ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FACULTY OF TECHNOLOGY

DEPARTEMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Evaluation of User Side Quality of Service Measurement Techniques for Addis Ababa LTE Data Service

By: Bethelhem Alemayehu

Advisor: Dr. Beneyam Berehanu

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Electrical Engineering

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Declaration

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

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Date of Submission: 25/07/2018

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

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Advisor Name

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Signature

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Abstract

Penetration of high-rate and innovative mobile data services has increased to the global mobile industry such as social media, video streaming, and other multimedia services. To accommodate such innovative mobile data services, Long Term Evolution (LTE) mobile technology is widely deployed and operational in several countries including Ethiopia where Ethio telecom has launched LTE data service in the capital Addis Ababa on March 2015.

To maintain and sustain satisfactory LTE data services, LTE quality of service (QoS) needs to be measured and analyzed so that informed optimization and other decisions are made by operators, regulators and users. Various QoS parameters of data services can be measured using different network and user side measurement techniques. Drive test is the most common user side QoS measurement method that is applied by mobile operators and recently crowdsourcing techniques, where client applications are used to measure and collect QoS data from users, are being applied.

In this thesis, we evaluate the performance of user side QoS measurement techniques for LTE data services focusing on selected crowdsourcing techniques: OpenSignal and Speedtest. We also present accuracy performance comparison between the crowdsourcing techniques and the conventional drive test. The performance evaluation and comparison are performed using measurement data that we have collected for selected 'Tikur Anbesa' area route of Addis Ababa. Detail analysis of the measurement techniques based on measured data is provided using Matlab. Furthermore, to understand LTE quality perception by various actors of the mobile industry, at the beginning of the thesis, we undertook a survey for Addis Ababa LTE network to the enterprise, end users, Internet Service Provider (ISP) and to the ISP regulator Ministry of Communications and Information technology (MCIT).

Results show that, there is a limited awareness to the available measurement techniques and the observed LTE data service is below the expected average value, a summarized result of the survey are discussed in chapter two Section 5.3.3 of this thesis work.

To access the quality of experience for LTE data service a downlink throughput and latency key performance indicators (KPI) are measured. Through the analysis of the measurement techniques: OpenSignal, SpeedTest and Nemo Handy for the KPI, we identify a significant difference in latency between OpenSignal and Nemo Handy; on the contrary the difference in latency between SpeedTest and Nemo Handy is minimal. The downlink throughput difference between OpenSignal and Nemo Handy is minimal, whereas SpeedTest and Nemo Handy has a major difference. We have quantified and evaluated the accuracy between the measurement techniques using Root Mean Square Error (RMSE) metric. The key factors affecting the results in addition to the test server location are discussed.

Key Words: LTE; Crowd Sourcing; Drive Test, QoE and QoS

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Acronyms and Abbreviations

3G	3rd Generations
3GPP	Third Generation Partnership Project
4G	4th Generations AMPS Advanced Mobile Phone Service
AWGN	Additive White Gaussian Noise
CDN	Content Delivery Network
CFI	Control Format Indicator
CS	Crowd Source
DCI	Downlink Control Information
DL	Download
DT	Drive and Test
ENG	Engineering
eNodeB	Enhanced Node Base Station
ET	Ethio Telecom
E-UTRAN	Enhanced Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FTP	File Transfer Protocol
GPS	Global Positioning System
GSM	Global System for Mobile communication
GUI	Graphical User Interface
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
HTTP	Hypertext Markup Language
ICMP	Internet Control Multi-Protocol

IP	Internet Protocol
ITU-T	International Telecommunication Union
LTE	Long Term Evolution
MCIT	Ministry of Communication & Information Technology
MT	Measurement Technique
MTS	Mobile Telephone Service
NGMN	Next Generation Management Network
NNOC	National Network Operation Center
OFDMA	Orthogonal Frequency Division Multiple Access
PDCCH	Physical Downlink Control Channel
PDN	Packet Data Network
P-GW	Packet Data Network Gateway
QoE	Quality of Experience
QoS	Quality of Service
RMSE	Root Mean Square Error
SC-FDMA	Spatial Carrier Frequency Division Multiple Access
S-GW	Serving Gateway
SIM	Subscriber Identity Module
SNR	Signal to Noise Ratio
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UE	User Equipment

Chapter 1

1. Introduction

1.1 Background

The number of mobile subscribers and penetration of high-rate innovative data services has been significantly increased in emerging markets during the last decade [1, 7, 8]. To address quality demand of innovative data services, the 3rd Generation Partnership Project (3GPP) has standardized Long Term Evolution (LTE) that has been deployed and operational in various countries across the globe including Ethiopia. Guarantying quality of service (QoS)/quality of experience (QoE) for LTE individual and enterprise data users is an important factor to be tracked and maintained [1, 7, 8].

QoS and QoE are two different but inter-linked quality concepts. QoS is quality measure of a system or network that refers to transmission quality, service availability, delay and other quality parameters [4, 14]. QoS parameters can be measured, improved, and, to some extent, guaranteed in advance.

On the other hand, QoE is a service quality measure that determines the degree of satisfaction of a user of the service [4, 14]. QoE can be seen as how end-user perceives QoS. These QoS and QoE concepts are explained in Figure 1.1 and Figure 1.2.

Mobile network QoS parameters are commonly measured from network or user side with their own advantage and disadvantages.

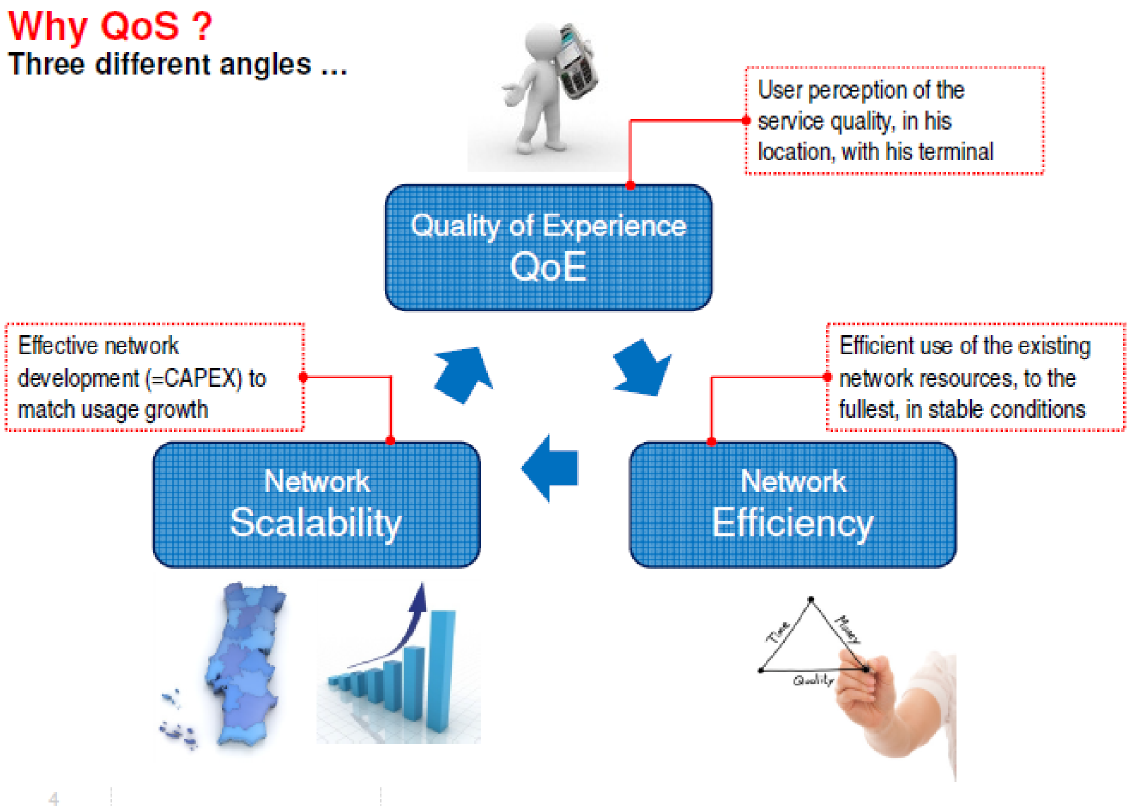

Figure 1.1. Quality of service [4]

Figure 1.2. Four viewpoints of QoS according to ITU-T E.800 [4, 5]

On the network side, there are performance and quality tools that measure and track network QoS from the network management system of mobile core network. Traditionally, mobile operators apply drive test measurement technique to attain the understanding of QoS of the network. Recently, crowdsourcing techniques are being applied to measure and track user side QoE.

1.2 Statement of the problem

A crowdsourcing based QoS measurement techniques have recently used to monitor mobile user side QoE by mobile operator and regulator as they provide benefits in terms of cost, time, flexibility and scope relative to the conventional drive test technique. Yet, their accuracy relative to one another and drive test method is not independently analyzed well. Furthermore, perspective on usage of such techniques in the Ethiopian mobile industry is not well formulated although a few mobile users abroad are using client side applications to measure performance of their network and provide quality data for foreign third parties, mostly unconsciously. With this understanding, this thesis aims to address the following research questions:

1. What are important components affecting the accuracy of crowdsourcing QoS measurement techniques?
2. How good the accuracy of crowdsourcing based QoS measurement techniques, particularly relative to drive test method?
3. How shall the actors of Ethiopian mobile industry exploit the crowdsourcing QoS measurement techniques?

1.3 Objective

1.3.1 General Objective

The general objective of this thesis is to study, investigate and compare user side QoE measurement techniques for Addis Ababa LTE data service. To achieve this general objective, specific objectives of the thesis are presented.

1.3.2 Specific Objectives

- Survey end users, ISP and regulators LTE data quality of service perception and the measurement techniques awareness.
- Prepare LTE data service QoS measurement techniques framework.
- Collect throughput and latency data with the measurement techniques.
- Analyze the accuracy of the selected measurement techniques.
- Discuss on the difference with an appropriate bandwidth estimation methods.

1.4 Methodologies

This thesis bases on LTE network in Addis Ababa. It has 500,000 registered LTE customers and nearly 8, 000 customers are actively using the service as of March, 2017. The service covers dense urban parts of Addis Ababa.

The research has started by enquiring customer satisfaction on quality of service for Addis Ababa LTE data service. The research work is followed by surveying the measurement techniques used by the service provider (ET) and the regulator (MCIT) for LTE data service. Crowd sourcing, drive test measurement techniques and existing measurement techniques will be evaluated. The best crowd sourcing quality of service measurement techniques for LTE data service will be suggested.

The methodology that is applied in this thesis is depicted in Figure 1.3.

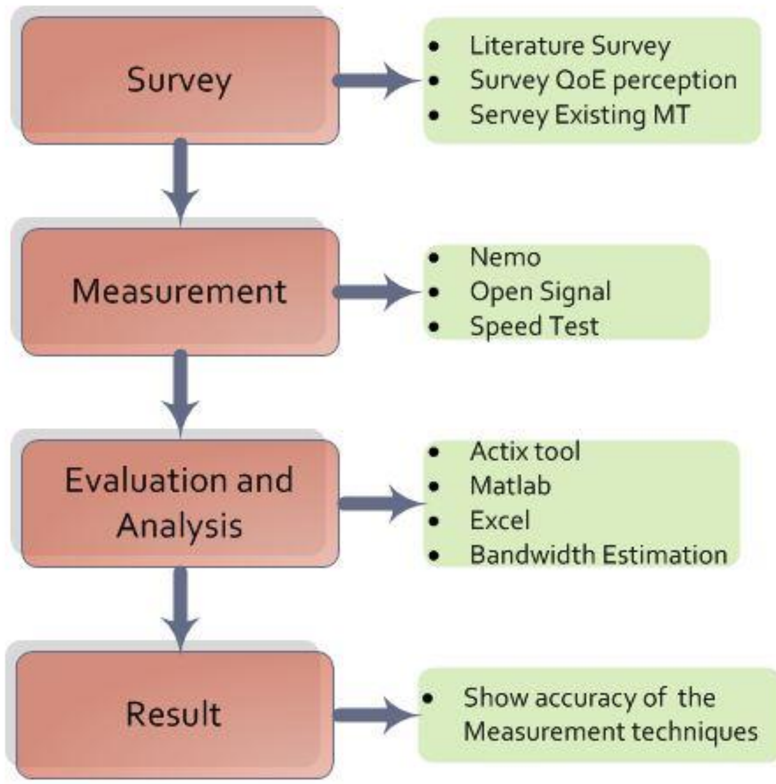

Figure 1.3 shows the thesis methodologies

1.5 Literature Review

According to [12] a study, measurement and understanding of the characteristic of the cellular data network behavior are done. A data from 3 mobile ISPs in Singapore were used for the research. The methods used to measure are 1. A laboratory experiment, for the experiment a 3G/LTE cellular data plans were purchased from the three ISPs and took measurement with different models of Smartphone's and USB modems. 2. Crowd Sourced, for the measurement an assistant of 23 real users with their mobile are involved in the research and a 6,048 sets of experiments were collected from the users. ISPCheck open source application developed by the researcher was used by the users in their mobile. LTE data were not collected in this paper. A continuous measurement for five months was performed.

The observed results from the experiment are a) transmitted packets tend to arrive in bursts; b) large variations in the instantaneous throughput in short period of time, even when the mobile device is stationary; c) large separate downlink buffers are typically deployed in mobile ISPs, which can cause high latency when the throughput is low. From this literature we can see and understand how the paper used ISPCheck crowd sourcing measurement technique. And evaluate throughput and latency key performance indicators.

According to [15], this paper analyzes existing open source monitoring tools and developed a new open source tool used to measure the service quality with Android phones, which also needs further improvement. In this paper it has been shown that development of new open source android application is to give users an opportunity to take part in data collection and also observe the service quality from their mobile device.

From this paper we can deduce that to achieve a global penetration an alternate measurement technique needs to be thoroughly evaluated for new mobile technologies; LTE data service for this thesis. We can also see that 3GPP and NGMN are currently working on minimization of drive test methods; and it has been appointed that working on alternative (crowd sourcing) quality of service measurement techniques would be ideal and up-to-date.

According to [16], this paper thoroughly discussed the list of opportunity and challenges of using crowd sourcing measurement techniques as an alternative to the conventional drive test measurement techniques. To see each challenges a case study on RTR (Austrian private company, which gives operational support to Austrian communication authority) open data containing over two million samples are done. A conclusion and future work on the challenges of crowd sourcing has also been proposed. From the paper a number of future works on crowd sourcing techniques of which one area of research related to this thesis is pointed as identification of appropriate benchmarking metrics of a crowd sourcing application.

The main reviewed literature in this thesis are organized in Table 1.1. The table shows the author of the literature and reference number, approaches, limitation and findings of the thesis are presented. And in the last column of Table 1.1 what is covered in this thesis related to the literature are mentioned.

Table 1.1 shows the main Literature Reviewed for this thesis work

No.	Author	Approach	Limitation	Findings	Discussed in Thesis
1	Z. Wang et al	- Both laboratory experiment and CS analyzed.	- 3G is evaluated.	-Burst packet	- 4G/LTE is evaluated.
		- Enough no. of samples used.	-Own developed CS is used (might biases the result).	-Variation in throughput.	- Throughput and latency KPI.
		- ISP check CS is developed.		-Large DL buffer. Low latency.	- CS performance is analyzed.
2	Fernando Molina Alberto	-DT side effect are discussed.	- OS needs further performance improvement.	- Thorough evaluation of QoS MT are needed.	-Evaluated CS support android, iOS, Windows etc.
		- Open source (OS) is developed	- OS is only for android phones.	- R12 of 3GPP is working on MDT of DT.	-From 3GPP it shows an active research area.
3	Cise Midoglu	-Discuss the opportunity & challenges in CS	-Measurement has not performed.	-Accuracy of the tech. should be evaluated.	-Evaluates the accuracy of the CS techniques.
		-DT side effect discussed.	-Open data is used & redundant info. Biases the result.	-Network performance should be analyzed from end nodes.	- QoE is accessed.

No.	Author	Approach	Limitation	Findings	Discussed in Thesis
		-Mentions in estimating BW HTTP represents real end user experience.		-Appropriate metrics to analyze CS should be used.	-RMSE metric is used to see the accuracy of the DT and CS measurement techniques.
4	Fahod Almary,	-QoS is evaluated for LTE cellular data.	-Drive test method only is used to evaluate the network performance.	-KPI is used as evaluation criteria.	- The MT techniques are evaluated.
	Ivica Kosta	-Live data is collected & Compared against wifi.		-HTTP, FTP, Video and ping measurement are accessed.	- KPI are used as QoE metric.
		-DQI metric is used.		-Captures user experience within the ntk QoS.	- DT and CS technique is evaluated.
		-Home, office, WiFi and LTE is accessed			-From the paper understood how FTP LTE data service DT is accessed.
5	Cise Midoglu	-Explore concept of CS.	-HTTP implementation to investigate the impact in deploying server in CDN is not analyzed.	-SP & OS TCP protocol impacts the result	-Nemo Handy, OS and SP analyzed.
	Leonhard Wimmer	-Analyzed Ookla SP, OS and more,		-A significant effect of server location in the measurement result is identified.	-Server location effect b/n Nemo Handy and OS observed from measured result.

No.	Author	Approach	Limitation	Findings	Discussed in Thesis
		-Developed new tool. -Identified key factors affecting the result in mobile measurement.		-For current mobile speed/4G measurement tools with 7TCP flows and Measurement duration of >= 8 second is identified as adequate.	-Measurement duration for SP=30Sec OS=10Sec NH=60Sec. -8 parallel flow of TCP and HTTP is used in OS and SP MT.
6		-Examined current approach to end to end mobile network.	-No practical measurement is accessed for confirmation on the shortcomings.	-Shared challenges; deployment, samples of users to install and run, privacy of user's resource.	-live data measurement is made.
	Utkarsh Goel et al	-Compares available test tools & access their shortcomings w.r.t developers, researchers, ntk operators and Regulators.	-The ability to run measurement against hosted server is discussed as not supported by speedtest.	-SP lacks programming interface to allow users. -OS uses hundreds of MB of data b/n mobile devices & servers is not suitable for low data plan.	- AA ET hosted server URL is identified and used during the test and is supported with Ookla SpeedTest.
7	Dahunsi Folasade Mojisola et al	-Drive test is addressed.	- MT are not analyzed rather the KPI	-Compare mobile ntk.	- MT is analyzed.

No.	Author	Approach	Limitation	Findings	Discussed in Thesis
		-OpenSignal CS is used to see the KPI and asses the QoS.	of operator is evaluated.	-Address the gap between the reported techniques.	
		-Data gathered from NMS system.		-Capture QoE.	
				-Shortcoming of DT is discussed.	
				-NMS is costly, security risk.	

1.6 Contribution

The contributions of this thesis work are:

- ✓ Provide a survey result on;
  - How Addis Ababa LTE data service end users' and enterprise users' perceives QoE of the service.
  - How operator (Ethio telecom) monitors QoS of LTE data service and identify the measurement technique used to monitor the QoS.
  - How the regulator (MCIT) monitors the QoS of Addis Ababa LTE data service provided by the operator and how it monitors the QoE from user side.
- ✓ Provide understanding of the crowd sourcing measurement techniques (OpenSignal and SpeedTest) to users, operator and regulator of Addis Ababa LTE data service as an alternative to the traditional existing measurement technique used by the operator.
- ✓ Provide the drawbacks of the existing drive test measurement technique (Nemo Handy) from user side.

- ✓ Evaluate and present an accuracy comparison result of OpenSignal, SpeedTest and Nemo Handy measurement techniques in Ethiopian mobile industry.

1.7 Thesis organization

This thesis shows how crowdsourcing tools can help to understand the user side QoE of LTE data service and depict the limitation of existing drive test measurement technique. The organization of this thesis. In order to get deeper knowledge on the available measurement techniques detailed theoretical study and the preformed qualitative survey are discussed in Chapter 2. In addition, in this chapter a brief description of ITU-T measurement standards and the general proposed frameworks are described. How to estimate the end to end performance in IP data network are discussed. Then, the drive test (Nemo Handy) and crowdsourcing (OpenSignal and SpeedTest) measurement techniques (MT) for LTE network QoS and QoE are respectively are presented briefly.

