Modeling Connectivity for e-Learning in Tanzania: Case-Study of Rural Secondary Schools

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Blekinge Insitute of Technology Licentiate Series No 2010:05 ISSN 1650-2140 ISBN 978-91-7295-178-5

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Blekinge Institute of Technology

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© Fatuma Simba 2010 Division of Technoscience Studies School of Planning and Media Design Graphic Design and Typesetting: Bildbolaget i Kyrkhult Publisher: Blekinge Institute of Technology Printed by Printfabriken, Karlskrona, Sweden 2010 ISBN 978-91-7295-178-8-5 um:nbn:se:bth-0462 This work is dedicated to my lovely little kids Rahma & AbdulRahim (Kaka). It is a special gift for them to adopt a spirit of learning and sharing.

Abstract

In response to different development challenges, Tanzania is striving to achieve its fourth attribute of the National Development Vision, i.e. to have a well educated and learning society by the year 2025. One of the earmarked methods is to integrate ICT in education through e-learning. However, limited or non-existent connectivity to the majority of secondary schools, especially those in the rural and remote areas, creates difficulties against e-learning initiatives. One of the limitations of connectivity problems in rural areas of Tanzania is the high cost of establishing connectivity infrastructures. The cost of connectivity varies from one technology to another and at the same time, cost is also different from one operator (service provider) to another within the country. It should be noted that providing network connectivity to rural regions in developing world is an economically challenging problem, especially given the low income levels and low population density in such areas. Many existing connectivity technologies have a high deployment cost that limits their affordability.

This research focuses on the connectivity component of the ICT for Rural Development project which aims to provide e-learning services to rural secondary schools. The other components are: Development of an Interactive e-Learning Management System; Development of e-Learning Contents and Delivery for Self Learning Environment, which collectively form the Tanzania Secondary Schools e-Learning system, abbreviated as TanSSe-L.

The licentiate thesis presents development of software system prototype to calculate the cost of connectivity for the pilot rural secondary schools in Tanzania. The system is developed to provide easy access to connectivity cost of different technologies and different operators. Development of the connectivity cost calculator follows the V-model software development lifecycle. The licentiate thesis also presents a simulation modeling approach to study performance of the earmarked connectivity technology for rural areas. The research uses both quantitative and qualitative research methodologies. It is inspired by the interdisciplinary component of mode 2 type of scientific knowledge production and Participatory Action Research (PAR). It spans software engineering in connectivity cost calculator system development, teletraffic engineering and simulation modeling in the connectivity performance evaluation. This is an applied type of research to solve a practical problem. Thus, the end product of this research is a model of an optimal connectivity solution in terms of cost and performance for rural secondary schools in Tanzania to access e-Learning resources from TanSSe-L.

Acknowledgements

First and foremost, I thank the Almighty God, the beneficent, the merciful, an architect of all creations, for enabling me to accomplish this task. I am also very grateful to my supervisors, Prof. Bakari Mwinyiwiwa, Prof E.A.M.Mjema of UDSM-Tanzania, Prof. Lena Trojer of BTH Sweden and Prof. N.H.Mvungi of UDOM-Tanzania for their valuable time, guidance, support and co-operation throughout the whole study period. Sincere appreciation is extended to Prof. Lena Trojer for her extra effort in making sure that everything goes smoothly during my stay in Sweden.

I wish to express my gratitude to Sida/SAREC through the ICT for e-learning project for sponsoring this study. College of Engineering and Technology, UDSM and The Division of Technoscience Studies, School of Planning and Media Design, BTH are acknowledged for providing conducive studying environment. Teachers from pilot schools and technical staff from commercial companies as stakeholders of this research are appreciated for their contribution and collaboration. Thank you very much for your input and cooperation during participatory activities.

Many people, especially staff from BTH and ECSE-CoET have contributed in different ways in this research; I deeply thank all of you. However, few names worth to be mentioned: Mr Mattias Schertell & Ms. Kerstin Gustavsson of BTH for their Object-Oriented Programming and Web Development courses. Mr Bakari Rashid of UDSM for his valuable assistance in web based software systems development. Eng. Dr. Zaipuna O. Yonah; thank you for sharing your knowledge of Data Communication Networks while in SIMUNET-TTCL. That's where my career in Communication Networks had its history.

I really do not know how to express both my apologies and my thanks to you my husband, Mufa. During my stay abroad; I know how much you have suffered from my absence and all the hard work you have done of taking care of our little kids. Despite all, you have always offered me a helping hand (ensuring that I am never lonely). I admit that your love has been a source of inspiration, my strength, my hope and my success. I am very proud of you!

I feel indebted to you my little angels, Rahma & AbdulRahim. Despite your little age, you seem to have an intuitive understanding and patience for my long absences from home. You have also tolerated long periods of pre-occupation even when I was actually at home. I have nothing equivalent to repay you with, please just receive my special thanks for, well everything. I deeply appreciate the support I got from Zai (Zaituni Rashid) and Dogo (Chiku Ramadhani), you have a high degree of patience, responsibility and motherly love in taking care of my children plus the overall house-keeping; for all the nights and days I was away, wrestling with this research task. May the Almighty God reward your efforts.

I am grateful to my parents, brothers, sisters and brothers in-law for their support, understanding and patience for the whole period of my study. Thank you, all of you, for your prayers and encouragement.

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List of Abbreviations and Acronyms

AMC	Adaptive Modulation and Coding
AMPS	Advanced Mobile Phone Service
AMREF	African Medical and Research Foundation
ASCII	American Standard Code for Information Interchange
BTH	Blekinge Tekniska Högskola (Blekinge Institute of Technology)
CAPEX	Capital Expenditure
CoET	College of Engineering and Technology
CITCC	China International Telecommunication Construction Corporation
CD-ROM	Compact Disk- Read Only Memory
CDMA	Code Division Multiple Access
CN	Core Network
CSS	Cascaded Style Sheets
DBMS	Database Management System
DS	Direct Sequence
DVD	Digital Versatile Disc
DSL	Digital Subscriber Line
EASSy	East African Submarine Cable
EIR	Equipment Identity Register
ECSE	Electrical and Computer Systems Engineering
EDGE	Enhanced Data Rates for GSM Evolution
ERD	Entity-Relationship Diagram
ETACS	European Total Access Communication System
ETSI	European Telecommunications Standards Institute
FEC	Forward Error Correction
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FHMA	Frequency Hopped Multiple Access
FM	Frequency Modulation
FTP	File Transfer Protocol
GERAN	GSM Edge Radio Access Network
GoS	Grade of Service
GGSN	Gateway GPRS Support Node
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HARQ	Hybrid Automatic Repeat reQuest
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HS-DPCCH	High Speed Dedicated Physical Control CHannel
HS-PDSCH	High Speed Physical Downlink Shared CHannel
HS-SCCH	High Speed Shared Control CHannel
HSUPA	High Speed Uplink Packet Access
HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrical and Electronics Engineers
ICT	Information and Communication Technologies
ICT4E	ICT in basic Education
ICT4RD	ICT for Rural Development
ILPC	Inner Loop Power Control
IMEI	International Mobile Equipment Identity

IMS	IP Multimedia Subsystem	
IMT-2000	International Mobile Telephone 2000	
IP	Internet Protocol	
IPSec	Internet Protocol Security	
ISP	Internet Service Provider	
IT	Information Technology	
ITU	International Telecommunications Union	
ITU-D	ITU -Telecommunication Development	
ITU-R	ITU - Radio Communication	
ITU-T	ITU - Telecommunication Standardization	
LAMP	Linux, Apache, MvSOL & PHP	
LAN	Local Area Networks	
LTE	Long Term Evolution	
MAN	Metropolitan Area Networks	
MoEC	Ministry of Education and Culture	
MIMO	Multiple Input Multiple Output	
MCST	Ministry of Communication Science and Technology	
MGW	Media Gateway	
MMS	Multimedia Messaging Service	
MRTC	Multi Router Traffic Grapher	
NCO	Non Covernmental Organization	
NGO	Nordia Mobile Telephone	
$OOA \ & D$	Object Oriented Analysis and Design	
OUARD	Object Oriented Analysis and Design	
OPEY	Optical Fible Cable	
OLDC	Operational Experior Constant	
OLFC	Outer Loop Power Control	
DAD		
PAK	Participatory Action Research	
PAN	Personal Area Networks	
PSIN	Public Switched Telephone Network	
QoS	Quality of Service	
RNS	Radio Network Subsystems	
RRM	Radio Resource Management	
RRN	Rural Resource Network	
RRS	Rural Resource Server	
SONGAS	Songo Songo Gas Company	
SDU	Service Data Unit	
SDLC	System Development Life Cycle	
SG	Study Group	
SGSN	Serving GPRS Support Node	
TANESCO	Tanzania Electric Supply Company	
TanSSe-L	Tanzania Secondary Schools e-Learning system	
TAZARA	Tanzania Zambia Railways Authority	
TET	Tanzania Education Trust	
TCP	Transport Control Protocol	
TCRA	Tanzanian Communications Regulatory Authority	
TDMA	Time Division Multiple Access	
TRC	Tanzania Railways Corporation	
TTCL	Tanzania Telecommunication Company Limited	
UE	User Equipment	
UCAF	Universal Communications service Access Fund	

UDOM	University of Dodoma
UDP	User Datagram Protocol
UDSM	University of Dar es Salaam
UML	Unified Modeling Language
UMTS	Universal Mobile Telecommunications System
USA	United States of America
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
VPN	Virtual Private Network
VSAT	Very Small Aperture Terminal
WAN	Wide Area Networks
WAP	Wireless Access Point
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability Microwave Access
WCDMA	Wideband Code Division Multiple Access
WRP	Wireless Rural Points
WWW	World Wide Web
2G	Second Generation
3G	Third Generation
3GPP	Third-Generation Partnership Project
3GPP2	3rd Generation Partnership Project 2

Chapter One INTRODUCTION

1.1 Background Information and Motivation

Tanzania has a national development vision – Vision 2025 that lists five attributes achievable by the year 2025; namely (1) High quality livelihood (2) Peace, stability and unity (3) Good governance (4) A well educated and learning society (5) A competitive economy capable of producing sustainable growth and shared benefits. The motivation for this research is the fourth attribute of the Vision 2025; that is to achieve "a well educated and learning society by 2025". However, the current teaching-learning process in Tanzania is mostly teacher-led; based on "chalk and talk" methods. It happens in an environment with insufficient numbers of teachers, teaching-learning resources, and limited or outdated textbooks (MoEC, 2002). The "chalk and talk" method assumes that learning is merely listening, which in turn denies students the chance to actively participate in the learning process. This method uses a small part of the learning pyramid; hence it hampers the rate of retention and therefore limits the degree of achieving the desired objectives of imparting quality education.

In partnership with the people of Tanzania, the Government of the United Republic of Tanzania succeeded to build over 3000 secondary schools within 3 years. Today (2010), secondary school attendance has grown over 200%, complementing the nearly 98% of Tanzania's primary school children attending school daily, over 9 million students in total. Tanzania's significant achievements have not been without challenges. It has not been possible to match the schools expansion programme with the supply of qualified teachers. Hence, Tanzania is now faced with two simultaneous challenges: (1) To provide the present generation of 1.6 million enrolled secondary students with the opportunity for a comprehensive and effective education; and (2) To enhance the classroom environment and teaching capacity in the secondary education system (http:// tanzaniaeducationtrust.org/tet/index.html). These shortcomings and challenges in the teaching-learning process provide opportunities to deploy Information and Communication Technologies (ICT) to improve the process.

One way to use ICT in education is through e-Learning (ICT Policy, 2003; Mason and Rennie, 2004). The e-Learning includes a wide variety of learning strategies and technologies, from Compact Disk-Read Only Memory (CD-ROMs) and computerbased instruction to videoconferencing, satellite-delivered learning and virtual educational networks (Lating, 2009; Talavera et al., 2001). In contrast to traditional forms of teaching-learning that require participation in specific courses at specific times and locations, e-Learning can take place anytime and anywhere and from any source. The e-Learning's "anytime, anywhere" approach places different responsibilities on the individual learner, who must now be able to find, analyze, integrate, store and retrieve information in self-directed ways.

