ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

Techno-Economic Analysis of LTE Deployment: A Case Study of Addis Ababa, Ethiopia

By

Haimanot Desalegn

Advisor

Dr.-Ing. Dereje Hailemariam

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1. Introduction

Over the years, users' requirements for higher data rates, access to new and innovative services and applications have resulted in faster and continuous evolution of wireless technologies. The technology advancement tried to meet various requirements such as reduced latency, increased performance with substantial reduction in costs and seamless mobility. However, transitional technologies such as General Packet Radio System (GPRS) and Enhanced Data for Global System for Mobile Communications (GSM) Evolution (EDGE) were needed between two generations as huge gap in technical requirement existed [1].

GSM is one of the main standards for second generation (2G) cellular networks [2]. It handles voice efficiently but provides limited support for data and internet applications. A data connection is established in just the same way for a regular voice call; the user dials in and a circuit-switched connection continues during the entire session. The circuit switched feature of GSM coupled with the limitation that users are billed for the time that they are connected, created a need for packet data for GSM.

2.5 generation (2.5G) was introduced to allow service providers to provide a better data service than 2G, smoothly move from 2G to third generation (3G) systems and provide customers limited 3G features before it is fully available. 2.5G is an informal term invented solely for marketing purposes, unlike 2G and 3G which are officially defined standards by International Telecommunication Union (ITU) [2].

GPRS built on GSM technology is one of 2.5G technologies that applied a packet radio principle to transfer user data packet in an efficient way. It also uses improved digital radio with relatively new modulation techniques to increase data rates, system efficiency and overall performance [3].

EDGE is also known as 2.75 generation (2.75G). It is a superset to GPRS and can function on any network with GPRS deployed on it, provided the carrier implements the necessary upgrades. The objective with EDGE is to offer higher bandwidth efficiency using the same channel as GPRS. This higher bandwidth efficiency is achieved using a different modulation scheme from GPRS.

3G is a technology based on ITU initiative for a single global wireless standard called International Mobile Telecommuncation-2000 (IMT-2000) [4]. The basic feature of 3G technology include enhanced audio and video streaming, higher data speed, video-conferencing support, web and Wireless Application Protocol (WAP) browsing at higher speeds and TV through the Internet (IPTV).

Long Term Evolution (LTE) as defined by the 3rd Generation Partnership Project (3GPP) is a highly flexible radio interface with the objective of meeting the increasing performance requirements and quality of service (QoS). Some of the key features in its first release, 3GPP Release 8, include high spectral efficiency, very low latency, support of variable bandwidth and simple protocol architecture [5].

LTE is quickly growing on the mobile broadband market worldwide presenting itself as the more cost-effective and spectrally efficient evolutionary path to herald the next generation of high-speed IP-based communication networks, the fourth generation (4G) [6]. This technology is about to be introduced in Ethiopia in order to support the ever increasing capacity demands. However, in the light of analyzing migration the technical relevance and economic viability of this technology should be critically investigated.

1.1 Literature Review

On his M.Sc. thesis, Timo Sumra carried out a techno-economic analysis to determine the feasibility and competitiveness of IEEE 802.16a-based Fixed Wireless Access (FWA) networks, such as the Worldwide Interoperability for Microwave Access (WiMAX), in providing broadband internet access to residential customers [8]. The popularity of broadband internet access services has increased significantly among the subscribers at that time. And FWA networks have been proposed as a possible competitor to other broadband access technologies, such as Digital Subscriber Line (DSL) system. Despite its popularity, Timo Sumra proved the cost structure of FWA network was not competitive with DSL in densely populated urban and suburban areas. This was mainly due to the high equipment prices, relatively low coverage and range of the networks. Eventhough deployment of FWA was found unprofitable for that specific time; his analysis indicated FWA networks will provide access also for portable and mobile terminals in the near future making the business case more favourable. Similar works in [7], [8], [9], [10] and [11] were carried with which they indicated the importance of techno-economic analysis before the introduction of various technologies.

Similarly, various works have been carried out on LTE planning which is one part of this thesis. Based on general wireless cellular network planning process, Abdul Basit suggested dimensioning methods for LTE network describing the possible models and tools for coverage as well as capacity estimations [14]. Bethelhem Seifu studied and described the nominal radio access network planning in LTE, modelling approaches for the case of Addis Ababa in specific, in [15]. She used COST 231 W/I propagation model to carry out LTE planning in her sample site around National Hotel. With her analysis, she suggested proper network planning with real-environment factors for nominal coverage planning. Her result indicated the coverage estimation was refined by a value greater than 400meters which substantially brought reduction in the number of sites to cover the area. Her work also proposed optimization of the existing GSM network or even implementing of newly developed cellular technologies such as LTE will surely improve the coverage area which is used as an input in this thesis.

1.2 Statement of the Problem

Technological advancements in a new technology only cannot always guarantee its acceptance by subscribers as its introduction involves a lot of uncertainties. These uncertainties are usually associated with customer’s slow awareness about the benefits of a new technology. Thus, techno-economic analysis has to be done to ensure the feasibility of the technology considering defined time duration. Techno-economic evaluation incorporates results from both investment and performance analysis with the aim of selecting the most cost-efficient solution for a certain scenario and performance requirements.

This thesis intends to indicate the importance of undertaking a techno-economic analysis before introducing a new technology into a market inorder to guarantee its profitability.

1.3 Objective

1.3.1 General Objective

The main objective of this thesis is to study and describe how to undertake a techno-economic analysis of a new technology that is about to be implemented into a potential market. It is the intention of the work to understand the different techno-economic modeling approaches and required input and output parameters. Furthermore, this thesis work is done to provide techno-economic analysis of LTE in Addis Ababa, Ethiopia by considering a sample site.

1.3.2 Specific Objectives

Specifically, it aims to:

- Undertake network performance evaluation of existing network. The selected deployment location which is considered in this thesis is 2Km radius from Tekelehaimanot roundabout in Addis Ababa ;
- LTE radio interface dimensioning to determine the number of sites to cover the service area;
- Calculate costs related to CAPEX and OPEX and;
- Perform investment and performance analysis to determine its feasibility and profitability.

1.4 Methodology

One of the research method used in this thesis work is studying books, 3GPP standardization documents, different Institute of Electrical and Electronics Engineers (IEEE) articles and journals.

Review on previous related studies is also used for the indication of the importance and significance of techno-economic analysis. Data collection, estimation and analysis is used in performance evaluation, LTE planning and also in the techno-economic analysis part of this thesis.

1.5 Scope and Limitation

1.5.1 Scope of the Thesis

This thesis is a case study addressing the importance of techno-economic analysis before introducing a new technology to the market. It should be able to indicate why a new technology is needed in the first place and give insight into the different techno-economic models.

1.5.2 Limitations of the Thesis

This thesis has some limitations mainly due to inability to access data concerning the exact number of subscribers. In addition to this, total cost of LTE deployment had to be estimated based on previous experiences because it was impossible to find network equipment's cost due to confidentiality reasons.

1.6 Contribution

Contributions of this thesis work are:

- Asses the network performance of the existing cellular networks in the selected area;
- Identify and recommend the best techno-economic model for the introduction of a new technology in the selected area and Ethiopia as well;
- Calculate CAPEX and OPEX costs, revenues and evaluate the profitability of the project for two scenarios (VOIP only service and mixed service).

1.7 Thesis Layout

This thesis work is organized in seven chapters. Chapter one introduces objectives, methodologies and scope; and Chapter two deals with performance evaluation of an existing network. Chapters three and four introduce LTE technology and give insight about LTE dimensioning, coverage and capacity based site determination. The importance of techno-economic analysis and the different techno-economic models are explained in Chapter five while Chapter six includes detail work on the performance evaluation of the selected network, coverage and as well as the profitability analysis.

Finally, summary of results, analysis, conclusion and recommendation for future work are included in Chapter seven.

2. Network Performance Evaluation

Network performance refers to measures of service quality of a network. Once a network is made operational, the next concern will be whether or not QoS standards are met and there are different ways to measure the performance of a network [16]. Before dealing with network performance evaluation, a brief introduction into GSM and 3G network is given below.

2.1 Introduction to GSM

GSM is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe protocols for 2G digital cellular networks used by mobile phones. It has maximum data speeds of 9.6 Kbit/s and is based on circuit switching technology [17]. System architecture and multiple access scheme of GSM network is discussed below.

2.1.1 System Architecture

GSM network consists of three main components that are Mobile Station (MS) carried by the subscriber, Base Station Subsystem (BSS) which controls the radio link with mobile station and Network and Switching Subsystem (NSS) that is responsible for mobility management and switching of calls between mobile users, and between mobile and fixed network users [18]. A brief introduction about the above components and subsystems is given below.

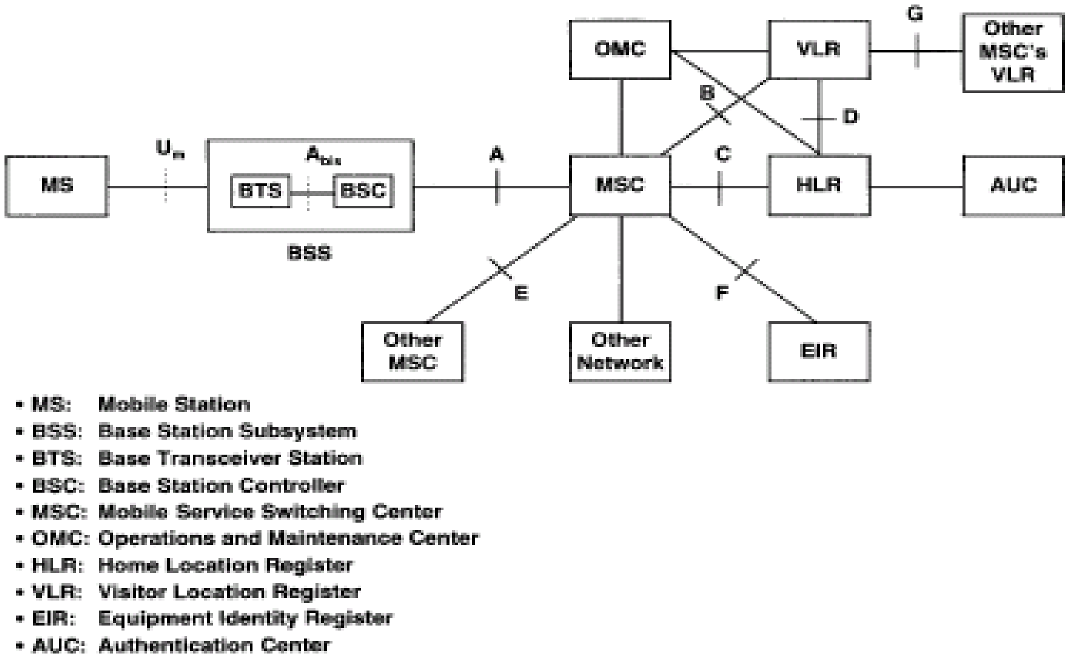

Figure 2-1: Basic structure of GSM network [19]

Mobile Station (MS)

MS consists of Mobile Equipment (ME) such as hand portable and vehicle mounted unit and Subscriber Identity Module (SIM), which contains the entire customer related information such as identification, secret key for authentication, etc...

Base Station Subsystem (BSS)

BSS consists of Base Transceiver Station (BTS) that is responsible for radio link protocols with the Mobile Station. It also contains Base Station Controller (BSC) that controls multiple BTSs and manages radio channel setup, and handovers. The BSC is the connection between the MS and Mobile Switching Center (MSC).

Network and Switching Subsystems (NSS)

NSS has MSC as its central component that operates all switching functions for the mobiles within its jurisdiction. It manages the location of mobiles, switches calls, controls handover between BSCs, resource management, interworks with and manages network databases, collects call billing data and sends to system and also collects traffic statistics for performance monitoring.

Home Location Register (HLR)

HLR contains all the subscriber information for the purposes of call control, and location determination. There is logically one HLR per GSM network, although it may be implemented as a distributed database.

Visitors Location Register (VLR)

VLR is a temporary storage while the particular subscriber is located in the geographical area controlled by the MSC/VLR. It contains only the necessary information provision of subscribed services.

Authentication Center (AuC)

AuC is protected database that stores the security information for each subscriber (a copy of the secret key stored in each SIM).

Equipment Identity Register (EIR)

EIR is a list of all valid mobile equipment on the network.

Operation and Maintenance Center (OMC)

Network control functions are monitored and initiated from an OMC. The OMC configures the BTS through the BSC and allows the operator to check the attached components of the system.

2.1.2 Multiple Access Schemes

Multiple access techniques are used to allow a large number of mobile users to share the allocated spectrum in the most efficient manner. As the spectrum is limited, the sharing is required to increase the capacity of cell or over a geographical area by allowing the available bandwidth to be used at the same time by different users.

GSM utilizes a combination of frequency division multiple access (FDMA) and time division multiple access (TDMA) on the air-interface.

