UNIVERSITY OF NAIROBI

SCHOOL OF COMPUTING AND INFORMATICS

Benchmarking Quality of Experience (QoE) offered by Mobile Network Operators in Kenya: A User-Centric Approach.

BY

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A Research report submitted in partial fulfillment for the requirement of Master of Science in Computer Science

DECLARATION

The project presented in this report is my original work and has not been presented for any other university award.

Signature………………………………… Date………………………….

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This project has been submitted in partial fulfillment of the requirements of the Master of Science in Computer Science of the University of Nairobi with my approval as the University supervisor.

Signature………………………………… Date………………………….

DR. CHRISTOPHER CHEPKEN

DEDICATION

To my loving wife Sophie for allowing me to further my studies and supporting to completion.

To my lovely children Allan, Lewis, Levynne and Leandra you have been a source of joy, learning and healing to my life. I love you all and am proud of each one of you.

To my beloved parents Jackson and Margaret Simatwa for their resilience in educating me amidst the absolute poverty at that time.

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I would like to sincerely thank the almighty God for the endless blessings that has led me to this achievement.

My gratitude and heartfelt thanks goes to my supervisor Dr. Christopher Chepken for his guidance and motivation throughout my project. Special thanks to the panel Dr. Andrew Mwaura and Ms. Pauline Wambui for the constructive feedback and invaluable contributions in all the presentations.

ABSTRACT

Quality of Experience (QoE) is a concept which represents measuring of end-to-end performance of a service from a user perspective. This research presents the study of QoE offered by mobile network operators in Kenya. An android prototype application was developed to benchmark user experience by way of making voice calls, internet sessions and capturing signal strengths. In total, we analyzed 3,178 voice calls, 682 internet connections and 1,266 signal strengths measured in nine major towns in Kenya. Parameters measured in voice calls included: Completed Call Rate, Call Setup Success Rate (accessibility to the network), Dropped Calls (call retainability), Blocked Calls and Call Setup Time. Parameters measured in internet calls are: File Download Speed, File Upload Speed, Network Latency and Web Browsing Time. The results from the study enables consumers to be able to make informed decisions while using any service offered by mobile network operators and also be able to compare service level agreed between themselves and service operators. The results provide the regulator alternative ways to understand the state of services provided by the mobile network operators and compare against what they promised when they were issued with the license to operate. Mobile network operators may also use the results by cushioning themselves against legal and regulatory pressures by how customers experience services offered. This study contributes to the understanding of performance of services provided by mobile network operators and use of smart phone applications to measure performance of the services. Finally, it suggests that having better signal strengths and network latency does not guarantee you a better quality of experience. We recommend that the regulator not only checks if mobile network operators meet key performance indicators related to voice but also those related to data (internet). Currently Communication Authority of Kenya (CAK) does only for voice.

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List of Abbreviations

3GPP – 3rd Generation Partnership Project
CAK – Communication Authority of Kenya
CCK – Communication Commission of Kenya
CDMA - Code Division Multiple Access
CID - Cellular Identification Number
dBm - Decibels (dB) measurement (m)
EDGE - Enhanced Data Rates for GSM Evolution
ETSI - European Telecommunications Standards Institute
GPRS - General Packet Radio Service
GPS - Global Positioning System
GSM - Global System for Mobile Communications
HSDPA/HSUPA - High Speed Downlink/Uplink Packet Access for 3G networks.
HSPA - High Speed Packet Access
HTTP - Hypertext Transfer Protocol
ICMP - Internet Control Messaging Protocol
IMEI - International Mobile Equipment Identifier
IMSI - International Mobile subscriber identity
IP - Internet Protocol
ITU - International Telecommunication Union
LAC - Location Area Code
LTE - Long Term Evolution
Mbps - Megabits per second
MCC - Mobile Country Code
MNC - Mobile Network Code
MNO - Mobile Network Operator
MNP - Mobile Number Portability
MOS - Mean Opinion Score
MSIN - Mobile Station Identification Number
MSISDN – Mobile Subscriber Integrated Services Digital Number
OS - Operating System
PSTN - Public Switched Telephone Network
QoE - Quality of Experience
QoS - Quality of Service
RSSI - Receive Signal Strength Indicator.
RxLev - Received signal level
SIM - Subscriber Identity Module.
SLA - Service Level Agreement
SMS - Short Message Service
UMTS - Universal Mobile Telecommunication System
WIMAX - Worldwide Interoperability for Microwave Access

Chapter One: Introduction

1.1 Background

Since 2001 Communication Authority of Kenya (CAK), then Communication Commission of Kenya (CCK) has benchmarked mobile network operators and regularly published performance reports listing key voice performance indicators (KPI) that affect consumer experience. Benchmarking of Quality of Experience of communication services offered by mobile network operators can be done by the regulator (CAK), mobile network operators or consumers.

When choosing services from mobile network operators, customers choose the one that makes them comfortable, simple or engaged. Therefore the Quality of Service (QoS) is not enough means of measuring services as user perspective is also key.

However there is no easy way of collecting this data. Therefore in this project we developed a prototype to collect the data from the users of mobile services. It runs on Android Operating System (OS) and collects data representing experience of the user as he/she is using the service. The application runs as a background service and transmits collected data to a hosting server on internet.

Regular and continuous monitoring can provide empirical evidence of the quality of service of broadband to help regulators and policymakers make informed decisions. (Chetty, Marshini et al. 2013)

Use of mobile network operators services and penetration in Kenya has been on the increase as stated by CCK Quarterly Sector Statistics Report for First Quarter of the Financial Year 2013/14 (Jul-Sept 2013) states that "In mobile telephony, the number of subscriptions grew by 2.5 per cent to reach 31.3 million up from 30.5 million registered during the previous quarter. Mobile penetration however declined by 0.4 percentage points to 76.9 per cent from 77.3 per cent during the previous quarter"

1.2 Problem Statement

A consumer who take a service from a mobile network operator may most likely experience adverse problems e.g. inability to make calls, unable to maintain a call while the call is in progress or poor data speeds which may result in severe financial losses.

Decision making by consumers while deciding on which service providers to choose is not **informed** on the current quality of experience from customer perspective. Consumers might not get value for money if they make uninformed decision. Reliability of the service provider in providing service whenever it is required is also an important factor.

The **regulator** also needs to understand the state of services provided by the mobile network operators from a user point of view and compare against what they promised when they were issued with the license to operate.

1.3 Significance of the Study

This work may benefits users, regulator and providers.

The **regulator** may now be able to understand the state of services provided by the mobile service providers from user perspective and compare against what they promised when they were issued with the license to operate.

It provides **consumers** informed purchasing decisions due to increased knowledge of performance levels of mobile network operators. They know what kind of service to expect before they enrol into the service. It also answers questions to do with connections and network issues. Corporate consumers are able to compare service level agreed between themselves and service operators

Mobile network operators may benefit by cushioning themselves against **legal and regulatory pressures** by how customers experience services they are offering. By understanding the service delivered to customers from a customer perspective, **mobile network operators** can make business decisions that improve QoE, reduce overhead and justify operational spend. With adequate information, **operators** are able to **manage subscriber Quality of Experience** (QoE) which leads to less subscriber calls to support services, greater subscriber use of chargeable services, less churn and a higher propensity to refer their service provider.

While the developed world is reaping the benefits of being connected to a fast and reliable broadband infrastructure, studies have shown that broadband can also be an **enabling infrastructure to improve the lives of citizens in developing countries** (Chetty, Marshini et al. 2013) at the same time measuring broadband allows **regulatory authorities** and policy makers to meet their **mandate of ensuring a reliable and affordable access to communications services** for all (Chetty, Marshini et al. 2013).

1.4 Research Objectives

The Objectives of this study are to:

1. Find out parameters for measuring quality of experience offered by mobile network operators
2. Develop an application running on android smartphone to be used to measure experience of customers using services of mobile network operators in Kenya.
3. Compare performance of mobile network operators in Kenya in the provision of voice services against what the regulator expects.
4. Measure Signal Strengths of mobile network operators in Kenya using the developed application.
5. Compare performance of mobile network operators in Kenya in the provision of internet services using the application developed.

1.5 Research Questions

To meet objectives stated in section 1.4 this research aimed to answer the following research questions:

1. Which mobile network operator in Kenya provides the best voice services?
2. Which mobile network operator in Kenya has the best signal strength?
3. Which mobile network operator in Kenya provides the best voice services?

1.6 Limitations and Assumptions

The research was not done across the whole country. Key towns (**Nairobi, Mombasa, Kisumu, Nakuru, Eldoret, Nyeri, Thika, Kitale and Machakos)** were picked for the scope of the project due to time and cost limitations.

SMS experience and inter Operator testing was not part of the study due to time limitation of the research period.

73.7% of population in urban areas own mobile phone while its 35.9% in rural. Therefore, measuring of quality of experience in urban areas will provide us better sample space population (Aker, Jenny et al. 2009).

Kenyan Bureau of Statistics (KBS) list the following as the top 10 urban centers in terms of population Nairobi, Mombasa, Kisumu, Nakuru, Eldoret, Ruiru, Machakos, Meru, Nyeri and Kitale. This formed the basis of our choice of towns.

Data collection was done only with the use of a smartphone running on android. Other types of phones experience were not measured.

Assumption is that results achieved through use of Smartphone were assumed to apply to all types of phones

1.7 Definitions of terms

The following section defines how key terms will be used in this study.

2G: 2nd generation radio and network technology.

3G: 3rd generation radio and network technology.

Audio communication: use of a service that transmits voice in real-time over a telecommunication network, such as ordinary telephony with a handset and loud-speaking audio conferencing

Bandwidth: range of frequencies which can safely be conveyed in a communication channel

Blocked Calls Rate: These are calls that are unsuccessful because of lack of resources for connection due to congestion expressed as a percentage of total call attempts.

Call Drop Rate: A percentage of calls that are unintentionally disconnected in the middle of the conversation without the user's intervention. This indicator describes calls that are terminated by the network unexpectedly as a result of technical reasons, including entry into a dead zone. Call drops may be as a result of poor handoff or lack of network coverage.

Call Setup Rate: These are the percentage of calls that are successfully setup to a valid number, properly dialed and where called party busy tone, ringing tone or answer signal is recognized at the Network Termination Point of the calling user.

Call Setup Success Rate (CSSR): This is a KPI that measures the number of times a consumer tries to make a call that results in a connection to the dialed number. It is considered one of the most important KPIs because it reflects the consumer's Quality of Experience (QoE) when making a call.

Call Setup Time: The call setup time is the time from a send button is pressed or when the address information required for setting up a call is received by the network to when the called party busy tone or ringing tone or answer signal is received by the calling party.

Completed Calls: These are calls that were successfully set up and received by the called party including the release failed calls.

Congestion: Probability of not accessing the services (a traffic channel)

Contention: A slowdown in performance caused when multiple users share the same limited bandwidth.

Download speed or Throughput: The rate of data transmission from a network operator's access node to a customer, typically measured in Megabits per second (Mbps).

Dropped Calls Rate: A percentage of calls that are unintentionally disconnected in the middle of the conversation without the user's intervention.

Duration: length of time of the communication task

EDGE: Enhanced Data rates for GSM Evolution – an improved data solution for GSM GPRS

End-users: people who use a communication service.

Hand over Success Rate: Handover success rate refers to the percentage of handovers that are successfully completed out of the total handover requests made. Call handover occurs when a mobile handset moves out of one cell to the next and is handed over automatically from the base station of the first cell to that of the next with no discernible disruption of the call.

Kbps: Kilobits per second. 1,000kbps is the same as 1Mbps.

Latency: The time it takes a single packet of data to travel from a user's device to a third-party server and back again. Most commonly measured in milliseconds.

LTE: abbreviation for Long-Term Evolution, commonly marketed as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements.

Mbps: Megabits per second. 1Mbps is the equivalent of 1,000kbps.

MNO: Mobile Network Operator.

Network Latency: The time it takes a single packet of data to travel from a user's device to a third-party server and back again. Most commonly measured in milliseconds.

Packet Loss: This is the disappearance of data packets or other message units in a network during transit

Packet size: magnitude of a data being transmitted over a packet switching network in number of Bytes

Quality of Experience (QoE): overall acceptability of an application or service, as perceived subjectively by the end-user

Quality of Service: totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service

Signal Strength (Rx level): The Rx level is the power in decibels (dBm) of the received signal.

Speech Quality (MOS): Refers to the clarity of the conversational speech without noise or echo interference.

Upload Speed or Throughput: The rate of data transmission from a customer device to a network operator's access node, typically measured in Megabits per second (Mbps).

Usability: effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments

User satisfaction: comfort and acceptability of the task performance to the service user

Web Browsing Time: The time it takes to locate and download a web page within a web browser application (measured in seconds on a reference ETSI page)

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1.8 Organization of the Report

The structure of this document is as follows: Chapter two presents critic of the literature review and previous work done. Chapter three provides the methodology used while Chapter four discusses the architecture and its implementation. Chapter five discusses the testing and evaluation of QoEApp developed in Chapter four. Chapter five provides the functional tests done and its results. Discussion of the study together with recommendations for future work is presented in Chapter six and Conclusions in Chapter seven.

Chapter Two: Literature Review

2.1 Introduction

This chapter discusses the existing study that has been done in the area of measuring quality of experience. It further discusses android development kit and parameters that are currently being used by communication authority of Kenya (CAK) to determine if they are meeting the target set while being issued with the license.

2.2 Investigating Broadband Performance in South Africa

A recent study (Chetty, et al. 2013) states that while the developed world is reaping the benefits of being connected to a fast and reliable broadband infrastructure, studies have shown that broadband can also be an enabling infrastructure to improve the lives of citizens in developing countries.

The study (Chetty, et al. 2013) further says that regardless of the type of measurement technique, there are many **factors that can affect mobile and fixed line broadband performance**. On fixed line connections, the following factors can affect the speeds observed e.g.: **Time of day**, **Distance to the nearest measurement server**, **Consumer's equipment**, **Shared connections -** the more people using the same connection, the worse the speeds that may be observed, particularly for host based measurements.

Unlike fixed line connections, **mobile connections are subject to many more confounding factors** such as whether a **user is indoors or outdoors**, whether a **user is in a crowded area or not** (e.g., at a soccer match), the **handset used to access the Internet**, **signal strength** and the **"app" being run** (Bennett, 2010).

2.3 Regulatory Challenges for Measuring National Broadband Performance - Epitiro

A study (*Epitiro, 2011*) on Regulatory Challenges for Measuring National Broadband found out that whilst both service providers and regulators may use common test apparatus and also collect similar data, the test challenges are quite different between the two groups.
Some of the challenges are: **Clarity of Information, National Benchmarking - Fair Representation, Validation and Procedure**

The study (*Epitiro, 2011*) further recommends that Smartphones can serve as an economical alternative to Drive/Walk test equipment or fixed probes

2.4 BBC 3G Challenge: Create a 3G Coverage Map to compare all UK Mobile Network Operators.

In a case study (*BBC 3G, 2011*) states that **knowing where 3G service is available** is essential to both consumers and operators. Yet 3G coverage maps provided by UK operators are based on limited drive testing results and predictive modelling which fall short of showing the actual coverage available at street level. Further, no "independent" map was available that compared actual operator 3G services nationwide.

This **lack of publicly available information triggered the BBC to partner with Epitiro** and jointly undertake a pioneering 'crowdsourcing' study into 3G coverage across the UK. The BBC aimed to show results on a **single 'all operator' 3G Coverage Map** where consumers could easily compare coverage in their area.

The case study states that "Yet while the BBC project gave an interesting snapshot of the UK's coverage, if the map is to be widely adopted, the industry is keen to include other metrics, such as **signal quality**."

2.5 Communication Authority of Kenya (CAK)

The Communications Authority of Kenya (CAK) is the regulatory authority for the ICT sector in Kenya. Established in 1999, the Authority's mandate is to license and regulate postal, information and communication services. The Commission is also mandated to facilitate development of the ICT sector including broadcasting, multimedia, telecommunications, postal services and electronic commerce.

Table 2.1 provides parameters set by CAK and is what each mobile network operator should meet.

QoS Parameter	2012/13 Targets	2009/ 10 to 2011/12 Targets
Completed Calls	≥95%	≥90%
Call Set up Success Rate	≥95%	≥90%
Dropped Calls	≤2%	≤2%
Blocked calls	≤5%	≤10%
Speech Quality (MOS Values)	95% of calls to have MOS >.3.1	95% of calls to have MOS >2.7
Handover Success Rate	≥95%	≥85%
Call Set up Time	<13.5 sec	<13.5 Secs
Signal Strength (RxLev-dBm)	Outdoor = - 102 dBm, Indoor = -95 dBm, In car = - 100 dBm	Outdoor (≥) -102 dBm

Source: Communications Commission of Kenya

Table 2.1: Communication Authority of Kenya – QoS Parameters

2.6 Summary of Literature Review

From the literature review more has been done on measuring data/internet performance than voice and with the use of computer or laptop as a measurement tool.

Some of the questions arising from the literature review are: "How well does mobile service operators compare to each other?", "What was the performance level actually realized by the consumer?" and "How well does each mobile operator perform with respect to the others?"

Chapter Three: Methodology

3.1 Introduction

The purpose of the study was to benchmark mobile network operators in Kenya by measuring the performance delivered by the four operators in major cities/towns in Kenya.

