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Quality of Service Assessment on Fixed-Wireless Broadband Internet Service the case of ethiotelecom

By

Abdulkerim Seid

Advisor

Yalemzewd Negash (PhD)

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Abstract

Commonly regulators and Internet service providers (ISPs) monitor and publish the offered quality of service (QoS) to improve broadband Internet QoS focusing on transparency and customer empowerment. This is aimed mainly to create competition between ISPs and provide freedom of choice on best operators for customers which is mainly crucial in multi-operators environment. Some of the researches done on differentiated customer traffic to improve QoS mainly used metrics throughput, delay & packet loss only. While others use hardware QoS measurement approach which is expensive than the software and challenging. Moreover other researches on operators and regulators tried to improve QoS based only on performance measurement which does not show the E2E QoS. Whereas in ET, the sole operator of Ethiopia, fixed wireless broadband Internet (FWBBI) is provided in traditional or similar/ equitable manners that is based on best efforts. Despite various customer traffics require variable QoS requirements, some traffics require guaranteed bandwidth such as business critical data applications and others like real time interactive application services such as Voice over Internet (VoIP) and video conferencing are highly sensitive to delay, jitter and packet loss. Hence best effort service offering does not guarantee business critical data applications and user satisfaction.

This research identifies important QoS metrics to apply in service level agreement (SLA). It also provides QoS assessment result on FWBBI service from end-user perspective. The QoS measurement is done by ICMP ping and testmy.net tools to get the actual quality the customers are offered. Additionally MATLAB analysis is mainly done by probability distribution to show the network capability in the design of QoS-SLA. The QoS result in FWBBI service showed that there is fair quality on average throughput (52% of subscription speed) and packet loss (12%), while delay (>400 ms) and jitter (>50 ms) values showed poor quality. The design of appropriate QoS-SLA is also delivered by this research. The FWBBI service QoS-SLA comprises three customer traffic classes - gold (A), silver (B) and bronze (C). This classification is done by defining threshold values for the metrics throughput, delay, jitter, and packet loss. Where this guaranteed level of QoS allow ET to enhance QoS and support the current works to provide BB Internet SLA, improve efficiency in resource utilization and creates transparency for enhancing customer satisfaction.

***Key words**: Delay, FWBBI, ICMP, Jitter, Packet Loss, PING, QoS, SLA, Throughput*

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This is to certify that the thesis prepared by Abdulkerim Seid Ali, entitled: *Quality of Service (QoS) Assessment on Fixed Wireless Broadband Internet Service the case of ethiotelecom and* submitted in partial fulfillment of the requirements for the degree of Master of Science (Telecommunications Engineering – Telecommunication Information Systems Track) complies with the regulation of the University and meets the accepted standards with respect to originality and quality.

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Yalemzewd Negash (PhD) ________________

Advisor Signature

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Acronyms and Abbreviation

3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
AA	Addis Ababa
BB	Broadband
BI	Business Interface
CDF	Cumulative Distribution Function
CoS	Class of Service
DIA	Dedicated Internet Access
DiffServ	Differentiated Service
DNS	Domain Name System
E2E	End to End
ET	ethiotelecom
ETSI	European Telecommunication Standards Institute
FCC	Federal Communication Commissions
FTP	File Transfer Protocol
FWBBI	Fixed Wireless Broadband Internet
GTTP	Guaranteed Time to Provision
HTML5	5^{th} Version of Hypertext Markup Language
HTTP	Hyper Text Transfer Protocol
ICMP	Internet Control Message Protocol
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPDV	IP Packet Delay Variation
IPER	IP Packet Error Ratio
IPLR	IP Packet Loss Ratio
IPTD	IP Packet Transfer Delay

IPTV	Internet Protocol Tele-Vision
ISO	International Organization for Standardization
ISP	Internet Service Provider
ITU-T	International Telecommunication Union Telecommunication Standardization Sector
IXP	Internet Exchange Point
Kbps	Kilobits Per Second
KPI	Key Performance Indicator
LTE	Long Term Evolution
Mbps	Megabits per Second
MCIT	Ministry of Communication and Information Technology
MCMC	Malaysian Communication and Multimedia Commission
ms	millisecond
NGN	Next Generation Network
Ofcom	Office of communication
Pdf	Probability Distribution Function
QoE	Quality of Experience
QoS	Quality of Service
RFC	Request for Comments
RTT	Round Trip Time
SLA	Service Level Agreement
SP	Service Provider
TCP	Transmission Control Protocol
TEP	Telecom Expansion Project
TI	Technical Interface
TIPHON	Telecommunications and Internet Protocol Harmonization over Networks
UDP	User Datagram Protocol
UK	United Kingdom
VoIP	Voice over IP
VSAT	Very Small Aperture Terminal

CHAPTER 1

1. Introductions

When we see the trend in Internet traffic usage before the year 2000 the number of users, application types and services provided on Internet was limited or small. According to [1], [2] Internet users in Ethiopia was only around 10,000 in 2000 which is 0.02% of the total population. But from figure 1-1 it can be seen that there is a higher growth rate still with its penetration rate around 15 % of the population (16,437,811) compared to Africa (37.3%) and world (56.8%) average in 2016. Hence showing higher user traffic growth demanding higher bandwidth is generally required to preserve QoS but in the real world telecom services increasing bandwidth indefinitely is impossible.

The heterogeneity of applications/services is also growing with demanding different level of QoS requirement. Some enterprise applications require strict bandwidth guarantee such as ERP (Enterprise Resource Planning), CRM (Customer Relation Management) etc. whereas services like e-commerce/online transactions demand low level of packet loss, jitter and delay. Industrial applications like telemetry defined in [3] as the telemetering and tele control of industrial processes which is an example of a data service that requires real time streaming performance. It needs two-way control with a tight limit on the allowable delay in telemetry. Moreover, various types of emerging real time services like VoIP (Voice over Internet Protocol), video conferencing, online gaming and banking services require low packet loss, strict delay, jitter and guaranteed throughput to adequately run the system.

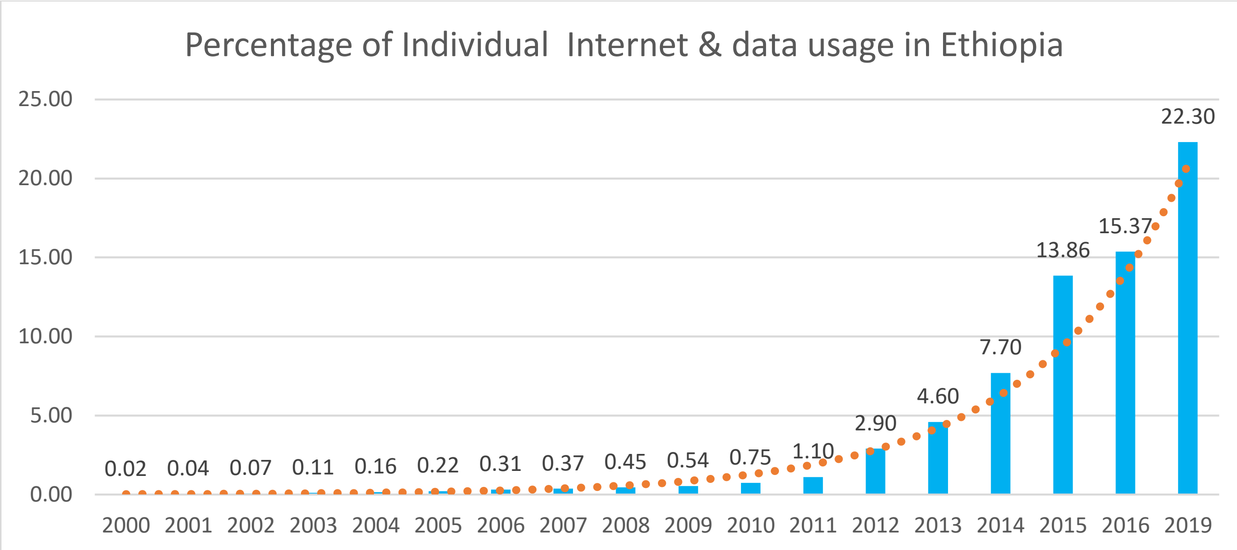


Figure 1-1 Broadband Internet usage growth in Ethiopia (2000-2019) adapted from [4]

Commonly the ultimate objective of all telecommunication service provider (SP) is considered to provide satisfactory services to their customers at a reasonable price. So Internet Service Provider (ISPs) should keep the QoS provided, prevent degradation and improve QoS to achieve their objectives. From the ITU international QoS experiences in [5] three approaches were expressed to achieve a better QoS provided by ISP to its esteemed customers and regulatory bodies assurance: command and control (setting target and control), consumers empowerment (speed testing tools and customer feedback), encouragement and transparency (operators set their own targets and publicize results) which are applied by different ISPs and countries in the world.

European standardization and regulatory bodies approach to QoS has been focused on transparency and end user empowerment [5]. Regulatory bodies are enforcing improving fixed broadband (BB) Internet QoS by creating competition between ISPs through publicizing their QoS achievement/performance/ of their esteemed customers which allow them to compare and select operators based on their needs. For instance countries like Italy [6] used software based QoS (latency and throughput) monitoring to control the quality of BB Internet provided by themselves from their service provider. Accordingly subscribers can withdraw from their ISP on Service Level Agreement violations without any penalty additionally the ISPs publicize their QoS achievements.

The American and Canada regulatory approach to improve QoS is mainly applying transparency [5]. For instance the American Regulatory body Federal Communication Commissions (FCC) measure the performance of each BB ISPs in America and publicize the report on a website so as each user is able to choose its best ISP and the ISPs could also optimize their network. Whereas the Latin American QoS approach mainly focused on command and control, setting targets/objectives and sanctioning of ISP on non-compliance of the target though they are shifting to transparency and end-user empowerment mechanisms. For instance the Brazil telecom regulatory demands all ISP should guarantee 60% of the average advertised speed as compared to the actual speed for the year 2014. In Peru as of 2014, fixed and mobile BB providers can only sell service plans which guarantee at least 40% of the maximum speed indicated in end users' contracts.

On the other hand the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) 2018 report, best fixed broadband Internet service provider, Singapore, and some other countries like Malaysia, South Africa regulatory bodies set benchmarking on service quality to create competition between service providers and monitor operators QoS, ISP's optimize their network and users got improved services. Moreover recent studies also [7] showed that fixed BB Internet SLA based service quality offering is possible with low cost of implementation for achieving improved service quality, optimizing ISPs network and enhanced customer satisfaction.

Hence in telecom service it is impossible to have unlimited resource to provide for customers i.e. bandwidth resource is limited. So since there is a higher traffic growth (due to customer demand, evolving applications and services) and diversity the demand to guaranteed bandwidth with other QoS parameters (delay, jitter, packet loss ratio) requirement is becoming crucial. Hence there should be a way to classify services with their QoS requirement and guarantee with SLA to enhance service quality as well to prevent QoS degradation and efficiently utilize resources.

This research presents details on ethiotelecom FWBBI service offered quality to customers and SLA in a way briefing the approach of QoS. What the SLA trend seems in ET, What is required to effectively Implement SLA on FWBBI service i.e. it is required to study appropriate QoS metrics (like throughput, latency, jitter and packet loss). And the capability of the network should also be measured (from user-centric approach) to provide QoS-SLA services, service/application requirement study and design SLA, which is focused on this research.

1.1 Statement of the Problem

Recently ET began to implement huge national projects, Telecom Expansion Project (TEP) - I & II to improve wired and wireless service quality, coverage and capacity. Moreover it has a plan to implement expansion mainly on Fourth Generation (4G)/Long Term Evolution (LTE) network the different parts of the country. 4G LTE network is currently available in Addis Ababa. And also BB Internet coverage and quality shown improvements especially on coverage of Third Generation (3G) mobile BB networks throughout the country.

Moreover ET launched SLA service to provide its services based on SLA in a way to improve and guarantee customer services and efficiently utilize its resources. According to [8] ET began to launch SLA framework (for both wired and wireless) to its customer in 2013 based on service availability and guaranteed time to provisioning (GTTP) ,then the frame work also revised in 2016. But due to disagreement on price related issues between customers and ET the SLA was not executed /implemented. Moreover the new revised SLA framework (July 2019) advertised with improvements on such as pricing, billing, availability metrics without specifying the technical QoS parameters (delay, jitter, packet loss, and throughput) of BB Internet service.

Hence currently ET is providing FWBB Internet service without specifying the minimum level of guaranteed QoS metrics which is based on best effort. With best effort technique it is difficult to guarantee user satisfaction, inadequate for major enterprise applications and services (such as critical data bandwidth demanding to guaranteed QoS, services like multimedia, e-commerce with stringent delay, jitter or packet loss QoS level) and lacks accountability. So un-guaranteed minimum QoS level might lead to ineffective customer application/service operation and lower customer satisfaction which results in increasing complaints on slow speed, delayed response time etc.

Therefore it is crucial to solve these problems and improve QoS and prevent its degradation. To achieve this it is essential to study appropriate BB QoS metrics (like throughput, latency, jitter and packet loss), study or measure the end-to-end ET network capability, design/define appropriate QoS-SLA for FWBBI service. And support the gaps in the current works on commitment to provide SLA based BB Internet service by ET to its esteemed customers.

Research questions

- Which technical-QoS parameters/metrics should be defined in FWBBI SLA?
- What is the network infrastructure capability in FWBBI service (user-centric aspect)
- How much does ET achieved from the advertised FWBBI speed to its customers
- How and why SLA design/define in BB Internet
- What is the level of transparency, how to achieve it in ET FWBBI service?

1.2 Objective of the Study

1.2.1 General Objective

The main objective of this research is to define/design the technical-**QoS-SLA** for FWBBI service based on measurement of ET network Infrastructure capability from a user-centric aspect to enhance QoS, prevent its degradation and improve customer satisfaction as well to optimize resource utilization.

1.2.2 Specific Objectives

Specific objectives of this research are:

- ***To identify*** appropriate QoS metrics for FWBBI service SLA
- Measure ET infrastructure capability from user-centric aspect
- ***Define/design*** technical-QoS-SLA for FWBBI service supporting guaranteed threshold and customer traffic differentiation
- Recommend solution and further research areas

1.3 Methodology

In this research, the QoS assessment of FWBBI for the designing of QoS-SLA based on measurement of ET network infrastructure QoS a user-centric aspect, methodologies and tools are described as follows:

- State-of-the-art documents and standards reviewed to identify FWBB Internet service technical QoS metrics/parameters for defining/designing of QoS-SLA
- The approach used to collect/measure QoS is active measurement/testing approach in which [9] regulators and standard bodies mostly used for benchmarking purposes. This approach used injecting traffic to get the maximum bandwidth or line capacity. Moreover testing point used is based on ITU recommendation [9], [10].
- To measure the throughput (download and upload speed) from end user aspect, web based measurement system which does not need java or flash plugin applied to minimize security. The Testmy.net web tool has a periodic monitoring/measuring system which is easy to user to test FWBBI throughput. Where measurement is done on 12 randomly selected sample sites and 5 ET regions. One of the sample site is located at Afar (Semera), three at Assosa, Tsore and Sherkole, One at Gambella, Nekempte, Jigjiga and Dollo and four in Addis Ababa. The sample measurement data from each sites is done on the day time (morning and afternoon) for a period of two weeks.
- The metrics delay, jitter and packet loss is measured using ping-ICMP (Internet Control Message Protocol) from end user to a more stable google DNS server IP address (8.8.8.8). Measurement (probe) of 1000 (100x10) sample packets are taken from each sites at different time and dates to get the actual quality data.
- Measurement data is normalized to use a common scale, without distorting differences in the ranges of values or losing information and then probability distribution (mass and cumulative) of test data calculated to get the likelihood of each data/or cumulative likelihood of how data is distributed. In this case MATLAB functions/code and pdf (Probability distribution function) and CDF (Cumulative Distribution Function) analysis used. Probability distribution function (CDF and pdf) is recommended QoS assessment method for BB Internet at ITU-T-Rec.E.803 [11].