Frequency Division Multiple Access (FDMA)

FDMA is the most straightforward of the multiple access schemes that have been used. As a subscriber comes onto the system, or swaps from one cell to the next, the network allocates a channel or frequency to each one. In this way the different subscribers are allocated a different slot and access to the network. As different frequencies are used, the system is naturally termed Frequency Division Multiple Access.

Time Division Multiple Access (TDMA)

The second system came about with the transition to digital schemes for cellular technology. Here digital data could be split up in time and sent as bursts when required. As speech was digitised it could be sent in short data bursts and any small delay caused by sending the data in bursts would be short and not noticed.

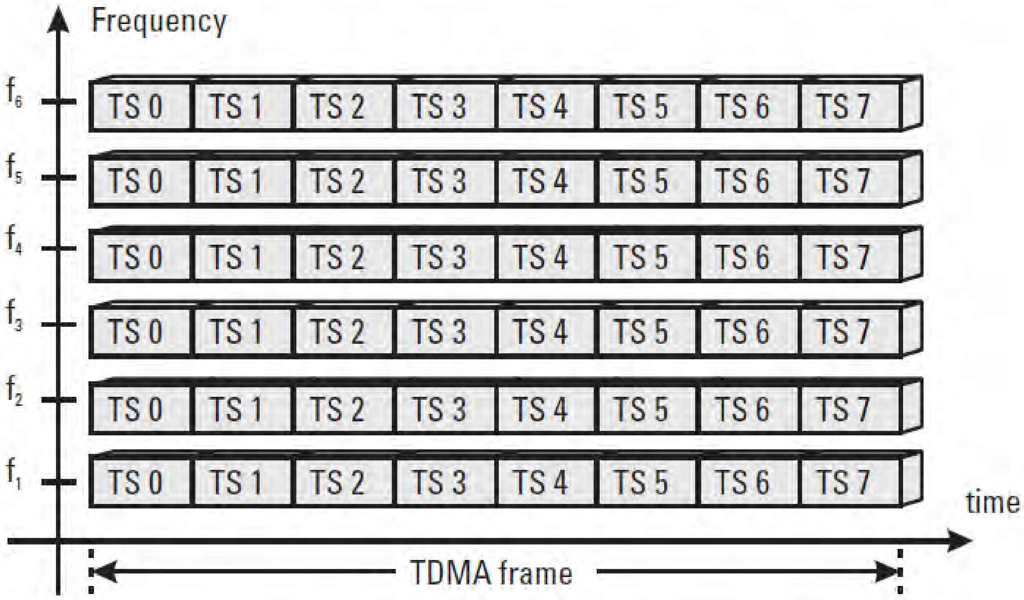

Figure 2-2: The FDMA/TDMA structure of GSM

Each subscriber would be allocated a different time slot in which they could transmit or receive data. As different time slots are used for each subscriber to gain access to the system, it is known as time division multiple access. As this scheme only allows a certain number of users to access the system, another channel is used in GSM systems that will have FDMA operation as well.

2.2 Introduction to 3G Network

3G is a wireless industry term for a collection of international standards and technologies aimed at increasing efficiency and improving the performance of mobile wireless networks. 3G telecommunication networks support services that provide an information transfer rate of at least 200kbits/s [2]. System architecture and 3G multiple access scheme techniques are discussed below to give a brief insight into the technology.

2.2.1 System Architecture

The main purpose of the 3G Radio Access Network is to provide a connection between the handset and the core network and to isolate all the radio issues from the core network. So it has two parts: Radio Access Network (RAN) and Core Network (CN).

RAN is the part of the network that handles all radio related functionalities. It contains two types of nodes namely radio base station and radio network controller.

Radio base station (NodeB)

NodeB is used to facilitate wireless communication between user equipment (UE) and a network. Its functions include handover channel management, base-band conversion (TX and RX), channel encoding and decoding, interfacing to other network elements, etc.

Radio network controller (RNC)

RNC controls all radio access network functions and is in charge of call setup, QoS handling and radio resource management in cells.

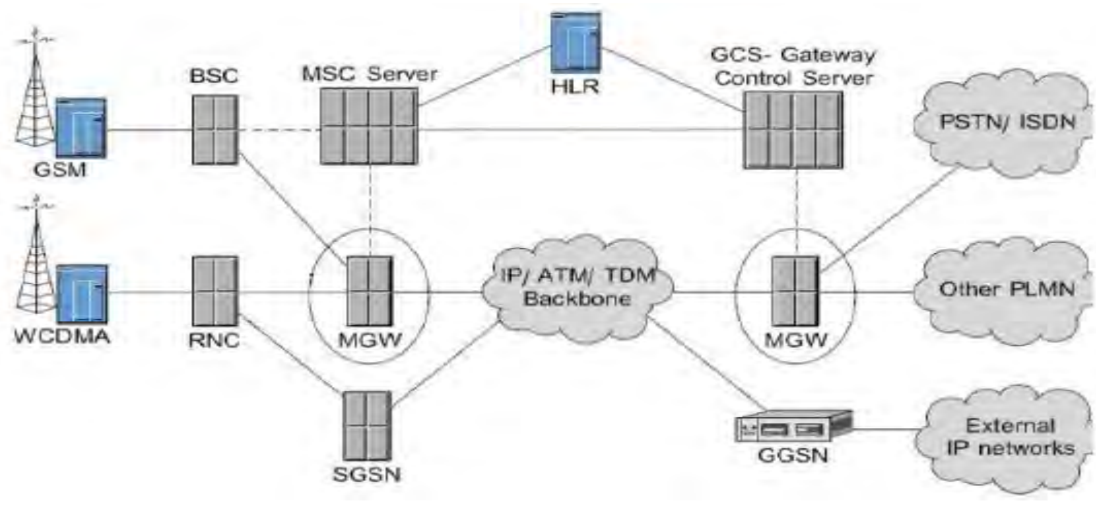

Figure 2-3: 2G and 3G hybrid network structure [21]

2.2.2 Multiple Access scheme

The multiple access scheme used in 3G networks is Code Division Multiple Access (CDMA). With CDMA different spreading or chip codes are used. When generating a direct sequence spread spectrum, the data to be transmitted is multiplied with spreading or chip code. This widens the spectrum of the signal, but it can only be decided in the receiver if it is again multiplied with the same spreading code. All signals that use different spreading codes are not seen, and are discarded in the process. Thus in the presence of a variety of signals, it is possible to receive only the required one. In this way the base station allocates different codes to different users. And when the base station receives the signal, it will use one code to receive the signal from one mobile, and another spreading code to receive the signal from a second mobile. In this way the same frequency channel can be used to serve a number of different mobiles [22].

2.3 Network Performance Evaluation

Different countries have different standards or Key Performance Indicators (KPIs) that help them determine the quality of service. Factors like service requirements, market benchmarks and customer expectation influence the KPI standards. As every operator wants to offer the best service in a competitive market, the KPIs of a country with a competitive market are re-adjustable and fast moving towards achieving customer expectation and satisfaction.

The comparative performance evaluation between the KPIs and the actual performance is done using different techniques. The most known and common way of determining the QoS of a network is done in OMC.

Several counters such as counters for the number of incoming or outgoing handovers, call drops before, during and after assignments, and dropped calls due to missing network or radio resources can be activated in the BSS and in the NSS from the OMC [18]. These counters provide the central office with the most important data about the state and network quality.

The outputs of the counters for each event are used as input information for network performance analysis. Service availability and retainability are among the different parameters.

2.3.1 Network Availability

Availability is defined as the ability of a service to be obtained when requested by the user within specified acceptable duration and conditions set by the operator [17].

$$Availability = \frac{Total\_No\_of\_Successful\_Calls}{Total\_Calls\_Accesses\_to\_Network} \quad (2.1)$$

Listed below are different KPIs that are associated with availability.

Paging Success Rate (PSR)

PSR measures the percentage of how many paging attempts that have been answered, either as a result of the first or the second repeated page.

$$PSR = \frac{Time\_of\_Paging\_Response}{Time\_of\_Paging} \quad (2.2)$$

SDCCH Drop Rate (SDCCH DR)

SDCCH DR compares the total number of SDCCH losses as a percentage of the total number of call attempts for SDCCH channels. It is intended to give an indication of how good the cell or system is at presenting calls.

$$DCCH\_DR = \frac{SDCCH\_Drops}{SDCCH\_Seizures} \quad (2.3)$$

Call Setup TCH Congestion Rate

The Call Setup TCH Congestion Rate statistic provides the percentage of attempts to allocate a TCH call setup that were blocked in a cell.

$$Call\_Setup\_TCH\_Congestion\_Rate = \frac{Number\_of\_TCH\ \_Blocks\ (Excluding\_HO)}{Number\_of\_TCH\_Attempts} \ldots\ldots \quad (2.4)$$

2.3.2 Network Retainability

Retainability is defined as the ability of a service, once obtained, to continue to be provided under given conditions for a requested duration [17].

$$Retainability = \frac{Total\_Calls\_Completed}{Total\_Successful\_Calls\_Setup} \ldots\ldots\ldots\ldots \quad (2.5)$$

Listed below are different KPIs that are associated with retainability.

Call Drop Rate (CDR)

This KPI gives rate of drop call. It is the rate of call where connection is succeeded but disconnected or lost due to abnormal call release.

$$CDR = \frac{Number\_of\_\ Dropped\_Calls}{Total\_Number\_of\_Established\_Calls} * 100 \ldots\ldots\ldots\ldots \quad (2.6)$$

Handover Success Rate (HSR)

HSR shows the percentage of successful handovers of all handover attempts.

Technical standards and procedures for the provision of telecommunication services are specified by Ethiopian Telecommunication Agency (ETA), the regulatory body of the telecommunication services in Ethiopia. Minimum Quality of Standards and the means and how to perform measurements are specified by this body.

Service Type	QOS parameters	Targets/standards	Averaged over a period of one year
Cellular Mobile Services	Call Setup Success Rate	>98	One quarter of a year
	Dropped Call Rate	<2%	
	Handover Success Rate	>95%	
	Blocked Call Rate	<2%	
	SDCCH Blocking Rate	<0.5%	
	TCH Blocking Rate	<5%	

Table 2-1: ETA network performance QoS standards [16].

2.3.3 Network Optimization

Network optimization amounts to finding a network configuration to achieve the best possible performance using the available network equipment and spectrum efficiently.

Various network planning phases involve different optimization problems. In the network dimension phase, evaluating possible configurations and the amount of network equipment needed is to be done. The result of this phase delivers the number of network elements and their configurations needed to provide services to customers in a service area with certain quality and within a specific period of time. In the next phase, using the predicted service demand, user distribution and propagation measurements, the main tasks become site planning, initial network configuration, and parameter tuning. It involves detail planning that includes field tests at the actual site of deployment. This helps to verify the system behaviour in a real environment for assumptions regarding antenna direction, down tilting, power level etc… In the network maintenance phase, optimization tasks such as capacity maximization, load balancing and improving the link budget by adjusting different performance parameters are carried out. The network performance analysis carried out in this phase is repeated until achieved results are acceptable.

As mentioned above, optimization can be used in different phases and contexts. For this specific thesis part, optimization is referred as one of the network maintenance activities and involves monitoring, verifying and improving the performance of the radio network.

A cellular network covers a large area and provides capacity to many people, so there are lots of parameters involved that are variable and have to be continuously monitored and corrected. The network is always growing through increasing subscriber numbers and increases in traffic. This means that the optimization process should be on going to increase the efficiency of the network.

Inputs of drive tests are one of the main sources to optimize the GSM or any other mobile network. Drive test method process starts with the selection of an active region of the network where the tests need to be performed, and the drive testing path. It gives insight into the designed network as it is experienced in the field and because the quality of the network is ultimately determined by the satisfaction of the users of the network.

With the help of data found by DT, optimization will be implemented to improve the existing network coverage, capacity and the offered service quality. The data is used in KPI calculation under a pre-defined threshold and compared with standards set by the country.

The different measurements of quality used in DT are listed below:

- RxLev: This parameter represents the received signal strength.
- RxQual: The received signal quality level is indicated with this parameter. Its value corresponds to an estimated number of bit errors in a number of bursts. RxQual value is between 0 and 7 with lower values implying better quality.

RxQual = 0	BER < 0.2%
RxQual = 1	0.2 < BER < 0.4%
RxQual = 2	0.4 < BER < 0.8%
RxQual = 3	0.8 < BER < 1.6%
RxQual = 4	1.6< BER < 3.2%
RxQual = 5	3.2 < BER < 6.4%
RxQual = 6	6.4 < BER < 12.8%
RxQual = 7	12.8 < BER

Table 2-2: Standard values of RxQual vs. BER

- **Frame Erasure Rate (FER):** FER is the percentage of numbers of blocks with incorrect cyclic redundancy check (CRC) to the total number of blocks.

Analysis on the results of optimization works of a selected area is useful in order to determine whether the engineering parameters of the network are well optimized or not.

