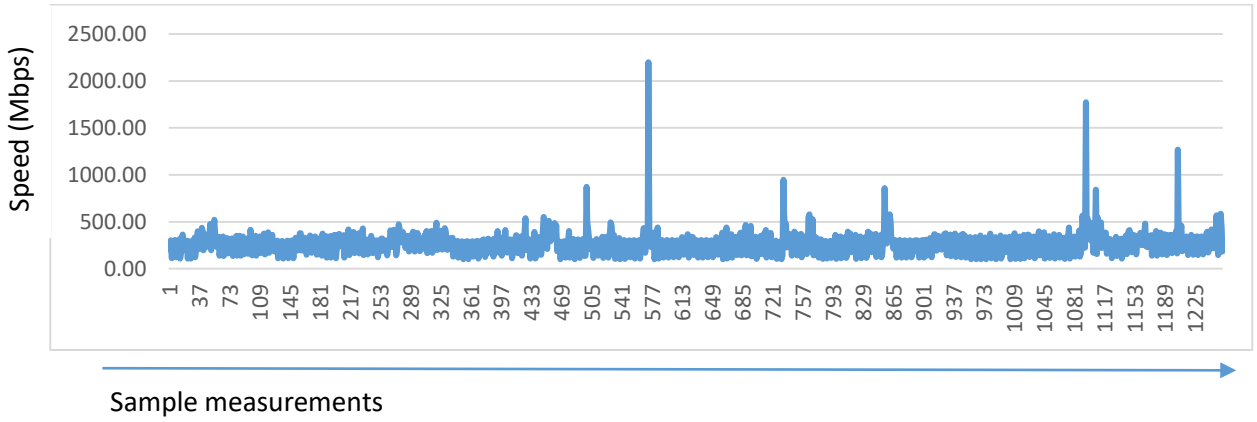


Figure 5-14. Average latency signal

The average signal shows stability but the signal is too high when compared to ITU standard the maximum latency not greater than 350ms [5].

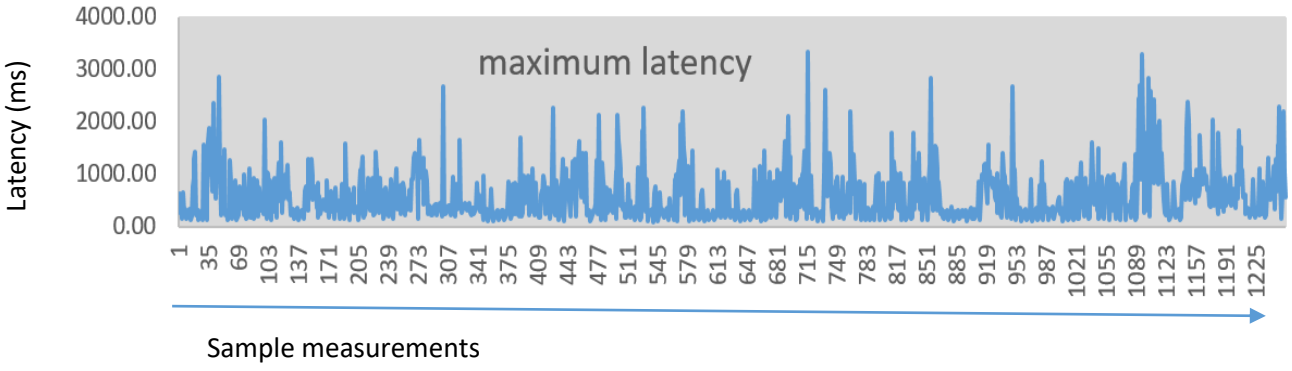


Figure 5-15. Maximum latency signal.

The maximum latency is the main problem for user satisfaction as shown the above

Figure 5-15 there is a high variation of maximum latency. Latency affects negatively user perception 77.99% negatively from the quality metrics to user MOS correlation as shown in *Table 5-4*, page 48.

Latency variation of the collected data in terms of digit

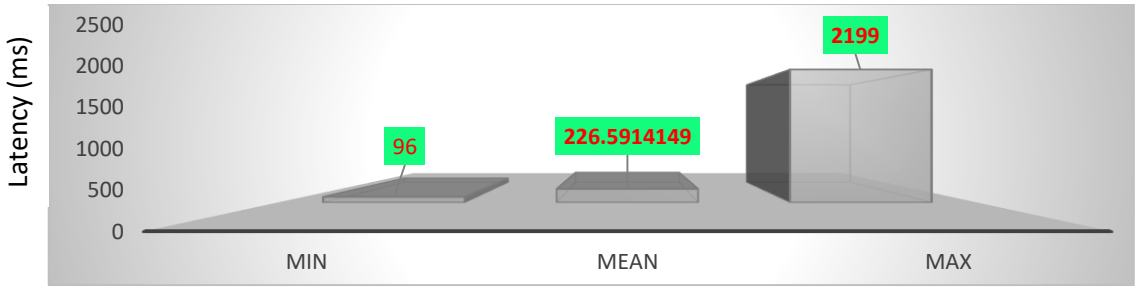


Figure 5-16. Minimum latency variation with time in millisecond (ms).

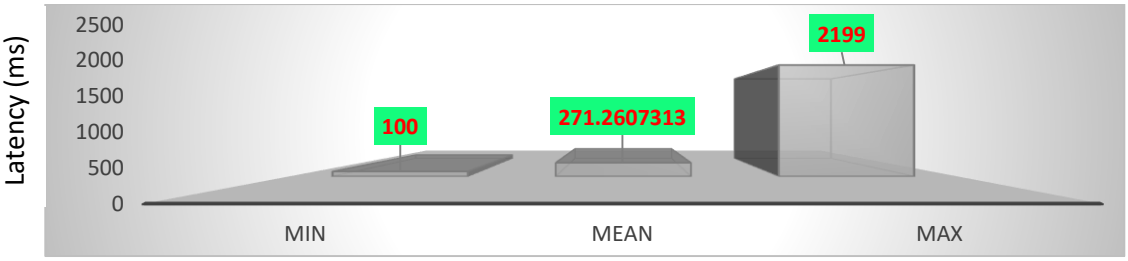


Figure 5-17. Average latency variation with time in millisecond.

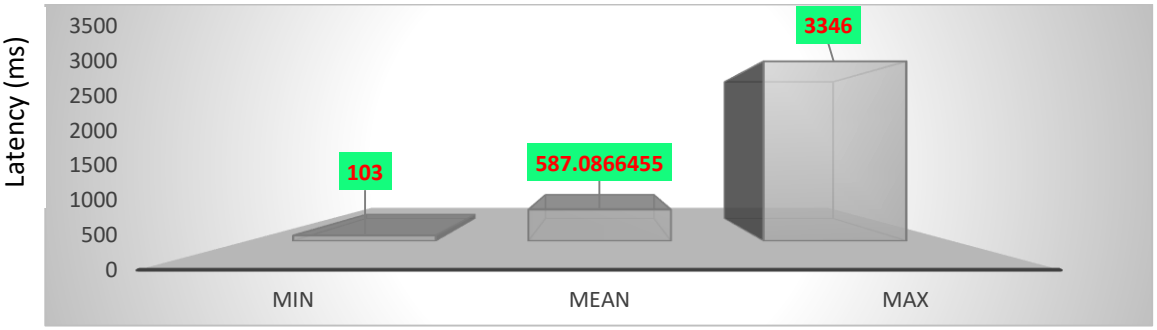


Figure 5-18. Maximum Latency variation with time in millisecond

Figure 5-16, Figure 5-17 & Figure 5-18 shows the latency variation with different traffic time, the tools generate minimum, average and maximum at one time, the three terms can create its own range of minimum, average and maximum due to measuring with different traffic time. Therefore the graph used to visualize how much the latency variation with time. The maximum latency according to ITU [5] recommendation should be less than 350ms but our analysis gives a mean of maximum is 2199ms, therefore, latency is the main problem for user dissatisfaction.

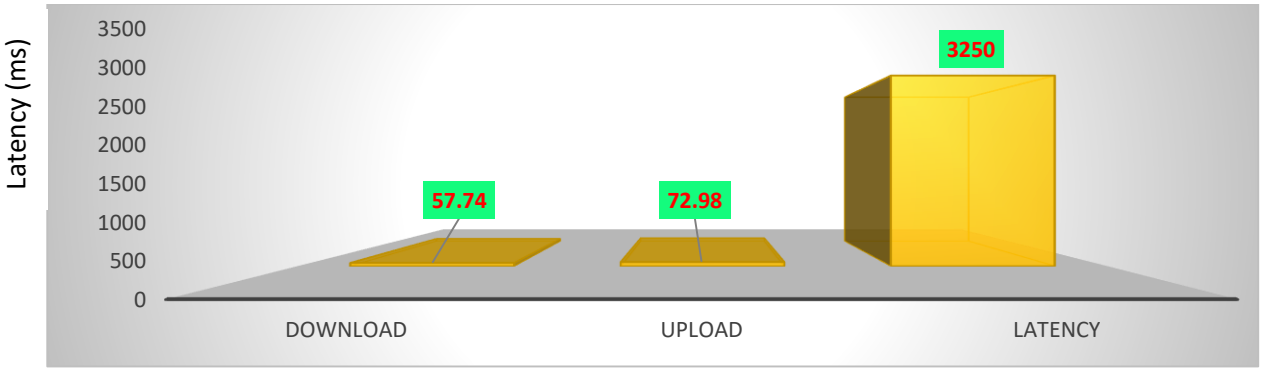


Figure 5-19. The three metrics variation difference

Figure 5-19 shows the quality metrics variation value between minimum and maximum, all the three parameters shows a wide range of variation, especially latency has a large variation (maximum-minimum=3250ms) which is the main problem for the quality of experience, based on ITU recommendation the maximum latency should be less than 350ms [5]. With actual data latency impact to download and upload speed as shown

Figure 5-20 page 38, when latency greater than 350ms upload and download speed less than 1Mbps, so it needs special attention to minimize the latency variation.