This chapter will cover in detail the methodology used to complete this project. It discusses design of framework used for data collection, data samples, and actual procedure to be used during data collection, data processing and analysis. It also discusses limitations of the methodology used.

A wide range of performance measurements were captured during testing by use of a prototype including call setup success rate, call drop rate, download speed, upload speed, latency, web browsing time and signal strengths.

3.2 Framework and Design for Data Collection

3.2.1 Framework

Data collection followed the framework illustrated in Figure 3.1. One phone was used for each mobile network operator i.e. Safaricom, Airtel, Orange and Essar (Yu) for the purpose of data collection for each parameter under study.

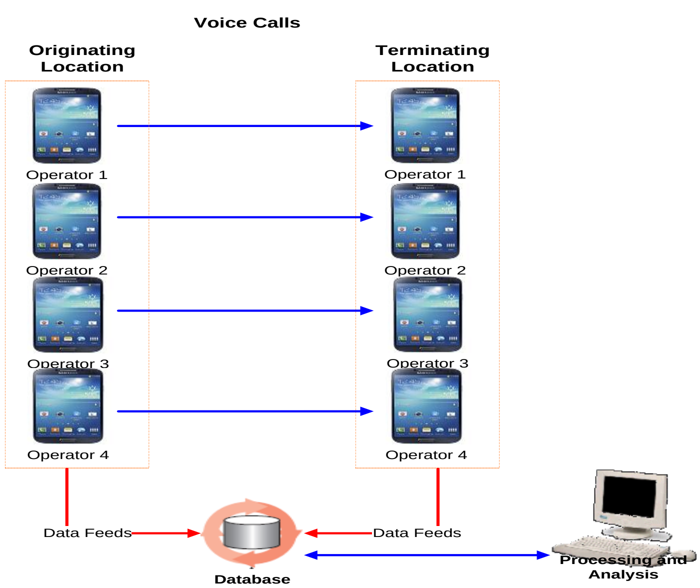


Figure 3.1: Voice Calls Measurement Framework

We used the architecture in Figure 3.1 to collect data while measuring voice performance. Two smartphones were used per mobile network operator to perform test calls. An application was developed to initiate calls from originating location and another application on terminating location to automatically receive calls.

The database which was hosted on an internet server received voice related data feeds which were later processed and analyzed for reporting.

Voice: We performed random test calls for three hours per location per mobile network provider. That gave us 1800 test calls samples per mobile network provider (3hrs x 60min x 10locations). Each call lasted 1minute giving 60 calls per hour.

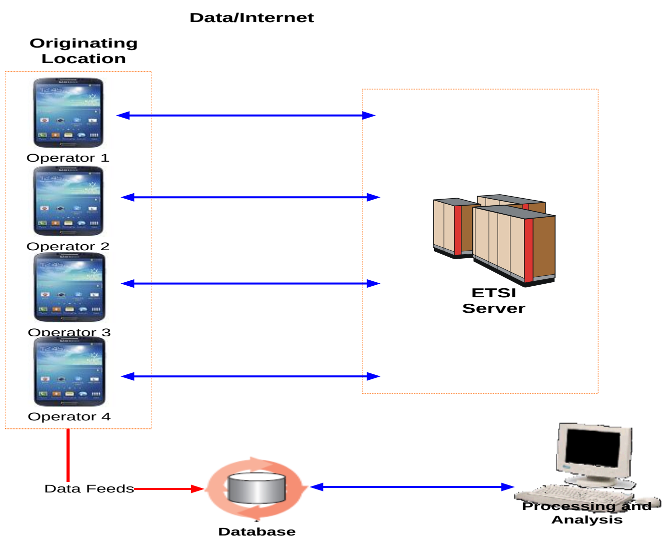


Figure 3.2: Data Session Measurement Framework

We used the architecture in Figure 3.2 to collect data while measuring data/internet performance. One smartphone was used per mobile network operator to perform data/internet performance tests. An application was developed to download a file from ETSI server, upload file to ESTI server, and perform latency checks to ETSI server and web browsing on an URL pointing to ETSI.

The database which was hosted on an internet server received data/internet related data feeds which were later processed and analyzed for reporting.

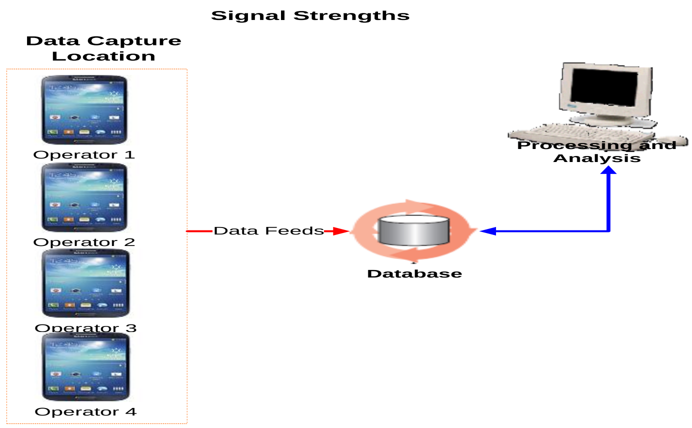


Figure 3.3: Signal Strengths Measurement Framework

We used the architecture in Figure 3.3 to collect data while measuring signal strengths. One smartphone was used per mobile network operator to measure signal strengths received on the phone. An application was developed to capture signal strengths of each network operator.

The database which was hosted on an internet server received signal strengths related data feeds which were later processed and analyzed for reporting.

3.2.2 Overall System Design

System overall design provides the steps we followed during the study from the research hypotheses formulation to results reporting. This is illustrated in Figure 3.4.

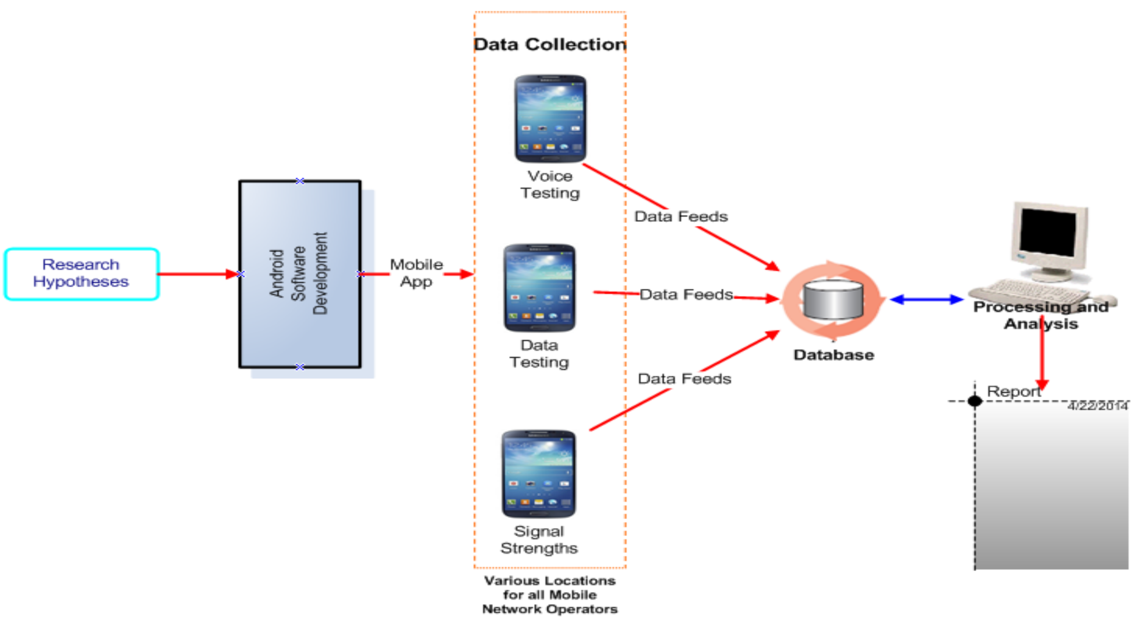


Figure 3.4: Overall Design

The overall design of the research included coming up with research hypotheses followed by use of Android development tools to come up with the prototype to be used during data collection. Data collection was done in various locations for all MNO where testing for voice, data/internet and signal strengths was performed. Data collected was transferred to a database running on a server hosted on web servers. Processing and analysis was performed before the reports were generated.

The study followed quantitative approach to research which involved generation of data in quantitative form and was subjected to rigorous quantitative analysis in a formal and rigid fashion. It also followed inferential approach to research in which we formed a data base from which to infer characteristics or relationships of population. This means during the study a sample of population was studied to determine its characteristics, and then inferred that the population has the same characteristics.

Some of the justifications for quantitative research approach are:

Purpose of the study was to test hypotheses, look at cause & effect, & make predictions. Specific variables were studied. Types of data collected are numbers and statistics. Form of data collected is Quantitative data based on precise measurements using structured & validated data-collection instruments. Type of data analysis identifies statistical relationships. Results are generalizable findings that can be applied to other populations. Focus was narrow-angle lens to test specific hypotheses. Final report provided statistical report with correlations, comparisons of means, & statistical significance of findings.

3.3 Application Development

The Android Software Development Kit (SDK) provides the tools and APIs necessary to begin developing applications on the Android platform using the Java programming language. Android SDK is a plug-in that has been installed into Eclipse Integrated Development Environment (IDE).

Android platform components

The Android system is a full software stack, which is typically divided into the four areas as depicted in the following graphic.

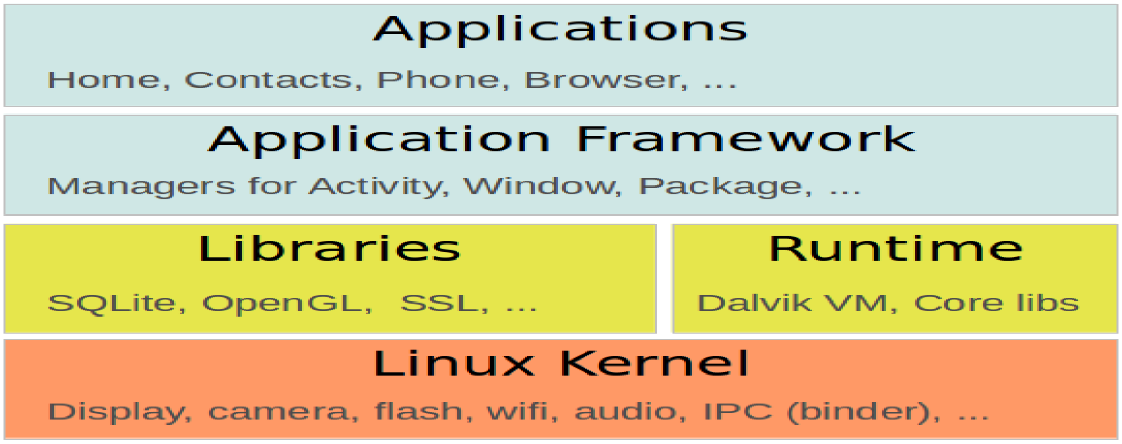


Figure 3.5: Android Platform Components [Android Architecture]

The levels indicated in Figure 3.5 can be described as:

Applications - The Android Open Source Project contains several default applications, like the Browser, Camera, Gallery, Music, Phone and more.

Application framework - API which allows high-level interactions with the Android system from Android applications.

Libraries and runtime - Libraries for the Application Framework for many common functions (graphic rendering, data storage, web browsing, etc.) as well as the Dalvik runtime and the core Java libraries for running Android applications.

Linux kernel - Communication layer for the underlying hardware.

The Linux kernel, the libraries and the runtime are encapsulated by the application framework. The Android application developer typically works with the two layers on top to create new Android applications.

QoEApp application for data collection was developed using Java programming language with the aid of Eclipse development tools.

The Android software stack as shown in figure 3.6 can be subdivided into five layers: The kernel and low level tools, native libraries, the Android Runtime, the framework layer and on top of all the applications. Android operating system is a stack of software components which is roughly divided into five sections and four main layers as shown in the architecture diagram on Figure 3.6

QoEApp application developed sits at the applications layer utilizing the other layers.

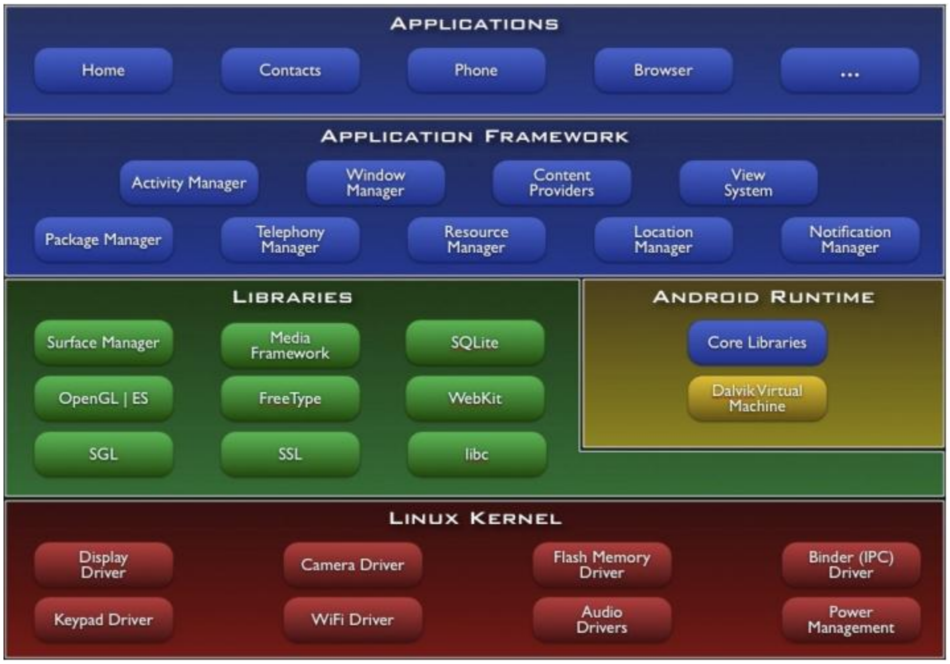


Figure 3.6: Android system architecture [Android Architecture].

QoEApp directly interacts with Application framework layer which contains the following blocks:
Activity Manager: Manages the activity life cycle of applications
Content Providers: Manage the data sharing between applications
Telephony Manager: Manages all voice calls. We use telephony manager if we want to access voice calls in our application.
Location Manager: Location management, using GPS or cell tower
Resource Manager: Manage the various types of resources we use in our Application

The Application Framework layer provides many higher-level services to applications in the form of Java classes.

3.4 Sampling Technique

Non-probability sampling strategy was used which included quota sampling, self-selection sampling and convenience sampling. The relative cost and time required to carry out a convenience sample is small. This enabled us achieve the sample size we wanted in a relatively fast and inexpensive way. This reduced the amount of time necessary to search for appropriate samples.

The four mobile network operators provide services across the whole country. For the purpose of this study performance was measured in selected towns namely Nairobi, Mombasa, Kisumu, Nakuru, Eldoret, Nyeri, Thika, Kitale and Machakos

Selection of samples was based on the size of the city/town. Top cities and towns in Kenya were selected as part of the sample areas.

3.5 Application Experimentation

Data was collected using the framework described in section 3.2.1 between 8am to 8pm. Measurements that formed the basis of the study were conducted by drive testing, walk testing and stationary testing in cities and towns under study. Each city/town was tested for a period of one day. Smartphones running android were used with the help of QoEApp application developed.

For each data samples we also collected the following location metrics **Latitude (**Latitude of the data collection point), **Longitude (**Longitude of the data collection point), **Altitude (**Altitude of the data collection point) and **Speed (**Speed of the device being used over ground in meters/second *(for in-motion testing))*.

Location metrics of each test were recorded by employing the GPS capabilities of the smartphone. Therefore smartphones had GPS functionality. If a GPS signal was not available, then the network location was used.

For each data samples we also collected the following network metrics Network Operator Name, Location Area Code (LAC), Cell ID (ID of serving BTS), Received Signal Strength (The current received signal strength in dBm) and Network Type (GPRS, EDGE, CDMA, UMTS, HSDPA, HSUPA, HSPA) and Phone Type (GSM, CDMA)

Also important data collected are device related information (device id and SIM serial number) used to tag each data collected

3.5.1.1 Voice Performance Measurement

Key Performance Indicators measured for voice performance are: Accessibility (Call Setup Success Rate) and Retainability (Dropped Calls).

The dropped call rate is defined as the percentage of calls that are disconnected prior to the completion of the full defined call duration, divided by the number of call attempts that are successfully placed on the network (Metrico Wireless, Ltd. July 2011)

The call setup success rate is defined as the percentage of calls that are successfully placed on the network divided by the total number of call attempts (Metrico Wireless, Ltd. July 2011)

Four smartphones loaded with developed application were deployed during the drive testing, walk testing and stationary testing to enable concurrent testing of the four mobile network operators.

Calls were initiated and terminated after every one minute for 60minutes while recording success and failures. Reasons for the failures were also recorded.