- Then to define/design SLA based on QoS metrics, the actual measurement of infrastructure capability, standards such as ITU, ETSI (European Telecommunication Standards Institute) and state-of-the-arts applied for the appropriateness of SLA and solutions recommendation

Summary of the Methodology

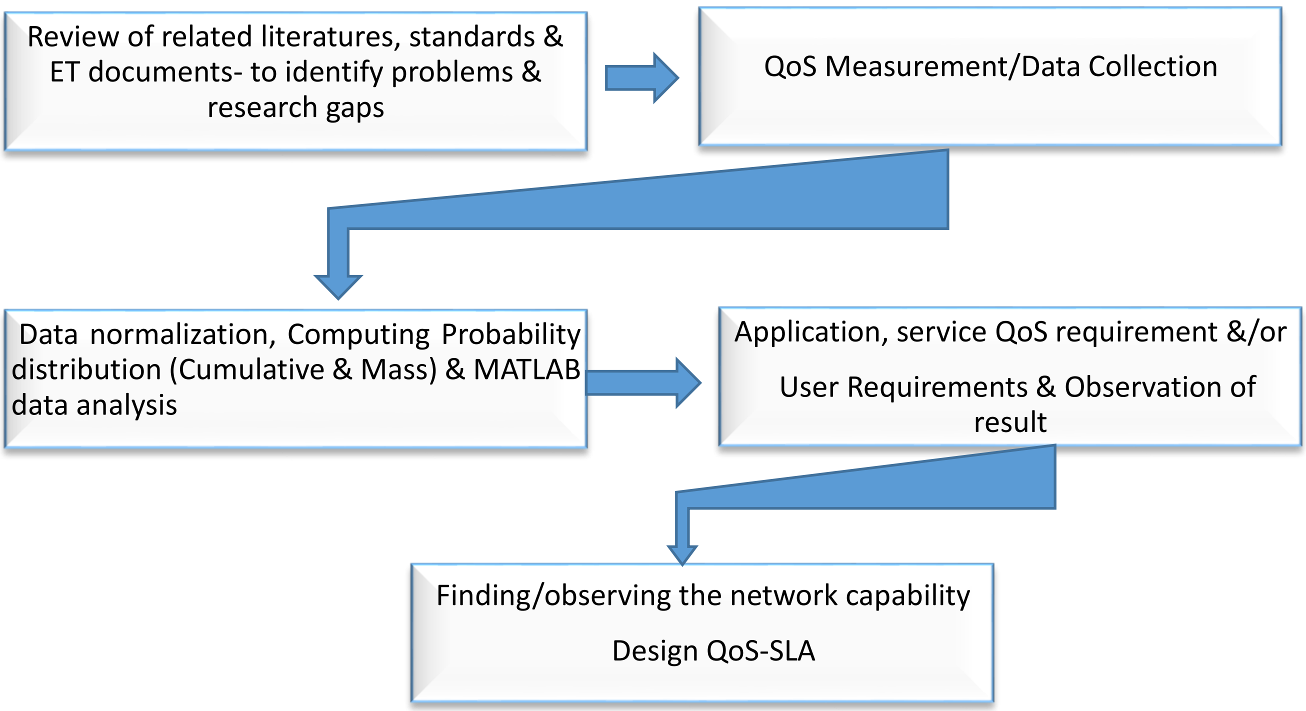


Figure 1-2: The research methodology in FWBB Internet QoS

1.4 Related Literature

A number of researches done on measurement/monitoring of QoS, benchmarking and SLA for service quality improvement in BB Internet. On research [6] the main objective of the authors was to develop free software (Ne.Me.Sy) tool and infrastructure for customer to be able to monitor his own QoS provided by Italian ISP and SLA. Monitoring (Ne.Me.Sys) software, cheaper and scalable than hardware based measurements, allowed customers monitor their QoS wireline QoS based on throughput (upload and download speed) up un ETSI standard and latency (ping test) parameters measurement for FTP and HTTP protocols. It requires user registration for participation on quality/SLA monitoring. As a main contribution, New QoS and SLA monitoring software tool and novel network infrastructure to monitor QoS and also with actual speed as half of theoretical/headline speed as a finding. Hence it constituted a valid instrument to assert the right of consumers in BB Internet. But the QoS measurement performed without including one of the common service quality influencing factor, jitter.

Research [7] study design of BB Internet SLA and explore trade-off between level of SLA and cost of delivering it. The authors used three QoS metrics throughput (upload, download), latency and packet loss for SLA. The designed SLA has three main classes, A for strict QoS like real time services, B for most common services and C for basic services. They used FCC publicly available throughput, latency and packet loss data set/measurement data, normalize the data and compute for CDF and CCDF of the data to get the distribution or likelihood. Based on that they found the feasibility of moderate SLA (up-to 90%) and able to provide by ISP while Strict SLA (>99%) compliance challenge to ISP.

The authors contributed in [7] was defining a set of BB SLA , show the cost of supporting SLA for different technologies and risk of offering SLA. The authors finally concluded that certain level of SLA could be offered with small impact on retail and investment price and also ISP's could take risk of offering SLA to customers. The research has gaps in not considering other QoS factors such as jitter and congestion. In addition though the research showed the possibility of BB SLA it did not described the relationship between the theoretical and practical implementation.

Other study [12] done on wired BB Internet QoS assessment for best benchmarking and network operation management by Malaysian Communication and Multimedia Commission (MCMC). The regulatory body, MCMC set QoS KPI at latency, throughput (two benchmarks 70% and 90%), packet loss and Jitter. It was done by Active testing at multi OSI layer (2, 3, and 4) for UDP (User Datagram Protocol) and TCP (Transmission Control Protocol) protocols with applications data (web browsing, file transfer), streaming (voice and video) applications. Software tools used ICMP ping to measure latency and jitter, throughput (upload, download), packet loss by simulating TCP and UDP, traceroute from end user to Broadband remote access server (BRASS). The assessment was done on 5 locations with 100 samples in the morning and afternoon time.

In research [12] the authors found that all five assessment locations meet the mandatory benchmark/KPI, 70% set by MCMC. But for throughput measurement benchmark of 90% for 95% of time did not meet by all operators. They also produced benchmarking for online video streaming, downloading, and web browsing baseline matrix. Moreover the Authors concluded that to improve service quality provided by ISP's to end users, QoS assessment should be implemented as normal maintenance practice. They also found that Malaysian wired BB had problem with the backhaul pipe which should be solved. Some of the limitation related to this research are the QoS metrics used are limited (3 parameters), does not show the effect of not fulfilling the benchmark and limited number of sample (100 data packets).

The paper [13] on Measuring QoS for mobile Internet services, objective was to obtain the service quality of Internet data for mobile operators in the Indonesian city of Samarinda,. It used mobile application software (Voiptester) dedicatedly installed on client mobile devices. The measurement was done at 5 district, 4 regions and 28 test points repeatedly performed at different measurement time through QoS parameters (delay, jitter, packet loss and throughput). And also the measurement was done from client devices to server with public Internet address

The evaluation/explanation/ on [13] to each QoS parameters was based on Telecommunications and Internet Protocol Harmonization over Networks (TIPHON) standards. The authors showed that the (three) ISPs services average QoS values on parameters delay, jitter and throughput belong to the bad category through TIPHON standard evaluation. While the packet loss average value belong to good category (<3%) with some variations based on locations. Whereas the throughput in download and upload is also variable through the three ISPs. This research mainly focus the problematic area of QoS compared to ETSI QoS standards without recommending solution or ways to solve the QoS problem.

In addition the authors in [14] research work necessitated monitoring BB performance to ensure subscribers got what they paid for service and regulators, ISPs to make informed decisions. The paper aimed to develop/adapt a method and tools for performance monitoring at fixed and mobile BB in South Africa for reducing gap in empirical performance data. It was done based on 16 testing sites in 15 ISP openWRT based home routers for fixed and 3G data, hundreds mobile phones performance by their own speed test application supported with speedtest.net (locally hosted) for both fixed and mobile. Throughput and latency were used as a main performance metrics.

Authors in [14] found that many users do get less speed than what they paid-for/advertised/ BB Internet and mobile ISP's provide faster download speed than fixed-line. They showed the need to consistent, continual and open performance measurements to increase accountability and help in policy making. The research offers the first publicly available performance data for fixed-mobile BB (for transparency), described the challenges in broadband performance measurements and ways how to address challenge in developing countries and illustrate significant performance bottleneck in infrastructure in South Africa. They finally concluded that policy makers should implement BB performance monitoring system, regulators should investment on local server infrastructure to improve quality/reduce latency/. This research is also made based on performance metrics throughput, latency and packet loss without justifying the not-covering of jitter as a metric.

Generally, some of the researches focus on evaluating ISP broadband Internet QoS only from standards point of view such as ETSI or ITU to optimize their network and enhance QoS based on assessment. While others evaluate the QoS of ISPs with limited number of samples which is difficult to generalize the total QoS offered. And also some of the researches are done to show the performance of operators which does not indicate E2E QoS of Internet. Moreover there is also limitation on QoS/SLA measurement metrics such as jitter is not commonly included which is one of the influential metric in highly interactive enterprise services and others focus on only availability metric.

1.5 Scope and Limitation of the Study

This study focus on ET FWBBI customer service (on VSAT and Aironet/RADWIN) QoS assessment to get the actual network capability (end-user-aspect) and design of SLA based on QoS. It does not focus on Fixed-Wireless CDMA services, wireless mobile broadband or wired services. Moreover quality of experience (QoE) evaluation is not the focus of this research.

1.6 Contribution

Currently ET is performing projects taking the commitment to implement SLA on different types of its services provided to customers. This research has contribution to ET, customers or regulators mainly to FWBB Internet service:

- For planning QoS on considering influential technical QoS metrics at SLA design
- To differentiate customers on their QoS requirements and efficient resource utilization
- Flexibility to customers on selecting appropriate SLA metrics to their service/application
- Allow ET to provide services based on current network capability/performance and to prevent QoS degradation and improve QoS.
- Allow ET to perform optimization of network and improve network performance/QoS
- Allow the regulatory agencies to revise their policy, monitoring ISP/ET/ services and protect customer rights.
- Feedback to ET on measurement methods, tools, procedure, point of measurement etc.

1.7 Thesis Organization

The remaining parts of this research is organized in the following manner. Chapter two describes FWBBI service types and architectures, QoS concepts, objectives of QoS measurement, QoS classes and parameters in Broadband Internet, QoS Monitoring/measurement Systems and tools. Chapter three describes QoS measurement methodologies, tools and scenario used in this thesis. Chapter four focus on SLA management: definition of terms, SLA requirements and specification, classification and ET SLA trends. Chapter five on result and discussions. Finally chapter six on conclusions and recommendations on future works.

CHAPTER 2

2 QoS Fundamentals

2.1 Overview of FWBBI Service

2.1.1 FWBBI Definitions and Concept

According to [15] fixed BB Internet Service is classified into fixed wired access network (wired) and fixed wireless access networks (last mile). Moreover, FWBBI service is defined in [16] as a BB service with a wireless access as a last mile but fixed in a given location where end user/receiver/ antenna or dish device mounted in a fixed location. There is also a need to have line-of-sight to receiver antenna/end user/ to get the service. Unlike to mobile wireless where end-user not restricted to a fixed location or wired where transmission is using cable/wired from ISP main switching center to user terminal.

ET is mainly using two technologies Aironet/Radwin and VSAT satellite to provide BB Internet service from various types of FWBB last mile access technologies as a good startup. The available BB Internet speeds are with narrowband (128 Kilobits per second (Kbps)) and broadband (>256Kbps up to 20 Megabits per Second (Mbps)). It is used as a good alternative for businesses where there is no wired network coverage or serve as a backup link to wired BB Internet network.

2.1.2 VSAT /Satellite Broadband Internet

Currently ET is using the VSAT satellite network as a last mile access providing voice, data or Internet services mainly for remote rural areas to expand its coverage to satisfy its customers' requirements. The Internet and data described in [16] where the available service in its narrowband 128Kbps and also broadband from 256Kbps up to 2Mbps using VSAT satellite for its enterprise or business customers. The satellite network also applied as one of the international Internet gateway options. According to ET Next Generation Network (NGN) project document the Satellite Internet Gateway is located in Addis Ababa connecting one country with 64M bandwidth which is desired for new Internet Gateways providing load-balancing and redundancy for Internet traffic.

One of the benefit of satellite Internet is its accessibility in different geographical areas especially at rural remote areas where wired/cable or mobile BB Internet is coverage not available or not feasible. The following diagram, figure 2-1 shows the graphical representation of a typical ET VSAT Internet network diagram.

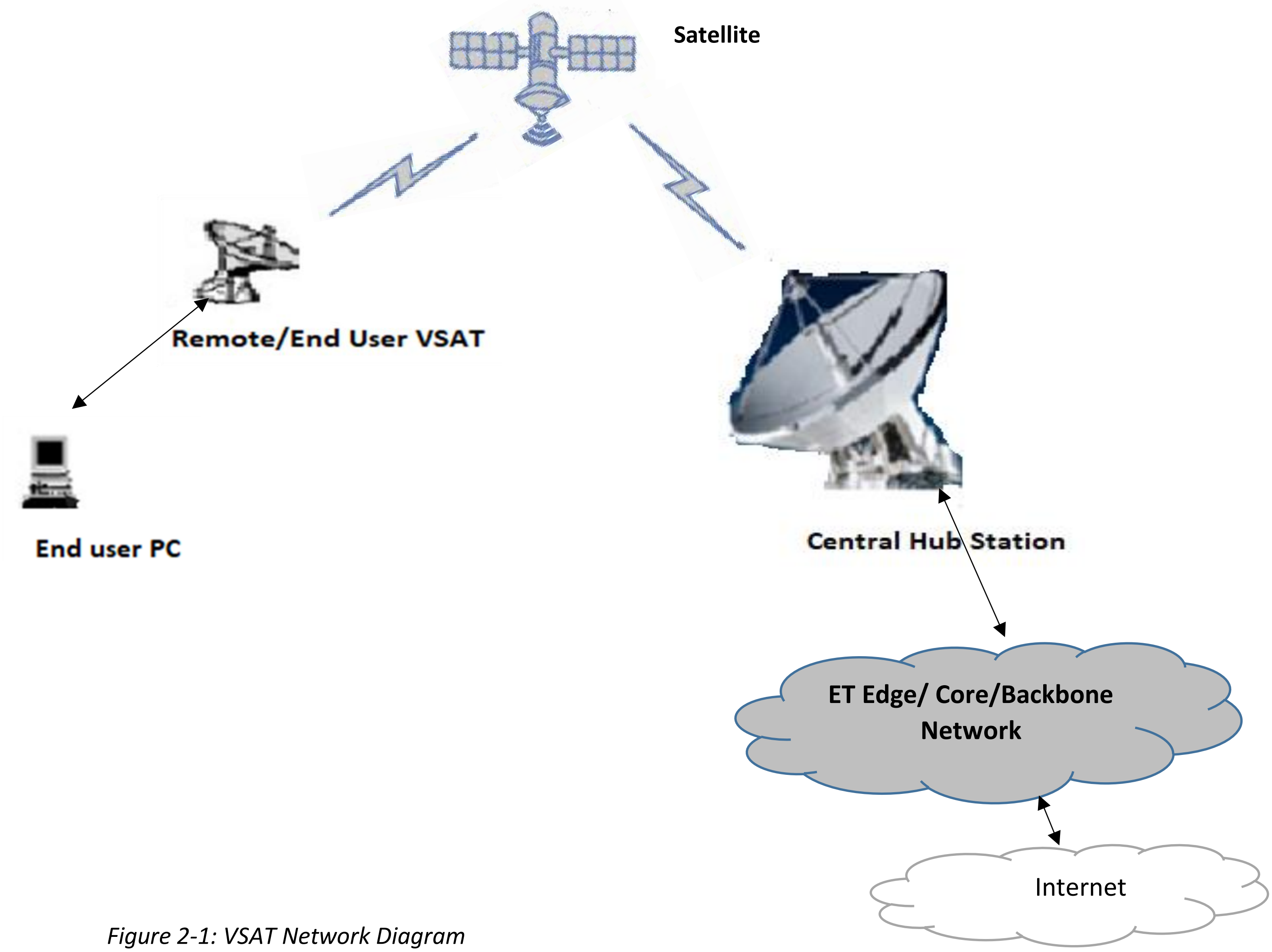


Figure 2-1: VSAT Network Diagram

2.1.3 Aironet/Radwin Broadband Internet

It is one of the FWBBI service used by ethiotelecom for its enterprise business customers. It requires a clear line of sight between ET base station site and the receiver antenna /end user to provide Internet service. Unlike the satellite network this service uses microwave transmission between receiver and ISP base station. It works on point-to-point and point-to-multipoint (shared) forms of connection. According to [16] ET is currently using this technology as a last mile access to provide Internet and data up to 40 km distance away from the fixed network or base station with speeds varying from 256 Kbps up to 20Mbps.It is also being used as the main backup link for customers wired BB network service. A typical ET FWBB Aironet/Radwin point-to-point network diagram for a customer is shown by figure 2-2.