In Chapter 3, drive test and crowd sourcing measurement techniques scientific framework is formulated and presented graphically. Furthermore; the performance parameters, throughput and latency, used by the measurement techniques to access their accuracy, are defined.

In chapter 4, Addis Ababa LTE data collection and measurement processes carried out are discussed. A downlink throughput and latency output using Nemo Handy, OpenSignal and SpeedTest measurement techniques are presented. In this chapter, the measurement route and the measurement process implemented with each techniques are also explained.

In Chapter 5, the analysis of the measured data for the comparison of Nemo Handy, OpenSignal and SpeedTest are depicted. The measurement result using Matlab simulation is displayed and results are explained. The performance comparison of the MT with RMSE metric is articulated. The bandwidth estimation technique used for OpenSignal and SpeedTest MT are mentioned. From the results observed in Chapter 5, conclusion and considerations for future work are proposed on Chapter 6.

Chapter 2

2. LTE QoS Measurement Techniques and Available Solutions

In this chapter, a survey conducted to understand the perception of LTE data service from users, operator and regulators for Addis Ababa is discussed. The available QoS measurement techniques are discussed. A measurement standard recommended by ITU-T are discussed in detail. LTE data service measurement requirement and the available measurement techniques are also discussed under this chapter.

2.1 Survey on Addis Ababa LTE Data Network Observation

Customer complaints are a vital source of feedback on QoE, and must not be ignored by service providers. This being said a survey is performed before starting the thesis work. The survey greatly helps to see the available problem related to LTE data service as seen by different communities of the Ethiopian mobile users. It also emphasizes the problem statement and motivation of this thesis work. A questioner is prepared and distributed to understand the service perception for all parties. The number of questions prepared for an end user and enterprise user are twenty-three, a separate form of questions have been prepared for ISP and regulator each with ten and seven questions respectively.

- ✓ For end users the questions are distributed through Google form to be filled online and few are filled in a hardcopy.
- ✓ Five enterprise users are involved in filling the questioner.
    - Commercial Bank of Ethiopia (CBE)
    - GiZ
    - Sivatix IT Solutions
    - ET Switch Payment Solution and
    - Tafra Multimedia
- ✓ For the ISP a survey was filled by departments;
    - Marketing
    - Service management center (SMC)

- Customer service(CS)
- Engineering (ENG) and
- National network operation center; to understand and see how they involve in the service quality monitoring for LTE network.

During the survey we identified how the ISP handles LTE data service network related issues from end user and enterprise users. The work flow during and after measurement of LTE data service quality from end user and enterprise users through the customer service center department and it is depicted in Figure 2.1.

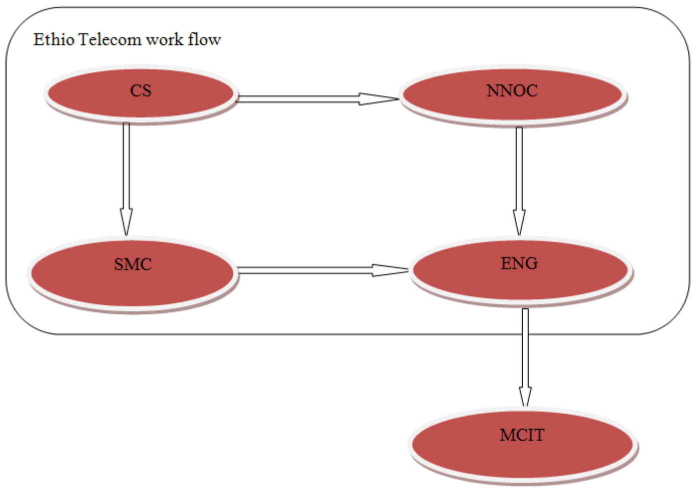

Figure 2.1 Mapping of user-centric QoS requirements [18]

The work flow in Figure 2.1 handles a customer complaint as follows;

- ✓ CS receives complain from end user and enterprise users. CS send to SMC for management purpose and to NNOC to troubleshoot the problem.
- ✓ NNOC monitors and try to solve central from a system. If a drive and test is required it sends to Engineering department.
- ✓ The ENG department does a drive and test for specific time in a specific route.
- ✓ After the drive and test a report is sent to MCIT quarterly, since currently MCIT does not own a measurement techniques to monitor LTE data service.

By identifying the QoS troubleshooting work flow of the service provider we can understand the gap/drawback in monitoring LTE data service and is a motivation for this thesis work on the end user QoE identification problem;

- ✓ Does not monitor user side QoE.

- ✓ The monitoring is not real time as the problem occurred.
- ✓ Drive test is done on a specific location.

For further reference to the survey result; the summarized form from with the list of questions raised are attached to this thesis paper.

2.2 General QoS Measurement Methods

QoS can be measured using approaches that are implemented in the network side or user side. [2, 9, 10]

2.2.1 Network side measurement

QoS data can be measured and obtained from the network side using Network Management System (NMS):

- ✓ Easy to have 24/7 data
- ✓ Provides cell-level data used for deep analysis
- ✓ Lack user location based information
- ✓ Less marketing value

2.2.2 Mobile side measurement

QoE in LTE data service is measured and obtained from the user side. Drive and Test and Crowdsourcing techniques are part of mobile side measurement techniques.

- Drive and Test:

These allows the mobile network to be tested through the use of a team of people who take the role of users and take the QoS measures discussed above to rate the QoS of the network. This test does not apply to the entire network, so it is always a statistical sample. Some of the drive test methods are; Nemo Handy, Nemo Outdoor and GL. These methods are;

- Localized data from user perspective
- Costly
- Does not apply to the entire network, so it is always a statistical sample

- Crowdsourcing:

Users download free application from online stores and can conduct performance tests from their mobile devices. This emerging technique proposed for improving service quality through improved measurement methods which will give a true state of services provided to users. This is not limited by the location of users either rural or urban and it offers a larger database based on real time experience by individual users. Some of the Crowdsourcing performance test tools are; Netradar, SpeedTest and OpenSignal. These methods are;

- Relatively inexpensive
- Limited in terms of user adoption, distribution, data consistency
- May be synthetic rather than application-focused

A Crowdsourcing and Drive test methods are evaluated to assess the QoE of LTE data service. The measurement techniques accuracy are analyzed.

General comparison of the measurement techniques for different performance characteristics are depicted in the following table.

Table 2.1 Comparison of Quality of service Measurement Techniques [2, 16]

Performance Characteristics	Drive Test	NOC Measurement	Crowd sourced Applications
Required Equipment	Special test phones, RF scanners	Special hardware and additional server	Smart phones
Cost availability	Expensive and hardware are not readily available	Very expensive and requires permission	App is free

Performance Characteristics	Drive Test	NOC Measurement	Crowd sourced Applications
Target users	Team of network specialist	Usually used by academicians	Anyone that installs the application
Measurement level	Radio level measurement, service level measurements	Radio level measurement, service level measurements	Radio level measurement, service level measurements and QoE (Quality of Experience)
Measurement size	Measurements are only during the test drive	Measurements are only for a certain period	Measurements are continuous
Position accuracy	GPS, current cell	Current cell	GPS, current cell
Traffic overhead	Little or no overhead traffic	High overhead	No overhead traffic
Requires human intervention	Trained users required (active)	Yes	No (passive)
Scalability	Reduced, more drive test requires more specialized equipment	Difficult, technology dependent	Handles all sizes of traffic/ measurements

2.3 ITU-T End-user QoS Categories

The ITU-T G1010 recommendation defines a model for Quality of Service (QoS) categories from an end-user viewpoint. By considering user expectations for a range of applications, eight distinct categories are identified, based on tolerance to information loss and delay. It is intended that these categories form the basis for defining realistic QoS classes for underlying transport networks.

A major challenge for emerging wired and wireless IP-based networks is to provide adequate Quality of Service (QoS) for different services. This requires a detailed knowledge of the performance requirements for particular services and applications. The starting point for deriving these performance requirements must be the user. [18] User-driven performance requirement include key parameters impacting the user and performance considerations for data. These are discussed in the next paragraph.

- Key parameters impacting the user:

Some of the parameters impacting the user are Delay, Delay variation (Jitter) and Information loss.

- **Delay:**

The time taken to establish a particular service from the initial user request and the time to receive specific information once the service is established. It has a direct impact on user satisfaction depending on the application, and includes delays in the terminal, network, and any servers. Note that from a user point of view, delay also takes into account the effect of other network parameters such as throughput.

- **Delay variation:**

Delay variation is generally included as a performance parameter since it is very important at the transport layer in packetized data systems due to the inherent variability in arrival times of individual packets. However, services that are highly intolerant of delay variation will usually take steps to remove the delay variation by means of buffering, effectively eliminating delay variation as perceived at the user level.

- **Information loss:**

It has a very direct effect on the quality of the information finally presented to the user, whether it be voice, image, video or data.

- **Performance Considerations for Data:**

From a user point of view, a prime requirement for any data transfer application is to guarantee essentially zero loss of information. At the same time, delay variation is not generally noticeable to the user. The different applications therefore tend to distinguish themselves on the basis of the delay which can be tolerated by the end-user from the time the source content is requested until it is presented to the user.

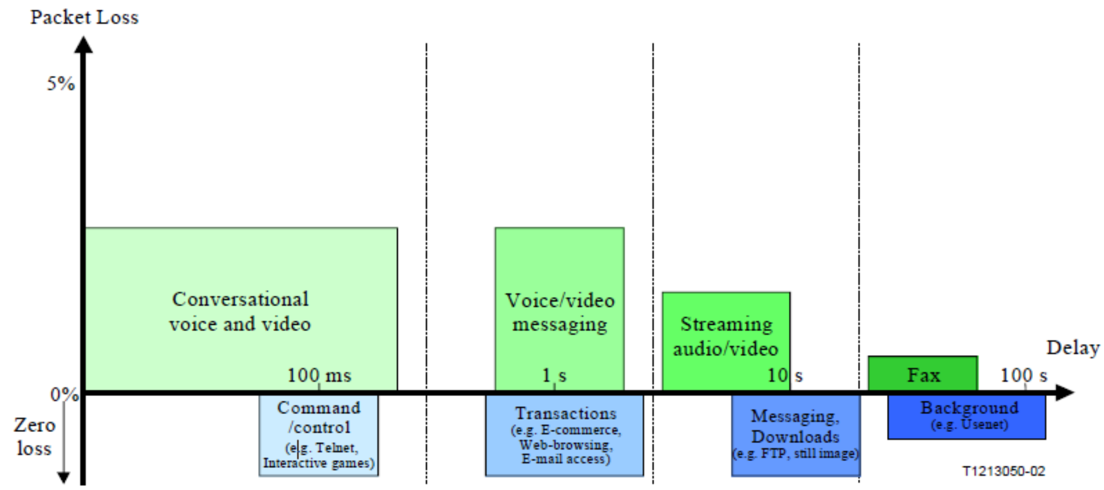

Figure 2.2 Mapping of user-centric QoS requirements [18]

In Figure 2.2 it can be seen that there are eight distinct groupings which encompass the range of applications identified. Within these eight groupings there is a primary segregation between applications that can tolerate some information loss and those that cannot tolerate any information loss at all, and four general areas of delay tolerance.

This mapping can be formalized in Table 2.2 to provide a recommended model for end-user QoS categories, where the four areas of delay are given names chosen to illustrate the type of user interaction involved.

Table 2.2 Model for user-centric QoS categories [18]

Error tolerant	Conversational voice and video	Voice/video messaging	Streaming audio and video	Fax
Error intolerant	Command/control (e.g. Telnet, interactive games)	Transactions (e.g. E-commerce, WWW browsing, Email access)	Messaging, Downloads (e.g. FTP, still image)	Background (e.g. Usenet)
	Interactive (delay <<1 s)	**Responsive** (delay ~2 s)	**Timely** (delay ~10 s)	**Non-critical** (delay >>10 s)

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2.3.1 Estimating end-to-end performance in IP networks for data applications

This recommendation covers the process of estimating end-to-end performance of applications operating on IP networks, using: [20]

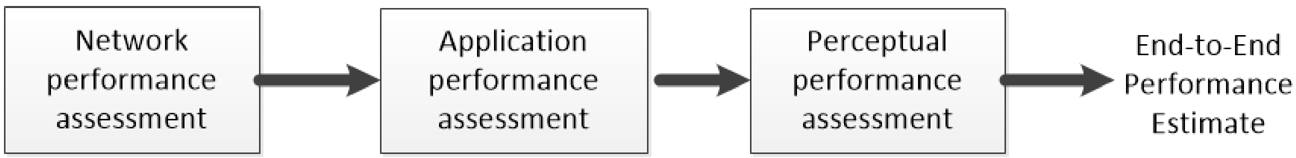


Figure 2.3 Process to obtain end-to-end performance estimate [20]

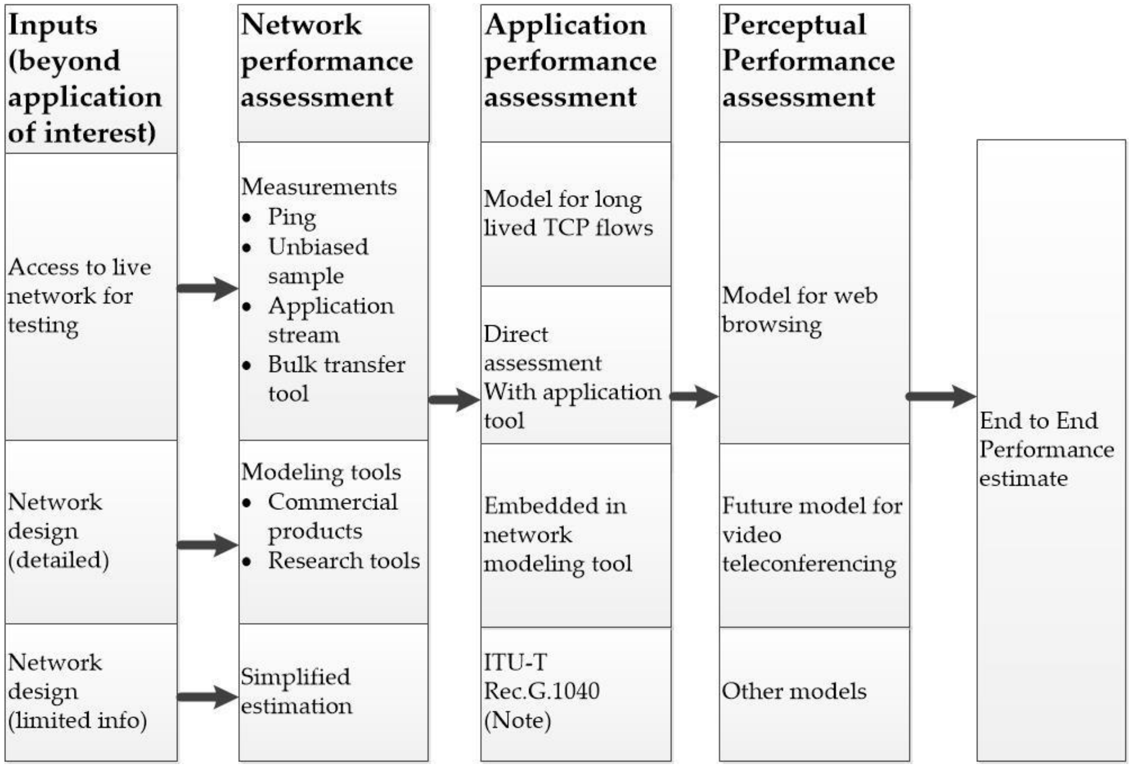
Note that the steps to obtain network and application performance may be combined in some cases, such as when a simulation provides a means to measure the performance of a particular session, or set of sessions. Figure 2.3 illustrates the general process to develop an end-to-end performance estimate.

1. Network performance assessment: There are two principal sources of network performance information, measurement and modelling. Network measurements allow the assessor (evaluator) to treat the network as a black-box, and produce information that may be useful in the remaining steps of the modeling chain.
2. Application performance assessment: Application models take the estimates of network performance and information describing application device performance as inputs, and produce one or more key metrics of application performance as outputs.

2.3.2 Framework in the end-to-end performance assessment

Table 2.3 illustrates the various alternatives in the process to estimate the end-to-end performance of applications on IP networks. This figure indicates that there are many options available to complete the process, although in practice the assessor (evaluator) must combine options that are consistent with the goal of an end-to-end estimate (and with one another).

Table 2.3 Framework for developing end-to-end IP performance estimate [20]



QoS parameters is measured objectively by technical means (by measuring physical attributes of circuits, networks, network elements and signals) or subjectively (perceived QoS) via surveys and subjective tests amongst users. [24]

- **Objective measurements:**

Measurements can be made either on real traffic or on artificially generated traffic on public traffic or private networks. Since QoS may be different with respect to location, the geography of the network should be taken into account for the measurements, particularly if the choice is not to monitor all parts of the network. Objective measurement types can be; Intrusive measurements, Non-intrusive measurements and use of models.

- **Subjective measurements:**

Subjective measurements are the only means to assess the user perception aspects of the QoS, e.g., those aspects that cannot be measured easily by technical means or that may be missed due to a reduced number of measurement points.

There are **two** ways to perform a measurements;

1. **Direct measurement:** The service provider itself does the measurement with a drive and test method
2. **Indirect measurement**: The third party authorizes other parties to perform the measurement. This may be the service providers themselves or any other independent party.

The advantages and disadvantages of the direct and indirect measurements can be seen in the Table 2.4: [24]

Table 2.4 General measurement type

Measurement Type		Measurement Advantages	Measurement Disadvantages
Direct		High confidence in the information provided Immediate proactive action by the third party is possible (adoption of measurement methodology, additional parameters if needed)	High costs mainly if measurements have to be performed on a number of providers and services
Indirect	**Certified**	Confidence in the information provided	Another party is involved and that has to be managed. (independent or indirect certification office)
	Uncertified	Low cost	Low confidence in the QoS statistics provided

2.3.3 LTE QoS Performance Elements Affecting Measurement

Figure 2.4 shows the real world conditions affecting LTE device performance. The channel and network factors that impact mobile device performance are included. These are; fading conditions, degree of spatial diversity, noise and interference condition and transmission mode are among impacting factors for LTE device performance.

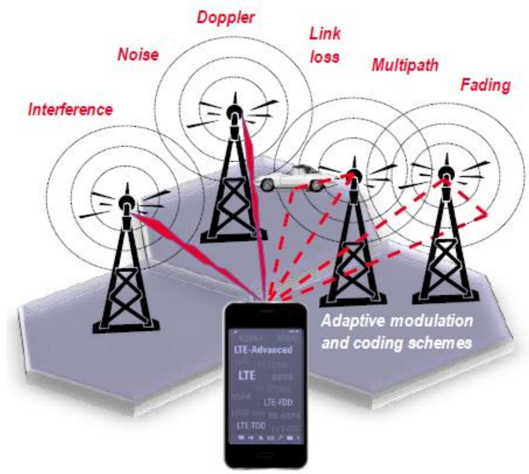


Figure 2.4 Real world conditions affecting LTE throughput [25]

- Prime factors which determines LTE throughput and the performance factors are; [25]

  The prime factors determining the LTE throughput are;

  - The user end (UE) category
  - The cell bandwidth, variable from 1.4MHz to 20MHz
  - The space allocated to the physical downlink control channel (PDCCH) (Control Format Indicator (CFI) setting), PDCCH is a physical channel that carries downlink control information (DCI). CFI is an indicator telling us how many OFDM symbols are used for carrying control channel (e.g., PDCCH) at each sub frame.
  - The number of Resource Blocks (RB’s) or Resource Block Groups (RBG’s)
  - The allocation of Sub-Frames (SF’s), full allocation = 10

- ❖ The modulation coding scheme
- ❖ Transport Block Size (I-TBS) – defined block data rates
- ❖ The number of spatially multiplexed data streams or code words, single input single output (SISO) or multiple input and multiple output (MIMO); MIMO can be of 2*2, 4*2, 4*4 etc.
- ❖ Whether carrier aggregation is employed or not
- ❖ In the real world, the channel conditions, noise, interference, number of users all contribute

Performance factors which determines LTE throughput are;

- Data Rate:
  - Instantaneous downlink peak data rate of 100Mbit/s in a 20MHz downlink spectrum (i.e. 5bit/s/Hz)
  - Instantaneous uplink peak data rate of 50Mbit/s in a 20 MHz uplink spectrum (i.e. 2.5 bit/s/Hz)
- Cell Range
  - 5 km (optimal size)
  - 30 km sizes with reasonable performance
  - Up to 100 km cell sizes supported with acceptable performance
- Cell Capacity
  - Up to 200 active users per cell (5 MHz) (i.e., 200 active data clients)
- Mobility
  - Optimized for low mobility (0-15km/h) but supports high speed
- Latency
  - User plane < 5ms
  - Control plane < 50ms
- Improved spectrum efficiency and broadcasting.

