Evolving 4G KPIs to improve end user QoE for 4G LTE broadband systems.

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Abstract

In the last half decade data traffic has surpassed voice traffic in telecommunications networks. Legacy networks could not cope with the overwhelming data traffic and exponential increase in subscribers. To address legacy systems limitations in this regard 4G LTE was introduced. With reduced network elements and advanced robust modulation technologies 4^{th} generation systems offer data speeds much more than 3G and wired networks. In addition, 4G offers a variety of services which could not be offered by earlier systems.

Challenges in 4^{th} generation systems arise from managing the complexity in user requirements that accompanies increase in subscribers. For legacy networks performance requirements was defined from operator perspective, gauging it against some performance metrics thresholds. But with so much services on offer from content providers service quality definition has also included user perspective.

This thesis provides a detailed technical analysis of 4^{th} generation systems and associated KPIs, users' perception of quality requirements and how best these user QoE requirements can be combined with traditional KIPs to come with performance metrics that are used centric rather than operator centric.

TO

My mother, wife and daughter

Approval

This dissertation/thesis entitled "Evolving 4G KPIs to improve end user QoE for 4G LTE broadband systems" by **Darlington Maposa** meets the regulations governing the award of the degree of *BSc Telecommunications Honours* of the Midlands State University, and is approved for its contribution to knowledge and literal presentation.

Supervisor…………………………….............Date……………………………………………......

Declaration

I, **Darlington Maposa**, hereby declare that I am the sole author of this dissertation entitled *Evolving 4G KPIs to improve end user QoE for 4G LTE broadband systems*. I authorize University of Midlands State to lend this thesis to other institutions or individuals for the purpose of scholarly research.

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

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- My Mother, My Wife, My Daughter Autillia and Chikandamina Family

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List of Abbreviations

GSM	Global Systems for Mobile Communications
UMTS	Universal Mobile Telecommucation Systems
3GPP	Third Generation Partnership Project
LTE	Long Term Evolution
UE	User Equipment
eNB	Evolved Node B
EUTRAN	Evolved Universal Radio Access Network
MME	Mobility Management Entity
P-GW	Packet Data Gateway
PDN	Packet Data Network
EPCN	Evolved Packet Core Network
SAE	System Architecture Evolved
HSS	Home Subscriber Service
QoE	Quality of Experience
QoS	Quality of Service
HO	Handover
KPI	Key Performance Indicators
KQI	Key Quality Indicators
OFDMA	Orthogonal Frequency Division Multiple Access
SCDMA	Single Carrier Division Multiple Access
UL	Uplink
DL	Downlink
VoLTE	Voice over LTE
MIMO	Multiple In Multiple Out
CSFB	Circuit Switched Fall Back

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CHAPTER 1

INTRODUCTION

1.1 Background

The introduction of 4G LTE on the Zimbabwean telecommunications market in 2014 has brought revolutionary opportunities to the fore. In recent years the mobile phone has become the primary device for access to internet connectivity and this has resulted in exponential growth in mobile broadband traffic.

Besides traditional services and applications like voice and SMS other services and applications like web browsing and streaming media are also using the mobile broadband pipe [1].

In order to implement the concept of “anywhere” and “anytime” as well as to support new and emergent services users are demanding more and more from cellular communication systems. New requirements include increased throughputs and bandwidth, enhanced spectrum efficiency, shorter delays and greater network capacity made available by the air interface [2].

Cellular systems by nature have finite resources. Radio spectrum and transport (backhaul) resources are limited, expensive and shared between many users. Mobile broadband networks must support multiple applications of voice, video and data on a single IP-based infrastructure. These converged services have unique traffic handling and QoE requirements [3]. The increase in mobile penetration has posed some challenges to MNOs. For example, how can they measure user experience of different services and thus realize QoE oriented network management? [4]. The increase in mobile penetration has also led to billions of connections, various traffic profiles and coexistence of 2G, 3G and LTE thus leading to more KPIs.

3GPP has defined KPIs for 4G but these are only related to network performance and generic and do not factor the QoE of the various markets in which the technology has been deployed.

While the goal of MNOs is to quickly identify and address LTE network performance issues before they impact subscribers many lack the necessary insight into subscriber and network data to accomplish this. As a result, LTE network optimization can become very challenging often leading to subscriber churn when QoE falls short. To combat this MNOs should look beyond the traditional KPIs and think of network performance from the subscriber's perspective [1].

1.2. Overview of Analysis of Evolving 4G KPIs to improve end user QoE for 4G LTE broadband system.

The research project is going to address the challenges faced by MNOs in finding the right KPIs which correctly reflect the user QoE in 4G wireless systems. The proposed solutions seek to narrow the gaps in MNOs' for maintaining a high QoE throughout LTE networks and to redefine and align their network KPIs using the information they have about every subscriber [2] [3. This information can be used to understand LTE traffic profiles like:

i. Where subscribers use their mobile phones
ii. What services they are using
iii. When they are most likely to connect from their phones
iv. LTE call traces
v. Network configuration
vi. Drive tests data to accurately identify root causes of network failures

1.3. Current Challenges

The current challenges in 4G networks is the lack of appreciation of the evolving profiles of the system users. As MNOs are evolving their networks to meet the ever increasing data demands of the market it is important to factor in the user perception of how the system is performing [4]. MNOs are still using traditional KPIs for system performance evaluation in 4G systems with little regard for QoE of the users. In addition, lack of technical knowledge has had a severe effect on system optimization during the life cycle of the network.

1.4. Scope and Objectives of the Research.

The project's scope is to propose the use of KPIs which correspond to the target market and which reflect the user experience of the system.

Objectives of the project:

a) To do a detailed analysis of LTE architecture
b) To evaluate any changes in traffic volumes since the introduction of 4G.
c) To evaluate quality requirements users based on geographical location and social status
d) To evaluate the acceptance of the 4G system by the Zimbabwean market.
e) To come up with a common KPI analysis approach for different network vendors.
f) To propose the use KPIs that reflect QoE in combination with network performance indicators.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The evolution of mobile networks from 1G systems to the latest LTE advanced systems has been mostly driven by an ever changing user demands. In recent years' mobile communication systems have evolved from being voice centric systems to data centric systems offering the concept of connectivity 'anywhere' and 'anytime'. In December 2009 global mobile data surpassed voice traffic according to wireless equipment vendor Ericsson [1]. Since then, there has been a rapid and overwhelming rise in data traffic in mobile networks. At the same time the mass adoption of smartphones and the data centric applications that run on them has sparked a revolution in user behavior and expectations and the transformation of the whole telecommunications industry [1]. Whilst 3G coverage in Zimbabwe has not even reached 70%, local MNOs have also joined in the massive 4G LTE deployments to make their customers enjoy the broadband experience and to have a competitive edge over other MNOs offering the same services. The rapid deployments have resulted in serious optimization and aggregation problems for the MNOs as most of the technical staff are yet to fully understand the 3G technology let alone 4G. The performance metrics for the new system are still based on the traditional KPIs which can hardly meet the operator's QoE management needs [2]. Though some of the KPIs are defined by 3GPP for 4G and are industry recognized, they sometimes do not reflect operator objectives and market trends and fail to effect positive change.

2.2 Background

At the beginning of the 1990s, GSM, the Global System for Mobile Communications triggered an unprecedented change in the way people communicate with each other [3]. While earlier analog wireless systems were used by only a few people, GSM at its peak had over 3 billion subscribers by 2010. This section describes the evolutionary trend of mobile communication systems from the first (1G) generation wireless networks to fourth (4G) generation systems.

2.2.1 First Generation Systems (1G)

The design foundations of 1G or first generation systems were laid down in the 1970s.It was based on analog technology and the basic cellular structure.1G introduced seamless mobile connectivity introducing mobile voice service [4].

2.2.2 Second Generation Systems (2G)

The second generation or 2G systems were developed in the 1980s. These were digital circuit switched systems which were mainly optimized for voice traffic with a support low circuit switched data rates. 2G wireless technologies increased voice capacity delivering mobile to the masses. The most popular and successful variant of 2G systems is GSM and designed to operate in the 900 and 1800 MHz bands and was also made available in the in 850 and 1900 MHz frequency bands. GSM is a TDMA and employs 8 timeslots on a 200kHz carrier [4]. Other variants of 2G systems are cdmaOne based on IS-95 standards and DAMPS used in North America, New Zealand and some other parts of Asia Pacific.

2.2.3 Second Generation Systems (2.5G and 2.75G)

2.5 G was developed in the late 1990s and may make use of 2G infrastructure but it implements a packet-switched domain in addition to a circuit-switched domain. 2.5G and 2.75G are evolved GSM systems whose standard names are GPRS and EDGE respectively.

2.2.4 Third Generation Systems (3G)

3G system was introduced during 1990s to eliminate incompatibilities in earlier systems and thus it is a truly global system. The 3G system supports higher quality voice channels, as well as broadband data capabilities, up to 5 Mbps. UMTS was specified with air interface of 5MHz. Unfortunately, it does not scale well as an increase in bandwidth to achieve higher transmission speeds will result in reduction in time between transmission steps [3]. UMTS has a circuit switched domain for handling voice traffic and a packet switched domain for handling data traffic.

2.2.5 Fourth Generation Systems (4G)

Long Term Evolution (4G/LTE) foundations began in the early 2000s and implemented in 2010. LTE was introduced to meet the increased demand for higher access speed for multimedia applications. 4G LTE delivers more capacity for faster and better mobile experiences, and is also expanding into new frontiers. Figure 2.1 below shows the 3GPP releases and Table 2.1 shows a comparison of the main elements of 2G, 3G and 4G systems

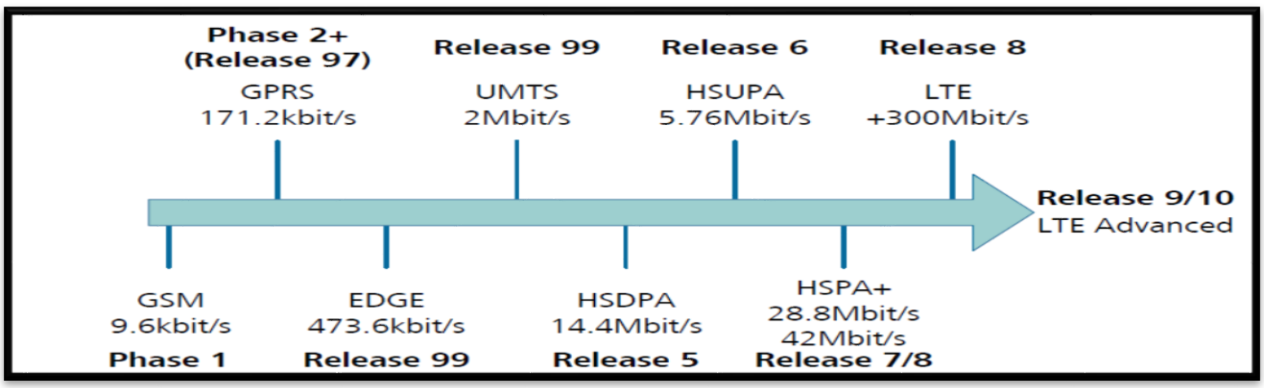

Figure 2.0 3GPP Releases

2.2.6 2G vs 3G vs LTE

Table 2.0 Comparison of 2G, 3G and 4G main elements

Feature	2G	3G	4G
Year	1990	2000	2010
Speed(DL)	9.6kbps	5MBps	300MBps
Handset	MS	UE	UE
Radio Elements	BTS + BSC	NodeB +RNC	eNodeB
Circuit Core Elements	MSC or MSS + MGW	SGSN +MGW	NONE
Packet Core Elements	SGSN +GGSN	SGSN +GGSN	MME+S-GW
Subscriber Database	HLR +VLR	HLR+VLR or HSS	HSS

2.3 Evolution from 3G to 4G

Since the formal definition of third generation (3G) was officially completed by ITU-R in 1997, 4G networks began to be a topic of interest. ITU-R through IMT-2000 specified a set of requirements for 3G standards. The requirements included 2048 kbps for an indoor office, 384kbps for outdoor to indoor pedestrian environments, 144kbps for vehicular connections and 9.6 kbps for satellite connections [5]. In 1998 3GPP was formed to create collaboration between the different telecommunication associations. 3GPP started working on the radio, core network and service architecture of a globally compatible and acceptable 3G technology specification. The earlier systems like UMTS did not meet the initial requirements and hence the system architecture was enhanced with the so called HSPA specification which was a combination of HSDPA and the Enhanced Dedicated Channel HSUPA.

While voice communication was the main motivation for GSM systems, the emergence of the internet and its data centric applications began to play an ever more important role in wireless communications and networks. As a result, the convergence of voice and data services in a communications system were the driving force behind UMTS standardization from the beginning [3]. In essence the 3G system still used several components of GSM system architecture with the only addition being the completely new UMTS radio network access (UTRAN). New core and radio network enhancements were specified and added in subsequent steps. 3GPP refers to the different versions of the evolving GSM, UMTS and LTE as “Releases”, and each release has many features for each of the three radio access technologies. 3G networks continue to evolve and improve so much that some call it 4G.

2.3.1 Motivation for 4G LTE

In recent years many MNOs have dubbed their later 3G network systems as 4G or LTE, but none of these are actually compliant with the specifications set forth by 3GPP as 4th generation standards. For a system to be truly 4G it must offer at least a DL speed 100 Mbps to a moving user and 100Gbps to a stationary user [6]. 3G systems uses a hybrid of circuit switching and packet switching whilst 4G systems are wholly packet switched networks. 4th generation systems have higher data rates providing an end-to-end Internet Protocol. While 3rd generation systems offer amazing DL and UL speeds the increase in the number of connected mobile devices required a system that could handle the enormous volumes of traffic. In 2009 data surpassed voice traffic and is now 10 times greater. The mass adoption of the smartphone and the data centric applications that run on them has seen rapid and overwhelming data traffic in mobile networks. This has sparked a revolution in user behavior and expectation and transformation of the whole industry [1]. Whilst some MNOs are still deploying 3G systems, attention is shifting to the integrated, global network that is based on an open system approach. The core network of 4G is based on IP for control, video, packet data and VoIP and enabling an affordable broadband access solution for the applications of secured wireless mobile Internet services with value added QoS [7].

2.4 LTE ARCHITECTURE AND INTERFACES

Figure 2.2 below shows the LTE system architecture and interfaces. Similarities with GSM and UMTS in that the system is distinctly divided into two parts, the radio part and the core network, however, in LTE the number of logical nodes have been reduced to streamline the overall architecture and reduce cost and latency in the network [3].