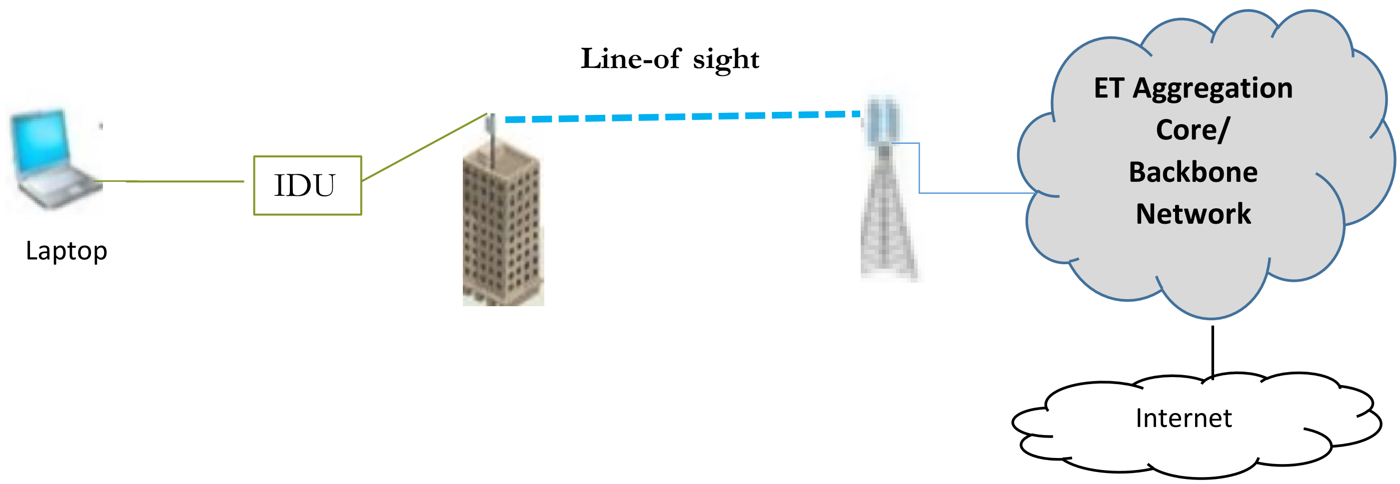


Figure 2-2: Aironet/RADWIN Broadband Internet Network diagram

From a report on [17] RADWIN as one of FWBBI technology deployed by different service providers as a backhaul solution besides to last mile access solution. It works up to a long range coverage distance of 120 Km from the base station site to a receiver end site with a line of sight between them. The spectrum usage is both on unlicensed and licensed. Moreover it supports around 750 Mb aggregated capacity for backhaul solution and also more than 100Mb speed for last mile access connectivity for enterprise customers.

2.2 QoS and its Classifications

2.2.1 QoS Concepts

QoS commonly expressed as end-to-end QoS. It is defined by ITU [18] as the Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service. The characteristics should also be observable and/or measurable. In other expressions QoS is expressed as the collective effect of service performances, which determine the degree of satisfaction of a user of the service. International

Organization for Standardization (ISO) in [19] defined QoS as a "set of qualities related to the collective behavior of one or more objects.“ similarly ISO 8402 defined quality as the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs. Likewise QoS is described by Internet Engineering Task Force (IETF) in [20] as a set of service requirements to be met by the network while transporting a flow, a flow means a packet stream from source to a destination. In other words, QoS is a measurable level of service delivered to network users, which can be characterized by such as packet loss ratio, bandwidth availability, end-to-end delay, and jitter. Such QoS can be provided by network service providers in terms of some agreement (Service Level Agreement, or SLA) between network users and service providers.

2.2.2 Objectives of QoS Assessment/Evaluation

Some of the objectives of QoS evaluations described at [15][21] performed to get benefits in broadband Internet access provision by providers/regulators are to:

- Ensure transparency by making known the minimum and maximum QoS level of service limit, which the service provider is required to provide, and the user has a right to expect, enabling consumers make informed choices among several service providers.
- Verify operators’ Service Level Compliancy by benchmarking their performance against standards, technology, measurement method and criteria imposed by country’s regulatory authority.
- Protect the interests of consumers and enhance consumer satisfaction: Increasing and Diversified Complaints BB Internet Services, Unfair charges and unfair subscription, Provisioning of chargeable Value added services, BB Speed not provided/ extreme variation/ as per plan or advertised.

2.2.3 QoS Degradation Factors

Common or influential factors which affect QoS in telecommunication services as described in [5] are as follows:

- congestion, which is caused by traffic overflow (bottlenecks);
- Delays, caused by networking equipment low performance in large loads, as well as caused by distance or retransmission of lost packets;

- Shared communication channels, where collision and large delays become common, and limited bandwidth networks with poor capacity management

2.2.4 Effective Internet QoS Regulation or QoS Viewpoints

From ITU recommendation [22] definition of QoS management criteria in any communication service could be seen from four different perspectives. The QoS criteria for determining and application of QoS parameters or the usefulness and practicality of QoS framework is determined from the four viewpoints/perspectives which are customers' QoS requirements, service provider's offerings of QoS (planned/targeted), QoS achieved/delivered and customer's survey ratings of QoS. The relationship of viewpoints illustrated in the following figure 2-3.

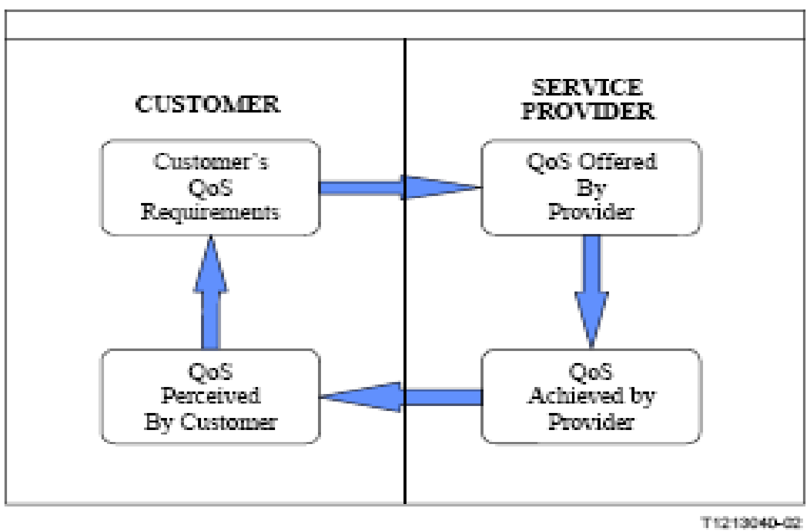


Figure 2-3: Four Viewpoints of QoS [22]

Customer's QoS requirement

It states the level of end-to-end service quality required for a particular application/service. The QoS requirement might be expressed in non-technical terms which can be used for ISP service offering/ planning.

QoS offered by service provider

It is the expected level of quality offered to customer by the service provider. The level of quality expressed in QoS parameter could be used/applied in SLA. Accordingly QoS offered by ISP could be expressed in terms of non-technical and technical terms.

QoS achieved by Service provider

It express the level of quality achieved or delivered by ISP to the customer. QoS assessment on the bases of metrics could be done comparing the QoS offered and achieved by ISP/regulators for publication to customers right/benefit.

QoS perceived by Customer

It expresses the level of quality experienced by customer/user. It is usually expressed in non-technical terms/degree of satisfaction/.

2.2.5 QoS Traffic Classification

Telecommunication services and applications sharing common features can be classified to common QoS classes. Some of the common QoS classes are defined in [23] as described by ITU,IETF, Institute of Electrical and Electronics Engineers (IEEE) and 3G Partnership Project (3GPP). Each QoS classes characterized by a set of parameters. The description of ITU, IETF and ETSI QoS classes expressed bellow.

IETF QoS classification

It recommended/ proposed a 12 QoS classes in its Request for Comments (RFC) 4594 recommendation with the bases of differentiated service (DiffServ) specifications. The requirements of each service class are described qualitatively as a tolerance to packet loss, delay and jitter. The Service class definitions are based on the different traffic characteristics and required performance of the applications/services. It allows to map current and future applications/services of similar traffic characteristics and performance requirements into the same service class. It also provides recommendation for the treatment method of the QoS classes that is recommendations of how to construct the classes using PHBs, AQM mechanisms, and implementations. Four QoS classes designed by RFC 5127 recommendation by aggregating the

12 QoS classes in RFC 4594 (DiffServ QoS classes). It used performance requirements (tolerance to loss, delay and jitter) from end user to map service classes into specific treatment aggregates.

Treatment Aggregate	Tolerance to Loss	Tolerance to Delay	Tolerance to Jitter	Service Class	Tolerance to Loss	Tolerance to Delay	Tolerance to Jitter
Network Control	Low	Low	Yes	Network Control	Low	Low	Yes
Real-Time	Very Low	Very Low	Very Low	Telephony	VLow	VLow	VLow
				Signaling	Low	Low	Yes
				Multimedia Conferencing	Low - Medium	Very Low	Low
				Real-time Interactive	Low	Very Low	Low
				Broadcast Video	Very Low	Medium	Low
Assured Elastic	Low	Low - Medium	Yes	Multimedia Streaming	Low - Medium	Medium	Yes
				Low-Latency Data	Low	Low - Medium	Yes
				OAM	Low	Medium	Yes
				High-Throughput Data	Low	Medium - High	Yes
Elastic	Not Specified			Standard	Not Specified		
				Low-Priority Data	High	High	Yes

Figure 2-4: Aggregation of Diffserv Service Classes [24]

ITU QoS classes

According to [5] ITU defines/proposed six classes of QoS. Each class is assigned to a dedicated group of different applications as indicated in table 1 bellow. The class presents upper bounds on network performance between user network interfaces (UNI). The network provider should support users in QoS traffic flow as far as they do not exceed the agreed capacity. It also indicated that distance and complexity of the path determines the actual QoS offered. The QoS parameters bounds for each different class of service to be guaranteed are as follows:

- IP Packet Transfer Delay (IPTD) (upper bound on the mean IPTD)
- IP Packet Delay Variation (IPDV) (upper bound on 0.999 quantile of IPTD minus minimum IPTD)
- IP Packet Loss Rate (IPLR) (upper bound)
- IP Packet Error Rate (IPER) (upper bound)

Table 2-1: ITU-T Classes of Service, application examples and QoS parameters' values :[5]

CoS	Applications (examples)	IPTD	IPDV	IPLR	IPER
Class 0	Real-time, jitter sensitive, high interaction (VoIP, video teleconference)	100 ms (millisecond)	50 ms	$1 X 10^{-3}$	$1 x 10^{-4}$
Class 1	Real-time, jitter sensitive, interactive (VoIP, video teleconference)	400 ms	50 ms	$1 X 10^{-3}$	$1 x 10^{-4}$
Class 2	Transaction data, highly interactive (signaling)	100 ms	U	$1 X 10^{-3}$	$1 x 10^{-4}$
Class 3	Transaction data, interactive	400 ms	U	$1 X 10^{-3}$	$1 x 10^{-4}$
Class 4	Low loss only (short transactions, bulk data, video streaming)	1 s	U	$1 X 10^{-3}$	$1 x 10^{-4}$
Class 5	Traditional applications of default IP networks	U	U	U	U
U: Undefined/Unspecified					

3GPP/ETSI QoS classes

The 3GPP, working on mobile system defined four QoS traffic classes based on difference in delay requirements each classes are either error tolerant or error intolerant application characteristics. The four traffic classes are conversational, streaming, interactive and background. Similar QoS traffic classification is defined by ETSI in [25] as Universal Mobile Telecommunications System (UMTS) traffic classes in the same way as of 3GPP. The following tabular diagram show the four QoS traffic classes.

Table 2-2: 3GPP QoS traffic Classification: [25]

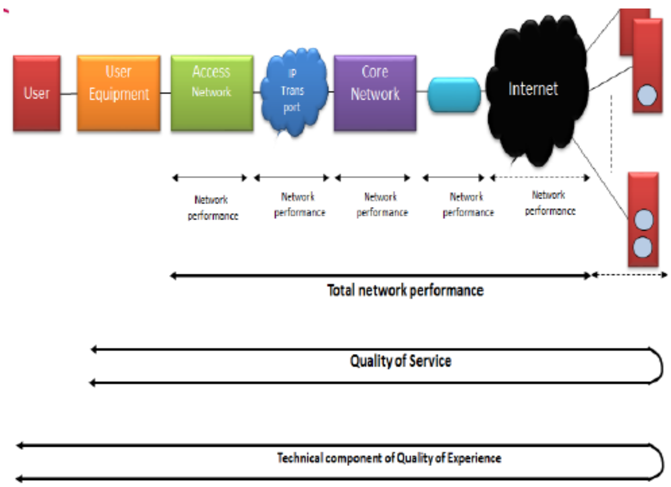
Traffic class	Conversational	Streaming	Interactive	Background
	Conversational real time	Streaming real time	Interactive best effort	Background best effort
	Delay << 1s	Delay <10 s	Delay ~ 1 s	Not guaranteed
Fundamental characteristics	Preserve time relation (variation) between entities of stream (stringent and low delay)	Preserve time relation (variation) between information entities	Request response pattern Preserve payload	Destination is not expecting within a certain time
Error tolerant applications	Voice/video	Streaming audio/video	Voice messaging	Fax
Error intolerant applications	telnet, interactive games	FTP, still image, paging	Web browsing, e-commerce, email server access	e-mail arrival notification

2.3 QoS Parameters in Broadband Internet

Some of applications/uses of QoS parameters in telecommunications services especially in broadband Internet as described by ITU [11] are monitoring quality objectives/goals, to manage and improve quality or SLA service assurance by ISP, defining service quality levels for regulatory authorities/ISP as well QoS parameters allow for quality assessment and evaluation purpose.

In addition the common parameters to measure QoS in broadband Internet from International experiences and standards are indicated in [26] and [15] as download and upload speed, round trip time, packet loss, DNS Response time and availability. The QoS parameters are also classified in [11] into key technical parameters such as packet error ratio, delay, delay variation and packet loss ratio) and non-technical parameters such as service provision (activation-deactivation), network availability (mean down time, mean time to repair, mean time between failure),billing information and service availability.

As indicated in the following figure 2-5, since QoS parameters are user-oriented and end to end (service oriented) they are applied from end user equipment to specified service access point such as server on Internet. Whereas performance parameters might be limited to ISP network which allow to identify and examine specific network-related quality problems moreover QoE parameters expresses user perceptions.



Quality of Experience (QoE)	Quality of service (QoS)	Network Performance (NP)
User oriented		Provider oriented
User behavior attribute	Service attribute	
Focus on user expected effects	Focus on user observable effects	Focus on planning, development (design) operation and maintenance
User subject	Between (at) service access points	End-to-end or network elements capabilities

Figure 2-5: Application areas of End-to-End (E2E) QoS parameters compared to QoE [11]

The common QoS parameters used to measure broadband Internet QoS which are applied in this research for SLA design are described bellow

- Throughput (upload and download speed)
- Round trip time (RTT) delay
- Jitter
- Packet loss

Throughput (Upload and download speed): is a measure of how much data is transferred across a link or a network in a certain time (specific time interval).The rate of transmission at which data passes through a device usually measured in bits per second. It is expressed by the following formula.

$$Throughput = \frac{\sum sent\ data(bit)}{time\ to\ deliver\ data(s)}$$

Round trip time delay: delay can be measured in terms of one-way or two way. RTT-delay could be termed as two-way or bi-directional delay, is the round trip time interval taken by a packet to go from the origin to the destination and return back. The ICMP ping delay is an RTT-delay in which half of it is one-way delay while RTT-delay is also described by IETF RFC 2681 as twice the time required for a packet to traverse the network or segment of the network. The end-to-end delay (one-way) includes processing delay, propagation delay, queuing delay and transmission delay. As indicated by cisco [27] one-way delay could be calculated dividing RTT-delay by two. It is influenced by network congestion, link failure or device performance [28].

The different types of delays could be describes as **Processing delay** is the sum of delays caused by all the intermediate nodes on the network path processing the packet. **Transmission delay** (or serialization delay) is the time it takes to send out a packet at the bit rate of the link or the amount of time required by a router to push the entire packet onto the link. **Propagation delay** is the time required for the signal to travel from one end of the transmission medium to the other. **Queuing delay** is the amount of time a packet spends inside routers' queues.

. *[Ping delay] = [$t_{Packet\_received} - t_{Packet\_transmited}$] in ms (millisecond)*

Where $t_{Packet\_received}$ is the time when packet is received at destination

$t_{Packet\_transmited}$ is the time when packet is transmitted or originated

Jitter/delay variation: is defined as variation between packets transfer delay measured in ms. It can be expressed by the following formula:

$$\text{Jitter} = \frac{\sum Variation\ in\ delays}{\sum packets\ received}$$ *Or* Jitter = $|D_{n+1} - D_n|$ where D is delay in ms and for n=1, 2 ….N

Packet Loss: can be defined as the rate of lost data packet during delivery from/to the origin to/from the destination in a specific time interval. Or rate of packet loss per transmission or ratio of total lost IP packet to total transmitted in a population. It can be expressed by the formula:

$$\text{Loss} = \frac{N_{Lost\_packets}}{N_{all\_packets\_transmited}} \times 100\%$$

Where N_lost_packets: total number of data packets lost during delivery from origin to destination and

N_all_packets: total number of data packets

$$Or \quad \text{Loss} = \frac{\textbf{total transmited packets} - \textbf{total received}}{\textbf{total transmited}}$$

2.4 QoS Measurement Methods and Systems/Tools in BB Internet

2.4.1 QoS Measurement/Monitoring Approaches

Measurement /monitoring the quality of BB Internet service is important to know the quality provided/achieved by ISP to its customers. Measurement is done based on the identified QoS parameters for Internet-based service/applications. According to ITU recommendations, IETF and papers [15][9][29] the types of methodology for measuring the QoS of Internet services are active, passive or hybrid testing mechanisms.