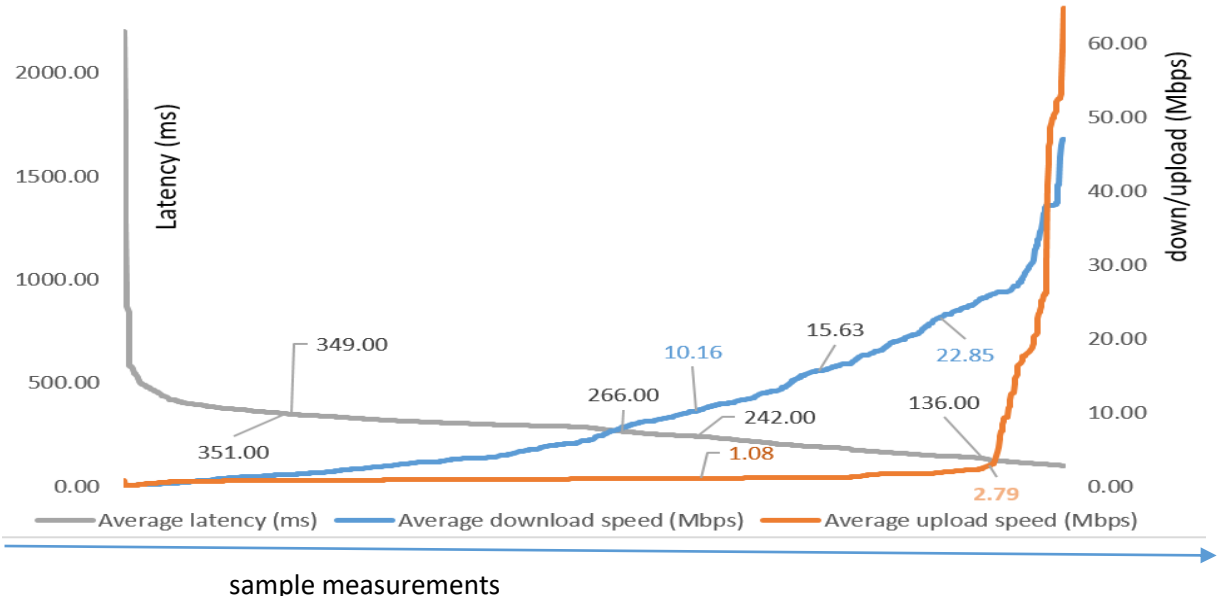


Figure 5-20. Impact of average latency on download and upload speed

Figure 5-20, shows the impact of average latency on download and upload speed, which is download speed is less sensitive to latency than upload speed, for instance at a latency of 136ms the download speed about 22.85 Mbps but upload speed about 2.79 Mbps or download speed

significant increase start at latency around 266ms but upload speed at latency value 136ms, in general, download speed better than upload speed with the same value of network latency as shown in

Figure 5-20. Ethio Telecom can achieve Ofcom recommendation download and upload speed at a latency value of 242ms [19]. As we see

Figure 5-20 , download speed is better when latency less than 266ms, because at this latency value download speed and latency curves intersection each other (optimized value), And for upload speed, the latency should be less than 136ms, it is an Intersection value of latency with upload speed Curve, For both cases latency less than the intersection point the speed will increase significantly, because intersection point is an optimized value between speed and latency.

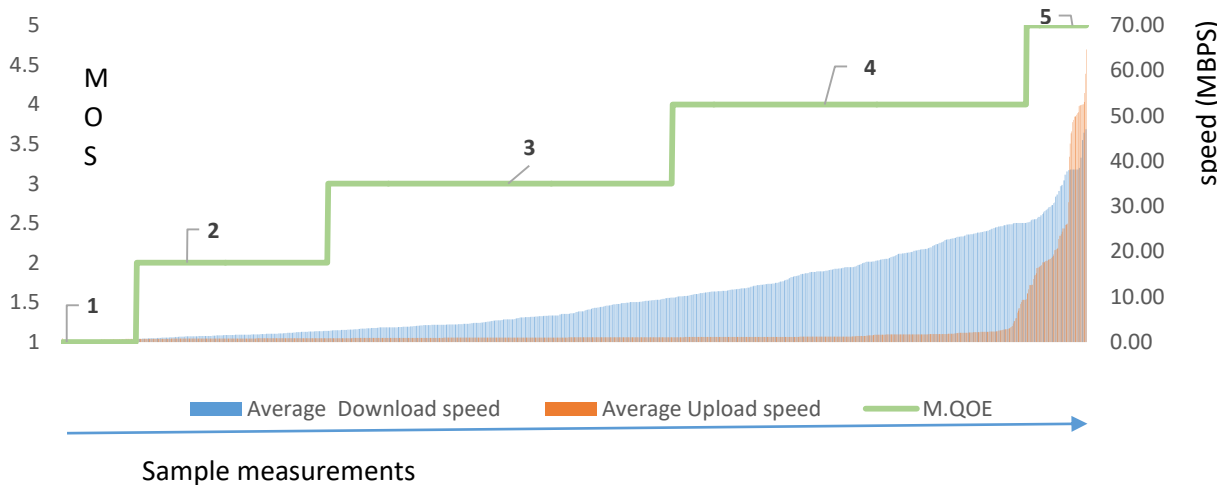


Figure 5-21. Impact of average download and upload speed on QoE

Download and upload speed is not equally affected QoE as shown in

Figure 5-21, download speed (blue area) contribute more than upload speed (red area), this also shown by correlation results, that is the correlation of quality metrics with MOS affected by download speed 83.88% and upload speed 45.70% as shown Table *5-4* , page 48, therefore, the company should work accordingly on the ISP on download/upload speed ratio, as shown in Table 1-2, page 9. And also download actual speed is 76% of advertising speed and the actual speed of upload is 88% of advertising speed as shown *Table 1-1* page 3, since download speed has high traffic than upload speed, that is why during sharing the operator give more weight for download speed see Table 1-2 page 9. Our mat lab simulation output also shows this .i.e. download speed aggregated output from input range (0.02-57-76Mbps) at the user end is 28.9Mbps and upload

speed aggregated output from input range (0.02-73Mbps) is 36.5 Mbps is achieved at the user end, this indicates upload speed has better performance than download speed at the user end, due to traffic load for download speed.

5.1.4 Objective Data Analysis Discussion

Table 5-1. Summary of objective data

Ethio Telecom maximum latency(ms)	ITU Maximum latency Recom[5].	Ethio Telecom average download speed	Ofcom Average download speed [19] Recom.	Ethio Telecom average upload speed	Ofcom Average upload speed[19] Recom.	Quality metrics degree of impact on QoE see page 49
346 even mean of max. 2199	350 ms	9.97 Mbps	10 Mbps	2.76 Mbps	1 Mbps	Latency -77.99% Download speed +83.88% Upload speed +45.70%

All the above figure of minimum, average and maximum of download and upload speed and latency to visualize the network stability, but the most important signal or data are average value of download and upload speed [6] and the maximum of the latency to fulfil user satisfaction based on Ofcom analysis [19] and ITU recommendation of maximum latency [5]. Download speed 10Mbps and upload speed 1Mbps on the average benchmark value of Ofcom recommendation and also in our case of actual data download speed 9.97 and upload speed 2.76Mbps almost fulfil the benchmark but latency far from ITU recommendation of maximum latency. It should be less than 350ms but our case mean of maximum 2199ms, therefore latency is the Main problem of user satisfaction degradation than download and upload speed. The main source of latency are

$$Network\ Latency := sender + receiver + \sum_{\substack{switches,routers,\\ gateway,appliances\\ in\ path}} (processing + forwarding + queuing) + \sum_{\substack{links\\ in\ path}} propagation$$

[41].

The main reason for user dissatisfaction during on-peak (high traffic) is latency due to queue.

5.2. Mat lab Data analysis with fuzzy logic

The summarized steps for the implementation of the model I used as shown in Figure 1-9 page 11, its membership functions and fuzzy rules extraction to generate QoE from QoS metrics.