3.5.1.2 Data/Internet Performance Measurement

Key Performance Indicators measured for data/internet performance are: File Download Speed, File Upload Speed, Network Latency and Web Browsing Time (time it takes to locate and download a web page within a web browser application)

The main consideration for evaluating web surfing is the time for the device to fully render the target web page. What is testable in reality is the time it takes to download the data, not final appearance on a screen. (Regulatory Challenges for Measuring National Broadband Performance. Epitiro ltd. March 2011)

Testing using popular websites both nationally and overseas provides insight into QoE whilst testing to a common, unchanging test site URL on a controlled server is a preferred test for QoS. Consideration for cached or non-cached testing is required in each case, especially when benchmarking to ensure like-for-like comparisons. (Regulatory Challenges for Measuring National Broadband Performance. Epitiro ltd. March 2011)

Four smartphones loaded with QoEApp application were deployed during the drive testing, walk testing and stationary testing to enable concurrent testing of the four mobile network operators.

File Download Speed: A 3MB file was downloaded from ETSI server for 15seconds then the session was terminated. Paused for three seconds (to allow for the impact of TCP slows start) and initiate another download session for 1hour. Download speeds during the session was recorded.

File Upload Speed: A 500KB file was uploaded to ETSI server for 15seconds then the session was terminated. Paused for three seconds (to allow for the impact of TCP slows start) and initiate another upload session for 1hour. Upload speeds during the session was recorded.

All tests were configured as time bounded with both downstream and upstream speeds being measured for a period of 15 seconds each in order ensured accurate results regardless of the speed being delivered by the mobile broadband service

Network Latency: Ping ETSI server and measure amount of time it took to transmit the data between the source and destination and receiving the expected response.

Web Browsing Time: Tests recorded time taken to download the webpage, and also the HTTP status code returned by the hosting web server, so that failures could be excluded from analysis.

Tests were executed for 30minutes at each location

3.5.1.3 Signal Strengths Measurement

A mobile phone signal (also known as reception) is the signal strength received by the mobile phone from the cellular network (on the downlink). Depending on various factors, such as proximity to a tower, obstructions such as buildings or trees, etc., the signal strength will vary. Most mobile devices use a set of bars of increasing height to display the approximate strength of the received signal to the mobile phone user.

Signal strength is usually measured in dBm. dBm is an abbreviation for the power ratio in decibels (dB) of the measured power referenced to one milliwatt (mW). It is used in radio, microwave and fiber optic networks as a convenient measure of absolute power because of its capability to express both very large and very small values in a short form. A signal of -60dBm is nearly perfect, and -112dBm is call-dropping bad. If you're above about -87 dBm, Android will report a full 4 bars of signal.

Four smartphones loaded with QoEApp application were deployed during the drive testing, walk testing and stationary testing to enable concurrent capturing of signal strengths of the four mobile network operators. Data collections were executed for 30minutes at each location.

3.6 Data Processing and Analysis

The data, after collection, were processed and analysed in order to achieve purpose of the research. During data processing and analysis we decided what to Measure and How, Collected Data, Summarized and Displayed Data, Analysed Data and Interpreted Results.

At the analysis phase we explored relationship between various variables and compared the various parameters.

3.6.1.1 Processing of Data

Collected data were processed prior to analysis stage. Processing involved editing, coding, classification and tabulation of collected data so that they are amenable to analysis.

3.6.1.2 Analysis of Data

Kothari (1985, p122) states that the term analysis refers to the computation of certain measures along with searching for patterns of relationship that exist among data-groups. Analysis of data in a general way involves a number of closely related operations which are performed with the purpose of summarising the collected data and organising these in such a manner that they answer the research question(s). The type of analysis that we used is Inferential analysis which is concerned with the various tests of significance for testing hypotheses in order to determine with what validity data can be said to indicate some conclusion or conclusions. It is also concerned with the estimation of population values (Kothari C. R., 1985). Inferential statistics also is concerned with making predictions or inferences about a population from observations and analyses of a sample. That is, we can take the results of an analysis using a sample and can generalize it to the larger population that the sample represents. In order to do this, however, it is imperative that the sample is representative of the group to which it is being generalized (Kothari C. R., 1985). Amongst the measures of central tendency that was used are the arithmetic average or mean, median and mode (Kothari C. R., 1985). From among the measures of dispersion, variance, and its square root—the standard deviation was used (Kothari C. R., 1985). For comparison purpose, we used the coefficient of standard deviation (Kothari C. R., 1985).

3.7 Limitations of Methodology

Some of the limitations of the methodology used were high cost of voice calls and data, national representation to ensure test data is fairly representative of all the mobile network operators and directly comparable and comparable device used to collect data.

Chapter Four: System Implementation, Experimentation and Testing

4.1 Introduction

The QoEApp Android application is the implementation of the Methodology specified in the previous chapter three.

The previous chapters focused on the overview of measuring quality of experience of customers using services offered by mobile network operators , smartphone application development and the methodology used to collect and transmit data between both components - the Mobile Application (QoEApp) and the Central Server hosted on the internet. The conceptual framework and workflow was also covered. As this point, the frameworks are defined. The next stage of the development is detailing the QoEApp platform and results, which is the focus of this project.

QoEApp smartphone application is not fully developed. The main goal was to design a prototype for collection of data to be used to measure quality of experience of mobile network operators in Kenya. At the end of this chapter it is shown that we completed the development and also provided the opportunity to test it in real life situation.

Procedures for testing and results are discussed in the next chapter.

4.2 Prototyping

The Rapid Application Development (RAD) process was used in the development of QoEApp. Special focus was in its implementation it let us create the prototype and test the application faster. It also let us test and validate the functionalities faster. As the development went on the prototype got richer and solid allowing trying new features and taking informed decisions as validation of requirements went on.

To enable us prototype QoEApp extensive knowledge of Android was required there we had to first read Android Design Guidelines (Android Design Guidelines, 2014)

4.2.1 Choice of Android

Android was the choice of development platform due to availability of the smartphones running android. Android is the Dominant Mobile Operating System (GlobalWebIndex's quarterly report - GWI Device Summary, February 2014). Android continues to increase its share of the mobile OS market: 65% of the mobile internet populations are using it, representing a climb of 38% across 2013 and an impressive 270% since Q4 2011. It is most prevalent in South Korea, China and Malaysia (75%+ in each market). iOS for the iPhone is a distant second – used by 20% of the global mobile internet audience. However, this still represents an increase in estimated user numbers of 181% since the end of 2011 and iOS has a much greater than average market share in nations such as the

US (42%), Australia (40%) and Canada (37%). Just 5% are now using the BlackBerry OS, down from 9% at the end of 2011.

We had to learn and research on Android framework before starting this project since we did not have any prior knowledge or skills.

4.2.2 Causes of Disconnection in Mobile Network

Disconnect causes for both successful and unsuccessful calls appears on disconnect or release signaling messages. The cause code reveals if the call was disconnected normally (typically cause no. 10) or abnormally. We will discuss some of the standard causes values that may appear in the trace files as part of disconnect processing.

The cause value is returned on the trace file and it's used to map to the description to determine the reason for disconnect.

The following codes are received by the phone when a call is disconnected. The codes are important since they will help us determine the reason for call disconnection and eventually assist in measuring the quality of experience of the services provided by the mobile network operators.

Cause No. l - Unallocated (unassigned) number [Q.850]
This cause indicates that the called party cannot be reached recluses although the called party number is in a valid format. It is not currently allocated (assigned).
Cause No. 2 - No route to specified transit network (national use) [Q.850]
This cause indicates that the equipment sending this cause has received a request to route the call through a particular transit network which it does not recognize. The equipment sending this cause does not recognize the transit network either because the transit network does not exist or because that particular transit network. While it does exist does not serve the equipment which is sending this cause.
Cause No. 3 - No route to destination [Q.850]
This cause indicates that the called party cannot be reached because the network through which the call has been routed does not serve the destination desired. This cause is supported on a network dependent basis.
Cause No. 4 - send special information tone [Q.850]
This cause indicates that the called party cannot be reached for reasons that are of a long term nature and that the special information tone should be returned to the calling party.
Cause No. 5 - misdialed trunk prefix (national use) [Q.850]
This cause indicates the erroneous inclusion of a trunk prefix in the called party number. This number is to be sniped from the dialed number being sent to the network by the customer premises equipment.

Cause No. 6 **-** channel unacceptable [Q.850]

This cause indicates that the channel most recently identified is not acceptable to the sending entity for use in this call.

Cause No. 7 **-** call awarded. being delivered in an established channel [Q.850]

This cause indicates that the user has been awarded the incoming call and that the incoming call is being connected to a channel already established to that user for similar calls (e.g. packet-mode x.25 virtual calls).

Cause No. 8 **-** preemption [Q.850]

This cause indicates the call is being preempted.

Cause No. 9 **-** preemption - circuit reserved for reuse [Q.850]

This cause indicates that the call is being preempted and the circuit is reserved for reuse by the preempting exchange.

Cause No. 10 **-** normal call clearing [Q.850]

This cause indicates that the call is being cleared because one of the users involved in the call has requested that the call be cleared. Under normal situations, the source of this cause is not the network.

Cause No. 17 **-** user busy [Q.850]

This cause is used to indicate that the called party is unable to accept another call because the user busy condition has been encountered. This cause value may be generated by the called user or by the network. In the case of user determined user busy it is noted that the user equipment is compatible with the call.

Cause No. 18 **-** no user responding [Q.850]

This cause is used when a called party does not respond to a call establishment message with either an alerting or connect indication within the prescribed period of time allocated.

Cause No. 19 **-** no answer from user (user alerted) [Q.850]

This cause is used when the called party has been alerted but does not respond with a connect indication within a prescribed period of time. Note - This cause is not necessarily generated by Q.931 procedures but may be generated by internal network timers.

Cause No. 20 **-** subscriber absent [Q.850]

This cause value is used when a mobile station has logged off. Radio contact is not obtained with a mobile station or if a personal telecommunication user is temporarily not addressable at any user-network interface.

Cause No. 21 **-** call rejected [Q.850]

This cause indicates that the equipment sending this cause does not wish to accept this call although it could have accepted the call because the equipment sending this cause is neither busy nor incompatible. This cause may also be generated by the network, indicating that the call was cleared due to a supplementary service constraint. The diagnostic field may contain additional information about the supplementary service and reason for rejection.

Cause No. 22 **-** number changed [Q.850]

This cause is returned to a calling party when the called party number indicated by the calling party is no longer assigned. The new called party number may optionally be included in the diagnostic field. If a network does not support this cause, cause no. 1, unallocated (unassigned) number shall be used.

Cause No. 26 - non-selected user clearing [Q.850]

This cause indicates that the user has not been awarded the incoming call.

Cause No. 27 - destination out of order [Q.850]

This cause indicates that the destination indicated by the user cannot be reached because the interface to the destination is not functioning correctly. The term "not functioning correctly" indicates that a signal message was unable to be delivered to the remote party; e.g., a physical layer or data link layer failure at the remote party or user equipment off-line.

Cause No. 28 - invalid number format (address incomplete) [Q.850]

This cause indicates that the called party cannot be reached because the called party number is not in a valid format or is not complete.

Cause No. 29 - facilities rejected [Q.850]

This cause is returned when a supplementary service requested by the user cannot be provide by the network.

Cause No. 30 - response to STATUS INQUIRY [Q.850]

This cause is included in the STATUS message when the reason for generating the STATUS message was the prior receipt of a STATUS INQUIRY.

Cause No. 31 - normal. unspecified [Q.850]

This cause is used to report a normal event only when no other cause in the normal class applies.

Cause No. 34 - no circuit/channel available [Q.850]

This cause indicates that there is no appropriate circuit/channel presently available to handle the call.

Cause No. 35 - Call Queued [Q.850]

Cause No. 38 - network out of order [Q.850]

This cause indicates that the network is not functioning correctly and that the condition is likely to last a relatively long period of time e.g., immediately re-attempting the call is not likely to be successful.

Cause No. 39 - permanent frame mode connection out-of-service [Q.850]

This cause is included in a STATUS message to indicate that a permanently established frame mode connection is out-of-service (e.g. due to equipment or section failure) (see Annex A/Q.933)

Cause No. 40 - permanent frame mode connection operational [Q.850]

This cause is included in a STATUS message to indicate that a permanently established frame mode connection is operational and capable of carrying user information. (see Annex A/Q.933]

Cause No. 41 - temporary failure [Q.850]

This cause indicates that the network is not functioning correctly and that the condition is no likely to last a long period of time; e.g., the user may wish to try another call attempt almost immediately.

Cause No. 42 - switching equipment congestion [Q.850]

This cause indicates that the switching equipment generating this cause is experiencing a period of high traffic.

Cause No. 43 - access information discarded [Q.850]

This cause indicates that the network could not deliver access information to the remote user as requested. i.e., user-to-user information, low layer compatibility, high layer compatibility or sub-address as indicated in the diagnostic. It is noted that the particular type of access information discarded is optionally included in the diagnostic.

Cause No. 44 - requested circuit/channel not available [Q.850]

This cause is returned when the circuit or channel indicated by the requesting entity cannot be provided by the other side of the interface.

Cause No. 46 - precedence call blocked [Q.850]

This cause indicates that there are no predictable circuits or that the called user is busy with a call of equal or higher preventable level.

Cause No. 47 - resource unavailable, unspecified [Q.850]

This cause is used to report a resource unavailable event only when no other cause in the resource unavailable class applies.

Cause No. 49 - Quality of Service not available [Q.850]

This cause is used to report that the requested Quality of Service. as defined in Recommendation X.213. cannot be provided (e.g., throughput of transit delay cannot be supported).

Cause No. 50 - requested facility not subscribed [Q.850]

This cause indicates that the user has requested a supplementary service which is implemented by the equipment which generated this cause but the user is not authorized to use.

Cause No. 52 - outgoing calls barred

Cause No. 53 - outgoing calls barred within CUG [Q.850]

This cause indicates that although the calling party is a member of the CUG for the outgoing CUG call. Outgoing calls are not allowed for this member of the CUG.

Cause No. 54 - incoming calls barred

Cause No. 55 - incoming calls barred within CUG [Q.850]

This cause indicates that although the calling party is a member of the CUG for the incoming CUG call. Incoming calls are not allowed for this member of the CUG.

Cause No. 57 - bearer capability not authorized [Q.850]

This cause indicates that the user has requested a bearer capability which is implemented by the equipment which generated this cause but the user is not authorized to use.

Cause No. 58 - bearer capability not presently available [Q.850]

This cause indicates that the user has requested a bearer capability which is implemented by the equipment which generated this cause but which is not available at this time.

Cause No. 62 - inconsistency in outgoing information element. [Q.850]

This cause indicates an inconsistency in the designated outgoing access information and subscriber class

Cause No. 63 - service or option not available. unspecified [Q.850]

This cause is used to report a service or option not available event only when no other cause in the service or option not available class applies.

Cause No. 65 - bearer capability not implemented [Q.850]

This cause indicates that the equipment sending this cause does not support the bearer capability requested.

Cause No. 66 - channel type not implemented [Q.850]

This cause indicates that the equipment sending this cause does not support the channel type requested

Cause No. 69 - requested facility not implemented [Q.850]

This cause indicates that the equipment sending this cause does not support the requested supplementary services.

Cause No. 70 - only restricted digital information bearer capability is available (national use) [Q.850]

This cause indicates that the calling party has requested an unrestricted bearer service but the equipment sending this cause only supports the restricted version of the requested bearer capability.

Cause No. 79 - service or option not implemented unspecified [Q.850]

This cause is used to report a service or option not implemented event. Only when no other cause in the service or option not implemented class applies.

Cause No. 81 - invalid call reference value [Q.850]

This cause indicates that the equipment sending this cause has received a message with a call reference which is not currently in use on the user-network interface.

Cause No. 82 - identified channel does not exist [Q.850]

This cause indicates that the equipment sending this cause has received a request to use a channel not activated on the interface for a call. For example, if a user has subscribed to those channels on a primary rate interface numbered from one to 12 and the user equipment or the network attempts to use channels l3 through 23, this cause is generated.

Cause No. 83 - a suspended call exists, but this call identify does not [Q.850]

This cause indicates that a call resume has been attempted with a call identity which differs from that in use for any presently suspended call(s).

Cause No. 84 - call identity in use [Q.850]

This cause indicates that the network has received a call suspended request containing a call identity (including the null call identity) which is already in use for a suspended call with in the domain of interfaces over which the call might be resumed.

Cause No. 85 - no call suspended [Q.850]

This cause indicates that the network has received a call resume request containing a Call identity information element which presently does not indicate any suspended call within the domain of interfaces over which calls may be resumed.

Cause No. 86 - call having the requested call identity has been cleared [Q.850]

This cause indicates that the network has received a call resume request containing a Call identity information element indicating a suspended call that has in the meantime been cleared while suspended (either by network time-out or by the remote user).

Cause No. 87 - user not a member of CUG [Q.850]

This cause indicates that the called user for the incoming CUG call is not a member of the specified CUG or that the calling user is an ordinary subscriber calling a CUG subscriber.

Cause No. 88 - incompatible destination [Q.850]

This cause indicates that the equipment sending this cause has received a request to establish a call which has low layer compatibility. high layer compatibility or other compatibility attributes (e.g., data rate) which cannot be accommodated.

Cause No. 90 - non-existent CUG [Q.850]

This cause indicates that the specified CUG does not exist.

Cause No. 91 - invalid transit network selection (national use) [Q.850]

This cause indicates that a transit network identification was received which is of an incorrect format as defined in Annex C/Q.931

Cause No. 95 - invalid message, unspecified [Q.850]

This cause is used to report an invalid message event only when no other cause in the invalid message class applies.