The Government of Tanzania through its Ministry of Education promoted literacy in ICT by issuing a syllabus of computer studies for secondary schools in 2000, which was revised in 2002. In 2007, the government took further steps by developing an ICT policy to guide integration of ICT in basic Education (ICT4E). The strategic integration of ICT in education is expected to improve access, equity, quality and relevance at all levels of basic education (ICT4E, 2007). Furthermore, the Tanzania Ministry of Education in partnership with high technology companies (Accenture, Intel, Microsoft and Cisco) and NGOs (NetHope, AMREF, World Vision) has launched an innovative e-learning initiative called "Tanzania beyond Tomorrow" in 19th April, 2010. The initiative is part of Tanzania Education Trust (TET) and it is expected to bring e-learning to 4,000 public schools in Tanzania, helping to improve the learning environments (WEForum, 2010). Therefore ICT is taken as an enabling tool to achieve the fourth attribute of the development vision 2025. In addition to the government efforts, there are other non-governmental initiatives such as the introduction of websites with learning materials for secondary schools e.g. http://www.iicd.org/projects/ tanzania-distant-education/. The learning materials in these websites can only be accessed online. Therefore schools with no internet connection cannot access such online learning resources. It has been further observed that there are few e-learning initiatives in Tanzania and most of them do not facilitate self-learning. Therefore, rural and remote schools are still the disadvantaged group even with the availability of online e-Learning resources.

1.2 Definition of Rural Area and Rural Secondary School

Traditionally, the term rural is applied to the countryside and often used as the opposite of "urban". In this study, the term "rural" refers to the areas poorly served by ICT facilities, where various factors interact to make the establishment of ICT services difficult. A rural area may consist of scattered settlements or small towns located several tenths or hundreds of kilometers from an urban or city center. However, in some cases a suburban area may also be considered a rural area. A rural area in this case will exhibit at least one of the following characteristics (Chitamu and Vaunucci, 2002):

• Low population density, low per capita income and low level of economic activities mainly based on agriculture, fishing and handcrafts.

- Scarcity or absence of public facilities such as electricity, water, access roads and technical personnel.
- Difficult topographical conditions e.g lakes, rivers, hills, mountains or deserts which results in a high cost in construction of telecommunication/ICT networks.
- Underdeveloped social infrastructures (such as health and education)
- High cost of ICT based services, reflecting the scarcity of the service and the fact that a large number of people rely on single service point.

However, rural secondary schools are not necessarily located at the defined rural areas. In this research, a school will be referred to as a rural school regardless of its geographical location as long as it is characterized by a shortage of teachers, limited teacher competence, shortage and/or use of outdated textbooks, ineffective teaching-learning processes, the "chalk and talk" method, and a lack of or limited access to basic ICT infrastructures. This definition is in line with the definition provided by Kalinga (2008).

1.3 Challenges for Rural Connectivity in Tanzania

Rural schools have shortage or total lack of ICT infrastructures like computers, ICT literate personnel, telephone infrastructures and electricity. These are some of the challenges when establishing connectivity in the rural areas since the missing infrastructures are the prerequisite for connectivity establishment. Another challenge is the high cost of maintaining last-mile connectivity in rural areas. Last-mile connectivity is the last piece of connection from a nearby point of access to the end users' machine. Usually a customer is responsible for paying the cost of establishing and maintaining this piece of connection in order to access Internet based services. The costs of establishing and maintaining last mile connectivity consist of initial installation cost, equipment cost and monthly maintenance charges. However, the cost varies widely depending on the amount of bandwidth and the different types of connectivity technology.

Contributing majorly to the high connectivity costs is the fact that most ISPs are located in urban settings. This situation creates a costing structure where prices become relatively higher for rural end users (Sherrif, 2007). The mismatch between the type of service requested and the service offered is also another factor that contributes to the high cost of connectivity. Most ISPs have a fixed charging system that does not take into consideration different types of access needed. For example, if a videoconference session with participants only from within the country needs 512kbps of bandwidth, the ISP will charge for 512kbps link to the internet which is expensive (Sherrif, 2007). However, if the ISP were to offer 512kbps local link with no access to the internet, the cost would be relatively lower. This can be achieved if ISPs are connected to the local Internet Exchange Point and hence local traffics are routed within the country. This mismatch between service provided and service required is also due to the ICT illiteracy of end users. The few trained IT personnel are concentrated in cities since the supply is short and the demand is high.

1.4 Positive Indicators for Rural Connectivity in Tanzania

In 2002, Tanzania set off a multi-stakeholder ICT policy development initiative that led to the development of a national ICT policy and its adoption by the Government in 2003. The National ICT Policy made an explicit commitment to regulatory convergence and ICT infrastructure development. In response to the National ICT Policy theme on convergence, the government established the Tanzanian Communications Regulatory Authority (TCRA) in 2003, by merging the Tanzanian Communications Commission and Tanzania Broadcasting Commission to regulate telecommunications, broadcasting, ICT applications, the provision of postal services and management of the radio spectrum. Subsequently, TCRA adopted a new converged licensing framework to guide the ICT sector. The converged licensing regime allows leasing of excess capacity of communications infrastructures owned by utility companies such as Tanzania Electric Supply Company (TANESCO), Tanzania Railways Corporation (TRC), Songo Songo Gas Company (SONGAS) and Tanzania Zambia Railways Authority (TAZARA); to provide communication services to customers after acquiring the necessary licenses from the Authority. Moreover, it provides a framework for all communication service providers to build a nationwide backhaul and interconnect to each other. The framework provides a technological and service neutral regime where a licensee has the freedom to choose technology which is most efficient.

The Government of the United Republic of Tanzania committed itself to promote open and competitive backbone infrastructure as outlined in its National ICT Policy. The National ICT Policy stipulates that, "Tanzania should have a universally accessible broadband infrastructure and ICT solutions that enhance sustainable socio-economic development and accelerate poverty reduction national-wide; become a hub of ICT Infrastructure regionally and be a full participant in the global Information Society." (ICT Policy, 2003). Following the adoption of a national ICT policy and a converged licensing regime, Tanzania embarked on an initiative for development of ideal and open national backbone network architecture in 2005. The multi-stakeholder initiative aims to create a national Optical Fibre Cable (OFC) backbone network through consolidation of segments of the existing and planned OFC networks from different national utility companies and the incumbent as shown in figure 1.1. The implementation strategies of national ICT backbone project intends to use existing segments and planned networks by multiple national utility institutions like TANESCO, TRC, SONGAS, TAZARA and TTCL. The planned national ICT backbone aims to establish three main rings, namely northern, western and southern rings to form a carrier of carriers network which can be leased to network services or content providers. The design principle of the national backbone emphasizes convergence and interconnection with emerging regional broadband networks such as the East African Submarine Cable (EASSy) Project (Perhson and Ngwira, 2006).



Figure 1.1: The National ICT Backbone in Tanzania (Perhson and Ngwira, 2006)

Furthermore, Tanzania developed the law to establish Universal Communications Access Fund (UCAF), which was passed by the Tanzania parliament on 5th January, 2007 (UCAS Act, 2006). Establishment of UCAF is the requirement stated by the Government through the National Telecommunications Policy (1997), National ICT Policy (2003), and the Declaration of Principles of the World Summit on the Information Society (WSIS) of 2003 (Geneva) and 2005 (Tunisia). The goals and objectives of the fund are to subsidize investment in rural and underserved urban areas by rolling out connectivity (communications infrastructure and services) in order to facilitate the bridging of the Digital Divide, promote use of ICT and thus foster social and economic growth (Perhson and Ngwira, 2006).

1.5 Initiatives for Rural Scondary Schools' Connectivity

To address connectivity challenges, the Government through its Ministry of Education is working on 'eSchools programme' which is under formulation and is aimed at equipping a number of Tanzanian secondary schools with broadband connectivity and ICT facilities for a better and more efficient education system. On the other hand, the ICT for Rural Development project under the College of Engineering and Technology (CoET) at the University of Dar s Salaam (UDSM) is another initiative to support rural connectivity. The project aims at developing an e-Learning system for rural secondary schools in Tanzania. The project has three components, as shown in figure 1.2. The projects components have been tailored to address the shortage of teachers and/ or use of outdated books. This is to be achieved by providing schools with connectivity solutions to access content made available on the Interactive e-Learning Management System and prepared in line with Tanzania's secondary school curriculum. This research deals with the project's component on Modeling Connectivity for e-Learning. The other components are being worked on by other researchers.



Figure 1.2: The e-Learning Project Components

1.6 Statement of Research Problem

Rural areas in developing countries present challenges in establishing connectivity/ networks and sustainable business projects. These challenges include unreliable electricity, limited or non-existent of ICT and road infrastructure, diverse topology and low population density. In addition to the above challenges as members of the rural community; rural secondary schools in Tanzania are also characterized by shortage of teachers and limited teacher competence, shortage and/or use of outdated books, and ineffective teaching-learning process; the "chalk and talk" method.

It is anticipated that e-Learning has the capability to address the shortage of teachers, books and the inefficient teaching-learning process. However, a proper solution to the lack of connectivity and electricity is a prerequisite for e-Learning. It is worth noting that wireless technologies like Wireless Fidelity (Wi-Fi), Worldwide Interoperability Microwave Access (WiMAX) and Very Small Aperture Terminal (VSAT) have been realized as potential candidates for communication in rural and low density environments of developing countries (Islam et al., 2006; Raman and Chebrolu, 2007). But practical experiences in various developing countries like Tanzania showed that implementation of such technologies at affordable installation and operational costs is still a problem (Anatory et al., 2004). Therefore this research aims to find an alternative connectivity solution which is effective and affordable to the rural secondary schools.

The general objective of this research is:

• Modeling of an optimal last-mile connectivity solution in terms of cost and performance, for rural secondary schools to access e-learning services.

While the research specific objectives are:

- To design and implement connectivity cost calculator that calculates costs of last-mile connectivity solutions to selected secondary schools and hence identify a cost-effective solution.
- To conduct performance evaluation to determine the connectivity's QoS in delivering e-Learning contents.

Having a model that can provide the cost of last-mile connectivity to rural areas is a useful input to the Government and other stake holders such as donors or projects, determining suitable technology and the cost of establishing last-mile connectivity to rural secondary schools. The information can also help the Government in its budgeting processes in deciding how much is to be allocated for ICT to secondary schools. With the connectivity solution that provides access to the e-learning resources and/or internet, students and teachers will benefit by improving their knowledge through accessing up to date teaching/learning materials. It is envisioned to overcome problems of outdated books and shortage of teachers. Interconnecting rural schools can facilitate sharing of limited resources and teacher competence in different subject areas. The fundamental aim of performance evaluation is to come up with an optimal connectivity solution that can provide e-learning services with the required quality of service. The e-Learning system is envisioned to provide an environment and relevant resources for self-learning. Therefore a culture and motivation for self-learning will be cultivated in the youths' mind. Schools may use the connectivity as an income generating project by giving access-for-fee to the nearby community, hence facilitate ICT literacy. The generated income can pay connectivity cost, thereby making a sustainable connectivity solution model.

1.7 Thesis Organization

This thesis is organized into five chapters. Chapter one is background information and motivation; challenges, indicators and initiative for rural connectivity; Statement of research problem and thesis layout. Chapter two presents concepts overview and technology framework. Chapter three is the research methodology and connectivity cost modeling. Chapter four is on connectivity performance evaluations and finally a chapter on concluding discussions.

Chapter Two CONCEPT OVERVIEW AND TECHNOLOGY FRAMEWORK

2.1 Technologies and Models for Rural Connectivity

It has been pointed out that an IP based network is a cost effective solution for communicating in non-urban and lowly populated areas (Chitamu and Vaunucci, 2002). However, wireless networks, comprising of mobile/cellular, Wi-Fi, WiMAX and satellite (VSAT) have become technologies of choice for increasing access to phone and internet services in developing countries. They are not only cheaper, easier and faster to deploy than traditional wired alternatives, but also make possible business and service delivery models better adapted to rural, low income communities (Islam et al., 2006; Raman and Chebrolu, 2007).

Tanzania has different connectivity options that are categorized as wired and wireless connectivity technologies. Wired technologies include broadband on Digital Subscriber Line (xDSL), leased line on copper wire and fiber optic cables. The wireless counterpart comprises of satellite-based VSAT, fixed wireless technologies, (e.g WiMAX, WiFi) on licensed band and on unlicensed spectrum and mobile cellular technologies such as CDMA, GPRS & HSDPA (Sherrif, 2007).