- Define the linguistic expressions (Initialization)
- Design the membership function using triangle shape (Initialization)
- Convert crisp input value to fuzzy value using the MFs (Fuzzification)
- construct the fuzzy rule base (Fuzzy inference engine)
- Evaluate the fuzzy rules in the rule base (Fuzzy inference engine)
- Aggregate the results of each rule (Fuzzy inference engine)
- Convert the fuzzy value to crisp output value (Defuzzification)

The collected data representing the correlation between QoS parameters and the measured QoE was translated into fuzzy membership functions. Three fuzzy sets (minimum, average, maximum) were assigned to each of the chosen QoS input variables. These fuzzy sets were converted into equivalent forms (shapes) of the membership function using a curve fitting method. The curve values of the membership functions represented the degree (from 0 – 1) [42] to which a particular QoS parameter value resulted in different MOS scores. In the proposed system, the fuzzy set was converted into an equivalent triangular shape, which was efficient, easy to implement and increased the speed of computation [32]. A membership value of 1 represents a high degree of membership to the underlined output. The relationships represented by the membership functions reflect the effect of each QoS parameter's value on the QoE. This effect is categorized into three fuzzy sets (minimum, average, maximum). Each of them has a degree of impact to QoE calculated by the following algorithm formula

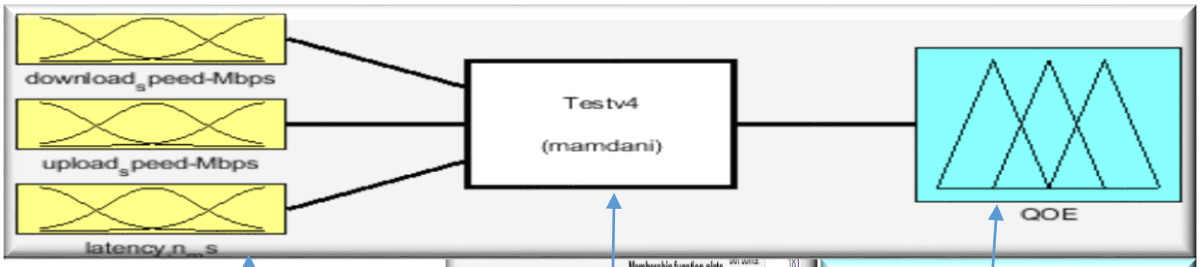
For the three quality metrics

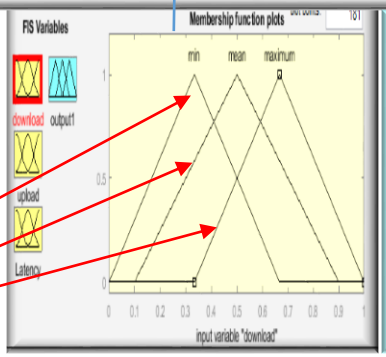
$$\mu(x) = \begin{cases} 0 & \text{if } x < a1 \\ x - a1/a2 - a1 & \text{if } a1 <= x < a2 \\ a3 - x/\ a3 - a2 & \text{if } a2 <= x < a3 \\ 0 & \text{if } x >= a3 \end{cases} \quad (1)$$

Where

μ(x) is the degree of membership of the fuzzified input to the underline output (QoE), a2 defines the triangular peak location (average value), while a1 and a3 define the triangular endpoints. x = (latency, Download, Upload and QoE). Each quality metrics has minimum, average and maximum and also QoE has five steps from Excellent to bad as shown in Table 5-2 insert the value in the above equation (1)

Table 5-2 Fuzzification model and range of value [43].





Excellent [4 4.5 5]
Good [3 4 5]
Fair [2 3 4]
Poor [1 2 3]
Bad [0 1 2]

[24]

Input, download, upload speed,& latency	
Fuzzy set	**Value**
Minimum	**[0.02 2.05 44.30]**
Mean	**[0.04 9.97 47.01]**
Maximum	**[0.04 23.99 57.76]**
Minimum	**[0.02 0.81 59.27]**
Mean	**[0.04 2.76 64.7]**
Maximum	**[0.05 4.47 73]**
Minimum	**[96 226.59 2199**
Mean	**[100 271.26 2199]**
Maximum	**[103 587 3346]**

d.load

up.load

Latency

After performing all the necessary fuzzy logic setting of input variable value of the collected objective data, as organized as shown Table 5-2 the right side input includes the three metrics range of value [25], the right side QoE output which is Likert scale [37],[24]. After setting all the value in the triangular membership function [44] from the given range of value (fuzzy set). We can see the simulation value of the crisp output of QoE value and the optimized crisp value is performed off-peak and on-peak hours by changing the defuzzification methods in mat lab, the value of output differs due to variation of traffic, the user opinion also confirms this logic.

5.2.1 Fuzzy logic result

The overall quality of experience of the fuzzy logic evaluation (centroid method)

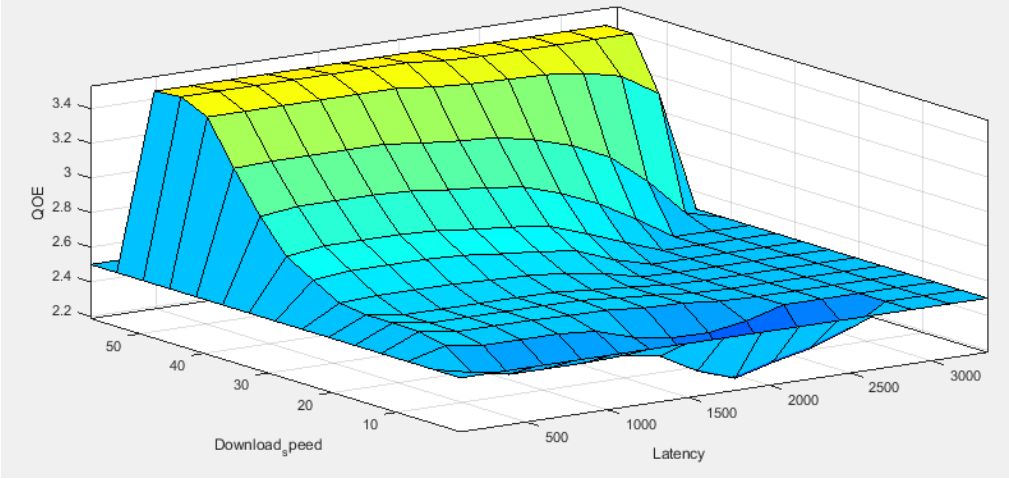


Figure 5-22. Download and latency correlation to QoE

Figure 5-22 shows a simulation of mat lab output that indicates the negative correlation of latency (ms) and positive correlation of download speed (Mbps) to the quality of experience, the colour and slop variation indicates quality of experience variation, the top deep yellow part indicates the best QoE that shows maximum download speed and minimum latency from the given data and the deep blue show worst QOE means decreasing download speed and increasing latency area. According to Ofcom [19] when download speed less than 10Mbps the quality of experience becomes poor it reflects in *Figure 5-22*

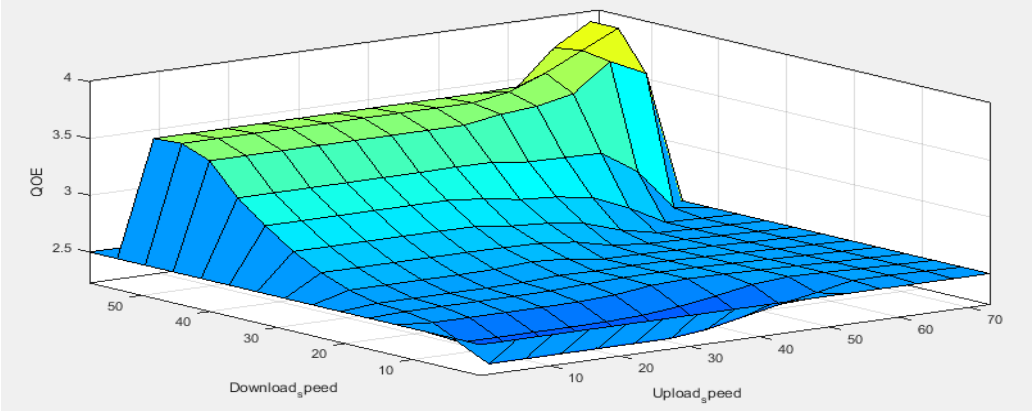


Figure 5-23. Correlation of download and upload speed with QoE

the simulation of mat lab output shows the positive correlation of download speed and upload speed to the quality of experience as shown *Figure 5-23*, the top yellow area indicates an increasing part of both upload and download speed which indicates the best QoE and the deep blue low land indicates the minimum part of both parameters i.e. worst QoE. According to Ofcom

[19] when download speed less than 10Mbps the quality of experience becomes poor which reflects in the *Figure 5-23*.