3. Introduction to LTE

Users demand for higher data rate and higher quality of mobile communication of services over the years resulted in fast progression of technology. LTE system can be seen as completing the trend of expansion of service provision beyond voice calls towards a multiservice air interface [5]. This was already a key aim of 3G but LTE was designed from the start with the goal of evolving the radio access technology under the assumption that all services would be packet-switched, rather than following the circuit-switched model of earlier systems.

3.1 LTE Standards

At the start of the work towards the development of the technology, the 3GPP defined first the requirements for LTE. As defined in [24], the key elements included in the target setting for the LTE feasibility study work were as follows:

- Better data rates:-
    - The peak rate requirements for uplink and downlink were set at 50 Mbps and 100 Mbps respectively.
- Spectrum flexibility with 1.25/2.5, 5, 10, 15 and 20 MHz allocations;
- Reduced latency:-
    - The requirement for the LTE radio round trip time was set to be below 10 ms and access delay below 300 ms.
- Simplified network architecture.

A key requirement for LTE is to make possible a seamless transition from current telecommunication systems. This can be made possible by reuse of the current spectrums, interoperability between current and upcoming system and reuse of existing sites [14].

3.2 System Architecture

LTE is accompanied by an evolution of the non-radio aspects of the complete system, under the term 'System Architecture Evolution' (SAE) which includes the Evolved Packet Core (EPC) network. The radio access part is known as Evolved UMTs terrestrial Radio Access Network (E-UTRAN).

The LTE network architecture is designed with the goal of supporting packet-switched traffic with seamless mobility, QoS and minimal latency [24]. A packet-switched approach allows for the supporting of all services including voice through packet connections. Thus, LTE network architecture is a highly simplified flatter architecture with only two types of nodes namely eNB and mobility management entity/gateway (MME/GW).This is in contrast to many more network nodes in the current hierarchical network architecture of the 3G system. One major change in LTE is that RNC of 3G system is eliminated from the data path and its functions are incorporated in eNB. LTE network architecture is briefly discussed below.

Serving gateway and Packet data network gateway (S-GW and P-GW)

These two nodes are logical gateway entities that act as a local mobility anchor forwarding and receiving packets to and from the eNB serving the UE and interfaces with external packet data networks (PDNs) such as the Internet and the IMS respectively. The P-GW also performs several IP functions such as address allocation, policy enforcement, packet filtering and routing.

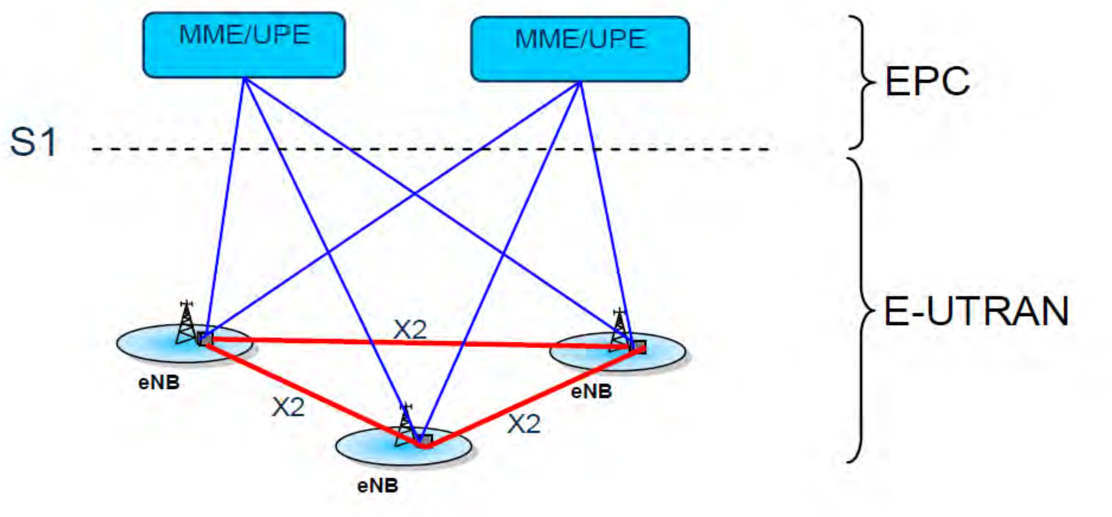

Figure 3-1: LTE network architecture [29]

MME (Mobile Management Entity)

The MME is a signaling only entity and hence user IP packets do not go through MME. An advantage of a separate network entity for signaling is that the network capacity for signaling and traffic can grow independently. The main functions of MME are idle-mode UE reachability including the control and execution of paging retransmission, tracking area list management, roaming, authentication, authorization, P-GW/S-GW selection, bearer management including dedicated bearer establishment and security negotiations.

Enhanced/evolved NodeB (eNB)

LTE is designed to give eNB a greater degree of intelligence to reduce the overhead. Thus, eNB implements Node-B functions as well as protocols traditionally implemented in RNC. The main functions of eNB are header compression, ciphering and reliable delivery of packets. On the control side, eNB incorporates functions such as admission control and radio resource management.

Interfaces of LTE

The components of the E-UTRAN, the eNBs, are interconnected by the X2 interface [13].

3.3 Multiple Access Schemes

3.3.1 Downlink

The candidate schemes for the downlink were Orthogonal Frequency-Division Multiple Access (OFDMA) and Multiple WCDMA. The choice of multiple-access schemes was made in December 2005, with OFDMA being selected for the downlink mainly due to the simplicity of the receiver [6].

3.3.1.1 OFDMA

OFDMA extends the multicarrier technology OFDM to provide a very flexible multiple access schemes. OFDM subdivides the bandwidth available for signal transmission into a multitude of narrowband subcarriers, arranged to be mutually orthogonal, which either individually or in groups can carry independent information streams. The spacing between two sub-carriers is fixed at 15 KHz. As the spacing of sub-carriers is fixed, the transmission bandwidth is varied by changing the number of sub-carriers. A resource block is defined to consist of 12 sub-carriers in frequency and 14 continuous symbols in time. This makes one resource block to span 180 KHz and 1ms in frequency and time respectively. This sub-frame is also the minimum transmission time interval (TTI) that helps to achieve the requirements of low latency of LTE [27].

In detail, OFDMA is an extension of OFDM in which available sub-carriers are assigned to different users based on their capacity demand and radio channel propagation conditions.

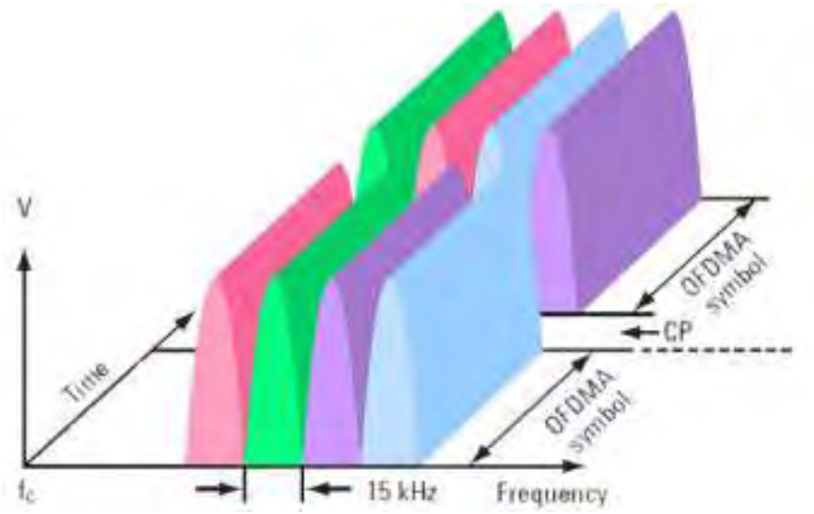

Figure 3-2: OFDMA scheme

Out of the many advantages of the OFDMA technology, its robustness to time-dispersive radio channels is the important one. This robustness is due to the subdivision of the wideband transmitted signal into multiple narrowband subcarriers enabling inter-symbol interference to be largely constrained within a guard interval at the beginning of each symbol. The main drawback of OFDMA is the high Peak-to-Average Power Ratio (PAPR). Since OFDMA consists of several sub-carriers in the frequency domain, that is several sinusoidal waves in the time domain, it is characterized by a strong variation of the signal envelope. This results in a need for a highly linear RF power amplifier with low power consumption mainly at UE side.

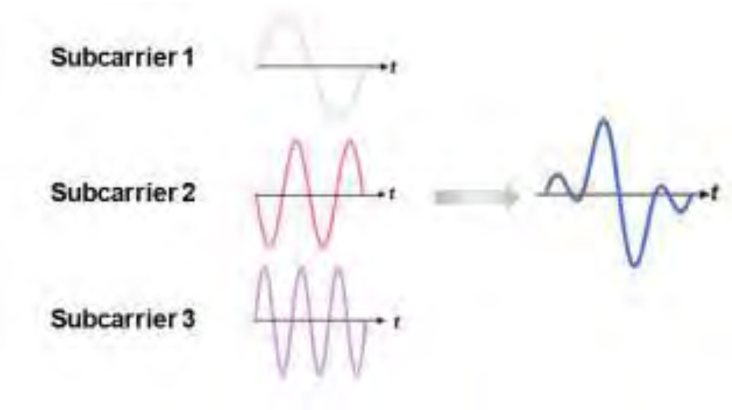

Figure 3-3: High PARP challenge

3.3.2 Uplink

OFDMA was not considered as the multiple access technology for the uplink of LTE because the high PAPR of OFDM is difficult to tolerate for the transmitter of the mobile terminal. In addition, it is necessary to compromise between the output power required for good outdoor coverage, the power consumption and the cost of the power amplifier. Therefore, Single-Carrier Frequency-Division Multiple Access (SC-FDMA) was selected as the access technology for the uplink among the candidate schemes that were OFDMA and Multiple WCDMA.

3.3.2.1 SC-FDMA

SC-FDMA is a power efficient multiple access technology that is a variant of OFDM and is generated through a Discrete Fourier Transform OFDM (DFTS-OFDM). It provides a multiple-access technology which has much in common with OFDMA. Its similarity in particular is its flexibility in the frequency domain and the incorporation of a guard interval at the start of each transmitted symbol to facilitate low-complexity frequency-domain equalization at the receiver [28].

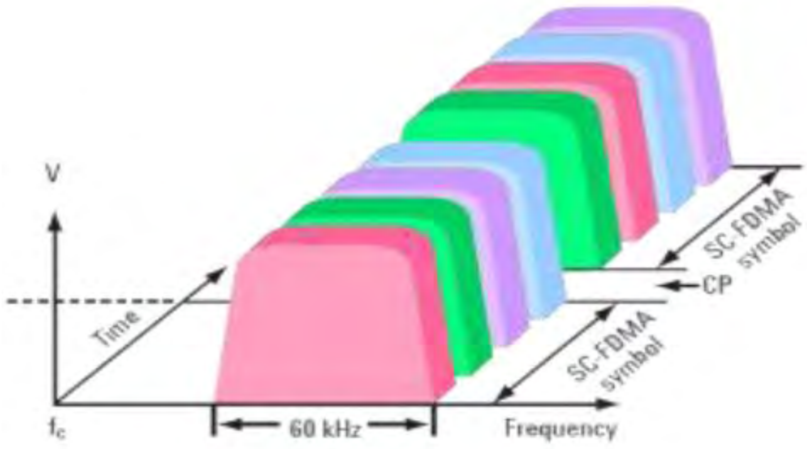

Figure 3-4: SC-FDMA scheme

Like in OFDM, the channel bandwidth is divided into multiple sub-carriers. However, the sub-carriers are transmitted sequentially and not in parallel. In the uplink, a DFT pre-coder is used prior to the OFDM modulator to preserve the single-carrier properties. The DFT pre-coder does not compromise orthogonally between subcarriers. Therefore, PAPR is reduced and consequently, a more efficient power amplifier implementation can be carried out.

3.4 Multiple Antenna Technology

The value of multiple antenna systems as a means to improve communications was recognized in the very early ages of wireless transmission. In the quest for higher spectral efficiencies, use of multiple antenna technology becomes evident and allows the exploitation of the spatial-domain.

While traditional wireless communications (Single-Input Single-Output (SISO)) exploit time or frequency domain pre-processing and decoding of the transmitted and received data respectively, the use of additional antenna elements at either the base station (eNB) or User Equipment (UE) side opens an extra spatial dimension to signal pre-coding and detection.

There are basically three advantages associated with Multiple-Input Multiple-Output (MIMO) technology over their SISO counterparts [29]:

- **Diversity gain**: - corresponds to the mitigation of the effect of multipath fading, by means of transmitting or receiving over multiple antennas at which the fading is sufficiently decor related.
- **Array gain**: - corresponds to a spatial version of the well-known matched filter gain in time-domain receivers. This also allows multiple users located in different directions to be served simultaneously.
- **Spatial multiplexing gain:** - refers to the ability to send multiple data streams in parallel and to separate them on the basis of their spatial signature.

Support for multi-antenna transmission was an integral part of LTE from its first release. LTE performance requirements are set assuming all terminals support at least two receiver antennas. This is important because it enables the networks to be planned, assuming at least the presence of downlink-receive diversity [29].