Wireless technologies are the candidate for access to areas that are remote, difficult or expensive to reach with traditional wired infrastructures (such as optical fiber, or telephone copper-wires). However, each wireless technology is designed to serve a specific usage segment, categorized as IEEE 802.15 standard for Personal Area Networks (PANs) e.g Bluetooth, IEEE 802.11 standard for Local Area Networks (LANs) e.g. Wi-Fi, IEEE 802.16 standard for Metropolitan Area Networks (MANs) e.g. WiMAX and 3GPP standard for Wide Area Networks (WANs) e.g 2.5G, 3G. The requirements for each usage segment are based on a variety of variables, including: bandwidth, distance, power, user location, services offered and network ownership.

The Wi Fi also known as IEEE 802.11 was originally designed to be a wireless replacement of LANs (WLANs). Four major revisions to the physical layer have been released:

- 802.11a supports bandwidth speeds up to 54 Mbps
- 802.11b supports bandwidth speeds up to 11 Mbps
- 802.11g supports bandwidth speeds up to 54 Mbps
- 802.11n supports bandwidth speeds up to 248 Mbps

Using directional antennas or implementing pre standard Wi-Fi mesh topologies have been able to increase performance beyond 54 Mbps and to cover over ten kilometers using the 802.11 standard (Chebrolu et al., 2006). The increase in range has placed 802.11 into two usage segments: LAN and MAN. The three key modified deployment types for IEEE 802.11 access are backhaul, last-mile and large-area coverage (referred to as hot zones or mesh networks). Wireless last-mile coverage typically uses the IEEE 802.11 standard with high-gain antennas, while hot zones use modified IEEE 802.11 equipment in a mesh deployment (Raman and Chebrolu, 2007).

The IEEE 802.11 Wi-Fi has been proposed as a cost-effective option to provide wireless broadband in rural areas and has been used well beyond its original target of WLANs connectivity. Of particular interest is its use in long-distance networks as a cost-effective option to provide wireless broadband in rural areas. In the developing and the developed world alike, 802.11 links have been used in long-distances of up to several tens of kilometers in rural settings (Chebrolu et al., 2006). Some examples are: (a) the Ashwini project, in Andhra Pradesh, India, (b) the Akshaya deployment in Kerala, India, (c) the Digital Gangetic Plains testbed (Chebrolu et al., 2006) in Uttar Pradesh-India (d) DjurslandS.Net: a deployment in Denmark (e) ICT for Rural Development (ICT4RD) project in Tanzania succeeded in providing ICT access between Bunda and Mugumu through an optic fiber, which is then extended to Mugumu Nyerere Hospital about 1km away by using IEEE 802.11 long-distance link (Genesis, 2007).

Long-distance wireless technologies, especially those based on standards can enable networking in rural regions. The attractive features of these networks include the low-deployment cost, ease of deployment and the ability to cater a wide-range of geographic terrain. On the flip side, these wireless networks have capacity constraints that limit the maximum available bandwidth and also suffer from reliability problems. The modified standards for wireless long distance last-mile and hot-zone coverage are proprietary, thus providing little or no interoperability with the standards-based backbones. In addition, the modified IEEE 802.11 deployments are usually implemented in the unlicensed frequency bands. Generally, the unlicensed bands are subject to interference because deployment is open to anyone.

WiMAX, also known as IEEE 802.16 standard relates to Wi-Fi hotspot technology but operates at much longer distances and has much higher data capacity than cellular networks. WiMAX networks currently extend the reach of optical fiber backbones by up to 40 kilometers per hop (point-to-point) or distribute service to individual communities at distances of 5-10 kilometers (point-to-multipoint). The technology can provide Internet connectivity to reach the rural community, especially the hub of a community network (Hammond and Paul, 2006). Cellular networks are expanding rapidly and provide some rural coverage, with the pattern varying widely by country. They are good for voice communication, while most of them have no or very limited capacity to transmit data. However, there are newer network technologies such as Code Division Multiple Access (CDMA), General Packet Radio Service (GPRS) and High Speed Downlink Packet Access (HSDPA) which have increased data capacity and carriers; they are deployed in higher capacity networks like 2.5G, 2.75G and 3G in developing countries. Practical experiences in Tanzania are provided by Vodacom (T) Ltd through its HSDPA mobile services, TTCL mobile through its CDMA network and Z-Connect from Zantel through its GPRS network (Sheriff, 2007). Generally, cellular systems are relatively expensive solutions for data communication, even though cellular networks reach individual end-users directly and mobility is often a useful benefit (Hammond and Paul, 2006).

Another wireless option, especially for more remote communities, is a satellite based networks; VSAT, that is designed for data transmission. The VSATs have higher data transmission capacity and generally lower costs for ground stations (Sherrif, 2007; Hammond and Paul, 2006). The VSAT technology has been utilized by a government initiative to provide broadband internet connectivity to all 32 government owned teachers training colleges.

In addition, there are models proposed or developed for rural connectivity in developing countries, an example being: "Next Generation Rural Wireless Connectivity Model for Developing Countries" by Islam et al., (2006). This is a proposed cost-effective rural connectivity model for Bangladeshi. The approach is to implement wireless stationary end points which will be termed as Wireless Rural Points (WRP). Several WRPs will be connected to a central Wireless Access Point (WAP). Several WAPs will form a Rural Resource Network (RRN) with its server; the Rural Resource Server (RRS) is connected to IP backbone.

Another model is presented by Hammond and Paul (2006) called "A new model for rural connectivity". It is a fully functional community-based telecommunications network built to serve the latent demands for local-community voice communications. It consists of voice services that are provided through VoIP in a wireless distribution, either Wi-Fi or WiMAX links. VSAT links are used for connecting the more remote rural systems to the Internet. In this model, the local network is easily deployed, provides multiple telephony access points for both inter-community and long distance calling in addition to supporting data. Practically it has been done by turning an existing satellite ground station into a local community telecommunication network by adding Wi-Fi/WiMAX distribution capabilities and Wi-Fi phones. To the best of my knowledge, there is no model developed for rural connectivity in Tanzania. However, the implementation of the proposed models in the Tanzanian environment is challenged by affordability of high bandwidth and limited infrastructures.

2.2 Evolution of Wireless Mobile Networks

Mobile communication is not a recent technology. It started far back in the ancient times. It has kept on evolving due to capacity demands and improvement forces. A rapid involvement is noted in the past decades when the cellular concept and frequency reuse techniques were introduced (Schiller, 2003; Liu, 2009). The first cellular telephone system named the Advanced Mobile Phone Service (AMPS), an analog mobile phone system working at 850 MHz, was developed by AT&T Bell Laboratories in the late 1970s (Schiller, 2003, Liu, 2009). Other first generation mobile networks such as European Total Access Communication System (ETACS) deployed in Europe, which was virtually identical to the AMPS except for some minor differences in frequency bandwidth and the Nordic Mobile Telephone (NMT) system, which operated in the whole of Scandinavia region (Liu, 2009). To maintain the first generation subscriber service quality, especially in a heavily populated area, was a hard task due to tremendous system complexity and lack of control. As a result, these analog networks were switched off in 2000 (Schiller, 2003; Svoboda and Karner, 2009).

The early 1990s marked the beginning of fully digital systems. Due to the fact that the techniques in the first generation analog system were not able to satisfy the growing demand for capacity, cellular systems using digital modulation techniques emerged. These digital systems offer large improvement in capacity and system performance (Schiller, 2003; Liu, 2009). Unlike the first generation networks that exclusively rely on Frequency Division Multiple Access/ Frequency Division Duplex (FDMA/ FDD) and analog Frequency Multiplexing (FM), the second generation (2G) systems conform to the standards which use digital modulation formats and Time Division Multiple Access (TDMA)/FDD and CDMA/FDD multiple access techniques. The Global System for Mobile Communication (GSM) is the 2G mobile network widely deployed in Europe, which later gained worldwide acceptance and became the world's most popular mobile technology. FDD and a combination of TDMA and Frequency Hopped Multiple Access (FHMA) schemes are employed for multiple accesses by mobile users, while Gaussian Minimum Shift Keying (GMSK) is used for digital modulation. Each frequency channel is further divided into eight time slots so that they can be shared by several subscribers in order to achieve higher capacity. However, by then, the popular system in USA was IS-95 (also known as CDMAone), one of the 2G cellular systems based on Code Division Multiple Access (CDMA).

End terminals in the 2G networks could only process audio/voice as input data. Therefore, users had to use a modem to transfer data traffic via GSM. This method of data transport is quite inefficient. In order to support modern Internet applications, like web browsing, e-mail and file transfer, some new standards have been developed on the basis of 2G technologies, such that the existing 2G equipment can be upgraded with higher data rate transmissions, while still operating on the same carriers. They are generally categorized as 2.5G mobile communication systems, which are General Packet Radio Service (GPRS) and Enhanced Data Rates for GSM Evolution (EDGE). The 2.5G technologies only serve as a temporary data solution for the exploding internet services. The eventual 3G systems provide much higher data rates as well as much more services. The 3G technologies emerge with the International Mobile Telephone 2000 (IMT-2000) plan suggested by the International Telecommunications Union (ITU), which aims to implement a global ever-present mobile communication standard based on Wideband-CDMA throughout the world. However, as different 2G systems were already deployed in Europe and USA, the 3G evolution path diverges as well in order to be backward compatible, and accordingly forms two major camps. The GSM systems in Europe lead to UMTS which is standardized by the 3rd Generation Partnership Project (3GPP) community, while in USA, with the existence of 2G CDMA systems, the standardization activities of CDMAone are organized in the 3rd Generation Partnership Project 2 (3GPP2) association. This thesis focuses on the evolution of GSM, hence UMTS networks. The choice is based on the fact that UMTS is the technology currently available in the area where this research study is conducted. Hence all the releases and protocols mentioned in the later sections refer to those in the 3GPP only.

The UMTS discussed and introduced in many countries relies on the initial release of the UMTS standard called Release 99 or R99. It was finalized in 1999 - hence the name R99. This release described the new radio access technologies UMTS Terrestrial Radio Access (UTRA) FDD and UTRA TDD, and standardizes the use of a GSM/ GPRS network as a core within 440 separate specifications. This enables a cost effective migration from GSM to UMTS. The R99 was further followed by two other releases, called Rel-4 and Rel-5, which eventually forced R99 to be also named as Rel-3. The 3GPP specifies UMTS in several steps; from Rel. 99 and Rel. 4 offering theoretical bit rates of up to 2Mbit/s, to Rel. 5 and 6 reaching higher bit rates beyond 10 Mbit/s. Rel-4 introduces quality of service in the fixed network plus several execution environments and new service architecture. Rel-5 specifies a radical different core network. The GSM/GPRS based network is replaced by an almost all-IP-core network. This standard integrates IP based multimedia services, provides a High Speed Downlink Packet Access (HSDPA) with speeds in the order of 8-10 Mbit/s as well as wideband 16 kHz Adaptive Multi-Rate (AMR) codec for better audio quality. Additional features are end-to-end messaging with Quality of Service (QoS) and other several data compression mechanisms. Rel-6 comprises the introduction of High Speed Uplink Packet Access (HSUPA) and the use of Multiple Input Multiple Output (MIMO) antennas, enhanced Multimedia Messaging Service (MMS), security enhancements, WLAN/ UMTS interworking, broadcast/multicast services, IP emergence calls etc (Schiller, 2003). By the introduction of HSDPA in Release 5, the packet throughput is boosted tremendously for the increasing bandwidth demands in the downlink direction. And the recent Enhanced Uplink (HSUPA) in Release 6 aims to meet the growing traffic demands in the uplink direction. Both HSDPA and HSUPA enable the efficient transport of packet-switched Internet traffic, thus they are sometimes respectively referred to as 3.5G and 3.75G mobile systems (Liu, 2009).

2.3 UMTS Architecture

The network architecture of 3G cellular mobile networks is shown in figure 2.1. Figure 2.2 is a block diagram of the same network showing architecture and interfaces. The UE stands for User Equipment domain. The UMTS Terrestrial Radio Access Network (UTRAN) handles cell level mobility and comprises of several Radio Network Subsystems (RNS). The RNS's function includes radio channel ciphering and deciphering, handover control, radio resource management etc. The UTRAN is connected to the user equipment (UE) via the radio interface Uu. The UTRAN communicates with the Core Network (CN) via Iu interface. The CN contains functions for inter-system handover, gateways to other networks (fixed or wireless) and performs location management if there is no dedicated connection between UE and UTRAN.