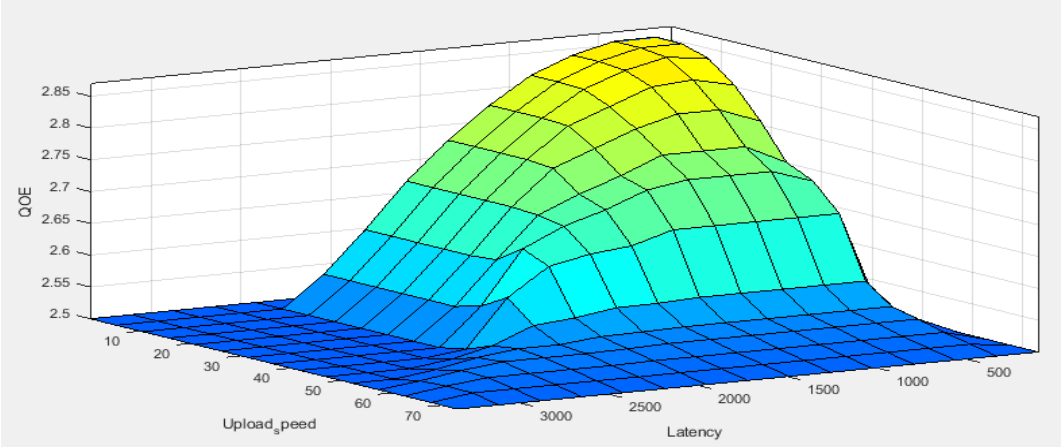


Figure 5-24. Impact of upload speed and latency to QoE

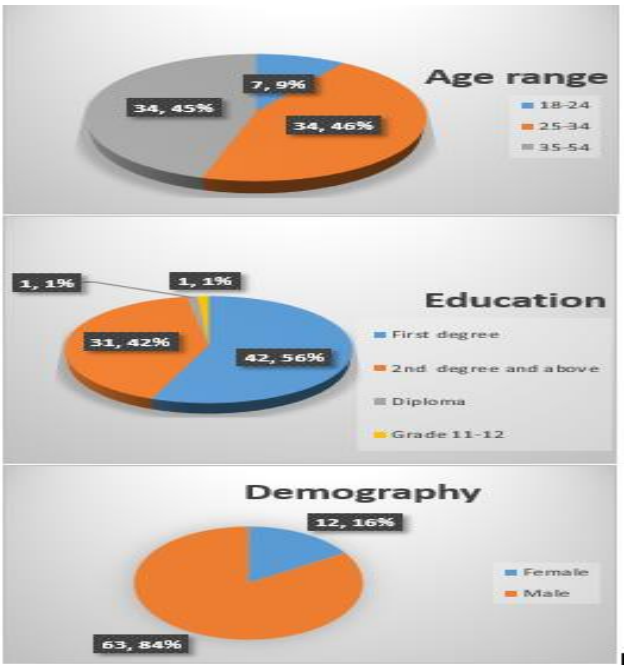
Figure 5-24 the simulation of mat lab output shows the negative correlation of latency and positive correlation of upload speed but both parameters change in the same direction together, but the fuzzy logic search the optimized area of better quality of experience at the top deep yellow area is the best quality of experience with the given data that means the graph bend to search less latency value of area from 3000ms towards 500ms to get better output of QOE (top flat yellow area) but according to ITU latency should not exceed 350ms [5] and according to Ofcom average upload speed should not less than 1Mbps [19] to get better quality of experience. Area) but according to ITU latency should not exceed 350ms [5] and according to Ofcom average upload speed should not less than 1Mbps [19] to get better quality of experience.

```
Latency = 1.72e+03    Download_speed = 28.9    Upload_speed = 36.5    QOE = 4
```

The above output (QoE=4) can achieve during off-peak hours by changing defuzzification method of the fuzzy logic, that means selecting mean of maximum (MOM) method, the maximum value of download and upload speed occurs during off-peak hours, therefore non-working hours objective experience is 4 implies during non-working hours the network performance is good.

5.3 Subjective method data analysis

As discuses in chapter 4 subjective quality metrics grouped into three for analysis purpose. Subjective metrics are the response of the end-users fixed wire-line broadband service Enterprise customers, the selected user profile as shown in Figure 5-25.



The left three-figure demonstrates the user profile of the respondents of the questionnaires which shows gender, age-range and educational background of the fixed wire-line broadband user, the majority of the respondent is male with age range 25-34 and educational background first degree.

Figure 5-25. Questionnaire Respondent profile

5.3.1 Quality-Related Metrics

As mentioned in chapter 4 subsection 4.2 quality-related metrics are from Q01—Q06 the detail in Appendix B The option of the response with different traffic time.

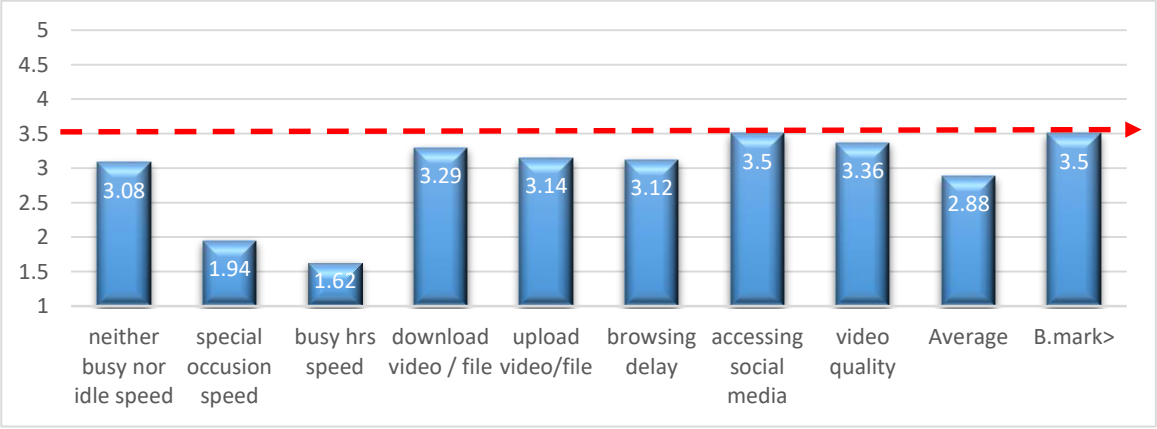


Figure 5-26. Working hours' user perception (on-peak hours)

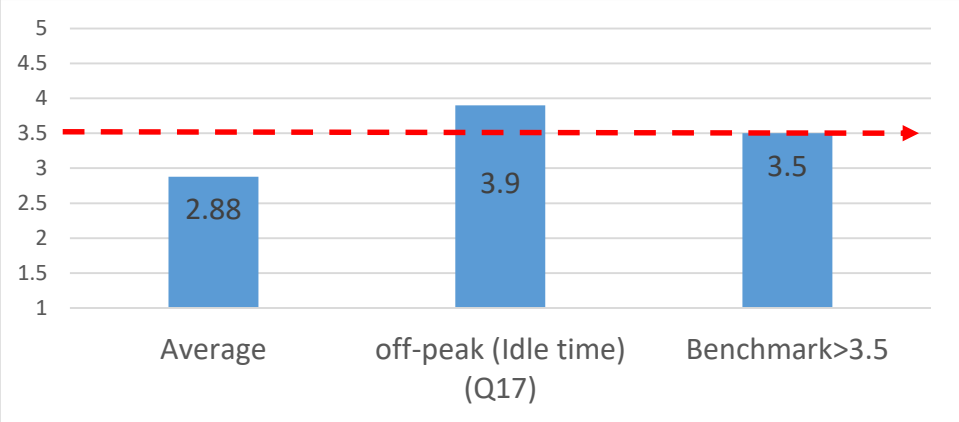


Figure 5-27. Overall vs. Idle time user perception (off-peak hours)

User perception with different time request with different question due to variation of traffic, the user satisfaction also varies with time as shown in Figure 5-26. Off-peak hours quality of experience is good (3.9) as shown in Figure 5-27 based on MOS benchmark value [45] which is the acceptable value of MOS should be above 3.5. on-peak hours quality of experience 1.62 which is under benchmark in Figure 5-26, overall user experience 2.88 in Figure 5-27, therefore the user response reflects the reality which is on-peak response is not good and off-peak response is good (3.9) experience, in addition, fuzzy logic also about a similar result that is on-peak 2.67 and off-peak hours 4.0, so it also used as a validation for fuzzy logic output, since both results (subjective and objective) show the same scenario with traffic change.

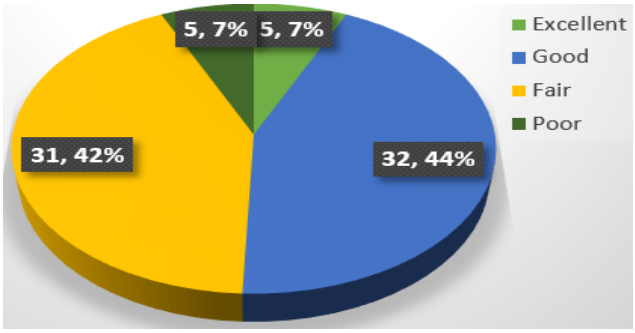


Figure 5-28. Overall fixed wire-line broadband user perception

5.3.2 Spatiotemporal Metrics

The Spatiotemporal metrics are included in this study to see when Enterprise Customers perceive the best and worst performance of fixed broadband data service. As shown in Table 5-3, the participant's response indicates the best speed and the worst speed time period when the user use fixed wire-line broadband network.

Table 5-3 Temporal metrics

Time period	Best speed response with two time period option	Worst performing response with two time period option
Early morning (5:00 AM to 8:30 AM)	**52**	0
Morning (8:30 AM to 12:00 PM)	8	47
Lunchtime (12:00 PM to 1:30 PM)	13	19
Afternoon (1:30 PM to 6:00 PM)	2	46
Evening (6:00 PM to 9:00 PM)	15	15
Night (9:00 PM to 10:00 PM)	**34**	0

From the Table 5-3, the worst speed time is from morning 8:30 AM-12:00 PM number of respondent 47 and afternoon from 1:30 PM - 6:00 PM, number of respondent 46, this also justified by quality metrics value measured during this period as shown in Table 5-6 page 50, latency is too high, throughput is too low, the user response clearly reflects the network traffic load, On the other hand Table 5-3 best speed time early morning 5:00 AM-8:30 AM number of respondent 52 and night 9:00 PM -10: PM respondent 34, this also justified by quality metrics measurement value as shown in Table 5-7 page 51, therefore the company should give attention to balance the network performance during on-peak and off-peak hours.