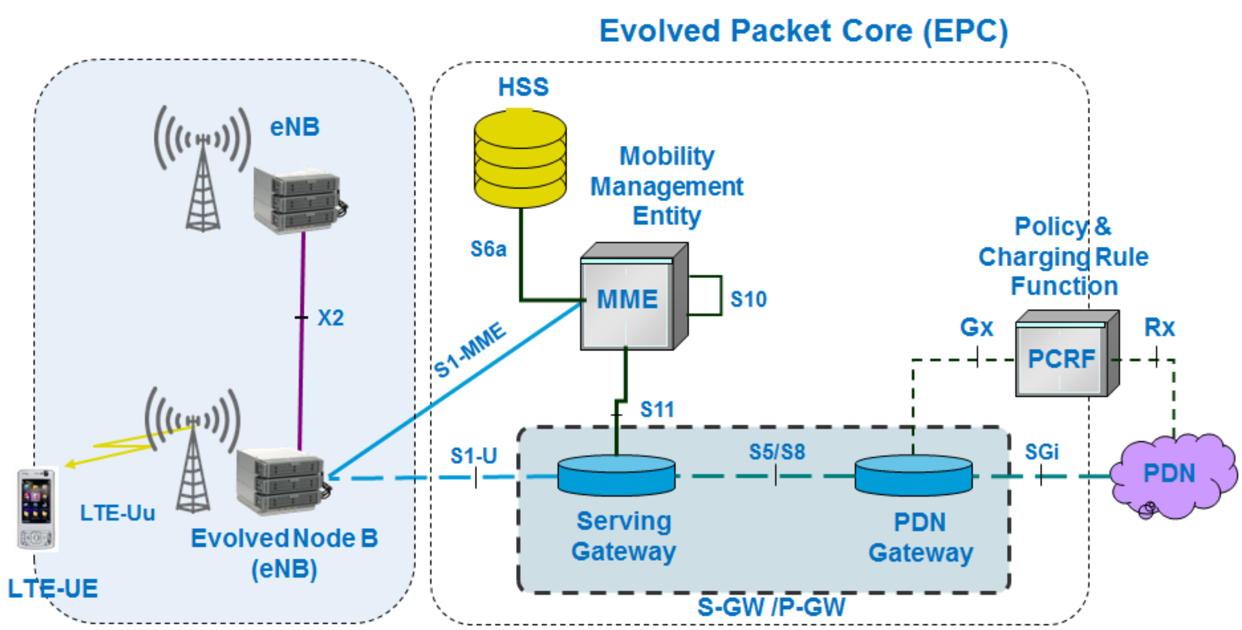

Figure 2.1 LTE Architecture

2.4.1 The UE and LTE Uu interface and frequency bands

The mobile device for LTE has the same name as in UMTS standards and is referred to as a User Equipment (UE). 3GPP TS 36.306[8] defined five different mobile UE classes in 3GPP Release 8 with each UE supporting the very fast 64 QAM and antenna diversity in the downlink and a multistream data transmission method which is called MIMO transmission. In the uplink direction UE categories support the slower but more reliable 16 QAM except class 5 devices which support 64 QAM. With the exception of UE category 1, all mobile devices have to support the advanced MIMO transmission scheme in which multiple data are transmitted on the same carrier frequency from multiple antennas from the base station. The mobile devices will be will be able to distinguish the different transmissions due to the spatial separation of the transmitter and receiver to recreate the original data streams [3].

Table 1.1 LTE UE Categories

Category	1	2	3	4	5
Max DL datarate (20MHz carrier)	10	50	100	150	300
Max UL datarate	5	25	50	50	75
Number of receive antennas	2	2	2	2	4
Number of MIMO UL streams	1	2	2	2	4
Max UL modulation	16-QAM	16-QAM	16-QAM	16-QAM	64-QAM

LTE uses multiple frequency bands depending on geographical location [8] and these bands are assigned by national frequency regulators based on the decisions of the World Radio Conference [9]. FDD is used to separate UL and DL except China which uses TDD. Most LTE-capable devices are downward compatible, thus most devices also support GSM and UMTS technologies [3].

The LTE air interface is called Uu, with the capital “U” indicating the “User to Network” interface and the lower case “u” indicating “Universal”. The LTE interface can also be identified as the E-UTRA and can support varying bandwidth ranging from 1.4MHz to 20MHz. The UE will utilize a channel bandwidth depending on eNodeB configuration. However, to improve capacity and as part of a frequency reuse mechanism the eNodeB may implement multiple channels [10].

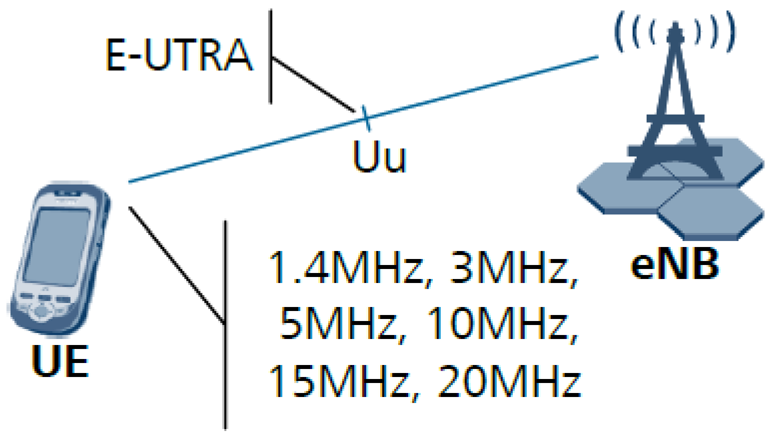

Figure 2.2 LTE Uu Interface

2.4.2 eNodeB and the S1 and X2 interfaces

The eNodeB or evolved NodeB is the most complex device in the LTE network and consists of three major elements [3]:

- antennas
- radio modules for modulation and demodulation of signals
- digital modules for processing of signals transmitted and received on air interface and to act as an interface to the core network over a high-speed backhaul connection.

In UMTS the base station is a little more than an intelligent device, LTE base stations are autonomous units integrating some of the functionality reserved for the radio network controller. As a result, the eNodeB is not only responsible for the air interface but also for

- user and air interface resource management
- ensuring QoS through ensuring latency and minimum bandwidth requirements for real-time bearers
- load balancing
- mobility management
- interference management

The interface between the UE and eNodeB is called Uu interface and the theoretical speeds for LTE can be achieved over this interface depending on the amount of spectrum used by the cell. The flexibility of LTE allows bandwidth allocation of between 1.25 and 20MHz. Peak speeds of up to 150Mbits/s can be achieved with 20MHz using 2x2 MIMO configuration. In practice the maximum achievable speeds are limited by several factors such as the distance from the mobile station, interference from neighboring base stations etc.

The interface between the base station and the core network is known as the S1 interface and is usually carried by high speed copper, fiber cable or alternatively over high speed microwave links. The single backhaul links can also carry GSM and UMTS traffic from collocated sites. The S1 interface is usually split into two logical parts which are both transported over the same physical connection. The S1-UP (S1 User Plane) is used for data transportation and the S1-CP (S1 Control Plane) is used for signaling and for connection purposes [3].

In previous 3GPP access network control of base stations was done by a central device, the BSC in GSM and the RNC in UMTS. To remove latency from user path and to distribute management tasks this concept was abandoned in 4G systems and access network control is done in the eNodeB. As a consequence of this eNodeBs autonomy the X2 interface was created to allow the base stations to communicate directly with each other. Thus:

- HOs are now controlled by the base stations if the target cell is known and reachable over the X2 interface otherwise the HO is done through S1 and core network
- Interference coordination can be done between neighboring base stations

The X2 interface is carried over the same backhaul link as S1 interface up to the aggregation router. From here S1 is routed to the core network and X2 data packets are routed back to the access network as shown in Figure 2.4 below shows the physical routing of S1and S2 interfaces

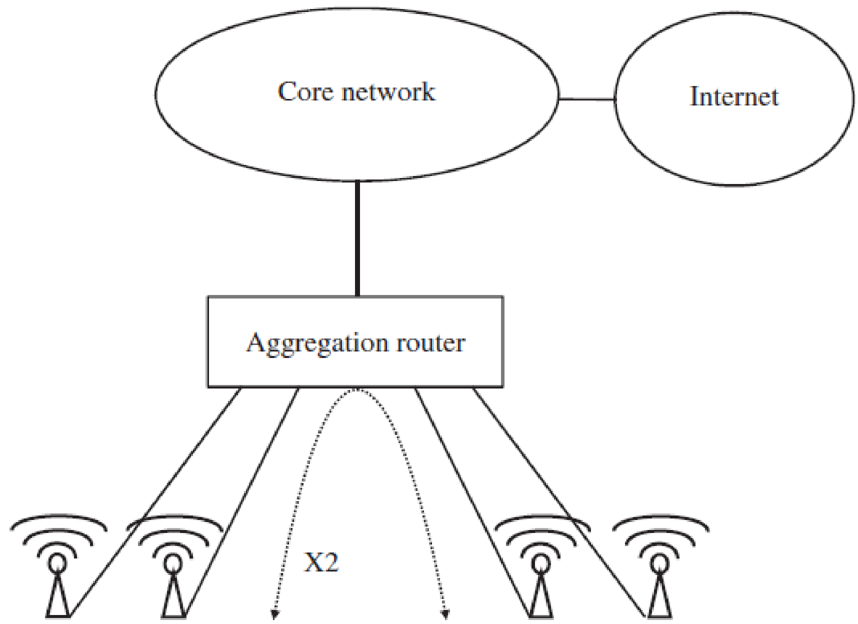

Figure 2.3 Physical routing of the S1 and X2 interfaces

2.4.3 The Mobility Management Entity(MME)

Even though eNodeBs handle users and their bearers once they are established, overall user control is centralized in the core network. This is necessary since there needs to be a single point over which data should flow between the user and the internet. In addition, a centralized user database is required for access in the home network and for roaming subscribers.

The MME is the node responsible for all the signaling between the base stations and the core network and between the users and the core network. There may be are several MMEs in large networks to cope with the large amounts of signaling and for redundancy purposes. The MMEs is not involved in air interface matters and for this reason the signaling it exchanges with the radio network is referred to as Non-Access Stratum (NAS) signaling [3][4]. The MME is responsible for the following:

- Authentication: requests user authentication information from HSS by communicating user information with eNodeB over the S1 interface
- Bearer establishment: Although not directly involved in the exchange of data between UE and Internet, the MME communicates with other core network components to establish an IP tunnel

between the eNodeB and the gateway to the Internet. In the event of several gateways, the MME is responsible for selecting a gateway router to the Internet.

- NAS mobility management: There may be cases where data from the Internet is sent when air interface connection and resources in the radio network are released due to prolonged dormancy and the MME sends paging messages to all eNodeBs that are part of the current TA.
- Handover support: The MME helps to forward HO messages between two eNodeBs in case no X2 interface is available.
- Interworking with other radio networks: The MME is the overall manager for HO between LTE coverage area and a GSM or UMTS network
- SMS and voice support: Provides some of the functionality required to support traditional services such as voice calls and SMS [3][5][8].

2.4.4 The Serving Gateway(S-GW)

a) The S-GW is responsible for managing user data tunnels between the eNodeBs and the PDN-GW. The S-GW terminates S1-UP tunnels on the radio network side and terminates the S5-UDP tunnels on the core network side to the gateway to the Internet. Commands from MME to the S-GW are sent over the S11 interface.

b) The Packet Data Network Gateway (PDN-GW)

The PDN-GW is the gateway to the internet and some network operators use it to interconnect intranets of large companies over an encrypted tunnel to offer employees of those companies direct access to their private internal networks [3]. The PDN-G terminates the S5 interface. The PDN-G is also responsible for allocating IP address to the UEs.

2.4.5 The Home Subscriber Service (HSS)

The HSS is the subscriber database in LTE and uses the IP based protocol called DIAMETER, S6A in the standards, communicate with the MME. This is different with the GSM and UMTS systems which calls the subscriber database the HLR and uses the MAP protocol for exchanging information with system relevant entities [3][6]. The HSS has the following functions:

- Keeps the IMSI which uniquely identifies a subscriber and whose copy is in the UE
- Subscriber authentication information and generation of encryption keys on a session basis

- Circuit switched properties such as the user's telephone number referred to as MSISDN number
- Packet switched properties such as access point names (APNs) which the subscriber is allowed to use which in turn references the connection properties to the internet and determines the throughput
- ID of current MSC for correct routing incoming circuit switched calls and SMS messages
- ID of SGSN or MME, for updating of the user's HSS profile

2.4.6 Policy and Charging and Rules Function(PCRF)

The Policy Control and Charging Rules Function (PCRF) is a component which is responsible for policy control decision-making, as well as for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF), which resides in the P-GW. The PCRF enables the policy function for bandwidth and charging on multimedia networks. PCRF can be used to charge subscribers based on volume of usage of high bandwidth applications, charge extra for QoS guarantees, limit app usage while the subscriber is roaming or lower subscriber bandwidth during peak times [3].

2.5 DL LTE air interface: OFDMA

LTE uses OFDMA in the downlink direction instead of the common FDMA. Thus instead of sending a date stream at a very high speed over a single carrier as in UMTS, OFDMA splits the data stream into many slower data streams that are simultaneously transported over many carriers. The major problems with FDMA systems is the issue of power leakage between adjacent subcarriers which causes Inter-Carrier Interference (ICI). To tackle ICI guard bands should be introduced between subcarriers thus wasting system resources. To save the bandwidth the subcarriers are spaced in such a way that the power of each subcarrier is zero at the sampling instant of the neighboring subcarrier [10]. This property is known as 'orthogonality' and to decode data transmitted this way, a mathematical function known as Inverse Fast Fourier Transformation (IFFT) is used [3]. The downside of OFDMA systems is that they require very accurate frequency synchronization otherwise there will be ICI. Figure 2.5 below shows the OFDMA subcarrier structure

LTE uses the following physical parameters for the subcarriers

- Subcarrier spacing: 15 kHz;
- OFDM symbol duration: 66.667 seconds;
- Standard cyclic prefix: 4.7 microseconds.

The 15 kHz subcarrier is narrow by comparison to the 200 kHz for GSM.