Figure 2.1: Elements of 3G Cellular Mobile Networks (Svoboda and Karner, 2009)



Figure 2.2: UMTS Network Architecture and Interfaces (Svoboda and Karner, 2009)

The UE consists of the physical equipment used by a subscriber, which comprises the Mobile Equipment (ME) and the Subscriber Identity Module (SIM). It is called the UMTS Subscriber Identity Module (USIM) for Rel. 99. The ME encompasses the Mobile Termination (MT), which, depending on the application and services, may support various combinations of Terminal Adapter (TA) and Terminal Equipment (TE) with functional groups to provide end-user applications and to terminate the upper layers (Svoboda and Karner, 2009).

The biggest difference between GSM and UMTS is the radio interface Uu. The duplex mechanisms are the same as in GSM FDD and TDD, however, the Direct Sequence (DS) CDMA used in UMTS is new. This technology multiplies a stream of bits with a chipping sequence. This spreads the signal and if the chipping is unique, can separate different users. To separate different users, the codes used for spreading should be (quasi) orthogonal, that is their cross correlation should be zero. UMTS uses a constant chipping rate of 3.84 Mchip/s, different user data rates can be supported using different spreading factors (i.e number of chips per bit). The UMTS uses the so-called orthogonal variable spreading factor (OVSF). The FDD mode for UTRA in UMTS uses wideband CDMA (UTRA-FDD (W-CDMA)) with direct sequence spreading. As implied by FDD, uplink and downlink use different frequencies. The radio frame in WCDMA comprises for 15 time slots. These time slots are not used for user separation, but to support periodic functions. A radio frame consists of 38,400 chips and has duration of 10ms. Each slot consists of 2,560 chips, which roughly equals 666.6 microseconds. The occupied bandwidth per WCDMA channel is 4.4 to 5 MHz. The UTRA-TDD mode in UMTS (UTRA TDD (TD-CDMA)) separates up and downlink in time using a radio frame structure similar to FDD: 15 slots with 2,650 chips per slot form a radio frame with duration of 10 ms. The chipping rate is also 3.84Mchip/s to reflect different user needs in terms of data rates. The TDD can be symmetrical or asymmetrical i.e the frame can contain the same number of uplink and downlink slots or any arbitrary combination (Schiller, 2003).

The UTRAN consists of several Radio Network Subsystems (RNS). Each RNS is controlled by a Radio Network Controller (RNC) and comprises several components that are called Node B. Each Node B can control several antennas which make a radio cell. The mobile device, UE, can be connected to one or more antennas wih regard to the handover context. Each RNC is connected to the core network (CN) with an interface Iu. The RNC is connected with node B via interface Iub and the RNCs are connected to each other via interface Iur. The main task of NodeB is the performance of physical layer processing including channel coding, interleaving, rate adaptation, spreading and so on. Furthermore, some Radio Resource Management (RRM) operations such as the Inner Loop Power Control (ILPC) as well as the fast Hybrid Automatic Repeat reQuest (HARQ), scheduling and priority handling for HSDPA have to be performed in the NodeB. The RRM tasks performed in the RNC are the load and congestion control of its own cells, admission control and code allocation for new radio links to be established in those cells as well as handover decisions and the Outer Loop Power Control (OLPC). The RNC performs the layer-two processing of the data to/from the radio interface and macro diversity combining in case of soft handover (Svoboda and Karner, 2009; Schiller, 2003).

While the UE and the UTRAN contain new specific protocols as well as a new radio interface (WCDMA), Rel. 99 UMTS Core Network was inherited from the GSM system and both UTRAN and GSM Edge Radio Access Network (GERAN) connect to the same core network. The core network consists of the circuit switched domain for the real time data and the packet switched domain for non-real-time packet data. In the CS domain the Mobile Switching Center (MSC) including the Visitor Location Register (VLR) connects to the RNCs. It switches the CS data transactions and stores the visiting user's profiles and location. The Gateway MSC (GMSC) connects UMTS to external networks such as, for example, the Public Switched Telephone Network (PSTN). In the Home Location Register (HLR) the user's service profiles and the current UE locations are stored and the Equipment Identity Register (EIR) is a database for identification of UEs via their International Mobile Equipment Identity (IMEI) numbers. The Serving GPRS Support Node (SGSN) is equivalent to the MSC but for the Packet Switched (PS) domain. It is responsible for the user mobility and for security (authentication). The Gateway GPRS Support Node (GGSN) provides connection to external networks such as the Internet (Svoboda and Karner, 2009; Schiller, 2003).

In the recent 3GPP Release 4/5/6, the network architectures have been improved in order to offer significantly higher data rate than the legacy UMTS network. The main difference between the Release 99 architecture and Release 4 architecture is that the CN circuit-switched domain becomes a distributed network, where the traditional circuit-switched MSC is divided into an MSC server and a Media Gateway (MGW), and also the GMSC is divided into a GMSC server and a MGW. The next step in the UMTS evolution is the introduction of an all-IP multimedia network architecture. In Release 5, it contains the first phase of IP Multimedia Subsystem (IMS), which enables the standard approach for IP based service provision via packet-switched domain. The functions of the IMS are further enhanced in Release 6, where the services similar to circuit-switched domain are allowed to be provided via the packet-switched domain. In this architecture, both voice and data traffic is handled in the same manner all the way from UE to the ultimate destination, which can be considered as the convergence of voice and data (Schiller, 2003; Liu, 2009).

The goal of introducing upper releases of UMTS e.g. Rel-5 was to provide higher bit rates for the UE, hence keeping architectural changes to a minimum. The net data rate that is available to the UE in a wireless mobile network is called the bearer speed. User data in UMTS may be transferred using two different implementations: DCH or High Speed Packet Access (HSPA) (3GPP TS 25.213 (2006); 3GPP TS 25.308 (2007)). In case a very low amount of user data has to be transmitted, a random or common channel can also serve for data transmission. However, normal Internet applications will initiate data transfers triggering a DCH or HSPA channel assignment.

The DCH channel has different bearer speeds depending on the chosen spreading factor. For a fixed transmit power, a larger spreading factor allows more reliable trans-

mission at the cost of a lower user data rate. Therefore, users with a higher distance to the base station will only achieve a lower data rate. In addition to this, as part of the network optimization process, the RNC monitors the actual data rate the user needs and adjusts it accordingly, via the spreading factor. Table 2.1 shows the available options for the DCH.

User Data Rate (kbit/s)	Interface Data Rate	Spreading Factor
	(kbit/s)	
12.2	30	128
32	60	64
64	120	32
128	240	16
384	480	8

Table 2.1: DCH Data Rate for Different Spreading Codes (factors)

HSPA extends the radio interface of the UMTS network. A data symbol on the radio interface can transmit up to 4 bits of data, while standard UMTS symbols transmit only 2 bits of data. The data rate assignment in HSDPA differs from DCH. The physical channel is set to a fixed spreading factor of 16, which equals a data rate of 14.4Mbit/s. This is a strong improvement over the 384 kbit/s in the DCH. However, 14.4Mbit/s is the total rate of the entire HSDPA cell. All users have to share this resource. HSDPA uses a slot length of 2 ms; within each slot 15 different code channels are transmitted. A scheduler in the NodeB assigns code channels to the specific users according to the UE capabilities and the data rate need. For example, a UE capable of class five data rates can decode five code channels within one time slot, which equals a user data rate of 3.6Mbit/s.

2.4 Traffic Engineering

Traffic engineering also known as Teletraffic theory is defined as the *application of probability theory to the solution of problems concerning planning, performance evaluation, operation and maintenance of telecommunication systems.* More generally, teletraffic theory can be viewed as a discipline of planning where the tools (stochastic processes, queuing theory and numerical simulation) are taken from the disciplines of operations research. The term *Teletraffic* covers all kinds of *data communication traffic* and *telecommunication traffic.* The objective of teletraffic theory can be formulated as follows:

"To make the traffic measurable in well defined units through mathematical models and to derive the relationship between grade-of-service and system capacity in such a way that the theory becomes a tool by which investments can be planned" (Iversen, 2006).

The main task of teletraffic theory is to find a balance between quality of service, network capacity and traffic demand. That is to find a cost effective solution (network capacity) to fulfill the need of the customer (Grade of Service - GoS). Therefore the demand in traffic is supposed to be forecast; with measurements and/or forecasting techniques. The parameters of teletraffic are: QoS, network capacity, and traffic demand. These three components are closely related; given two parameters, the third can be calculated. It is the task of the teletraffic theory to find the exact mathematical relationship between these three parameters. This may include some statistics and cannot be always solved in a closed form (Svoboda, 2008).

Performance analysis is also identified as another task that can be solved using teletraffic theory. This analysis searches for the maximum achievable performance of a system, therefore, QoS is an output parameter, while demand and capacity are input parameters. Such analysis is crucial in the setup phase of a network, and later on in the optimization process. The optimization process finds out how much capacity needs to be added in order to meet the target QoS for a given increase in demand. There are three different approaches to solve a teletraffic engineering problem:

- Analytical
- By simulation
- Based on Measurement

The analytical solution is a closed form equation, or at least a numerical approximation, describing the relationship between QoS, demand and capacity. This has several advantages for the understanding of the investigated network elements. The solution can be calculated directly, be tractable and hence provides a deep insight into how the three parameters are linked together. Analytic solutions exist for many queuing models (Kleinrock, 1975; Zukerman, 2008).

However, in the case of more complex systems it is often necessary to use a high abstraction level; the simulation approach. The simulation software will simulate properties of all network elements between sender and receiver of the traffic, including the protocols. Ideally, the simulation provides the same results as an evaluation based on measurement. However, due to computational restrictions simulations often use simplifications, such as, omitting the protocol stack. The output of a simulation is only a point of the function connecting QoS, demand, and capacity. Therefore, simulations have to be repeated for various input parameters, e.g., radio conditions or user load. The big advantage of simulations is the fact that they are simpler to implement than analytical methods and more flexible than measurements. They are often used in performance evaluations and optimizations. Both, analytical and simulation based, approaches often have to make assumptions to simplify the problem. Measurement based evaluations are important in verifying the results of these two approaches (Svoboda, 2008; Maria 1997).

2.5 Quality of Service (QoS)

The term Quality is defined by the International Standards Organization, ISO 9000-2000, (1994) as "Degree to which set of inherent characteristics fulfils requirements". Characteristics may be defined as distinguishing features such as electrical, mechanical, sensory or biological. For the purpose of understanding Quality of Service (QoS)

in Telecommunications; the term quality is further defined by the ISO 8402, (1988) as *"The totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs"*. The stated and implied needs of the user (quality) of a product, service, process or an organization may be expressed by a set of relevant parameters in a defined unit of measurement. On the other hand, ITU-T Recommendation E.800 defines QoS as *"The collective effects of service performance which determine the degree of satisfaction of a user of the service"*. The term QoS is extensively used today, not just in the telecommunications world in which it has its roots, but increasingly in IP–based services like broadband, wireless and multimedia services (ITU –T Rec. G 1000, 2001).

However, the QoS definition can be viewed in four different perspectives: Customer's QoS requirements, QoS planned by service provider, QoS achieved by the service provider and QoS perceived by the customer as shown in figure 7 (Oodan et al., 2003, ITU-T Rec. G. 1000, 2001).



Figure 2.3: The Four Viewpoints of QoS

Oodan et al., (2003) and ITU-T Rec. G 1000, (2001) has defined the characteristics of the four viewpoints of QoS as follows: QoS requirements by the customer are the statement of the level of quality of a particular service. The level of quality can be expressed by the customer in technical or non-technical language. A typical customer is not concerned with how a particular service is provided or with any of the network's internal design, but only interested with the resulting end-to-end service quality. QoS planned by the service provider is a statement of the level of quality expected to be offered to the customer by the service provider. The level of quality is expressed by values assigned to QoS parameters. The service provider may express the offered QoS in non-technical terms for the benefit of customers and in technical terms for use within the business. QoS achieved by the service provider is a statement of the level of quality provided to the customers. It is expressed by values assigned to parameters, which should be the same as those specified for the planned QoS so that the two can be compared. QoS perceived by the customer is a statement expressing the level of quality they believe they have experienced. It is expressed in terms of degree of satisfaction and not in technical terms.
The International Telecommunications Union is a body of the United Nations responsible for aspects of telecommunications. It has three sectors — Radio Communication (ITU-R), Telecommunication Development (ITU-D) and Telecommunication Standardization (ITU-T). The ITU-T sector is responsible for the creation of telecommunications standards, which are published as ITU-T Recommendations. Recommendations are developed by technical groups known as study groups, each of which is responsible for a specific technical area, e.g. ITU-T Study Group 12 (ITU T SG 12) is the lead study group for work on performance and QoS (Mustil and Willis, 2005).