- IP-optimized, Scalable bandwidth and Co-existence with legacy standards

The tables below show key performance parameters that should be mate when performing the measurement with an appropriate measurement method discussed in the previous sections. Table 2.5 describes the performance target for data application from 3GPP standard about UE category and data rate. The 4G ITU-T standard IMT advanced requirements are shown in Table 2.6.

Table 2.5 Performance targets for data applications [18]

Medium	Application	Degree of symmetry	Typical amount of data	Key performance parameters and target values		
				One-way delay(Note)	Delay variation	Information loss
Data	Web-browsing - HTML	Primarily one-way	~ 10 KB	Preferred < 2 s /page Acceptable < 4 s /page	N.A.	Zero
Data	Bulk data transfer/retrieval	Primarily one-way	10 KB- 10 MB	Preferred < 15 s /page Acceptable < 60 s /page	N.A.	Zero
Data	Command/control	Two-way	~ 1 KB	< 250 ms	N.A.	Zero
Data	Interactive games	Two-way	< 1 KB	< 200 ms	N.A.	Zero
Data	Telnet	Two-way (asymmetric)	< 1 KB	< 200 ms	N.A.	Zero
Data	E-mail (server access	Primarily one-way	< 10 KB	Preferred < 2 s Acceptable < 4 s	N.A.	Zero
Data	E-mail (server to server transfer)	Primarily one-way	< 10 KB	Can be several minutes	N.A.	Zero
Data	Fax ("real-time")	Primarily one-way	~ 10 KB	< 30 s/page	N.A.	< 10^{th} BER
Data	Low priority transactions	Primarily one-way	< 10 KB	< 30 s	N.A.	Zero
Note: In some case, it may be more appropriate to consider these value as response time						

Table 2.6 IMT-Advanced LTE Data Rate Requirement [19]

Item	IMT-Advanced
Peak Data Rate (DL)	1 Gbps
Peak Data Rate (UL)	500 Mbps
Spectrum Allocation	>40 MHz
Latency (User Plane)	10 ms
Latency (Control Plane)	100 ms
Peak Spectral Efficiency (DL)	15 bps/Hz (4 X 4)
Peak Spectral Efficiency (UL)	6.75 bps/Hz (2 X 4)
Average Spectral Efficiency (DL)	2.2 bps/Hz (4 X 2)
Average Spectral Efficiency (UL)	1.4 bps/Hz (2 X 4)
Cell-Edge Spectral Efficiency (DL)	0.06 bps/Hz (4 X 2)
Cell-Edge Spectral Efficiency (UL)	0.03 bps/Hz (2 X 4)
Mobility	Up to 350 km/h

Table 2.7 LTE UE category and Data rates [25]

Category	DL peak data rate	UL peak data rate	UL Mod	DL Mod	Carriers	DL MIMO
1	10 Mbps	5 Mbps			1CC	SISO
2	50 Mbps	25 Mbps			1CC	2x2
3	100 Mbps	50 Mbps			1CC	2x2
4	150 Mbps	50 Mbps			1CC	2x2
5	300 Mbps	75 Mbps	64QAM UL	256QAM DL	1CC	4x4
6	300 Mbps	50 Mbps	64QAM UL	256QAM DL	2/1CC	2x2
7	300 Mbps	100 Mbps	64QAM UL	256QAM DL	2/2CC	2x2
8	3 Gbps	1.5 Gbps	64QAM UL	256QAM DL	5/5CC	8x8
9	450 Mbps	50 Mbps	64QAM UL	256QAM DL	3/1CC	2x2
10	450 Mbps	100 Mbps	64QAM UL	256QAM DL	3/2CC	2x2
New categories (11, 12, ...)			64QAM UL	256QAM DL	4/4CC+	8x4+

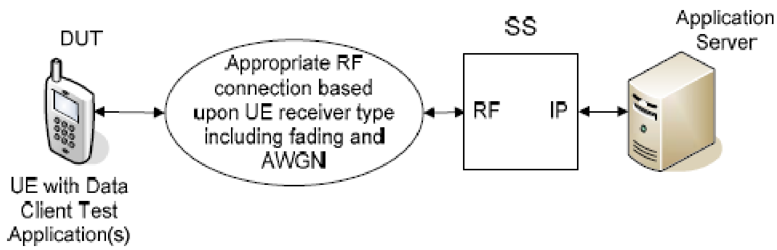


Figure 2.5 UE Application Layer Data Throughput Connection Diagram [26]

In Figure 2.5, the test equipment utilized for UE Application Layer Data Throughput shall consistent of the following items. Some of the elements below may be implemented in the same piece of test equipment depending on implementation [26]. The components making the application layer data throughput in Figure 2.5 are;

- User end (UE).
- Data client test application(s) for the UE for both tethered and embedded mode operation.
- System Simulator (SS) suitable for the radio technology(s) used for testing with necessary IP connectivity and Application Servers.
- Faders and Additive White Gaussian Noise (AWGN) sources that are capable of supporting the radio environments defined.

2.4 LTE Data Service QoS Measurement Techniques

Service providers are interested in gathering information about the quality of signal coverage to improve the placement of cellular antennas, but building detailed maps that span whole countries is overwhelming task. Monitoring activities provide more accurate information when carried out where the end users are; the required amount of work is, in many cases, beyond the possibilities of a single institution like the service provider; environmentally distributed monitors enables fine grained measurements like the crowd sourcing clients. Deploying data services over LTE has posed significant challenges for service providers, due to backward-compatibility, inter-operability, and high quality requirements these requires rigorous testing [22,23].

An understanding on the detail measurement flow enables us to see the accuracy of the techniques and helps in working on measurement techniques that best shows the service providers network to see the performance of the LTE data service. These measurement techniques are discussed in more detail in the following sub-sections.

2.4.1 Drive Test Measurement Techniques

Drive tests are the most common measurement tool used by operators, to probe the quality status and solve network problems. Drive Testing allows the mobile network to be tested through the use of a team of people who take the role of users and take the QoS measures to rate the QoS of the network [17].

- **Drive Testing in LTE data network:**

In Long Term Evolution (LTE), the main benefit of drive testing is that it measures the actual network coverage and performance that a user on the actual drive route would experience on that particular instance. It is argued that in today's networks with modern simulations, network engineers can mathematically model how a network will perform [17]. Drive test systems are generally built around two measurement components;

1. Instrumented mobile phones (test engineering phones): Phone based systems can respond to problems within network-controlled constraints.
2. Measurement receivers: Receiver based systems give a complete overview of Radio Frequency (RF) activity but cannot duplicate network-related problems.

These measurement devices are controlled with data logging software on a laptop PC together with a global positioning system (GPS) to provide geo-location of the collected data. The collected data can be analyzed using Actix software that allows for plotting the results on digital maps enabling visualization of the RF environment.

Network operators have shifted their focus from purely measuring RF performance to measuring customer experience, and this has driven the integration of many data application tests such as video streaming and voice over IP (VoIP) into drive test systems so that engineers can correlate end-user application performance with detailed RF measurements. With LTE many of the measurement themselves have had to adjust to take into account the much higher data rates that LTE provides [17].

- **Importance of Drive test for LTE:**

Many different strategies and methods to monitor network performance have been described. Network "Probing" in which the signaling traffic is monitored at control points and then centrally analyzed can provide valuable insights into the overall network health.

This strategy works well where, as in Global System for Mobile Communication (GSM) and UMTS networks, much of the control traffic is consolidated through radio network controllers (RNCs) or base station controller (BSCs) so that by monitoring relatively few major interfaces, a good view of a wide range of base station end- points can be obtained [17].

As the industry has moved ahead for emerging market with HSPA and now LTE technologies, more and more of the network intelligence has moved out from the core to the edge of the network and into the E-UTRAN Node Base Station (eNBs), also taking the traffic management towards the network edge. This means that much of the control and decision making is now deployed with in the eNBs, and interaction between the user Equipment (UE) and base stations can be most effectively monitored by instrumented phones involved in the actual transactions. This move of the decision point in traffic management has been needed to realize the reduced latency requirement for LTE performance- signaling control traffic no longer has to traverse multiple network nodes when a change is made for a UE. One of the measurement of LTE performance is Nemo Handy. The next section briefly discusses Nemo Handy drive test measurement tool.

Nemo Handy:

Nemo Handy provides smart and discreet solutions for thorough and advanced measurement and optimization of wireless air interface and mobile application Quality-of-Service (QoS) and Quality-of-Experience (QoE) [27]. Nemo Handy has set the standard for handheld network measurement devices since 2005. Make outdoor and indoor wireless network measurements with a smart and inconspicuous application installed on an android-based device.

- Create complex measurement scripts more easily and effectively
- Reduce test time with the intuitive user interface
- Test FTP, HTTP, Browsing, YouTube, Facebook, and more
- Use map navigation based on Google Maps.
- Enhance system integration with the open Nemo file format; integrate with Nemo Outdoor, Nemo Analyze, or third-party post-processing (Actix analyzer) tools.
- Use with Qualcomm and Samsung Shannon chipsets.
- Streamline operations and improve responsiveness with the Nemo Cloud option, a cloud-based platform for centralized remote control.
- Create fast and efficient reports in the field with the Nemo Instant Report option

In addition to a rich variety of real-time displays, all RF and signaling data is logged to the phone's internal storage. Log files are made available in Nemo file format for easy post-processing with Nemo post-processing tools or third-party post-processing (Actix software) tools. The testing environment consists of a Nemo Handy-A compatible smartphone or tablet. The Nemo Handy software is preinstalled in the mobile. The Nemo Handy mobile can be used as a regular phone while Nemo Handy-A is logging in the background.

- **Nemo Handy Application throughput view for LTE**:

Application layer data throughput (Downlink and Uplink) are recorded semi-periodically when application layer data is transferred or Received from the server (operating system). The minimum time period between two measurement events is one second; the maximum is ten seconds (zero values are recorded when data has not been transferred at a point in time). Application Throughput Downlink displays the data throughput rate in downlink direction. The gauge view displays the application throughput in downlink direction in kb per second and the amount of data transferred in downlink and in uplink direction in bytes. Application Throughput Uplink displays the data throughput rate in uplink direction. The gauge view displays the application throughput in uplink direction in kb per second and the amount of data transferred in downlink and in uplink direction in bytes [32].

Figure 2.6 shows sample nemo handy mobile application throughput measurement graphics. The measured data should be uploaded to display the Key performance indicators.

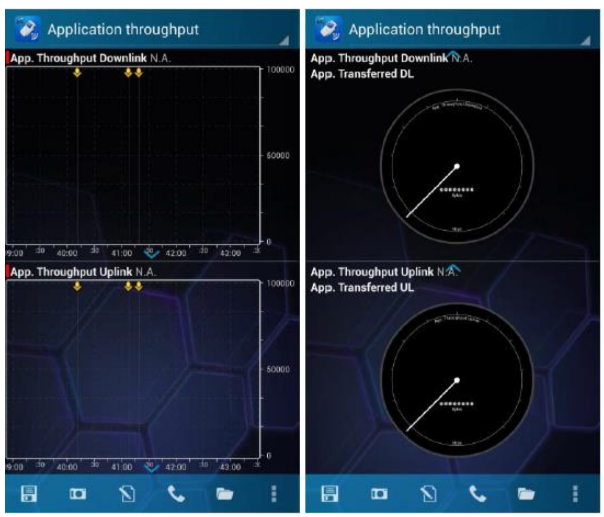


Figure 2.6 Nemo Handy downlink application measurement sample

2.4.2 Crowd sourced Measurement Techniques

A crowdsourcing-based solution for network monitoring lies in the power of crowds. Since monitoring activities are executed on users' hardware, the organization that coordinates the monitoring activity is relieved from the economical and practical burden of managing a dedicated system. Shifting network monitoring towards the end systems. Networked services and applications can be observed where they are used, and this paves the way to an evaluation of performance metrics from the end user perspective [29].

- **Why smartphones:**

A prerequisite for every successful crowdsourcing-based system is having a large user base, as the power of crowdsourcing directly comes from the number of participants. Advantage of using smartphones are;

- Always on, this eases automation of tasks.
- They can be easily geo-localized through the embedded GPS unit; enables the analysis of networked systems along additional dimensions. Provides the opportunity for more sophisticated studies based on geographical locality as well.
- Easy mechanisms for software installation and upgrade. Since end users are accustomed to the guided process for application download and installation. The built-in mechanisms for software upgrade ease and accelerate the development of network monitoring applications.
- Detection of mis-calibrated sensors through rendezvous.
- Smartphones visit a possibly large number of wireless networks and Access the Internet from different entry points.

Users just download free apps from online stores and can conduct performance tests from their mobile devices. This emerging technique proposed for improving service quality through improved measurement methods which will give a true state of services provided to users. From the available crowdsourcing applications two of which the most common are discusses in the following paragraph these are, OpenSignal & Speed Test. The next sections discusses Open Signal and Speed Test crowdsourcing LTE data QoS measurement.

Open Signal

Open Signal is crowd sourcing application that tracks users' mobile phone coverage across the board, and makes this data available. The OpenSignal data is collected from real world consumer smartphones, and is recorded under conditions of normal usage. Rather than approximate the user experience, open signal directly measures it from the users' client application. The download and upload measurement processes are organized as shown in Figure 2.7 and 2.8 respectively [30].

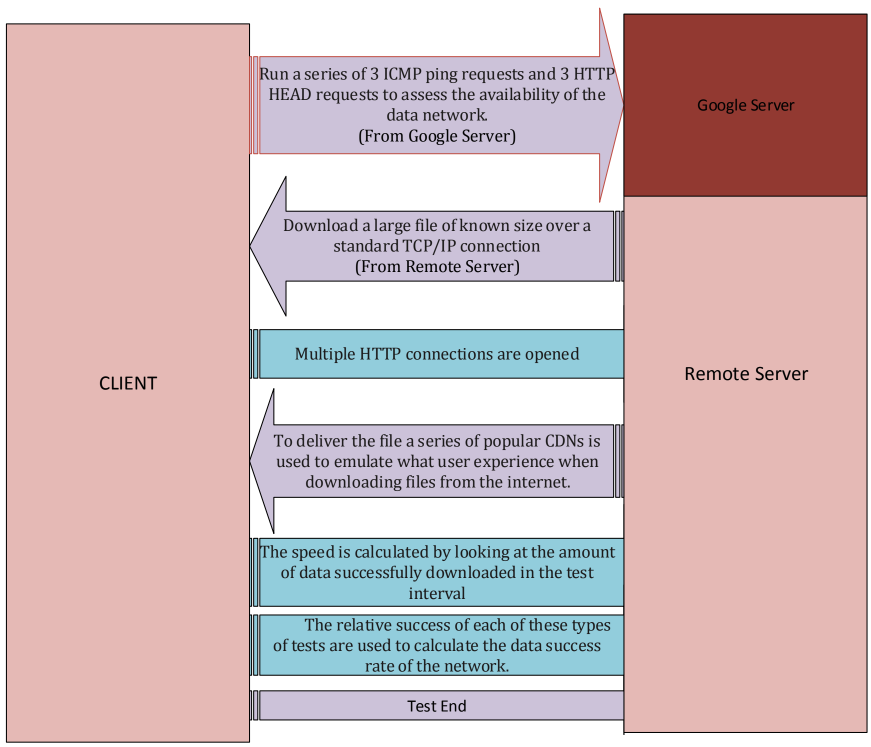


Figure 2.7 Open Signal Download speed measurement processes

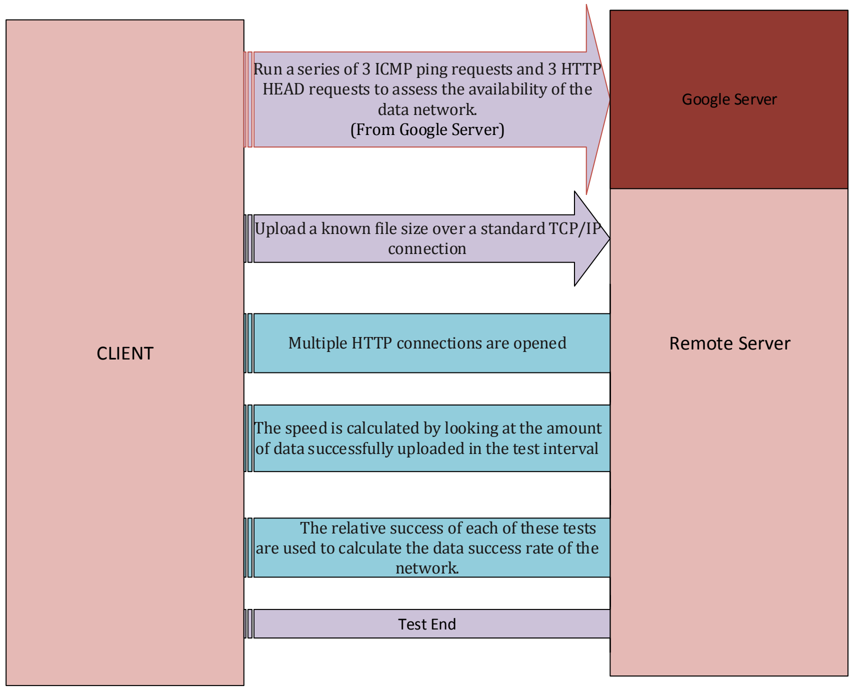


Figure 2.8 OpenSignal upload speed measurement processes

Ookla SpeedTest

Ookla SpeedTest is a global mobile and internet test tool. As of May, 2018 speed test has 7,214 Global testing servers, 5,324 Global hosts, and 19,996,978,522 tests taken with Speedtest [31].The accuracy and high-quality performance of Speedtest is made possible through the 7,000+ servers around the world. This robust network of servers enables to ensure that our users get local readings wherever they are on the planet.

SpeedTest operates mainly over TCP testing with a HTTP fallback for maximum compatibility. Speedtest.net measures ping (latency), download speed and upload speed. The measurement process for TCP and HTTP are discussed in the next paragraphs [31].

- **TCP test process:**

A TCP test process components are comprised of latency, download and upload KPI. The latency test is performed by measuring the time it takes for the server to reply to a request from the user's client. The client sends a message to the server, upon receiving that message; the server sends a reply back. The round-trip time is measured in ms (milliseconds). This test is repeated multiple times with the lowest value determining the final result. TCP/IP Download and TCP/IP Upload measurement steps are organized and described in Figure 2.9 and Figure 2.10 respectively.