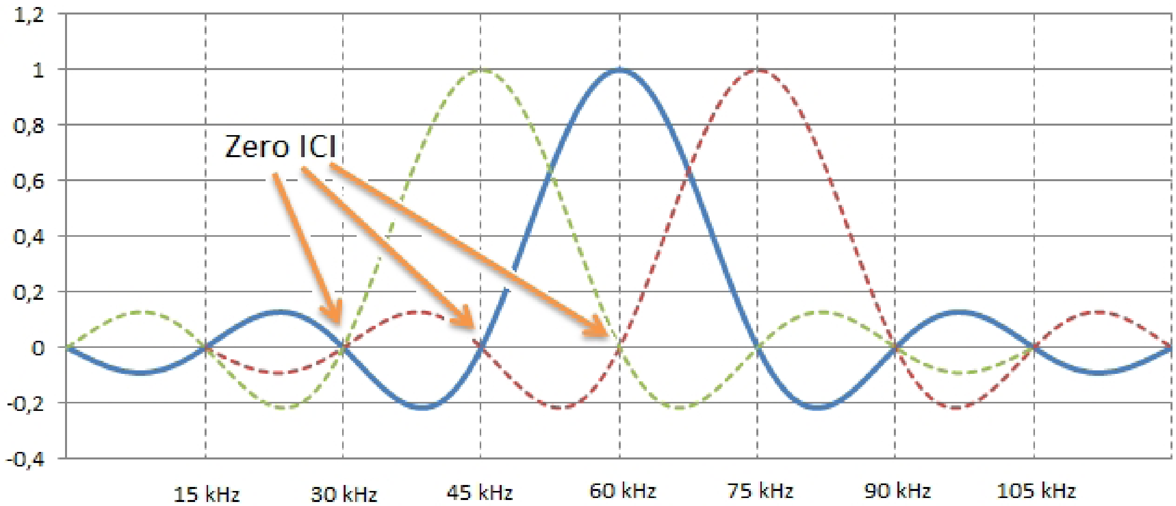

Figure 2.4 OFDMA subcarrier structure

2.5.1 Frame structure, Cyclic Prefix and Inter Symbol interference

The transmissions of each subcarrier is divided into 10ms frames which can be divided into subframes of 1ms. Each subframe consist of 0.5ms timeslots. A subframe represents the LTE scheduling time in which the eNodeB decides as to which users are to be scheduled and which resource blocks are assigned to which user [11]. In a radio environment a phenomenon called multipath fading causes several copies of transmitted symbols to be seen at the receiver. The sum of these copies causes Inter-Symbol Interference (ISI) between the symbols. To mitigate ISI a cyclic prefix (CP), whose length is determined by the delay characteristics of the radio channel, is added at the beginning of each symbol. CP copies a small part of the initial information (hence prefix) to the end of each symbol (hence the name cyclic). In this way the receiver can identify the end points of each symbol and correctly correlate the information, thereby eliminating the interference problem. LTE introduces two CP lengths: normal and extended. In the normal mode, the cyclic prefix length of the first symbol in a time slot is 5.2 µs and for other six symbols 4.7 µs. In extended mode, the cyclic prefix length is 16.7 µs for all symbols [12]. The length of the cyclic prefix is a tradeoff between the capacity and the maximum tolerable delay variation of different radio paths between the transmitter and the receiver. If the delay variation of the radio paths exceeds the maximum allowed value, delayed signal components from the previous symbols will degrade the quality of the current symbol. The relations between the cyclic prefix length, the maximum allowed distance difference between the radio paths and the proportional capacity used for the cyclic prefix at the physical layer are illustrated in Table 2.3.

Table 2. 2 The effects of the cyclic paths length to the maximum allowed radio path difference and capacity utilized for the

Cyclic Prefix length(µs)	Max. distance difference radio between radio paths(m)	Capacity used for the cyclic prefix(%)
4.7/5.2	1406	7
16.7	5000	23

It should be noted that although these values are typically strongly correlated, the maximum cell size is typically much bigger than the maximum distance between the radio path [11].

2.5.2 LTE Resource Allocation and Reference Symbols

In OFDMA LTE, 12 subcarriers can be allocated to a user and as a result 180kHz can be allocated in the frequency domain. In the time domain resources can be allocated in a subframe with a minimum allocation time of 1ms. Hence, the basic allocation unit denoted as a resource block has a bandwidth of 180 kHz and is 1ms long. The resource block allocation can be arbitrary though the actual implementation of the resource scheduler can have some limitations. As mentioned in sections 2.4.0 and 2.4.1, the orthogonality of the subcarriers limits ICI and the use of cyclic prefix diminishes ISI. However even without ICI and ISI the symbols' phase and amplitude are altered by the radio channel between transmitter and receiver. To mitigate against this, reference symbols are added to the transmitted and since these are known to both transmitter and receiver they can help the receiver in estimating the original symbols [9] [12]. The accuracy of the channel estimation is a function of the density of reference symbols in the transmitted data. But, reference symbols do not carry information and are just overhead which consume the system capacity. The reference symbol density depends on the coherence of time/frequency of the channel. Rapidly changing time/frequency channels require a dense reference grid and slow changing channels, a sparser reference symbol grid.

Reference symbols are also used for cell selection and reselection and HO processes. The UE constantly measures the average power of the reference symbols denoted as Reference Signal Received Power (RSRP), from the serving and adjacent cells and these measurements are used to determine the cell with the strongest signal. Furthermore, an estimate of the signal quality can be deduced from the Reference Signal Received Quality (RSRQ) which is calculated by dividing the RSRP value with a Received Signal Strength Indicator (RSSI). RSSI is a measure of the total received wideband power [10] [12].

2.5.3 UL LTE Air Interface (SC-FDMA)

For uplink data transmissions LTE does, use of OFDMA is not ideal because its high Peak to Average Power Ratio (PAPR) when the signals from multiple subcarriers are combined. 3GPP uses a different transmission scheme, referred to as Single-Carrier Frequency Division Multiple Access (S-CDMA). Though similar to OFDMA in several aspects, S-CDMA does not suffer from a high-peak-to average ratio and the information for a user is sent using a single carrier. Figure 2.6 below shows the comparison between OFDMA and S-CDMA [3] [12]. The symbol rate for S-CDMA is much higher than that for OFDMA since information for an individual is sent via a single carrier instead of utilizing multiple carriers. To mitigate ISI cyclic prefixes are added as in OFDMA with the only difference being that in S-CDMA the cyclic prefixes are added after a block of symbols rather than after every symbol.

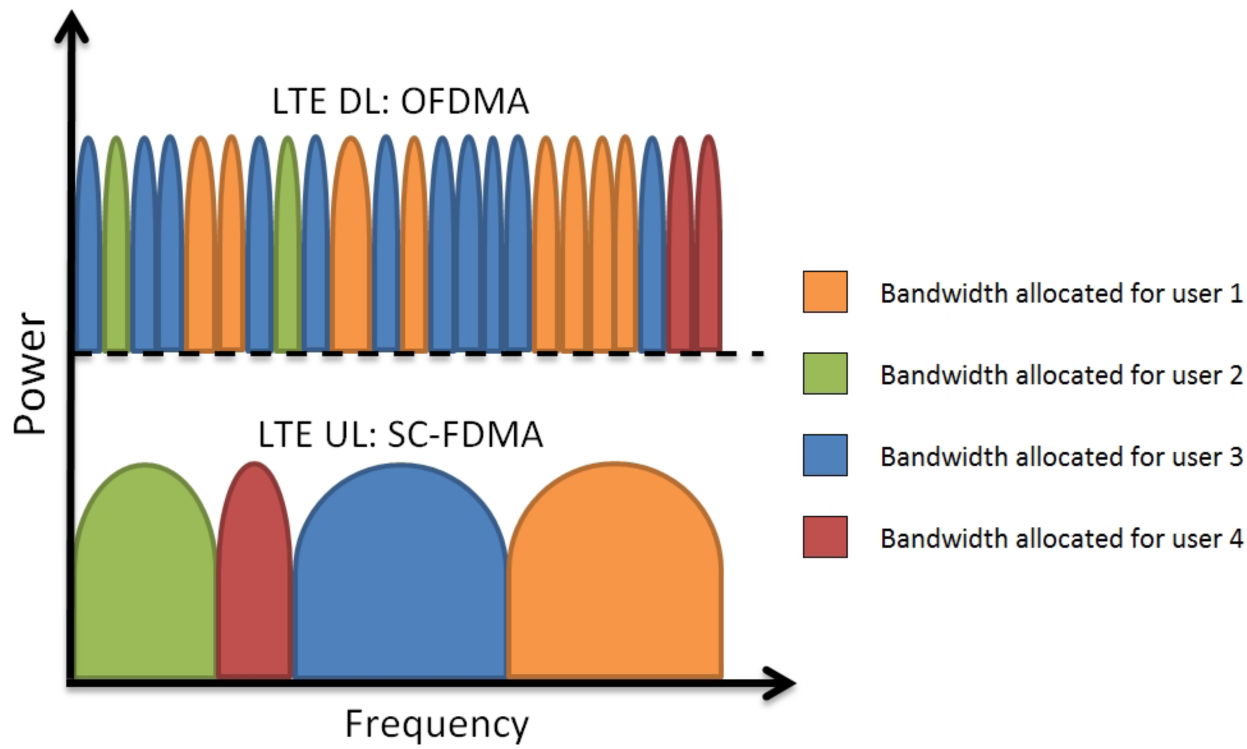

Figure 2.5 LTE DL and UL

2.6 4G Optimization and KPIs.

2.6.1 Introduction

With the initial target of DL peak data rate reaching above 100Mbit/s, the next-generation LTE system is set to meet the increasing demands on a higher data rate due to fast expansion of multimedia applications. Operators have been deploying 4G networks without a deep knowledge of the underlying technology. Sections 2.3 introduced the evolution of wireless communication systems and a detailed analysis of 4G LTE systems highlighting some of the complexities which may be involved in optimizing such networks. The LTE optimization process is a complex and demanding task, in which the effects of multiple factors must be considered separately. MNOs are facing a myriad of challenges like changing service requirements, new technologies, industry consolidation, deregulation and competition from non-traditional telecom providers. This has changed the operator's business model and new tools are now not just to manage the network, but the subscribers as well. Traditionally MNOs have relied on O&M KPIs that hardly meet the operator's QoE management needs [1]. The following sections introduces the concept of KPIs and their generation, network based performance KPI formulas for 4G networks, reasons for high and low values for particular KPIs, the need to combine network based KPIs and KQIs that take into account the user's perceptions, proposition for MNOs to use performance metrics that reflect target market and provide E2E analysis of network in coming up with KPIs. The identification and measurement of the right KPIs is a critical step in managing and evolving the network and business. The purpose of KPIs is to give an operator quantifiable metrics deemed important for long-term profitability from operations.

2.6.2 Network Optimization

Network optimization is mainly concerned with improving the performance of the network using existing resources. The main goal is to use existing resources to solve current and potential problems and identification of possible solutions for future planning. Thus service quality and resource usage are greatly improved through optimization. For an operator optimization network optimization is equal to: [13]

i. Better return for investment
ii. Less need for costly hardware updates
iii. Less needs for new sites (which are expensive)

Figure 2.7 below shows the optimization flow chart [14]

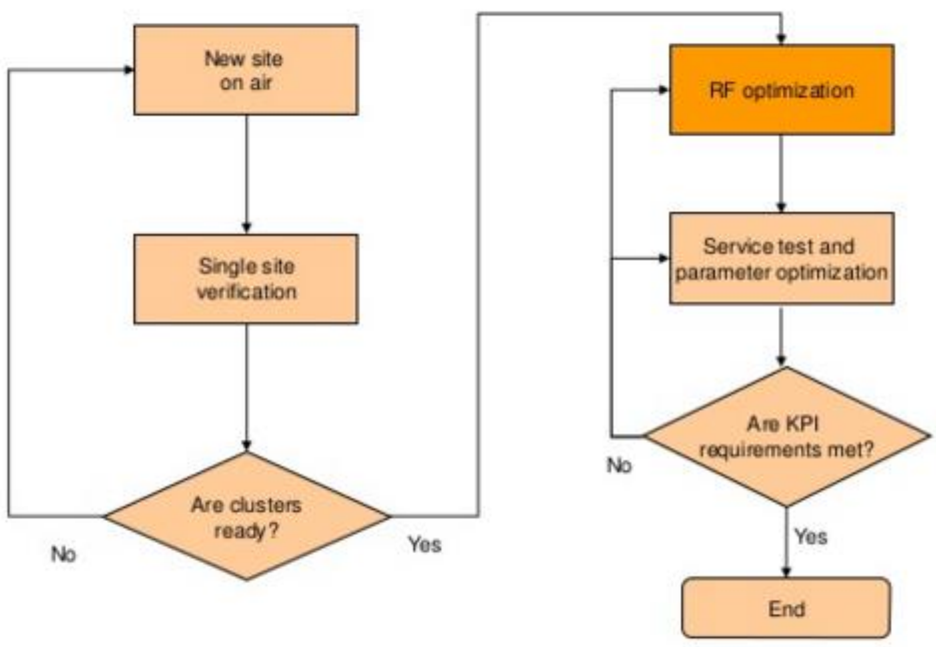

Figure 2.6 Network Optimization Flow Chart

i. Single Site Verification:

The single site verification is the first phase of optimization and involves function verification of each new site. The purpose of SSV is to ensure proper installation and correct parameter configuration

ii. RF optimization:

RF (or cluster) optimization is done after installation and verification of all sites in a planned area. The purpose of RF optimization is to minimize and control pilot pollution while optimizing signal coverage, increasing HO success rates and ensuring the normal distribution of radio signals before parameter optimization. RF optimization involves the adjustments of antenna hardware and neighbor lists and the first RF optimization must traverse all cells in an area to rectify hardware faults. The figure below shows the RF optimization flow chart

2.6.3 KPI generation

Counters are used for generating KPIs. Subscriptions define what shall be collected. Initially the eNodeB will automatically start a predefined default subscription for collecting the most essential statistical counters and these are automatically transferred to the OSS-CR. Additional subscriptions can also be defined and to stop the predefined and only use self-defined subscriptions. Counters can be collected periodically or collected in real time using commands. Events can be collected at cell level on selected cells using a predefined trace called Cell Trace (CTR) and is also possible to choose UEs to collect events from using UE Trace (UETR). FTP is used for file transfer and OSS-RC collects and stores the information for later retrieval [14] [15].

2.6.4 Challenges in ensuring service delivery and QoE for customers

- Variations in vendor equipment and different OSS/BSS applications makes it difficult to achieve E2E performance visibility for customers
- Complexities in network functionality makes it difficult to isolate performance events thus putting service at risk
- Exponential increase in UEs, connections and high data volumes traversing the network makes scalability of the monitoring system problematic
- Speed of reporting in large scale networks is low and this slows troubleshooting

2.6.5 LTE Bearers

The bearer concept is a virtual concept and defines a set of network configurations which provide prioritization to certain sets of traffic. Thus different bearers support different QoS requirements.

Radio bearers are layer 2 (L2) services responsible for the transfer of information on the air interface, thus they describe L2 interface per bit stream (flow) [16]

Bearer Categorization

i. Signaling Radio Bearers (SRB): They carry RRC messages using the CCCH channel
ii. Data Radio Bearers (DRB): Carry user plane content on the Air interface.