In November 2001, ITU-T SG12 approved Recommendation G.1010 'End-user Multimedia QoS Categories'. This Recommendation defines a broad classification of user-centric QoS categories for a range of services and applications. The intention behind this categorization is to aid in the derivation of a set of realistic QoS classes and QoS control mechanisms for underlying transport networks. ITU-T Recommendation G.1010 gives the delay and information loss performance requirements for a range of audio, video and data applications based on published research on user requirements. The range of delay and loss sensitivities is then formalized into eight categories as illustrated in Table 2.2.

	Error Tolerant	Error Intolerant
Interactive (delay<1 sec)	Conversational Voice and Video	Command/Control (e.g. telnet, interactive games)
Responsive (delay~2 sec)	Voice and Video Messaging	Transactions (e.g. e-commerce, web browsing, e-mail access)
Timely (delay~10sec)	Streaming Audio and Video	Messaging and Downloads (e.g. FTP, still images)
Non-Critical (delay>10sec)	Fax	Background (e.g. Usenet)

Table 2.2: The Model for User-Centric QoS Categories (ITU T Rec. G 1010, 2001)

Some key points to note about this model of categorization are: As it is based on user perception, it is suitable for use with any underlying transmission technology. It provides upper and lower bounds for delay and loss — providing poorer quality for a given set of applications is likely to result in user dissatisfaction and providing higher quality may mean that network resources are being wasted. It provides a simple way to assess the suitability of a given bearer channel for supporting particular applications. It shows how QoS classes for differentiating service performance can be appropriately grouped without implying that one class is better than another. Furthermore, the ITU T Recommendation G.1010 provides a summary indication of suitable performance targets for data application as shown in table 2.3.

Medium	Application	Degree of	Typical	al Key performance parameters and target		
		symmetry	amount of data		values	
				One-way delay (Note)	Delay variation	Information loss
Data	Web-browsing – HTML	Primarily one-way	~10 KB	Preferred<2s/ page Acceptable< 4s / page	N.A.	Zero
Data	Bulk data transfer/retrieval	Primarily one-way	10KB-10 MB	Preferred < 15s Acceptable< 60 s	N.A.	Zero
Data	Transaction services– high priority e.g. ecommerce	Two-way	< 10 KB	Preferred < 2 s Acceptable<4 s	N.A.	Zero
Data	Command/ control	Two-way	~ 1 KB	< 250 ms	N.A.	Zero
Data	Still image	One-way	< 100 KB	Preferred <15 s Acceptable<60 s	N.A.	Zero
Data	Interactive games	Two-way	< 1 KB	< 200 ms	N.A.	Zero
Data	Telnet	Two-way (asymmetric)	< 1 KB	< 200 ms	N.A.	Zero
Data	E-mail (server access)	Primarily one-way	< 10 KB	Preferred < 2 s Acceptable<4 s	N.A.	Zero
Data	E-mail (server to server transfer)	Primarily one-way	< 10 KB	Can be several minutes	N.A.	Zero
Data	Fax ("real- time")	Primarily one-way	~ 10 KB	< 30 s/page	N.A.	<10 ⁻⁶ BER
Data	Fax (store & forward)	Primarily one-way	~ 10 KB	Can be several minutes	N.A.	<10 ⁻⁶ BER
Data	Low priority transactions	Primarily one-way	< 10 KB	< 30 s	N.A.	Zero
Data	Usenet	Primarily one-way	Can be 1 MB or more	Can be several minutes	N.A.	Zero
NOTE – In	some cases, it ma	y be more app	propriate to cons	der these values a	s response	times.

Table 2.3: Performance Targets for Data Applications

The third generation partnership project (3GPP) has specified a series of QoS classes, which are also referred to as traffic classes, for its Universal Mobile Telecommunications System (UMTS). The four traffic classes defined by 3GPP are distinguished by the delay sensitivity of the traffic they are intended to support. The four classes: *conversational, streaming, interactive and background* are defined in terms of the applicability of the set of UMTS bearer attributes to each class. Three of the attributes that relate to the performance of the UMTS bearers are Transfer delay, Service data unit (SDU) error ratio and the Residual bit error ratio. The fundamental characteristics of the four classes, along with the values that can be associated with their performance-related bearer attributes are shown in Table 2.4. It should be noted that the performance limits shown in Table 2.4 are not end-to-end across the network. Rather, they apply to the mobile access part of a 3G path (i.e. they are applicable to the UMTS terrestrial radio access network (UTRAN)). Certain combinations of parameter values may not be pos-

sible under some network conditions, e.g. it may not always be possible to simultaneously have a short transfer delay and a low SDU error ratio.

The conversational class is intended to support delay-sensitive real-time applications where the information flow is bi-directional, as in a telephone conversation or video-conference. The streaming class is also intended to support delay-sensitive real-time applications, but those that that have information flows which are primarily uni-directional, such as video-on demand. These uni-directional applications are generally less delay sensitive than conversational flows, hence the less stringent delay objective.

The interactive and background classes are intended to be used by traditional Internet applications, such as e-mail, Web browsing and FTP downloads. As these applications are significantly less delay sensitive than conversational or streaming applications, better SDU error ratio and residual bit error ratios can be achieved, at the expense of delay, by appropriate channel coding and retransmission in the UTRAN. The interactive class is intended for use by applications where there is a request and response nature to the information flow, such as in interactive Web browsing. The background class is intended for background traffic, such as the background download of e-mail or other files. In order to ensure that the interactive applications do not suffer excessive delays, 3GPP TS 23-107 (2003) recommends that the interactive and background flows be separated by giving interactive traffic a higher priority in scheduling than background traffic, with background applications only using transmission resources when interactive applications do not need them. Such scheduling is particularly important in a wireless access environment due to the constraints on bandwidth.

	QoS Class (or Traffic Class)				
	Conversational Class	Streaming Class	Interactive Class	Background Class	
Intended for:	Real-Time Conversation	Real-Time Stream	Interactive best-effort	Background best effort	
Fundamental Characteristics	Preserves time relation and variation between information entities of the stream Traffic follows a conversational pattern and has a stringent	Preserves time relation and variation between information entities of the stream	Traffic follows a request/response pattern	Destination is not expecting data within a given time	
	delay requirement		content	content	
Example Application supported	Speech	Streaming video	Web Browsing	Background download of e-mail	
Transfer Delay	Maximum 100ms	Maximum 280ms	n/a	n/a	
SDU error ratio	10 ⁻² , 7x10 ⁻³ ,10 ⁻³ , 10 ⁻⁴ ,10 ⁻⁵	10 ⁻² , 7x10 ⁻³ ,10 ⁻³ , 10 ⁻⁴ ,10 ⁻⁵	10-3, 10-4, 10-6	10-3, 10-4, 10-6	
Residual Bit error ratio	5x10 ⁻² ,10 ⁻² ,5x10 ⁻³ , 10 ⁻³ ,10 ⁻⁴ ,10 ⁻⁵ ,10 ⁻⁶	5x10 ⁻² ,10 ⁻² , 5x10 ⁻³ , 10 ⁻³ ,10 ⁻⁴ , 10 ⁻⁵ ,10 ⁻⁶	4x10 ⁻⁴ ,10 ⁻⁵ ,6x10 ⁻⁸	4x10 ⁻⁴ , 10 ⁻⁵ ,6x10 ⁻⁸	

Table 2.4: The 3GPP UMTS QoS Classes (3GPP: TS 23-107, 2003)

2.6 Traffic Models

Modeling is the process of producing a model (Maria, 1997). A model can be a physical, logical or mathematical representation of a system, entity, phenomenon or process. In other words, modeling refers to the process of applying quantitative reasoning to generate a conceptual representation of a system or process. It enables to discover aspects of reality that were not obvious before (Churchman, 1968). In science and engineering disciplines, mathematical modeling is commonly used (Faharani and Fathy, 2005; Ufongene, 2002; Scientific Modeling, 2008). Typically a model will refer only to some aspects of the phenomenon in question, hence, two models of the same phenomenon can be different, and this may be due to different requirements of the model's end users or due to conceptual differences and decisions made during the modeling process (Silvert, 2001). The purpose of modelling is to represent the essence of a problem in a concise form. This has several advantages. First, it enables an analyst to understand the problem better. In particular, it helps define the scope of the problem, the possible solutions, and the data requirements. Second, it allows the analyst to employ a range of available solution procedures. The modelling process itself, if done correctly, presents a logical framework and provides insights into the assumptions, information and implications of a modeller's understanding of the system. Finally, correct results from the model may lead to the decision of whether the real world model implementation is to be done or not. This will overcome risks and expenses of implementing wrong systems (Cadman et al., 2006).

Traffic models are designed to generate an input load for evaluation, either analytically or by simulation. In the case of analytical investigations it must be possible to describe the model in a closed mathematical form. Simulation based experiments are not limited to such restrictions; in fact some simulations use recorded traces as input vectors. A traffic model can be attached to different layers of the protocol stack, e.g., packet level, flow level, or application level including high layers. At packet level the parameters for the traffic model define the arrival process for each packet and the size distribution of all packets. The models usually use stochastic processes to describe the arrival. At the packet layer there is no differentiation between packets, such as userdata and application signaling. Therefore, this approach is strongly limited in the event that QoS on the application layer is a target output for the simulation. Properties of the underlying protocols may not be reproduced correctly, e.g., TCP retransmissions in case of a bottleneck. Such properties can be captured on the flow level. A flow level model reproduces flows at the UDP and/or TCP layer of the network. A flow consists of at least one packet and is defined by the quadruple: host IP-address and corresponding port and client IP-address and corresponding port. The model describes the arrival process, the volume, and the duration of the flows (Svoboda, 2008; Khalifa and Trajkovic, 2004; Roughan et al., 2001).

Both models (packet and flow level) cannot reproduce user interactions at the client side. This input can only be implemented in the so-called source traffic models (Staehle et al., 2000). These models reproduce the usage of applications and their objects, e.g.,

a source model for HTTP browser application describes the arrival process of user sessions in terms of requests to a web server and the properties of the web pages. A webpage is a resource for information in the World Wide Web (WWW). It has properties like size of images, size of other objects, etc., all linked to the requested page via the number of objects per page. The advantage of such an approach is the fact that the parameters are related to application properties, e.g., a question like how much traffic is generated in case the user population doubles can be answered. In addition to that, source models are independent of the underlying transport network, e.g., the same e-mail model can be used for 2G and 3G networks. This is not the case for the packet and flow level models. However, this is in contrast to the packet modeling, where one model is able to describe all the traffic on a link, source traffic model for each service has to be modeled separately. It is therefore not possible to simulate an Internet backbone based only upon source models. Another approach to generate traffic is the playback of measurement based traces. These traces are used as an input vector for network simulations. Although it looks as if it is a very precise method to reproduce traffic, as it was recorded in a real network, the playback of a trace lacks all of the interaction that took place on the network level. For example a bottleneck in the simulation will not impact the trace, or the packet arrival process, from the trace file. In a real world setup TCP congestion control would reduce the data rate of each flow as congestion arises. In general, trace driven simulations work in a system with a small to medium load and they do not work in systems with high to overload situations (Svoboda, 2008).

2.7 Research Approach

The research presented in this licentiate thesis is based on both quantitative and qualitative research methodologies. The research approach adopted is motivated by the interdisciplinary component of mode 2 type of scientific knowledge production and Participatory Action Research (PAR). Below follows a short description of the research concepts used, which are not yet mainstreamed in a traditional, academic context.

2.7.1 Participatory Action Research (PAR)

Participatory Action Research is defined as systematic investigation, with the collaboration of those affected by the issue being studied, for educational purposes and/or taking action to effect the required changes for development purposes. Action Research employs methods from both experimental and naturalistic (interpretive) traditions, but it is more reliant on naturalistic inquiry in that all research occurs within its natural context (Walsham, 1993). The philosophy of action research is interpretive, incorporating social inquiry based on the views and interpretations of the participants (De Villiers, 2005). Dick (2002) explains action research as a research approach, which has the dual aims of action and research: (a) action to bring about change in some community, organisation or programme, and (b) research to increase understanding on the part of the researcher, the client, or both. The important distinction between Action Research and other kinds of research is the researcher's involvement in the whole action process as a change agent. Action Research has ambitions to help alter certain conditions experienced by the community as unsatisfactory with the intention of helping the participants to control their own destinies more effectively (Greenwood and Levin, 1998; Nielsen and Svensson, 2006). Action Research is distinguished from consultancy work because it is practical and useful; research based, collaborative, democratic and involves dialogue between insiders and outsiders (Rolfsen and Knutstad, 2007). Selener (1997) describes four types of action research: diagnostic, empirical, experimental, and participatory. In the diagnostic approach, a consultant collects data on a problem identified by the client and then provides a recommendation. Changes may or may not be implemented. In empirical research, a consultant tests a hypothesis about the impact of actions taken by either researcher or client, while in experimental research, control groups are used to test the relative effectiveness of the changes implemented (Selener, 1997). These three approaches have similar characteristics; they are not participatory, in that there is a clear division in terms of the roles of the researcher/consultant and the client. In contrast, participatory action research involves participants in both the research and change process and it integrates research and action in an ongoing participatory process (Selener, 1997).