5.3.3 Other metrics

The access type of network preference

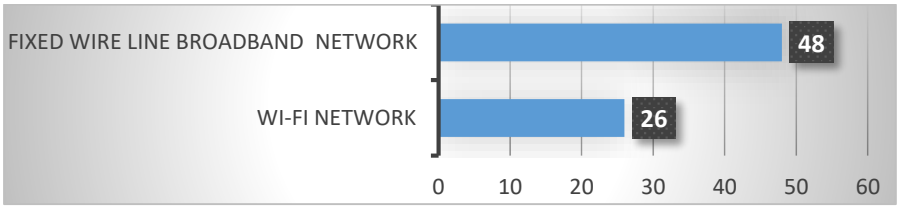


Figure 5-29. User access preference response

Figure 5-29 shows Most of the user (65%) prefers fixed wireline broadband service rather than Wi-Fi network (35%). And their reason reflected in Figure 5-30 that means the majority (39%) to get faster download speed and the other to get faster upload speed (28%) and to get better overall quality (28%). shows the majority of the user response to the choice between fixed wire-line broadband and Wi-Fi network is fixed broadband with a big difference this indicates the company should work on the expansion of the service and maintain the quality of the network.

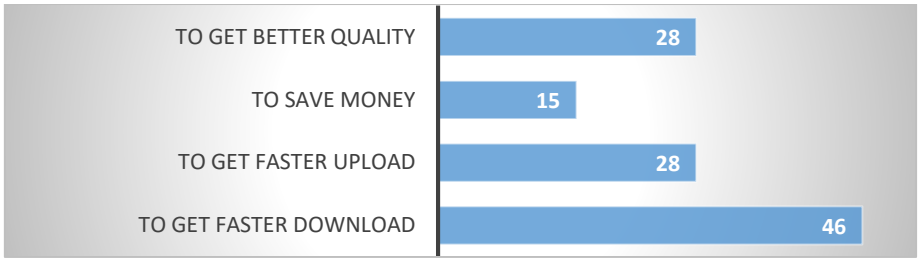


Figure 5-30. Reason to the response of access type preference

Figure 5-30 shows the majority of the user preference of fixed wire-line broadband is to get faster download speed, therefore the company should implement download upload ratio in the ISP like another operator which is incorporated in the document as a sample [17], and they give more emphasis to download speed. See in *Table 1-2* page 9, on the other hand, contact center satisfaction MOS is 3.28, Maintenance quality satisfaction MOS is 3.3 and fault clearing satisfaction of fixed wire-line broadband response is 3.25 when we observe both cases which are below recommendation which should be above 3.5 [45] to be satisfied the user.

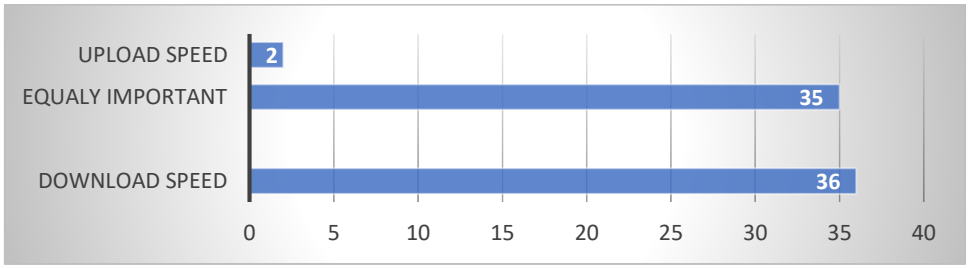


Figure 5-31.User speed importance for their business

The user speed preference the majority prefer better download speed for their business, from the analysis there is a limited number of user to upload certain content to the other user as shown in Figure 5-31, such kind of information used to prepare contention ratio in the ISP [17]

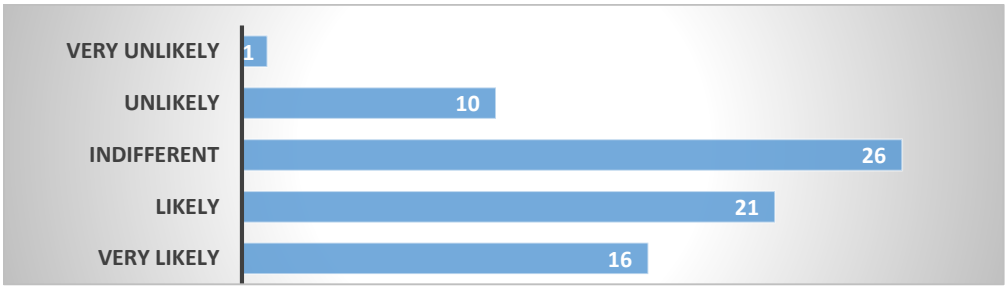


Figure 5-32. Shift to new operator response

Figure 5-32 Shows the majority of the response whether the user shifts to another operator if exist is indifferent, that means they are neutral, their choice depends on the current situation of the operators to decide their choice.

5.4 Objective and subjective combination data analysis as a validation

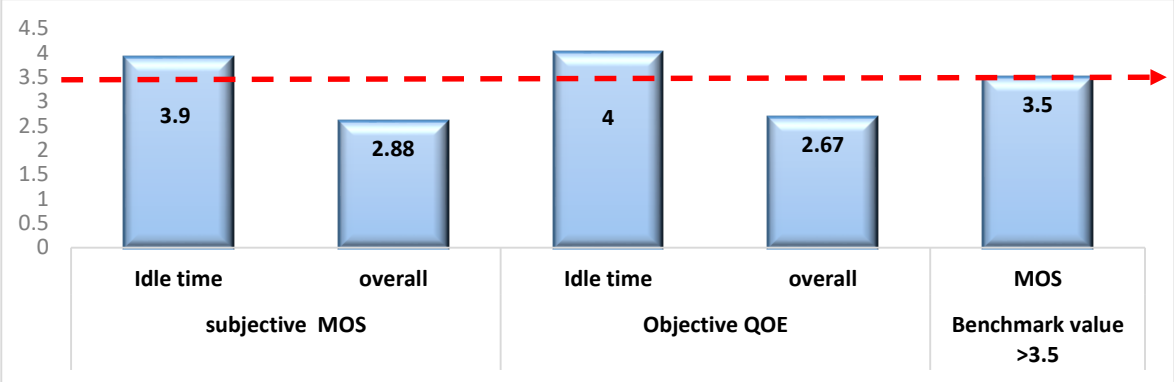


Figure 5-33. Comparison of Subjective, objective with different time and Benchmark MOS

Table 5-4, page 49 shows the correlation of the input parameters with the underline output of user experience with fixed broadband data service. Download and upload quality metrics show a positive correlation with a different weight that is download speed 83.88% and upload speed 45.70%, but latency shows a negative correlation with the degree of 77.99%.

Table 5-4 Correlation between quality metrics with the underline output of user MOS

Metrics- U-MOS correlation	*Average* Download	*Average Upload*	*Average Latency*	*QOE*
Average D	1			
Average UP	0.557416871	1		
Average L.	-0.72425799	-0.371542641	1	
MOS	0.838830694	0.457061886	-0.779958408	1

The need for correlation between quality metrics and QoE is to indicate how the parameter affects the user MOS, the parameter relation weather negatively, positively or they are an independent correlation. Furthermore, how much degree affects to the underline output (quality of experience), for example in Table 5-4, even if we know the correlation of download and upload speed have positive correlation and latency has negative correlation with the user MOS, but we don't know the degree of impact before correlation, After correlation average download

and upload speed affects positively with a degree of 83.99% and 45.70% respectively, and also latency affect negatively 77.88 % to the underlined output of user perception.

Regression of the collected quality metrics value with the MOS of the user as y-value (dependent variable) or output value with the collected data the quality metrics (download, upload speed and latency) independent variable as an input, the purpose of regression is to get regression line, the line is formulated after getting the y-intercept and the coefficient of the independent variable as shown in Table 5-5.

Table 5-5 Regression output

Regression Statistics		
Multiple R	0.875312768	
R Square	0.766172441	
Adjusted R Square	0.765585917	
Standard Error	0.455918294	
Observations	1200	
ANOVA		
	Df	*SS*
Regression	3	814.584324
Residual	1196	248.6023426
Total	1199	1063.186667
	Coefficients	*Standard Error*
Intercept	3.244200219	0.061737422
Average D	0.068054696	0.00268741
Average UP	0.000918455	0.009250644
Average L.	-0.002780352	0.00015566

After regression performed we can formulate regression line with y intercept=3.244, download speed coefficient=0.068, upload speed coefficient=0.00092 and latency coefficient=-0.00278.

The regression line given by y=0.068D+0.00092U-0.00278L+3.244

Where D =download speed, U=upload speed and L-latency

After getting the regression line equation we can substitute the value of quality metrics average value collected from the live system of the network and generate the quality of experience and hence we can visualize the user opinion graph with the newly generated graph, we can see the relationship less or more the graph related to each other.