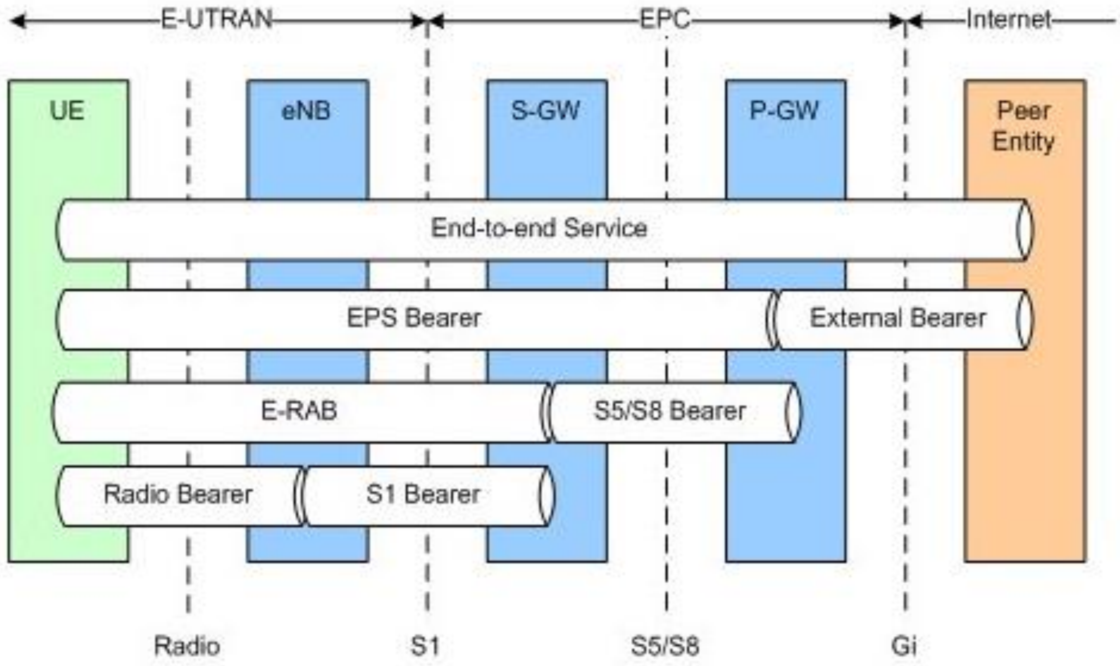

Figure 2.7 LTE Bearer Architecture

2.7 4G Network Performance Indicators

a) 2.7.1 Importance of KPIs for MNO

The purpose of detailing Key Performance Indicators is necessary for correlation between long-established drivers for Network Management indicators and the current Telecommunications Industry's aggressive 'business focus'. Currently, there continues to be a lack of correlation between the functions carried out by Network Management groups and the contribution of these functions to the organizational level business objectives such as, revenue (growth and protection) and reduction of costs etc. The definition and adoption of monitorable performance indicators helps policy makers and company executives responsible for policy implementation to measure the level of achievement. In most countries most regulatory authorities publish KPIs and target levels and the KPI parameters and target levels are mandatory minimum standards that SPs should comply with [13] [17]. A network evolution system can have many KPIs hence selection depends on the types of problems being addressed. In telecommunications the problems to be addressed may include the following:

a) poor quality of service

b) lack of qualified manpower

c) demand for next generation telecommunications services which may be unavailable

d) poor financial performance and lack of financial resources.

b) 2.7.2 Network Performance KPIs categorization

Network performance KPIs are categorized into the following [15]:

- Accessibility
- Retainability
- Mobility
- Integrity
- Availability

c)Accessibility KPIs:

Accessibility KPI measurements assists the network operator with information about whether the services requested by a user can be accessed with specified levels of tolerance in some given operating conditions. The service by E-UTRAN is defined as EPS or ERAB, RRC and SAE (ERAB) setup are the fundamental procedures for accessibility KPIs. [15] [18]

i. RRC Setup Success Rate (RRCSSR): RRCSSR evaluates service related causes in a cell or cluster involved and is based on counters measured at eNB upon receiving RRC Connection Request from UE as shown in the figure below [18]

$$RRCSSR_{service} = \frac{RRCConnectionsSuccess_{service}}{RRCConnectionAttempt_{service}} \times 100\%$$

ii. RRC Setup Success Rate (Signaling): The KPI evaluates RRC Setup Success rate of signaling related causes in a cell or cluster

$$RRCSSR_{signaling} = \frac{RRCConnectionSuccess_{signaling}}{RRCConnectionAttempt_{signaling}} \times 100\%$$

iii. ERAB Setup Success Rate (VoIP): The KPI is used to evaluate the ERAB Setup success rate of the VoIP service at cell or cluster level

$$VoIPERABSSR = \frac{VoIPERABSetupSuccess}{VoIPERABSetupAttempt} \times 100\%$$

iv. ERAB Setup Success rate (All): The KPI is based on the setup success rate of all services at cell or cluster level

$$ERABSSR = \frac{ERABSetupSuccess}{ERABSetupAttempt} \times 100\%$$

v. Call Setup Success Rate (CSSR): This KPI is used to evaluate all call setup success rate of a services at cell or cluster level. The KPI is calculated based on KI of RRCSSR(service) and ERABSSR(all)

$$CSSR = \frac{RRCConnectionSuccess_{service}}{RRCConnectionAttempt_{service}} \times \frac{ERABSetupSuccess}{ERABSetupAttempt} \times 100\%$$

d) Retainability KPIs:

If end users are interrupted often during use of service, or the service is aborted during use, then it becomes difficult for operators to charge for the time for which the services is not provided. Retainability KPIs measure the capacity of systems to endure consistent reuse and perform its intended functions. The retainability of an end application covers a wider area than the E-UTRAN hence, the KPIs given area limited to the parts that E-UTRAN has control of [15] [18].

i. Call Drop Rate (VoIP) (CDR): The Call Drop rate is calculated by monitoring the VoIP ERAB abnormal release rate. Call drop rate may be due to abnormal release in ERAB radio bearer or S1 bearer

$$VoIPCDR = \frac{VoIPERAB_{AbnormaRelease}}{VoIPERAB_{Release}} \times 100\%$$

ii. Service Call Drop Rate (All): The KPI is used to evaluate the drop services of all services in a cell or cluster. It measures abnormal release at the eNodeB

$$Service\ CDR = \frac{ERAB_{AbnormalRelease}}{ERAB_{Realease}} \times 100\%$$

e) Mobility KPIs

Mobility is a fundamental functionality that provides continuous service to the users moving around the network. Mobility KPIs are concerned with handovers (HOs). The measurements include both intraE-UTRAN and interRAT Hos. The measurements are done at cell and cluster levels. Hos define the transfer of an active UE connection from one cell to another. All HOs in LTE are hard, that is, the connection between the UE and RAN are temporarily broken during Hos [18] [19].

i. Intra-frequency Handover Out Success Rate: The KPI is used to evaluate the intra-frequency HO out success rate at cell or cluster level

$$IntraHOOutSR = \frac{IntraFHOOutSuccess}{IntraHOOutAttempt} \times 100\%$$

ii. Inter-frequency Handover Out Success Rate: This KPI is used to evaluate the intra-frequency handover out success rate at cell or cluster level

$$InterFHOOutSR = \frac{InterFHOOutSuccess}{InterFHOOutAttempt} \times 100\%$$

iii. Inter-RAT Handover Success Rate (LTE to WCDMA): The KPI is used evaluate HO success rate from LTE to WCDMA in a cluster [22]

$$IRATHO\_L2W\_SR_{out} = \frac{IRATHO\_L2W\_SuccessOut}{IRATHO\_L2W\_Attempt} \times 100\%$$

iv. Inter-RAT Handover Success Rate (LTE to GERAN): The KPI is used to evaluate inter-RAT HO success rate from LTE to GERAN

$$IRATHO\_L2G\_SR_{out} = \frac{IRATHO\_L2G\_Success}{IRATHO\_L2G\_Attempt} \times 100\%$$

f) Integrity KPIs:

Integrity KPIs indicate the impact of E-UTRAN on the service quality provided to the user. Service integrity KPIs can be calculated at cell or cluster level with cluster level KPIs being an aggregation of cell level counters [15] [19].

i. Service Downlink Average Throughput: The KPI consists of nine sub-KPIs that can be used to evaluate the busy-hour downlink (DL) throughput of a service with a specific QCI per user in each cell. Units are kbps.

ii. Service Uplink Average Throughput: The KPI is used to evaluate the busy-hour uplink (UL) (with a specific QCI) per user in each cell. Units are kbps

iii. Cell DL Average Throughput: The KPI evaluates the average throughput when there is data transfer in the downlink direction: Units are kbps

iv. Cell DL Maximum Throughput: The KPI evaluates the maximum throughput when there is data transfer in the downlink: Units are kbps [22]

$$CellDLMaThp = \frac{CellDLMaxTrafficVolumeforEach1s(bit)}{1000(ms)}$$

v. Cell UL Maximum Throughput: The KPI is calculated based on the maximum value of traffic volume which are transferred at each second

$$CellULMaxThp = \frac{CellULMaxTrafficVolumefoorEach1s(bit)}{1000ms}$$

g) Utilization KPIs:

Utilization KPIs are used to evaluate the system capability to meet the traffic demand.

i. Resource Block Utilization Rate: The KPI consist of two sub-KPIs, UL resource block (RB) utilization rate and DL RB utilization rate [22] [21]

$$RB\_UR_{DL} = \frac{RB\_Used_{DL}}{RB\_Available_{DL}} \times 100\%$$

$$RB\_UR_{UL} = \frac{RB\_Used_{UL}}{RB\_Available_{UL}} \times 100\%$$

Note: $RB\_Available_{DL}$ and $RB\_Available_{UL}$ are fixed values which can be calculated from the system bandwidth

h) Availability KPIs

Availability KPIs measure the percentage of time that a cell is available. A cell is available when the eNodeB can provide EPS bearer services [19].

i. Radio Network Unavailability Rate: The KPI measures the percentage of time a cell is unavailable in order to evaluate the degradation and impact on network performance. The KPI is measured at cluster level.

$$RAN\_Unavail\_Rate = \frac{\sum_{cluster} CellUnavailTime}{The\ TotalNumberOfCellsinCluster * \{SP\} * 60} \times 100\%$$

2.8 Traffic KPIs

Traffic KPIs are used to measure the traffic volumes on LTE RAN. Traffic KPIs are categorized based on the type of traffic: radio bearers, downlink traffic volume and uplink traffic volume [20]

2.8.1 Radio Bearers

Radio bearer KPIs are used to evaluate the average radio bearers at cell or cluster level and consists of ten sub KPIs of which one is for the total radio bearers and the other nine are for nine QCIs

2.8.2 Downlink Traffic Volume

DL traffic volume KPIs are used to evaluate the DL traffic volume in a cell. Similar to Radio bearers KPIs, the DL traffic volume consist of 10 sub KPIs of which one is for the total RDBs and the other nine are for nine QCIs. The traffic is measured at the PDCP layer excluding the PDCP header. Units are Bits

2.8.3 Uplink Traffic Volume

The group of KPIs is used to evaluate the UL traffic volume in a cell. The traffic is measured at the PDCP layer excluding the PDCP header. Units are Bits

2.9 Trends in Mobile Telecommunications Market

The commoditization of services is leading to decreases in service revenue globally. There is also value shifts from operators' managed services to content and terminals with Smartphone OS ecosystems and indications are that current models will result in end of profit [17].

2.9.1 Performance Metrics vs QOE metrics

The 4G KPIs outlined in Section 2.7 show the metrics associated with measuring the network performance. The KPIs were inherited from legacy systems KPIs where network performance was the key factor in network measurements. The MNO defines some thresholds for each KPI below which the network is deemed to be underperforming. Operators are constantly focused on end users' QOE in order to increase revenue, yet challenges still remain. The challenges arise from changing user culture which is driving rapid evolution of mobile broadband and IP transformation. User demand and expectation from network quality has increased and created a new definition for network quality. In some cases, even though network KPIs indicate good network performance, many operators still face user complaints about background noise during voice calls and slow loading of web pages. A question then arises: Are traditional KPIs enough to fulfill operator's needs? [1].

2.9.2 What is QoE?

QoE involves complex psychological and physiological factors. QoE refers to an end user's satisfaction level when it comes to a service provider or specific network performance. Factors affecting QoE can be divided into technical and non-technical factors. Technical factors are those associated with terminals and network and non-technical factors are closely related to the policies and services provided by the MNO. It is difficult to quantify QoE and currently there is no unified criteria to measure QoE in the industry [1].

2.9.3 QoE determines competitiveness

As mobile networks trend towards IP following a boom growth in services; besides traditional voice and SMS other services and applications like web browsing and streaming media are also using the broadband pipe. Richer services, higher quality and enhanced QoE are becoming essential in running a profitable business. The provision of higher service quality helps in retaining existing customers and win new ones, while a degraded service quality leads to increased churn rate and poor brand image [1]. The growth in services has resulted in problems such as low downloads speeds, delays and wrong billing. To maintain competitiveness MNOs must improve quality of subscriber experience [21].

2.9.4 Customer Experience Management

In legacy networks MNOs were the sole providers of communications services and there was not much competition among operators. As a result, operators were not much concerned about customer experience as the assumptions were that everyone needed to communicate regardless of service quality. In recent years there has been a shift from operator's managed services to content and terminals offering a variety of services. There is also the emergence of competing technologies offering similar services to customers. This has resulted in a tight competitive environment for customers. Customer experience management has become as important as network performance, and MNOs should find strategies for managing users' QoE [17]. Figure 2.3 below shows the four pillars of customer experience management

Figure 2.8 Pillars of customer management

2.9.5 User Centric Service Model

Operators should adopt a user centric service model to help service quality of data and voice services and attract more subscribers to new services thereby building up a competitive edge. The model helps MNOs reduce user complaints, improve QoE and raise user loyalty, especially the high value users.