2.7.2 Triple Helix

Triple helix is a collaborative venture between Industry, Institute and the Public sector with the aim of promoting financial growth and social development (Etzkowitz, Leydesdorff 1997). Lating (2009), Kalinga (2008) and Lujara (2008) explain that, future development in the knowledge economy is driven by incremental innovation within industry. Innovation can be achieved as a result of an alliance between government, industry and the academia. This is a triple helix alliance. The purpose of the triple helix is in stimulating knowledge-based economic development, drawing resources from all the three members of the helix.

2.7.3 "Mode 2" of Scientific Knowledge Production

"Mode 2" is a concept used to describe a way of scientific knowledge production. According to Gibbons et al., (2004); this form of knowledge production is context driven, problem focused and transdisciplinary. It is in contrast to "mode 1" where knowledge is produced strictly within a given discipline. The mode 2 knowledge production involves different mechanisms of generating knowledge and of communicating them; it involves more actors coming from different disciplines and backgrounds, as well as different sites/locations in which knowledge is being produced. The triple helix processes are considered as implementations of mode 2 type of scientific knowledge production. The mode 2's dispersed and transient way of knowledge production leads to results which are highly conceptualized. Another characteristic of mode 2 is that it is trans-disciplinary. It corresponds to a movement beyond a disciplinary structure in the constitution of intellectual agenda, in the manner in which resources are deployed and in the way in which research is organized, results communicated and outcomes evaluated. In the production of trans-disciplinary knowledge, the intellectual agenda is not set within a particular discipline; it is prepared from the context of usage or application; and so it cuts across disciplines. Knowledge produced under these conditions (mode 2) is characterized by aiming a use or action that is towards application in its broadest sense (Gibbons et al., 1994).

Chapter Three RESEARCH METHODOLOGY

3.1 Research Design

The general objective of this research is to model an optimal connectivity solution in terms of cost and performance for rural secondary schools in accessing e-learning resources. It is an applied (action-oriented) type of research looking to find a solution for rural secondary schools' connectivity problem. This research adopts both quantitative and qualitative research approaches. The qualitative approach/method was used mainly to understand/identify the ICT readiness of the pilot schools, types of available connectivity technologies for rural areas, their respective coverage and costing structure. Quantitative research method has been used in the connectivity cost calculation and in connectivity performance evaluation.

The methodological approach employed is motivated by an interdisciplinary (Mode 2) knowledge production and Participatory Action Research (PAR). The interdisciplinary approach in this case is represented by a combination of knowledge from software engineering in the development of connectivity cost calculator, teletraffic engineering and simulation modeling in the network performance evaluation. The collaboration and working together with teachers from pilot schools and technical staff from commercial companies creates good relationships for PAR. This research selected methodologies that can implement Mode 2 principles of knowledge production for the research results to be relevant, contextualized and hence be of direct use by the intended beneficiaries.

This study aims to identify connectivity technology and implementation strategies to provide rural secondary schools with connectivity solution to access e-Learning resources. The employed methodological approach brings together academia (researcher from UDSM), industry (connectivity/internet service providers) and the Government (pilot school management) in finding a solution for the rural schools' connectivity. It reflects some elements of triple helix where researchers and commercial companies form a team with rural schools to find a solution for their connectivity needs seeking to improve teaching and learning process.

3.2 Data Capturing Procedures

Data was collected from various sources with both qualitative and quantitative approaches. The techniques for data collection were consulting literature – based documents, semi-guided oral interviews via telephone or face-to-face and observation during the researcher's site visit/survey. On the school side, a particular interest was the availability of basic ICT infrastructure, cost and coverage of networking technologies that can connect such a school to the internet. From operators' survey, data were collected by conducting oral interviews with the operator's technical staff as well as consulting their respective websites and other documents like technical reports and brochures. The intention was to collect data/information on the network coverage, technology constraints/limitations and costing structure of the earmarked technology for rural connectivity solution. The collected data was used in the development of a software system for connectivity cost calculation. Technologies surveyed/visited are wireless cellular mobile networks, VSAT and fiber optic. They are the technologies with wide coverage in the country and they have potential to connect rural schools. Table 3.1 summarizes the networks coverage survey results.

		Technology Coverage				
	Operator	GSM	EDGE/GPRS	3G		
1	Tigo	Countrywide	Countrywide	-		
2	Zantel	Countrywide	Countrywide	-		
3	Zain	Countrywide	Countrywide	Dar es Salaam,		
				Only city centre.		
4	Vodacom	Countrywide	Countrywide	Dar es Salaam,		
		-		Arusha, Moshi,		
				Mwanza, Mbeya,		
				Bukoba, Kahama,		
				Geita, Shinyanga,		
				Tabora, Singida,		
				Namanga, Tanga,		
				Dodoma,		
				Morogoro,		
				Makambako,		
				Mbeya, Tunduma,		
				Lindi, Mtwara and		
				Masasi		

Table 3.1: Wireless Cellular Networks Coverage

The fiber optic is not a wireless technology, but it has been included here because Tanzania is currently implementing a National ICT backbone infrastructure by using fiber optic technology as explained earlier in chapter 1 section 1.4. The implementation of the National ICT backbone is under the Ministry of Communication, Science and Technology (MCST) of The United Republic of Tanzania as the client, while China International Telecommunication Construction Corporation (CITCC) is the contractor. The Ministry has handed over the onsite supervision and management of the National ICT backbone to TTCL, which is also a service provider. Phase 1 of the project which includes utilization of existing Tanesco fiber system and construction of direct buried fiber system, where they don't exist, is already completed as shown in figure 3.1 (NICTBB, 2009).



Figure 3.1: Coverage of Fiber Optic Network (NICTBB, 2009)

Pilot schools visited/surveyed are Kibaha Secondary School, Waliul –ASR Girls Seminary and Ruvu Girls' Secondary School all from Kibaha district in Coast region and Bagamoyo Boys Secondary Schools in Bagamoyo district, Coast region. The choice is guided by, among other factors, accessibility for the researcher and budgetary constraint for the project. The survey aimed to find out the e-readiness of the school in terms of coverage by the earmarked technologies, availability of operators for that technology and their costing structure. Table 3.2 summarizes results obtained from the survey.

S/N	School	Technology	Operator	Equipment	Installation	Recurrent	Total
			-	Cost (\$)	Cost (\$)	Cost (\$)	Cost (\$)
1	Kibaha	Fiber-Optic	TTCL	105	50 (4km)	260	414
		VSAT	AfricaOnline	4500	1500	4500	10500
		Cellular	Vodacom	800	0	162	962
			Zantel	800	0	310	1110
2	Waliul-ASR	Fiber-Optic	TTCL	105	40 (3km)	260	404
		VSAT	AfricaOnline	4500	1500	4500	10500
		Cellular	Vodacom	800	0	162	962
			Zantel	800	0	310	1110
3	Bagamoyo	VSAT	AfricaOnline	4500	1500	4500	10500
		Cellular	Vodacom	800	0	162	962
			Zantel	800	0	310	1110
4	Ruvu	Fiber-Optic	TTCL	105	220(20km)	260	585
		VSAT	AfricaOnline	4500	1500	4500	10500
		Cellular	Vodacom	800	0	162	962
			Zantel	800	0	310	1110

Table 3.2: Viable Technologies, Operators and Costs Information

The study also surveyed ICT readiness of the pilot schools to determine availability of the basic ICT infrastructures in the school. Table 3.3 summarizes the ICT readiness of the pilot schools.

Table 3.3: Schools ICT Readiness

S /	ICT Infrastructures	Schools					
n		Kibaha	Waliul-ASR	Ruvu Girls	Bagamoyo		
1.	Number of Students	800	400	766	1200		
2.	Availability of computer laboratory room	Yes	Yes	No	Yes		
3.	Number of computers	3	25	1	20		
4.	Availability of Local area network (LAN)	No	Y e s Administration block only	,No	No		
5.	Availability of Internet Connectivity	No	No	No	No		
6.	Availability of electrical power/ provider	Yes/TANESCO	Yes/TANESCO	Yes/TANESCO	Yes/TANESCO		
7.	Availability of landline- telephone service/Provider	Yes / TTCL	Yes / TTCL	No	Yes / TTCL		
9.	Mobile operators accessible in the area	Vodacom, Zain, Tigo and Zantel	Vodacom,Zain, Tigo and Zantel	Vodacom, Zain, Tigo and Zantel	Vodacom, Zain, Tigo and Zantel		

3.3 Connectivity Cost Modeling

In planning any network, costs are important aspects to consider. The importance increases, especially when planning for rural and low income customers. This section aims to identify a feasible technology for rural connectivity. Selection of the feasible technology is usually based on technical consideration as well as on financial investment of the network. In order to understand the cost implication; this research carries out CAPEX and OPEX calculations of technologies for rural connectivity: Cellular, VSAT and Fiber optic. Jerman-Blažič (2007) and Mishra et al., (2005) define the following economic terms as follows: CAPEX as an initial, one-time investment, for example the price of the equipment, the software and the installation costs. OPEX represent the recurring cost expended by the service provider. This may include maintenance of the network connections, monitoring of the system, system support and the cost of the transmission media. The CAPEX and OPEX values give a picture of an economic standpoint of different technologies. In this research; the CAPEX comprises of network equipment costs and installation costs while the OPEX is made up of monthly charges (recurrent costs), network management and maintenance costs. The CAPEX are technology dependent while OPEX depends on both technology and the required capacity (bandwidth). Therefore, connectivity costs for a particular client (school) can be calculated by using (1).

C = Capital Expenditure (CAPEX) + Operational Expenditure (OPEX)(1)

From the collected data, it has been observed that the cost of connectivity varies widely depending on type of technology and the respective operator's charges. Figure 3.2 – Figure 3.5 show CAPEX, OPEX and total cost values of different technologies per school.



Figure 3.2: Kibaha Secondary School Connectivity Cost Analysis



Figure 3.3: Waliul-ASR Secondary School Connectivity Cost Analysis



Figure 3.4: Bagamoyo Secondary School Connectivity Cost Analysis



Figure 3.5: Ruvu Secondary School Connectivity Cost Analysis

3.4 Connectivity Cost Calculator System Development

It consumed a lot of time consuming to calculate cost of connectivity for a particular pilot school from different technologies and different operators. Alternatively, the connectivity costs of a given area can be identified by using cost models. The cost models are usually used to calculate cost of providing a given service (Cadman et al., 2007) to a particular customer in a specified location. In this section, a cost model called connectivity cost calculator is designed and implemented. Thereafter, the calculator is used to identify costs of establishing connectivity to the selected pilot schools by using different available technologies. The selected technologies are from the wireless family and fiber optic, which has a potential to reach rural areas in the country; mobile phone network infrastructures (cellular), satellite-based technology (VSAT) and fiber optic. The fiber optic network is not a wireless technology, but it has been included because Tanzania is currently building its National ICT backbone by using fiber optic technology. The backbone is planned to reach up to the district level within the country. This implies that some rural schools in the district can be connected by using the fiber optic network. The cost calculator is a software system developed using the Object Oriented Analysis and Design (OOA & D) principles. The System Development Life Cycle (SDLC) employed is the V-Model approach.

The V-model is a software system development life cycle which can be presumed to be the extension of the waterfall model. Instead of moving down in a linear way, the process steps are bent upwards after the coding phase, to form a typical V shape as shown in figure 3.6. The V-Model demonstrates the relationships between each phase of the development life cycle and its associated phase of testing. Testing of the product is planned in parallel with a corresponding phase of development.