Active Monitoring/Measurement/Testing Approach

It is performed based on artificially generated traffic or probing packets between destinations sending and receiving sites. The probing of injected packets in the network connection allowed to measure the QoS over the Internet. It provides a proactive approach to network troubleshooting a potential problem that affects a user. As described in [26] It is commonly used by regulators and ISPs since it allowed controlling service types, easy benchmarking or comparison between measurements over the Internet. While it requires line to be fully available, leads additional cost in implementation and some possible disturbances.

Passive Monitoring/Measurement/ Approach

The measurement is done on the bases of sniffing of user data no need of additional traffic injection to the network. The actual or real user traffic data might be collected for a period of time. This type of traffic monitoring between destinations used for service quality analysis mainly for identifying network bottlenecks/troubleshooting. It needs only one connection point to the network and does not affect or inconvenience to end users. But it is difficult to test maximum line capability since traffic/service type not known and difficult to average different tests as the data traffic is not consistent.

Hybrid Monitoring/measurement

It uses the combination of both active and passive measurement approach. It uses passive monitoring where possible and active monitoring when passive information is unavailable. Intrusive/non-intrusive, active-passive, user centric-network centric, subjective-objective

2.4.2 QoS Monitoring Systems and Tools in Broadband Internet

There are different tools which are applied to check or measure the quality of Internet services. From [15][21] [21] two systems of measurement tools listed which are privately owned or third party measurement systems like NetIQ, Opticom and public domain tools or freely available over Internet tools like speedtest.net and measurementlab.net. These measurement tools are categorized into hardware-based and software based in [9].

Hardware-based tools

The hardware based testing tool approach usually performed by deploying hardware-based probes tools or white-boxes to clients to perform quality measurements while users are not actively using Internet. It is commonly used by Samknows in FCC, BISmark and Dasu projects. According to [9] it can be implemented in four ways: In the first option probes replace the end user's equipment and no other equipment can be connected to the Internet access while the probe is performing measurements. In the second option probes shares the Internet access with ordinary traffic and perform the tests only when there are no traffic being transferred. The third option is where a testing API is embedded into the customer's residential gateway through a firmware update, in order to act as a probe and test the fixed Internet connection. The Fourth option is used in mobile drive test.

Software-Based tools

This approach is inexpensive since it does not require additional hardware device and offers flexibility in service quality measurement. Three types of tools listed in [9] these are:

- Web based tools: the measurement software is initiated with the end user web browser. e.g. https:// speedtest.net
- Dedicated software client: the measurement software should be installed in end user equipment/device to perform test.
- Testing API: the code included/embedded in a popular website to perform test every time a user access a website.

CHAPTER 3

3. QoS Measurement Methodology

3.1 Techniques to Measure QoS

3.1.1 ICMP Ping

A common use of a ping tool is for probing a remote device to test if the host is functional or reachable. In this research the essential ping utility software tool is used to measure RTT-delay, jitter (delay variation) and packet loss. Where researches like [30] described that ping is a widely used latency (RTT delay) measurement utility which uses ICMP, the part of IP suite for error reporting and diagnostic utility. Ping works by sending a sequential number of the ICMP echo requests and replies which is used to calculate RTT value. A round-trip time can be calculated from the request time was sent to the time when reply was received. The computed RTT values then displayed as minimum, average and maximum.

Furthermore jitter or delay variation and packet loss could be calculated or determined from the returned ping utility data. Packet loss rate is computed by dividing the amount of lost replies with the total amount of requests sent. Jitter is calculated from variance of packet inter-arrival time or from two successive packets' delays. The ICMP ping is commonly and widely used by different research works like [12][31] [32] for RTT-delay, jitter and packet loss measurement. The following diagram, figure 3-1 shows how ICMP ping works.

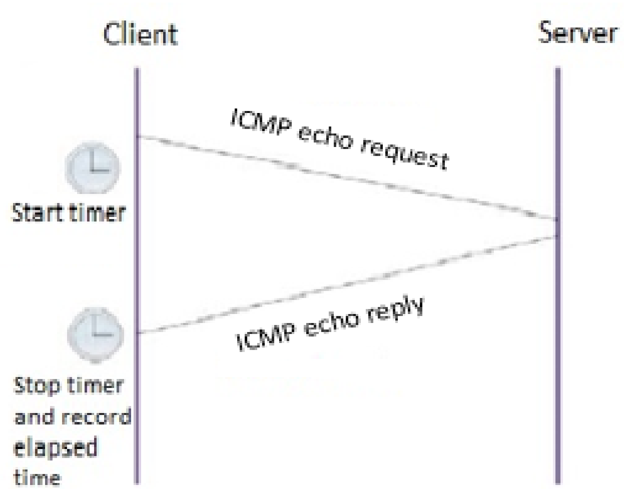


Figure 3-1: The Process of ICMP ping:[30]

3.1.2 Throughput Measurement (Testmy.net)

Testmy.net is web based software which applied to measure the throughput (download and upload speed) traffic data easily. It is a testing method which uses latest 5th revision of HTML (HTML5) where most web pages are based on the technology which supports both on desktop/laptop/ and mobile devices. As well it does not use flash or java plugin testing to reduce security vulnerability and application overhead. Moreover It uses single threaded measurement feature but has additional feature for multithreading speed test. It works on either wired or wireless including mobile BB Internet services.

According to [33] in flash based testing like Ookla speedtest.net make adjustments in test result, about 10% fastest and 30% slowest results discarded and the remaining average result taken which might affect the accuracy of the test while it is not performed in testmy.net i.e. all the actual measurement results used for calculation. In addition speed test tools like Ookla speedtest.net are multithreading which might result in network congestion. In [34] though multithreading show the maximum connection speed which assumed has benefit to ISPs it has issues/influence on creating network congestion which affects end user throughput.

The testmy.net tool works on active monitoring method generating random traffic data to test the throughput (download and upload speed) on real time. The traffic is under controlled conditions from known server to check the quality and benchmarking the result. The test result is calculated with simple calculation (size/time) in a way that the final result is calculated based on it. It does not reject or adjust test result, everything is calculated. It also shows issues related to protocols, bad hardware or performance issues while testing. This tools is applied in different researches such as [31][32][35] for bandwidth related performance measurement and reviewed by lifewire.com (technology information and advice website) as one of the common Internet bandwidth measurement sites and no associating to any ISP.

3.2 Measurement Methods in FWBBI QoS

The measurement activities in this research is carried out where more of the FWBBI service customers are provided by ET. In ET FWBBI service specifically VSAT and Aironet/ Radwin services mainly used in remote/ rural locations where the wired/mobile broadband services not covering or not available and as wired link backup purpose. So the QoS test areas focus mainly at remote ET regions Afar, Somali, West, Gambella and Addis Ababa (AA). Then twelve sites were randomly selected from each of the different regions for QoS measurement where four from west region, two from Somali, one from Gambela, one from Afar and four from Addis Ababa regions.

The Measurement is done by the customer's technical personnel through their desktop or laptop device which has a dedicated FWBB Internet connection. It is assumed that while the test/ measurement is performed no other computer is allowed to connect Internet connection for accuracy of the test. The test is basically done on active measurement approach by generating traffic data during working hour for user convenience. The measurement time/session is also classified into morning and afternoon to get the consistency of the service quality.

The QoS metrics- RTT delay, jitter and packet loss measurement data is found using ICMP ping. The windows ICMP ping is initiated from a client computer with FWBBI connection to a commonly stable (not affected by congestion related factors) google DNS server IP address (ping 8.8.8.8) to get the actual RTT-delay, as well jitter and packet loss are also derived from ping result. Based on ping test /measurement/ a total of around 12000 packet sample collected with each sites 1000 packets. The measurement is done at different days, time and period to get the consistency on RTT-delay, jitter and packet loss level of the service quality.

Throughput (download and upload speed) measurement is performed by using testmy.net web tool. The measurement is done in the morning and afternoon period initiated from client computer through a browser by testmy.net website to a server (testmy.net server) selected appropriately by the testmy.net algorithm. The size of data is selected randomly using the site algorithm based on connection speed for testing download and upload speed. It has a feature for periodically (per hour, 2 hour...) or automatically test both download and upload speed without user interference once it is configured. Based on this download and upload data is collected in two weeks period at the morning and afternoon sessions of working days and hours. The collected data is saved in comma separated values (csv) format containing different measurement information such as day, time, type (download, upload), test data size, speed, test ID etc.). The measurement session is shown in table 3-1.

Then the data for metrics download, upload speed, RTT-delay, jitter, packet loss prepared in Ms excel. The jitter and packet loss metrics calculated in excel based on the equation 3 and 4 section 2.3 chapter 2. The data in excel then entered into MATLAB normalized to use a common scale. Where the data used in MATALB for further probability distribution analysis, pdf (probability distribution function) and CDF graphical analysis as well SLA design purpose.

Table 3-1: Measurement Session/Period/

No	Measurement session	Period/time (local time)	Remark
1	Morning	2:00 - 6:30	
2	Afternoon	7:00 - 12:00	Somali and Gambella regions have different working hour

3.3 FWBB Internet QoS Measurement Scenario/Test Model/

The basic network architecture/test-scenario/ applied in this thesis to measure end-to-end QoS delay, jitter and packet loss test is from end user device to *international server* on Internet which is to the common public IP (google DNS server IP address) and for throughput (download and upload speed) measurement starting from end-user device to testmy.net server on Internet using ITU recommendation for E2E broadband Internet QoS assessment as shown in the following diagram, figure 3-2.

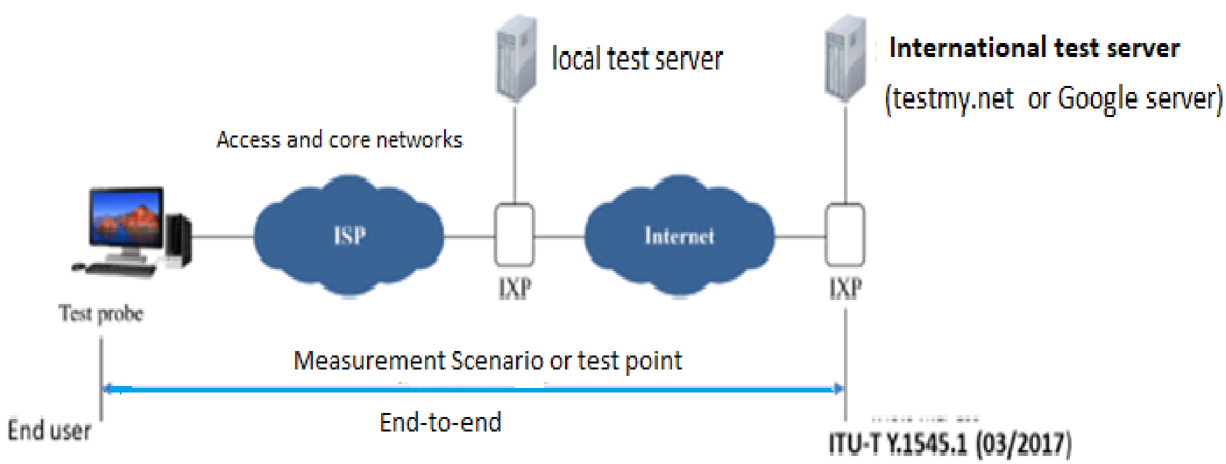


Figure 3-2: End-to-end QoS measurement setup

CHAPTER 4

4 SLA Management

4.1 SLA Concepts and Definitions

SLA is defined by [36] as a contract between service providers (SP) or between SPs and customers specified by measurable terms that the SP delivers and what penalties the SP will compensate if it could not met the committed goals. In [37] SLA is expressed as a mechanism by which the customers measure how well their service is performing. It should include a list of objective measures to demonstrate the service quality. It is also defined by ITU in [38] as a formal agreement between two or more entities that is reached after a negotiating activity with the scope to assess the service characteristics, responsibilities and priorities of every part. Its goal is to reach to the agreed QoS with end user and obtain user satisfaction. Similarly TeleManagement Forum (TM Forum) in [39] defined SLA as a formal negotiated agreement between two parties. It is a contract that exists between the SP and Customer. It is designed to create a common understanding about QoS, priorities, responsibilities, etc. SLA could cover many aspects of the relationship between the Customer and the SP, such as performance of services, customer care, billing and service provisioning. Although SLA could cover such aspects, agreement on the level of service is the primary purpose of a SLA.

4.2 Components and Structure of SLA

The general structure of SLA is described in the Figure 4-1 bellow. It is referred by multiple service SLA agreed between parties which has one common part and other service specific parts.

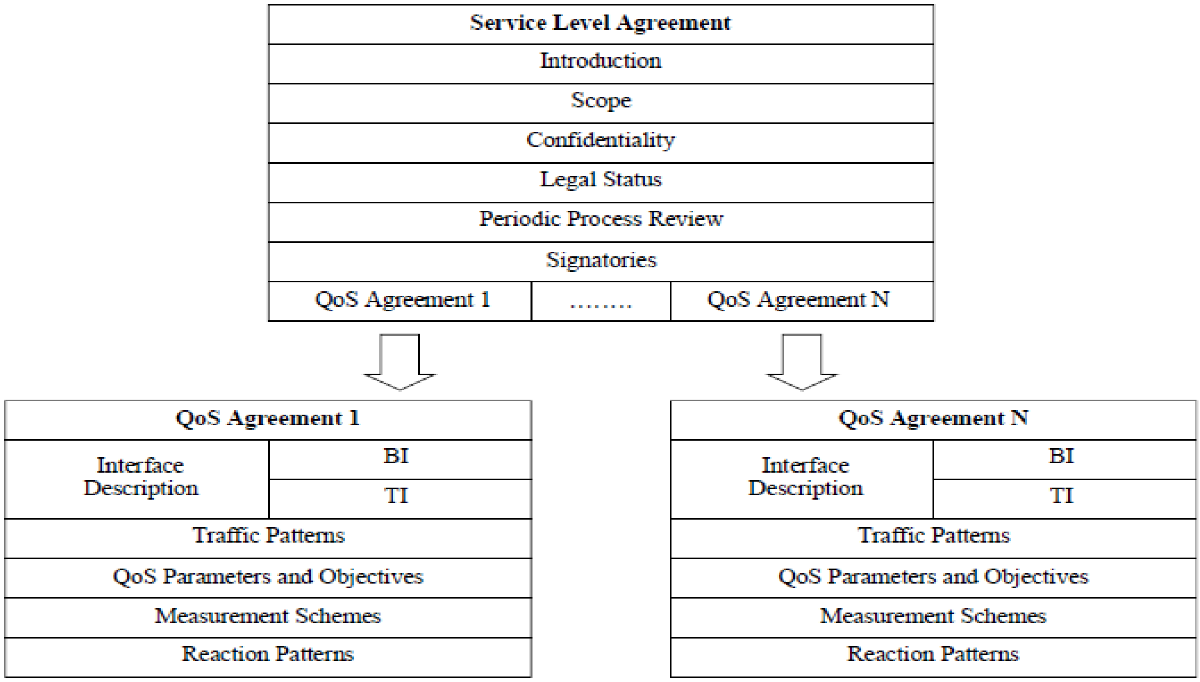


Figure 4-1: General Structure of SLA [38]

Description of major SLA parts/structure [38]

Introduction: describes the purpose of SLA i.e. define service levels all entities to guarantee and notions of measurements and parameters for realization of the agreement.

Scope: describes the SLA service with the target performance or quality.

Review process: defines the QoS exchange information with the frequency of review process on QoS agreement and formats.

Compensations: describes the compensation provided to customer for unreached level of QoS.

Signatories: representatives should sign the agreement to ensure obligations are undertaken.

Interface description: logical boundaries between entities and composed of Business (BI) and Technical interface (TI). BI located between user and SP for QoS agreement, negotiation, performance reporting. While TI is for service specific function and QoS measurement.

Traffic pattern: QoS agreement must include description of all the exchanged traffic and easily justifiable. Additionally the threshold should have to be specified.

QoS parameters and objectives: the QoS parameters should have to be specified for end user in a clear, convenient and simple language. Moreover the QoS objectives are expressed by target values and thresholds.

Measurement: Once the QoS parameters and related target values have been agreed, both parties should agree on measurement definitions and schemes. Measurement descriptions should include a description of what, when, where and who should perform measurement, procedures and test processes.

Reaction pattern: a process activated when commitments are not fulfilled on traffic patterns and QoS parameters. Possible reaction might be

- No action
- Monitoring the achieved QoS
- Traffic flow policing
- Reallocating resources
- Warning signals
- Suspending or aborting the service

Generally in order to define the SLA contract between two parties or actors,[36] stated that SLA should contain the following information:

- Customer and SP responsibilities. For instance it can define who is responsible of maintaining the hardware and software of the Customer Premise Equipment (CPE).
- SP procedures to be invoked in case of violation of service level specification (SLS) guarantees (e.g. mail, call).
- Service pricing and discounting policies to apply when SLA commitments are not satisfied.
- Service description and the QoS commitments.
- Reporting to the customer QoS delivered.
- Other features should be defined such as there is ability (privilege) of a customer to change some of the SLA parameter settings himself.