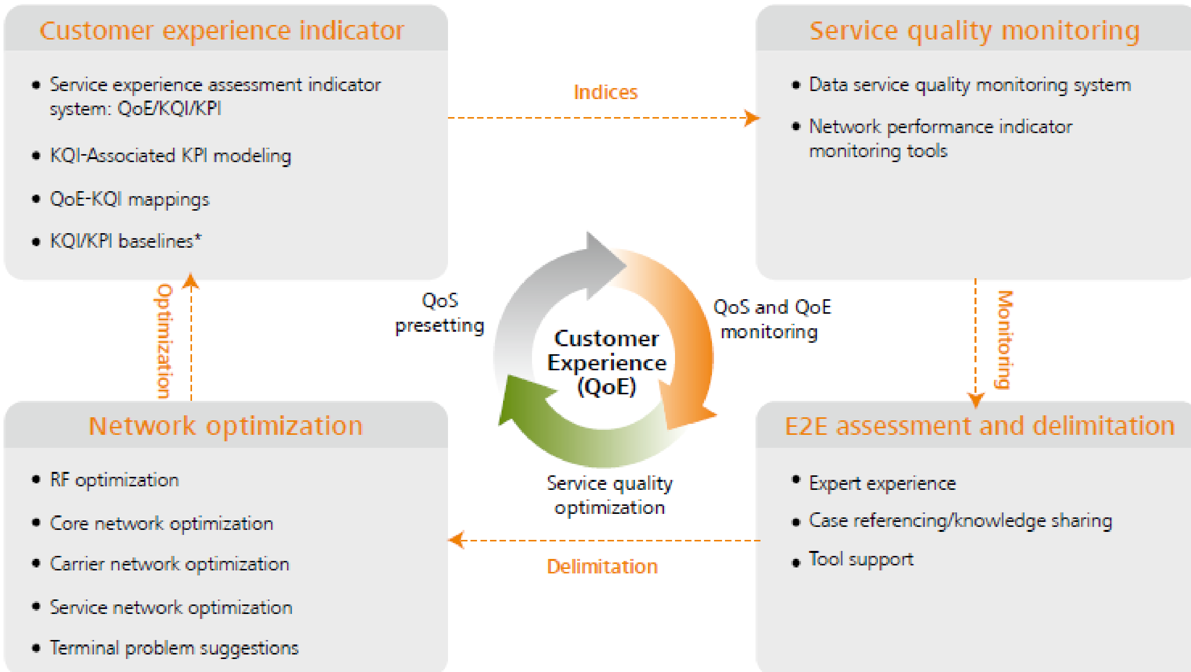

Figure 2.9 The User Centric Model

2.9.6 Customer Experience Indicator System

The system establishes a QoE based indicators. The key is to map KQI, QoE and KPI together. For example, define IP pool utilization as a KQI. IP pool utilization helps in calculating the available IP addresses in each individual service or cell site area. As a result, customers cannot be denied service because all the IP addresses are exhausted. The MME sending success rate can also be defined as a KQI. Thus one would look at how many UEs are connected to each of the different devices and how many active subscribers are active from each eNodeB.

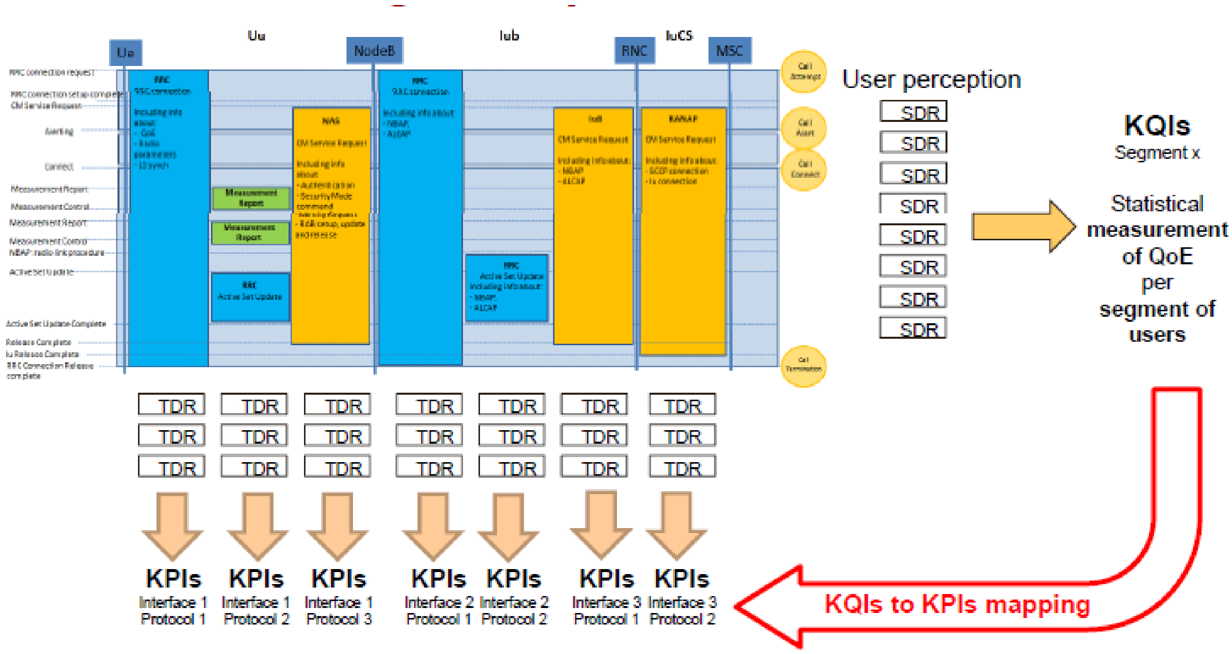

Figure 2.10 Mapping KQIs to KPIs

2.9.7 Service Quality Monitoring

A service quality management system is used to monitor E2E KPIs in real time and indicate the quality in real time. Traffic must be captured E2E between UE and SP. A traffic capturing probe can be placed on any interface on the user plane to monitor video QoE. For troubleshooting the probe must be correlated with lower level probes. For segmentation/analysis the probe must be correlated with other information like HSS and MME records [17]. Figure 2.6 below shows how an and-to-end observation is achieved on the 4G system.

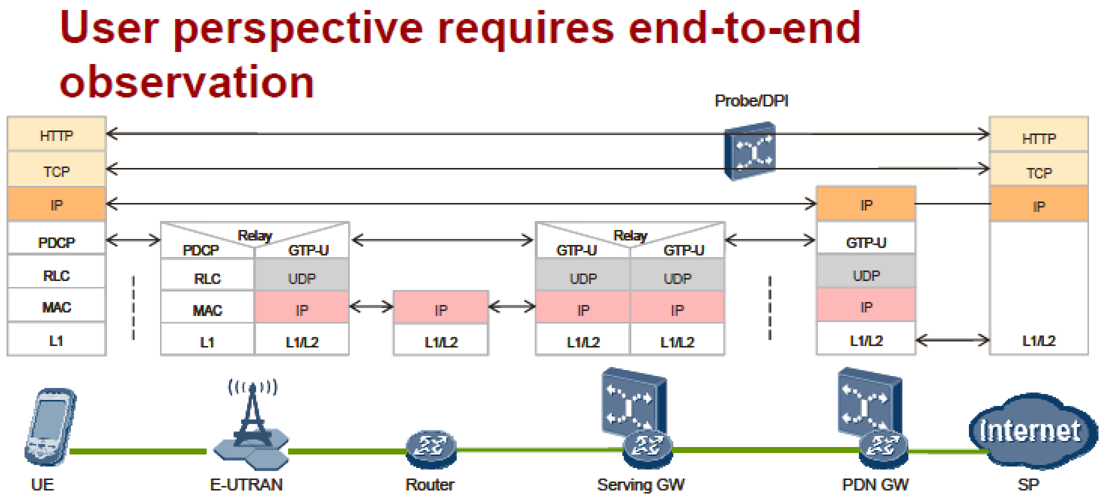

Figure 2.11 End-to-end monitoring

2.9.8 End-to-End assessment and delimitation

To improve service quality, monitoring KQIs are not enough. Operators often have problems in identifying whether reported problems have come from the wireless network, core network or, service network. The solution is to use a tool that can monitor and asses through active testing and passive monitoring. When service quality deteriorates the tool can analyze the problem from the service layer down to the bottom layer, thus locating the root cause of the service degradation.

2.9.9 E2E Network Optimization

After QoE problems are delimited and located, operators can perform network optimization tasks according to relevant service features, including their wireless network, core network, bearer network and service network. This improves network and service quality, thus attracting more users to data service [21] [22].

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CHAPTER 3

RESEARCH METHODS AND TECHNIQUES

3.1 Introduction

This chapter gives a detailed overview of the research methods and techniques employed in the study. The chapter also outlines the sources of data, population of study subjects, location of study subjects, the processes, procedures and techniques of data collection and presentation and constraints and challenges faced by the author in gathering the data. A quantitative research approach is used in the study.

3.2 Justification of research method

The main objective of the study is to show the need for MNOs to evolve their KPIs in line with evolving systems and markets. Thus the continued use of traditional network performance KPIs is no longer enough to gauge system performance. User QoE requirements should be combined with traditional KPI in order to come out with reliable performance metrics. Hence the choice of a quantitative and descriptive study was necessary in order to elicit as much information as possible from the MNOs and subscribers in particular. The conclusions drawn were qualitative but based on quantitative collected data.

3.3 Study Population

Population refers to number of entities of a group in the same area and sharing the similar attributes. Population for the study was drawn from 5 MNOs and 85 individual subscribers. The MNOs in the study are Econet, NetOne, TelOne, Telecel and Africom. The individuals were subdivided into various social groups ranging from vendors, students, peasants and workers. From the large sample used in the study there is assurance that the study’s outcomes are representative of the whole population’s views.

3.4 Sampling methods

Selection for subjects of study was based on random sampling thus elements of the study had equal chances of being selected for the study. Specific representatives are represented proportionally in each group. The KPI data collected from MNOs was selected from a random day showing the busy hour thresholds for the data. Selection of MNOs was limited to only those MNOs which offer 4G services or intend to offer the services in the future.

3.5 Location of study

Data for the study was collected from different social groups from different geographical locations. This was done in order to highlight location or geographical dependency on QoE requirements of the different social groups that comprise the subscribers. Data was collected from MNOs NetOne (Harare), Econet Wireless (Harare), and for subscribers from Harare CBD, Gweru CBD and suburban areas, Mkoba, Zvishavane rural and MSU.

3.6 Data collection processes and procedures

Raw KPI data for 4G was sent by NetOne cellular. The study used open ended questionnaires to gather data from respondents. Open ended questionnaires were used in order to have quantitative data that is easy to interpret in the analysis. Questionnaires also allowed the author to gather finding s in a small time frame at a minimum cost. In addition, questionnaires allow the respondents to give objective information. A total of one hundred and ten questionnaires were used to get data from MNOs technical departments and from the individual subscribers. The breakdown of the number of questionnaires is shown in Table 3.1 below.

Table 2.0 Number of Questionnaires Issued

	Number of Questionnaires Issued
NetOne	5
Econet	5
Telecel	5
TelOne	5
Africom	5
Suburban (Gweru)	15
University Students (MSU)	20
Townships (Mkoba)	15
Rural Area (Zvishavane)	10
Vendors (Gweru)	10
Vendors (Harare)	10
Total	**110**

3.7 Data presentation

Data collected is presented in tables and bar graphs as indicated in the next chapter.

3.8 Constraints and challenges

Whilst data collection from subscribers was not difficult the same could not be said of MNOs. From the 25 questionnaires issued to MNOs only 2 were completed. Application letters stating reasons for wanting the data were required by all the MNOs earmarked for the study. The companies were not ready to provide data citing company policies even though requisition letters clearly stated that the data will be used for academic purposes only. Most companies' reasons for withholding data was fear that the data might eventually fall into the hands of their competitors. NetOne provided raw 4G KPI data and this was not enough since the author wanted to compare KPI definition trends between 2G, 3G and 4G. Challenges from subscribers was the problem of subjectivity instead of objectivity in answering the given questions.

CHAPTER 4

DATA PRESENTATION, INTERPRETATION AND ANALYSIS

4.1 Introduction

The results obtained in Chapter 3 are presented in tables and graphs. A critical analysis of the results in relation to theoretical expectation is done in order to check feasibility of the system.

4.2 Response Rate

The subscriber response rate was very high and there was poor response rate from telecommunications companies due to company policies. Table 4.0 below shows the response rate of the interviewees. The table clearly show the low response from MNO and high response from and since the research is mainly concerned about the perceptions of the users with regard to the 4G system the response rate is enough to justify the findings.

Table 3.0 Questionnaire response rate

	Number of Questionnaires Issued	**Questionnaires Completed**	**Response Rate (%)**
NetOne	5	1	20
Econet	5	1	20
Telecel	5	0	0
TelOne	5	0	0
Africom	5	0	0
Suburban (Gweru)	15	13	87
University Students (MSU)	20	19	95
Townships (Mkoba)	15	14	93
Rural Area (Zvishavane)	10	10	100
Vendors (Gweru)	10	10	100
Vendors (Harare)	10	7	70
Total	**110**	**75**	**68.2**

4.3 Data from MNOs

Data from MNOs was very limited with only NetOne able to avail limited data on 4G KPIs. Table 4.1 below show some network performance KPIs for the target areas in which the research was conducted. The KPIs are for March 2016. The KPIs are from Huawei's network management system and no data was availed from for the other NetOne network vendor, Nokia Networks' NetAct management system because some Nokia sites were being migrated to Huawei leading technical issues in collection of network statistics from the NetAct platform.

Table 4.1 4G LTE KPIs

NE Name	LTE Av Throughput DL (Kbps)	LTE Av Throughput UL (Kbps)	LTE Traffic Vol DL (MB)	LTE Traffic Vol UL (MB)	LTE CSSR Service(%)	LTE E_RAB SSR (%)	RRC Connection Attempt Service(%)	LTE Intra_freq HOSR (%)	HO_SRE_UTRAN to GERAN (%)	HO_SRE_UTRAN to WCDMA (%)	HO_SRE_UTRAN to GSM (%)
Gweru CAIPF_900_1800_3G_LTE	2780	140	130	13	100	100		100	Nil	Nil	Nil
MSU_LTE	4700	190	9000	2400	100	100	20	100	Nil	Nil	Nil
Mkoba 3G_LTE	4000	120	200	23	100	100	25	100	Nil	Nil	Nil
Zvishavane Exchange 3G_LTE	1000	300	10	8	100	100	5	100	Nil	Nil	Nil
GWERU EXCHANGE 900_1800_3G_LTE	2700	100	350	30	100	100		100	Nil	Nil	Nil
GWERU VHF_900_3G_LTE	3500	100	1000	100	100	100	44	100	Nil	Nil	Nil
THROGMORTON 900_1800_3G_LTE	3000	150	200	30	100	100	30	100	Nil	Nil	Nil
ATLAS HOUSE_900_3G_LTE	2500	124	100	26	100	100	20	100	Nil	Nil	Nil