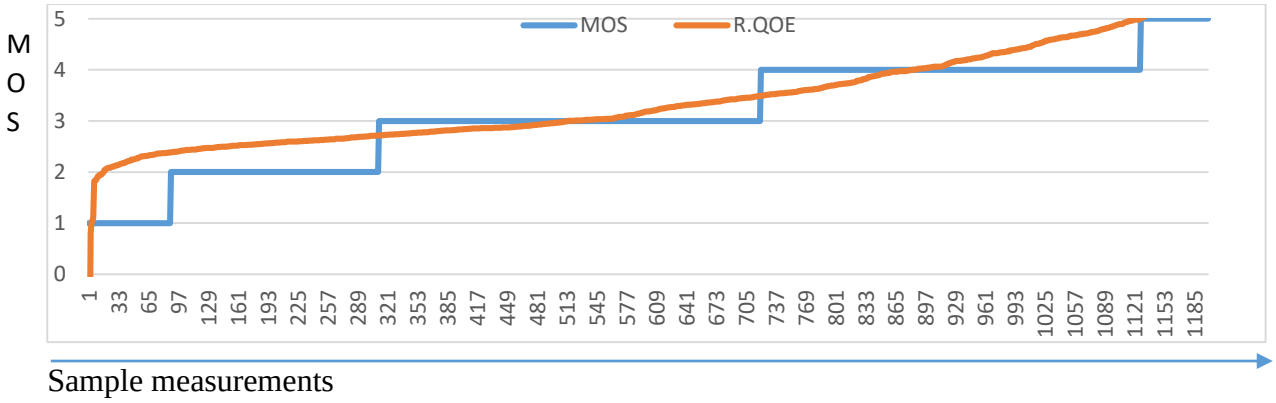
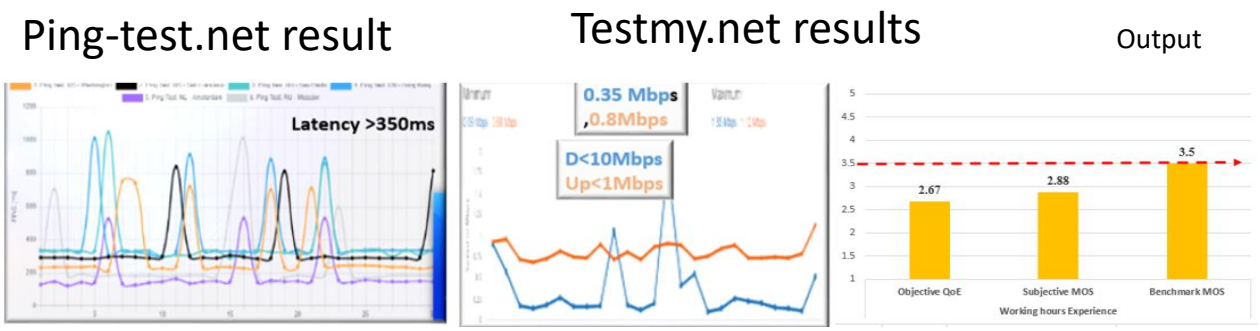


Figure 5-34. User MOS vs. Regression MOS

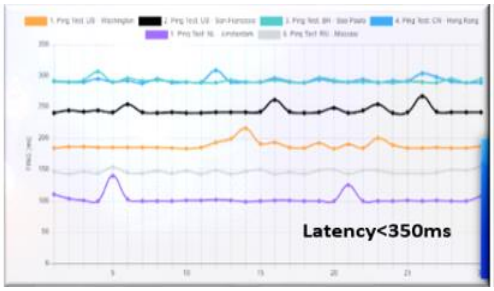
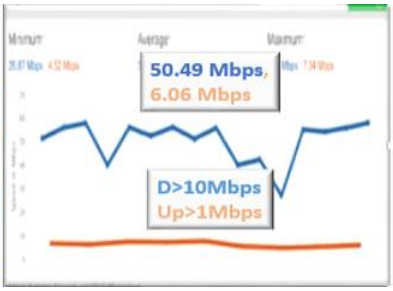
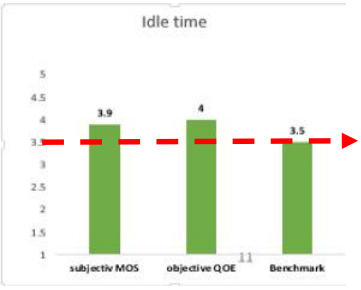
The graph almost the same except the regression QoE is a smooth curve and the user MOS line is a step up the line as shown Figure 5-34, because the regression graph input value includes decimal value, hence it is smooth cure, but the user MOS input is choice of natural number (1, 2, 3, 4 &5) that is Likert scale as shown in Figure 5-34.

Table 5-6 means of Result validation working hours



The Table 5-6 does not fulfil latency ITU recommendation during peak hours, the maximum latency should be less than 350ms [5] and speed is not fulfilled Ofcom recommendation, it should be at least download 10Mbps and upload 1Mbps [19] and hence the user response and Fuzzy logic output of QoE(2.67) and MOS (2.88) shows below the benchmark MOS 3.5 [45] that is working hours response (on-peak hours).

Table 5-7 Means of result validation during non-working hours

Ping-test.net result	Testmy.net results	Output
		

The Table 5-7 shows fulfil the two organization recommendation and hence subject and objective method quality of experience is good during off-peak hours in terms of the user response MOS (3.90) and objective method of QoE (4.0) both above the benchmark MOS of 3.5 [45].

5.5 Discussion of objective and subjective data analysis

That means the download speed at least should be 10Mbps and upload speed 1Mbps [19] on the average, in our actual data the average value of download is 9.97Mbps and upload speed is 2.76Mbps that means it fulfils Ofcom recommendation whereas according to ITU benchmark which considers the maximum value of latency it should be less than 350ms [5]. This fact is shown in Figure 5-20 when the latency greater than 350 the download and upload become almost less than 1Mbps in our case the maximum found 3346ms during busy hours but on the average the maximum latency is 2199ms still greater than ITU recommendation less than 350ms which has too much different, therefore the main problem is the poor quality of experience is latency not upload and download speed.

Fuzzy logic output also indicates the above problem during idle time selection of defuzzification method that means MOM mean of maximum method, the maximum of upload and download occurs during idle time it is logical and practically tested and hence MOM defuzzification method generates QOE 4.0 which is above the benchmark value of MOS 3.5 [45] but when consider overall of centroid method the fuzzy logic mat lab output is 2.67

The subjective quality of experience also agrees with the above results overall mean opinion score is 2.88 and idle time MOS is 3.9 in both cases of the objective and subjective method during idle time (off-peak hours) experience is good it greater than benchmark value 3.5 [45] but during working hours the experience is not good.

Chapter 6 Conclusion and feature work

6.1 Conclusion

The introduction of capable modern technologies with innovative data Services has brought business opportunities for telecom operators. Yet, for exploiting the Opportunity, ISP operators are expected to monitor and evaluate the satisfaction of their enterprise customers by taking relevant optimization, resource reallocation, network redesign and other relevant decisions. Operators can assess and monitor the performance of their networks using QoS metrics that contribute to user QoE, which is also a function of user capability and opinion. In the case of Ethiopia, there have been establishing an important section to improve fixed broadband service provided by the sole official operator of the country, ethio telecom. Fixed broadband data service is one popular service being delivered across the country. Yet, a considerable number of customers are not satisfied with fixed broadband data service regardless of the implementation of the projects of NGN which includes redesigning the network, changing access device such as MSAG, MSAN instead of DSLAM because of their better network performance in case of data transmission. In this thesis work, we have analyzed user side QOE with QOS metrics and MOS towards the network to thoroughly understand user perception, user-side network quality and their correlation, focusing on selected Enterprise customers of Addis Ababa. After dealing with the quality monitoring process in Ethio telecom, three quality metrics have been identified – download speed, upload speed and latency for network side assessment. In addition to the quality metrics, subjective metrics have been collected and identified which can show us the perception of the users. Data has been collected for quality evaluation from NMS, ping-test.net for latency, testmy.net for download and upload speed in Addis Ababa. The subjective quality indicator metrics have also been collected by preparing a questionnaire for enterprise customers of Ethio telecom in Addis Ababa. From the collected data, we emphasize the average value of download and upload speed from Testmy.net is 9.97 Mbps, 2.76Mbps respectively, because the average value has more weight to user satisfaction in terms of subjective method logically and objective method of fuzzy logic in triangular membership [46]. From ping-test.net the average of maximum latency is 2199ms but ITU recommends the maximum value of latency should not greater than 350ms [5] but the maximum value obtained is 3346ms even mean of maximum is 2199ms. For better customer satisfaction, the recommended download speed on the average has to be at least 10 Mbps and for upload speed is 1Mbps for fixed broadband service [19]. The results obtained from our analysis are almost similar to the recommended value for download

speed 9.97Mbps and upload speed 2.76Mbps. Based on the recommended value latency bring to customer dissatisfaction which has been reflected in the responses of the Enterprise customers with a MOS value of 2.88 for overall quality of experience and from fuzzy logic evaluation 2.67 in both cases the user is not satisfied with working hours (on-peak hours).

The quality metrics have a direct effect on the satisfaction of the participants which resulted in a MOS value for accessing fixed broadband data service in Addis Ababa is 2.88 value for working time, for fuzzy logic Q0E 2.67 but the recommended value of MOS should be greater than 3.5 [45]. In both cases result indicates not a good experience and idle time (off-peak hours) satisfaction MOS 3.9 and Fuzzy logic evaluation are 4.0 The result shows good experience, there is too much gap between the satisfaction of off-peak hours and on-peak hours, therefore, the company should invest to minimize the gap especially latency reduction as discussed in the recommendation.

6.2 Future work

- The research can be done with the same methodology for the residential customer of fixed broadband service.
- The research can be done other major city in Ethiopia for the fixed wire-line broadband user to identify their perception.
- the research can be done with the same methodology to identify 3G user perception
- The research can be done to fixed wire-line service with different technology of XDSL, cable and fiber individually.
- The research can be done an analysis of the proxy cache server implementation algorithm

6.3 Recommendation

All the three quality metrics contribute to its own weight to QoE, according to the correlation of the collected data download speed affects the quality of experience 83.88%, and upload speed 45.70% positively and latency affects 77.99% negatively as shown in *Table 5-4* page 48,

But download and upload speed almost fulfil Ofcom (British communication regulatory body) recommendation. On the other hand latency, ITU recommends the maximum latency of the network should not be greater than 350ms [5], but ethio telecom according to survey average of the maximum latency is 2199ms very large compare to ITU recommendation. This effect observed with the collected real data in Figure 5-20, page 37, it shows when latency greater than 350 ms the download and upload speed less than 1Mbps. Based on the above analysis the main

problem for the quality of experience during working hours is latency, so the company must give priority to latency reduction. To minimize latency the following methods are recommended:

1. With minimum cost avoid the below type of network installation to minimize unnecessary cabling distance and route path, because when distance increase latency also increases. The propagation delay increased by 4.76 microseconds per km and a round trip almost 1ms [41].