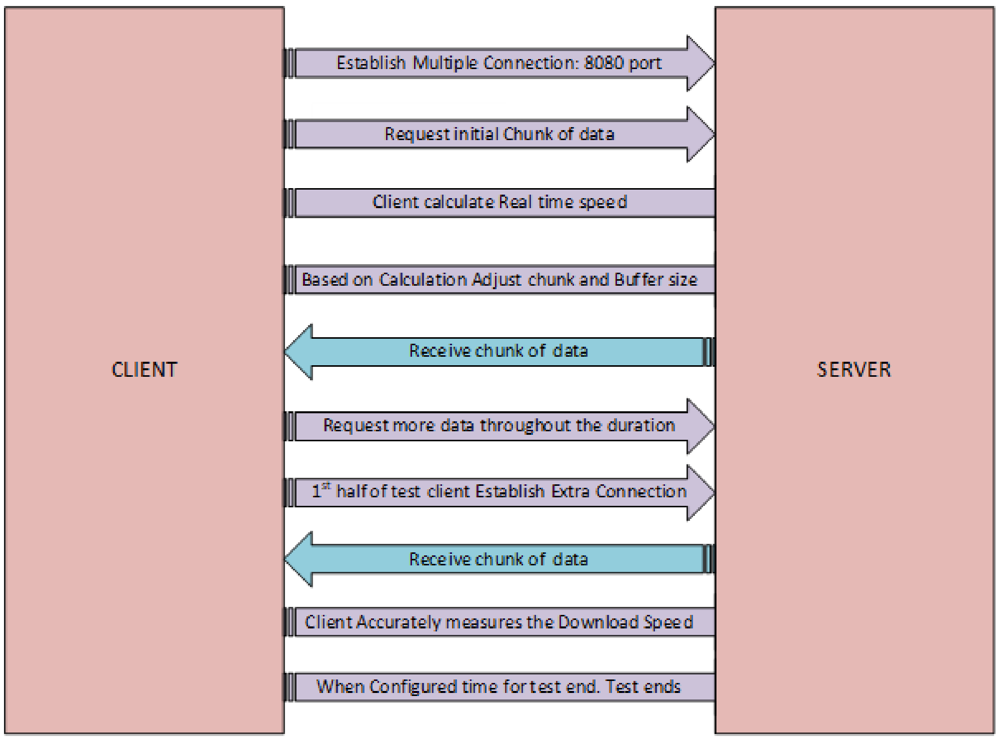


Figure 2.9 Speedtest TCP/IP Download speed measurement processes

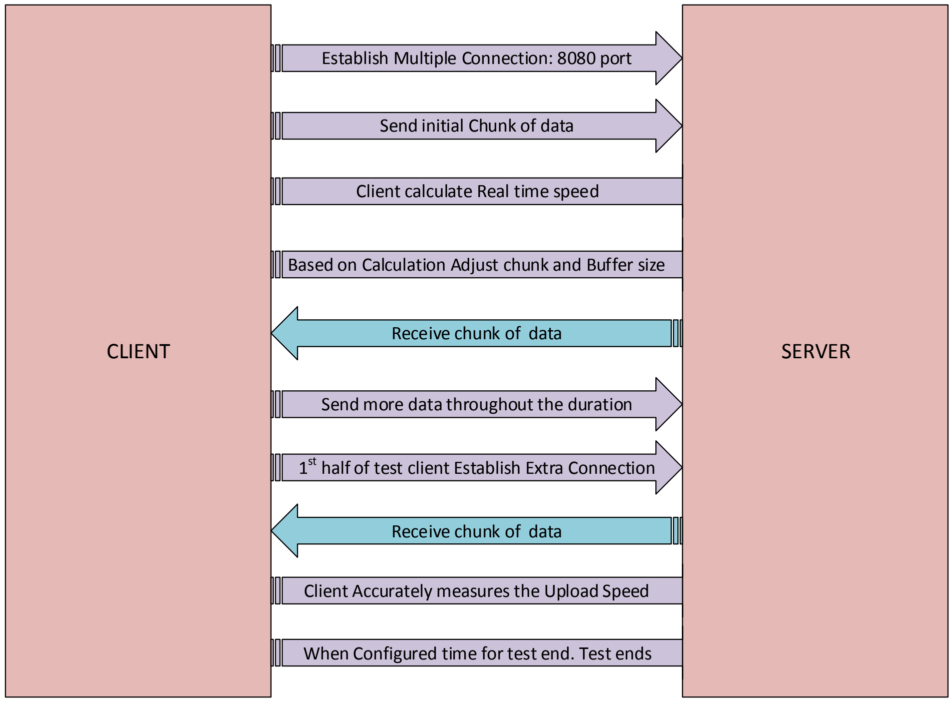


Figure 2.10 Speed Test TCP/IP Upload speed measurement processes

For TCP upload and download speed process the client calculates the real-time speed of the transfers, and then adjusts the chunk size and buffer size based on the calculation to maximize usage of the network connection. During the first half of the test, the client will establish extra connections to the server if it determines additional threads are required to more accurately measure the download speed.

- **HTTP test process:**

The HTTP testing includes latency, download and upload KPI. The latency test is performed by measuring the time it takes to get a response for a HTTP request sent to a web server. This test is repeated multiple times with the lowest value determining the final result. HTTP download test and HTTP upload test measurement steps are organized and described in Figure 2.11 and Figure 2.12 respectively.

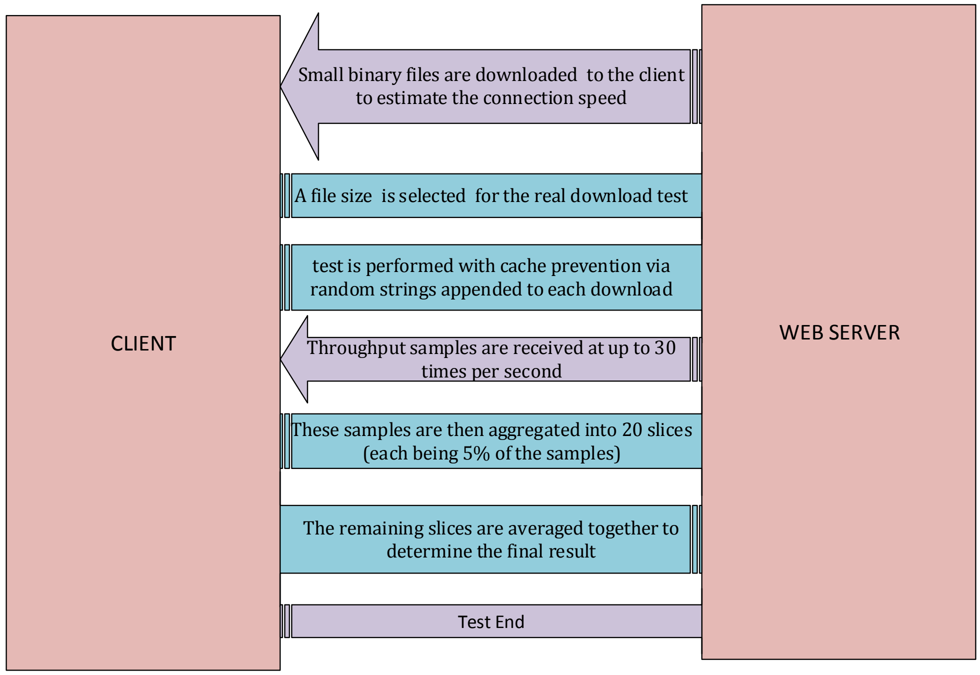


Figure 2.11 Speed Test HTTP Download speed measurement processes

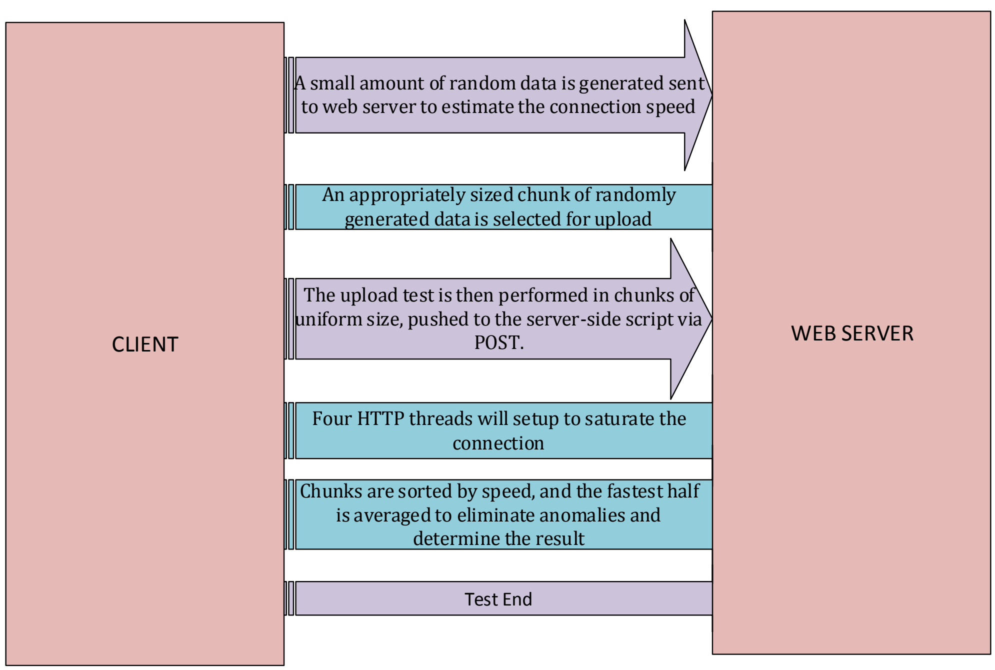


Figure 2.12 Speed Test HTTP Upload speed measurement processes

The Ookla SpeedTest result is calculated as; the measured samples are sorted by speed. The two fastest results and the bottoms ¼ (which are approximately 22% of the total) are removed. Everything else is then averaged. The ping is the reaction time of your connection–how fast you get a response after you've sent out a request. A fast ping means a more responsive connection, especially in applications where timing is everything (like video games).

Chapter 3

3. Selected Framework and E-UTRAN Impact on Performance of Measurement Techniques

A measurement framework has to be deployed for the end to end performance of an application that are used in drive test and crowdsourcing techniques before a measurement is carried out. From the lists of proposed measurement framework by ITU-T under section 2.3.2, in this thesis we choose an appropriate flow to evaluate the performance of Nemo Handy, OpenSignal and SpeedTest measurement tools. To complete the processes the steps followed are clearly depicted in Figure 3.1. A measurement framework for drive test and crowdsourcing technique including the detail LTE network components are separately discussed under Section 3.1 and 3.1 respectively.

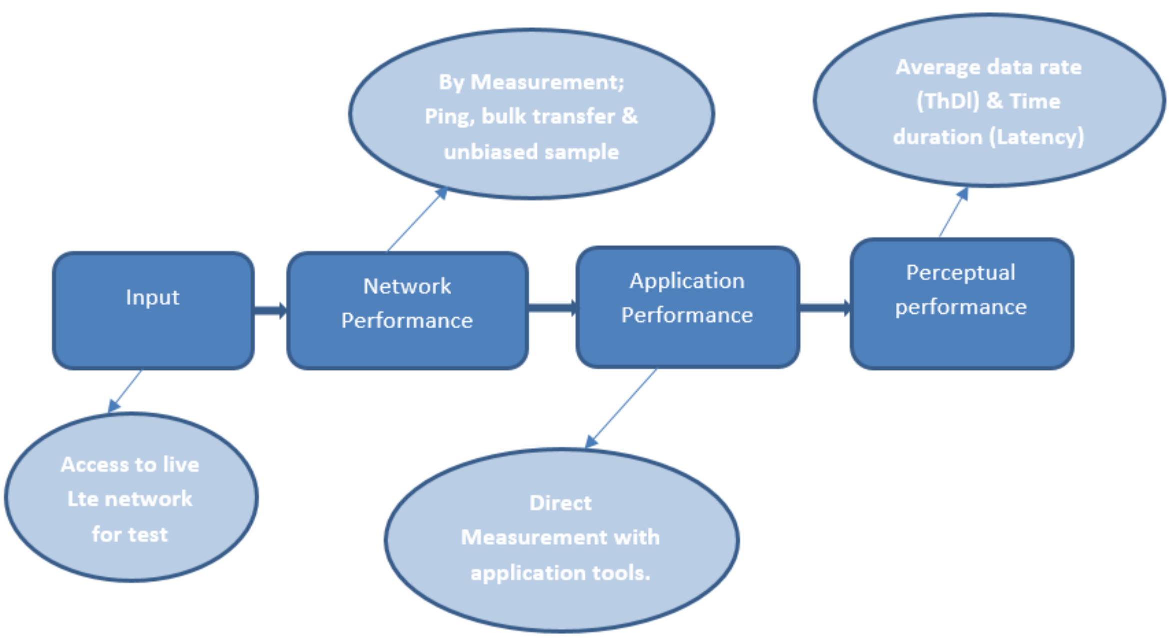


Figure 3.1 Framework for the end to end measurement techniques

3.1 Drive Test Measurement Technique Framework

In Figure 3.2 LTE data service drive test end to end measurement flow. It includes the network elements involved in the measurement process and the communication protocol used between each network elements and the end users tools used in the measurement. Once the nemo apps run for performance test it will take the red data path to download and upload a specified file on the FTP server located locally. Drive test LTE data service measurement components carried by Nemo Handy are;

- ✓ Preparation of UE installed with Nemo Hany application.
- ✓ Preparation of site information (Map, Cell plan,)
- ✓ Verify Location of serving cell
- ✓ Search Good dominant RF environment
- ✓ RSRP>-65dBM, RSRQ>-10dB, SINR > 20.
- ✓ Single Cell functionality check
- ✓ Ping Test RTT < 15ms (Local ISP Server)
- ✓ DL Throughput (Specify file size in Mbps)
- ✓ UL throughput (Specify file size in Mbps)

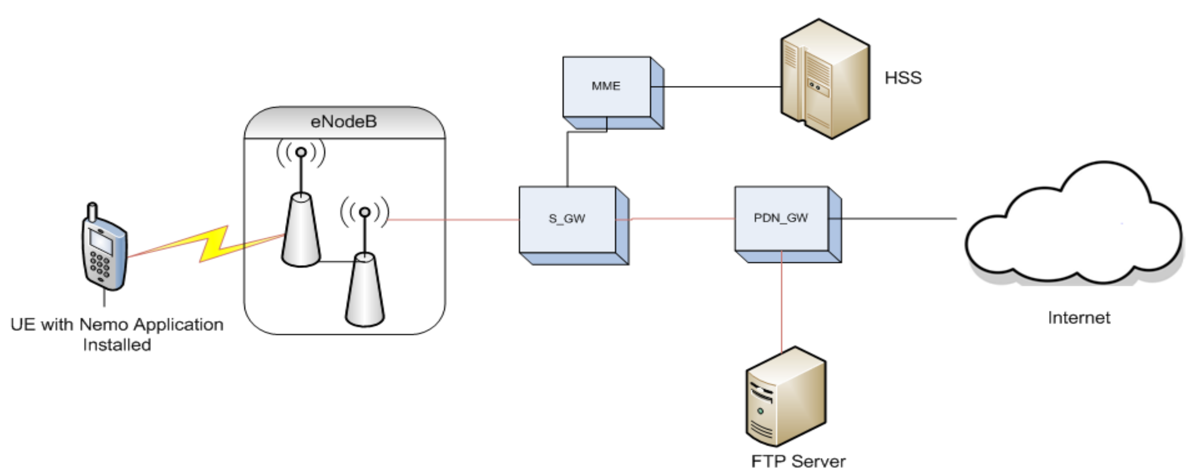


Figure 3.2. Shows the path Nemo Handy follows to perform a test

3.2 Crowd Sourcing Measurement Technique Framework

In Figure 3.3 LTE data service crowdsourcing end to end measurement flow are shown. It includes the network elements involved in the measurement process and the communication protocol involved between each network elements, and the end users tools. The crowdsourcing LTE data service measurement process:

- ✓ Preparation of UE installed with OpenSignal and SpeedTest application
- ✓ Preparation of site information (Map, Cell plan,)
- ✓ Ping Test to the client application Server
- ✓ Specify transport and application layer protocol (TCP/UDP and FTP/HTTP)
- ✓ DL Throughput (Specify file size in Mbps)
- ✓ UL throughput (Specify file size in Mbps)
- ✓ Specify number of test samples and duration.
- ✓ Insure RSRP>-65dBM, RSRQ>-10dB, SINR > 20.

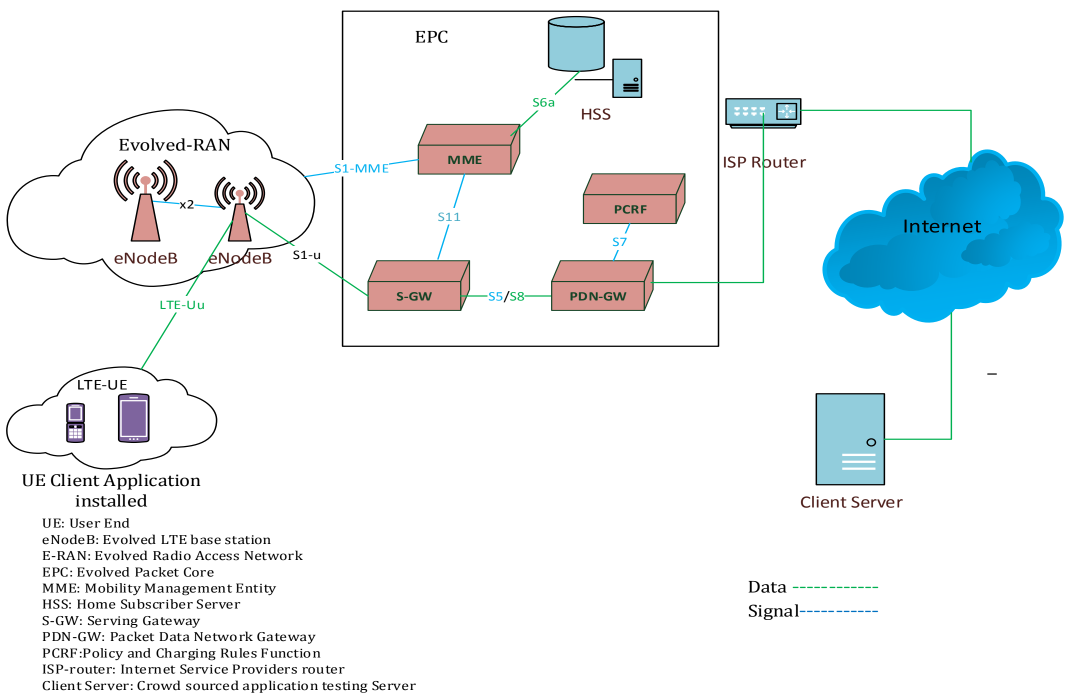


Figure 3.3 Crowd Sourcing LTE data service end to end measurement framework

3.3 E-UTRAN Impact on LTE QoS Parameters

Under this Section and Subsections we discussed a throughput and latency Key Performance Indicators (KPI) that shows how Enhanced Universal Terrestrial Radio Access Network (E-UTRAN) impacts the service quality provided to an end user. The throughput parameters shows how the payload data volume on IP level per elapsed time unit on the Uu interface. Latency is a measurement that shows how E-UTRAN impacts on the delay experienced by the end user. It is the time from reception of IP packet to transmission of first packet over the Uu [21]. The next Subsections depicts the calculations beheaded the parameters in E-URAN.

3.3.1 LTE Throughput calculation

In this section performance parameters consider to calculate a throughput under E-URAN network are described. Figure 3.4 shows how IP throughput is calculated and clear view of the data transfer to the user end. A downlink IP throughput for a single Quality Class Identifier (QCI) is the same as Data Radio Bearer IP throughput Downlink QCI (*DRB.IPThpDl.QCI*). Similarly, an uplink IP throughput for a single QCI is the same as Data Radio Bearer IP throughput uplink QCI (*DRB.IPThpUl.QCI*).

To achieve a throughput measurement that is independent of burst traffic pattern, it is important to make sure that idle gaps between incoming data is not included in the measurements. That shall be done as considering each burst of data as one sample. ThpVolDl is the volume of IP level and the ThpTimeDl is the time elapsed on Uu for transmission of the volume included in the ThpVolDl Figure 3.5.