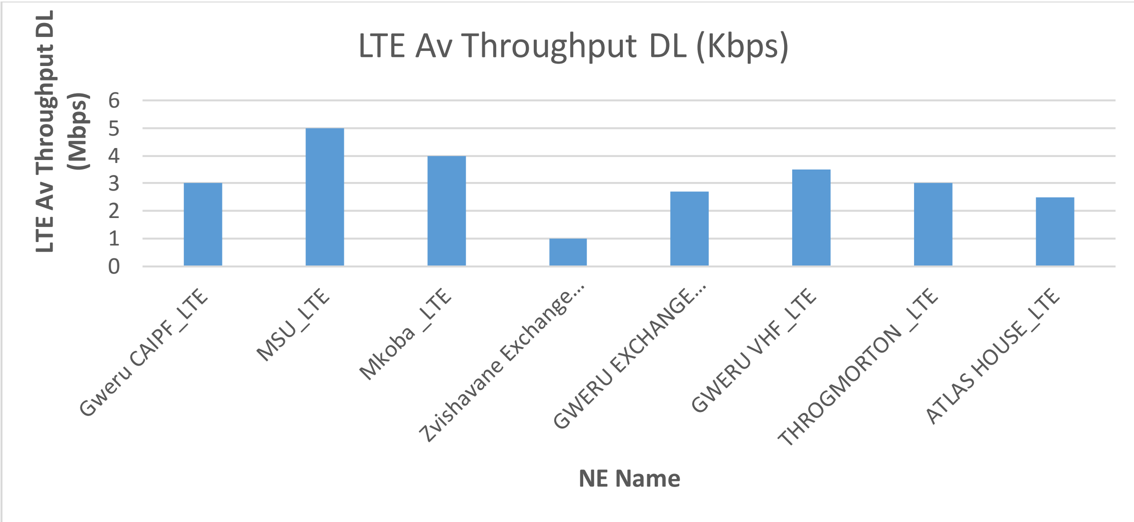

Figure 4.0 LTE Throughput for the target coverage areas

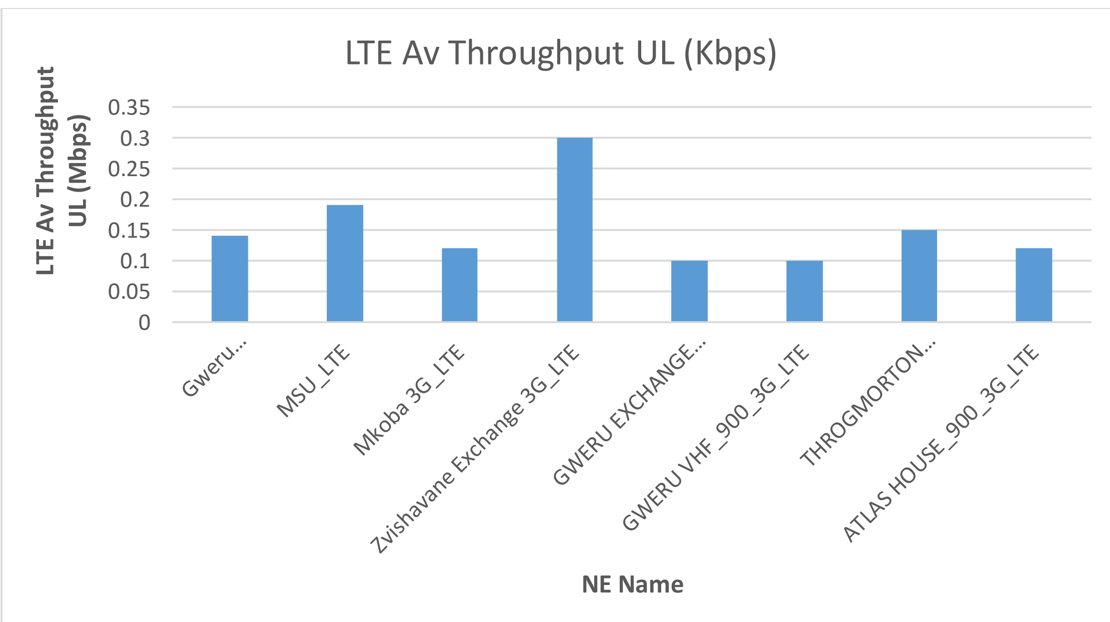

Figure 4.1 LTE UL Throughput for the target coverage areas

4.4 Analysis of the KPIs

4.4.1 KPI Template

Table 4.1 is an extract of Huawei KPI statistics template for 4G. Whilst the MNO has ensured that the vendors have provided standard templates for KPI analysis as required by 3GPP standards it is important to note that their Network Management System (M2000) is zeros for some important KPI statistics data on handovers (HOs). Although this has been attributed to migration issues the impact on network performance assessment and optimization is profound. The lack of data on HOs between the 4G system and the still dominant legacy systems leads subscribers to shun 4G since it cannot handover to 2G and 3G which have wide coverage in the country. In addition, since the MNOs are yet to offer Voice over LTE (VoLTE) and LTE falls back to 3G (CSFB) for voice calls, the templates do not show the call setup success, completion, drop rates of this functionality.

4.4.2 Site Names (NE Name)

The column heading for site names is NE Name for Network Element name. Each site name has either one or more of the suffixes 900, 1800, 3G or LTE. A site name with all the suffixes indicate that LTE has been collocated on existing GSM 900 and DCS 1800 and 3G. Although this is a cost cutting measure as far as new eNB tower construction costs are concerned, the problem with site colocation is the difference in requirements of coverage modelling between the different technologies. Colocation of sites also leads to tower congestion which sometimes leads to antenna blockage and coverage issues for some technologies. In the template MSU has been named as a standalone LTE site, but physical site visits by the author showed the site with both GSM and WCDMA systems. This inconsistence in naming of site leads to problems in determining the actual physical and logical count of the sites within the network system.

4.4.3 Data Speeds (Throughput)

Fourth generation networks have now been operational for one and half years in Zimbabwe with NetOne leading in the network rollout of these networks. When measuring network speeds there are two situations which are of interest, theoretical and the real network. Theoretical speeds are obtained under perfect conditions and real speeds are those expected when the device is used in real live networks where there are some impediments. The theoretical values for 4G DL and UL are 150 Mbps and 50Mbps respectively and in real and live networks it is around 20Mbps for DL and 10Mbps for UL. While MNOs are claiming to offer these speeds their data show a different picture. The DL speed being offered by the networks averages around 3Mbps and that for UL averages around 0.15 Mbps. With not so many users using 4G at the moment the speeds are bound to go down further as more subscribers migrate to 4G. In May 2016 POTRAZ, the Zimbabwe telecommunications regulator issued regulations they cited as Postal and Telecommunications QoS Regulations 2016 [2]. In the document thresholds for 3G HSPA+ DL and UL are set at 5Mbps and 1Mbps, for good QoS, respectively and since LTE has faster speeds than 3G systems the average speeds for LTE shown in Figure 4.0 falls short in meeting the required levels of performance even for HSPA+.

4.4.5 Responses from MNOs' and Subscribers

The author used open ended questionnaires issued to MNOs and various subscriber groups in different locations. The questionnaires were designed to elicit the user perception on the broadband system performance, whether the services being offered to the subscriber by the MNO met his/her expectations and whether the MNOs delivered advertised DL and UL speeds. For the operators the questionnaires were designed to gather information about the MNOs' position in addressing network performance statistics for 4th generation mobile broadband systems against the ever increasing data demands and complexities in user requirements for quality.

4.4.5 MNOs and legacy networks

In wireless legacy networks MNOs were not overly concerned about user perceptions. The primary concern was on getting as much coverage as possible to maximize profits. Networks were deemed performing so long as the system KPI reports indicated good performance. But as networks evolved to cater for increasing data demands so did user complexity. Users started to demand more from networks to meet their expectations. More worrying for the MNOs is the trend that profits are not increasing linearly with demand. MNO systems are carrying so much volumes of traffic yet the profits are actually decreasing.

4.4.6 Services offered

In legacy systems voice was the primary service offered by MNOs. 4G systems offer a variety of services which include but is not limited to the following: IP telephony, mobile web access, HD mobile TV, live streaming and so on. Thus 4G systems offer a rich content of services in comparison to GSM and 3G systems. In reality some of the potential services which can be offered by 4G systems are not yet known. In order to have good ROI from 4G network systems the MNO should be able to offer most of the services delivered by 4G systems otherwise subscribers would continue using 2G and 3G services which are cheaper. The MNOs provided some data on the 4G services they offer as shown below in Table 4.2

Table 4.2 4G Services offered

MNO/Services	**NetOne**	**Econet**	**Telecel**	**TelOne**	**Africom**
VoLTE	No	No			
Mobile web access	Yes	Yes			
Live Streaming	Yes	Yes			
Mobile HDTV	No	To be launched July 2016			
Gaming Sevices	Yes	Yes			

The data provided by the MNOs shows that elementary 4G services are provided by the MNOs. The blank spaces on the table indicate that there no responses from the respective MNO. The table also show that all the MNOs are yet to introduce VoLTE and mobile HDTV which are also some of the primary services that must be offered to customers in 4G services. Since these services are offered by competing technologies like Wi-Fi there is a threat that the services may not find sufficient utilization when they are introduced.

4.4.7 LTE bands

Frequency is a scarce resource and as such it must be utilized with efficiency. The booming in wireless services puts a constraint on the available spectrum. As a result, global regulators are freeing up more spectrum to accommodate emerging technologies since most of the attractive frequency bands are already in use by other systems. Operation for most MNOs is in the licensed 1800MHz band while plans are being mooted to also shift to the licensed 800MHz band and the unlicensed spectrum bands as demand increases as shown in Table below. In most countries (including Zimbabwe) the 1800 band is used for GSM (DCS 1800) which the band is now being shared by the two systems

Table 4.3 LTE frequency bands in use by Zimbabwe MNOs

MNO/LTE Band	NetOne	Econet	Telecel	TelOne	Africom
900	No	No			
1800	Yes	Yes			
2100	No	No			
800	In the future	In the future			
Unlicensed band	In the future	In the future			

4.4.8 Subscriber base

Subscribers are the most important assets of any operator. Operators are constantly improving their services in order to retain their loyal customers and lure new ones. The more subscribers an operator have the more money the operator can generate at from a legacy network perspective. Thus subscriber base is directly linked to network coverage. That is wider your network coverage is the more subscribers you are expected to have if all other factors are kept constant. In 4G systems this might not be the case since some of the 4G services might not be relevant to some sections of the subscribers. Hence it is imperative for MNOs to evolve their KPIs to factor such scenarios. The MNOs could not provide figures of the subscribers who have so far taken up 4G systems. They claimed that it was against company policies divulge such figures for research or for any other purpose.

4.4.9 Aggregation Issues with legacy systems

System aggregation is a very serious problem for MNOs when new systems are introduced. The new systems should be able to seamlessly integrate and be backward compatible with existing ones. Totally replacing a system with a new one is not an option in most cases and has political implications. Aggregation should also be at KPI level since the new system would have its own KPI definition. The MNOs could not provide quantifiable data on the challenges experienced in aggregating legacy networks with the all IP based 4G networks. On KPIs the MNOs pointed out that aggregation was a seriously challenge at the moment due to licensing issues between different vendors providing services to the MNOs.

4.4.10 Colocation of sites

As a cost cutting measure MNOs often deploy new systems on existing infrastructure. The problem with collocation is the availability of space on the towers and rooftop sites. Since 4G systems utilizes the 1800 band which is also used for DCS 1800 systems colocation could not be avoided. Another issue is also the cost of acquiring new sites. Although site collocation is cost effective often leads to main antenna beamwidth blockage on congested towers leading to coverage problems. In addition, different systems require different propagation modelling and colocation of systems leads MNOs to adopt propagation models of earlier systems which leads to more coverage problems. Collocation of sites often leads to a KPI definition that is not in sync with the new system. The respondents could not provide a physical count of collocated sites within their networks, only providing percentages with NetOne 60% and Econet 50% collocated sites.

4.4.11 4G Services Marketing

As early as 2010 MNOs around the world started talking about 4G LTE although systems they deemed 4G were later variants of 3G which did not meet 4G standards. Thus as early as 2012 some MNOs started advertising that they had operational 4G networks but in reality these were HSPA+ networks which offered better speeds quality but did not meet the standards specification for 4G. In Zimbabwe 4G systems deployment started in late 2014 and 4G networks were operational in early 2015. The question was then whether MNOs did enough marketing of the new product to its subscribers. With an overwhelming demand for data from subscribers and with 4G able to meet these demands it is imperative that MNOs market 4G and the rich content of services it is able to offer. Quantifiable data on marketing could not be obtained from the MNOs but since this could be obtained directly from system users this question was also posed to the subscribers.

4.4.12 Service Level Agreements (SLA)

The network service provider role is to optimize the capacity available through service level agreements based on the QoS. As the user moves across access networks the issue of mapping resource reservations between different networks to maintain QoS becomes crucial. As a result, it is important for MNOs to negotiate SLA contracts relevant to the QoS requirement. KPIs for 4G should show SLA since in developing markets some of the 4G services are yet to find relevance. Thus most 4G deployments would start in urban and suburban areas where it is deemed the services are most wanted. The MNOs could not provide numerical figures on SLA and the criteria the use to come with SLA.

4.4.13 Network Performance Indicators (KPs)

KPIs are metrics that are used to gauge network performance. Network outputs are compared with thresholds below which the network is deemed not to be performing to standards. Network KPI analysis requires a thorough knowledge of the system since they involve all the system nodes especially for 4G systems. From KPI analysis engineers can carry out network planning, troubleshooting, optimization and controlled network expansion as demand increases. Thus KPIs are important during all the network phases. MNOs pointed out they perform KPI analysis on a daily basis with KPIs like the total traffic per site per day data volumes being sent to management for key decision making. A sample of daily traffic totals for 3G is shown in Figure 4.3 below.

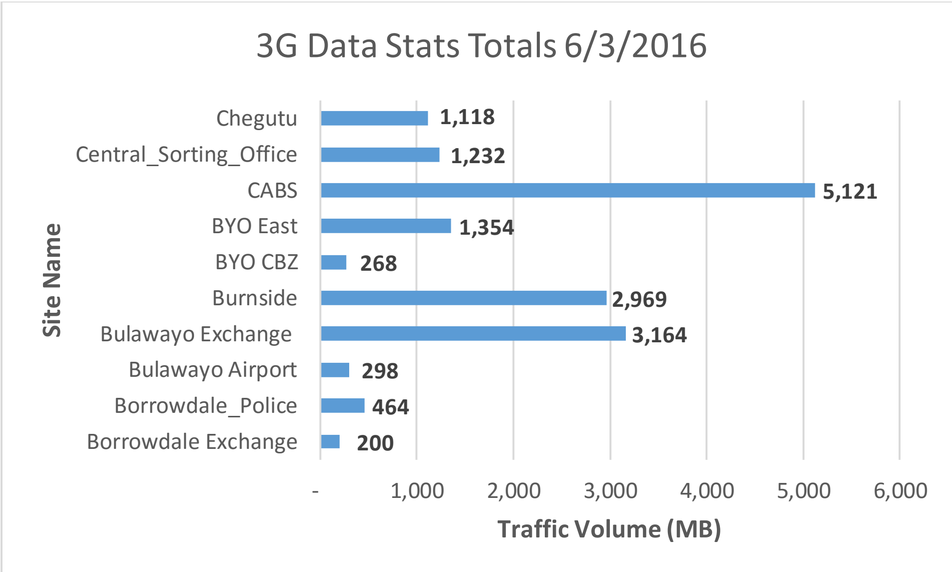

Figure 4.2 Sample of total traffic volume for 3G data sent to management for analysis

4.4.14 KPI reflection of user experience

Since the research is based on the user QoE of the network the question was centered on whether the MNOs' KPIs reflected the true experience of the users. QoE involves a lot of factors most of which cannot be quantified. Sometimes network performance metrics can meet all the required thresholds but without meeting the users' QoE. Users' QoE can only be gauged by profiling and factoring the users' requirements in the KPIs. Though it is difficult to profile each individual user MNOs can get user profile based on clusters. From KPI data provided by MNOs in Table 4.1.0 it is clear that the MNOs are not doing enough in coming up with KPIs that reflect user QoE. In addition, some KPI data are missing from the Table thus making it difficult for troubleshooting and optimization.