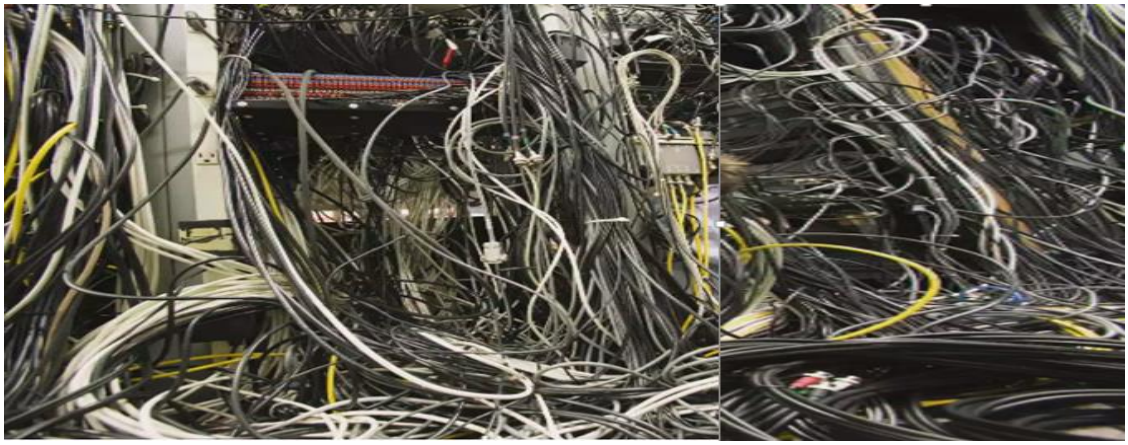


Figure 6-1. One cause of latency [47]

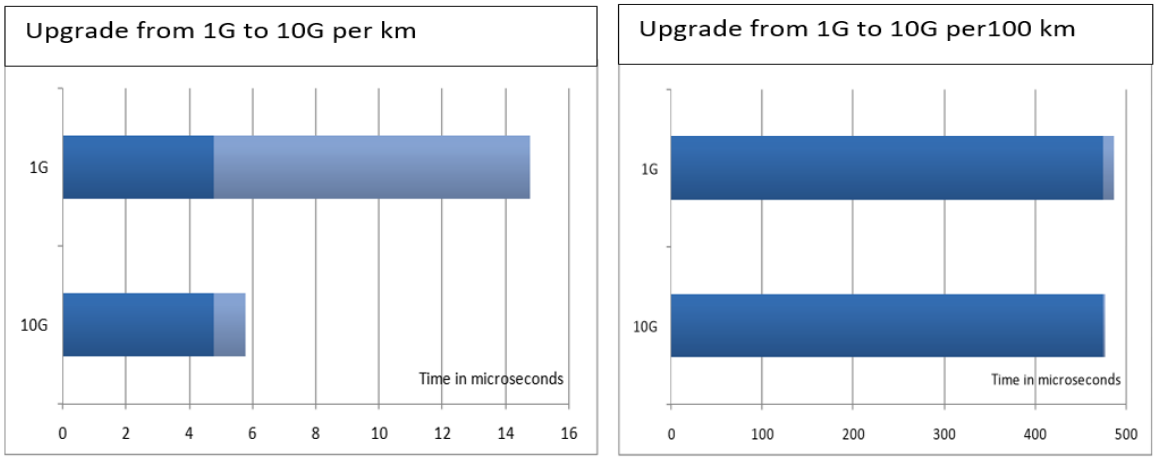


Figure 6-2. Upgrading in fiber 1 GB to 10 GB with 1km and 100km latency decreasing rate

When upgrading the bandwidth from 1Gb to 10Gb with 1km, latency reduced about 60% but upgrading bandwidth from 1Gb to 10Gb with 100km, latency reduced by less than 2% [41], and also use straight layout of cable as much as possible without unnecessary twist or rolling [48], therefore distance is one of the main factors for increasing latency, increasing latency means decreasing network performance and reducing revenue [41].

2. Implement a proxy server: That means install locale database for frequently requested data to reduce data queues or traffic on the gateway (international link) when the queues increase latency also increase [8].

3. Implement proxy Cache server: Network caching is a helpful technique to cope with today's Internet traffic explosion and to help sustain the demand for an increasing user quality of experience with reducing latency and increase data rate without increasing link capacity [9]. This is the main solution of the problem as mention before the main source of latency is processing, forwarding, queuing and propagation delay [38], since the user experience is under satisfaction during traffic time, latency which is related to traffic is queue, therefore the main solution to satisfy user is reducing queue by using proxy cache server which reduces the traffic over 50% [12] as shown in Figure 6-3

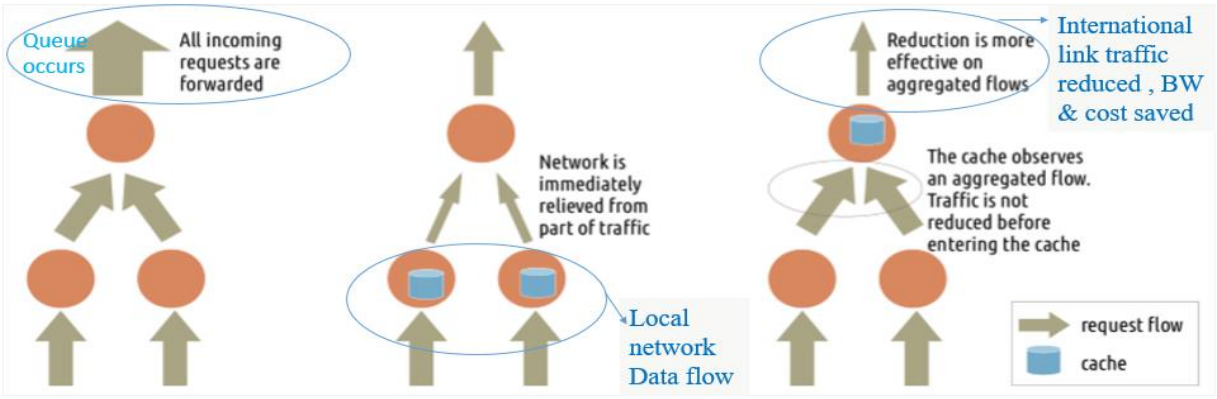


Figure 6-3. Content cache can be deployed in different segments of the network [11].

The benefits of a cache server are to reduce the load on the origin or remote servers which can reduce link cost [11], Users enjoy a faster speed, more reliable experience. Enterprises see higher customer satisfaction, Enterprises also see lower administration costs since infrastructure can be outsourced to third parties such as a content delivery network (CDN), reduces the bandwidth consumption by over 50%, eliminates 30% to 95% of the protocol CPU overhead [10].

4. Hardware optimization: when there is an unnecessary device within the network latency will be increased due to the serialization delay increase [41].

5. If there is two or more ISP provider use fusion technology that means integrate the ISP together regardless of their bandwidth difference which helps reduction of latency during uploading or downloading with the help of increasing bandwidth but not the initial latency which is most cost-effective [7].

The main target of this thesis is finding the user satisfaction level of fixed wire-line broadband data service, point out the problem for user perception and recommend to reduce the problem. The main problem that we found is latency due to queue, the summarized solution we recommend to reduce latency is implemented proxy cache server, but make an analysis of cache implementation

algorithm is out of scope it should be incorporated in feature work, however, by observing from previous work we propose Cost Aware of Caching strategies. And provide a greedy algorithm that gives the optimal solution [9] its advantage is easy to implement, require much less computing resource, much faster to execute and used to an optimization problem. It has classic hit ratio maximization and cost reduction and gives cost-benefit caching can achieve. Cost minimization cannot be the sole objective of an ISP, user quality of experience is another decisive factor. Most of the traffic today is encrypted between the user and the Content Provider (CP). As a consequence, all network caching techniques are practically inapplicable by the ISPs. To overcome this limit, the paper proposes a Content Oblivious Caching algorithm [9].

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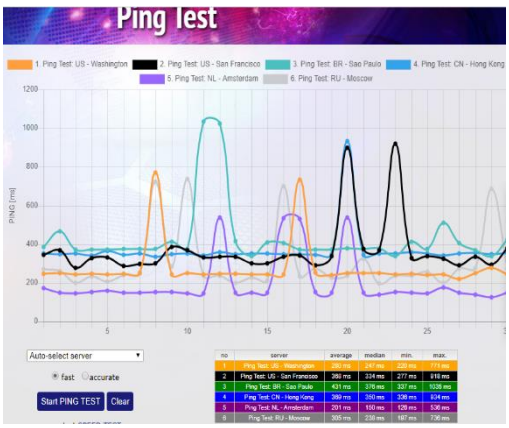
Appendix A

1. Testmy.net:

Connect your device with fixed broadband network, create an account to Testmy.net application on line to get your data with some other day. Run download and upload speed individually and run my result to get the summarized result of one time run as follows.