4. LTE Radio Network Planning

Radio network planning is a very vital step for a wireless communication technology. It contains number of phases [30].

- **Initial phase:** This includes collection of pre-planning information and starting network dimensioning i.e. Link Budget preparation, coverage and capacity calculation.
- **Nominal and detailed planning:** Selection and use of radio planning tool is included in this phase. It involves propagation model tuning, defining thresholds from Link budget, creating detailed radio plan based on the thresholds, checking network capacity against more detailed traffic estimates, configuration planning, site surveys, site pre-validation, site validation and eNB parameter planning.
- **Defining KPIs and Parameter Planning:** This includes defining performance KPIs and its target values based on vendor's promise, verification of the KPIs and target values using planning and dimensioning tools nominally along with pre and post-launch optimization.

The first phase which includes link budget preparation, coverage and capacity calculation provides the first estimate of the network element count as well as the capacity of those elements.

Network Dimensioning includes computation of number of sites required to serve the target areas while fulfilling the coverage and capacity requirements. Thus, it basically includes the following analyses;

- Site count and location of sites;
- Cell ranges and cell areas;
- Site throughput and sector throughput.

The results from dimensioning can be used as an input for a business case analysis. The number of network elements and their associated configuration allow the cost of the network to be quantified. Thus, it helps in calculation of cost of the network, planning the tariff strategy, overall business planning, etc.

4.1 Coverage Determination

Coverage planning gives an estimate of the resources needed to provide service in the selected area with the given system parameters, without any capacity concern [30]. Coverage planning consists of evaluation of DL and UL radio link budgets calculations.

4.1.1 Link Budget Calculation

The link budget calculations estimate the maximum allowed signal attenuation, called path loss, between the mobile and the base station antenna. There are several parameters fed to the link budget which in turn calculates maximum allowable path loss that exists in the link path. The maximum path loss allows the maximum cell range to be estimated with a suitable propagation model. The calculated path loss can be used with the selected propagation model to find the cell coverage. The cell range also gives the number of base station sites required to cover the target geographical area.

For LTE, the basic RLB equation can be written as:

$$PL(dB) = TxP + TxG - TxL - RequiredSINR + RxG + RxL - RxN \qquad (4.1)$$

Where: PL- Path Loss encountered by the signal from transmitter to receiver (dB)

TxP- Transmitted Power (dBm)

TxG- Transmitter antenna Gain (dB)

TxL- Transmitter Losses (dB)

RequiredSINR- Minimum required SINR for the signal to be received at the receiver with the required quality or strength (dB)

RxG- Receiver antenna Gain (dB)

RxL- Receiver Losses (dB)

RxN- Receiver Noise (dBm)

The Inputs for link budget calculation and determination of coverage area are:

- Available frequency band:-
  - As stated in the LTE standard target, LTE supports spectrum flexibility with 1.25/2.5, 5, 10, 15 and 20 MHz allocations. Bandwidth selection is based on users demand on the target area;
- Path loss model;
- System gain and
- Modulation/Coding scheme.

4.1.1.1 Modulation and Coding Scheme

The principle of link adaptation is fundamental to the design of a radio interface which is efficient for packet-switched data traffic. LTE is a packet optimized network thus, all the traffic is carried in form of data packets. Therefore, using a modulation scheme will affect the amount of data carried by the network. For the downlink data transmissions in LTE, the eNB typically selects the modulation scheme and code rate depending on a prediction of the downlink channel conditions. An important input to this selection process is the Channel Quality Indicator (CQI) feedback transmitted by the UE in the uplink. CQI feedback is an indication of the data rate which can be supported by the channel, taking into account the Signal-to-Interference plus Noise Ratio (SINR) and the characteristics of the UE's receiver.

The LTE specifications are designed to provide the signalling necessary for interoperability between the eNB and the UEs. This is required so that the eNB can optimize the link adaptation and in response to the CQI feedback, select between QPSK, 16-QAM and 64-QAM schemes and a wide range of code rates.

Low-order modulation schemes such as QPSK is more robust and can tolerate higher levels of interference but provides a lower transmission bit rate. High-order modulation such as 64-QAM offers a higher bit rate and thus allows a better utilization of the network. But high-order modulation schemes are more prone to errors due to its higher sensitivity to interference, noise and channel estimation errors and can only be used in favourable channel condition.

Maximum coverage is the primary criteria, which is usually used for RLB. In maximum coverage criteria, it is assumed that lowest MCS is used. Lowest MCS corresponds to the lowest data rate and allows the estimation of farthest reach of eNB. In this way, an estimate of maximum possible cell radius is obtained.

4.1.1.2 Downlink Link Budgets

The LTE link budget in downlink take several parameters as inputs to determine the maximum path loss allowed in the downlink from the base station of LTE (transmitter) to the mobile station (receiver).

The parameters in brief are [6]:

- Base station maximum transmission power:-
  - A typical value for macro cell base station is 20–60 W at the antenna connector.
- Base station antenna gain;
- Cable loss between the base station antenna connector and the antenna:-
  - The cable loss value depends on the cable length, cable thickness and frequency band.
- UE RF noise figure:-
  - The noise performance of a receiver is described by a figure of merit called the noise figure. It is a measure of the degradation in the received SNR as a result of the components in the RF signal chain. Mathematically the noise figure in logarithmic scale can be expressed as:

$$Noise\_Figure = 10\log\left(\frac{Noise\_Ouput\_of\_Actual\_Receiver}{Noise\_Output\_of\_Ideal\_Receiver}\right) \quad (4.2)$$

   - UE RF noise figure depends on the frequency band, duplex separation and on the allocated bandwidth.
- Terminal noise:-
   - It can be calculated as Boltzmann constant (K) × T (290K/ room temperature) ×bandwidth. The bandwidth depends on bit rate, which defines the number of resource blocks.
- Signal-to-noise ratio from link simulations or measurements:-
   - The value depends on the modulation and coding schemes, which again depend on the data rate and on the number of resource blocks allocated.
- Interference margin:-
   - It accounts for the increase in the terminal noise level caused by the other cell. In the DL direction, due to the OFDM access technology and assuming the appropriate length of cyclic prefix, we can assume there is no own cell interference. Other Cell Interference is the total average power received from other cells in the allocated bandwidth.
- Control channel overhead:-
   - It includes the overhead from reference signals, Physical Broadcast Channel (PBCH), Physical Downlink Shared Channel (PDCCH) and Physical Hybrid ARQ Indicator Channel (PHICH). PBCH carries basic system information which allows the other channels in the cell to be configured and operated. PDCCH is used for all user data, as well as for broadcast system information which is not carried on the PBCH. PHICH is used for paging messages and carries the HARQ ACK/NACK, which indicates whether the eNB has correctly received a transmission.

4.1.1.3 Uplink Link Budgets

Similar parameters used in the downlink link budget calculation are also used in uplink.

- UE maximum transmission power;
- UE antenna gain:-
  - It depends on the type of device and on the frequency band.
- Body loss:-
  - It is typically included for voice link budget where the terminal is held close to the user's head.
- Base station RF noise figure:-
  - It depends on the implementation design. The minimum performance requirement is approximately 5 dB but the practical performance can be better.
- Interference margin in the uplink:-
  - It is also called Noise Rise and accounts for the increase in the terminal noise level caused by the interference from other users. Since LTE uplink is orthogonal, there is no intra-cell interference but we still need a margin for the other cell interference. The interference margin in practice depends heavily on the planned capacity; there is a tradeoff between capacity and coverage. The LTE interference margin can be smaller than in WCDMA where the intra-cell users are not orthogonal. In other words, the cell breathing will be smaller in LTE than in CDMA based systems.
- Cable loss between the base station antenna and the low noise amplifier:-
  - The cable loss value depends on the cable length, cable type and frequency band. Many installations today use RF heads where the RF parts are close to the antenna making the cable loss very small. The cable loss can also be compensated by using mast head amplifiers.

After obtaining the maximum path loss, the cell radius is calculated with the appropriate path-loss model chosen.

4.1.1.4 Cost-231 Hata Propagation Model

COST-231 Hata model is also known as COST Hata model and it is the extension of Hata model. This model requires only central frequency and distance between the transmitter and the receiver as its input variable for computation. Cost-231 Hata Propagation Model is normally used for carrier frequencies between 1500 and 2000 MHz. The same COST231 model can be used for higher carrier frequencies, since we assume that the loss due to the higher frequency is compensated by the increase in the antenna gain. The model is a simplified model as it does not require the actual geographical information of the deployment area i.e. street width, height of buildings in the area and building separation distance. The expression for median path loss in urban areas is given by

$$PL = 46.3 + 33.9\log(f) - 13.02\log(hb) - a(hr) + [44.9 - 6.5\log(hb)]\log(d) \quad (4.3)$$

Where: PL- Path Loss in dB

f- Frequency in MHz

d- Distance between the transmitter & receiver

hb & hr- Base station height and receiver height respectively.

The correction factor a(hr) for urban area is defined as:

$$a(hr) = 3.2\,(\log(11.75hr))^2 - 4.97 \quad (4.4)$$

And for rural & suburban areas:

$$a(hr) = 1.1\log(f) - 0.7hr - (1.58f - 0.8) \quad (4.5)$$

Given the cell radius, the cell coverage area depends on the site configuration. For hexagonal cell model and tri-sector site, the area of the cell is given by:

$$Cell\_Area = 1.95 * d^2 \quad (4.6)$$

Where: d- Cell radius.

Then the number of sites required to cover the area can be found by:

$$Number\_of\_BTS = \frac{Total\_Area\_to\_be\_Covered}{Area\_Covered\_by\_Each\_BTS} \quad (4.7)$$

4.2 Capacity Planning

Capacity planning gives an estimate of the resources needed for supporting a specified offered traffic with a certain level of QoS [14].

Listed below are the inputs for capacity planning and determination of network equipment demand.

4.2.1 Estimation of System Capacity Demand

Before proceeding with the deployment of LTE technology on a chosen area, the required system capacity on data density per end-user should be estimated.

- **Number of subscribers**

  Number of subscribers with the corresponding customer mix, percentage distribution of customers among the category of users, is important in capacity estimation. The commonly used customer category is business and residential user.

- **Average traffic demand**

  This input is predefined by the operator to set forth the capacity requirement. The peak busy hour (PBH) activity level and downlink duty ratio (DDR) has to be defined or assumed by the operator. PBH shows the percentage of active users simultaneously using the system and DDR shows the fraction of time the system is in active state.

- **Overbooking factor or contention ratio**

  This term describes the level of multiplexing of users sharing a given channel or capacity. It indicates the average number of users that can share the system bandwidth and still get the data rates they have paid for. Determining of overbooking factor is important because it saves precious resources that would otherwise be wasted due to over dimensioning based on requirements corresponding to the peak hour traffic.

4.2.2 Cell/Sector Capacity

Frequency band, channel bandwidth and modulation/coding type parameters are required to determine cell/sector capacity. The most accurate evaluation of cell capacity is given by running simulations. The average sector throughput is the most significant figure that defines the typical subscriber experience and more importantly network capacity. This throughput estimates how much bandwidth can be delivered within a sector under real world conditions. The aggregate throughput can then be used to estimate how many concurrent subscribers can be served in the sector [31].

Finally the site can be calculated as

$$Site\_Count = \frac{Estimated\_System\_Capacity\_Demand}{Aggregate\_Downlink\_Throughput\_per\_Basestation} \qquad (4.8)$$

And the number of sites required to cover an area will be determined by comparing the coverage determined number of sites with the capacity determined ones.

$$Site\_Required = Max\_No\_of\_Sites(Coverage\_Determined, Capacity\_Determined) \qquad (4.9)$$

Capacity based site count is usually higher than the coverage based counterpart in a fully functional network. In real networks, this number is smaller in the earlier years of network operation, when the number of users is quite less. But as the demand increases and more users are added to the service, the capacity based site count takes the lead and smaller cells are required.

5. Techno-Economic Models

Since various competing wireless technologies are made available for customers, a new technology that is about to be introduced to a market needs to have a significant advantage both in technological and economic terms, in order to justify its investment. Techno-Economic Analysis is evaluation of technical and economic aspects (in acquisition, system design and services) and thus can be useful to investigate the business case viability of the deployment of a new wireless technology [21].

The method used for evaluating the economic feasibility of complex technical systems is called Techno-economic modeling. It involves the processes of modeling, analysis, evaluation and finally assessment. Based on the calculated costs and revenues, a number of indicators are used to determine the profitability of the scenarios, including for example payback period, net present value (NPV) and internal rate of return (IRR).

The main objectives of techno-economic modeling are:

- To compare different technical options in order to find the most cost-effective solutions;
- To look at the feasibility of different evolution scenarios;
- To find what parts of the network contribute most to the overall cost and
- To identify strategies which are robust to different patterns of demand [22].

5.1 Economic models

Much of the terminology, methodology and tools related to techno-economic analyses of broadband access networks have been developed in the various research projects funded by the European Union during the 1990's and the early 2000's [21]. The different techno-economic models are listed below.