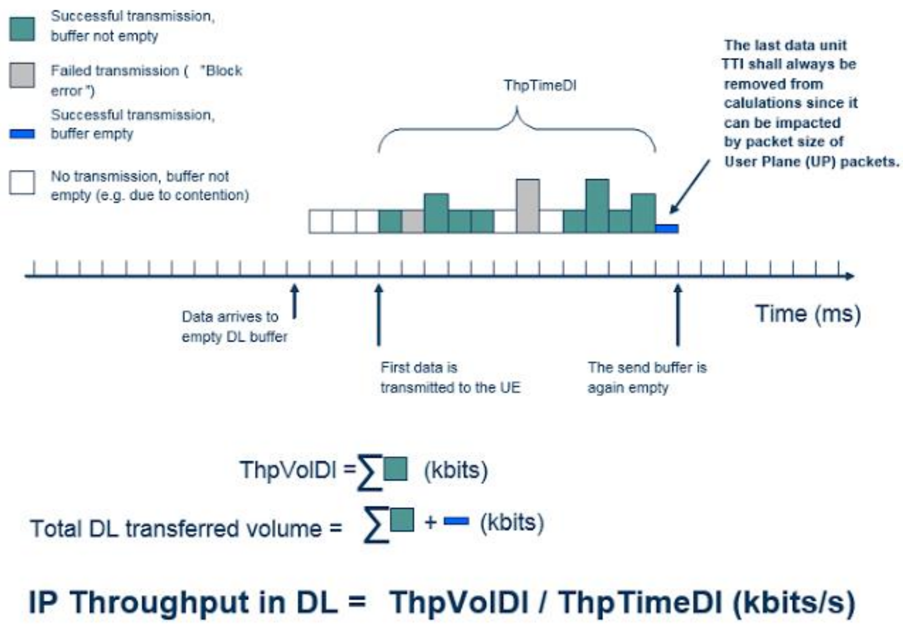
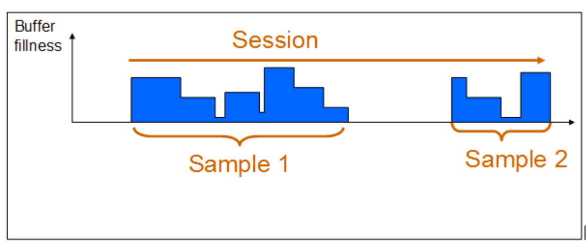


Figure 3.4 LTE data service IP throughput calculation [21].



$$IP\ Throughput\ DL = \sum_{Samples} \text{ThpVolDl} \Big/ \sum_{Samples} \text{ThpTimeDl}$$

Figure 3.5 LTE data service IP throughput per sample [21].

3.3.2 LTE Latency calculation

To achieve a delay measurement that is independent of IP data block size only the first packet sent to Uu is measured. To find the delay for a certain packet size the IP throughput measure can be used together with the IP latency (after the first block on the Uu, the remaining time of the packet can be calculated with the IP throughput measure) [21].

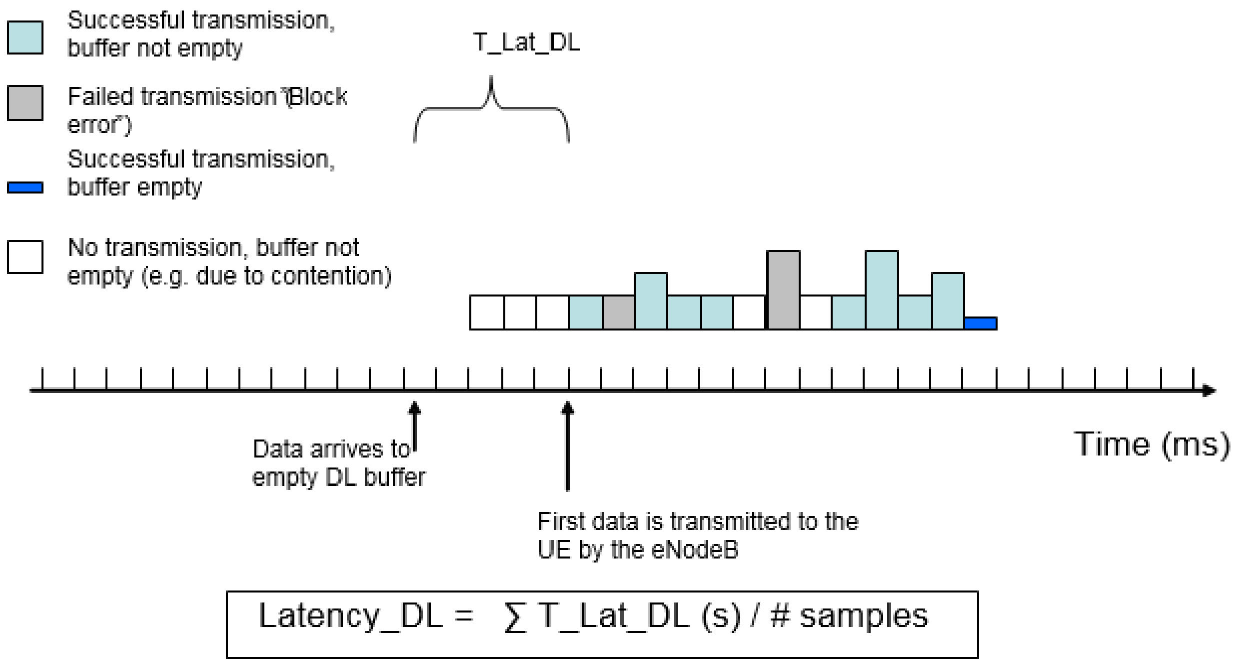


Figure 3.6 LTE data service IP latency calculation [21].

In Figure 3.6 T_Lat defined as the time between reception of IP packet and the time when the eNodeB transmits the first block to Uu. Since services can be mapped towards different kind of E-RABs (E-UTRAN Radio Access Bearer), the latency measure shall be available per QoS group.

Chapter 4

4. QoS Data Collection for Addis Ababa LTE Network

Data is collected with the measurement techniques to help analyze the performance on QoS in LTE data service of the techniques.

4.1 LTE Data Service Integrity Measurement Process for Addis Ababa Case

LTE data Quality of Service is measured with Nemo Handy, Speed test and Open Signal measurement tools. For data collection Nemo Handy tool installed on Ethio telecom mobile device with a brand Samsung S5 and Model SM-G900F and the crowdsourcing applications; Speed Test and Open Signal, is installed on a similar brand and model mobile phone. Hardware devices used for the measurement: Two Samsung S5, Model SM-G900F3 4G (LTE) SIM card (Subscriber Identity Module).

- How Nemo Tool is used to measure LTE data service

Nemo Script is configured to measure the download speed for FTP service from a server. Figure 4.1 above shows the paths on how the nemo script is configured as per the specific measurement need. The nemo application installed on Samsung S5 mobile phone is started. Activate the packet session for LTE, run the script editor. For our test FTP download is chosen. Input the FTP server IP address, fill the correct user name and password.

The download file is set to 100MB. Iteration time is the number of times the script repeats to download the specified size of data to calculate the average throughput. Deactivate the packet session. Save and exit. Finally, start the measurement with Nemo tool by running saved script.

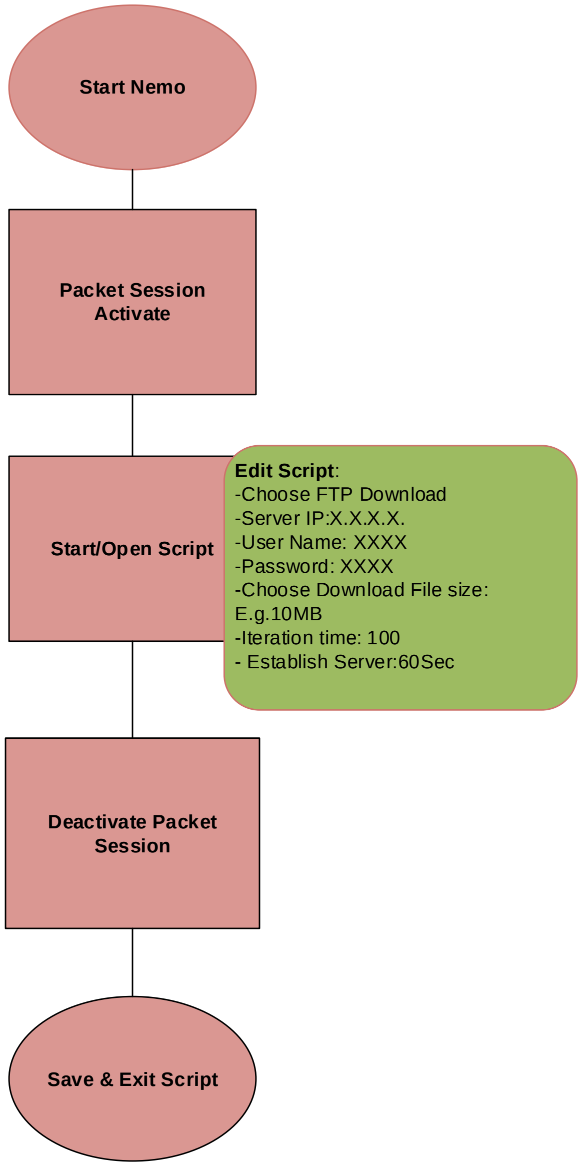


Figure 4.1 shows the Nemo Handy Parameter configuration on Mobile Device

- How Crowd Sourcing tools are used to measure LTE data service

Speedtest and OpenSignal crowd sourcing tools are installed on the Samsung mobile phone. When a measurement is need simply run the installed application and click on the start button will automatically start the measurement process. The measurement process with the crowdsourcing application are briefly described in Figure 3.2 under section 3.2.

The place for the measurement is at Ethio telecom's central microwave which is located in front of National meteorology agency. The route map followed while taking the measurement is shown in Figure 4.2 and Figure 4.3. Figure 4.2 shows the available near cells to the serving cell when the measurement is taken. The blue hashtag in the figure is the exact route map followed. Figure 4.3 shows the serving cell and the route covered while measuring LTE data service. A walking distance of 1.4 kilo meter is completed to keep the LTE (4G) and avoid the loss of the signal. When a long route is used and a handover is faced the 4G signal will be below the threshold and redirected to 3G signal.

- Measured Route Map with Nemo, OpenSignal and Speedtest tools

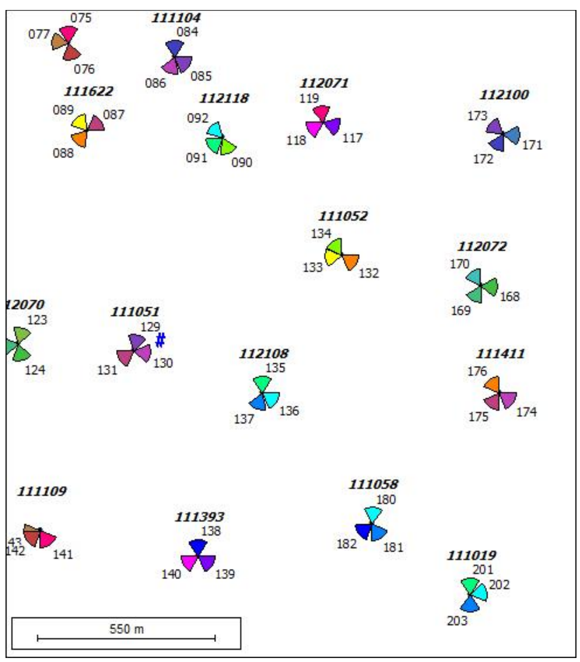


Figure 4.2 shows available active cells to near serving cell

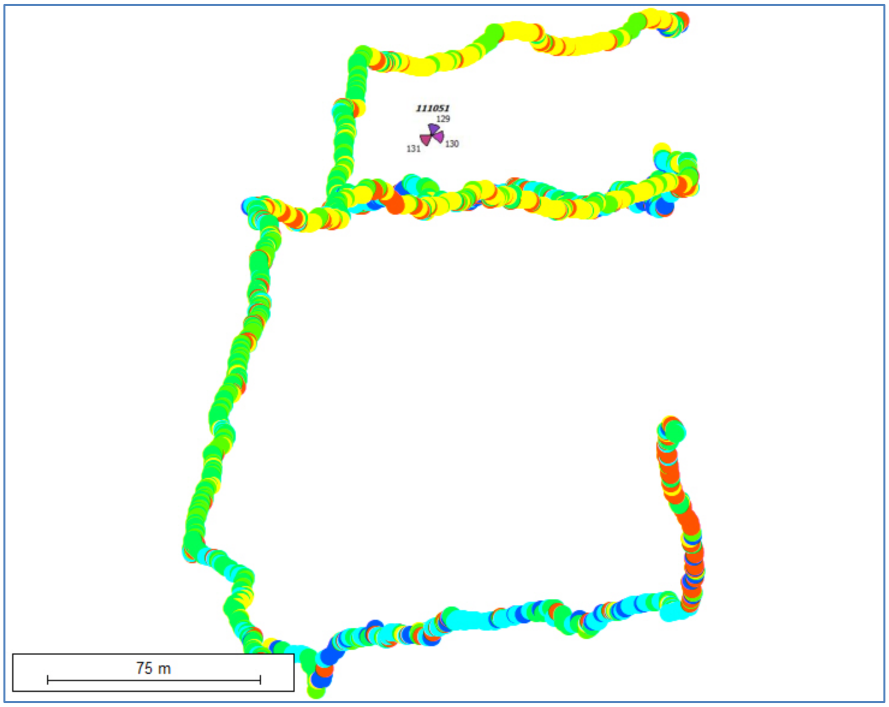


Figure 4.3 Route Map with serving cell 11051

Figure 4.4 Addis Ababa LTE network DT routes

- Number of Measured Samples

  - Downlink Throughput;

Nemo with Speedtest: 660 samples

Nemo with OpenSignal: 340 samples

- Latency;

Nemo with Speedtest: 220 samples

Nemo with OpenSignal: 350 samples

4.2 LTE Data Service Sample Measurement Data

The files measured with Nemo application are saved with nemo file type. The measured data is analyzed with Actix tool. Figure 4.5 shows downlink throughput and Latency (round trip time, RTT) key performance indicators (KPI) measurement respectively in parallel with Open Signal (OS) and Speed Test (SP) crowd sourcing measurement tools.

Nemo_RTT_OS_18Apr13_164311.1.nmf	4/13/2018 4:59 PM	NMF File	3,790 KB
Nemo_RTT_SP_OS_18Apr13_154218.1.nmf	4/13/2018 4:41 PM	NMF File	17,514 KB
Nemo-DLThroughput-OS_18Apr13_162356.1.nmf	4/13/2018 4:29 PM	NMF File	1,059 KB
Nemo-DLThroughput-OS_18Apr13_163058.1.nmf	4/13/2018 4:59 PM	NMF File	10,261 KB
Nemo-DLThroughput-SP_18Apr13_155311.1.nmf	4/13/2018 4:10 PM	NMF File	5,531 KB
Nemo-DLThroughput-SP_18Apr13_161340.1.nmf	4/13/2018 4:21 PM	NMF File	1,199 KB

Figure 4.5 Shows Measured Raw Data for Nemo Downlink Throughput and RTT

Figure 4.5 shows Nemo Handy measured raw data measured on 13th of April 2018. The file type is of nmf.

The crowd sourcing sample measured output from Open Signal and SpeedTest measurement tools are depicted in Figure 4.6 and Figure 4.7.

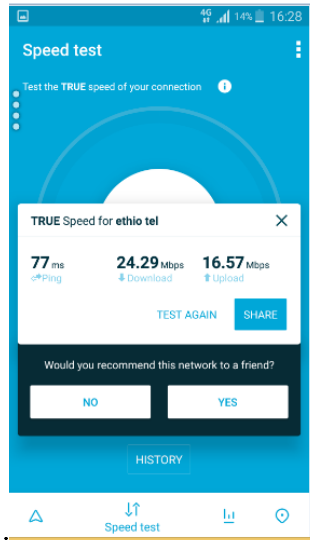


Figure 4.6 Open Signal Sample Speed Test Measured Output

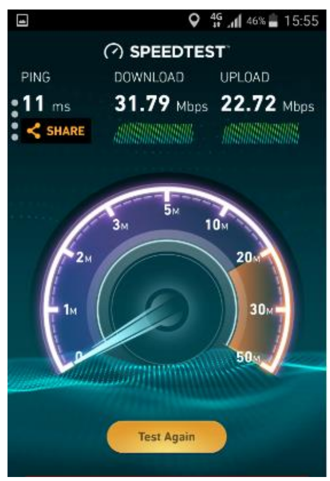


Figure 4.7 Speed Test Sample Measured Output

4.2.1 LTE Downlink Throughput and Latency Measurement with Nemo tool

- Nemo Downlink Throughput Measurement

Actix tool is used to read Nemo Handy raw data file. The file can be exported as a map, chart or as a workbook. A sample workbook as read directly from Actix tool is shown in Table 4.1.

Table 4.1 shows sample output of Nemo raw file Actix output in figure 4.5. It has included the time and date of the measurement, the message number between Nemo application and FTP server, distance covered during a particular measurement, location of the measurement and finally the downlink throughput in kilobits per second. These workbook output from Actix tool are used for the analysis using Matlab.

Table 4.1 Nemo Sample Downlink Throughput Actix output

Message	Time	Distance	Longitude	Latitude	App_Throughput_DL
17978	Apr/13/18 04:02:25	198.177948	38.74776	9.01817	
18012	Apr/13/18 04:02:26	198.289154	38.74776	9.01817	
18045	Apr/13/18 04:02:27	198.742279	38.74776	9.01817	11239.42
18077	Apr/13/18 04:02:28	200.855362	38.74775	9.01817	25668.08
18109	Apr/13/18 04:02:30	201.654175	38.74777	9.01816	23183.75
19123	Apr/13/18 04:03:00	211.045715	38.74778	9.01817	18132.7
19155	Apr/13/18 04:03:01	213.130219	38.74778	9.01813	26307.52

- Nemo Latency Measurement

Actix tool is used to read Nemo raw data file. The file can be exported as a map, chart or as a workbook.

A sample latency workbook as read directly from Actix tool is shown in Table 4.2. It has included the time and date of the measurement, the message number between Nemo application and FTP server, distance covered during a particular measurement, location of the measurement and finally the downlink throughput in kilobits per second. These workbook output from Actix tool are used for the analysis using Matlab.

Table 4.2 Nemo Sample Latency Actix output

Message	Time	Distance	Longitude	Latitude	Ping_RTT
2980	Apr/13/18 03:43:57	93.047005	38.74713	9.01866	28
3010	Apr/13/18 03:43:58		38.74712	9.01866	23
3042	Apr/13/18 03:43:59	95.387085	38.74712	9.01865	30
3074	Apr/13/18 03:44:00	98.328804	38.7471	9.01864	22
3102	Apr/13/18 03:44:02	99.805908	38.74709	9.01863	20
3127	Apr/13/18 03:44:02	101.137589	38.74707	9.01862	18
3156	Apr/13/18 03:44:03	102.87619	38.74707	9.01861	29
3185	Apr/13/18 03:44:05	104.206009	38.74705	9.01861	28
3210	Apr/13/18 03:44:05	104.645294	38.74704	9.0186	19

4.2.2 Downlink Throughput and Latency Measurement with SpeedTest and OpenSignal

Android version of SpeedTest and OpenSignal is used for the test in the result for both output are shown in excel. The excel data are used for analysis with Matlab. The output in Table 4.3 shows the final measured result as in Section 3.2.