2. ping-test.net: connect your device or pc to broadband internet network, create an account to get your data with some other day



min D	Ave D	max D	min UP	Ave UP	max UP	min.L	Ave.L	max.L
0.07	0.16	0.30	0.71	0.82	0.93	184.00	209.00	641.00
0.07	0.16	0.30	0.71	0.82	0.93	242.00	249.00	278.00
0.07	0.17	0.30	0.71	0.84	1.01	287.00	302.00	451.00
0.11	0.18	0.30	0.71	0.83	1.01	100.00	111.00	151.00
0.11	0.18	0.30	0.71	0.82	1.01	143.00	183.00	663.00
0.11	0.19	0.30	0.71	0.82	1.01	183.00	202.00	293.00
0.11	0.19	0.30	0.74	0.83	1.01	245.00	260.00	281.00
0.11	0.21	0.30	0.74	0.84	1.01	289.00	306.00	344.00
0.11	0.23	0.35	0.43	0.81	1.01	101.00	122.00	150.00
0.11	0.25	0.48	0.43	0.80	1.01	144.00	157.00	188.00
0.11	0.25	0.48	0.43	0.81	1.01	186.00	202.00	224.00
0.11	0.24	0.48	0.43	0.81	1.01	244.00	263.00	300.00
0.13	0.26	0.48	0.43	0.82	1.01	289.00	315.00	346.00
0.13	0.26	0.48	0.43	0.80	1.01	99.00	110.00	142.00
0.13	0.27	0.48	0.43	0.80	1.01	144.00	168.00	195.00
0.15	0.29	0.48	0.43	0.79	0.99	223.00	311.00	770.00
0.17	0.31	0.48	0.43	0.78	0.99	270.00	364.00	933.00
0.17	0.33	0.48	0.43	0.79	0.99	131.00	262.00	1801.00
0.17	0.42	1.31	0.43	0.79	0.99	184.00	270.00	1445.00
0.17	0.51	1.46	0.43	0.82	1.19	184.00	197.00	235.00
0.17	0.59	1.46	0.43	0.80	1.19	241.00	256.00	286.00
0.17	0.60	1.46	0.63	0.85	1.19	287.00	298.00	327.00
0.17	2.23	19.75	0.63	0.90	1.47	100.00	107.00	140.00
0.17	2.92	19.75	0.63	0.94	1.47	186.00	190.00	196.00
0.37	4.60	20.31	0.63	0.96	1.47	241.00	244.00	249.00
0.37	6.09	20.31	0.67	1.00	1.47	288.00	291.00	305.00
0.39	0.39	20.31	0.67	1.02	1.47	101.00	109.00	136.00
0.42	9.10	24.74	1.47	1.04	1.47	143.00	152.00	180.00
0.42	10.23	24.74	0.80	1.08	1.47	183.00	253.00	1576.00
0.42	10.84	24.74	0.80	1.09	1.47	242.00	264.00	286.00
0.42	11.62	24.74	0.80	0.10	1.47	289.00	330.00	866.00
0.42	12.49	24.74	0.80	1.10	1.47	102.00	123.00	146.00
0.49	12.75	24.74	0.85	1.12	1.47	145.00	206.00	580.00
3.05	12.96	24.74	0.95	1.14	1.47	225.00	344.00	1650.00
3.05	11.65	24.74	0.78	1.13	1.30	279.00	399.00	1894.00
3.05	12.23	24.74	0.78	1.08	1.17	327.00	376.00	1009.00
0.83	10.61	24.74	0.78	1.04	1.16	137.00	212.00	1318.00
0.83	9.20	24.74	0.78	1.04	1.47	184.00	270.00	682.00
0.20	8.21	24.74	0.78	1.02	1.16	224.00	306.00	735.00
0.12	6.16	15.72	0.78	0.99	1.16	279.00	435.00	2380.00
0.11	5.00	15.72	0.69	0.96	1.16	328.00	394.00	918.00
0.11	4.29	15.72	0.69	0.94	1.16	138.00	197.00	538.00
0.10	3.40	15.72	0.69	0.92	1.16	219.00	371.00	1638.00
0.09	2.43	15.72	0.69	0.89	1.12	279.00	349.00	1086.00
0.09	2.15	15.72	0.69	0.87	1.12	324.00	351.00	898.00
0.09	1.91	15.72	0.68	0.84	1.12	139.00	337.00	2864.00
0.09	3.55	27.41	0.68	0.87	1.21	179.00	256.00	1023.00
0.09	3.78	27.41	0.68	0.90	1.21	230.00	230.00	230.00
0.09	4.70	27.41	0.68	0.91	1.21	276.00	359.00	864.00
0.09	4.81	27.41	0.68	0.89	1.21	326.00	477.00	1259.00
0.09	5.51	27.41	0.68	0.91	1.21	134.00	196.00	541.00

min	0.02	0.04	0.04	0.02	0.04	0.05	96.00	100.00	103.00
mean	2.05	9.97	23.99	0.81	2.76	4.47	226.59	271.26	587.09
max	44.30	47.01	57.76	59.27	64.70	73.00	2199.00	2199.00	3346.00

Appendix B

Q1. How satisfied or dissatisfied are you with the overall quality of fixed wired broadband service? ◌Very Satisfied ◌somewhat satisfied ◌neither satisfied nor dissatisfied ◌somewhat dissatisfied ◌Very dissatisfied

Q2. How satisfied or dissatisfied are you when you download file or video/music? ◌Very Satisfied ◌somewhat satisfied ◌neither satisfied nor dissatisfied ◌somewhat dissatisfied ◌Very dissatisfied

Q3. How satisfied or dissatisfied are you when you upload file or video/music? ◌Very Satisfied ◌somewhat satisfied ◌neither satisfied nor dissatisfied ◌somewhat dissatisfied ◌Very dissatisfied.

Q4. The browsing delay when you access website is: ◌very low ◌low ◌moderate ◌high ◌very high

Q5. How satisfied or dissatisfied are you when you access social media networks? ◌Very Satisfied ◌somewhat satisfied ◌neither satisfied nor dissatisfied ◌somewhat dissatisfied ◌Very dissatisfied

Q6. How satisfied or dissatisfied are you with the quality of video /in YouTube or video chatting)? ◌Very Satisfied ◌somewhat satisfied ◌neither satisfied nor dissatisfied ◌somewhat dissatisfied ◌Very dissatisfied

Q7. Choose two time periods in which you will get the best speed of fixed wired broadband data connection: ☐ early morning (5:00AM to 8:30 AM ☐ Morning (8:30AM to 12:00 PM ☐ Lunchtime (12:00 PM to 1:30PM) ☐ Afternoon (1:30 PM to 12:00PM) ☐ evening (12:00PM to 9:00PM) ☐ Night (12:00PM to 10:00PM)

Q8. Choose two time periods in which you will get the worst speed of fixed wired broadband data connection:☐ early morning (5:00AM to 8:30 AM

☐Morning (8:30AM to 12:00 PM ☐Lunchtime (12:00 PM to 1:30PM)

☐Afternoon (1:30 PM to 12:00PM) ☐ evening (12:00PM to 9:00PM)

☐ Night (12:00PM to 10:00PM)

Q9.If there is Wi-Fi network available in your surroundings, do you prefer Wi-Fi network or fixed wired broadband network?

◌ Wi-Fi network ◌ fixed wired broadband network

Q10.If your answer for Q9 is Wi-Fi network, why do you choose it? (You can choose more than one option)

☐To get faster downloads for file or video ☐To get faster uploads for file or video ☐to save money ☐ to get better quality

Q11. If you have ever called ethio-telecom contact center regarding fixed wired broadband quality problem how do you rate the response? ◌ very satisfied

◌ somewhat satisfied ◌ Neither satisfied nor dissatisfied

◌ somewhat dissatisfied ◌ very dissatisfied

Q12. If you have ever registered for fault clearing regarding fixed wired broadband connection problem how do you rate the response? ○ very

○ somewhat ○ neither satisfied nor

● somewhat ○ very

Q13.How do you rate maintenance quality? ○ very ○ somewhat

○ neither satisfied nor ○ somewhat ○ very

Q14 the company (your) business mostly affected by? ◌ Download speed

◌ upload speed ◌ equally important ◌ neither

Q15 what would be your satisfaction level if both download and upload speed is average (neither busy nor idle time)? ◉ very satisfied ◌ somewhat satisfied

◌ neither satisfied nor dissatisfied ◌ somewhat dissatisfied ◌ very dissatisfied

Q16 what would be your satisfaction level if both download and upload speed is minimum (like busy hours)? ◌ very satisfied ◌ somewhat satisfied

◌ neither satisfied nor dissatisfied ◌ somewhat dissatisfied ◌ very dissatisfied

Q17 Your satisfaction level concerning download and upload speed when you use during non-working hours or idle time is

○ Excellent ○ Good ○ Fair ○ Poor ○ Bad

Q18 If a new service provider louches fixed wire line broadband data service network in Addis Ababa, will you shift to the new service provider?

○ Very likely ○ Likely ○ Indifferent ○ Unlikely ○ Very likely

Q19 your Gender is ○ Male ○ Femal

Q20 Your age range is ○ Under 18 ○ 18-24 ○ 25 - 34 ○ 35 - 54 ○ Above 54

Q21Your educational background is ○ Master's degree and above ○ Bachlor's degree

○ Deploma or Certificate ○ Grade 11 - 12 ○ Below grade