- **Tool for Introduction scenario and Techno-economic evaluation of Access Network (TITAN):-** TITAN is an economic model developed on the time frame from 1900-1994 [25]. The economic analysis is made based on different scenarios that try to resemble worst case, average and best economic condition of the market for the access network only.

  The TITAN project [26] developed a model that predicts the cost evolution of the network components and is based on a combination of learning curves and logistic models. In addition, for each network component, the prediction uncertainties have been specified as a function of time. The learning curve model, which presents the cost of a component as a function of production volume, can be transferred to a model predicting the costs as a function of time. The original methodology and tool have been enhanced to be able to cope with complex multimedia service and network structures. Furthermore, the methodology has been improved especially in the definition of services and assessment of operations, administration and maintenance costs.

- **OPTImised architectures for MUltiMedia networks and services (OPTIMUM):-** OPTIMUM is an economic tool that includes different services in the economic analysis which TITAN project failed to achieve.

- **TechnO-ecoNomics of IP optimized networks and services (TONIC): -**TONIC economic model uses a business case study approach to assess new broadband and IP service scenarios. It yields quantitative economic results and identifies and quantifies the associated risk factors. The main objectives of TONIC rely on service definition and impact on traffic. It defines service sets and usage patterns in order to determine the traffic load on the network and to provide means for demand forecasting.

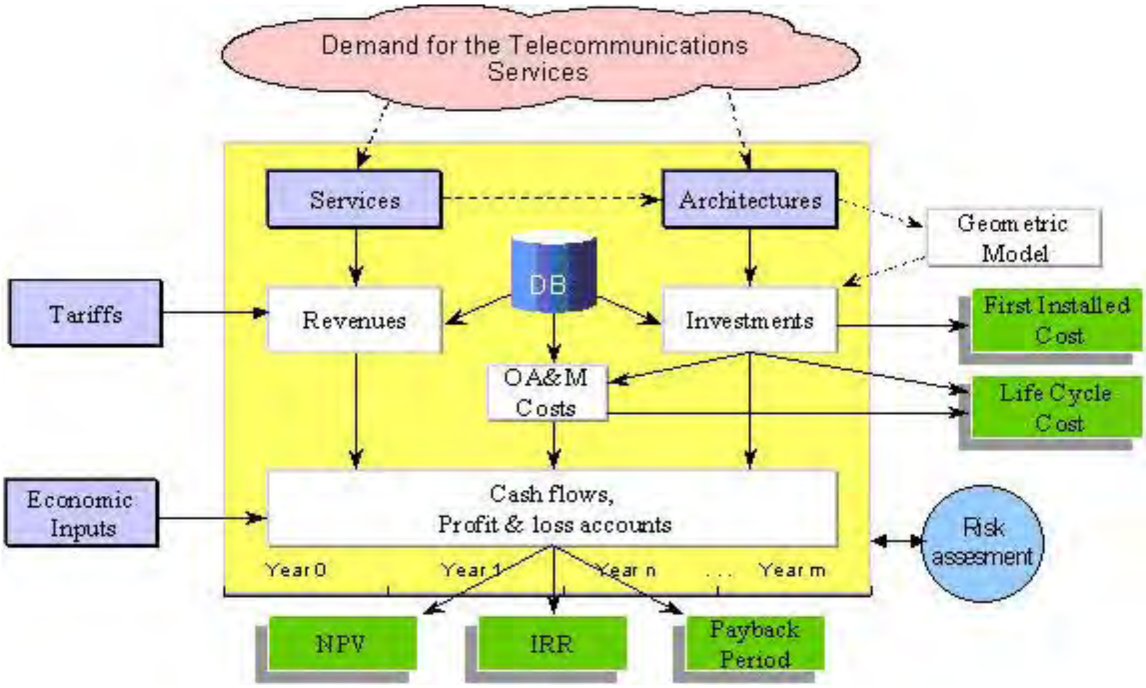

Figure 5-1: Structure of the techno-economic methodology used by TONIC [24].

- **Techno-ECOnomics of integrated communication Systems services (ECOSYS):-**. In one of the deliverables generated by the EU ITS ECOSYS project, it was stated that a "business model consist[s] of service and information flows, including a description of various business players, their roles and relationships, their relative position within a value network and descriptions of their costs structure and source of revenue" [25].

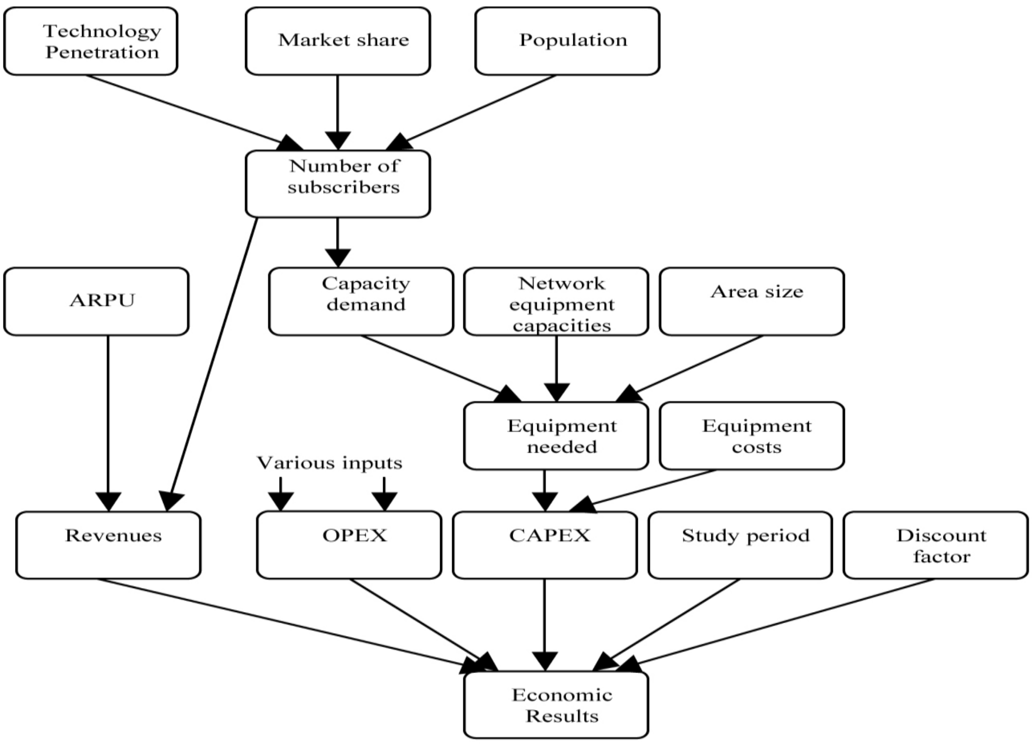

Figure 5-2: Model revenues and cost flows based on the ECOSYS project [7].

- **Techno-Economic Results from ACTS (TERA):-** TERA is the most popular and widely used techno-economic tool. It was developed within the European Union Advanced Communications Technologies and Services (ACTS) program during the period of the fourth framework program of scientific research and development (1994-1998) [25]. TERA tool enables techno-economic evaluations and strategic analyses that combine high level parameters, such as density of subscribers and service penetration, with relevant low level parameters, such as costs of key network components. The inputs of this tool are also used in network dimensioning of the technology.

  TERA tool requires certain market and technology related inputs, as well as general economic inputs in order to carry out the techno-economic analysis.

Outputs from the analysis include revenues, costs, and investments, as well as profits and cash flows.

In the TERA framework, the analysis of an investment project is always performed for a certain user-defined study period. The services to be provided and the market penetration of these services over the study period must be defined. For each service, a connection tariff and an annual tariff are defined as time series over the study period. The revenues for each year are calculated from the combination of yearly market penetration and tariff information.

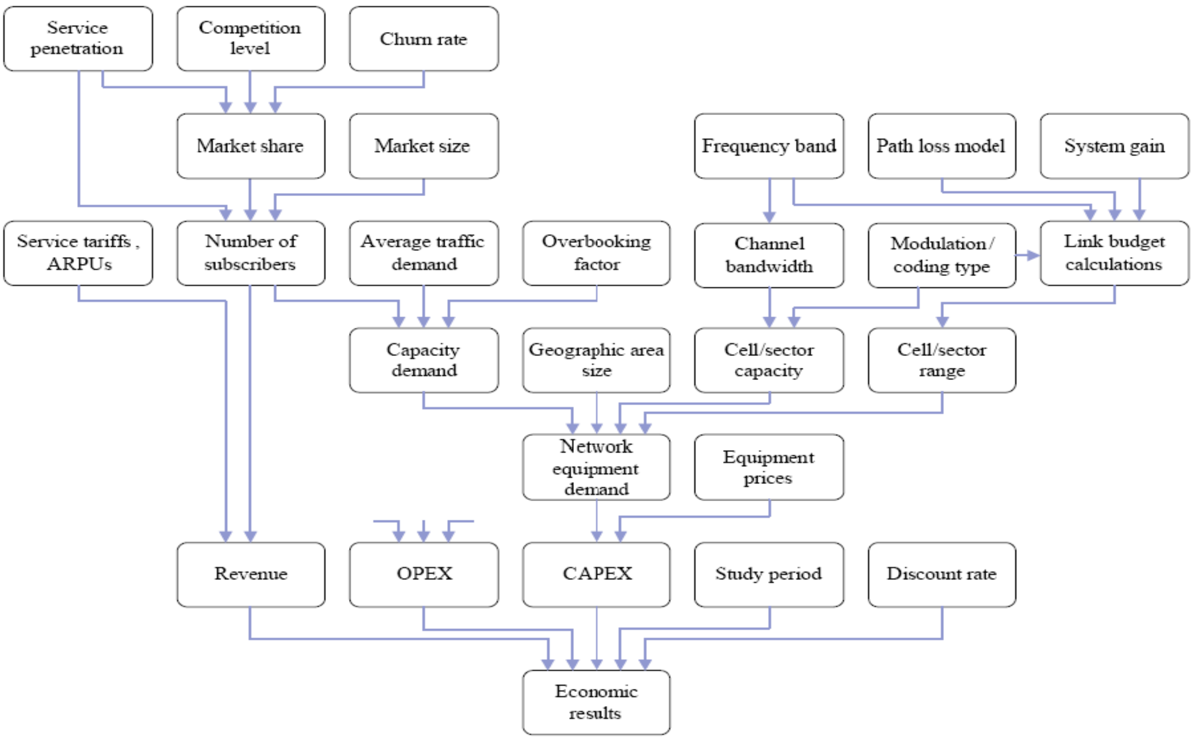

Figure 5-3: A techno-economic model based on TERA

5.2 Total Cost of Ownership (TCO)

Cost of network is important parameter that needs to be considered due to high competitions. The cost of network directly depends on coverage and capacity requirements. Large coverage area requires more base stations and network elements which influences the network cost while denser area requires more stations as well which increases the cost of network. The other factor for affecting the network cost is traffic demand requirements, higher traffic demand require more capacity from network which raises the network cost as well. As a consequence, network cost depends on network dimensioning results.

CAPEX includes the investments to the network infrastructure and devices i.e. the fixed initial costs necessary for the BS deployments, including the tower, antenna, installation and civil works, site acquisition, P2P equipment (peripheral), as well as the costs of the customer premise equipment (CPE) for each customer.

OPEX includes the labor costs and expenses originating from operating and managing the networks. It includes the BS site lease, maintenance and power supply, spectrum lease and equipment maintenance. Equipment cost is a summation of equipment at end user premises and equipment at the service provider's side.

The operational expenditures of network operators are often referred to as OA&M or OAM&P costs, the letters representing operations, administration, maintenance, and provisioning. Operations include the operation of support centers/systems as well as personnel and training required to install and maintain the network elements; administration ensures the service level once the network elements have established the service; maintenance includes carrying out the preventive measurements and locating and clearing faults; and provisioning makes available the service by installing and setting-up the network elements.

The operational expenditures related to a certain project are often more difficult to predict than the capital expenditures. This is especially true when new network technologies are considered, as previous experiences or data is not available.

Network deployment cost can be calculated by using the following general formula.

$$Total\_Cost = CAPEX + OPEX \quad \text{(5.1)}$$

Two approaches exist for cost modeling, differing in their starting point for the modeling process. In a top-down approach, the modeling starts from an existing business and network infrastructure, using the observed CAPEX, OPEX, and service usage levels as inputs to calculate costs per for example service or customer. In a bottom-up approach, the forecast demand for services is used as a starting point and the required costs are modeled so that all customers can be served with sufficient quality. In techno-economic modeling, the bottom-up approach is preferable and typically used when calculating investments. Operational costs are often modeled using a combination of the two approaches, e.g. by using top-down calculated reference values from a similar business or project as inputs in a bottom-up-structured model.