4.4.15 Evolution of KPIs to meet the user QoE requirements

The question was based on MNOs' ability to integrate KPIs that reflect the users' perception of the service quality offered to them by the SPs. Since network performance indicators are not enough to give the whole quality picture MNOs should evolve their KPIs to meet the complex requirements of system users. User KPIs like IP address utilization and App coverage should be included in the KPI template. Inclusion of QoE KPI is a complex task since it would require a lot of subscriber profiling but nevertheless should be carried out if the MNO is to avoid high churn rate in 4G systems. 100% of the respondents pointed out that they are still doing some researches on how to factor user perceptions in their KPIs.

4.5 Data from MNO subscribers

Questionnaires for subscribers were issued to various social groups as pointed out in Section 4.1. Since the network systems are intended for use by subscribers it is important for MNOs to take into consideration the perceptions of the users in view of system performance. User requirements has evolved with network evolution and with various competing technologies offered by various competitors the need to retain and lure subscribers has never been higher. As systems are rapidly shifting from being voice centric to data optimized systems and with infinite applications from content providers, users need fast connectivity anywhere, anytime.

4.5.1 LTE capable devices

With smartphone mobile penetration in Zimbabwe around 85% [3] and the mobile device now being the primary device for internet connectivity, the rapid deployment of 4G networks was expected to take advantage of the rise in usage of smartphone mobiles. In mature markets MNOs sell liaise with mobile equipment manufacturers to retail mobile devices on contract bases. This increases the penetration of mobile devices on the market and ties the subscribers to the MNO and hence increases the subscriber base. Table 4.4 and Figure 4.3 shows the number of 4G capable phone users in the various social groups interviewed. 78% of the respondents use 4G capable and 22% use legacy system networks. Around 85% of the owners of the phones are in an urban setup with the rest in rural setup.

Table 4.4 Respondents with 4G capable and without 4G capable phones

	Questionnaires Issued	4G Capable Phone	No 4G Capable Phone
Suburban(Gweru)	15	14 (93%)	1 (7%)
MSU	20	20 (100%)	0 (0%)
Mkoba	15	11 (73%)	4 (27%)
Zvishavane	10	5 (50%)	5 (50%)
Vendors(Gweru)	10	6 (60%)	4 (40%)
Vendors(Harare)	10	9 (90%)	1 (10%)

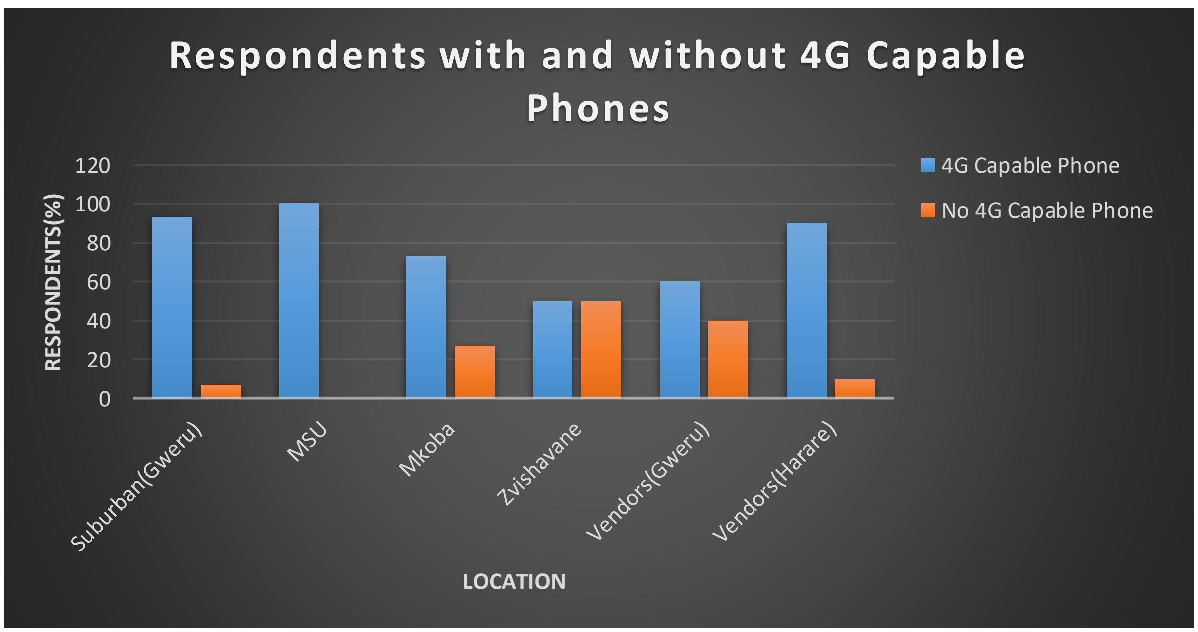

Figure 4.3 Graph of respondents with and without 4G Capable Phones

4.5.2 Knowledge of 4G

Users can only utilize a system whose capabilities they understand. Though a system can offer so much it might fail to attract users due to lack of knowledge on the part of the users. It is against this background that the respondents were asked if they had a general knowledge about 4G systems. The results are shown in Table 4.1.3 and Figure 4.1.3 below. Out of 80 respondents 33% had a general knowledge of 4G systems of which 60% are from the suburbs. 67% of the respondents had no knowledge of 4G systems at all. These figures show that the MNOs are deploying a system that is not being fully being utilized due to lack of knowledge of system capabilities on the side of subscribers.

Table 4.5 4G system knowledge

	Questionnaires Issued	Knowledge of 4G	No Knowledge at all
Suburban(Gweru)	15	9 (60%)	6 (40%)
MSU	20	6 (30%)	14 (70%)
Mkoba	15	3 (20%)	12 (80%)
Zvishavane	10	3 (30%)	7 (70%)
Vendors(Gweru)	10	2 (20%)	8 (80%)
Vendors(Harare)	10	4 (40%)	6 (60%)

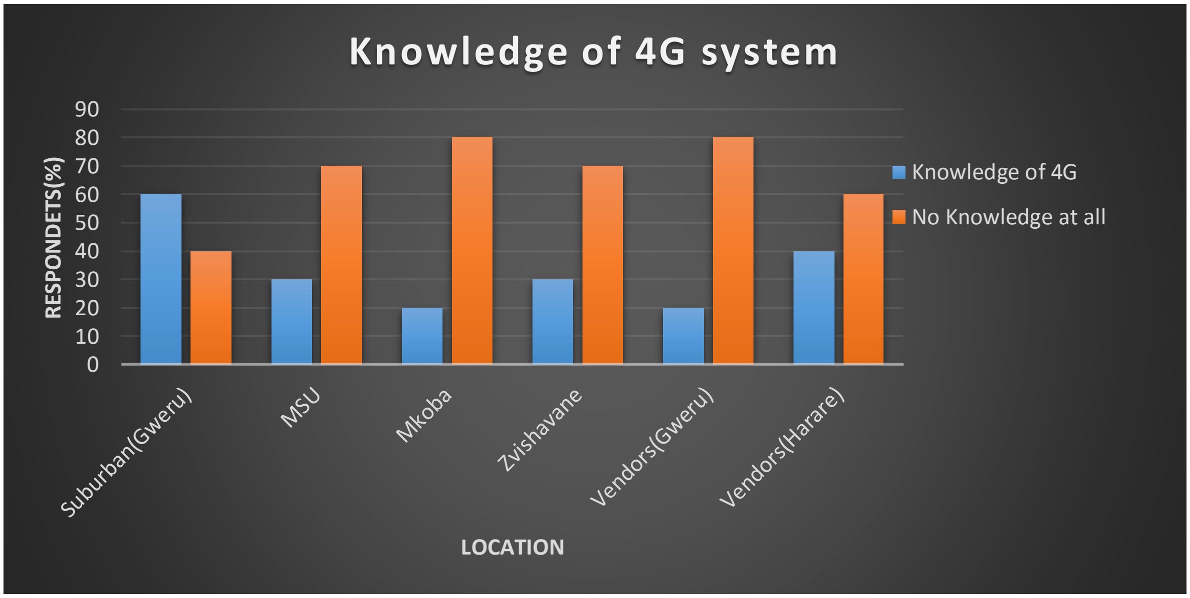

Figure 4.4 4G system knowledge

4.5.3 Mobile Phone Usage

Users use their mobile phone to access different services. In recent years data traffic has surpassed voice traffic and the Zimbabwean mobile market is no exception. Optimization of mobile networks should be optimized based on usage of the system resources by the users. Respondents were asked what they use their mobile phones mostly for. 83% of the respondents use their phones for making voice calls, another 85% for social activities like Facebook and WhatsApp and 21% for research and other activities. It can be observed from the data that usage of different services depends on location and social group. This should also be included in the KPIs and help in resource allocation.

Table 4.6 Mobile Phone Usage

	Questionnaires Issued	Voice calls	Social	Research/Other
Suburban(Gweru)	15	9 (60%)	12 (80%)	2 (13%)
MSU	20	11 (55%)	20 (100%)	19 (95%)
Mkoba	15	14 (93%)	12 (80%)	1 (7%)
Zvishavane	10	9 (90%)	8 (80%)	1 (10%)
Vendors(Gweru)	10	10 (100%)	8 (80%)	3 (30%)
Vendors(Harare)	10	10 (100%)	9 (90%)	2 (20%)

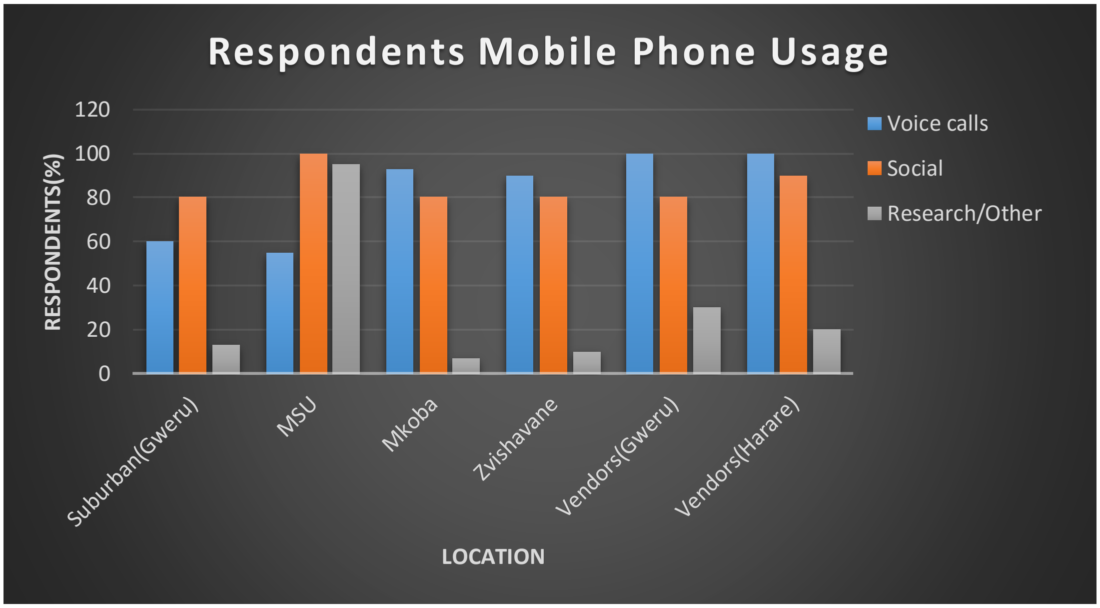

Figure 4.5 Service usage

4.5.4 User perception of speeds between 4G and 3G systems

4G offers significant improvements in speeds compared to earlier systems. The respondents were asked about noticeable changes in speeds between 3G and 4G systems. The responses are shown in Table 4.7 and Figure 4.6 below. Though the KPIs may indicate improvements in speeds from 3G to 4G systems the users may not feel the same especially if the improvements are not so significant. Most operators are faced with backhaul problems in their 4G systems. The speed of network deployment is in most circumstances more than the speed of improving shared backhaul facilities. This has the overall impact of limiting the performance of 4G systems. Users feel that the system is not performing up to their expectations and this impacts negatively on QoE and may result in high churn rate.

Table 4.7 4G vs 3G speed comparison

	Questionnaires Issued	There is improvement	No improvement	Not sure
Suburban(Gweru)	15	9 (60%)	6 (33%)	1 (7%)
MSU	20	14 (70%)	4 (20%)	2 (10%)
Mkoba	15	3 (20%)	6 (40%)	6 (40%)
Zvishavane	10	1 (10%)	3 (30%)	6 (60%)
Vendors(Gweru)	10	1 (10%)	9 (90%)	0 (0%)
Vendors(Harare)	10	6 (60%)	2 (20%)	2 (20%)

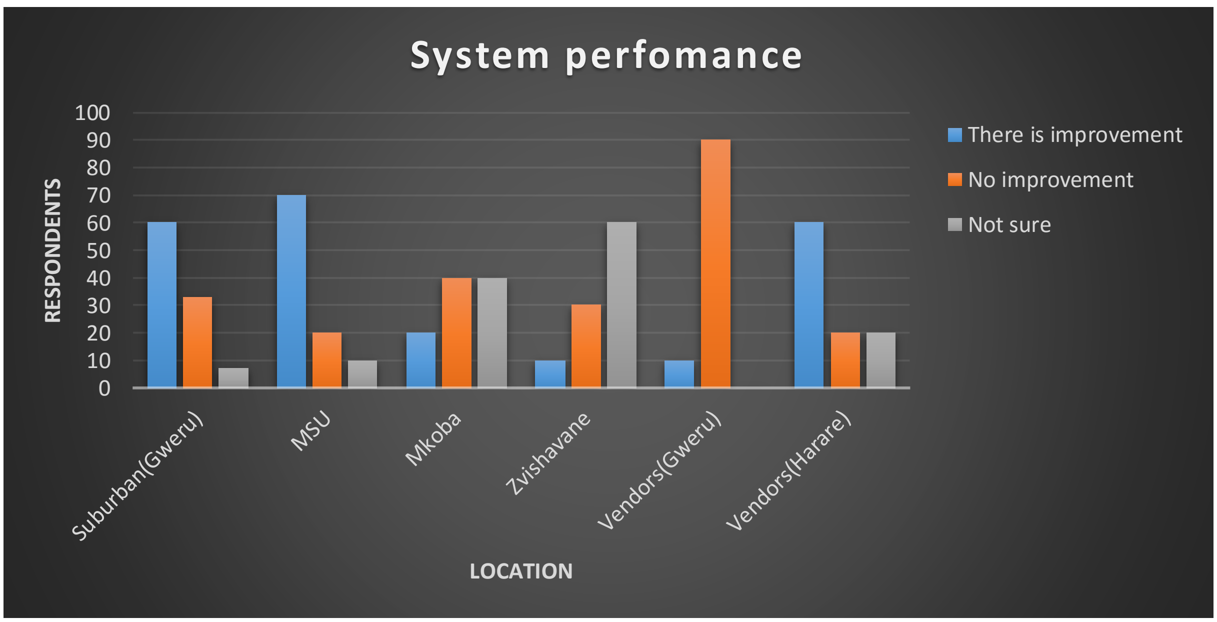

Figure 4.6 4G vs 3G speed comparison

4.5.5 Handover issues

Handover is critical issue in mobile cellular systems. As users move between cells, call or data session continuity is very important. HO failures leads to subscriber frustrations as their call or data sessions may be temporarily interrupted as they move between cells. As the systems evolve from legacy systems to all IP networks intra and inter- system HOs became an issue due to integration complications. Respondents were asked about noticeable changes in data and call sessions when mobile and the responses are shown in Table 4.8 and Figure 4.7 The high interruption rate in Table 4.8 is consistent with KPI data from the MNO which does not indicate intra-system handovers. Users do not like their active data and voice sessions to be interrupted and they perceive this as poor service from the service provider.