Table 4.3 Shows Speed Test Measured Output

Date	ConnType	Lat	Lon	Download	Upload	Latency	ServerName	InternalIp	ExternalIp
4/13/2018 16:16	Lte	9.01806	38.74647	33.11	21.22	13	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:16	Lte	9.01814	38.74662	26.66	30.87	15	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:15	Lte	9.01814	38.74662	41.52	24.46	13	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:14	Lte	9.0181	38.74663	41.09	22.84	13	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:13	Lte	9.0181	38.7466	31.1	23.4	14	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:08	Lte	9.01823	38.74716	37.11	18.42	14	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:07	Lte	9.01823	38.74716	28.61	22.93	12	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:06	Lte	9.01813	38.74728	27.42	24.19	13	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:06	Lte	9.01813	38.74728	24.97	21.74	14	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:05	Lte	9.01795	38.74745	23	21.89	14	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:04	Lte	9.01806	38.74752	17.08	16.6	13	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:03	Lte	9.01815	38.74762	38.28	21.39	15	Addis Ababa	10.50.189.232	197.156.95.225
4/13/2018 16:02	Lte	9.01813	38.74784	39.28	23.81	15	Addis Ababa	10.50.189.232	197.156.95.225

Table 4.3 shows sample output format of Speedtest measurement result. It has included the time and date of the measurement, the measured network technology as a connection type LTE, location of the measurement, downlink and uplink throughput in megabits per second (Mbps). Latency in millisecond (ms). The server name identified during the measurement is

Addis Ababa. Internal and External IP as indicated. The excel output is used for the analysis using Matlab. The output in Table 4.4 shows sample result from OpenSignal. The Table has included sample measurement output. In the list the time of the measurement for the downlink throughput in megabits per second (Mbps) and the latency in millisecond (ms) are shown. The excel output is used for the analysis using Matlab.

Table 4.4 Shows Open Signal Measured Output

Date	Download	Latency
16:24	25.92	77
16:26	14.14	81
16:28	24.29	77
16:29	73.16	87
16:31	43.68	107
16:32	55.98	110
16:33	63.21	113
16:34	27.06	108
16:34	21.52	112

Chapter 5

5. QoS Measurement Analysis for Addis Ababa LTE Network

A comparison analysis for the measured data output depicted under Chapter 4 from Nemo Handy, OpenSignal and SpeedTest tools are presented under this Chapter. From the measurement outputs a downlink throughput and latency KPI are used to compare the measurement tools. This Chapter also includes a summarized result of the collected questioner from end user, ISP and MCIT under Section 5.3.3. The software used for the analysis of the measured data output are:

- Actix tool
- Excel and
- Matlab

When working on comparing the results a similar and different parameter that are taken into consideration are listed;

- Similar considered measurement parameters;
  - ✓ General user equipment category (category 3).
  - ✓ Measured Mobile Network Technology (LTE).
  - ✓ 25 % Physical downlink shared channel overhead (PHDSCH).
  - ✓ Measurement client location (Same place).
  - ✓ Date and time of measurement (Same date and time (hour and minutes)).
  - ✓ Measured KPI (Downlink Throughput and Latency or Round Trip Time).
  - ✓ Measured transport protocol (TCP).
  - ✓ Number of times the test is repeated (Number of Samples).
- Different measurement parameters;

- ✓ Measured file size (packet size) per sample.
- ✓ Measured application protocol (HTTP and FTP).
- ✓ Test server performance (CDN, Web server, FTP server).
- ✓ Test server location.
- ✓ Transmission path after ISP network.

5.1 LTE Data Service Measurement Techniques Output and Comparison

Under this Chapter the measured output depicted in Chapter 4 with Nemo Handy, OpenSignal and SpeedTest tools are analyzed with Matlab and the factors affecting the difference are also discussed. Furthermore; for comparison analysis Root Mean Square Error (RMSE). The measured output value of the measurement techniques has a significant deviation therefore RMSE metric recommended. RMSE measures how much error there is between two data sets. It compares a predicted value and an observed or known value. [37]

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(y_j - \hat{y}_j)^2} \qquad \text{Equation 5.1}$$

Where;

n: Total number of sample.

y_j : Individual observed or measured output.

$\hat{y}_j$: Predicted value for each measured output.

The difference of the observed value and the predicted value is squared to get more accurate results and summed. In order to get the prediction values during the whole measurement we have considered;

- ✓ The serving cell is one and the cell identification no. is **111051**.
- ✓ From the survey result we identified that **Ethio telecom's** average downlink throughput per cell is **70Mbps** and the maximum latency value is **20ms**.
- ✓ For one measurement in one time window we assume **2 UE** category.
- ✓ During same time in the same location the two UE installed with one UE with Nemo Handy and the other UE with OpenSignal application.

- ✓ In a different time, from Nemo Handy and OpenSignal tools; Nemo Handy and SpeedTest application are installed on the two UE and are used to measure the KPI at the same time to compare the two tools.
- ✓ Assuming **equal resource sharing** downlink throughput for each UE would be **35Mbps**.
- ✓ Assume all factors contributing for throughput degradation in the ISP network affects the measurement techniques equal and are ignored.
- ✓ During the calculation we took the value 70Mbps downlink throughput as the actual value and **35Mbp**s downlink throughput as the predicted value. For latency the predicted and actual value would be **20ms**.

5.1.1 Throughput and Latency Measured Data Matlab Output

Matlab is used to analyze output data for Nemo, OpenSignal and Speedtest LTE quality of service measurement technique accuracy. RMSE results are presented.

5.1.1.1 Nemo Handy vs OpenSignal Downlink Throughput

Nemo measures a downlink throughput by downloading a specified file size in Megabyte from an FTP server located at microwave where the measurement is made. Whereas OpenSignal measures a downlink throughput by opening multiple HTTP connection from a global network of Amazon's global content delivery networks (CDNs) to represent the speed a user will get under normal data usage. This can be seen from the throughput output value. The value is smaller than both Nemo and OpenSignal measurement techniques. Figure 5.1 shows Nemo Handy measured data when compared with OpenSignal measured data during same time and same location.

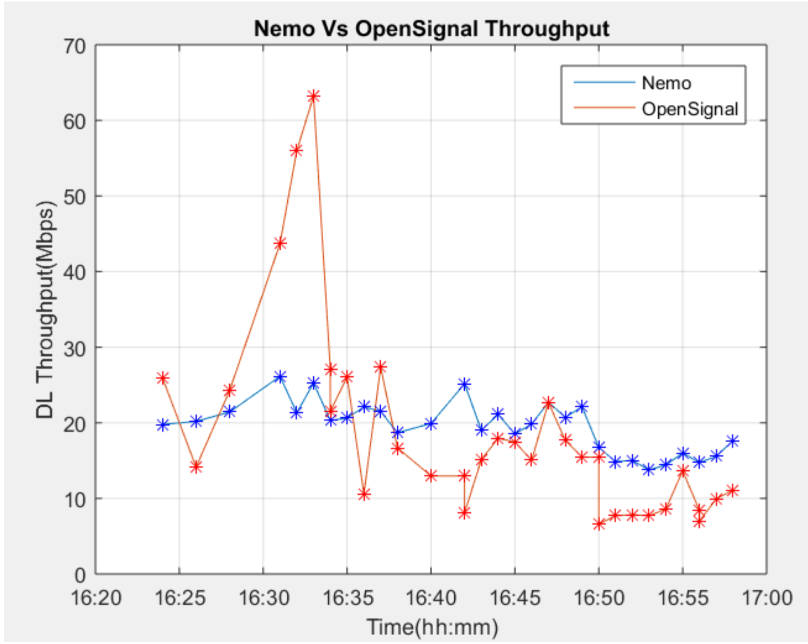


Figure 5.1 Nemo versus OpenSignal Throughput

Table 5.1 shows a sample observed results of Nemo Handy measurement techniques the same time OpenSignal Measurement is performed. These samples are used to calculate the RMSE of Nemo Handy. Similarly, for OpenSignal the same approach is done. Table 5.2 shows the RMSE result of Nemo Handy and OpenSignal. Nemo Handy has an RMSE value smaller from OpenSignal RMSE value. Small RMSE value mean closer to the predicted value and is comparatively considered a more accurate measurement technique.

Table 5.1 Nemo Handy Sample Observed and Predicted values

Observed value (Mbps)	Predicted value (Mbps)	Difference (Mbps)	Residuals
19.78	35	-15.22	3.244915
20.18	35	-14.82	3.159635
21.43	35	-13.57	2.893134
26.14	35	-8.86	1.888958
21.33	35	-13.67	2.914454
25.26	35	-9.74	2.076575

Table 5.2 RMSE value throughput comparison of Nemo Handy and OpenSignal.

Downlink Throughput	
Measurement Techniques	**RMSE**
Nemo	15.88
OpenSignal	20.89

5.1.1.2 Nemo Handy vs OpenSignal Latency

The OpenSignal measurement Content Delivery Network (CDN) nearest to Addis Ababa Tikur Anbesa area where the measurement is made is found in Israel Tel Aviv located 4,543km away. This is shown in the very high latency value of OpenSignal from Nemo Handy. Figure 5.2 shows these difference. Some of the factors affecting these significant difference in Figure 5.2 of latency values between Nemo Handy and OpenSignal are;

- OpenSignal for a single ping test;
  - ✓ Sends 3HTTP head request and 3ICMP request
  - ✓ In addition, HTTP is sent over TCP request to check the availability of the connection.
  - ✓ Distance of the test server from the client. (uses google server)
  - ✓ Application overhead
  - ✓ Transmission protocol overhead
  - ✓ Bandwidth is estimated during latency test and a large packet size is transferred which delays the ping response.

These listed OpenSignal parameters are impact for the high latency value of the measurement technique. Whereas Nemo Handy factors are minimal and result in a fewer latency value and better measurement technique.

- Nemo Handy
  - ✓ TCP request to check the availability of the connection
  - ✓ ICMP request to test the ping time.
  - ✓ Test server location from client is very near.

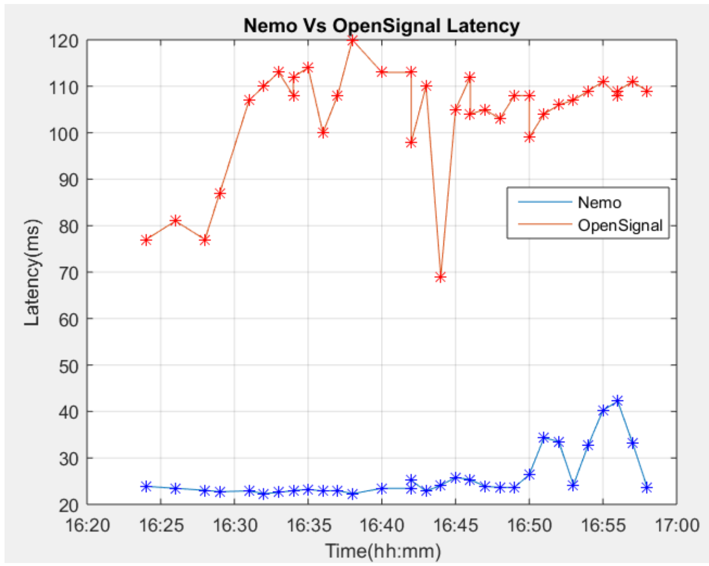


Figure 5.2 Nemo versus OpenSignal Latency

Table 5.3 shows a sample observed results of Nemo Handy measurement techniques the same time OpenSignal Measurement is performed. These samples are used to calculate the RMSE of Nemo Handy. Similarly, for OpenSignal the same approach is done. Table 5.4 shows the RMSE result of Nemo Handy and OpenSignal. Nemo Handy has an RMSE value smaller from OpenSignal RMSE value. Small RMSE value mean closer to the predicted value and is comparatively considered a more accurate measurement technique.

Table 5.3 Nemo Handy Sample Observed and Predicted values

Observed value (ms)	Predicted value (ms)	Difference (ms)	Residuals (ms)
23.88	20	3.88	0.827219
23.46	20	3.46	0.737674
23.03	20	3.03	0.645998
22.73	20	2.73	0.582038
22.91	20	2.91	0.620414

Table 5.4 RMSE value latency comparison of Nemo Handy vs OpenSignal.

Latency	
Measurement Techniques	**RMSE**
Nemo	8.55
OpenSignal	84.64

5.1.1.3 Nemo Handy vs Speedtest Downlink Throughput

Nemo measures a downlink throughput by downloading a specified file size in Megabyte (100MB) from an FTP server located at microwave where the measurement is made. Whereas Ookla Speedtest measures a downlink throughput testing the maximum possible speed of the network under ideal conditions. Ookla partners with carriers and internet providers to install a server physically close to the user. It is uses HTTP protocol which is faster in download from FTP. Figure 5.3 shows the downlink throughput output value which is greater than both Nemo and OpenSignal measurement techniques.

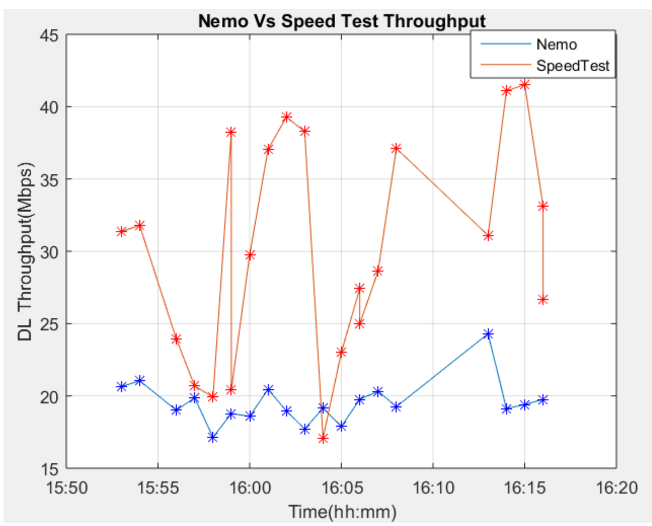


Figure 5.3 Nemo versus Speedtest Throughput

Table 5.5 shows a sample observed results of Nemo Handy measurement techniques from the predicted value. These samples are used to calculate the RMSE of Nemo Handy. Similarly, for SpeedTest the same approach is done. Table 5.5 shows the RMSE result of Nemo Handy and SpeedTest. SpeedTest has the RMSE value smaller from Nemo Handy RMSE value. Small RMSE value mean closer to the predicted value and is comparatively considered a more accurate measurement technique.

Table 5.5 Nemo Handy Sample Observed and Predicted values

Observed value (Mbps)	Predicted value (Mbps)	Difference (Mbps)	Residuals
20.64	35	-14.36	3.061562
21.05	35	-13.95	2.97415
19.01	35	-15.99	3.409079
19.87	35	-15.13	3.225727
17.14	35	-17.86	3.807765
18.78	35	-16.22	3.458116

Table 5.6 RMSE value throughput comparison of Nemo and SpeedTest.

Downlink Throughput	
Measurement Techniques	**RMSE**
Nemo	15.54
SpeedTest	8.78

5.1.1.4 Nemo Handy vs Speedtest Latency

Speedtest has a better latency value from Nemo. Figure 5.4 shows these difference. Speedtest has a good latency output from both Nemo and OpenSignal.

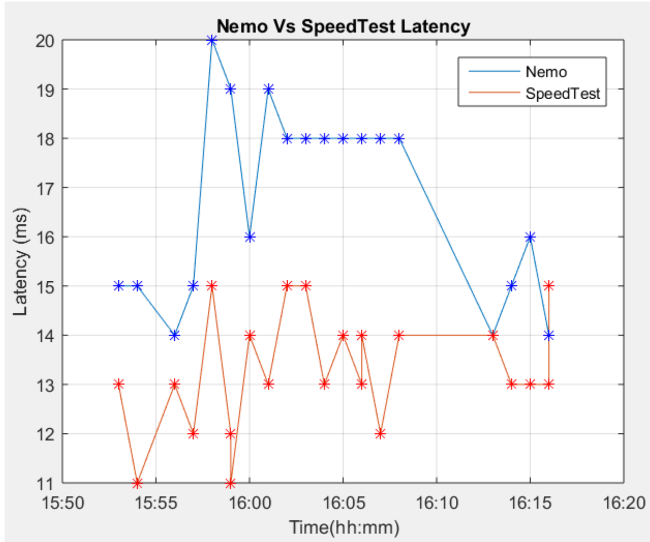


Figure 5.4 Nemo versus Speedtest Latency

Table 5.7 shows a sample observed results of Nemo Handy measurement techniques the same time SpeedTest measurement is performed. These samples are used to calculate the RMSE of Nemo Handy. Similarly, for SpeedTest the same approach is done. Table 5.8 shows the RMSE result of Nemo Handy and SpeedTest. Nemo Handy has an RMSE value smaller from SpeedTest RMSE value. For latency the predicted value is the maximum amount. Small RMSE value mean closer to the predicted value. A bigger RMSE (sample latency values are smaller) is better measurement technique of latency in LTE network, and SpeedTest is comparatively considered as a more accurate latency measurement technique.

Table 5.7 Nemo Handy Sample Observed and Predicted values

Observed value (ms)	Predicted value (ms)	Difference (ms)	Residuals
15	20	-5	1.066004
15	20	-5	1.066004
14	20	-6	1.279204
15	20	-5	1.066004
20	20	0	0
19	20	-1	0.213201

Table 5.8 RMSE value latency comparison of Nemo Handy and SpeedTest.

Latency	
Measurement Techniques	**RMSE**
Nemo	3.75
SpeedTest	6.82

5.2 Measurement Techniques Percentage Comparison

The percentage increase of OpenSignal and SpeedTest with Nemo Handy with respect to LTE downlink throughput and latency threshold is shown graphically in Section 5.2.1 and 5.2.2. The result is calculated with Matlab and the graphical representation is depicted.

5.2.1 Throughput Percentage Comparison Analysis

Nemo Handy and SpeedTest shows an increasing percentage difference since both uses bulk data transfer from remote server to measure and calculate the average throughput. In OpenSignal measurement more samples have higher throughput values and when compared to Nemo has higher increasing percentage difference the blue highlight shows these.

Figure 5.5 with a bar highlighted in red displays Nemo with respect to Speedtest downlink throughput percentage difference. A positive value does not mean a better throughput from Nemo Handy since their way of measurement differs.

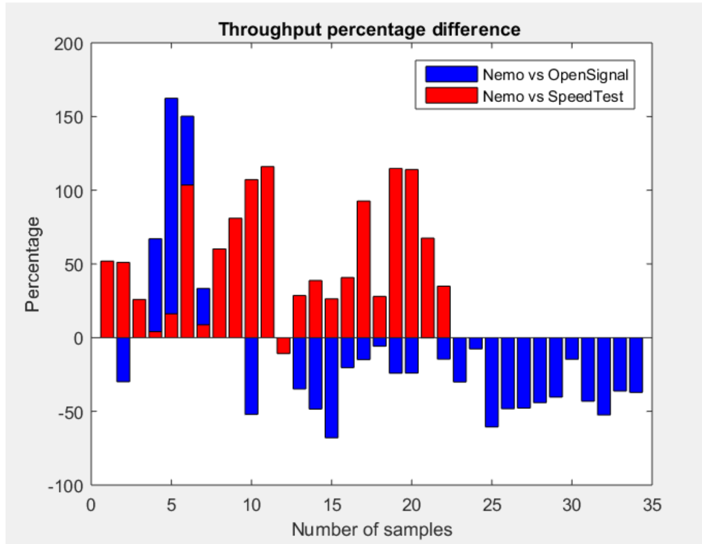


Figure 5.5 Downlink Throughput Percentage Difference

5.2.2 Latency Percentage Difference

The result for latency shows that SpeedTest has a better latency value from both Nemo and OpenSignal measurement techniques. OpenSignal uses 3 ICMP ping request and 3 HTTP head request to find the latency these two protocols takes too much time to get to the test server located outside the ISP premises. Speedtest has percentage decrease from Nemo Handy indicating a better latency value from the two measurement techniques.