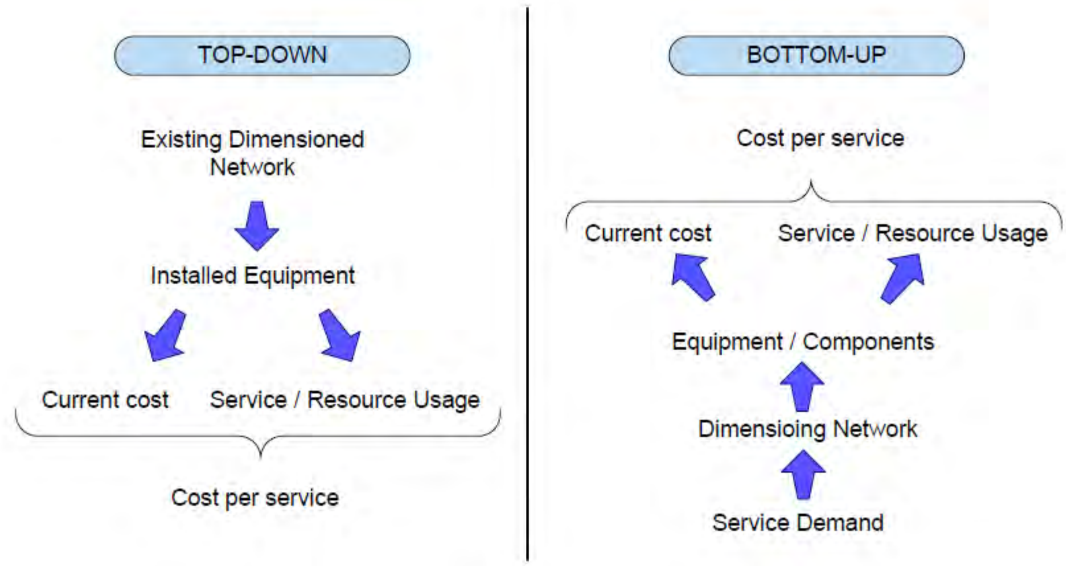

Figure 5-4: Top down vs. Bottom up cost modeling [8].

5.3 Revenue Modelling

The number of customers for the services and the tariffs charged are the main inputs for calculating the revenues. Therefore some traffic demand forecast is necessary for the area to be served. In the case of an over estimation of the traffic demand, the revenue received from subscriber pricing will not be sufficient to meet all the costs, which will result in a failure in the network investment, thus the traffic demand forecast should be carefully performed. The area specific traffic demand is dependent on the average capacity required per subscriber, the population density and total coverage area of the operators and the service penetration.

5.4 Profitability

A prime answer from a techno-economic analysis is whether or not the investment project in question is profitable or not i.e. the objective of each business case is to establish the related investments, revenue streams and operational expenditures.

Commonly used measures to determine the profitability of a project include the project's net present value and payback period.

Net Present Value (NPV)

NPV of an investment project is the most favorable measure of profitability. It is the present value of the future cash flows discounted using a factor that resembles the time value of money. The NPV of a project is calculated as the difference between the discounted value of the future incomes and the amount of the initial investment. If the NPV is positive, the project is judged profitable. The discount rate, also known as the opportunity cost of capital, represents the expected return that is forgone by investing in the project rather than in comparable financial securities.

NPV is the future stream of benefits and costs converted into equivalent values today. It is the indicator of how much value the investment can add to the project. And it gives a single figure of merit for a project. NPV is calculated according to the dynamic investment evaluation method that considers the life cycle of the investment (I), the positive cash flow in particular year, the interest rate and the initial investment.

$$NPV = \left[\sum_{t=1}^{n} \frac{D_t}{(1+r)^t}\right] - \left[\sum_{t=0}^{n} \frac{I_t}{(1+r)^t}\right] \ldots\ldots\ldots \quad (5.2)$$

Where: r- Interest rate

I- Investment

D- Positive cash flow in particular year.

t- Year

The calculation method clearly shows the dependence of the NPV from the value of the capital used for the investment in course of the time (1 to t) and the interest rate associated with it.

Cash Balance

Cash Balance (or Accumulated Cash Flow) curve for a network operator scenario goes first deeply down to the negative side because of the high initial investments. If the scenario is profitable, the cash flow turns positive fairly soon and the cash balance curve gives the amount of funding required for the project. The point in time when the cash balance turns positive gives the payback period for the project.

Payback Period

The payback period of a project is the number of years it takes before the cumulative incomes equal the initial investments. When using the payback rule in investment decisions, all projects that pay themselves back before a defined cutoff date are considered profitable.

6. Case Study Analysis

The area selected for deployment is Mercato area 2Km radius from tekelehaimanot roundabout, site named Sumali tera AA-ZTE 12N, as it is the most densely populated area with a lot of activities and where a large number of call drops and call blocks exist.

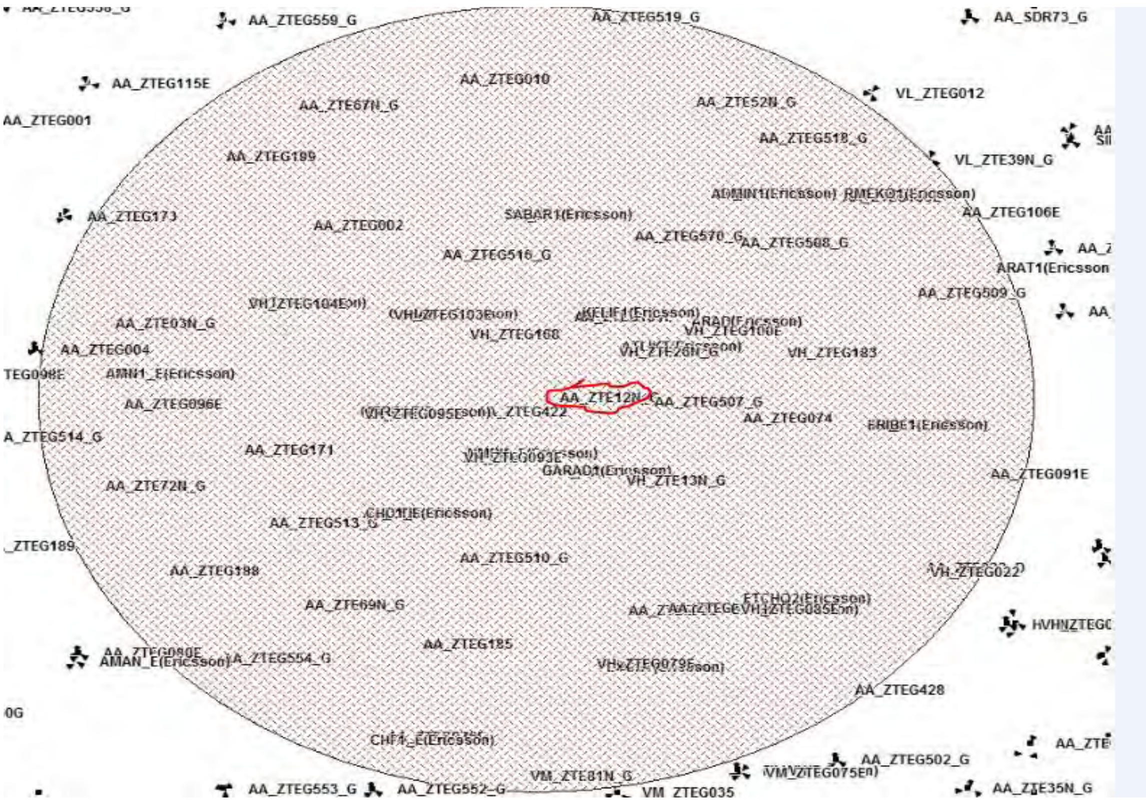

Figure 6-1: 2G sites 2km radius from AA ZTE 12N

A total of 42 2G sites exist in the area and each of the sites except black lion and semayawi building operate on dual band (i.e. on both 900MHz and 1800MHz). Thus the theoretical capacity is calculated based on the number of transceivers supported by the base station and antenna configuration. The antenna configuration implemented in the current network is s6/6/6, s8/8/8 or s12/12/12 with exception for black lion site with only 4 transceivers in only one sector. Each sector supports at maximum the number of transceivers multiplied with the number of timeslots.

$$Max\_Capacity = \sum Number\_of\_Transcievers * 8 \quad (6.1)$$

S.no	user label	Frequency	number of TRXS sector 1	sector 2	sector 3	maximum capacity
1	leila building	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
2	kelifa building	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
3	amanuel	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
4	a/ketema III /dire building	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
5	chid tera	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288

Table 6-1: Sample sites with their corresponding maximum capacity

Erlang B model is the most commonly used traffic model that provides the probability of blockage at the switch due to congestion. This model applies under the condition that an unsuccessful call, because the line is busy, is not queued or retried, but instead it is assumed that all blocked calls are cleared immediately. The Erlang B formula is:

$$P_B(C,A) = \frac{\frac{A^C}{C!}}{\sum_K^C \frac{A^K}{K!}} \quad (6.2)$$

Where: A - Traffic intensity

C – Number of channel

K= 0, 1, 2…..C

In this study, with a commonly used acceptable GOS=0.02 and the available channels calculated as the maximum capacity, traffic intensity is found from the Erlang B chart.

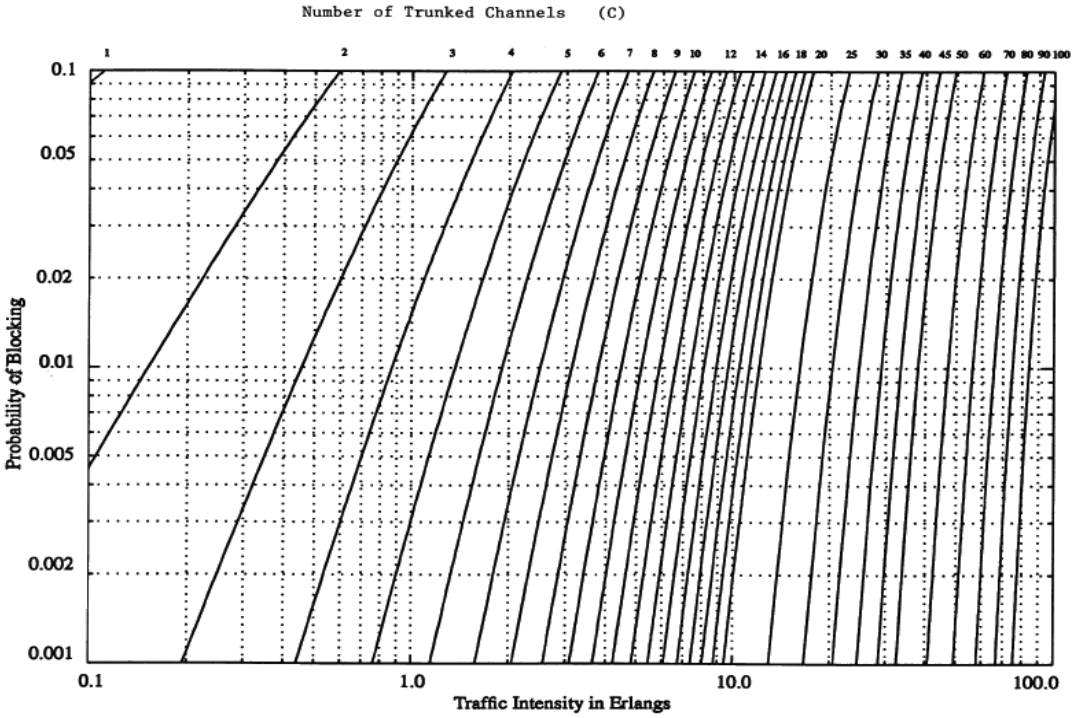

Figure 6-2: The Erlang B chart showing the probability of blocking as functions of the number of channels and traffic intensity in Erlangs.

For example: leila building site sector with maximum capacity of 64 has 50 Erlang(Erl) traffic intensity.

To calculate the operational capacity, data from OMC is used. For this thesis, OMC data was averaged between February and April 2013. Peak hour was found to be from 10-11AM on the selected area.

$A = BHCA * H$……………………………………………………………………………………….(6.3)

Where: A- Total offered traffic intensity

BHCA- Number of telephone calls made at peak hour

H- Average holding time of a call

For example, Leila building site with an average 3180 BHCA and 2minutes of holding time has a total traffic intensity of:

$$A = (\frac{3180\ calls/hour}{60min})*2\text{min} = 106\ \text{Erl}$$

The above result indicates the traffic demand is double the site's theoretical capacity.