Cause No. 96 - mandatory information element is missing [Q.850]

This cause indicates that the equipment sending this cause has received a message which is missing an information element which must be present in the message before that message can be processed.

Cause No. 97 - message type non-existent or not implemented [Q.850]

This cause indicates that the equipment sending this cause has received a message with a message type it does not recognize either because this is a message not defined of defined but not implemented by the equipment sending this cause.

Cause No. 98 - message not compatible with call state or message type non-existent or not implemented. [Q.850]

This cause indicates that the equipment sending this cause has received a message such that the procedures do not indicate that this is a permissible message to receive while in the call state. or a STATUS message was received indicating an incompatible call state.

Cause No. 99 - Information element / parameter non-existent or not implemented [Q.850]

This cause indicates that the equipment sending this cause has received a message which includes information element(s)/parameter(s) not recognized because the information element(s)/parameter name(s) are not defined or are defined but not implemented by the equipment sending the cause. This cause indicates that the information element(s)/parameter(s) were discarded. However, the information element is not required to be present in the message in order for the equipment sending the cause to process the message.

Cause No. 100 - Invalid information element contents [Q.850]

This cause indicates that the equipment sending this cause has received and information element which it has implemented; however, one or more Gelds in the I.E. are coded in such a way which has not been implemented by the equipment sending this cause.

Cause No. 101 - message not compatible with call state [Q.850]

This cause indicates that a message has been received which is incompatible with the call state.

Cause No. 102 - recovery on timer expiry [Q.850]

This cause indicates that a procedure has been initiated by the expiration of a timer in association with error handling procedures.

Cause No. 103 - parameter non-existent or not implemented - passed on (national use) [Q.850]

This cause indicates that the equipment sending this cause has received a message which includes parameters not recognized because the parameters are not defined or are defined but not implemented by the equipment sending this cause. The cause indicates that the parameter(s) were ignored. In addition, if the equipment sending this cause is an intermediate point, then this cause indicates that the parameter(s) were passed unchanged.

Cause No. 110 - message with unrecognized parameter discarded [Q.850]

This cause indicates that the equipment sending this cause has discarded a received message which includes a parameter that is not recognized.

Cause No. 111 - protocol error, unspecified [Q.850]

This cause is used to report a protocol error event only when no other cause in the protocol error class applies.

Cause No. 127 - Intel-working, unspecified [Q.850]

This cause indicates that an interworking call (usually a call to 5W56 service) has ended.

4.3 System Implementation

The Android Developer Tools provide a first-class development environment for building Android application. This integrated development environment is set up with the latest version of the Android platform and system so you can immediately begin building application and running them on the Android emulator or real device (Welcome to the Android Developer Tools).

The implementation involved defining what actions to run in the background and at what times and what should be transmitted to the hosting server.

4.3.1 Background Services

Background Services are services that run in the system and do not have a user interface.
QoEApp uses this kind of services to perform functionality tests, collect data and transmit the same to the hosting server. The communication to the hosting server is via internet.

4.3.1.1 QoE Workflow

We came up with the workflow described in Figure 4.1 which shows how the various components of the application interact with each other. QoEApp service starts when the user decides to perform functionality tests. This is done as shown in Figure 4.1. This activity is the interface for the service. When the users exits the application or starts other applications the service keeps running in the background as normal.

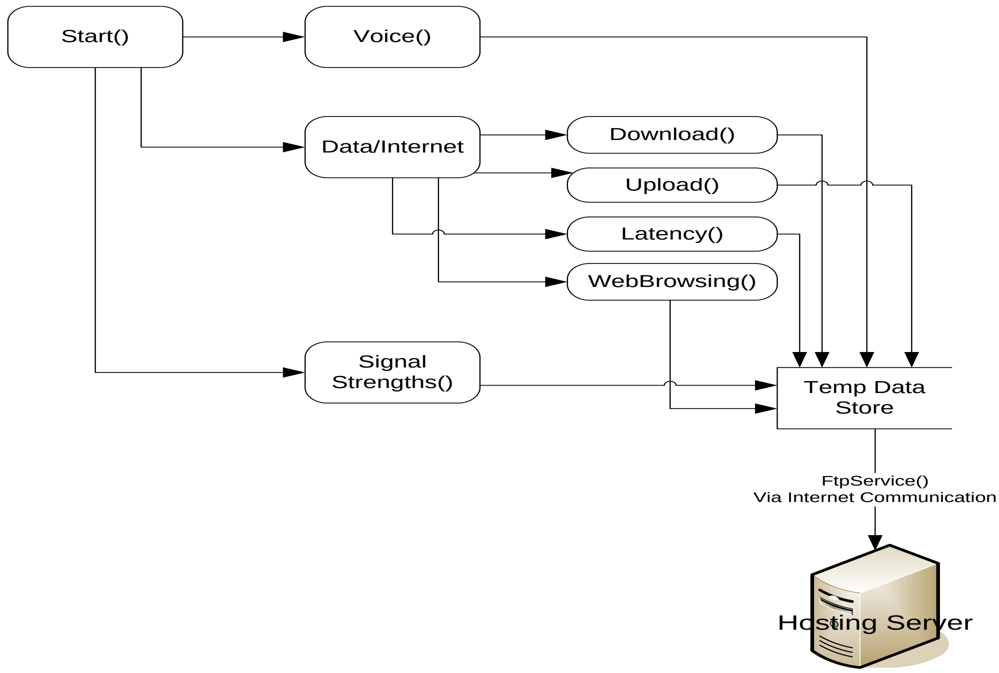


Figure 4.1: Background Services and Communication with Hosting Server

Background services are indicated in Figure 4.1 containing the following services:

Start(): This service starts the three services that will do testing of voice, data/internet and signal strengths.

Voice(): Voice service will perform all voice tests recording all success and failed calls including the reasons for failures

Data/Internet(): This service starts four other services that will perform download, upload, latency and web browsing tests.

SignalStrengths(): Signal Strength service records receive level of signals for the network.

Download(): Download service will perform downloading tests while recording the throughput and failures.

Upload(): Upload service will perform upload tests while recording upload speeds.

Latency(): Latency service will perform network latency tests while recording the round trip time

WebBrowsing(): WebBrowing service will perform web browsing time tests while recording the time it takes to access a web url successfully.

FtpService(): FtpService will transfer the data stored temporarily on phone to the web hosting server for processing and analysis.

4.3.1.2 Communication with Hosting Server

When functionality test finishes the application sends collected data to the hosting server via internet. We have a separate ftp service running in the background that sends all collected data to the hosting server. When internet is not available transmitting of collected data will be retried after 30minutes.

4.3.2 Database

Internal storage of the smartphone is used to store flat files temporarily before they are transmitted to the hosting server on internet.
This ensures collected data are not lost and they can be transmitted to the hosting server when connectivity is available. On the hosting server, MySQL is used to store data for analysis and reporting.

Voice	Download	Browse	Latency	Signal Strength
Field	Field	Field	Field	Field
direction	startDateandTime	startDateandTime	sr	date_time
msisdn	endDateandTime	endDateandTime	currentDateandTime	mcc
date_time	filename	url	host	mnc
dialing_time	total	latency	reachable	networkoperatorname
alerting_time	TimeDifference_Seconds	ResponseCode	time	latitude
incoming_time	TotalRxBytes	ResponseMessage	deviceid	longitude
active_time	rxSpeed_Kbps	deviceid	network	activenetworkinfo
start_lac	TotalTxBytes	network	operatorname	failover
start_cell	txSpeed_Kbps	operatorname	networkroaming	lac0
start_network_type	deviceid	networkroaming	simserialno	cid0
start_altitude	network	simserialno	subscriberid	psc0
start_latitude	operatorname	subscriberid	lac	networktype0
start_longitude	networkroaming	lac	cellid	signalstrength0
start_speed	simserialno	cellid	networktype	neighbors
start_locationprovider	subscriberid	networktype	phonetype	lac1
cause	lac	phonetype	altitude	cid1
drop_setup	cellid	altitude	latitude	psc1
lastcause	networktype	latitude	longitude	networktype1
lastcallfailcause	phonetype	longitude	speed	signalstrength1
deviceid	altitude	speed	accuracy	lac2
network	latitude	accuracy	locationprovider	cid2
operatorname	longitude	locationprovider	isGPSproviderenabled	psc2
simserialno	speed	isGPSproviderenabled	town	networktype2
subscriberid	accuracy	town		signalstrength2
stop_lac	locationprovider			town
stop_cell	isGPSproviderenabled			indoor_outdoor
stop_network_type	town			
stop_altitude				
stop_latitude				
stop_longitude				
stop_speed				
stop_locationprovider				
event				
error				

Figure 4.2: Schema of the database in the hosting server

"MySQL is a popular choice of database for use in web applications, and is a central component of the widely used LAMP open source web application software stack (and other 'AMP' stacks). LAMP is an acronym for "Linux, Apache, MySQL, Perl/PHP/Python." Free-software-open source projects that require a full-featured database management system often use MySQL." (http://en.wikipedia.org/wiki/MySQL)

4.3.3 User Interface and Features

In this section we discuss the features of the smartphone application that are visible to the user and what each feature does.

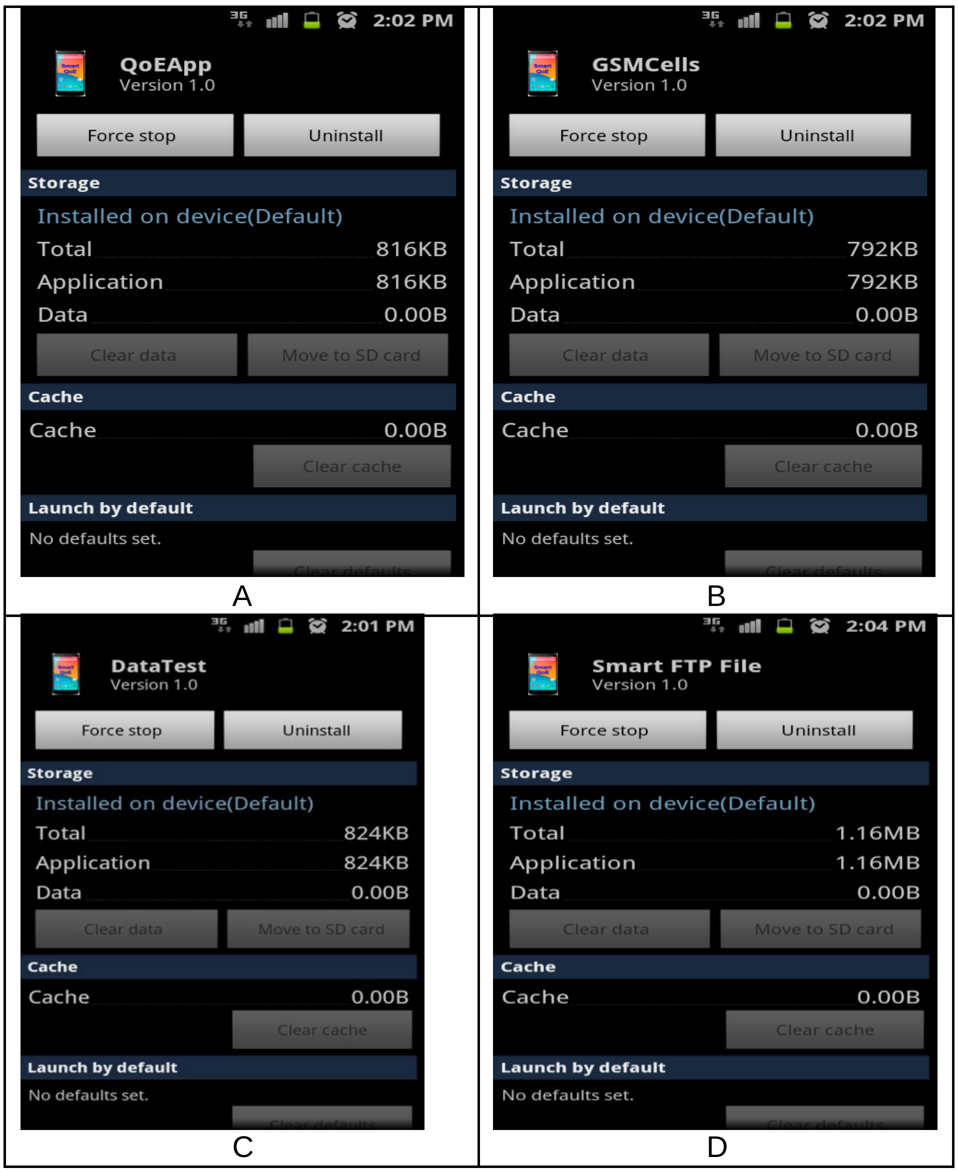


Figure 4.3: User Interfaces (A) QoEApp Service (B) GSMCells Service (C) DataTest Service (D) Smart FTP File Service

Figure 4.3 shows implemented services for the QoEApp. From screen (A) you can easily access all functionalities where you start the services from.

Subsequent screens give you the options to either stop the application or uninstall the application.

4.3.3.1 QoEApp Service

This service is responsible for collection of data related to calls status and performance. Sample of the data collected for one call is as follows:

MO|918|06-01-1980 03:40:30.090|315967230090|4502|50121|UMTS|0.0|0.0|0.0|0.0|0.0|null|false|OFFHOOK|06-01-1980 03:40:30.152|4502|50121|UMTS|IDLE|LOCAL|OK|0|null|31600483611 1|06-01-1980 14:07:16.111|06-01-1980 14:08:48.201|357160040048481|63905|yu|false|89254050001228041780|639050022804178|7000|10121|EDGE|0.0|0.0|0.0|0.0|0.0|null|false|ALERTING=01-06 14:07:15.910 ACTIVE=01-06 14:07:16.100|GENERIC_FAILURE-GET_CURRENT_CALLS|0-7000-10121-EDGE=>0-7000-10121-EDGE=>0-7000-10121-EDGE=>0-7000-10121-EDGE|null|472035910|null|472036100|

This data maps to the voice table illustrated in Figure 4.2

4.3.3.2 GSMCells Service

This service is responsible for collection of signal strengths data. Sample of the data collected for two measurements are:

01-07-2014 10:16:07.011|01-07-2014 10:16:07.167|639|07|Orange Ke|-0.69303|36.419773333333333|null|isFailover|14105|4553|-1|EDGE|-89|0|

29-06-2014 09:29:44.393|29-06-2014 09:29:59.745|639|02|Safaricom|0.0|0.0|null|isFailover|46000|47160|-1|UMTS|-91|1|0|65535|65535|467|UMTS|-73|

This data maps to the signal strength table illustrated in Figure 4.2

4.3.3.3 DataTest Service

This service is responsible for collection of internet performance data (download speeds, network latency and web browsing time).

Sample of the data collected for two download measurements which maps to the download table illustrated in Figure 4.2 are:

21-06-2014 16:13:38.909|21-06-2014 16:13:49.157|HTTP_3MB.mp3|3000000|10|3131318|2445.6|64788|50.4|861523013558373|63902|Safaricom|false|8925402894100208664 3|639028940208664|2505|28922|HSPAP|GSM|0.0|0.0|0.0|0.0|0.0|null|false

21-06-2014 16:14:04.591|21-06-2014 16:14:17.224|HTTP_3MB.mp3|3000000|12|3110976|2025.33|58912|38|861523013558373|63902|Safaricom|false|89254028941002086643|639028940208664|2505|28922|HSPAP|GSM|0.0|0.0|0.0|0.0|0.0|null|false

Sample of the data collected for two web browsing time measurements which maps to the browse table illustrated in Figure 4.2 are:

28-06-2014 06:57:11.787|28-06-2014 06:57:12.290|http://fr-01.p3-mobile.net/kepler06/index.html|0.5|200|OK|861523013558373|63902|Safaricom|false|89254028941002086643|639028940208664|45025|54170|HSPAP|GSM|0.0|0.0|0.0|0.0|0.0|null|false

28-06-2014 06:57:12.291|28-06-2014 06:57:12.718|http://www.safaricom.co.ke|0.43|200|OK|861523013558373|63902|Safaricom|false|89254028941002086643|639028940208664|45025|54170|HSPAP|GSM|0.0|0.0|0.0|0.0|0.0|null|false

Sample of the data collected for two network latency measurements which maps to the latency table illustrated in Figure 4.2 are:

0|01-07-2014 10:13:22.195|176.31.225.88|false|1|353561057554648|63902|Safaricom|false|89254028941002086643|639028940208664|45019|45805|HSPA|GSM|0.0|0.0|0.0|0.0|0.0|null|false

1|01-07-2014 10:13:22.197|176.31.225.88|false|0|353561057554648|63902|Safaricom|false|89254028941002086643|639028940208664|45019|45805|HSPA|GSM|0.0|0.0|0.0|0.0|0.0|null|false

4.3.3.4 Smart FTP File Service

This service is responsible for transmitting data collected by the three services discussed in section 4.3.3.1, 4.3.3.2 and 4.3.3.2. It periodically connects to the hosting server and pushes the files to hosting location.