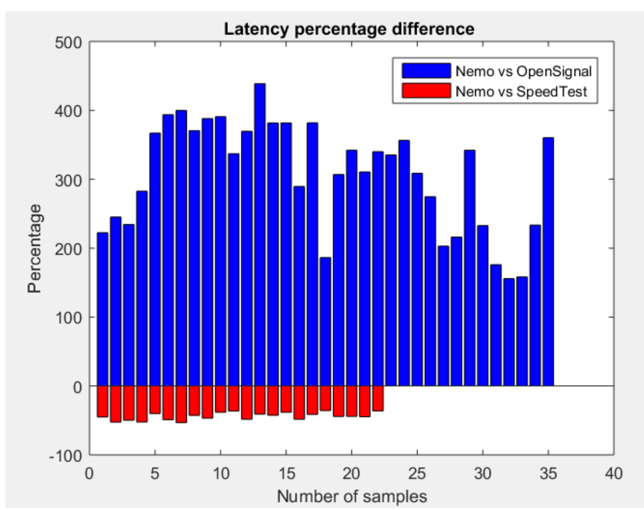


Figure 5.6 Downlink Latency Percentage Difference

5.3 Measurement Techniques Parameters Impacting the Difference

There are key parameters that impacts the difference in the measurement output of Nemo Handy, SpeedTest and OpenSignal applications. These are discussed in more detail under the next sub Section.

5.3.1 SpeedTest, Nemo Handy and OpenSignal Identified Parameters

- SpeedTest parameters

The SpeedTest operates entirely over HTTP (TCP port 80), our measurement uses an alternate port on the web server with a port number 8080. SpeedTest Ookla hosted web server used for the test is identified during a measurement as;

server id="4253" host="wwa.st.net.et:8080" sponsor="Ethio Telecom" cc="ET" country="Ethiopia" name="Addis Ababa" lon="38.7400" lat="9.0300" url="http://wwa.st.net.et/speedtest/upload.php" url2="http://wwb.st.net.et/speedtest/upload.php"/> [34]

✓ **Downlink Throughput**

Default values are identified for SpeedTest measurement technique when a downlink throughput is measured for LTE data service. These values are;

- To estimate the connection speed: Initialtest= 250kB
- Minimum download size: Minitestsize=250kB
- Maximum download size: Maximage= 40MB
- No. default thread for a single download: thread=2
- No of download HTTP parallel threads: threads= 8;

  (Threads per url is set to 4, our measurement server has two url so the measurement parallel thread will be 8).
- No of second download test should last: Testlength=10se
- File size used for the real download: SPdataUsed=x (Measured values)
- Cache prevention via a random string

- Throughput samples received: 30 Samples/second,
    - ✓ Maximum test length=10sec, 300 Samples/10 second
- To calculate the average
    - ✓ Each samples are aggregated (combined) in to 20 slices. (Each 5% of the samples) 6 samples per slice per second. Or 60 samples per slice per 10 second.
    - ✓ Fastest 10% and slowest 30 % of the slice are discarded.

In SpeedTest measurement technique samples are discarded in such a way; the measurement is done via data transported over HTTP via flash there is **potential protocol overhead**, **buffering** due to the many layers between the application and the raw data transfer and **throughput bursting** due primarily to CPU usage. This accounts for dropping the top (highest) 10% and bottom (lowest) 10% of the samples. Speed test keeps the **default test length short for the user experience**, and compared to this duration the ramp-up period is fairly significant SpeedTest eliminate another 20% of the bottom result samples [31].

✓ **Latency**

Latency in SpeedTest is defined as the time it takes to get a response for an HTTP request sent to a web server. Default values are identified for SpeedTest measurement technique when a latency is measured for LTE data service. These values are;

- No. of samples to calculate HTTP latency: testlengh=10
- No. of milliseconds to wait between each HTTP request: waittime= 50ms
- Lowest value determines the latency value.
- During one HTTP request: data value.

Nemo Handy parameters

Nemo version 5 operates entirely over FTP download. Nemo technology used is LTE FDD, UE Download bandwidth: 20MH.

- Nemo FTP server used for the test:
- Connection IP address: 10.187.97.20
- Service duration: Measurement start and end time

✓ **Downlink Throughput**

Default values are identified for Nemo Handy measurement technique when a downlink throughput is measured for LTE data service. These values are;

- Maximum download size: Maximage= 100MB
- Number of default thread during 60 seconds: thread=1
- No parallel thread for FTP download:
- The time a download test last: Testlength=60se
- File size used for the real download: NemDataUsed=x (Measured values)
- Throughput samples received: 1 Sample/second:
    - Maximum test length taken = 60sec, 60 Samples are averaged
- To calculate the average;
    - The number of samples received per 60 seconds are averaged.

✓ **Latency**

Latency in Nemo Handy is defined as the time it takes to get a ping response for a ping request sent to FTP server. Default values are identified for Nemo Handy measurement technique when a latency is measured for LTE data service. These values are;

- No. of samples during on measurement period: 60 ping samples per minute.
- We take the smallest value from the number the 60 samples for the comparison analysis. It implies the lowest value determines the latency value:
- During one ping request: 70-byte data is sent to the FTP server.

OpenSignal parameters

Test Server: Content Delivery Network (CDN): Amazon AWS Cloud and Google Cloud. Default values are identified for SpeedTest measurement technique when a latency is measured for LTE data service. These values are;

✓ Downlink Throughput

Default values are identified for SpeedTest measurement technique when a downlink throughput is measured for LTE data service. These values are;

- Minimum download size: Minitestsize=13.5MB
- Maximum download size: Maximage= 108MB
- Number of default thread during a single download: thread=8
- The time a download test last: Testlength=
- File size used for the real download: NemDataUsed=x (Measured values)
- To measure the download throughput, the application sends eight concurrent HTTP GET requests to download files of size 108Mb or 13.5MB each.
- The download throughput test is performed for a fixed amount of time after which the application computes the average throughput.

✓ Latency

In OpenSignal latency is defined as an ICMP ping request and HTTP head request to google server and the round trip time is recoded. Default values are identified for OpenSignal measurement technique when a downlink throughput is measured for LTE data service. These values are;

- 3ICMP request.
- 3HTTP head request and calculate the average of the three latency values.

Figure 5.8 shows the packet distribution of SpeedTest and Nemo Handy. Nemo uses large packet size to measure the throughput and the round trip time or the latency will be higher from the Speedtest with same time value. The fluctuation is caused by many factors, including path load (cross-traffic) and the number of users.

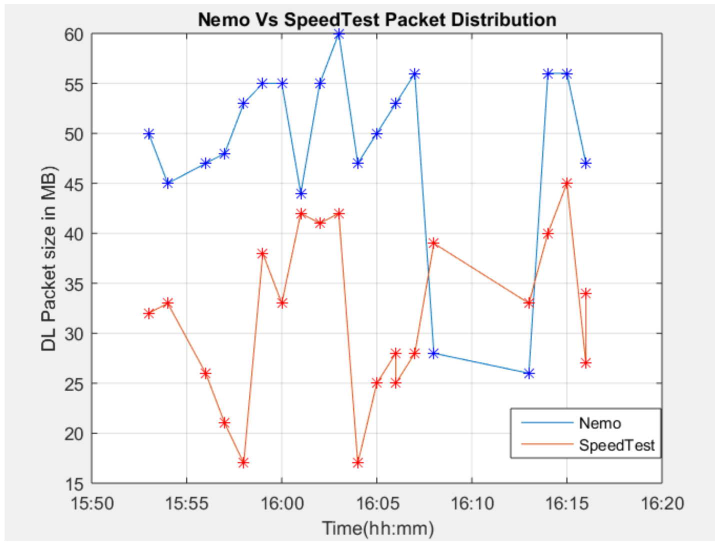


Figure 5.8 SpeedTest vs Nemo packet distribution

Table 5.9 shows Nemo and Speedtest packet size distribution. During the entire measurement different packet size are used by both measurement techniques. It helps to understand how big the packet size are to measure the throughput and latency in same time and location. OpenSignal doesn't show explicit value of the packet size during each sample due to this it is not presented in this thesis.

Table 5.9 Nemo & Speedtest packet size

Time	Nemo DL (Mbps)	Nemo Data Used (MB)	RTT Nemo (ms)	SpeedTest DL (Mbps)	SpeedTest Data Used (MB)	RTT Sp (ms)
15:53	20.64	50	15	31.36	32	13
15:54	21.05	45	15	31.79	33	11
15:56	19.01	47	14	23.93	26	13
15:57	19.87	48	15	20.69	21	12
15:58	17.14	53	20	19.91	17	15
15:59	18.78	55	19	38.22	38	12

Time	Nemo DL (Mbps)	Nemo Data Used (MB)	RTT Nemo (ms)	SpeedTest DL (Mbps)	SpeedTest Data Used (MB)	RTT Sp (ms)
15:59	18.78	55	19	20.42	38	11
16:00	18.59	55	16	29.77	33	14
16:01	20.46	44	19	37.04	42	13
16:02	18.96	55	18	39.28	41	15
16:03	17.72	60	18	38.28	42	15
16:04	19.15	47	18	17.08	17	13
16:05	17.89	50	18	23.01	25	14
16:06	19.76	53	18	27.42	28	13

5.3.2 BW Estimation Techniques for SpeedTest and OpenSignal

- **Download based estimation;**

Achievable bandwidth using the transferred packet/file size divided by the time it takes for the download or upload. Bulk transfer capacity. This brings overhead to the network path when we measure with the MT. Speedtest uses this technique to approximate the achievable bandwidth.

- **Packet round trip time:**

$$B_{achievable} = \frac{S_{packet}}{RTT + \beta}$$

Equation 5.2

β Is constant for the propagation delay (is different for different transmission medium). S_{packet} Is the packet size. OpenSignal uses this technique for multiple ICMP packets of increasing sizes to approximate the capacity (or the maximum achievable bandwidth in the perfect network conditions) of the path [36].

5.3.3 Collected Questioner Result

As it has been discussed under Chapter 2 questioner is distributed and summarized results are discussed in tabular form in this Section. The result has helped this thesis to focus on evaluating a measurement techniques performance for LTE data service particularly on the end user satisfaction.

- **Summarized Survey Result**;
  - ✓ Forty-eight enterprise and end users have participated in the survey
  - ✓ End users and enterprise users have limited awareness on the available measurement techniques;
  - ✓ ISP has a measurement technique and use it to troubleshoot the problem and limited awareness on the available crowd sourcing techniques.
  - ✓ As of March 2017 regulator has no measurement technique to control the quality of LTE data service.

Table 5.10 Survey Result on LTE data service satisfaction

Summarized Qn	End User (Google form & Hard Copy)	Enterprise Users (GiZ/CBE/ET-Switch, Sivatex PLC, Tafra)	Ethio-Telecom (Eng. CS (994), Marketing, NNOC)	MCIT
No. users	48	19	5	1
Throughput (DL)	< 3Mbps	< 3 Mbps	~28 Mbps (Eng.), 100Mbps (Mrk)	Fair
Latency	Average	Average	Good	Fair
MT Used	None	None	DT (Nemo Hany), M2000, PRS, Soft.	None, ET report
Coverage	Dense Urban	None	Dense Urban area	Good
Availability	Good	Good	Excellent	Good
Reliability	Good	Good	Very Good	Fair
General QoS	Fair	Fair	Good	Fair

Chapter 6

6. Conclusion and Recommendation for Future Work

6.1 Conclusion

In this thesis, survey of LTE data service quality is made to assess and understand the perception of mobile users' providers and regulators. From the result we identified end users and enterprise users have limited awareness on the crowdsourcing measurement technique. The ISP monitors quality of service for LTE network in NNOC and when issue is reported and a physical presence to the LTE air interface is needed the engineering department will do a drive and test measurement technique. The crowdsourcing measurement technique is currently not in use by the ISP. The LTE quality of service measured drive and test report will be sent to MCIT. As of March 2017 MCIT has limited measurement technique to monitor the LTE network quality and to monitor the ISP service.

In downlink throughput comparison, the minimum RMSE value in throughput is considered as a more accurate techniques and is closer to the predicted value. These from the evaluation Nemo Handy RMSE 15.88 has a better downlink throughput MT from OpenSignal with RMSE value of 20.89 and is shown in Table 5.2. It should be noted that OpenSignal uses Amazon CDN to run a speed test, this allows to approximate the user experience, as much the web also uses CDN's from Amazon and other content delivery network. Mostly a low value throughput is recorded and is broadly in line with what we will experience during the internet use. Table 5.6 Nemo Handy RMSE value is 15.54 and SpeedTest RMSE value is 8.78. These shows SpeedTest has lower RMSE value and is better downlink throughput measurement from Nemo Handy MT.

Latency comparison, the minimum RMSE value in latency does not necessary indicate a more accurate technique but rather it indicates a closer value to the predicted latency value.

OpenSignal RMSE value is 84.64 and Nemo Handy RMSE value is 8.5. These Nemo Handy has a value closer to the predicted latency value which is 20ms. Reasons a significant difference in latency are; 1. OpenSignal uses large file size 108MB size during a ping request to know the performance of the data network. 2. It uses 3 HTTP head request and 3 ICMP ping request to test the connection availability. 3. The location of the test server from the measurement point around Tikur Anbesa is greater (uses google.com server). 4. Internet backbone overhead. The latency comparison between Nemo and Speedtest is minimal. One of the reasons is Speedtest server is hosted to the local ISP and it uses HTTP protocol to measure the response time. Nemo uses FTP protocol this has less performance from HTTP. Nemo Handy RMSE value 3.75 and SpeedTest RMSE value is 6.88. Furthermore; to evaluate a percentage increase between the measurements techniques are depicted under Section 5.2.

A bandwidth estimation methods used are identified. A download based estimation for Speedtest latency and packet round trip estimation for OpenSignal throughput measurement technique are used and discussed under Section 5.3.2. The estimation technique have impact on performance difference between the measurement techniques.

In conclusion, Nemo does not measure the performance of the LTE data service in real time as the customer experience it. ISP should consider assessing the quality of the measurement technique used. Speedtest latency measurement is better compared to Nemo and OpenSignal. The throughput measurement compared between Nemo and OpenSignal has relatively closer RMSE output.

From this thesis; ISP Ethio telecom and regulator MCIT can understand the gap in the existing drive test measurement technique; they can also consider the alternative crowd sourcing techniques for the measurement of LTE network quality of service from the user side.

6.2 Recommendation for Future Work

Future work, after reviewing this paper, one can develop a suitable crowdsourcing tool to measure the ISP LTE data service for users and also assist the ISP to see the customer experience of the network in real-time.

- ISP (Ethio Telecom) have to invest and implement a user side end to end QoS measurement techniques for LTE data service.
- Regulator (MCIT) needs monitoring tools to inform their understanding of availability, reliability and performance of LTE network service quality.
- Developer can develop a local crowdsourcing tool to monitor LTE data service and assist the ISP to see the customer experience of the network in real-time. Benefit; Encourages large no. of users to use the tool and understand the network status. Protect the users' resource from abuse and preserve user privacy from external crowd sourcing application.

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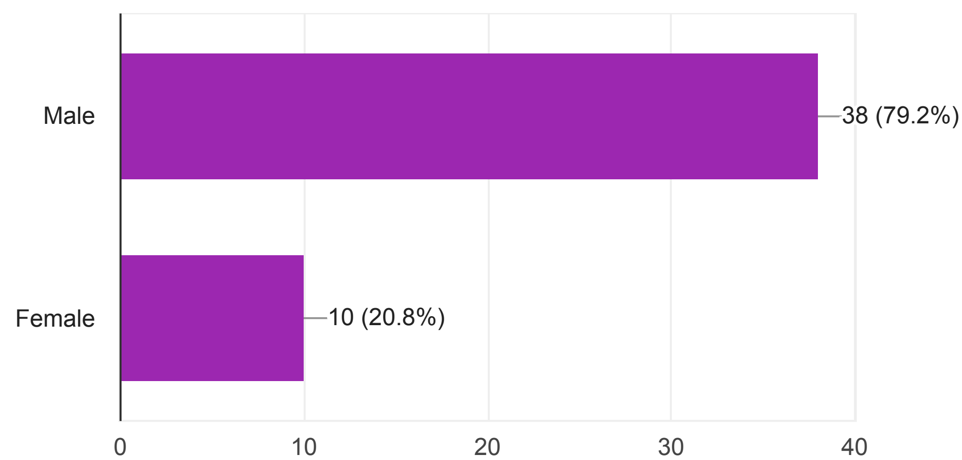
Quality of Experience on 4G/LTE service for the case of Addis Ababa

48 responses

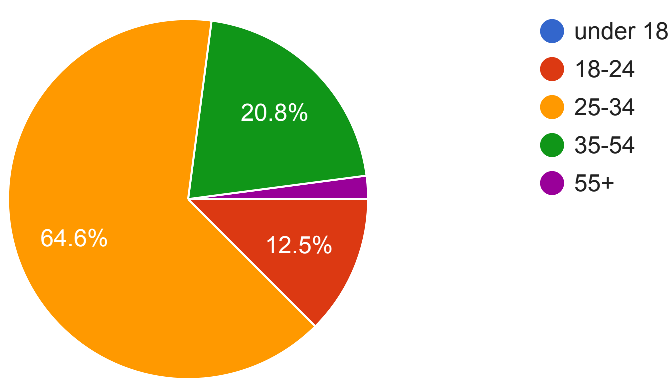
1. Please select your Gender?

48 responses



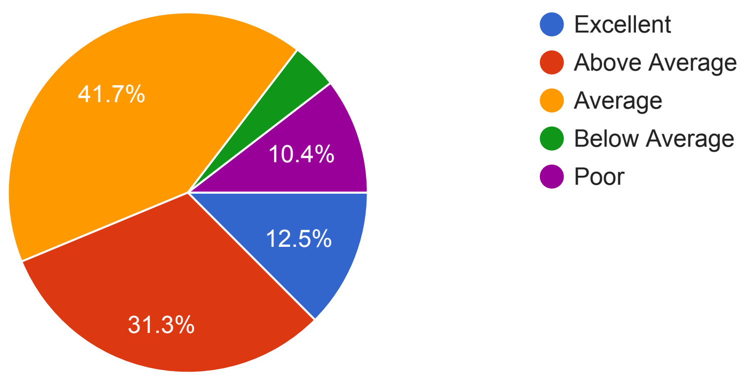
2. Please select your age range?

48 responses



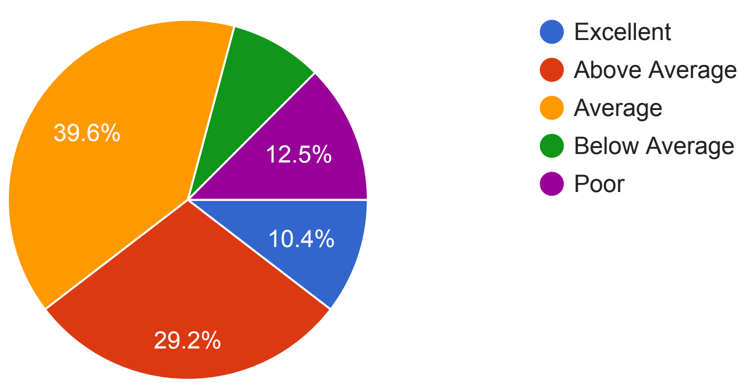
3. How do you describe the speed of your LTE data connection?

48 responses



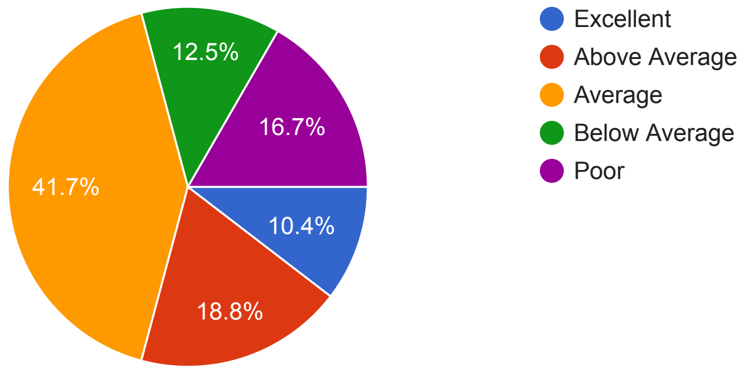
4. How is the voice quality when you use Viber/Skype/Messenger voice call service with LTE data Connection?