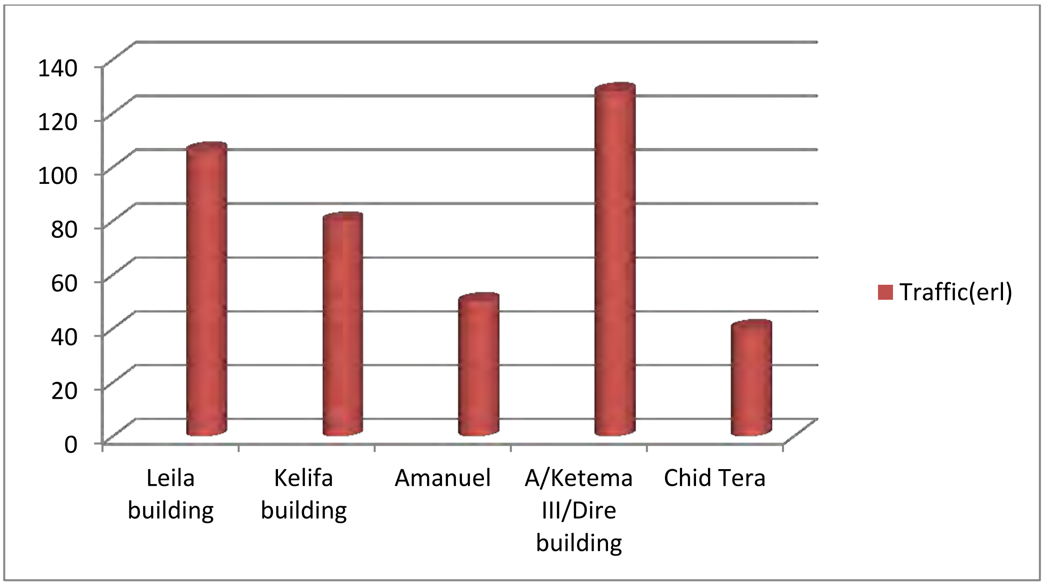

Figure 6-3: Sample sites traffic in Erlang

As it can be seen from Figure 6-3, three sites out of five had an average traffic above 50 Erlang. The comparison between the two parameters i.e. theoretical and operation capacity imply high activity and demand on the area resulting in network congestion, failure to setup call and call disconnection.

6.1 Network Performance Evaluation

6.1.1 Selected Area Availability and Retainability

As defined in previous chapter, availability is the ability of a service to be obtained within specified tolerances and given conditions when requested by a user and blocked call rate is defined as the ratio of number of blocked calls to total number of call attempts. Similarly, retainability is the ability of a service once obtained, to continue to be provided under given conditions for a requested duration and call drop rate is defined as the rate of number of dropped calls to total number of call attempts.

These performance evaluation parameters are done for each of the 42 sites using Equation (2.1) and (2.6). When compared with the standard requirement which states both of the parameters to be below 2%, the values clearly indicate that the area has poor availability and retainability and requires optimization.

Sites	Call Blocked Rate	Call Dropped Rate	Call Blocked Rate %	Call Dropped Rate %
Arada mobile	0.0324	0.0155	3.24	1.55
Bete-Mengist/Ras amba	0.01796	0.033	1.796	3.3
Ammanuel	0.009	0.09	0.9	9
Lideta Abinet	0.032	0.013	3.2	1.3
Melamaru Akababi	0.0203	0.004	2.03	0.4
Addis Ketema s/city kebele 14/21	0.022	0.007	2.2	0.7
Adis Ketema	0.039	0.0024	3.9	0.24
Dire building	0.017	0.068	1.7	0.8
Garad	0.0316	0.0046	3.16	0.46
Gojam Berenda	0.217	0.0339	21.7	3.39
Mercato S	0.0799	0.0023	7.99	0.23
Mesalemia	0.084	0.013	8.4	1.3

Table 6-2: Sample sites with poor availability and retainability

6.1.2 Optimization Works

Optimization is defined as finding a network configuration to achieve the best possible performance using the available network equipment and spectrum efficiently. Although optimization can be used in different contexts as mentioned in Chapter two, in this thesis it is used as a network maintenance activity.

2G - RXQUAL	
0 to 1	81.8%
1 to 2	2.5%
2 to 3	3.0%
3 to 4	2.9%
4 to 5	3.0%
5 to 6	2.9%
6 to 7	2.7%
7 to 8	1.1%

2G - RxLEV	
< -110	0.0%
-110 to -100	0.1%
-100 to -90	3.2%
-90 to -80	15.2%
-80 to -70	43.1%
-70 to -60	30.4%
-60 to -50	6.6%
> -50	1.5%

2G FER	
Avg. FER	1.1%

Table 6-3: Drive test result on November 2012

Most of the optimization measures taken after DT or alarms on OMC were due to Equipment Alarms such as

- PA temperature high
- A specific site serving a very long distance causing low coverage area due to neighboring sites down
- Site interface broken

The above analysis indicates the area is well optimized in terms of using the already installed network resources effectively and efficiently. But since the demand for service is growing and is beyond the capacity of the network as indicated in the availability and retainability calculation as well as theoretical vs. operational capacity, the introduction of a better technology is a necessity.

6.2 LTE Coverage and Capacity Planning

6.2.1 Coverage Determination

Coverage planning is the first step in the process of dimensioning and radio link budget calculation is the first phase done to plan the coverage. The coverage parameters are determined by first choosing area of deployment with total coverage area of 12.56Km^2. Most link budget parameters used in the calculation are based on LTE for UMTS- OFDMA and SC-FDMA Based Radio Access [24] with 10MHz of bandwidth and central frequency of 2000MHz.

	Downlink	Uplink
Max transmitter power (dBm)	46	24
Transmitter antenna gain (dB)	18	0
Antenna diversity gain	0	2
Body loss (dB)	2	3
EIRP (dBm)	62	23
Noise figure (dB)	7	2
Thermal noise (dB)	-104.5	-104.5
Receiver noise floor (dBm)	-97.5	-102.5
SINR (dB)	-5.4	-8.58
Receiver sensitivity (dBm)	-102.9	-108.08
Interference margin (dB)	3	3
Control channel overhead (%)	0.4	0
Receiver antenna gain (dBi)	0	15
Shadow fading margin	7.5	7.5
Maximum path loss	154	138.58

Table 6-4: Link Budget calculation

Cost 231 Hata model with carrier frequency 2000MHz, base station antenna height 34m and mobile station antenna height 1.5m is further used to determine the base station coverage area.

Using Equation (4.4), the correction factor for urban area, is calculated as below:

$$a(hr) = 3.2 * (\log(11.75 * 1.5m))^2 - 4.97$$

$$a(hr) = -0.00092$$

The path loss exponent (PE) and path loss constant (PC) are calculated using Equation (4.3) as:

$$PE = 44.9 - 6.55 * \log(hb) \quad and \quad PC = 46.3 + (33.9 * \log(f)) - 13.02 * \log(hb) - a(hr)$$

$$PE = 34.8 \qquad\qquad PC = 135$$

Range (d) is also calculated using Equation (4.3) as:

$$d = 10(\frac{PL-PC}{PE})$$

$$d_{uplink} = 1.2m \; and \; d_{downlink} = 3.5m$$

The minimum range with Equation (4.6) is then used to calculate the cell coverage area.

$$Cell_{Area} = 1.95 * (1.2m^2)$$

$$Cell\_Area = 3.2m^2$$

Finally, the number of sites required to cover the selected area are calculated using Equation (4.7) as:

$$Number\_of\_Sites = \frac{12.56m^2}{3.2m^2}$$

$$Number\_of\_Sites = 4$$

6.2.2 Capacity Planning

Coverage determined sites might not support a specified traffic demand with a certain level of QoS. This could be due to a high demand. Thus capacity planning that gives an estimate of the resources needed for supporting a specified offered traffic with a certain level of QoS is the next phase in determining the number of the sites required to cover a certain area.

One of the inputs for capacity determination is required system capacity of an area which is primarily dependent on market size. Market size, potential number of subscriber, in turn is solely dependent on population size of the area. Market share is another important factor that indicates the penetration of the new technology compared with the already deployed technologies. This factor is usually not more than 10% at service take-up [35].

Identification of subscriber type is important in determining the required data rate and in anticipating how end users will use the network. In this study, subscribers are categorized as business and residential users based on their service requirement. And since the area selected is a high activity area, it is assumed more business users exit.

$$SubCap = SubType\ (\%) * Marketshare\ (\%) * Marketsize \ldots\ldots\ldots\ldots \quad (6.4)$$

Where: SubCap- Estimated subscriber capacity

SubType- Subscriber type

As the exact number of potential subscribers in the selected area is hard to find, the market size is determined by averaging the number of population found from Sub-City data and the number of attempts made by users from previous data of OMC. Customer mix of 60 % for business and 40 % for residential users is used with a market share of 10 % at service take-up. It is assumed that there will be 5 % increase in market share along the years in the study period [35].

PBH and DDR are other parameters used in combination with estimated subscriber capacity to determine traffic demand for a given service area. Another important factor is CR which indicates the average number of users that can share a given unit of channel and still get the data rates they have paid for.

$$DL\_DataRate = SubCap * PBH\_AL * DDR * CR * ServiceDR \ldots\ldots\ldots\ldots \quad (6.5)$$

Where: DL_DataRate- Downlink data rate required to support users

SubCap- Estimated subscriber capacity

PBH_AL- Peak busy hour activity level

DDR- Downlink data ratio

CR- Contention ratio

Service DR- Service data rate.

Using the analysis of 2G and 3G OMC data, 60 % PBH, 50 % downlink duty ratio and 2 % overbooking factor is used for the capacity determination.

Two traffic models are used in order to compare the techno-economic profitability of providing VOIP only service and mixed services of VOIP, streaming, video call and file transfer services. The first one is based on only real time traffic that is delay sensitive which in this case is the VOIP service. The second one is M/G/1-(Fixed file transfer) traffic model with a consideration that a single traffic can utilize the link at once if there is no other user. For this study, the minimum data rate of 64kbps for VOIP is allocated for VOIP only service while 128kbps and 512kbps are allocated to residential and business subscribers respectively for mixed services.

	Year 1	Year 2	Year 3	Year 4	Year 5
Market size estimation	419,589	435,533	452,083	469,262	487,094
Market share	10%	15%	20%	25%	30%

Table 6-5: Market size and market share estimation of selected area

Estimated subscriber capacity for both subscriber types is calculated using Equation (6.4) as:

$$SubCap_{residential} = 40\% * 30\% * 487{,}094 \ and \ SubCap_{business} = 60\% * 30\% * 487{,}094$$

$$SubCap_{residential} = 58{,}451 \qquad SubCap_{business} = 87{,}676$$

Downlink data rate is then calculated using Equation (6.5) for VOIP only service and Mixed services separately.

For VOIP only service:-

$$DL\_DataRate = 146{,}128 * 60\% * 50\% * 2\% * 64kbps$$

$$DL\_DataRate = 56{,}113.2kbps$$

For Mixed services:-

$$DL\_DataRate_{residential} = \ 58{,}451 * 128kbps * 0.4 * 0.5 * 0.02$$

$$DL\_DataRate_{residential} = 29{,}926.9kbps$$

$$DL\_DataRate_{business} = 87{,}676 * 512kbps * 0.6 * 0.5 * 0.02$$

$$DL\_DataRate_{business} = 269{,}340.7kbps$$

$$DL\_DataRate_{total} = 299{,}267.6kbps$$

Finally, the sites required to support the capacity demand are calculated using Equation (4.8). The aggregate downlink throughput per base station is taken to be 50Mbps with 16.7Mbps average sector throughput on 10MHz and 2X2 MIMO on the downlink [31].

For VOIP only service:-

$$Site\_Count = \frac{56{,}113.2kbps}{50Mbps} = 1$$

For Mixed services:-

$$Site\_Count = \frac{299{,}267.6kbps}{50Mbps} = 6$$

According to Equation (4.9), a single site is able to support the demand for VOIP only service and six sites are required to meet the demand for mixed services on the selected area.

6.3 Profitability Analysis

6.3.1 Estimating CAPEX and OPEX

CAPEX cost includes the investments to the network infrastructure and devices i.e. the fixed initial costs necessary for the BS deployments while OPEX cost includes the labor costs and expenses originating from operating and managing the networks. Cost of MIMO enabled LTE base stations, Core network elements, backhaul per link and CPE equipment start-up cost are estimated as CAPEX costs. This cost is vendor specific and for this study, it is estimated based on already deployed ZTE WCDMA technology. With the assumption that the new sites will be deployed on already existing sites to avoid the cost for installation and acquisition of a new site, installation and site rental/lease charges are calculated only for co-location sites.

CAPEX costs	Price
MIMO enabled LTE base station	$40,000
Core network elements	$800,000
Backhaul per link	$20,000
Installation cost for co-location per site	$550
CPE start-up cost per equipment	$150
OPEX costs	
Site rental/lease charges (co-location) per annum	$250
Operations/maintenance per annum	$150,000

Table 6-6: CAPEX and OPEX costs

Total ownership cost (TCO) is calculated for four sites in the case of VOIP services as it is coverage determined and for six sites in case of mixed services as it is capacity determined using Equation (5.1) as:

For VOIP only service:-

$$Total_{Cost} = 40{,}000 * 4 + 800{,}000 + 20{,}000 * 4 + 550 * 4 + 150 * 100{,}000 + 250 * 4 + 150{,}000$$

$$Total_{Cost} = \$16{,}193{,}200$$

For mixed services:-

$$Total_{Cost} = 40{,}000 * 6 + 800{,}000 + 20{,}000 * 6 + 550 * 6 + 150 * 100{,}000 + 250 * 6 + 150{,}000$$

$$Total_{Cost} = \$16{,}314{,}800$$

6.3.2 Profit Analysis

Five year study period and 15% discount rate is considered in this study. By standard, a data optimized technology such as LTE is required to offer service with less cost than previous technologies. But in this thesis, the current pricing for 3G is used for revenue calculation. This is done inorder to avoid profitability loss that might occur due to poor customer awareness of a new technology based on previous experiences.