4.3.4 Backward Compatibility

QoEApp was developed for Android 4.2 (Jelly Bean MR1) API Level 17 which comes with new features for users and application developers. QoEApp can run on any flavor. Some of the Android flavors on market both earlier and later than what QoEApp was developed for are:

- Android alpha (1.0)
- Android beta (1.1)
- Cupcake (1.5)
- Doughnut (1.6)
- Eclair (2.0–2.1)
- Froyo (2.2–2.2.3)
- Gingerbread (2.3–2.3.7)
- Honeycomb (3.0–3.2.6)
- Ice Cream Sandwich (4.0–4.0.4)
- Jelly Bean (4.1–4.3.1)
- KitKat (4.4–4.4w)

Google provides library packages to allow backward compatibility. These packages were utilized to enable the application run on older versions of Android Operating System (OS)

4.3.5 Web Application

The final step was to develop interface to view data hosted on internet server. We used Perl and html to develop the website.

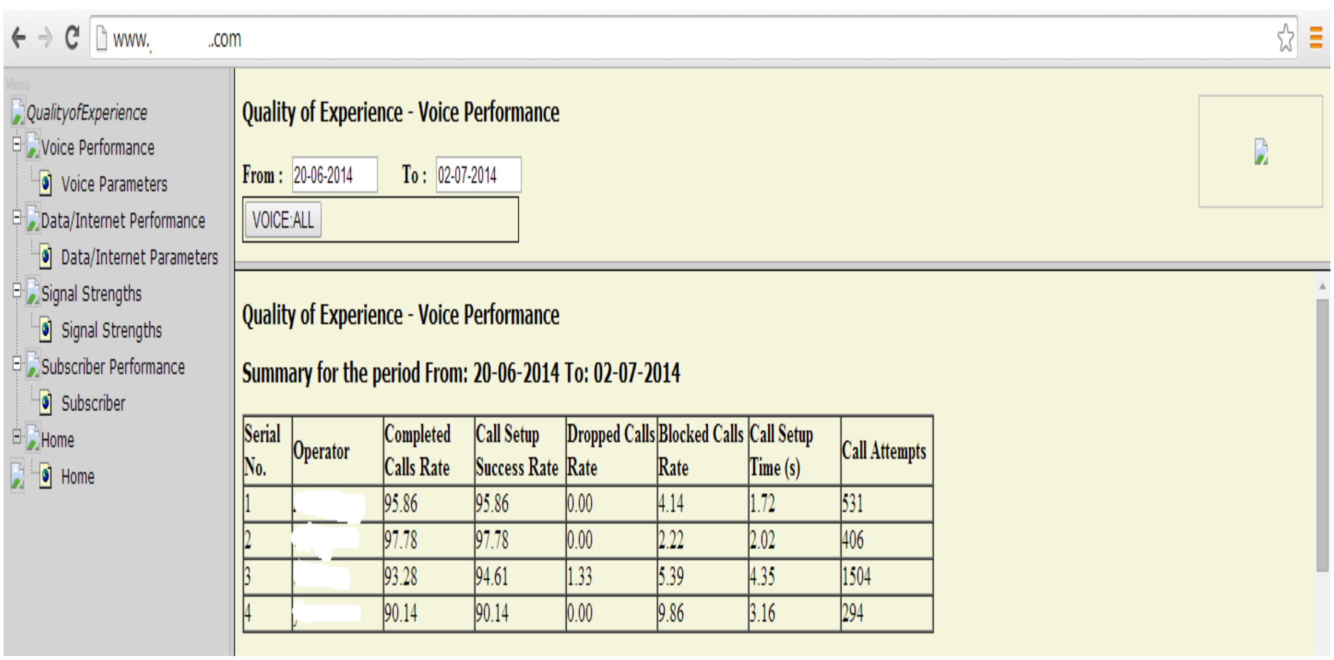


Figure 4.4: QoE Website – Voice Performance Page

The page that a user sees when seeing voice performance is as seen in Figure 4.4.

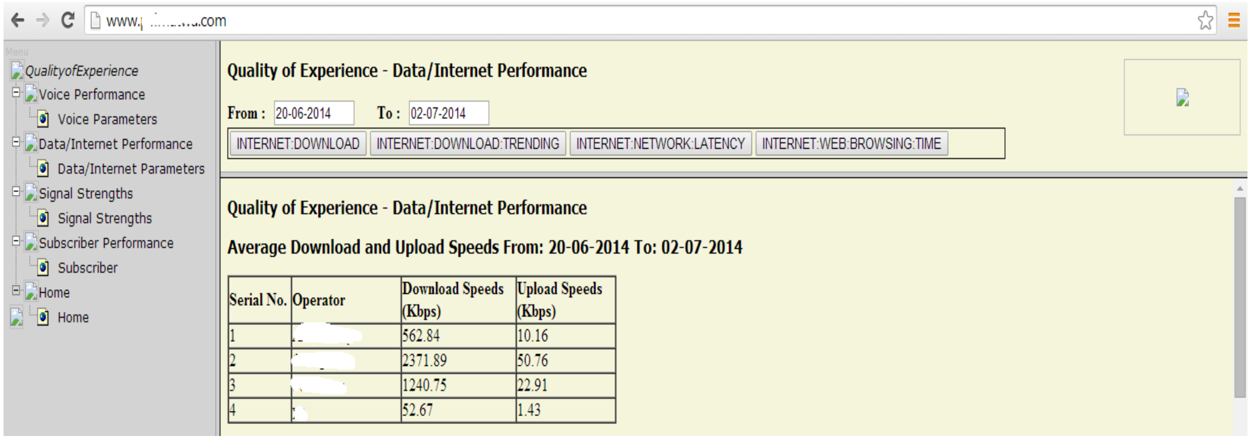


Figure 4.5: QoE Website – Data (Download Speeds) Page

The page that a user sees when seeing data/internet download speeds and upload speeds performance is as seen in Figure 4.5.

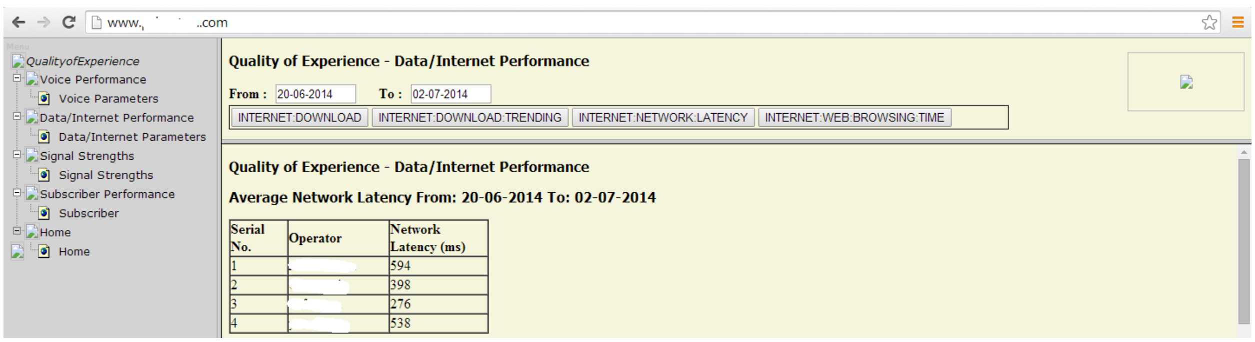


Figure 4.6: QoE Website – Data (Network Latency) Page

The page that a user sees when seeing data/internet network latency is as seen in Figure 4.6.

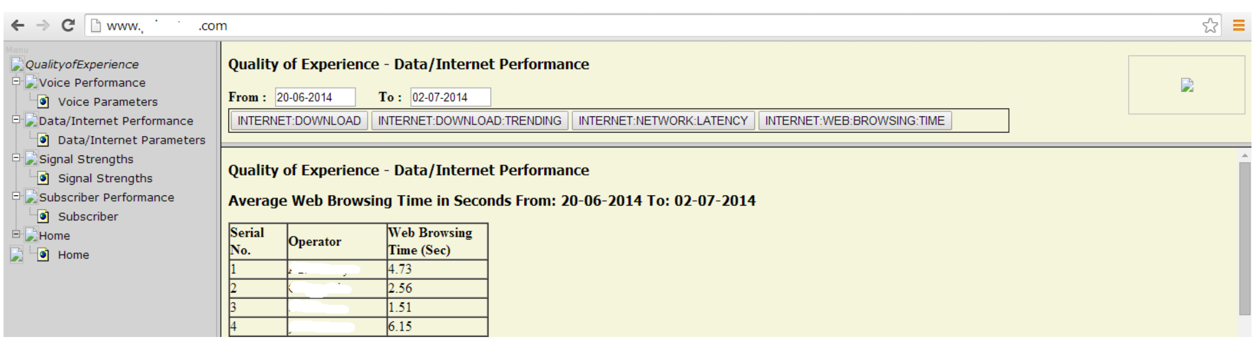


Figure 4.7: QoE Website – Data (Web Browsing Time) Page

The page that a user sees when seeing time it takes to browse web pages is as seen in Figure 4.7.

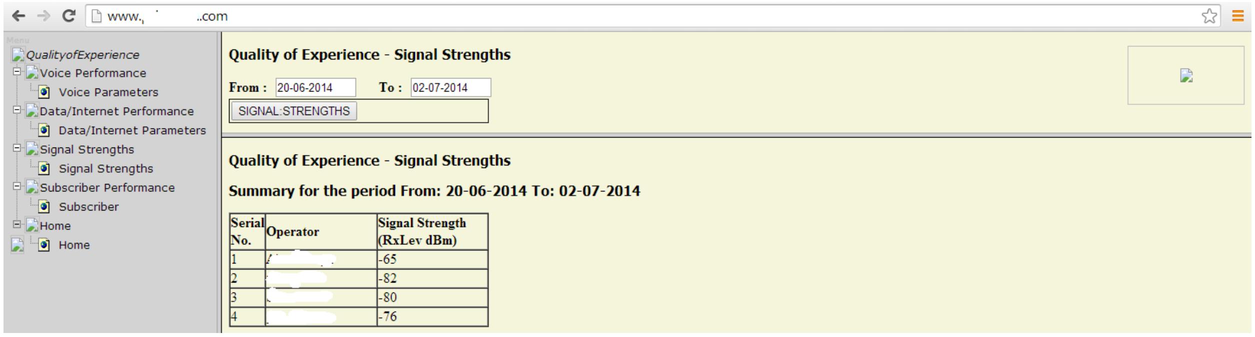


Figure 4.8: QoE Website – Signal Strengths Page

The page that a user sees when seeing receive levels of signal strengths of the phone is as seen in Figure 4.8.

4.4 Application Experimentation and Testing

4.4.1 Selection of the Data Collection Towns

Selection of towns to perform to collect data was based on size and population of people around that town. The four mobile network operators provide services across the whole country. For the purpose of this study performance was measured in selected towns namely Nairobi, Mombasa, Kisumu, Nakuru, Eldoret, Nyeri, Thika, Kitale and Machakos.

4.4.2 Data Collection Procedure

The data collection started with selection of towns, as stated in section 4.4.1, and QoEApp installation on smartphones running Android OS.

Data collection was conducted by drive testing, walk testing and stationary testing in cities and towns under study. Each city/town was done for a period of one day between 8am to 8pm from 20th June to 2nd July 2014.

Collected data is presented only when sample sizes were substantial such that accurate analysis and conclusions could be made. Significant effort was taken to ensure data collection for all four operators were done from the same locations, at the same time and using identical smartphones.

In excess of 3,178 voice measurements were captured during the data collection in nine towns summarized in table 4.1.

	Eldoret	Kisumu	Kitale	Machakos	Mombasa	Nairobi	Nakuru	Nyeri	Thika		Total
Operator 1	196	183	178	169	163	344	193	114	99		1,639
Operator 2	64	95	86	33	135	31	91	20	30		585
Operator 3	51	38	24	70	70	68	51	28	37		437
Operator 4	64	64	79	15	60	44	65	75	51		517
Total	375	380	367	287	428	487	400	237	217		3,178

Table 4.1: Voice Performance Collected Data

In excess of 682 internet measurements were captured during the data collection in nine towns as indicated in table 4.2.

	Eldoret	Kisumu	Kitale	Machakos	Mombasa	Nairobi	Nakuru	Nyeri	Thika		Total
Operator 1	24	34	18	32	28	61	10	21	17		245
Operator 2	15	13	13	6	5	7	9	6	2		76
Operator 3	51	22	3	20	26	25	49	19	28		243
Operator 4	18	15	9	15	14	6	16	20	5		118
Total	108	84	43	73	73	99	84	66	52		682

Table 4.2: Data Performance Collected Data

Online monitoring was done from the start of the data collection period until the end as the results were being received.

4.5 Summary of Implementation

In this chapter we have discussed the development process that was used to develop QoEApp smartphone application. Various tools used to prototype the application were also discussed. This prototype was used for usability which is discussed in the next chapter.

QoEApp architecture relies on background services for data collection, internet connection for transmitting collected data to hosting server and webpages for results viewing. Functionality tests, collection of data and transmitting of data are the three main tasks performed by background services.

QoEApp development is not completed and the missing features are discussed in future recommendations section. Backward compatibility with older versions of Android OS was also taken into consideration.

Finally, this model application provides a solution that can be used to measure customer quality of experience as they use services offered by mobile network operators.

Chapter Five: Results

5.1 Introduction

Data collection using QoEApp is one of the most important steps in improving the app. It serves to validate developed features to identify any problems that may require addressing.

The application was used in several parts of the country to collect data to verify its feasibility and provide more representative data for analysis.

In this chapter we are discussing the results obtained.

5.2 Results

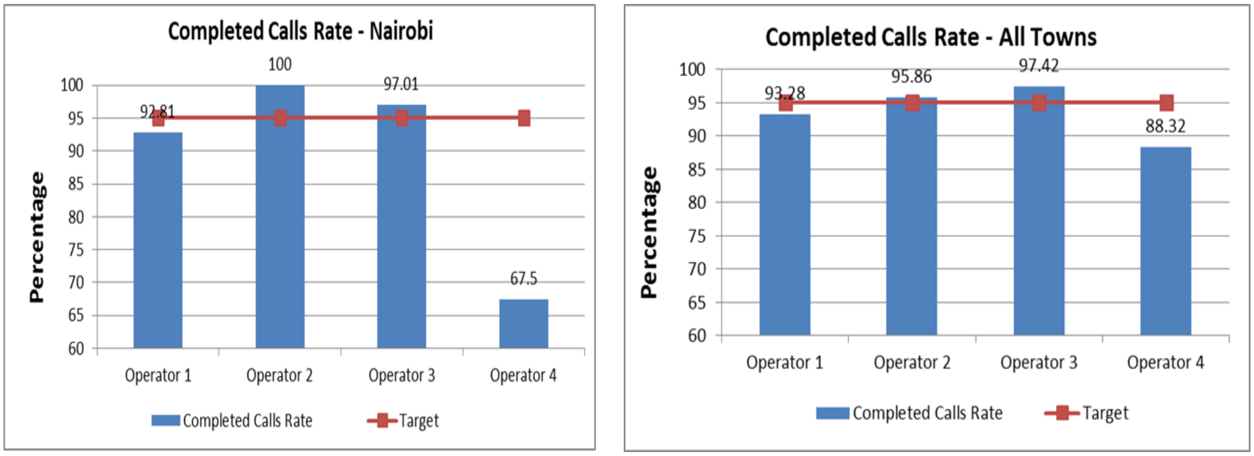
The results of the study were stored in the hosting server and analysis performed on the same data. We proceed to discuss performance of each operator in voice, data/internet and received signal strengths.

5.2.1 Voice Performance Results

We will discuss the results of the five parameters measured for the voice service i.e. Completed Calls rate, Call Setup Success Rate, Dropped Calls Rate, Blocked Calls Rate and Call Setup Time.

5.2.1.1 Completed Calls Rate

This parameter measures the number of calls that are completed/connected on a network satisfactorily compared to the total number of call attempts made by callers (percentage of call attempts that are successfully placed on the network and retained for the full defined call duration). Fig. 5.1 provides results of data collected.



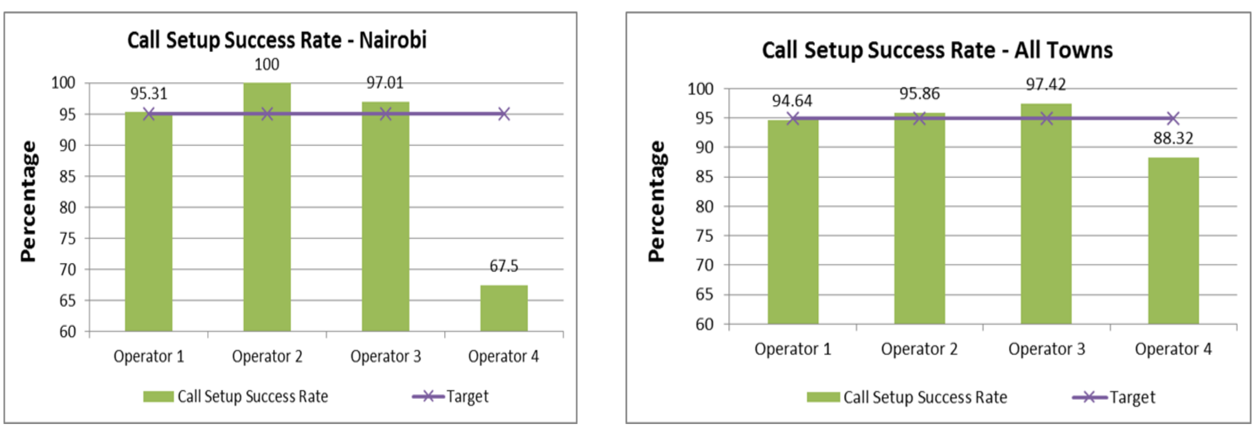
A B

Figure 5.1: Completed Calls Rate (A) Nairobi (B) All Towns

The requirement from CAK for completed calls is such that operators should ensure that at least 95% of all calls are completed. Two out of four operators met the threshold for completed calls rate in Nairobi and the same applied with all towns combined. Operator four completed calls rate was worse in Nairobi compared to other towns. This means customers using operator two and three have more calls being completed satisfactory.