Figure 3.6: The V-model Software Development Life Cycle

3.4.1 System Requirements Specification and Analysis

In this phase, the requirements of the proposed system are collected by analyzing the user needs. This phase is concerned with establishing what the ideal system has to perform. However, it does not determine how the software will be designed or built. Usually, users of the system are interviewed and a document called the user requirements document is generated. The user requirements document will typically describe the system's functional, physical, interface, performance, data and security requirements as expected by the user. It is one in which the software developer/system designers use to communicate their understanding of the system back to the users. The users carefully review this document as this document would serve as the guideline for the system designers in the system design phase. This stage usually provides a requirement specification of the software system to be developed.

The requirements specifications of the connectivity cost calculator system were collected through the qualitative research approach and then needs of the end users of the system were analyzed. Users of this system are the school management, government or donor projects who want to know the cost of establishing connectivity to a particular school. Results from requirement analysis show that users are interested in knowing which technologies are available, what are their associated costs and who can provide it (operator/service provider)? The requirement specifications were divided into functional requirements and non-functional requirement of the system. *Functional requirements* capture the intended behavior of the system. This behavior may be expressed as services, tasks or functions the system is required to perform. Non functional requirement accommodates architectural qualities such as extensibility and flexibility. It is the description of the features and characteristics of the system as well as any constraints that may limit boundaries of the proposed solution. Use cases are widespread practice for capturing functional requirements. A *use case* defines a goal-oriented set of interactions between external actors and the system under consideration. *Actors* are parties outside the system that interact with the system (Malan and Bredemeyer, 2001). An actor may be a class of users, roles users can play or other systems. This is especially practiced in the object-oriented community where they originated, however their applicability is not limited to object-oriented systems.

A use case is initiated by a user with a particular goal in mind, and completes successfully when that goal is satisfied. It describes the sequence of interactions between actors and the system necessary to deliver the service that satisfies the goal. It also includes possible variants of this sequence, e.g., alternative sequences that may also satisfy the goal, as well as sequences that may lead to failure in completing the service because of exceptional behavior or error handling. The system is treated as a "black box", and the interactions with the system, including system responses, are as perceived from outside the system.

Thus, use cases capture *who* (actor) does *what* (interaction) with the system, for what *purpose* (goal), without dealing with system internals. A complete set of use cases specifies all the different ways to use the system, and therefore defines all behavior requirement of the system, hence bounding the scope of the system. Generally, use case steps are written in an easy-to-understand structured narrative using the vocabulary of the domain. This is engaging for users who can easily follow and validate the use cases, and the accessibility encourages users to be actively involved in defining the requirements. The connectivity cost calculator use case diagram is as shown in figure 3.7. Actors of the system are the system administrator and registered users.



Figure 3.7: Use Case Diagram of the System

A system scenario is an instance of a use case; it represents a single path through the use case. Thus, one may construct a scenario for the main flow through the use case and other scenarios for each possible variation of flow (e.g., triggered by options, error conditions, security breaches, etc.) through the use case. Scenarios may be depicted using sequence diagrams. Figure 3.8 is a scenario for a registered user's attempt to login into the system.



Figure 3.8: Sequence Diagram of a Registered User Logs into the System

3.4.2 System Design

System design starts by analyzing and understanding the proposed system by studying the user requirements document. Possibilities and techniques by which the user requirements can be implemented are identified. If any of the requirements is not feasible, the user is informed of the issue. A resolution is found and the user requirement document is edited accordingly. This approach represents a form of participatory action research. The software specification document which serves as a blueprint for the development phase is generated. This document contains the general system organization, menu structures, data structures etc. It may also hold sample interfaces or reports for better understanding. Other technical documentation like Entity Relationship Diagrams (ERD) and data dictionary are also produced in this phase.

System design includes architecture design and module design. The architecture design phase is also called a high-level design. The baseline in selecting the architecture is that it should realize all the requirements of the system, which typically consists of the list of modules, brief functionality of each module, their interface relationships, dependencies, database tables, architecture diagrams, technology details etc. The integration testing design is carried out in this phase. The module design phase is also called a low-level design. The designed system is broken up into smaller units or modules and each of them is explained so that the programmer can start coding directly. Coding is to transform algorithms (the system blueprint) into software system. The low level design document or program specifications will contain a detailed functional logic of the module, in pseudo-code, database tables, with all elements, including their type and size, all interface and complete input and outputs for a module. In V-model development paradigm, testing is performed in parallel with other development stages. Testing involves checking that each module acts as expected (unit testing), checking that modules interconnect correctly (integration testing) and checking the entire software system in its environment (system and acceptance testing).

The developed connectivity cost calculator is a 3-tier architecture that comprises of Presentation (client) tier, Application tier and Database tier. The first layer which is a client tier, also known as presentation layer; provides the user interface. This layer is usually on the client side and it consists of a web browser. The second layer, an application layer is responsible for data processing and manipulation. In a web based system, this layer consists of a web server. The third layer is responsible for data storage and data manipulation. This layer holds a database and runs on a Database Management System (DBMS), refer to figure 3.9 (Sommerville, 2000).



3.4.3 System Implementation

The connectivity cost calculator system was implemented by employing the following technologies: LAMP (Linux, Apache, MySQL & PHP); an open source server stack. Linux is an operating system which provides a platform upon which user programs can be written. Apache is a web server for data processing and manipulation ready for presentation. MySQL is the database management system for data storage and manipulation and PHP is the server side scripting language for communication between database tier and client (presentation) tier. The Bluefish editor; an open source web interface development tool was used to create interfaces. Cascaded Style Sheets (CSS) was used to implement interfaces style, Java scripts implemented the alerts and pop – ups in the system. AJAX was used to implement the asynchronous background data transfer to/from the database server.

The system consists of two modules: administrator and registered users. Their different roles are as shown by the use case diagram in figure 3.7. Figure 3.10 shows the system home page. An administrator is responsible in registering users in the system. Once registered, users will be required to login prior to access the calculator.

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Figure 3.10: The Connectivity Cost Calculator's Login Page

When a user who attempts to login is successfully authenticated, he/she will be directed to the calculator page, as shown in figure 3.11. Once authenticated, the user has three choices for connectivity cost calculation: the cost for one particular selected solution, the most cost effective option or costs for all possible available options by selecting the respective tabs as shown in figure 3.11.

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Figure 3.11: The Connectivity Cost Calculator's Home Page

The system administrator, as shown in the administrator's page in figure 3.12 has more roles on the system than a normal user. The administrator is responsible for registering users and schools in the system. He/she is also responsible for filling in details about the districts where the registered schools are located, details about operators and technologies they can provide, describing types of technology, their coverage and costing structure (cost details). The administrator can also access the calculator and perform connectivity cost calculation as any other normal registered user.

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Figure 3.12: Administrator's Page

The CAPEX and OPEX values of different connectivity technologies per selected school can as well be calculated by using the connectivity cost calculator. A user has to select the *Cost Analysis* tab in the calculator page. Once a school is selected, the calculator will provide costs of all technologies capable of connecting such a school, with the breakdown of CAPEX and OPEX components of the total cost.

3.4.4 Requirement Analysis for Connectivity Technologies

CAPEX and OPEX calculations are not enough to identify a suitable technology for rural connectivity. This is due the fact that a cheap technology for one rural school might be too expensive for another rural school. Therefore, some other criteria are to be used to identify a suitable connectivity technology solution. To attain this objective, basic requirements for the provision of satisfactory e-learning services to rural schools are analyzed. Then, technologies that meet the identified basic requirements are then recommended to be used. The basic requirements for technologies can be summarized as follows: The technology should be able to provide broadband connectivity capacity in order to support multimedia (converged services) such as e-learning. The technology has to enable access to the distant e-learning resources without constraint regarding distance or geographic location. In order to accommodate rural secondary schools, even those that are in remote areas, the technology is required to have large coverage within the country.

The technology infrastructure should be easy to establish with fast deployment and at an acceptable cost. The easy and fast deployment can be achieved if basic infrastructure exists in place. The pre-existence of basic infrastructure cuts down the Capital Expenditure to implement such a technology. For example, the cellular network has almost covered the whole country (Tanzania), although in some areas the technology provides only voice service and is rather patchy in many rural and remote areas. However, the network can be upgraded easily to accommodate data and video services by only software configuration and addition of some few hardware. Therefore, this study identifies six (6) requirements that need to be considered as criteria in identifying a suitable connectivity technology for e-learning for rural secondary schools;

- Technology with broadband capacity
- Technology that supports multimedia triple-play services (video, voice and data) without distance limitations
- Technology with large coverage within the country (Tanzania)
- Technology that is fast and easy to deploy
- Technology with a reasonable/acceptable cost (low cost compared to the available technologies)
- Technology with pre-existing infrastructure for its final deployment as this has potential to cut down cost and time for its implementation.

Table 3.4 presents results obtained by analyzing the surveyed technologies with regard to the above criteria:

Table 3.4: Technology Analysis

Туре/	VSAT	Fiber Optic	Cellular
Characteristics			
Provide broadband capacity	V	V	V
Support converged services (voice, data and video)	N	N	N
Large coverage	х	V	N
Fast/Easy	x	x	V
deployment			
Acceptable	х	N	V
cost			
Pre-existing infrastructure to support fina	lx	x	N
deployment			

In Table 3.4, the results show that cellular technology meets all the basic requirements. Therefore cellular network technologies are recommended by this research to provide connectivity solution to the rural secondary schools for e-learning. The technology is selected based on the cost analysis done by this research where the 3G mobile networks and Fiber optic technologies appear to be relatively cheap options compared to VSAT technology. The 3G cellular networks further satisfied all the criteria used for requirement analysis in the search for a cost-effective connectivity technology. Data collected from Zantel and Vodacom mobile operators was used in the cost analysis. Zantel network is currently deploying a 2.5G (GPRS) network while Vodacom has upgdaded its network to 3G (HSDPA) network. The 3G mobile network has higher data capacity and supports multimedia services as explained earlier in chapter 2, section 2.3. Vodacom's 3G with HSDPA is available in Dar es Salaam, Arusha, Moshi, Mwanza, Mbeya, Bukoba, Kahama, Geita, Shinyanga, Tabora, Singida, Namanga, Tanga, Dodoma, Morogoro, Makambako, Mbeya, Tunduma, Lindi, Mtwara and Masasi (Vodacom, 2009). Therefore this research proposes Vodacom's 3G with HSDPA to provide connectivity solution to rural schools for e-learning services. In areas with neither wireline nor pre-existing infrastructure for Fiber or Cellular networks, and where the population is so dispersed, the fresh installation and maintenance costs of cellular or fiber optic networks will be expensive. Therefore, VSAT can be considered as a more viable option. However, equipment and bandwidth for VSAT satellite networks are expensive and hence should only be used in areas that are unreachable by any other communication technologies.

Chapter Four CONNECTIVITY PERFORMANCE EVALUATION

4.1 Connectivity Configuration

As mentioned earlier, this research is dealing with the connectivity component of the e-learning system for secondary schools ICT Projects. The other project components are: Development of an Interactive e-Learning Management System (Kalinga, 2008) and Development of an e-Learning Contents and Delivery for Self Learning (Lujara, 2008), that are now in their final stages of development. The developed e-Learning Management System (e-LMS) is a web-based three-tier architecture system. Its database and application servers will be located at CoET–UDSM for easy administration, updating and maintenance. However, online access has its drawbacks as pointed out by Yair et al., (2002); poor performance due to high server load or communication latency and availability problems due to server downtime or lack of connectivity. It is further explained that the central servers at CoET-UDSM will be mirrored to the local servers in schools. Hence configurations and contents of the central servers will be replicated at local servers, so as to address some of the drawbacks of online access (Kalinga et al., 2007). With this setup, teachers and students can access e-LMS resources from their local servers in addition to the online access as well. The final e-LMS with e-learning contents is named TanSSe-L which stands for Tanzania Secondary Schools *e*-Learning system (Kalinga, 2008).

Simba et al., (2009) further propose a connectivity configuration strategy where schools with internet connection can access e-learning resources online, while those without internet connection can be configured to access the service through their local servers.

Figure 4.1 illustrates online access and access of the replicated e-LMS at the local server.