4.3 SLA Lifecycle

According to research [40] SLA management has five common stages or distinct phases as illustrated in figure 4-2 bellow. The first phase is SLA Service development, negotiation and Establishment, second phase is SLA Deployment, the third is the measurement and reporting, the fourth is corrective management actions and the last is the SLA termination/withdrawal/

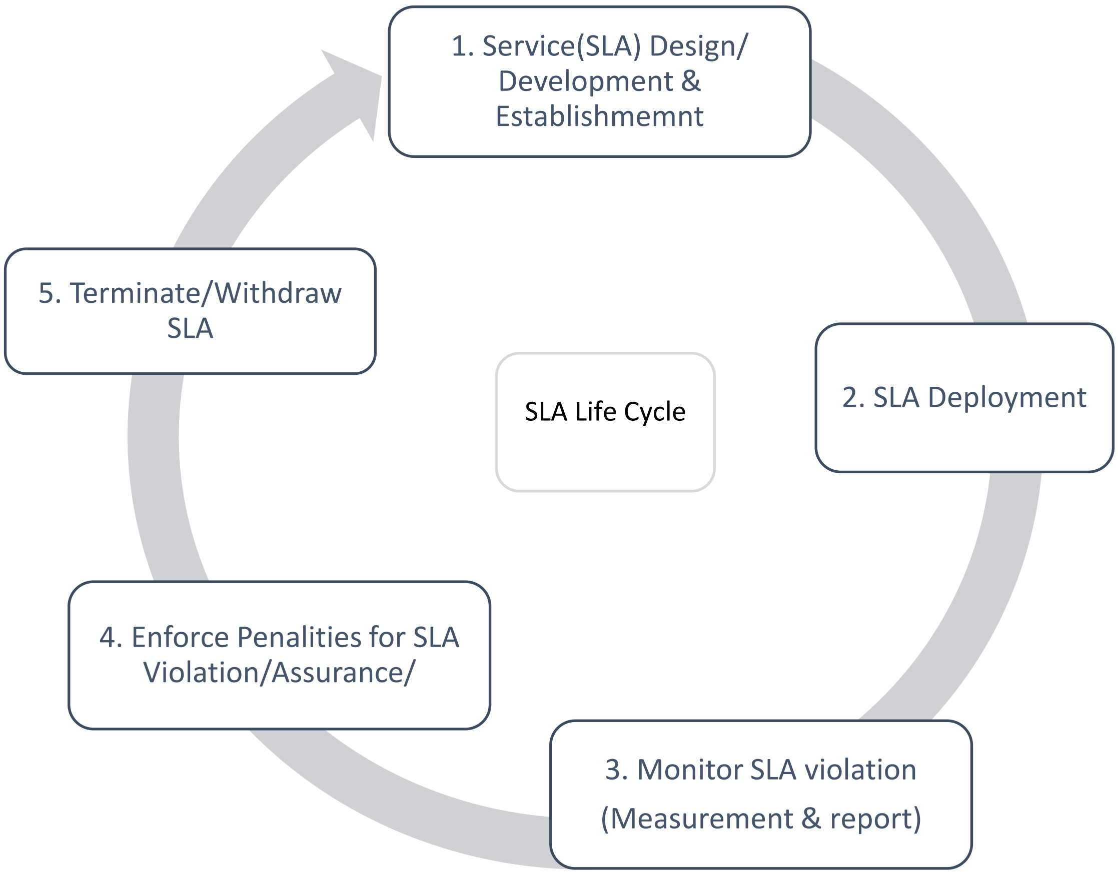


Figure 4-2: SLA Life Cycle: adapted from [41]

Common phases of SLA [40]

Phase 1: SLA Service development, negotiation and Establishment/sales/

It consists of the identification of customer requirements/needs/ and network capacity/ capability where the SLA template shall be prepared. Then both parties (customer and SP) should also sign the SLA on negotiation between them. In this phase the parties/signing parties/

establish SLA, price and sign on offering services. Both parties should approve on offered SLA metrics, define their responsibilities and make the SLA document available for deployment.

Phase 2: SLA Deployment/Provisioning stage/

The signing parties are also responsible for checking the validity of SLA, the supporting parties are clearly informed about their roles, duties and know definitions, metrics and analyze the SLA. Besides the ISP implementation of network resource provisioning and activation of service or configuration.

Phase 3: **Measurement and Reporting/Assessment/**

It deals with whether the SLA is met computing by metrics. It measures the SLA QoS parameters such as availability, speed, etc. based on the agreed time intervals/ frequency or duration. Then the QoS report compared against the threshold defined at SLA and/or notify the management/ periodically by the corresponding parties.

Phase 4: Corrective Management Actions /Assurance/

Once SLA violation is determined corrective action/functionality should be performed. Since the verification of SLA violation might result the SP to be penalized based on agreement, a customer might got a free service, reduction in monthly price or allow the customer to break SLA and shift to other SP (in multi-ISP environment) without penalty.

Phase 5: SLA Termination/withdrawal/

The SLA should specify conditions when it shall be terminated or the compensations/penalties incurred during breaking of SLA parameter (s) or unreached level of quality. An expiration/validity period/ date or renewal/review/ date of SLA should also be specified in SLA.

4.4 Characteristics of SLA

The characteristics of SLA are described in [42] as foundation, change and governance.

- **Foundation characteristics**: includes provisions which specify the key agreements and principles among actors, the SP and their responsibilities and roles, and the expected service performance levels. The aim is to share the objectives, responsibilities and clear procedures or conduct set by the provisions of the actors involved in the SLA.
- **Change characteristics**
  It is a legally binding expression related with SLAs including provisions concerning processes for resolving prospective demands, unpredictable outcomes, and processes for developing predicted contingencies. As well as transformations, operations for recommending new innovations coordinated with motivating force designs, and processes of efficient adjustments and feedback in the bilateral contract [42].
- **Governance characteristics**
  It is contractual qualifications connected to SLAs characterizing the ways to keep the relationships through clear measurement statements, incentives and penalty, options for termination and accountabilities. It is a well-defined processes for documented communication as well as processes for resolving and recognizing of potential disputes.

4.5 Applying SLA and Trends in ET

According to [8] to assure QoS for its esteemed customers ET began to launch BB Internet SLA service framework in Dec 2013. Where the SLA service was mainly with availability metric and its pricing scheme. However the SLA service did not has customer since the customers do not accept the tariff and business modality of SLA service framework, as it is specified in [8]. This framework was also revised in May 2016 and recently in July 2019 with improvements on pricing, penalty, customer care/support, or billing related metrics without specifying the minimum level of technical QoS guarantee. The SLA service has also compensation policy on SLA violation level with limited liability on monthly rental fee as specified on [8].

The penalty or compensation could be applied based on SLA monitoring by the ISP to its esteemed customer for un-fulfilment or unreached service level or target. The SLA violations or breaches could be of various types. The Service level the ISP provided and the customer experienced could be categorized in [43] and described as all or nothing provisioning where provisioning of service that meets all technical QoS in SLA, partial (under) provisioning where only some of QoS in SLA satisfied and weighted partial provisioning where weighting/influential/ QoS greater than the threshold.

The application of SLA in setting target/objectives, penalties or compensation, monitoring mechanisms schemes or mechanisms might vary from ISP and regimes/countries. For instance the Italian regulatory authorities allow the customer to terminate the SLA without penalties and shift to any other service provider if they got evidence on SLA violation or SLA not respected [6]. Comcast a known ISP in America has different compensation schemes based on service type as stated in [44] for instance if interruption occur for more than 24 hours to its business class Internet service the customer will receive a credit for each 24-hour period. In addition the Customer will receive a credit of 10% of the normal monthly bill for Video or Public View Video service for each 24-hour period that the Service Interruption continues.

Moreover according to [45] broadband business customers service quality under performance guarantee or totally service unavailability might resulted to compensation variable based on location/regime/ and service types. For instance the United Kingdom (UK), BT service provider has a compensation policy for loss of Internet connectivity service on the bases of unavailability range. The Australia Telestra compensates the monthly rental price of the service on service unavailability due to unfulfilled fault repair commitments. In Denmark service provider will pay a fixed amount of cost for each delayed repair or unavailability of service.as well the ISPs in Belgium are obliged to pay 150% of the daily rental fee per calendar day on the basis of service unavailability or unrepaired commitments. In addition ISPs in Netherlands compensation variable on daily basis 1-10 days, 11-20, and 21-30 days a fixed cost applicable on daily basis €1, €2, €4. The France Telecom Orange has also a compensation scheme for its business customers vary by service type and location.

CHAPTER 5

5 Result and Discussions

The QoS metrics, tools, measurement methodologies applied in this research and SLA concepts are well explained in the prior chapters. Whereas this section mainly describes about the QoS measurement results and analysis using the metrics throughput (download and upload speed), RTT-delay, jitter and packet loss. The QoS measurement data prepared in excel applied for analysis in MATLAB version 9.4. The analysis is made mainly based on the ITU recommendation [46] such as mean, median, tables and probability distributions functions (CDF and pdf) for QoS assessment in ISP services like BB Internet monitoring data. The analysis result is further used for defining/ designing SLA based on the objective QoS metrics.

5.1 Throughput

5.1.1 Download Throughput

The average download throughput measurement using testmy.net tool, from different test sites/location, days, times, on FWBB technologies (VSAT and Aironet) and available speed types are organized in excel. Then the customers' measured download speed of data (actual versus advertised) CDF and pdf values are normalized. In doing so the CDF and pdf of normalized data is analyzed graphically using MATLAB. Tabular analysis also performed using excel to get summarized average download throughput. The CDF of normalized download throughput for the overall FWBBI service as well as the comparative analysis of customers by technology is shown in the figure 5-1 bellow.

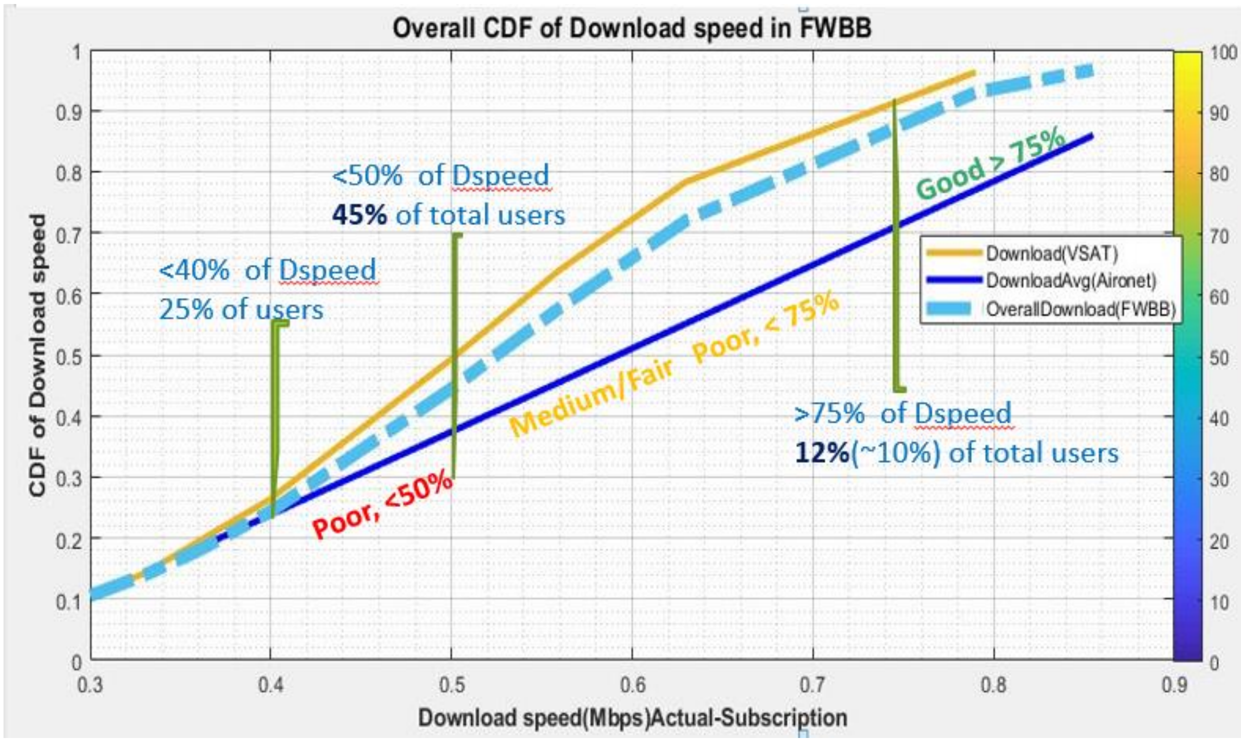


Figure 5-1: Overall FWBBI CDF of Actual-Subscription/Advertised Speed analysis graph

As shown from the above graph (Figure 5-1) the overall download speed of the customers which are provided with above 80% of subscription speed consistently is only around 10 %. Whereas ITU in [15] recommended BB Internet connection download speed minimum threshold from user to ISP should be greater than 80% of advertised speed. As it can be seen from the graph 5-1 the actual/measured/ average download throughput of FWBBI service customer is consistently above 30% and below 90% of the subscription speed. ET could offer above 75% of the subscription speed for about 12% (~ 10%) of its customers whom belongs to the good category from state-of-the-arts described in [13] [31] [47]. Whereas majority of the results, about 55% of customers download speed belonged to more than 50% of subscription speed which is fair/acceptable category. The remaining around 40% of the results shown in Figure 5-1 belong to the unsatisfactory/ poor service.

According to UK regulatory office of communication (Ofcom) 2010 report [48] around half of the customers actual average download throughput was 50% the advertised speed. While the UK 2018 fixed-line BB performance consumer report [49] showed a continued improvement in UK ISPs download throughput delivery, the actual download speed is generally lower than the advertised download speed. Similarly the Italian regulatory 2011 BB QoS monitoring research report [6] showed that the average actual download speed of customers was half of the advertised/subscribed/ speed.

In addition from figure 5-1 and 5-2 the overall FWBBI service average measured download speed is around 53% of advertised speed which is considered as fair/medium. Whereas when specifically seen the FWBBI service from sub-technological view the average download speed is better in Aironet (59%) than VSAT (50%). Some inconsistency of download speed is also shown both at Aironet (36% - 86%) and VSAT (30% - 80%) BB Internet services. Speed consistency is also important in services such as VoIP and streaming BB Internet traffic.

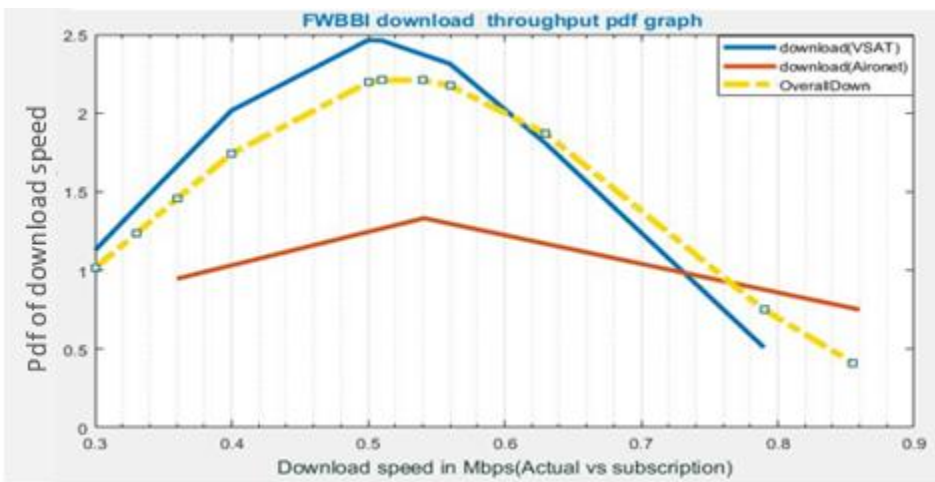


Figure 5-2: Overall FWBBI pdf of Actual-Subscription/Advertised Speed analysis graph

The overall average actual download speed measured in Mbps for FWBBI service is 2.78 Mbps and in its percentage from the subscribed speed is 53%, comparing by technology the download throughput result in VSAT is 0.26 Mbps in percentage 50% whereas in Aironet it is 8.86 Mbps and in percentage it is 59%, it could be seen in the following table 5-1.