5.2.1.2 Call Setup Success Rate

This parameter measures the number of times a consumer tries to make a call that results in a connection to the dialed number (percentage of calls that are successfully placed on the network divided by the total number of call attempts). It is considered one of the most important KPIs because it reflects the consumer's Quality of Experience (QoE) when making a call. Fig. 5.2 provides results of data collected – Nairobi and All towns combined.



A B

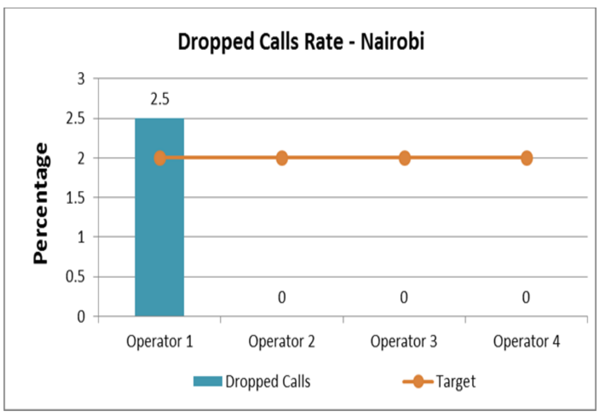
Figure 5.2: Call Setup Success Rate (A) Nairobi (B) All Towns

The threshold for this parameter is 95% as per CAK requirements.

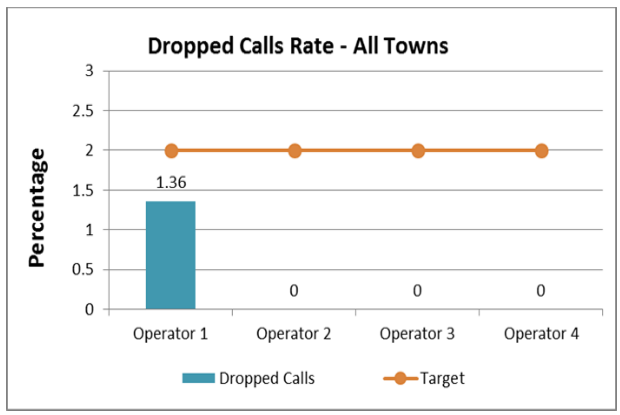
Three out of four operators met the 95% threshold in Nairobi whereas only two met in all towns combined. From the data Operator one seems to have a slightly better Quality of Experience in Nairobi than other towns whereas Operator four have better QoE in other towns than Nairobi. This means customers on operator four try many times to get connection on the network than customers on other operators.

5.2.1.3 Dropped Calls Rate

This parameter measures calls that are terminated by the network unexpectedly as a result of technical reasons including entry into a dead zone (percentage of calls that are disconnected prior to the completion of the full defined call duration, divided by the number of call attempts that are successfully placed on the network). Call drops may be as a result of poor handoff or lack of network coverage. Fig. 5.3 provides results of data collected – Nairobi and All towns combined.



A



B

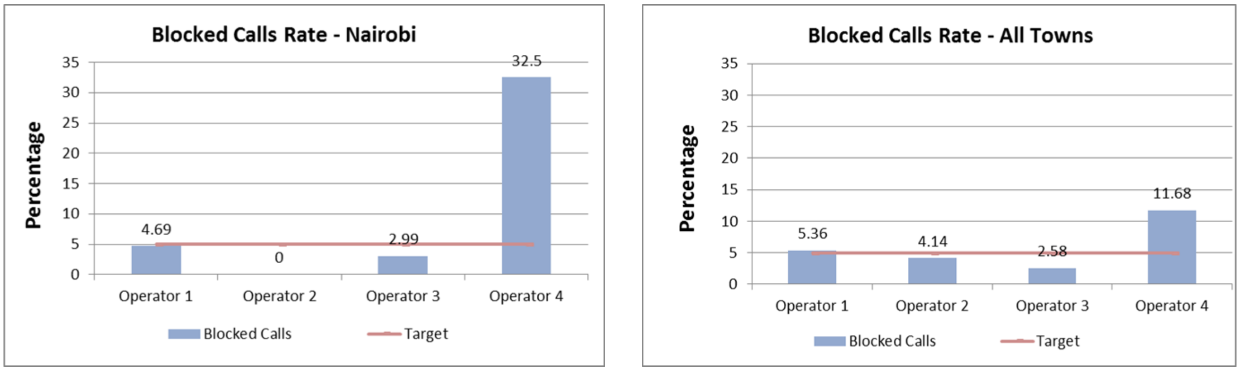
Figure 5.3: Dropped Calls Rate (A) Nairobi (B) All Towns

The requirement for dropped calls from CAK is such that operators should ensure that at not more than 2% of all calls are dropped.

Three out of the four mobile operators met the less than 2% requirement in Nairobi whereas all met the less than 2% in all towns combined. Operator one has more calls dropping before completion in Nairobi than all towns combined. This means customers on operator one have more calls being dropped than customers on other operators.

5.2.1.4 Blocked Calls Rate

This parameter measures calls that are unsuccessful because of lack of resources for connection due to congestion expressed as a percentage of total call attempts. Fig. 5.4 provides results of data collected – Nairobi and All towns combined.



A B

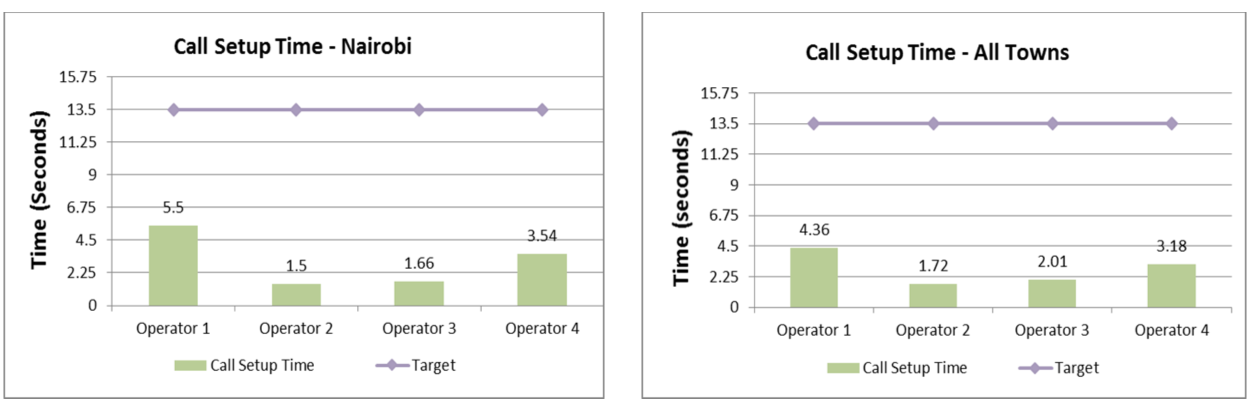
Figure 5.4: Blocked Calls Rate (A) Nairobi (B) All Towns

The requirement for blocked calls from CAK is such that operators should ensure that at not more than 5% of all calls are blocked.

Three out of four operators met the threshold in Nairobi whereas only two met in all towns combined. Operator four has a very high number of calls being blocked in Nairobi. This means customers using operator four have more calls being blocked due to resources constraint than other customers using other operators.

5.2.1.5 Call Setup Time

The call setup time is the time from when send/call button is pressed or when the address information required for setting up a call is received by the network to when the called party busy tone or ringing tone or answer signal is received by the calling party. Fig. 5.5 provides results of data collected – Nairobi and All towns combined.



A B

Figure 5.5: Call Setup Time (A) Nairobi (B) All Towns

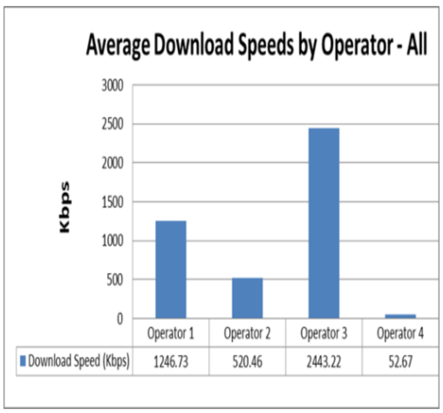
Threshold for this parameter from CAK is 13.5 seconds.

All the operators met the target for this parameter in all towns under study. This means all customers in all operators enjoy almost same quality of experience as pertaining time it takes from when a call button is pressed to when the ringing tone is heard on called party.

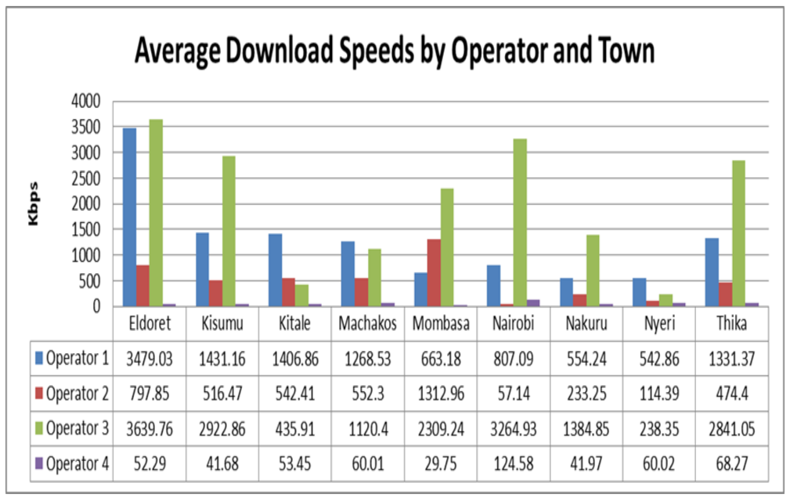
5.2.2 Data/Internet Performance Results

5.2.2.1 Download Speeds

Download speed is the rate of data transmission from a network operator's access node to a customer, typically measured in Megabits per second (Mbps). Higher bandwidth applications, such as video and audio applications, benefit significantly from faster throughput speeds (Fixed Line Broadband Performance (ADSL) in New Zealand. April – June 2013). Fig. 5.6 provides results of data collected.



A



B

Figure 5.6: Average Download Speeds (A) All Towns (B) By Operator and Town

During the data collection conducted in this study, download speed was measured using QoEApp by downloading a file from European Telecommunications Standards Institute (ETSI) server.

The average download speeds recorded for each operator are shown in Figure 5.6. Operator three delivered the fastest download speeds with an average of 2,443.22Kbps, which was 96% faster than the average measured for Operator two, and 369% faster than Operator three. Operator three consistently had faster download speeds in all towns under study apart from Kitale, Machakos and Nyeri where Operator One had the fastest speeds.

Summary of results of download speeds

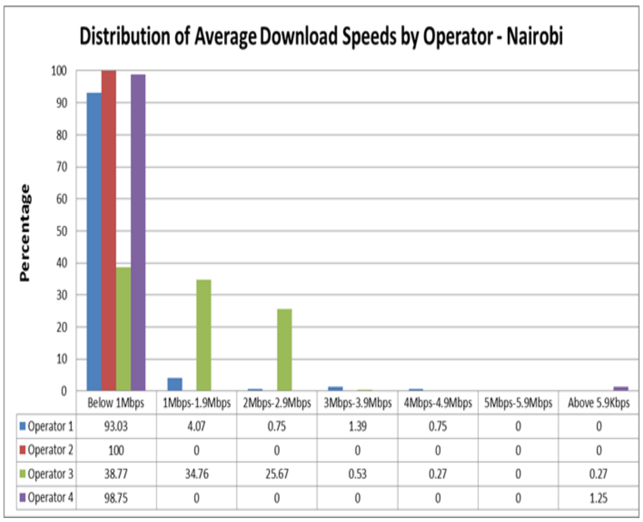
	Is slower than …..	Is faster than …..
Operator 1	Operator 3	Operator 2 and 4
Operator 2	Operator 1 and 3	Operator 4
Operator 3		Operator 1, 2 and 3
Operator 4	Operator 1, 2 and 3	

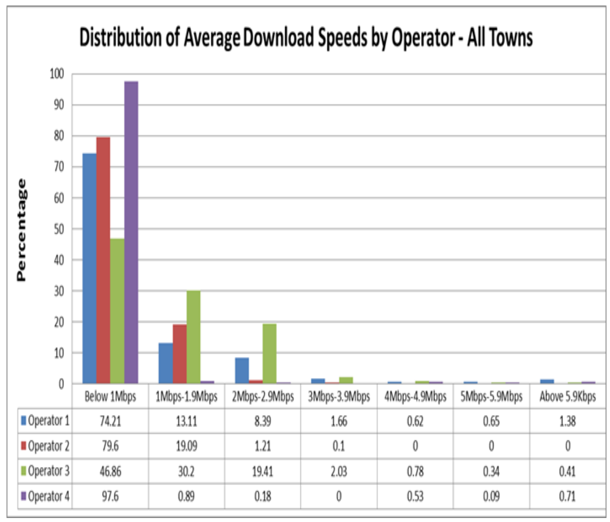
Figure 5.7: Comparison of Operators Download Performance

Our data also found that there were significant differences in the average speeds delivered by operators. Operator One and Operator three were on average faster than Operator two and four, while Operator four was significantly slower than all the other operators. Speed is an important parameter as it is an indication of the waiting times consumers experience when performing tasks such as downloading files and web browsing.

Download Speeds - Distribution

Fig. 5.8 provides distribution of download speeds.





A B

Figure 5.8: Distribution of Average Download Speeds (A) Nairobi (B) All Towns

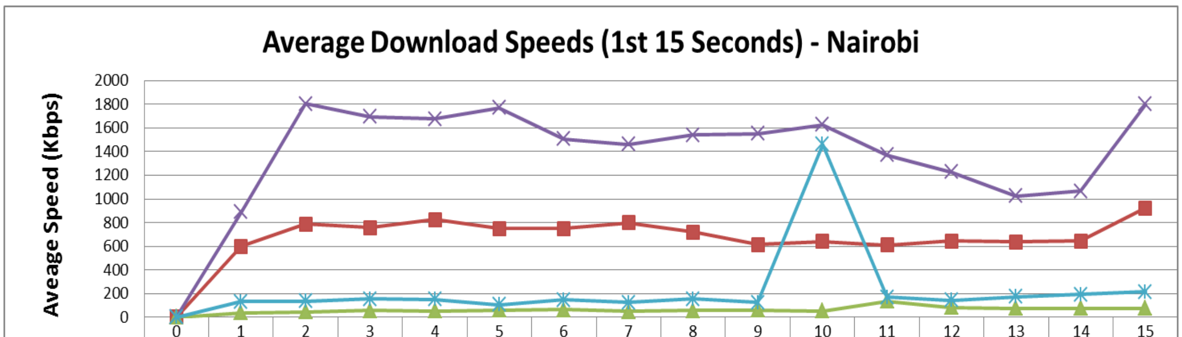
Figure 5.8 shows the distribution of average download speeds observed during the period under study. Overall, in three operators, over 90% of the recorded download speeds were slower than 1Mbps and in one operator less than 50% of the measurements were lower than One Mbps. One Operator recorded over 25% over 2Mbps in Nairobi. When considering the distribution of speeds for individual operators, all four operators were measured with the majority of their download speeds between 0 and 1Mbps in Nairobi and between 0 and 3Mbps in all towns combined.

Across all towns 74.21% of speeds on Operator one, 79.6% of Speeds on Operator two, 46.86% of Speeds on Operator three, and 97.6% of speeds on Operator four were within 0 and 1Mbps. Downloads speeds of more than 5.9Mbps were measured on only three out of four operators.

Over 50% of the recorded download speeds were more than 1Mbps across all towns for Operator One and almost 100% less than 1Mbps for Operator four. The fastest download speed recorded during the data collection was 5.97 Mbps on Operator One in Eldoret

Average Download Speeds

Distribution chart fig. 5.9 indicates the experience of a user over the first 15 seconds of downloading a file.