Year	Total cost	Revenue	Cash flow
Year 1	-16,193,200	1,024,645	-15,168,555
Year 2	-151,000	3,943,366	3,792,366
Year 3	-151,000	5,075,868	4,924,868
Year 4	-151,000	6,814,655	6,663,655
Year 5	-151,000	8,435,518	8,284,518

Table 6-7: Total cost, revenue and cash flow over 5-years for VOIP service

Year	Total cost	Revenue	Cash flow
Year 1	-16,314,800	4,769,348	-11,545,452
Year 2	-151,500	9,977,157	9,825,657
Year 3	-151,500	14,644,231	14,492,731
Year 4	-151,500	17,809,410	17,657,910
Year 5	-151,500	21,500,000	21,348,500

Table 6-8: Total cost, revenue and cash flow over 5-years for mixed services

Using Equation (5.2), NPV is calculated as:

$$NPV_{VOIPonly} = -16{,}193{,}200 + \frac{-15{,}168{,}555}{(1+0.15)^1} + \frac{3{,}792{,}366}{(1+0.15)^2} + \frac{4{,}924{,}868}{(1+0.15)^3} + \frac{6{,}663{,}655}{(1+0.15)^4} + \frac{8{,}284{,}518}{(1+0.15)^5}$$

$$NPV_{VOIPonly} = -15{,}348{,}657.65$$

$$NPV_{Mixed} = -16{,}314{,}800 + \frac{-11{,}545{,}452}{(1+0.15)^1} + \frac{9{,}825{,}657}{(1+0.15)^2} + \frac{14{,}492{,}731}{(1+0.15)^3} + \frac{17{,}657{,}910}{(1+0.15)^4} + \frac{21{,}348{,}500}{(1+0.15)^5}$$

$$NPV_{Mixed} = \ 11{,}314{,}435.61$$

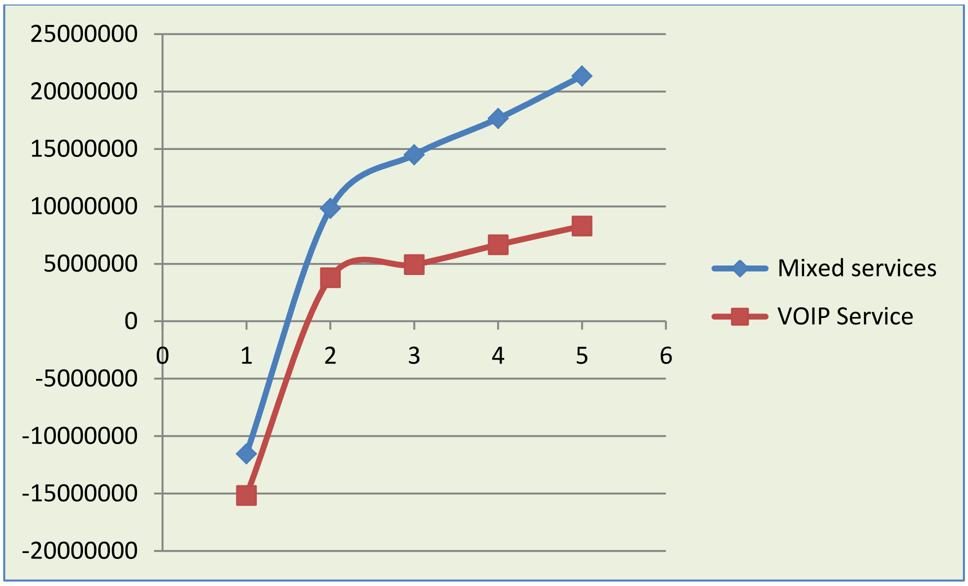

Figure 6-4: Accumulated cash flow for mixed services and VOIP (in dollar)

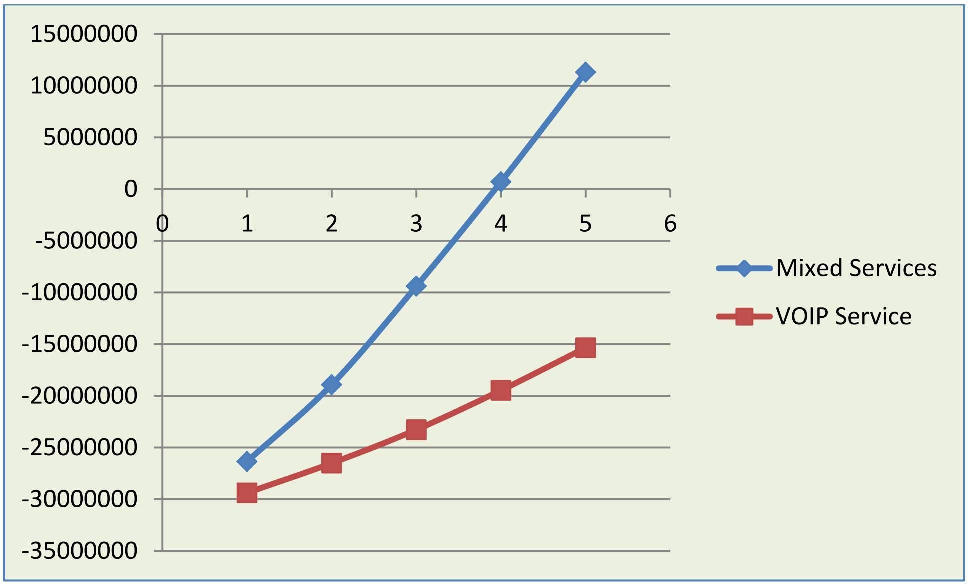

Figure 6-5: NPV for mixed services and VOIP service

From the graphs above, we can observe that:-

- The project is profitable only for mixed services with breakeven point between three and four years while VOIP service does not return profit with the considered five years study period.

7. Conclusion and Future Work

7.1 Conclusion

This thesis has described issues related with the importance of techno-economic analysis before deploying a new technology besides the need for assessment in terms of capacity, coverage and quality requirements. Nowadays, it has been integrated with the radio network planning of a technology as technological advancement alone cannot indicate the performance, acceptance and profitability of a project.

Different techno-economic models are introduced and compared in this thesis work. It is found that customers' traffic demand and total cost of ownership of the project along with economic models should be considered to assess economic viability of a project. As it can be seen from the result of the case study, the deployment of LTE on the selected area with only VOIP service is not profitable. From this we can also analyze that LTE might not be profitable in areas with majority of subscribers being VOIP only customers. And since deployment of LTE with mixed service in the selected area turned out to be profitable, LTE might be the best option on an area with high demands and different services.

With the current network capacity and service demand mismatch in ethio-telecom, a new technology such as LTE might look like the inevitable choice to alleviate the problem. But the results of this thesis indicate thoroughly studied scenarios should be conducted prior to the deployment in addition to the network planning and dimensioning process. The techno-economic model and techniques used in this thesis are helpful and can be used as platform for analyzing other new technologies and services to be introduced into a potential market.

7.2 Future Work

This thesis work is solely focused only on LTE which is part of 3rd Generation Partnership Project (3GPP) assuming WiMAX will not have any market. But this assumption should be proved and WiMAX dimensioning and implementation with a comparative techno-economic study should be carried out.

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Appendix A

Theoretical Capacity Calculation

No.	User Label	Frequency	Number of TRXS			Maximum capacity
			sector 1	sector 2	sector 3	
1	leila building	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
2	kelifa building	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
3	amanuel	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
4	a/ketema III /dire building	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
5	chid tera	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
6	gojam bernda	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
7	merkato_S	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
8	city hotel	900MHZ	6	6	6	144
		1800MHZ	8	8	8	192
9	neftegna sefer	900MHZ	8	8	8	192
		1800MHZ	8	8	8	192
10	mesalemia	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
11	dire building	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
12	extrim hotel/gola michael	900MHZ	6	6	6	144
		1800MHZ	12	12	12	288
13	garad	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
14	sumalie tera	900MHZ	6	6	6	144
		1800MHZ	12	12	12	288
15	sebara babur	900MHZ	8	8	8	192
		1800MHZ	6	6	6	144

16	piaca shewa suppermarket	900MHZ	6	6	6	144
		1800MHZ	8	8	8	192
17	media building	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
18	addis ketema sub city kebele 14/21	900MHZ	6	6	6	144
		1800MHZ	12	12	12	288
19	melamaru akababi	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
20	chefe meda	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
21	bete mengist/ras amba	900MHZ	8	8	8	192
		1800MHZ	8	8	8	192
22	arat kilo	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
23	arada mobile	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
24	lideta Geja sefer	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
25	de afric	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
26	arada	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
27	Ras mekonen bridge	900MHZ	8	8	8	192
		1800MHZ	8	8	8	192
28	3F building	900MHZ	8	8	8	192
		1800MHZ	6	6	6	144
29	3rd police station condominium	900MHZ	12	12	12	288
		1800MHZ	6	6	6	144
30	AA_ZTE G428	900MHZ	6	6	6	144
		1800MHZ	8	8	8	192
31	black-lion hospital	900MHZ				0
		1800MHZ	4			32
32	Eri-bekentu	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
33	sheraton hotel	900MHZ	8	8	8	192
		1800MHZ	6	6	6	144
34	semayawe building	900MHZ	8	8	8	192
		1800MHZ				0
35	Tele HQ	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288

36	central microwave	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
37	construction and business bank	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
38	a/ketema II/coca cola	900MHZ	8	8	8	192
		1800MHZ	8	8	8	192
39	lideta abinet	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
40	addisu michael	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
41	alkan health college	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288
42	addis ketema	900MHZ	8	8	8	192
		1800MHZ	12	12	12	288

Appendix B

Network performance calculation

No.	Sites	Blocked call	Dropped call	Blocked call rate	Dropped call rate
1	3F building	0.00526	0.0044	0.526	0.44
2	3rd police station condominum gibi	0.00765	0.00796	0.765	0.796
3	AA ZTE 428	0.00286	0.0023	0.286	0.23
4	Arada mobile	0.0324	0.0155	3.24	1.55
5	Arada	0.01248	0.00597	1.248	0.597
6	Bete-Mengist/Ras amba	0.01796	0.033	1.796	3.3
7	Black lion	0.0028	0.0019	0.28	0.19
8	Central Microwave	0.009	0.004	0.9	0.4
9	Construction and Business bank	0.007	0.0034	0.7	0.34
10	Eri bekentu	0.003	0.003	0.3	0.3
11	ETC HQ	0.004	0.003	0.4	0.3
12	Ras Mekonnen building	0.015	0.006	1.5	0.6
13	Semayawe building	0.002	0.001	0.2	0.1
14	Sheraton Hotel	0.008	0.007	0.8	0.7
15	Arat Kilo	0.0056	0.0054	0.56	0.54
16	A/Ketema II /coca cola	0.007	0.005	0.7	0.5
17	Chefe Meda	0.006	0.004	0.6	0.4
18	Ammanuel	0.009	0.09	0.9	9

19	De afric	0.007	0.0038	0.7	0.38
20	Lideta Abinet	0.032	0.013	3.2	1.3
21	Lideta Geja Sefer	0.09	0.012	9	1.2
22	Melamaru Akababi	0.0203	0.004	2.03	0.4
23	Addis ketema s/city keblele 14/21	0.022	0.007	2.2	0.7
24	Addisu Michael	0.007	0.005	0.7	0.5
25	Alkan Health college	0.0085	0.007	0.85	0.7
26	A/Ketema III/ Dire bldg	0.008	0.014	0.8	1.4
27	Adis ketema	0.039	0.0024	3.9	0.24
28	chid tera	0.0078	0.008	0.78	0.8
29	city hotel	0.0121	0.0079	1.21	0.79
30	Dire building	0.017	0.068	1.7	6.8
31	extrim hotel/gola michael	0.0054	0.002	0.54	0.2
32	Garad	0.0316	0.0046	3.16	0.46
33	Gojam Berenda	0.217	0.0339	21.7	3.39
34	Kelifa building	0.0146	0.003	1.46	0.3
35	Leila building	0.0135	0.0038	1.35	0.38
36	Media building	0.01	0.004	1	0.4
37	Mercato S	0.0799	0.0023	7.99	0.23
38	Mesalemia	0.084	0.013	8.4	1.3
39	Neftegna sefer	0.014	0.0047	1.4	0.47
40	Piaca shewa supermarket	0.005	0.002	0.5	0.2
41	sebara babur	0.007	0.0025	0.7	0.25
42	sumalie tera	0.011	0.005	1.1	0.5