Table 5-1: The average actual download and upload speed at FWBBI service

No	Description of service	Download speed (in Mbps)	Actual-advertised download speed (in %)	Upload speed (in Mbps)	Upload (%)
1	FWBBI (Total)	2.78	52%	0.68	70%
2	VSAT	.26 (260Kbps)	50%	0.096 ~ 0.1	75%
3	Aironet	8.86	59%	2.23	63%

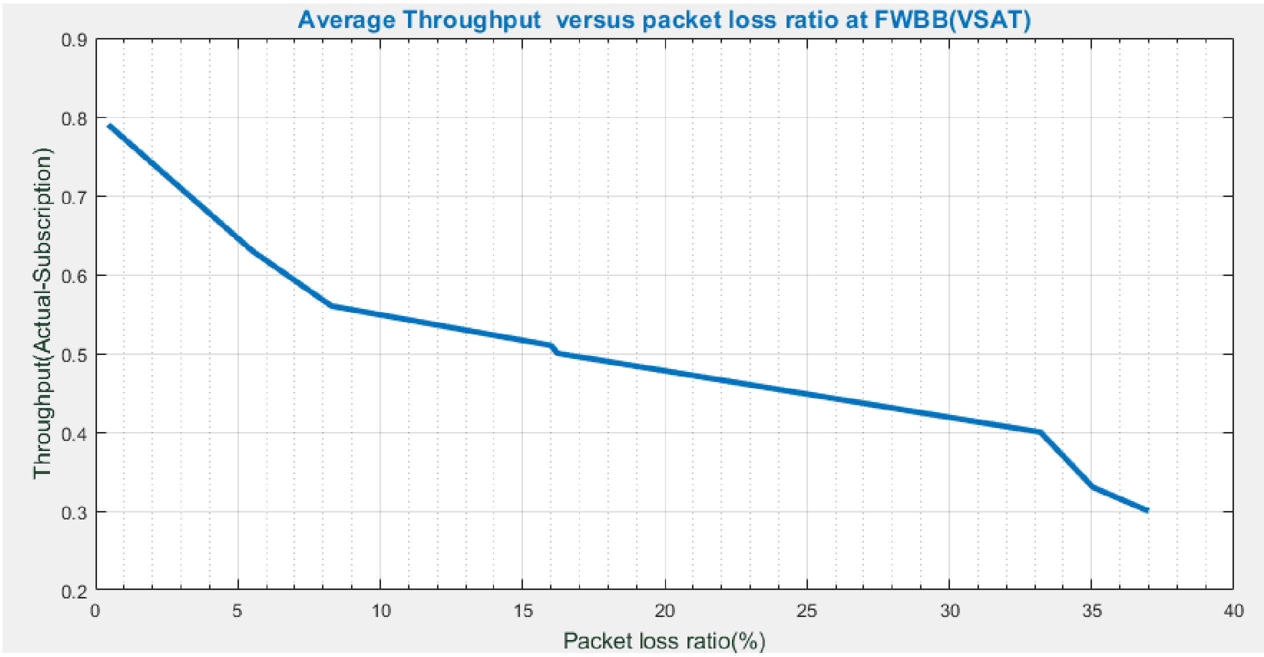


Figure 5-3: Download speed vs packet loss in FWBBI (VSAT) service

The above figure 5-3 showed the relationship between download speed and packet loss measured in FWBBI service specifically VSAT. Hence from the graph depicted above (Figure 5-3) while packet loss increases there is decrement in throughput (download speed). And also it showed the existence of higher packet loss rate which need to be solved otherwise highly influence the download speed quality of service and customer satisfaction. The sample test data is based on the average download speed versus packet loss monitored through morning to afternoon where there is more packet loss in the morning time whereas low packet loss is registered in the afternoon. The higher packet loss might be due to congestion rate occurred at the morning time.

5.1.2 Upload Throughput

Upload speed is important in some popular services/applications such as VoIP and video conferencing hence protecting the minimum level of guarantee is necessary. The upload speed is measured, CDF and pdf analysis is done in MATLAB in similar manner of the download speed. From the bellow graph figure 5-4 the average upload speed in FWBBI is consistently above 25% of subscription in FWBBI service and sometimes above subscription speed is seen. More than

50% of subscribers got above 70% of subscription speed 20% of subscribers got above 90% of subscription speed. When the FWBBI service upload speed is evaluated from state-of-the-arts described in [13] [31][47], 45% of the results belong to good, 35% fair/medium category and 20% of customers are with poor service.

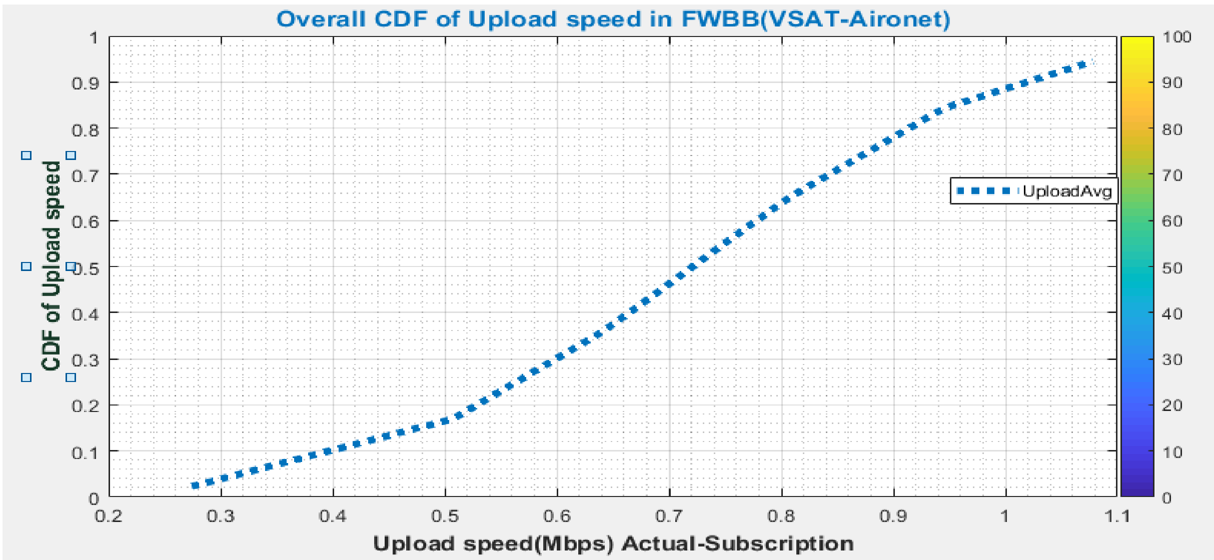
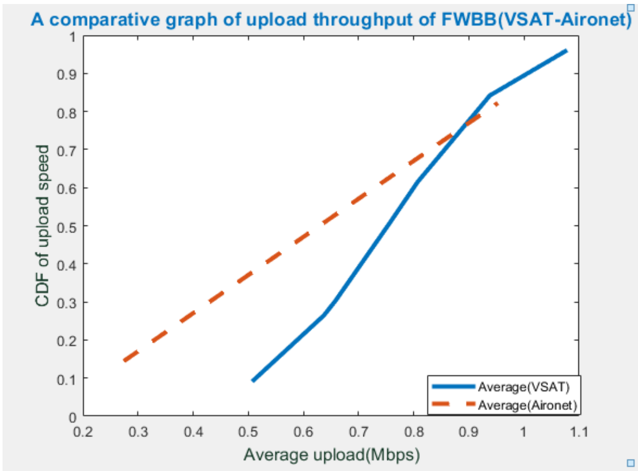


Figure 5-4: Overall FWBBI services upload throughput distribution

When compared to the download throughput from the graph 5-1, customers got slightly better upload throughput than download. Besides, from the graphs 5-5 and 5-6 upload throughput distribution is consistently above 50% and 30% of subscription speed in VSAT and Aironet respectively. As well from the graphs it can be concluded that there is higher variation in upload speed consistency both at Aironet and VSAT.



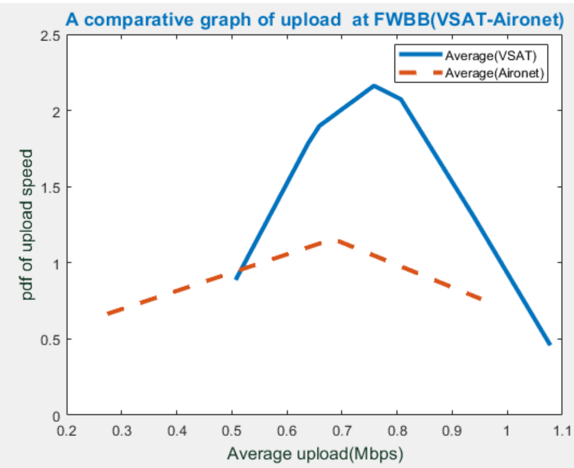


Figure 5-5: Comparative FWBBI CDF graph upload speed   Figure 5-6: A Comparative pdf of FWBBI

5.2 Packet Loss

Using ICMP ping sample packets sent from end user to server on Internet (google DNS server IP) succeeded and failed packets, the packet loss is calculated. Where the sample test measurement is performed at different days, time (morning /afternoon) of the working days each sites 1000 (10x100) and totally 12 sites (12000) number of packet sample collected. Then the data prepared in excel and analysis on MATLAB in which data normalization, distribution (pdf and CDF) calculation and graphical analysis. Finally the analysis is used in defining/designing QoS-SLA.

The details of CDF and pdf packet loss analysis in FWBBI service is shown in the following graphs figure 5-7 and 5-8. The overall average packet loss rate in FWBBI service is about 13% as it can be seen from the graphs 5-7 and 5-8 bellow, which belong to the medium/fair/acceptable category (<15%) as it is evaluated from the ETSI standards [50]. Similarly about 47% or half of the customers belong to the medium category (<15%), 25% belong to the good (<3%) and the remaining 20% belong to the excellent category (0%). Moreover the average packet loss ranges from minimum 0% which is excellent to peak 37% which is bad category.

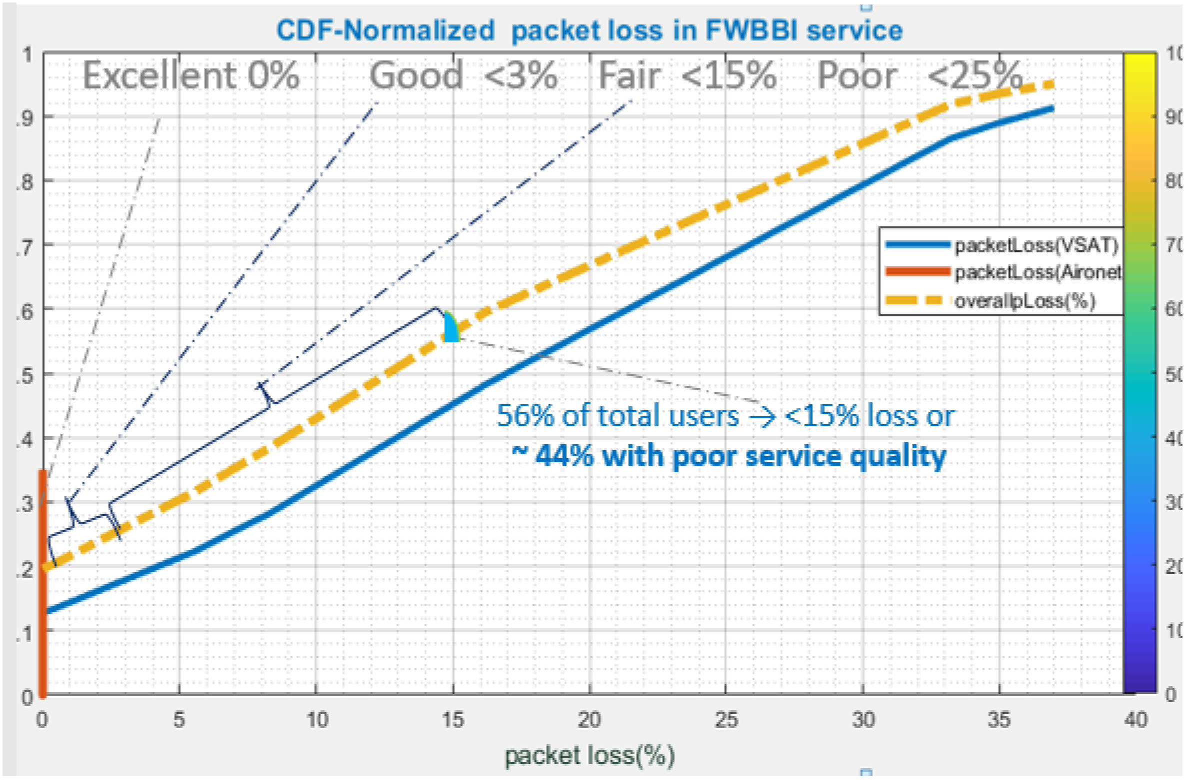


Figure 5-7: Overall CDF of normalized packet loss graph in FWBBI service

When it is specifically seen the packet loss rate based on FWBBI sub technologies from the graphs 5-7 and 5-8 , the average packet loss rate in Aironet is consistently about 0% which is excellent as it is evaluated from ETSI standards in [50]. However it has higher variation ranging from 0% (12% of customers) or excellent to maximum 37% which is bad in VSAT (FWBBI sub service). On average over 50% of customers got VSAT BB Internet service with around 17% packet loss rate which is poor. And also 18% of VSAT customers are affected by 3% of packet loss (good) and around 30% of customers affected by >25% packet loss which is under the bad category.

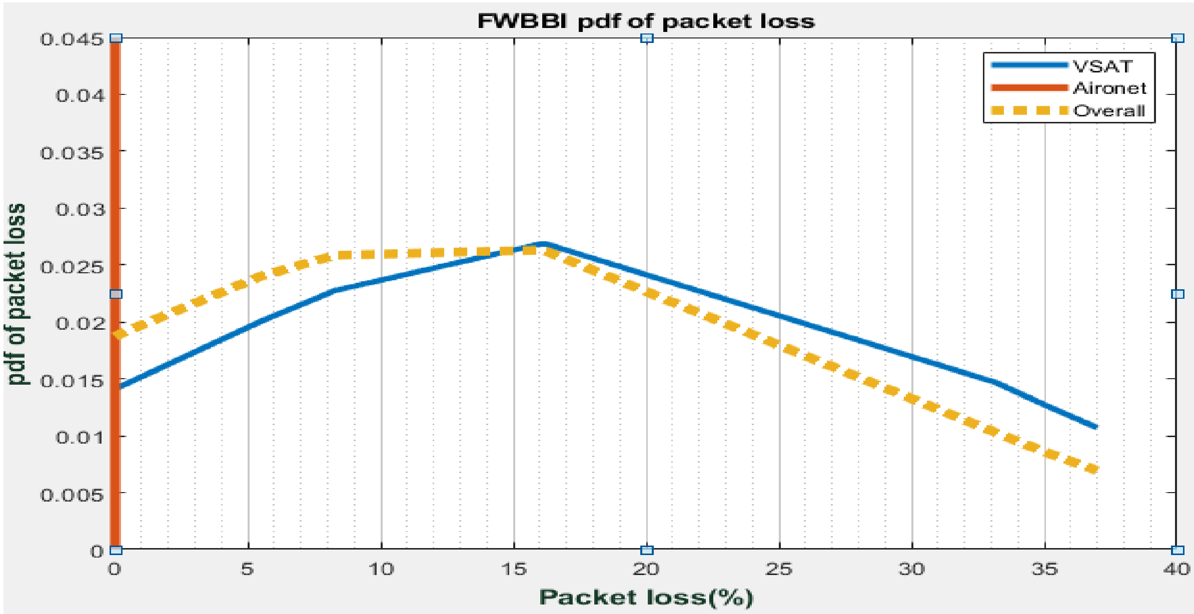


Figure 5-8: Overall pdf of normalized packet loss graph in FWBBI service

5.3 RTT Delay

Measurement is done with the windows ICMP ping to get the round trip time (RTT/bi-directional) delay from end user/customer to server (google DNS IP address) on Internet. The two-way delay or RTT delay measurement result for each site is obtained automatically in the form of minimum, maximum and average. The result is obtained based on the time packet received and transmitted. Then the pdf and CDF analyses performed using MATLAB as can be seen like in the figures 5-9 and 5-10 for showing the overall FWBBI services quality.

As it can be seen from figure 5-9 about 20% of customers are offered FWBB Internet service with RTT-delay bellow 300ms (or one-way 150 ms). Services/applications with bellow 300 ms RTT-delay is categorized as good from standards ITU-T G.114 [51][52]. Most common services or applications are good for RTT-delay bellow 300ms[26].About 44% of the total customers are getting the service with less than 800 ms (one-way <400) which is in the medium or acceptable service delay. Additionally around 70% of the total customers are offered with RTT-delay of bellow 1200ms (one-way 600 ms).Generally majority of customers (>50%) are affected by higher and unacceptable RTT-delay of above 800 ms. So on average FWBBI service is offered with poor quality of delay from ITU-T Rec-G.114 standards point of view[51] [50][26].