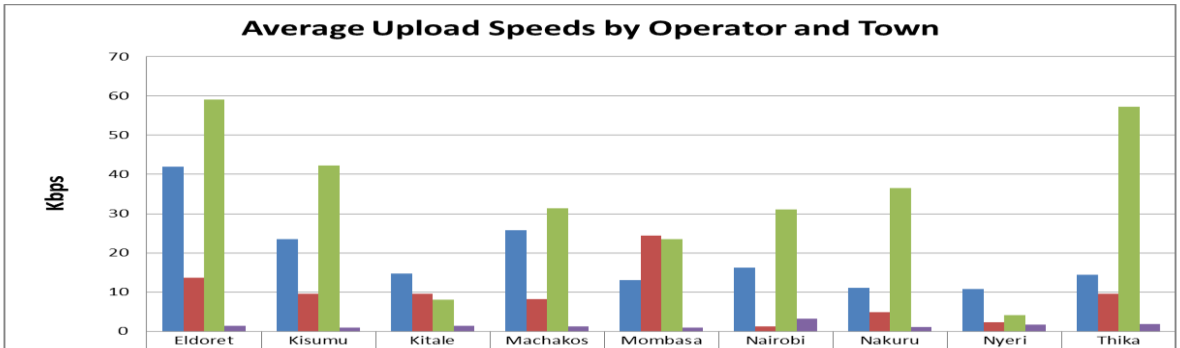
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Operator 1	0	600.68	788.53	756.19	824.28	748.61	749.13	797.56	718.29	612.62	640.03	611.59	642.38	637.64	643.89	923.84
Operator 2	0	37.54	46.32	55.51	53.61	60.85	63.37	49.28	56.16	59.61	51.65	133.5	84.31	75.41	75.41	75.41
Operator 3	0	888.66	1803.84	1695.66	1677.54	1770.37	1506.1	1461.02	1540.2	1553.04	1628.26	1373.14	1228.87	1026.47	1065.31	1802.64
Operator 4	0	131.76	134.15	155.57	150.06	106.61	147.87	125.33	153.17	123.59	1460.65	170.35	141.23	171.35	190.28	213.33

Figure 5.9: Average Download Speeds in 1st 15 Seconds – Nairobi

Operator three on average a user experienced consistently speeds over 1.2 Mbps from 2nd second to 15th second. User on Operator One also experienced consistently around 0.8 Mbps whereas Operator two and four measurements below 0.2 Mbps all the time.

5.2.2.2 Upload Speeds

Upload speeds is the rate of data transmission from a customer device to a network operator's access node, typically measured in Megabits per second (Mbps). Fig. 5.10 provides results of data collected



	Eldoret	Kisumu	Kitale	Machakos	Mombasa	Nairobi	Nakuru	Nyeri	Thika
Operator 1	42.02	23.52	14.69	25.77	13.05	16.24	11.04	10.77	14.42
Operator 2	13.69	9.64	9.59	8.2	24.43	1.3	4.92	2.28	9.6
Operator 3	59.06	42.31	8.13	31.4	23.48	31.12	36.58	4.08	57.28
Operator 4	1.36	1.03	1.39	1.2	0.93	3.3	1.09	1.77	1.81

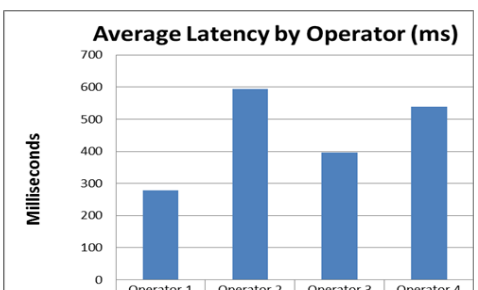
Figure 5.10: Average Upload Speeds by Operator and Town

During the data collection conducted in this study, upload speed was measured using QoEApp to upload a file to European Telecommunications Standards Institute (ETSI) server.

From figure 5.10, the average upload speed measured across all four operators was 28 Kbps. The average upstream performance on Operator One and Operator three was over 60% faster than the services from Operator two and Operator four. Analysis of upload speeds by operator and town showed that upload performance in Kitale and Nyeri was slightly down. Operator four delivered the slowest upload speeds.

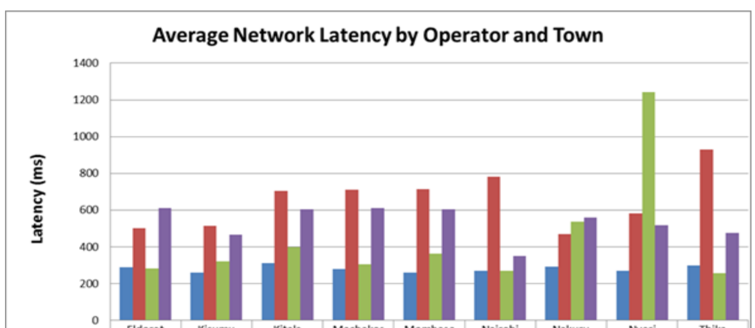
5.2.2.3 Network Latency

Network Latency is the time it takes a single packet of data to travel from a user's device to a third-party server and back again. Most commonly measured in milliseconds (Fixed Line Broadband Performance (ADSL) in New Zealand. April – June 2013). Results of Data Collected



	Operator 1	Operator 2	Operator 3	Operator 4
Latency (ms)	278	594	397	538

A



	Eldoret	Kisumu	Kitale	Machakos	Mombasa	Nairobi	Nakuru	Nyeri	Thika
Operator 1	288	259	310	278	259	268	293	268	298
Operator 2	500	513	704	709	714	782	470	583	931
Operator 3	282	321	399	304	364	268	536	1243	257
Operator 4	610	466	604	610	603	350	558	516	474

B

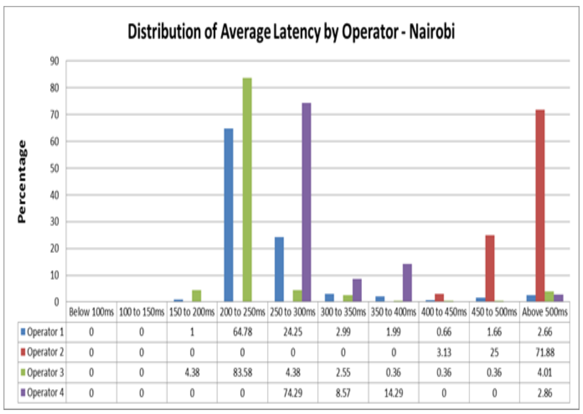
Figure 5.11: Average Latency (A) All Towns (B) By Operator and Town

During the data collection conducted in this study, network latency was measured using QoEApp to measure latencies to European Telecommunications Standards Institute (ETSI) server.

The latency measures in this analysis are network round-trip times, and indicate the time for data to be transmitted from the phone to ETSI server and back again. Low latency is critical for an acceptable quality of experience by users of such applications as voice and gaming.

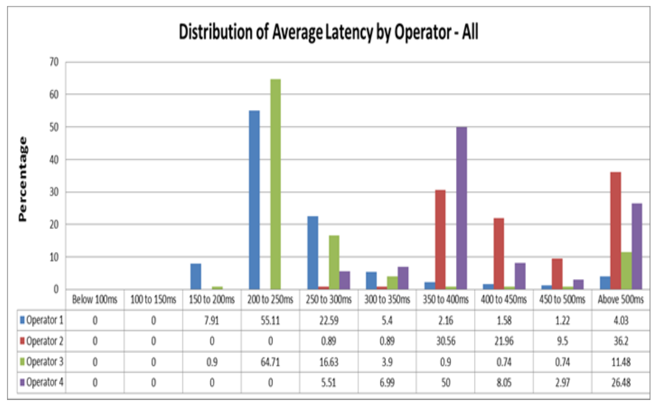
The average network latency measured across all operators was 451ms. The lowest network latency was observed on Operator One with average of 278ms. Operator One had lowest latency across all towns under study.

Network Latency - Distribution



	Below 100ms	100 to 150ms	150 to 200ms	200 to 250ms	250 to 300ms	300 to 350ms	350 to 400ms	400 to 450ms	450 to 500ms	Above 500ms
Operator 1	0	0	1	64.78	24.25	2.99	1.99	0.66	1.66	2.66
Operator 2	0	0	0	0	0	0	0	3.13	25	71.88
Operator 3	0	0	4.38	83.58	4.38	2.55	0.36	0.36	0.36	4.01
Operator 4	0	0	0	0	74.29	8.57	14.29	0	0	2.86

A



	Below 100ms	100 to 150ms	150 to 200ms	200 to 250ms	250 to 300ms	300 to 350ms	350 to 400ms	400 to 450ms	450 to 500ms	Above 500ms
Operator 1	0	0	7.91	55.11	22.59	5.4	2.16	1.58	1.22	4.03
Operator 2	0	0	0	0	0.89	0.89	30.56	21.96	9.5	36.2
Operator 3	0	0	0.9	64.71	16.63	3.9	0.9	0.74	0.74	11.48
Operator 4	0	0	0	0	5.51	6.99	50	8.05	2.97	26.48

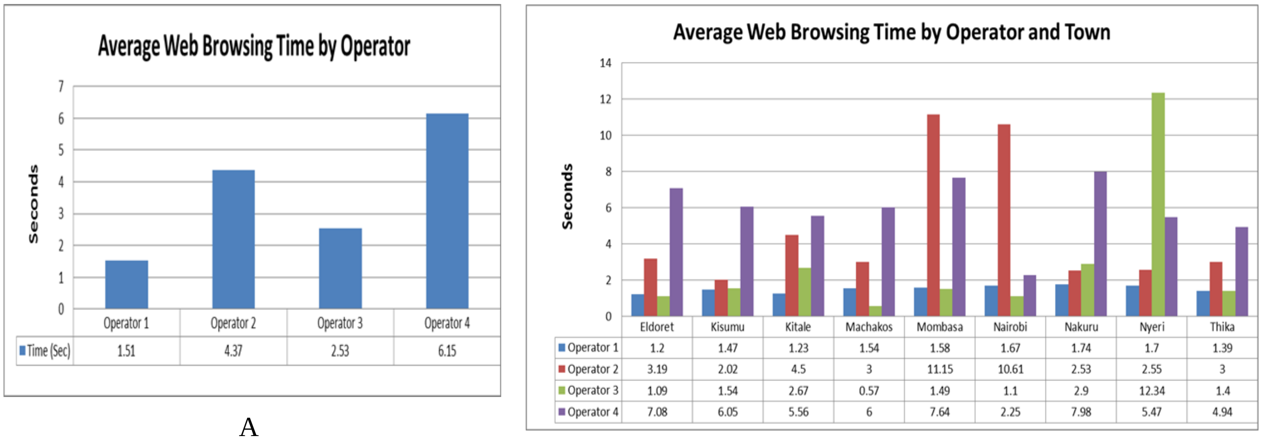
B

Figure 5.12: Distribution of Average Latency (A) Nairobi (B) All Towns

The distribution of average latency as shown in figure 5.12 shows that the latency for Operator One and three is consistently lower than 250ms with 65.78% and 87.96% respectively of measurements recorded below 250ms. Operator two recorded very high latency in Nairobi with 71.88% of measurements recorded above 500ms. No operator had latency less than 150ms across all towns under study.

5.2.2.4 Web Browsing Time

Web Browsing Time parameter is the time it takes to locate and download a web page within a web browser application. Fig. 5.13 provides results of data collected.



A

B

Figure 5.13: Average Web Browsing Time (A) All Towns (B) By Towns

During the data collection conducted in this study, web browsing time was measured using QoEApp to access a URL pointing to European Telecommunications Standards Institute (ETSI) server.

During this study, access to the web was done for all four operators, by measuring the speed of access and time to download HTML page. The analysis in this report looks at the average time taken to download the HTML content of the website.

The results show that the average time to download a web page was 1.51 seconds for Operator One being the fastest while the slowest was Operator four with 6.15seconds. Operator three recorded the fastest time of 0.57seconds in Machakos and slowest in Nyeri with 12.34seconds. Operator One recorded consistent speeds across all towns under study.

Web Browsing - Distribution

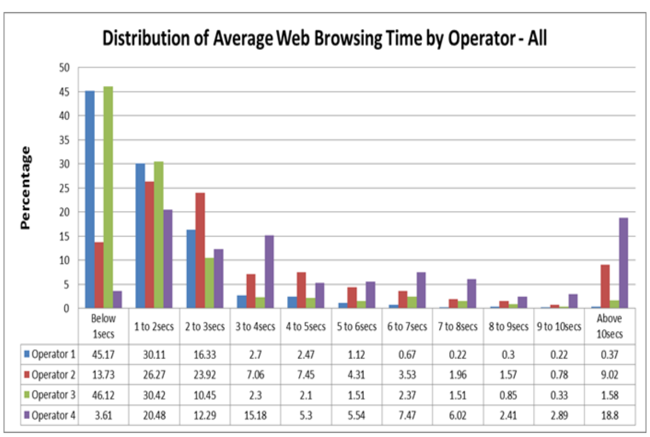


Figure 5.14: Distribution of Average Web Browsing Time All Towns

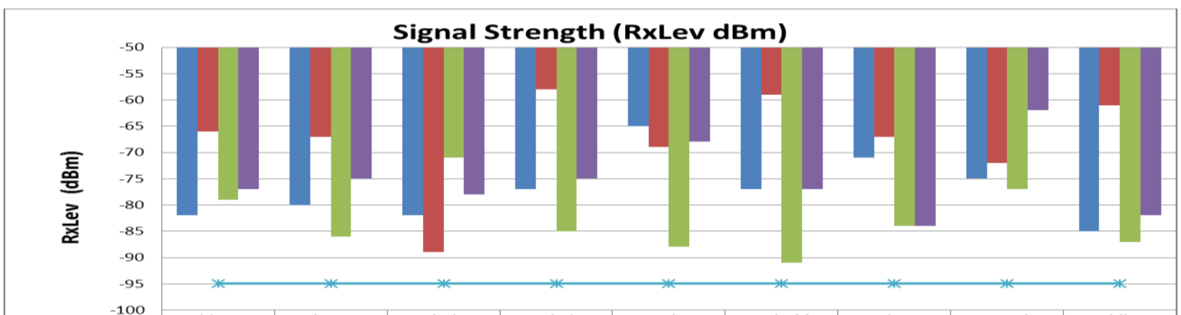
The distribution of web page download times is as shown fig. 5.14. Operator one and three took less than two seconds in over 70% of the measurements.

In Nairobi, Operator three and four web browsing time was less than seven seconds in all measurements conducted. Operator two had more than 30% of the measurements above 10 seconds in Nairobi being the worst performance.

There were some marked differences in the consistency of web page download times between operators. On around 75% of occasions the web page was downloaded in less than two seconds on Operator one and three; in contrast, fewer than 25% of web pages were downloaded in less than two seconds on Operator four. Around 18% of Operator four web page downloads took longer than 10 seconds, while almost all successful web page downloads on Operator one were completed in less than six seconds

5.2.3 Received Signal Strengths Results

The Rx level is the power in decibels (dBm) of the received signal. The target for this parameter is -95dBm. If the Rx level (or signal strength) is too high i.e. -95dBm, signal distortion may occur, leading to erratic connections. Signal strength is measured in "-dBm" where the larger the negative number the weaker the signal. Generally, a very strong signal is approximately -40dBm down to -75dBm. A weak signal is -95dBm or lower. Results of Data Collected



	Eldoret	Kisumu	Kitale	Machakos	Mombasa	Nairobi	Nakuru	Nyeri	Thika
Operator 1	-82	-80	-82	-77	-65	-77	-71	-75	-85
Operator 2	-66	-67	-89	-58	-69	-59	-67	-72	-61
Operator 3	-79	-86	-71	-85	-88	-91	-84	-77	-87
Operator 4	-77	-75	-78	-75	-68	-77	-84	-62	-82
Target	-95	-95	-95	-95	-95	-95	-95	-95	-95

Figure 5.15: Average Signal Strengths by Operator and Town

All the operators met the target in all towns.

Methodology used ensured that data collection for all operators was done at the same location and same time. It was however not possible to ensure that network conditions for each operator to be identical: signal levels varied in accordance with different network deployments in the different data collection locations.

5.3 Summary of Results

Data collection and validation is an important step in application development that many developers ignore. It reduces chances of releasing application with errors to the public. We were able to improve the quality of QoEApp application by testing and validation of implemented features which resulted in a more robust app. Functional test provided the steps necessary to validate all implemented features. Data collection was successfully completed without any problems. Huge amount of data was collected in all the nine towns under study and transmitted online to the hosting server. The results were able to differentiate the services offered by the various mobile network operators.

Chapter Six: Discussions

6.1 Introduction

This chapter discusses research on benchmarking of quality of experience (QoE) of mobile network operators in Kenya. It also provides limitations encountered during the research and also gives recommendations for future research work.

We achieved objectives of the study in the following ways:

6.2 Parameters for measuring quality of experience offered by mobile network operators

The following parameters were found to affect the quality of experience of services offered by mobile network operators:

In voice calls we found completed calls rate, call setup success rate, dropped calls rate, blocked calls rate and call setup time. In data/internet we found download speed, upload speed, network latency and web browsing time. Signal strengths affected both voices calls and internet performance.

6.3 Application to be used to measure quality of experience of customers using services of mobile network operators in Kenya.

An android application was developed that was used to measure quality of experience. We named the application QoEApp which was later used for data collection.

6.4 Compare performance of mobile network operators in Kenya in the provision of voice services against what the regulator expects.

Completed Calls Rate: The study suggests that customers using operator two and three have over 95% of their calls being completed or connected to the network and retained for the full defined call duration. Operator one and four had 93.28% and 88.32% which is considered by CAK as not meeting the target of completed calls rate. We can say customers using Operator two and three may have a better quality of experience in terms of calls taking the full call duration.

Call Setup Success Rate: The study suggests that only customers using operator two and three have over 95% of calls successfully being placed or connected on the network. Operators one and four have 94.64% and 88.32% below 95% target set by CAK. Therefore customers using services of operator one and two have a better QoE in terms of the percentage of calls that result in a connection to the dialed number. Results also suggest customers using operator four try many times calling in order to get connected to the network.