Table 4.8 Handover Issues

	Questionnaires Issued	Call or data session interruption	No interruption	Not sure
Suburban(Gweru)	15	3 (20%)	9 (60%)	3 (20%)
MSU	20	15 (75%)	2 (10%)	3 (15%)
Mkoba	15	6 (40%)	6 (40%)	3 (20%)
Zvishavane	10	1 (10%)	3 (30%)	6 (60%)
Vendors(Gweru)	10	6 (60%)	3 (30%)	1 (10%)
Vendors(Harare)	10	7 (70%)	3 (30%)	0 (0%)

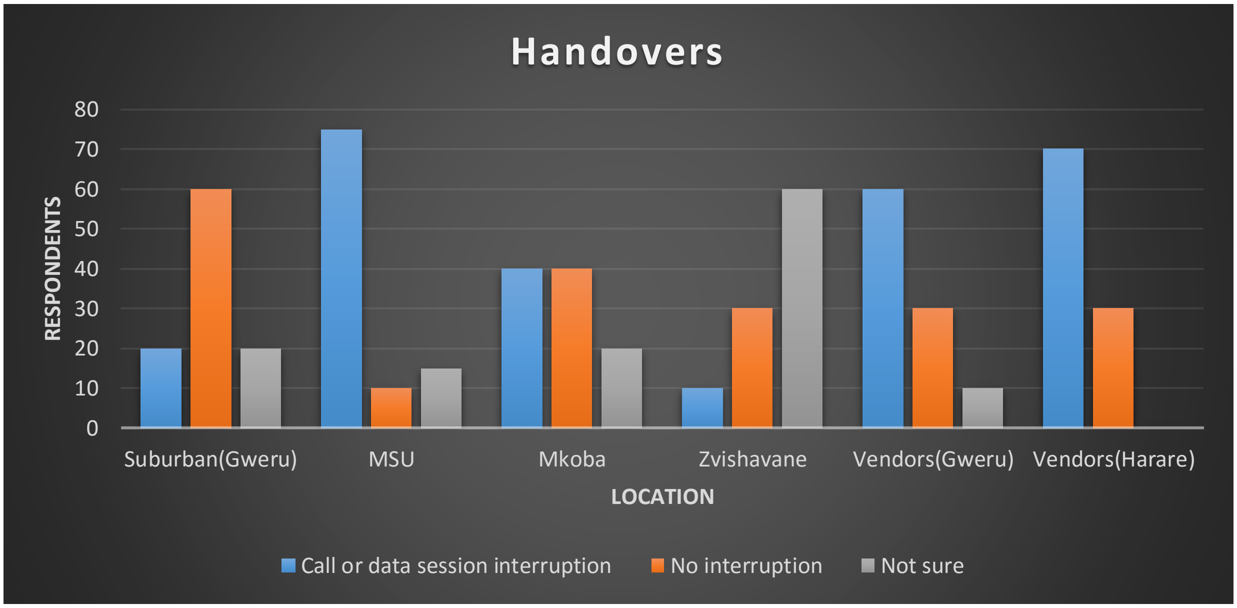

Figure 4.7 Handover Issues

4.5.6 User satisfaction

User satisfaction in terms of system performance is key in eliminating churn rate in the face of tight competition in the mobile telecommunications market. Users will never be loyal to a system which does not meet their levels of satisfaction. User satisfaction is difficult to quantify. Service complaints to customer care can be used as a measure of system users' satisfaction although some dissatisfied customers may opt for another operator without putting forward complaints. The respondents were asked if they were satisfied with system performance. Does the system really deliver to levels which meet their expectations? Are their complaints attended to in satisfactory time? The responses are shown in Table 4.1.9 and Figure 4.1.9. The data show that most system users are not satisfied with how the 4G system is performing. This leads to high churn rate and loss of revenue as subscribers opt for better services from competing technologies or companies.

Table 4.9 User levels of satisfaction

	Questionnaires Issued	Satisfied	Not satisfied	Not sure
Suburban(Gweru)	15	8 (53%)	7 (47%)	0 (0%)
MSU	20	6 (30%)	9 (45%)	5 (25%)
Mkoba	15	5 (33%)	7 (47%)	3 (20%)
Zvishavane	10	1 (10%)	8 (80%)	1 (10%)
Vendors(Gweru)	10	3 (30%)	6 (60%)	1 (10%)
Vendors(Harare)	10	5 (50%)	3 (30%)	2 (20%)

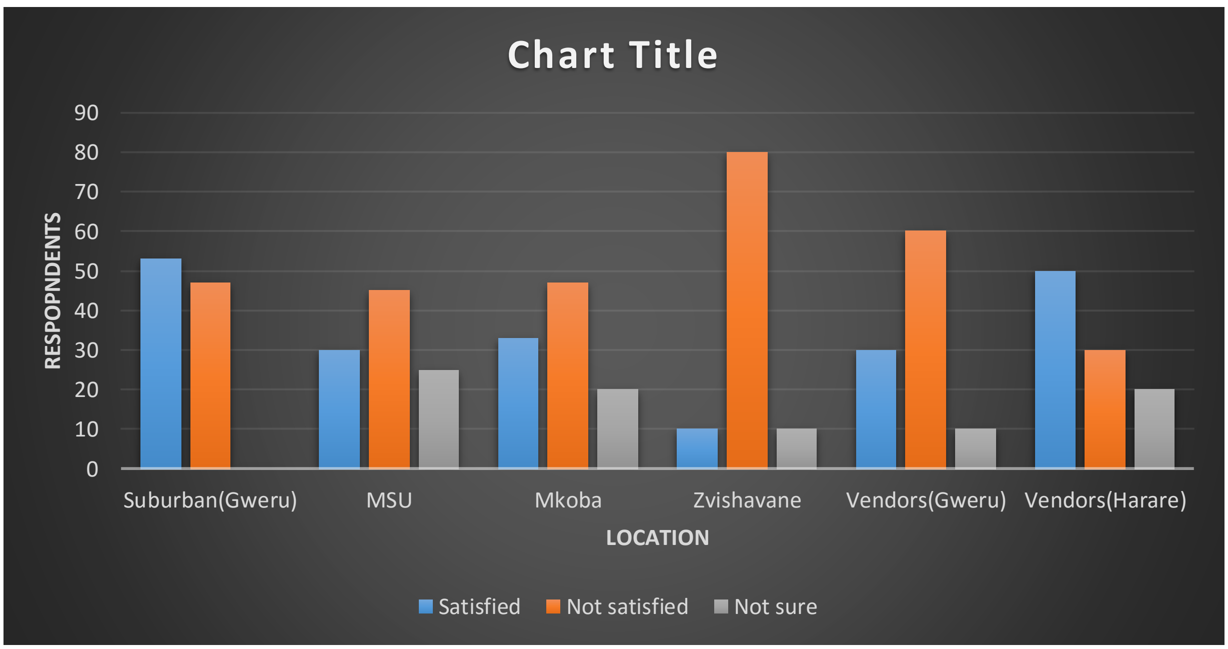

Figure 4.8 User levels of satisfaction

4.6 Summary of findings

Whilst 4G LTE deployment has been aggressive across all network providers, the system might suffer from underutilization thereby negatively impacting on return on investment. At the same time subscribers have mobile devices with overwhelming capabilities but underutilize them by using services which can be accessed by using cheaper and simper phones.

MNOs are only concerned with network performance from the perspective of functionality with little or no regard of subscribers' criteria for good performance.

CHAPTER 5

CONCLUSION

5.1 Summary of findings

The emergence of 4G LTE mobile broadband systems has brought unlimited access to data services to mobile subscribers. While later variants of 3G systems like HSPA+ offered relatively higher data speeds compared to 2G systems, they are failing to cope with the ever increasing data demands from subscribers. New smartphones, tablets, and machine to machine devices are providing a compelling mobile experience by allowing to engage their social networks, conduct business and manage their day to day lives. 4G LTE mobile broadband systems offers data speeds in the range of Gbps and a variety of services ranging from voice, video streaming, online gaming and a multitude of other services.

The main challenges faced by MNOs is how best can they balance business objectives and good network performance. Network performance criteria is also evolving with evolving systems more so with ever increasing subscribers. Subscriber QoE has become as important as the software and hardware entities of the network. It was in this context that this research was carried out. To evolve traditional KPIs integrating them with user QoE requirements.

One of the most critical challenges faced by MNOs is commitment in understanding the networks they are deploying. Most of the technical work is left in the hands of equipment vendors. The problems of such cases manifest during post deployment optimization and expansion during the lifecycle of the network. MNOs are forced to consult for expert advice at a cost for network optimization and controlled expansion.

Faced with competition from other service providers the deployment of 4G systems is carried out with speed without consideration of whether it is going to be used or not. The goal of MNOs is to deploy 4G on every 2G or 3G site. The result is a severely underutilized network and high OPEX.

MNOs are now carrying large volumes of data traffic on their networks to the extent that they assume that all their subscribers are ready to use 4G LTE. This leads MNOs to believe that all their subscribers know about the new service. But the results in chapter 4 clearly demonstrate that many subscribers know nothing about 4G though they use devices that are LTE capable. This shows that MNOs are not doing enough in marketing their services.

MNOs are still using traditional KPIs for network performance analysis and evaluation. Traditional KPIs may show the metrics meeting all the set thresholds but users still complaining about poor service. This means that MNOs are not meeting subscribers' criteria for quality of service.

5.2 Recommendations

a) MNOs should carry out feasibility studies before deploying networks. The studies should include the readiness of subscribers in different locations and different social groups in accepting the technology.

b) MNOs should market their services before, during and after deployment of a new technology. Thus subscribers will know the capabilities of such systems and start utilizing them making the MNOs have quick return on investments.

c) MNOs should optimize existing network technologies rather than fully committing to new technologies when existing ones are still to achieve wide coverage.

d) MNOs should define their 4G performance metrics based on inputs from subscribers. Thus traditional KPIs should be mapped to users' QoE requirements. Good network performance should be based on meeting KPI thresholds and having very few complaints from users.

e) Faced with overwhelming data traffic and increasing subscriber base, MNOs need to be in full control of KPI definition. KPI definition should reflect target market characteristics.

f) With rapid technological evolution of mobile systems MNOs should have research and development centers where staff learn and innovate on new ideas rather than relying on consultancy work and equipment vendors.

g) MNOs need to take advantage of the rich content of services possible with 4G systems by integrating all the services rather than underutilizing the system by offering services that can be offered by legacy networks.

h) MNOs need adopt an open door policy for exchange of information with academic research institutions. Solutions to various problems can come from the academic researches.

5.3 Limitations

The study required a lot of data on 4G KPIs and inputs from MNOs. MNOs were not willing to release the data citing company policies. Some MNOs were willing to release data but in a time frame in which the requirement period for the academic study would have lapsed.

The author would have liked to interview various departments in telecommunication companies like marketing, customer care, finance but was not able to do so because company policies did not allow employees to divulge any information related to company operations

5.4 Further Research

Since all MNOs in Zimbabwe are yet to offer various services that are possible with 4G systems like VoLTE and HDTV further research activities should be conducted on the acceptable level performance requirements of these functionalities from the uses' perspective.

Appendix A

Sample Open Ended Questionnaire

Midlands State University

Department of Physics and Telecommunications

BSc Telecommunications Honours Degree

Research Questionnaire for mobile cellular subscribers

By Maposa Darlington doing a research on the Evolving 4G LTE KPIs to improve user QoE

1. What do you understand by 4G?

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2. Did your MNO tell you about 4G and its capabilities?

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3. Can your phone connect to a 4G network?

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4. Where do you mostly use your phone?

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5. What mostly do you use your phone for? Voice calls, social or other uses?

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……… ………………………………………………………………………………………...

6. Are there any noticeable changes between 3G and 4G download and uploading speeds?

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7. When moving in a vehicle and you are on a call or browsing the internet does the call or internet connection sometimes interrupted (HO issues)?

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………………………………………………………………………………………………………

8. Are there any problems encountered when you receive a call on your 4G phone whilst you are browsing the internet?

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9. At what time of the day do you mostly use your mobile phone?

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10. Have there been any significant changes in the price of calls between 3G and 4G and do you think these changes are justified?

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11. Are you satisfied with the services you are being offered by your MNO if not what are the improvements you want the MNO to implement?

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Completed by:

Signature ……………………………………… Date……………/02/2016…

Appendix B

Sample Open Ended Questionnaire

Midlands State University

Department of Physics and Telecommunications

BSc Telecommunications Honours Degree

Research Questionnaire for mobile cellular professionals

By Maposa Darlington doing a research on the Evolving 4G LTE KPIs to improve user QoE

1. What kind of services do you offer to your subscribers?

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2. What is the trend in data and voice traffic in recent years?

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3. Can you justify 4G deployment when 3G is not found in most areas in Zimbabwe?

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4. Did the MNO market its 4G product and its capabilities to its subscribers?..

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5. In terms of 4G users so far, do you think the subscribers have embraced 4G LTE………………………

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6. What is the subscriber base in terms of numbers of the MNO?

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7. What version of LTE are you deploying and what is/are the frequency bands for the system?

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6. What are challenges in aggregation issues with legacy networks?

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7. What are KPIs and who defines the KPIs for your MNO?

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8. Do you think network performance metrics are enough in reflecting users' perception of the system performance

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9. Do your network performance metrics reflect users' perception of QoE?

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Completed by:

Signature ………………………………………

Position:……………………………………………………………………………………………...

Qualification:………………………………………………………………………………………...

Date……………/05/2016…