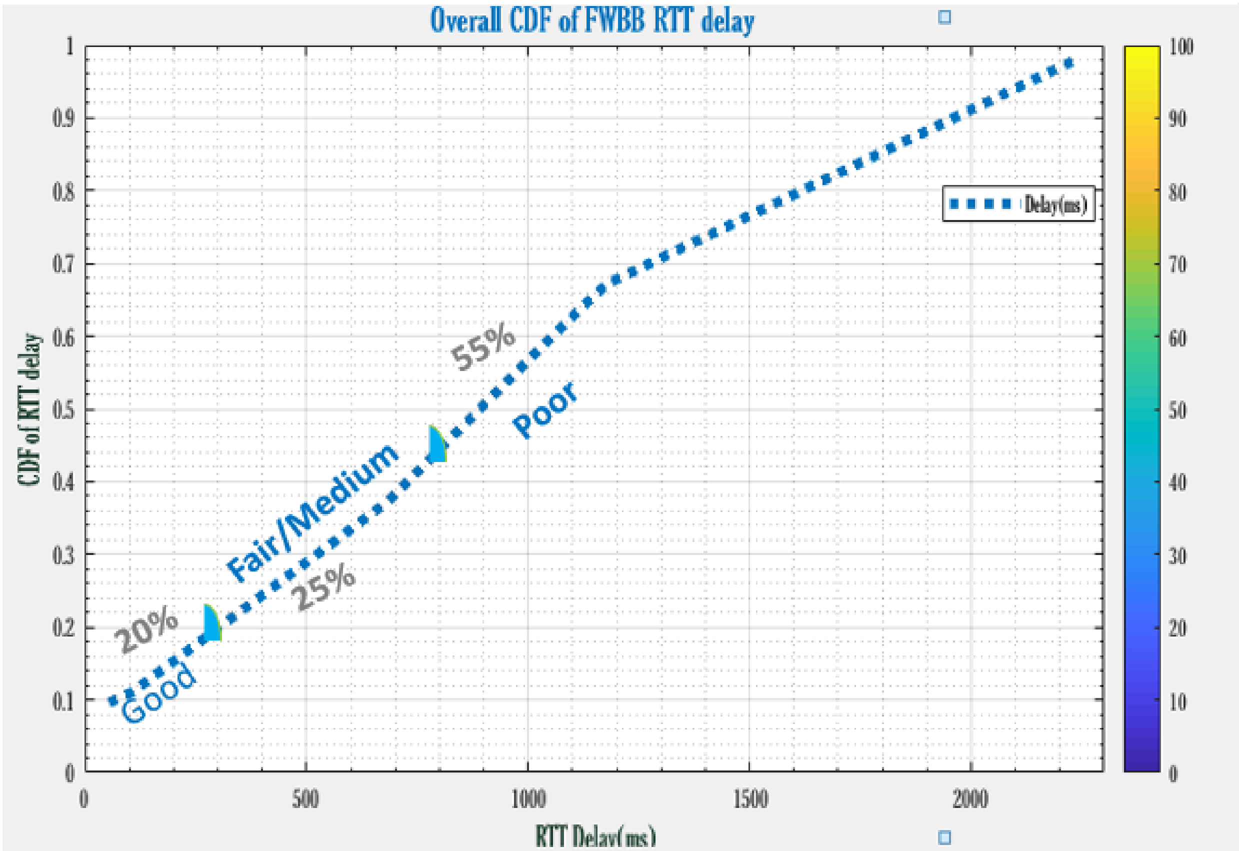


Figure 5-9: The Overall FWBBI service normalized CDF of RTT delay

The comparative detail analysis of the FWBBI service by technology, Aironet and VSAT is shown in figure 5-10 bellow. Customers with Aironet services are provided consistently with an average RTT delay of bellow 300 ms which is considered as a good category [26]. Whereas in VSAT satellite service all customers are getting services with an average delay of above 300 ms. Only 20% of VSAT satellite BB Internet service is with delay of less than 800 ms (medium/fair) while majority or 80% of the customers are affected by above 800 ms of delay which is poor. Applications/ Services with delay greater than 800 ms delay are considered as poor.

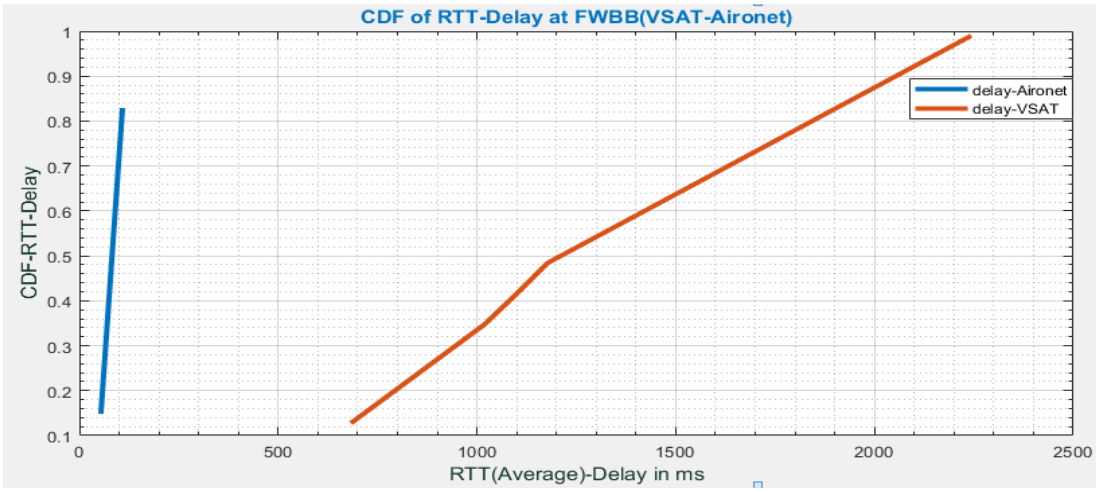


Figure 5-10: The FWBBI service comparative normalized CDF of RTT delay

5.4 Jitter

It is an inter-packet delay variation which is calculated based on the difference which exist between successfully transferred packets and expressed in ms. It is usually occurred due to congestion related factors and affects service quality[53]. On average from the CDF of jitter in FWBBI service 50% of the customers got service with less than 180 ms. Around 20% with less than 40 ms of jitter and 30% of customers of FWBBI got service with <100 ms as it is seen from the graph 5-11. From ITU-T G.114 [51] [52] standards, it can be derived that service with jitter (RTT) bellow 40 ms is good, bellow 100 ms is fair/acceptable and greater than 100 ms is poor.

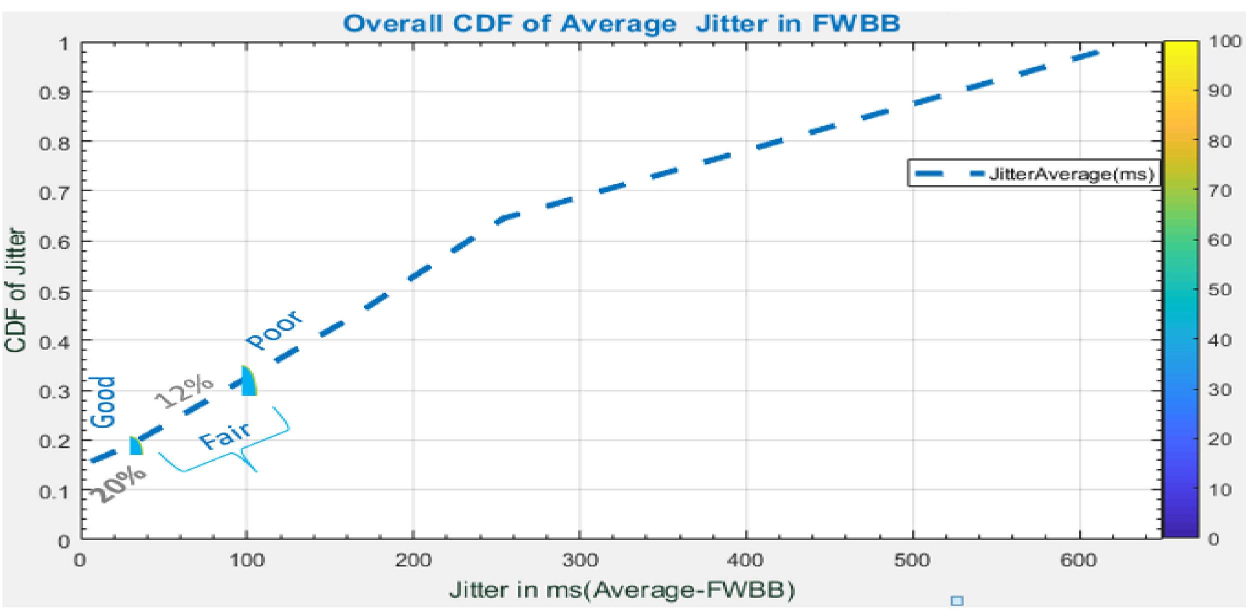


Figure 5-11: Overall average CDF of Jitter in FWBBI Service

Moreover from the figure 5-12 the details of jitter in FWBBI service interms of technology is shown. Hence from the given figure on average RTT jitter is generally consistently less than 150 ms in Aironet while in VSAT above 150 ms. On average RTT jitter in Aironet is good <40 ms while in VSAT is poor above 100 ms. So there is higher delay variation (jitter) and inconsistency exist in VSAT than Aironet.

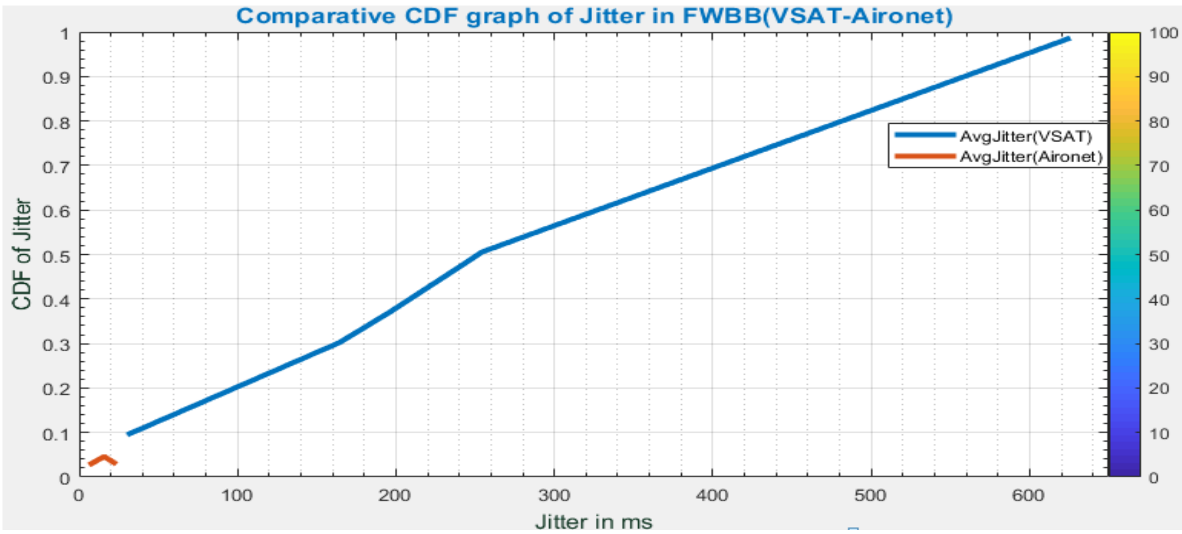


Figure 5-12: Comparative average CDF of Jitter in FWBBI Service

5.5 Definition/Design/ of Recommended QoS-SLA

The definition or design of SLA is made based on the actual QoS measurement results of FWBBI service, state-of-the-art researches, standards/recommendations, and application or service /user requirements. Three customer traffic classes are derived with different values of guaranteed thresholds for each QoS metrics. The minimum or maximum threshold level in each class is described by the metrics throughput (percentage from advertised speed in Mbps), delay (in ms), packet loss rate (%) and jitter (in ms). The service class/type in the SLA described with the minimum level of throughput (download and upload speed) and the maximum tolerable level of other QoS (packet loss, delay and jitter) guaranteed threshold as shown in table 5-2.

Table 5-2: Design of recommended QoS- SLA

Service Class	Throughput (%)	Packet loss (%)	Delay (in ms)	Jitter (in ms)	Remark
Gold (A)	>75%	<1%	<150	<25	Real time interactive services such as VoIP, Video conferencing services
Silver (B)	>50%	<5%	<400	<50	Streaming, interactive or critical transaction or advanced web/e-commerce
Bronze (C)	>40%	<15%	<600	<100	Bulk data transfer, backups, basic mail, basic web browsing etc.

State-of-the-art-researches on broadband Internet for SLA design such as [7] proposed the top ten results of **throughput** measurement for class A services. While ITU in [15] generally recommend the throughput offered by ISPs to customers should be greater than 80% of the service subscription speed. Other research [7] done on Malaysian ISPs QoS measurement for broadband Internet best benchmarking results showed that 70% of BB service subscription speed is fulfilled by all operators in the country. Moreover other state-of-the-art researches such as [13] [47] described that the throughput with greater than 75% of the advertised speed is good and satisfy the majority of customers or service requirements.

Hence in this research the top ten measurement results reference and state-of-the-arts described with greater than 75% of subscription speed adopted from [7][13][47] and the average of ITU and the Malaysian ISPs for class A/gold/ minimum threshold value of throughput. Nearly half of the customers belong to 50% of the advertised speed in UK ofcom 2010 [48] and in [5] the Italian BB Internet SLA regulatory research on ISPs report. Researches like [7] international conference for passive and active measurement (PAM) sets the throughput threshold value for class B services where around half of the customers subscription result. Similarly this minimum threshold value is adopted/defined for throughput threshold value in class B service where around 50% of the total customers' measurement result is shown. In addition the throughput threshold value in class C services is adopted from ITU [54] Latin American BB Internet quality experiences where operators are obliged to kept the minimum service quality (40%) of the advertised speed and it contains around 20% of measurement distribution result.

The maximum **Packet loss** rate which should be tolerated in class A traffic group is considered as 1% which cover 20% of the customers measurement distribution result. It is based on the fact that most common real time services applications such as VoIP and video conferencing are sensitive to packet loss and affected for loss >1% as indicated in research papers such as [55][56]. From ETSI-TIPHON TR 101 329 [50] standards for packet loss up-to 3% considered as good and some common video calls, audio calls and streaming services began to degrade QoS for loss >4% as indicated in [57]. So the maximum tolerable packet loss of the FWBBI service by customers considered in class (B) is up-to 5%.

Researches such as [57] described that when packet loss is greater than 10% (without limiting the upper bound) higher QoS degradation result is shown for some interactive services like iChat. Whereas packet loss up-to 15% on services/applications is considered as fair/acceptable to customers when it is seen from packet loss standards shown in ETSI-TIPHON TR 101 329. So the maximum tolerable packet loss in class C is defined/limited to/ as 15% since packet loss more than 15% might result the service to be poor and unacceptable by customers. Generally about 20% of the packet loss measurement distribution result belong to below 1%, 10% belonged to below 5% and 25% below 15% of packet loss.

Moreover the **delay and jitter** metrics in all the three classes of services defined based on the measurement results, adopting the standards (ITU-T G.114 and ETSI-TIPHON) and state-of-the-art literatures. ITU-T G.114 and ETSI-TIPHON [50] recommends less than 150 ms of delay (one-way) for good quality of common real time interactive services/applications such as voice, VoIP, industrial control applications /telemetry/. In addition ITU-T G.114 recommends less than 300ms of delay (one-way) for fair/acceptable level of quality to major common services.

Hence the delay limit/threshold/ for FWBBI service traffic classes of A and B respectively are defined/set/ based on ITU recommendation. And also the delay limit for traffic class C is also defined based on ITU-T G.1010 recommendation for end user timely critical services QoS where the maximum tolerable delay is described as around 600 ms and also ITU-T G.114 defines delay of less than 600 ms for audio service coherency/user acceptance/ . Similarly the average satellite delay performance expressed in research [58] is around 600 ms (one-way). The distribution of customers traffic delay measurement result in figure 5-1 shows that about 20% is less than 150ms, 40% below 400ms and 70% of the average total result is below 600ms.

ITU-T G.114 standards defined the maximum **jitter** value 20 ms (one-way) for high/good quality to jitter sensitive interactive multimedia services/application like VoIP, as well maximum acceptable jitter as 50 ms for common streaming or broadcasting services. Similarly Researches such as [56] done on applications QoS requirements on BB Internet described that for multimedia application services with strong bounds such as virtual reality the value of jitter should not exceed 30 ms. Moreover streaming with broadcast quality jitter should not exceed 100 ms and video conferencing 400 ms.

In addition [59] Cisco QoS best practices recommend <30 ms of jitter for interactive services like voice and video. Hence the maximum threshold for jitter value in class A is defined as 25 ms based on the average value of ITU G.114[52] and [56], [59]. For class B the threshold value for jitter is set to 50 ms on the bases of ITU-T G.114. Jitter value to for traffic class C is also defined based on QoS requirements in [59] where the maximum basic quality of jitter for non-interactive services as 100 ms. Considering the measurement result for jitter about 25% is below 30 ms, 35% below 50 ms and 55% of the total result is below 100 ms.

CHAPTER 6

6 Conclusions and Recommendations on Future Works

6.1 Conclusions

Generally in multi-service providers like ethiotelecom there are different types of traffics with variable QoS requirements or guarantee of the offered services. Also QoS requirement might vary due to customers demand or paying capability for services/applications. The business critical data applications demand bandwidth guarantee whereas real time applications/services like VoIP, video conferencing are sensitive to delay, jitter and packet loss so that requires minimum level of QoS guarantee otherwise it results to QoS degradation in case of congestions or bottlenecks. Currently ET is providing (shared) BB Internet services such as FWBBI with equal or similar QoS for each customers without setting minimum level of guarantee.