Dropped Calls Rate: The study suggests that customers using operator two, three and four do not drop any calls once connected to the network for the entire call duration. Customers using operator one have 1.36% of calls being dropped before ending their conversation. Results therefore suggest operator two, three and four provides better QoE than operator four.

Blocked Calls Rate: Operator two and three have less than 5% of calls being blocked because of lack of network resources for connection due to congestion. Operators one and four have 5.36% and 11.68% respectively. Results therefore suggest customers using operator four have more calls being blocked from accessing the network.

Call Setup Time: The study suggests that customers in all operators experience less than 13.5seconds as time it takes from when the call button is pressed to the time when the called party busy tone or ringing tone is received by the calling party. Therefore it means all customers in all operators have almost same experience in terms of call setup time.

In summary the study suggested that many operators are not meeting all voice parameters set by the regulator. Out of the five parameters under study operator one met two parameters, operator two met all parameters, operator three met all parameters and operator four met two parameters according to the targets set by CAK. Therefore the study suggests better quality of experience for customers using operator two and three.

6.5 Compare performance of mobile network operators in Kenya in the provision of data/internet services using the application developed.

Download Speeds: The results suggest operator three having a better quality of experience with average download speeds of 2,443.22Kbps while operator one, two and four had 1,246.73Kbps, 520.46Kbps and 52.67Kbps respectively. The speeds of operator three were 96% faster than the second fasters download speed. Distribution of download speeds per operator indicated most operators' download speeds being below 1Mbps at 74.21% for operator one, 79.6% for operator two, 46.86% for operator three and 97.6% for operator four. Therefore the results suggest customers using operator three more than half the time the experience download speeds of more than 1Mbps while customers using operator four experiences almost all the time download speeds of less than 1Mbps. Results suggest that users downloading movies, files, emails or documents may have a better quality of experience when using operator three.

Upload Speeds: The results suggest operator one, two and three having almost the same upload speeds. Operator four delivered the slowest upload speeds. Therefore the results suggest that if you are only sending email or uploading files to internet quality of experience may be the same for operator one, two and three.

Network Latency: The results suggest customers using operator one have network latency of 278ms and operator three 397ms. Operator two and three had more than 500ms. Distribution of network latency for operator one and three is consistently lower than 250ms with 65.78% and 87.96% recorded measurements being below 250ms respectively. Operator two had 71.88% of recorded measurements being above 500ms. No operator had any recorded network latency less than 150ms across all towns under study.

Web Browsing Time: The results suggests customers using operator one having better quality of experience in terms of the time it takes to locate and download a web page within a browser application. On average it took 1.51seconds for operator one and 2.53seconds for operator three. Operator two and four had 4.37seconds and 6.15seconds respectively. Distribution of web browsing time indicate more than 75% of the time it took less than two seconds to browse a page using operator one and three while for the other operators it was 25%.

Results suggest network latency is not only the limiting factor in download speeds (i.e. throughputs) and upload speeds as operator one has better network latency of 278ms against download speeds of 1,246.73Kbs and operator three has network latency of 397ms but with better download speeds of 2,443.22Kbps .

If mobile network operators are to ensure that consumers start using more and more interactive applications and cloud computing that require faster internet connection they need to invest in improving their network to provide high speeds.

6.6 Compare Signal Strengths of mobile network operators in Kenya using the developed application.

Results suggests all operator have better and almost same signal strengths in all towns under study

All operators met target set by CAK on Signal strengths. Results also suggest signal strength is not only the determining factor to have a better quality of experience since all operators met the target and have almost same Rx level of signal yet the performance in voice and data/internet performance differed greatly.

6.7 Limitations

It was not possible to measure experience of customers using smartphones running operating system other than Android and basic feature phones.

Smartphone battery life was a limitation as the application drained its power within a short period.

Chapter Seven: Conclusions and Recommendations

7.1 Study Achievements

We have presented results of the study of quality of experience of mobile network operators in Kenya. Our results suggest the following: One, smartphone application can be used to measure quality of experience of services offered by mobile network operators in Kenya; Two, across all towns operator three had higher percentage of calls that are successfully placed on the network and retained for the full defined call duration, Operator one had higher percentage of calls that are disconnected prior to the completion of the full defined call duration, Operator four had higher percentage of calls that are unsuccessful because of lack of resources for connection due to congestion while Operator one had longer time from when send/call button is pressed to when the called party busy tone or ringing tone or answer signal is received by the calling party. Three, all operators had on average very good signal strength meeting conditions set by the regulator. It therefore means signal strength is not the only factor determining the quality of experience. Four, across all towns operator three had high download speeds compared to other operators; Operator one had good network latency and web browsing time.

From the above we can imply the following: One, signal strength is not the only limiting factor to achieving better quality of experience. Two, network latency is not the only limiting factor to achieving better download speeds (throughput).

We recommend that the regulator not only check if mobile network operators meet key performance indicators related to voice but also those related to data (internet). We also recommend use of smartphone application to be used by consumers to measure if the operator is providing them the kind of service they promised.

The new emerging concept of Smartphone application is growing and many believe this is a new era as computer capabilities are moved to smartphones with high processing power.

Two recommendations we can make are: One, measurement of mobile network operators in Kenya is beneficial to consumers, regulators and operators. Second, continuous measurement across the country for all services is essential.

7.2 Recommendations for further work

Develop application to run on other smartphones operating system apart from Android, Make use of crowdsourcing to collect data from various places i.e. could speed up data collection and increase credibility of the results at the same time cover the whole country, make the smartphone application to be battery efficient and research on factors limiting good quality of experience of services offered by mobile network operators apart from signal strength and network latency.

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Appendices I: Source Code for Signal Strengths

```
public class MainActivity extends Activity {

	TelephonyManager        Tel;
	MyPhoneStateListener    MyListener;

    SimpleDateFormat sdf = new SimpleDateFormat("dd-MM-yyyy HH:mm:ss.SSS");
    SimpleDateFormat sdf2 = new SimpleDateFormat("ddMMyyyy");

    String servingCellSignal;
    String DateandTime;
    String imsi;
    String current_ext2 = sdf2.format(new Date());
    String cellsNeigboursFilename;
    String logcatFilename = "logcat_raw"+current_ext2+".txt";
    double latitude;
    double longitude;

    String DateandTime1 = sdf.format(new Date());
    String outgoingSavedNumber;
    String incomingSavedNumber;

	@Override
	protected void onCreate(Bundle savedInstanceState) {
		super.onCreate(savedInstanceState);
		setContentView(R.layout.activity_main);

		MyListener   = new MyPhoneStateListener();
	  Tel       = ( TelephonyManager )getSystemService(Context.TELEPHONY_SERVICE);

	  Tel.listen(MyListener ,PhoneStateListener.LISTEN_SIGNAL_STRENGTHS);

	TelephonyManager tm1 = (TelephonyManager)
	getSystemService(Context.TELEPHONY_SERVICE);
	imsi = tm1.getSubscriberId();

	  cellsNeigboursFilename =
"qoe_cells_neighbors_raw_"+imsi+"_"+current_ext2+".txt";

	}

	protected void getNeighbors() {

	  ConnectivityManager cm =
(ConnectivityManager)getSystemService(Context.CONNECTIVITY_SERVICE);
	  NetworkInfo activenetworkinfo = cm.getActiveNetworkInfo();
	  String failover = ConnectivityManager.EXTRA_IS_FAILOVER;

		try {

		File issueReport = new File(Environment.getExternalStorageDirectory(),
"QualityOfExperience");
		if (! issueReport.exists()) issueReport.mkdir();
```

```
                File cellsNeigboursFile = new File(issueReport,cellsNeigboursFilename);

                FileOutputStream fos2 = new FileOutputStream (cellsNeigboursFile, true);

                String stringNeighboring;

                TelephonyManager tm =
(TelephonyManager)getSystemService(Context.TELEPHONY_SERVICE);
                GsmCellLocation cellLocation = (GsmCellLocation) tm.getCellLocation();

                String networkOperator = tm.getNetworkOperator();
                String networkOperatorName = tm.getNetworkOperatorName();

                String mcc = networkOperator.substring(0, 3);
                String mnc = networkOperator.substring(3);

                getGpsLocation();

                stringNeighboring = DateandTime1 + "|" + DateandTime + "|" + mcc + "|" +
mnc + "|" + networkOperatorName + "|" + String.valueOf(latitude) + "|" +
String.valueOf(longitude) + "|" + activenetworkinfo + "|" + failover + "|";
//              stringNeighboring += "MNC: " + mnc + "\n";

                int cid = cellLocation.getCid();
                int lac = cellLocation.getLac();
                int psc = cellLocation.getPsc();
                int type = tm.getNetworkType();
//              int currentCellRSSI = getGsm.

                String networktype = getNetworkTypeString(tm.getNetworkType());
          List<String> Type2G = Arrays.asList("EDGE","GPRS");
          if (Type2G.contains(networktype)) {}
          else {
                  lac = lac & 0xffff;
                  cid = cid & 0xffff;
          }

                stringNeighboring += String.valueOf(lac) + "|" + String.valueOf(cid) +
"|" + String.valueOf(psc) + "|" + networktype + "|" + servingCellSignal  + "|"; // +
" rssi: " + String.valueOf(currentCellRSSI));

                String network = tm.getNetworkOperator();
                List<NeighboringCellInfo> cells = tm.getNeighboringCellInfo();
                stringNeighboring += cells.size() + "|";

                String dBm;

                for(int i = 0; i < cells.size(); i++)
                {
                        if(cells.get(i).getRssi() >= 0 && cells.get(i).getRssi() < 32)
                                {dBm = String.valueOf(-113 + (2 *
cells.get(i).getRssi()));}
                        else
```

```java
                        {dBm = "Unknown value:" +
Integer.toString(cells.get(i).getRssi());}

                    lac = cells.get(i).getLac();
                    cid = cells.get(i).getCid();
                    psc = cells.get(i).getPsc();
                    networktype =
getNetworkTypeString(cells.get(i).getNetworkType());
               if (Type2G.contains(networktype)) {}
               else {
                     lac = lac & 0xffff;
                     cid = cid & 0xffff;
               }

                    stringNeighboring += i + "|" + lac + "|" + cid + "|" + psc + "|"
+ networktype + "|" + dBm + "|";
             }

             stringNeighboring += "\n";

//           ReadCPUinfo();

             fos2.write(stringNeighboring.getBytes());

             AlertDialog.Builder builder1 = new AlertDialog.Builder(this);
             builder1.setTitle("QoEApp");
             builder1.setMessage(stringNeighboring);
             builder1.setCancelable(true);
             builder1.setNeutralButton(android.R.string.ok,
                          new DialogInterface.OnClickListener() {
                    public void onClick(DialogInterface dialog, int id) {
                          dialog.cancel();
                    }
             });

             AlertDialog alert11 = builder1.create();
//           alert11.show();

//           Toast.makeText(MainActivity.this, stringNeighboring,
Toast.LENGTH_SHORT).show();

             fos2.close();

             } catch (Exception e) {
                     e.printStackTrace();
             }
      }


      private String getNetworkTypeString(int type){
          String typeString = "Unknown";
          switch(type)
          {
                  case TelephonyManager.NETWORK_TYPE_EDGE:
                   typeString = "EDGE"; break;
```

```
                    case TelephonyManager.NETWORK_TYPE_GPRS:
                     typeString = "GPRS"; break;
                    case TelephonyManager.NETWORK_TYPE_UMTS:
                     typeString = "UMTS"; break;
                    case TelephonyManager.NETWORK_TYPE_1xRTT:
                     typeString = "1xRTT"; break;
                    case TelephonyManager.NETWORK_TYPE_CDMA:
                     typeString = "CDMA"; break;
                    case TelephonyManager.NETWORK_TYPE_EHRPD:
                     typeString = "EHRPD"; break;
                    case TelephonyManager.NETWORK_TYPE_EVDO_0:
                     typeString = "EVDO_0"; break;
                    case TelephonyManager.NETWORK_TYPE_EVDO_A:
                     typeString = "EVDO_A"; break;
                    case TelephonyManager.NETWORK_TYPE_EVDO_B:
                     typeString = "EVDO_B"; break;
                    case TelephonyManager.NETWORK_TYPE_HSDPA:
                     typeString = "HSDPA"; break;
                    case TelephonyManager.NETWORK_TYPE_HSPA:
                     typeString = "HSPA"; break;
                    case TelephonyManager.NETWORK_TYPE_HSPAP:
                     typeString = "HSPAP"; break;
                    case TelephonyManager.NETWORK_TYPE_HSUPA:
                     typeString = "HSUPA"; break;
                    case TelephonyManager.NETWORK_TYPE_IDEN:
                     typeString = "IDEN"; break;
                    case TelephonyManager.NETWORK_TYPE_LTE:
                     typeString = "LTE"; break;
                    case TelephonyManager.NETWORK_TYPE_UNKNOWN:
                     typeString = "UNKNOWN"; break;
                    default:
                     typeString = "UNKNOWN - " + type; break;
            }
            return typeString;
        }

        protected void getRadioLogfile() {
        try {
                     File issueReport = new
File(Environment.getExternalStorageDirectory(), "QualityOfExperience");
                     if (! issueReport.exists()) issueReport.mkdir();

                     File logcatFile = new File(issueReport,logcatFilename);

                     FileOutputStream os = new FileOutputStream (logcatFile, true);

                     String generateLogcatLogCommond = "logcat -d -v threadtime -b
main -b events -b radio -b system >> /sdcard/QualityOfExperience/log_all.txt";

                     Process process = Runtime.getRuntime().exec("/system/bin/sh -");
                     DataOutputStream fos = new
DataOutputStream(process.getOutputStream());
                     fos.writeBytes(generateLogcatLogCommond);
        //           os.writeBytes(generateLogcatLogCommond1);
                     fos.flush();
```

```
                    fos.close();
        } catch (IOException e) {
                e.printStackTrace();
        }

        }
        protected void getGpsLocation() {

            LocationManager lm =
(LocationManager)getSystemService(Context.LOCATION_SERVICE);
            // getting GPS status
            boolean isGPSEnabled = lm.isProviderEnabled(LocationManager.GPS_PROVIDER);
            // getting network status
            boolean isNetworkEnabled =
lm.isProviderEnabled(LocationManager.NETWORK_PROVIDER);
            // getting passive status
            boolean isPassiveEnabled =
lm.isProviderEnabled(LocationManager.PASSIVE_PROVIDER);

            Location location = null;
            LocationListener locationListener = new LocationListener() {
                public void onLocationChanged(Location location) {
                    if (location != null) {
                        Log.i("SuperMap", "Location changed : Lat: " +
location.getLatitude() + " Lng: " +
                            location.getLongitude());
                    }
                }

                    @Override
                    public void onProviderDisabled(String arg0) {
                        // TODO Auto-generated method stub

                    }

                    @Override
                    public void onProviderEnabled(String provider) {
                        // TODO Auto-generated method stub

                    }

                    @Override
                    public void onStatusChanged(String provider, int status,
                            Bundle extras) {
                        // TODO Auto-generated method stub

                    }
            };

            if (isGPSEnabled){
              lm.requestLocationUpdates(LocationManager.GPS_PROVIDER, 0, 0,
locationListener);
              location = lm.getLastKnownLocation(LocationManager.GPS_PROVIDER);
            }
```

```
            if (isNetworkEnabled && location == null) {
               lm.requestLocationUpdates(LocationManager.NETWORK_PROVIDER, 0, 0,
locationListener);
               location = lm.getLastKnownLocation(LocationManager.NETWORK_PROVIDER);
            }

            if (isPassiveEnabled && location == null) {
               lm.requestLocationUpdates(LocationManager.PASSIVE_PROVIDER, 0, 0,
locationListener);
               location = lm.getLastKnownLocation(LocationManager.PASSIVE_PROVIDER);
            }

            if (location != null){
               latitude = location.getLatitude();
               longitude = location.getLongitude();
            }
        }

        @Override
        public boolean onCreateOptionsMenu(Menu menu) {
               // Inflate the menu; this adds items to the action bar if it is present.
               getMenuInflater().inflate(R.menu.main, menu);
               return true;
        }

     /* Called when the application is minimized */
     @Override
     protected void onPause()
     {
         super.onPause();
         Tel.listen(MyListener, PhoneStateListener.LISTEN_NONE);
     }

     /* Called when the application resumes */
     @Override
     protected void onResume()
     {
         super.onResume();
         Tel.listen(MyListener, PhoneStateListener.LISTEN_SIGNAL_STRENGTHS);
     }

     /* ―――――――――― */
     /* Start the PhoneState listener */
     /* ―――――――――― */
     private class MyPhoneStateListener extends PhoneStateListener
     {
         /* Get the Signal strength from the provider, each time there is an update */
         @Override
         public void onSignalStrengthsChanged(SignalStrength signalStrength)
         {
             super.onSignalStrengthsChanged(signalStrength);

                     if(signalStrength.getGsmSignalStrength() >= 0 &&
signalStrength.getGsmSignalStrength() < 32)
```

```java
                    {servingCellSignal = String.valueOf(-113 + (2 *
signalStrength.getGsmSignalStrength()));}
                    else
                  {servingCellSignal = "Unknown value:" +
Integer.toString(signalStrength.getGsmSignalStrength());}

                    DateandTime = sdf.format(new Date());

            getNeighbors();
//           getRadioLogfile();
        }


    };/* End of private Class */
}
```