48 responses



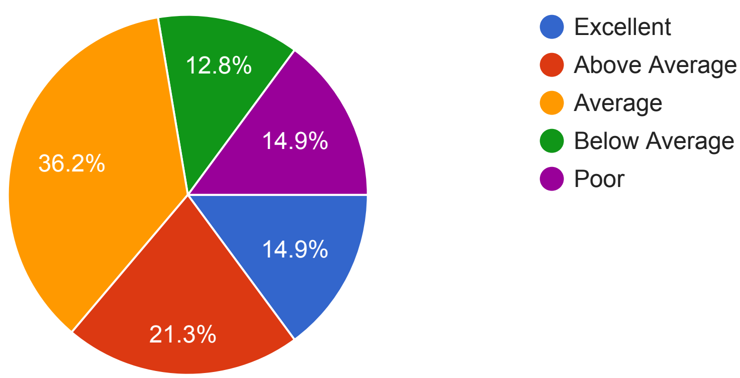
5. How is the video quality when you use Skype/ Messenger video call service with LTE data connection?

48 responses



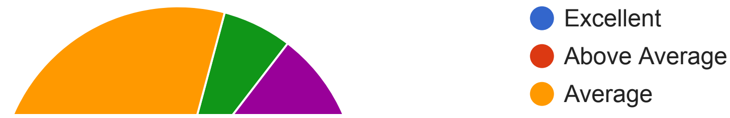
6. How is the quality of watching YouTube video with LTE data connection?

47 responses



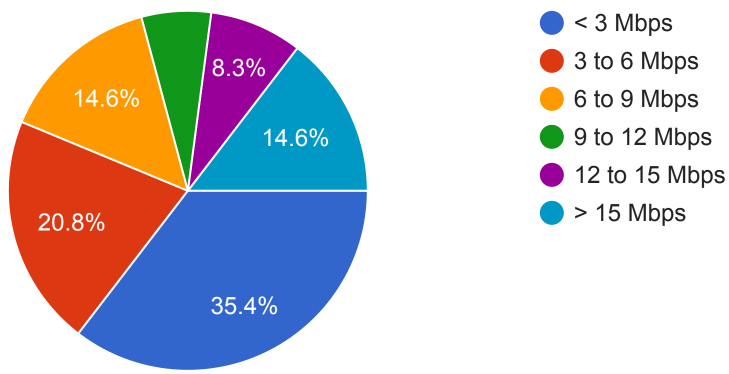
7. How is the downloading speed of your LTE data connection?

48 responses



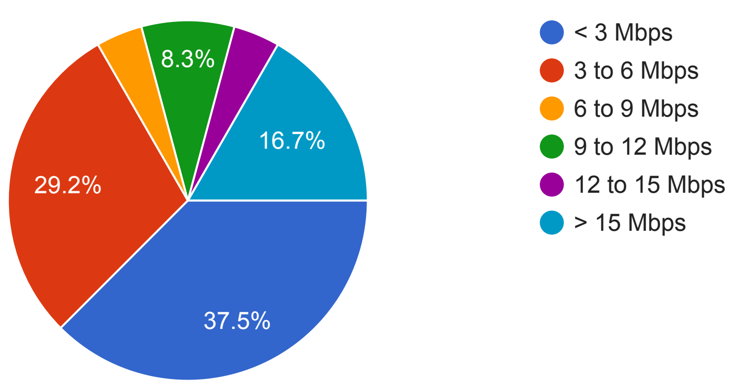
8. How much is your average exact download speed of your LTE data connection? (if you can please use SpeedTest app to measure)

48 responses



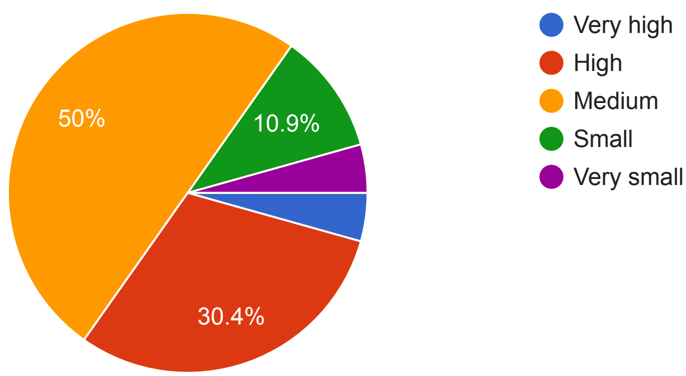
9. How much is your average exact upload speed of your LTE data connection? (if you can please use SpeedTest.net on your mobile to measure)

48 responses



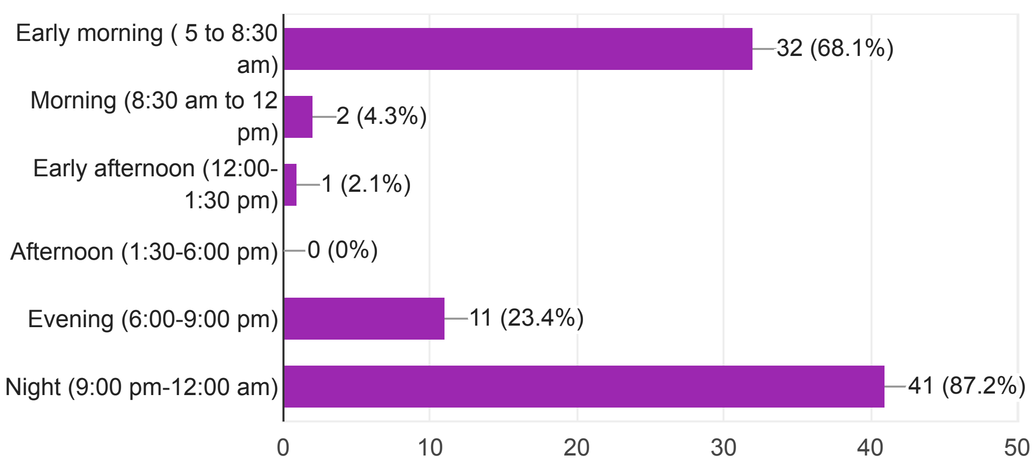
10. How do you rate the variation of your LTE connection speed?

46 responses



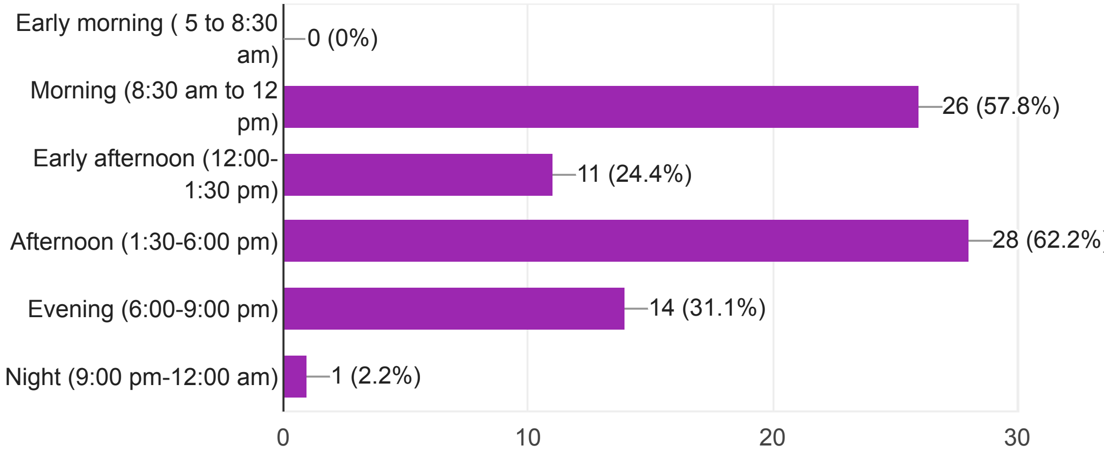
11. Choose two best time period you get the best speed connection

47 responses



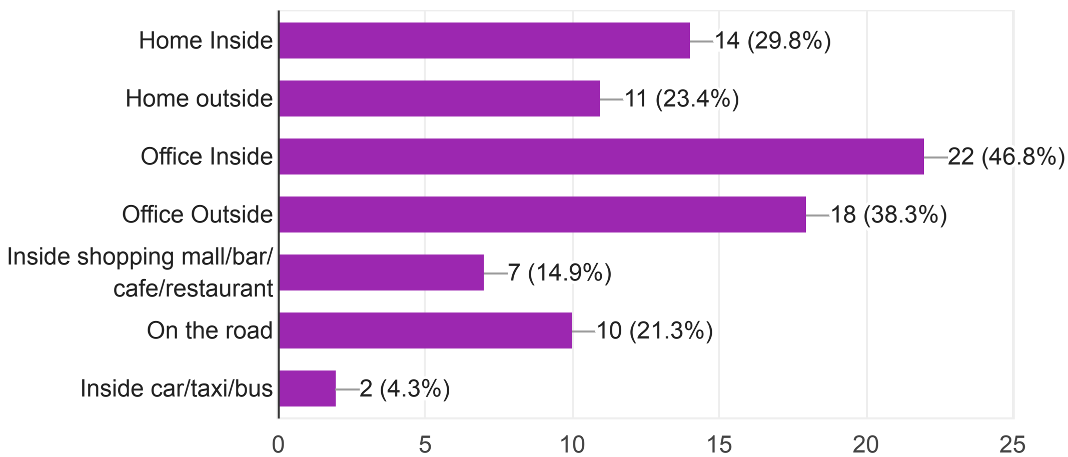
12. Choose two worst time period you get the worst speed connection?

45 responses



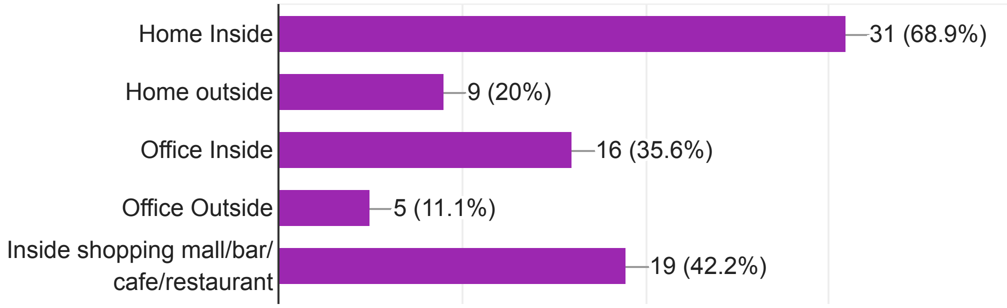
13. Choose two best locations where you find the best network speed?

47 responses



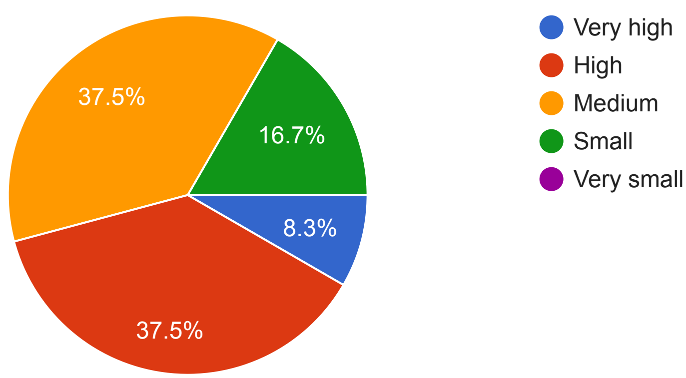
14. Choose three worst locations where you find the worst network speed?

45 responses



15. How do you rate the variation of the network speed in terms of location?

48 responses



16. Name place and time of any special event where you find the best data connection?

30 responses

Bole (2)

N/A

place: dense urban and urban area. Time: at holiday, before and after office hours

I do not understand the question

Around to Bole, kazanchis and Mexico

I never gate best data rate

Bole anytime

Software download at office during evening.

Around furi, and 5 killo

No observation

From home on weekend especially sunday morning.

Nega city mall April 4, 2017

Around summit

Sheraton addis

Nega city mall. 4th floor april 05,2017

lalibela restaurant

Not at all

I never get best data connection

Bole close to airport any time

ICT week at the expo

Leghear , Bole , 4killo , Piasa , Sarbet , Gotera , Gemo

High company with high speed DSL users

I don't really remember

Around 5killo before lunch

@bole afternoon around 11 to1 local time.

Kazanchis

Piasa

Signal

Bole.kazanchos

17. Name place and time of any special event where you find the worst data connection?

28 responses

around kality

Place : sub-urban area, Resident area surrounding A.A. Time: during office time b/c the number of users will increase.

I do not understand the question

South Western area

Everywhere

Bolebulbula anytime

viber or skype at home during day time

ayer tena

Around lebu, jemo.area

no observation

22, Bole medanialem

On the road

everywhere in ethiopia but, currently it is not working at all

24,bole april 06,2017

office abinet area gebon building

Everywhere

gerji anytime

Around megenagna ara

Asko , Wienget , 18 ,

Everywhere mole and business center offices

Same as the above

no worest connection so far

@ jemo from11 all the night

Semit

Gerji

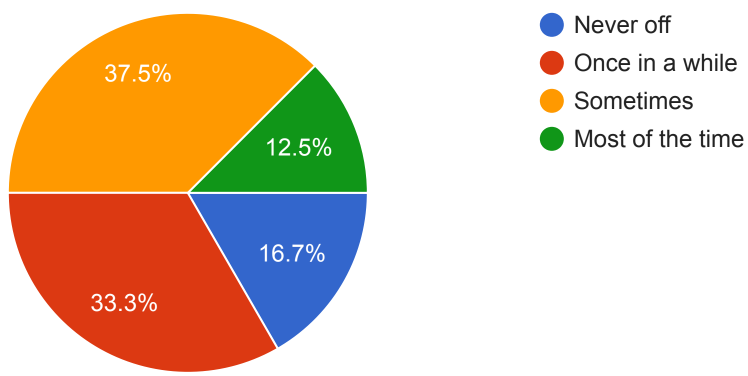
Asko

Shiromeda

Lebu

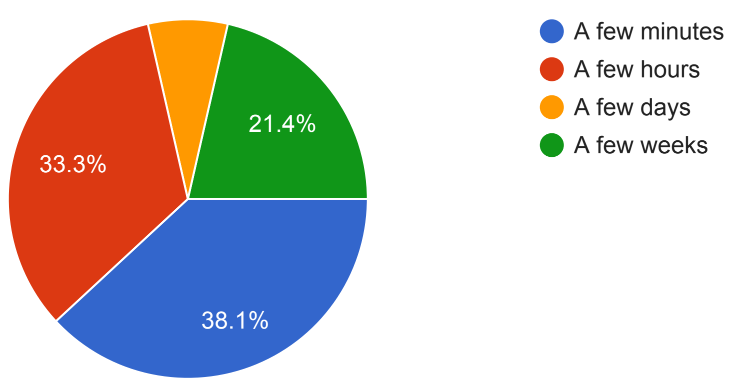
18. How often LTE data service is completely off?

48 responses



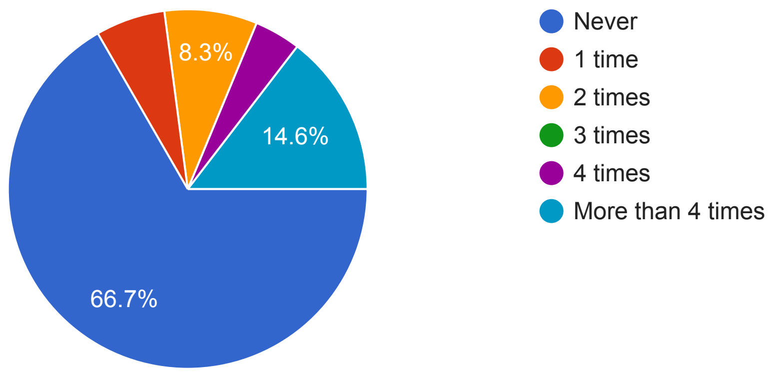
19. For how long does full service interruption have lasted?

42 responses



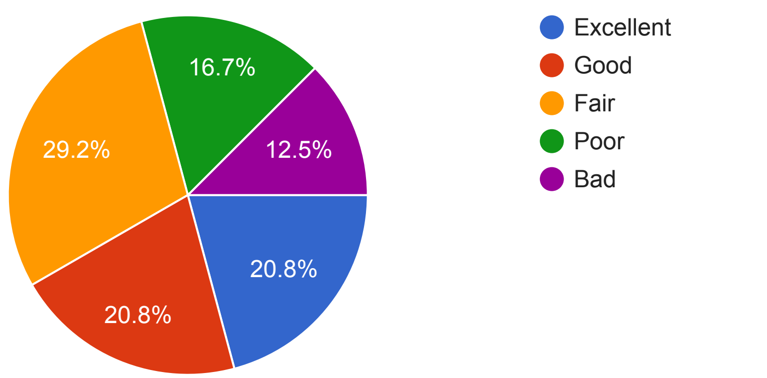
20. How many times have you called to 994 for any problem related to your LTE data connection?

48 responses



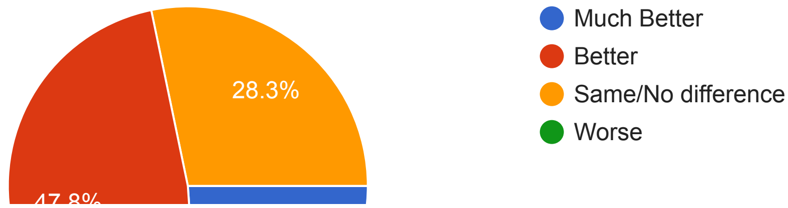
21. If you have called to 994, how has been the quality of the response for your problem?

24 responses



22. How do you rate quality of your LTE data connection experience relative to 3G data connection?

46 responses



23. If you can please give us your overall opinion on your LTE service when you compare it with 3G service?

28 responses

The LTE service is much better than 3G....

It is very fast in speed but fast in taking money as well.

4G more better than 3G of the data connection.

It is not working most of the time and off course, i am not a good candidate for the LTE survey,

Better connectivity

Both are nearly bad

Same no difference, costly,limitation and location

Infact it is better however 3G was good service.

4G Is better.but as the number of customers increases there is a chance that 4g will.also be congested as is 3g.

I was.expecting better speed than 3g service, but no.significant difference noticed. Also bk service usage tarrif is expensive

The sleed variation b/n the two service is incomparable. LTE is very fast but 3G is not. 3G used to be fast in the past few years but now, it has little difference from 2G.

we are getting a workable service from the service Provider, hoping we will get the desired service from the technology in the near future.

No difference between 3 g and 4g. But 4g is expensive.

4G lte has more speed than 3g service but the speed of LTE is not as expected. Sometimes video quality is poor. Especially in the morning and afternoon.

eventhough 4g/lte service is generally better than 3g service the speed greatly varies from place to place and not all locations have the signal strength for a convenient access of the internet from my 4g enabled mobile devices.

It is better to distribute all 4g infrastructure all over the country and charge is a little but high and ethio telecom shluld review the fee.

Price difference

4G better than 3g

There is no need to compare both servicess they both are realy bad.

The quality is not more than 3g as expected

the only significant difference that i have noticed is when i view you tube videos or other videos from other websites , the speed is fast, but the rest is the same as 3G.

It is more better than 3g connection, but still there is more room to impliment speacially the peakhours.

There is slight df
Ofference but not that much to put for comparison

4G was very good when it was start service , but currently it is almost same with 3G

same

It's just simply better

The 4g speed is very high compared to 3g but it is very costy to use as an ethiopian due.to.our low income.

Nothing better just change of name

Your email address please

9 responses

itisdanielg@gmail.com

Wondwossenmhdr3@gmail.com

ermiastes@gmail.com

Abelendale@gmail.com

yohanness.kahinu@ethiotelecom.et

amanualem@gmail.com

mhb4mahlet@gmail.com

surafelc@gmail.com

Bethelhem.alemayehu@gmail.com