Recently ET began performing different tasks (from small to huge) to improve the QoS offered to its customers like the huge telecom expansion projects which are implemented by phases (phase I &II). The projects aimed not only to improve service quality by increasing bandwidth which reduce bottlenecks/congestions but also improved the coverage areas and service flexibility to its esteemed customers. Moreover ET launched SLA frameworks beginning from 2014 which aimed to satisfy the customers or guarantee services/applications demand. In addition currently advertised dedicated BB Internet access/DIA/ service to provide guaranteed (100%) bandwidth with a more expensive price comparing to the current shared BB option while DIA is considered to require strict SLA than (the shared) BB Internet.

This research is aimed at the assessment of QoS offered in FWBBI service for the design/define of QoS-SLA. It used user centric QoS metrics for FWBB Internet delay, jitter, and packet loss, download and upload throughput. The QoS assessment is done based on ITU recommendation for QoS assessment (such as pdf, CDF, mean, min, max, charts). Measurement is done at five selected ET regions where more number of FWBBI service/customers are available and 12 sample sites performed in working days and times to get the actual QoS measurement data. QoS analysis is done mainly based on probability distributions functions (pdf and CDF) using MATLAB.

The common ping utility applied to measure the FWBBI service quality on metrics delay, jitter and packet loss. In ICMP ping directly show the minimum, maximum or average values of RTT delay in ms. Whereas jitter calculated from the successfully transmitted inter-packet delay differences and packet loss from the successful transmitted and failed packet of ping measurement result. The average result of RTT-delay is about 900 ms which is poor (>400 ms). Moreover the average jitter (200 ms) result showed that FWBBI service also belonged to the poor (>50 ms). Hence network optimization might be needed to provide improved service quality especially for delay and jitter sensitive real time application/services such as VoIP, video conferencing.

Moreover the measurement result on average packet loss rate is 13% which is acceptable or fair/medium when it is evaluated from state-of-the-arts and standards. But this amount of packet results higher QoS degradation for real time packet loss sensitive applications/services and customer dissatisfaction. So FWBBI service needs packet loss reduction/prevention tasks to improve QoS else further QoS deterioration might occur. In addition when FWBBI service is seen specifically interims of technology the VSAT showed that there is a high packet loss rate reaching max of 37% and average (17%) which is poor and needs further investigation on the causes of packet loss while Aironet show excellent (0%) quality.

As well the average download and upload throughput is measured by using testmy.net web tool which is less security vulnerable since it is based on the latest HTML (HTML5) and does not use java/flash plug in. The throughput measurement for both download and upload speed used artificial traffic injection/generation. The result for throughput showed that FWBBI service customers are offered with average of 52% of the subscription speed which is fair or acceptable (>50%). But it needs further improvement to better satisfy customer and service/application requirements.

Then based on analysis result, observation, standards and current state-of-the-art researches the design of QoS-SLA is performed. The design/definition of recommended SLA has three traffic classes with different QoS level of thresholds guarantee. Hence the metrics throughput (download and upload speed) minimum value of threshold for each customer traffic classes and other metrics delay, jitter and packet loss maximum tolerable thresholds set for each classes of FWBBI customer services. Generally the importance to QoS guarantee/SLA/ in BB Internet is due to the highly growth of customer/traffic/, variable QoS demands for customer/application/ service or performance requirements like VoIP, Internet Protocol Television (IPTV), business critical data services. In similar way it is in due that customer satisfaction is currently becoming important to service providers like ET which is influenced by QoS.

6.2 Recommendations for Future Works

As the focus of this research is on QoS assessment at FWBBI service for SLA design, some of the related areas where further investigation or research needed to be done for QoS improvement and prevention of QoS degradation in a way to enhance customer satisfaction are identified or listed below:

- To identify which part of the ET network has a problem or needed optimization and/or improve network performance/QoS/, performance evaluation of each network part the access, aggregation and core network is important.
- Current ET services like Dedicated Internet Access (DIA) needs stronger SLA. Moreover shared BB Internet such as mobile wireless (3G, 4G) and wired (Digital Subscriber Line (DSL) and Passive Optical Network (PON)) services QoS assessment and SLA design is also important. It is essential for planning and providing services according to the available network capacity, improve QoS and prevent network degradation.
- Analysis of the available ET SLA using the state-of-the-art prediction mechanisms is also important for revising or applying or pricing schemes on SLA.
- On the development of standardized tools and infrastructure, for evaluating BB Internet QoS offered by ET to its customer.

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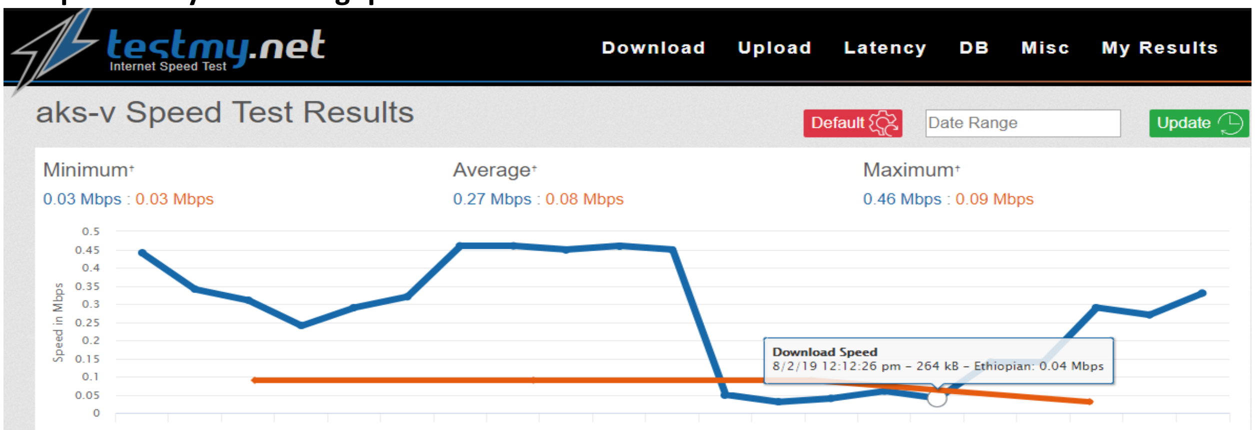
Appendices

Appendix A

Sample testmy.net throughput measurement result



mm/dd/yyyy hh:m	Type	Test Size	Score Mbp:	Score MB/	Username	Computer ID	ISP / Host	Extra Iden	Test ID
7/9/2019 2:41	UP	1.3 MB	0.94	0.12	AKS-A	17991389179695	ethiopian_telecom	65------et	XZYOze85
7/9/2019 2:41	DN	60.2 MB	8.26	1.03	AKS-A	17991389179695	ethiopian_telecom	65------et	Jx2YqHLec
7/9/2019 2:51	UP	888 kB	0.56	0.07	AKS-A	17991389179695	ethiopian_telecom	65------et	XCnNNgn
7/9/2019 2:51	DN	7.3 MB	7.99	1	AKS-A	17991389179695	ethiopian_telecom	65------et	jnaxrAu3n
7/9/2019 2:53	DN	22.7 MB	9.08	1.13	AKS-A	17991389179695	ethiopian_telecom	65------et	6MSIH09X.
7/9/2019 2:54	UP	6.4 MB	1.2	0.15	AKS-A	17991389179695	ethiopian_telecom	65------et	#NAME?
7/9/2019 3:08	UP	1.3 MB	1.17	0.15	AKS-A	17991389179695	ethiopian_telecom	65------et	f7wQNIVT
7/9/2019 3:08	DN	24.3 MB	8.62	1.08	AKS-A	17991389179695	ethiopian_telecom	65------et	xN7p-Y48
7/9/2019 3:14	DN	6.9 MB	8.34	1.04	AKS-A	17991389179695	ethiopian_telecom	65------et	GNQ4x5gx
7/9/2019 3:15	UP	1.3 MB	0.5	0.06	AKS-A	17991389179695	ethiopian_telecom	65------et	QMOMdP:
7/9/2019 3:28	DN	23.6 MB	9.09	1.14	AKS-A	17991389179695	ethiopian_telecom	65------et	ROqEoeZu
7/9/2019 3:29	UP	1.3 MB	0.7	0.09	AKS-A	17991389179695	ethiopian_telecom	65------et	#NAME?
7/9/2019 4:13	DN	15 MB	9.17	1.15	AKS-A	17991389179695	ethiopian_telecom	65------et	RL3jA8HYt
7/9/2019 4:13	DN	14.3 MB	8.62	1.08	AKS-A	17991389179695	ethiopian_telecom	65------et	BSthvaOG
7/9/2019 4:14	UP	1.3 MB	0.68	0.08	AKS-A	17991389179695	ethiopian_telecom	65------et	rsoXI5v6s
7/11/2019 2:38	DN	480 kB	0.29	0.04	AKS-V	1799142376300	ethiopian_telecom	65------et	ja6Mv77F
7/11/2019 2:38	UP	256 kB	0.11	0.01	AKS-V	1799142376300	ethiopian_telecom	65------et	bkGfG5hv
7/11/2019 3:23	DN	361 kB	0.36	0.04	AKS-V	1799142376300	ethiopian_telecom	65------et	C3LpU-3gr
7/11/2019 3:23	UP	256 kB	0.11	0.01	AKS-V	1799142376300	ethiopian_telecom	65------et	Yp_-i"rN2
7/17/2019 6:01	DN	96 MB	0.06	0.01		179914240314	ethiopian_telecom	65------et	c3lwaq1Tz
7/17/2019 6:01	UP	256 kB	0.09	0.01		179914240314	ethiopian_telecom	65------et	s38dnw8G
7/17/2019 6:09	DN	96 MB	0.06	0.01	AKS-V	179914240314	ethiopian_telecom	65------et	W09gM4E
7/17/2019 6:10	UP	256 kB	0.05	0.01	AKS-V	179914240314	ethiopian_telecom	65------et	uLM2LCah
7/18/2019 5:00	DN	480 kB	0.31	0.04	AKS-V	179914240314	ethiopian_telecom	65------et	jU"_ti7tj
7/18/2019 5:00	UP	256 kB	0.1	0.01	AKS-V	179914240314	ethiopian_telecom	65------et	40pYDZ8Q
8/1/2019 1:00	DN	480 kB	0.41	0.05	AKS-V	1799142376300	ethiopian_telecom	65------et	sHoZhTF4
8/1/2019 1:01	DN	480 kB	0.44	0.06	AKS-V	1799142376300	ethiopian_telecom	65------et	Yj2NhON-_
8/1/2019 1:02	DN	480 kB	0.34	0.04	AKS-V	1799142376300	ethiopian_telecom	65------et	f42ZGco8Z
8/1/2019 1:03	DN	480 kB	0.31	0.04	AKS-V	1799142376300	ethiopian_telecom	65------et	Lmn63VLn
8/1/2019 1:03	DN	480 kB	0.24	0.03	AKS-V	1799142376300	ethiopian_telecom	65------et	Dz9VDx6_
8/1/2019 1:04	UP	96 MB	0.09	0.01	AKS-V	1799142376300	ethiopian_telecom	65------et	uaADizu2
8/1/2019 1:04	UP	96 MB	0.09	0.01	AKS-V	1799142376300	ethiopian_telecom	65------et	aLtthrByP
8/1/2019 1:05	UP	96 MB	0.09	0.01	AKS-V	1799142376300	ethiopian_telecom	65------et	J_84TqcVA

Appendix B

Sample MATLAB Code

```
%%throughput computation
minDSpeed=sort(DownloadSpeed(:,1)); %Minimum Download Speed at VSAT(First Column)
maxDSpeed=sort(DownloadSpeed(:,2)); %Maximum Download Speed at VSAT(second column)
avgDSpeed=sort(DownloadSpeed(:,3));%Average Download Speed at VSAT(Third column)%
    %Normalization of the download speed data
    minMU=mean(minDSpeed);%compute mean value of Min,Max,Avg speed
    maxMU=mean(maxDSpeed);
    avgMU=mean(avgDSpeed); %compute Standard-deviation value of Min,Max,Avg speed
    sigmaMin=std(minDSpeed);
    sigmaMax=std(maxDSpeed);
    sigmaAvg=std(avgDSpeed);
minDownSpdf=normpdf(minDSpeed,minMU,sigmaMin);%pdf of download speed VSAT
maxDownSpdf=normpdf(maxDSpeed,maxMU,sigmaMax);
avgDownSpdf=normpdf(avgDSpeed,avgMU,sigmaAvg);
    minDownSCDF=normcdf(minDSpeed,minMU,sigmaMin); %CDF of download speed VSAT
    maxDownSCDF=normcdf(maxDSpeed,maxMU,sigmaMax);
    avgDownSCDF=normcdf(avgDSpeed,avgMU,sigmaAvg);
%Aironet
minDSpeedA=sort(DownloadSpeedA(:,1));%Assigning column values to variable
maxDSpeedA=sort(DownloadSpeedA(:,2));
avgDSpeedA=sort(DownloadSpeedA(:,3));
    minMuA=mean(minDSpeedA); %calculating mean/average values
    maxMuA=mean(maxDSpeedA);
    avgMuA=mean(avgDSpeedA);
sigmaMinA=std(minDSpeedA);%compute Standard-deviation value of Min,Max,Avg speed Aironet
sigmaMaxA=std(maxDSpeedA);
sigmaAvgA=std(avgDSpeedA);
    minDownSpdfA=normpdf(minDSpeedA,minMuA,sigmaMinA);% Normalizing the pdf throughput data
    maxDownSpdfA=normpdf(maxDSpeedA,maxMuA,sigmaMaxA);
    avgDownSpdfA=normpdf(avgDSpeedA,avgMuA,sigmaAvgA);
minDownSCDFA=normcdf(minDSpeedA,minMuA,sigmaMinA);    %Normalizing the CDF throughput data
maxDownSCDFA=normcdf(maxDSpeedA,maxMuA,sigmaMaxA);
avgDownSCDFA=normcdf(avgDSpeedA,avgMuA,sigmaAvgA);
%% pdf of download speed(Min,Max,Avg)VSAT     % subplot(1,2,1)
    plot(minDSpeed,minDownSpdf);    hold on
    plot(maxDSpeed,maxDownSpdf);    hold on
    plot(avgDSpeed,avgDownSpdf);    hold off
 %% CDF of download speed(Min,Max,Avg) VSAT %  subplot(1,2,2)
    plot(minDSpeed,minDownSCDF);   hold on
    plot(maxDSpeed,maxDownSCDF);   hold on
    plot(avgDSpeed,avgDownSCDF);   hold off
%% pdf of download speed(Min,Max,Avg)Aironet  %   % subplot(1,2,2)
    plot(minDSpeedA,minDownSpdfA);  hold on
    plot(maxDSpeedA,maxDownSpdfA);  hold on
    plot(avgDSpeedA,avgDownSpdfA);  hold off
 %% CDF of download speed(Min,Max,Avg) Aironet %    % subplot(1,2,2)
  plot(minDSpeedA,minDownSCDFA);   hold on
  plot(maxDSpeedA,maxDownSCDFA);   hold on
  plot(avgDSpeedA,avgDownSCDFA);   hold off

    %% PDF of  FWBBI Comparative VSAT & Aironet
    plot(avgDSpeed,avgDownSpdf);  hold on
    plot(avgDSpeedA,avgDownSpdfA);  hold on
    plot(avgDSpeedT,DownSpdfT); hold off
     %% CDF of  FWBBI Comparative VSAT & Aironet
          plot(avgDSpeed,avgDownSCDF,'DisplayName','Download(VSAT)','AlignVertexCenters','on',...
    'LineWidth',5,...    'Color',[0.87058824300766 0.490196079015732 0]);  hold on
           plot(avgDSpeedA,avgDownSCDFA,'DisplayName','DownloadAvg(Aironet)',...
    'MarkerFaceColor',[1 0.949019610881805 0.866666674613953],...
    'LineWidth',5,...
    'LineStyle','--',...
    'Color',[0 0 1]);  hold on
 % Overall throughput at FWBB(VSAT-Aironet)
 avgDSpeedT=sort(DownloadSpeedT);
meanT=mean(avgDSpeedT);
sigmaT=std(avgDSpeedT);
DownSCDFT=normcdf(avgDSpeedT,meanT,sigmaT);
DownSpdfT=normpdf(avgDSpeedT,meanT,sigmaT);
        plot(avgDSpeedT,DownSCDFT,'linewidth',5,'linestyle',':');
  %% throughput versus packet loss on FWBB(VSAT)
AvgS2=AvgSpeedLoss(:,2);
 AvgPloss2=AvgSpeedLoss(:,1);
 plot(AvgPloss2,AvgS2)
   %% throughput versus packet loss on FWBB(VSAT)
       mu1=mean(AvgS2);
      sigma1=std(AvgS2);
      cdfAvgSpeed=normcdf(AvgS2,mu1,sigma1);
      plot(AvgPloss2,cdfAvgSpeed)
```