Figure 4.1: Online and Replication Configuration

Schools that have no internet connection cannot access the online e-LMS resources. An alternative solution is to physically deliver the e-LMS contents using removable storage devices like CD-ROMs/DVDs, memory sticks/flash disks or mobile hard disks to the school's local servers. Therefore, students/teachers can access the e-LMS content from their local servers as shown in figure 4.2. This approach is called hybrid e-learning and it has already practiced in rural Uganda (Lating, 2009). The local servers will have the exact configuration as that of the central servers, but materials will be brought by using removable storages devices. All updates will be done at the central servers. For isolated local servers, updates will be done by using removable storages devices that requires physical visits to the sites (schools). This mode of operation serves as a temporary solution to be upgraded by providing a connectivity solution that will enable online access to the e-Learning resources and facilitate replication at the local server.



Figure 4.2: Local Servers Configuration

In all cases, schools are assumed to have client-server Local Area Network (LAN) architecture to access e-Learning resources from either local or centralized e-learning servers. The next task of this research is to evaluate the performance of the proposed connectivity setup (access through local servers and online access) in providing e-learning services. Therefore, the performance evaluation problems were formulated as follows:

 "Given client-server LAN architecture of a school and a local 3-tier webbased architecture for e-learning resources, how many computers can access the e-learning services simultaneously while satisfying the user-centric QoS?" • "Given client-server LAN architecture of a school, a centralized 3-tier webbased architecture for e-learning resources and a 3G UMTS wireless technology for connectivity solution, does the 3G technology offer e-learning services with the required QoS?"

The stated performance evaluation problems will be solved by using simulation modeling approach (a quantitative approach) where a system under study will be implemented as a simulation model in OPNET Modeler to evaluate its performance. The OPNET Modeler facilitates a process of analyzing and designing communication networks, devices, protocols and applications. The modeler can be used to analyze simulated networks in order to compare the impact of different technology designs on an end-toend behavior. Modeler incorporates a broad suite of protocols and technologies, and includes a development environment to enable modeling of different network types and technologies (OPNET, 2010). The OPNET Modeler Wireless Suite facilitates modeling, simulation and analysis of a broad range of wireless networks. The Suite supports any network with mobile devices, including cellular (GSM, CDMA, UMTS, IEEE 802.16 WiMAX, LTE, etc.), mobile ad hoc, wireless LAN (IEEE 802.11), personal area networks (Bluetooth, ZigBee, etc.) and satellite. Wireless network planners, architects, and operations professionals can analyze end-to-end behavior, tune network performance, and evaluate growth scenarios for revenue-generating network services (OPNET, 2010). The UMTS part of the OPNET Modeler Wireless Suite will be used to simulate and evaluate the 3G networks for e-learning. OPNET's UMTS Specialized Model allows modeling UMTS networks to evaluate end-to-end service quality, throughput, drop rate, end-to-end delay and delay jitter through the radio access network and core packet network. It can also be used to evaluate the feasibility of offering a mix of service classes given quality of service requirements (OPNET, 2010).

4.2 OPNET's Modeling and Simulation Basics

Modeling is fundamentally about creating a representation of a system or process. In other words, the modeling objective is to build a model that is equivalent to a real system, existing or proposed. Equivalent is a subjective term which needs to be defined more precisely; however, equivalence in this case, means that the model behaves in some sense like the real system. Nevertheless, for practical reasons, models are usually limited to representing only certain aspects of the system of interest. The model equivalence is usually defined with reference to the following objectives:

- The model must answer the questions of interest—the model is to be used to study a particular set of issues. Those issues need to be defined clearly before modeling effort starts. Knowing which questions are important will allow exercising good judgments in including or omitting certain features in the model.
- The model should have the desired level of accuracy—the model's accuracy can probably not be perfect; this might be due to assumptions or simplifica-

tion. Simplification is allowed but it should not be to the point where the answers provided by the model are no longer useful.

- The model should support validation—when designing a model, there should be plans for building confidence in the results it produces.
- The model should accommodate the necessary range of operating conditions—usually, the system of interest, and therefore the model, is subjected to a range of different stimuli. For a network model, this may mean increased application traffic, or new application patterns. If ranges of conditions to be studied are known, then the model should maintain its validity throughout these ranges.

As each modeling choice is made; such as which component to use from the model library, it is necessary to check if this choice could disturb the equivalence achieved so far, or if it enhances it. Even when in some sense, it lessen the equivalence between the model and the system, does it achieve another benefit that is worthwhile, such as reduced simulation run times? Finally, can the relative loss or gain of equivalence be measured in order to determine if it is acceptable? (OPNET, 2010).

4.2.1 The OPNET's Modeling Process Workflow

- The OPNET Modeler recommends six (6) steps to be followed in an overall modeling process. The steps are represented in figure 4.3. This is a general workflow of modeling and simulation projects. It is allowed to adjust it as necessary to meet the set objectives.
- Develop a list of questions to be answered by the model.
- Create a preliminary model that answers at least some of the questions in step (i). To do this, represent those aspects of the system that have the most impact on the questions of interest.
- Validate the model to gain confidence in its equivalence. For each discrepancy encountered through validation, decide if it is significant. Determine the sources of the discrepancies, if any. Correct them, and repeat this step until satisfied that the equivalence with the real system has been achieved. If it cannot be achieved with this model, go back to step (ii) and choose a different approach.
- Consider enhancements to the model to help in answering questions effectively. Do these changes disturb equivalence or enhance it? Experiment with the changes and validate them to understand them. This may amount to returning to steps (ii) and (iii).
- If satisfied with the model, use it to analyze the set of cases or operating conditions under study. For a simulation approach, this involves running simulations. Carefully examine the results of each simulation to ensure that they are acceptable. Investigate any results that do not make sense.

• When satisfied with the model's performances; publish results and document the modeling choices. This will support the appropriate use of the results, and the continued use of the model for future projects.



Figure 4.3: The Modeling Process

4.2.2 Traffic Models in OPNET

Applications are the main sources of traffic in the network. It is the traffic generated by applications that loads the network, makes demands on the bandwidth and the underlying network technology, and creates load on the servers. Applications are represented by application models which have the same traffic characteristics in terms of the size of the packets generated, the rate at which they are generated, the transport protocol over which it runs (e.g., TCP, UDP, fiber channel, etc.), the number of simultaneous connections, timeouts, retransmissions, failure and recovery, and so on. Together these characteristics create a run time traffic pattern of the application models each packet-related event (packet created, packet queued, packet transmitted, etc.) that occurs during the simulation. Explicit traffic modeling provides the most accurate results because it models all protocol effects. However, this also results in longer simulations and higher memory usage (because the simulation allocates memory for each individual packet). There are three general methods for explicitly modeling traffic in OPNET Modeler:

• Packet generation—it is done by configuring certain node objects to generate streams of generic packets. This is a basic method of adding traffic to a network topology. • Application demands—the application demands can be created by a representation of traffic flowing between two nodes. The traffic generated by application demands can be purely discrete (explicit), purely analytic (background), or a combination of these two (hybrid).

Application traffic models—OPNET Modeler includes a set of models for generating traffic based on standard applications such as FTP, HTTP, voice, video conferencing and e-mail. The available generic "custom application" model can be used to represent a broad range of applications that do not correspond to the traffic patterns of any standard network applications.

Background traffic is analytically modeled traffic that affects the performance of explicit traffic by introducing additional delays. Unlike explicit traffic, background traffic can affect not only discrete event simulations, but also flow analyses. Discrete event simulations that include background traffic use the hybrid simulation model. This model includes the effects of background traffic to calculate queue build-ups on intermediate devices and delays based on the queue length, at any time in the simulation. Because each packet that produces background traffic on the network is not explicitly modeled, using background traffic can speed up simulations considerably. Background traffic takes three forms in OPNET Modeler:

- Traffic Flows—a traffic flow describes an end-to-end flow of traffic from a source to one or more destination nodes. Traffic flow can be generated manually or imported from external files. The eXpress Data Import functionality can be used to import traffic from programs like Netflow Collector and Net-Scout nGenius.
- Baseline Loads—this type of traffic (also called "static background utilization") represents traffic as a background load on a link, node, or connection. Unlike a traffic flow, which can span multiple links and nodes, a traffic load is "static" and applies to one object. Existing link loads can be converted to traffic flows, which allow flow analyses to account for these loads. Baseline loads can be imported from external ASCII files or by using the eXpress Data Import functionality to import data from programs like MRTG.
- Application demands—application demands can be used to represent background traffic flowing between two nodes. Besides background traffic, the application demands can be configured to be purely discrete (explicit) traffic or a combination of the two (hybrid traffic).

4.2.3 Model Validation Basics

Validation is a key step before using results to draw conclusions. In fact, validation is a step that is generally performed repeatedly during the course of model development, as enhancements are added. By verifying fundamental behaviors of the model at each step, it is easy to identify which particular changes are responsible for new, unexplained behavior. Even though validation sounds like a formal term reminiscent of a mathematical proof, or formal verification, it need not necessarily be handled in that manner. Rather, validation is the process of maintaining confidence in the model's equivalence to the real system and in its ability to generate useful results. This confidence can be achieved through the following techniques:

- Common Sense and Intuition: This is the most important tool in model validation, despite its simplicity. By using common sense and intuition, it should be possible to explain the validity of the model with respect to the system under study. Even if it is not possible to tell if an answer is correct, or what its degree of accuracy is, it should be possible to tell whether an answer is in the right ball park, or significantly different than what would be considered reasonable. Even if it is not, the model could still be correct, hence, it's time to investigate further. Common sense and intuition may come from experience with the real system, or with the technologies at hand.
- Measurement: This is the most commonly used approach to validation. It is sometimes referred to as baselining against the real system. Of course, it can only be done if the real system, or some portion of it, is actually accessible. Measurement tools can consist of network analyzers, such as Network General's Sniffer, or other proprietary devices/software. Some networks, applications, or protocols are also instrumented to report on certain aspects of their performance. When the results differ, then it should be possible to note the differences between the model and the real system. The judgments can be made about whether the differences are due to simplifications in the model? Or is the model operates under all of the same conditions as the real system?
- Alternative Models: By building another model using a different approach, to gain insight into how both models behave and which one will do the best job. In other words, which model is providing more-valid results for the questions that need to be answered under the operating conditions that matter? The alternative model could have already been available or had its results published by another party. It could also be a model of a completely different nature, such as a mathematical or analytical model. Essentially, what is done here is very similar to the technique of performing measurements. However, in this case, measurements are taken from another model of the system instead of the system itself.
- The Control Experiment: This involves building a test case in which results are known with a high degree of confidence. Typically, this is done by using extreme operating conditions to isolate particular behaviors of the model. The fundamental concept of the control experiment is to remove most behaviors that are difficult to explain and to use common sense to perform validation in their absence. Then use incremental analysis, described below, to gradually re-introduce some of the other complex mechanisms in the system.
- Incremental Analysis: Making individual changes rather than many changes at once is emphasized as a sound strategy. As a validation technique, incremental changes and analysis of their impact helps to understand if each

change makes sense. In summary, the purpose of incremental analysis is to experiment with the model's parameters to gain confidence with the behavior of individual features.

While highly accurate results are generally desirable, it is important to emphasize that validation does not always mean an exact matching of results between simulation and measurements, or through any other form of validation (comparison). Discrepancies are to be expected and can be accepted, provided that they are understood and they can be controlled. In other words, it should be possible to explain differences and their importance relative to the questions of interest.

4.3 Simulation Modeling for Performance Evaluation

4.3.1 Connectivity Configuration with Local Servers - Scenario 1

A school is assumed to have a computer laboratory with forty five (45) personal computers. These computers are connected to a switch with 100BaseT Ethernet technology to form a LAN. The LAN is further connected to the e-learning local server by a 100BaseT Ethernet cable. The servers are running web based e-learning services. The e-learning server comprises of learning management system that controls the learning process and the contents repository where the learning materials are stored. The learning materials can be accessed by using a web browser from client computers. Therefore the e-learning server consists of web and database servers. The simulation model of the described scenario is prepared to answer the following question:

- What is the end-to-end delay experienced by users when accessing e-learning resources from the local server? Does it satisfy the QoS for e-learning service?
- What is the utilization of the link from the LAN switch to TanSSe-L server? Fully utilized or underutilized?
- What is the traffic load to the server (TanSSe-L)? Overloaded or not?
- How does increasing number of computers affect performance of the network? And therefore what is the maximum number of computers to be connected that satisfies the QoS?

A network topology simulation model of the wired LAN of a school's computer laboratory with forty five (45) personal computers connected to a switch was developed. The network topology is as shown in figure 4.4.



Figure 4.4: Scenario 1- Network Topology Simulation Model

A network supports users who access various network applications. Once the topology is created, it is necessary to specify traffic and users in the network. In OPNET, traffic and users entities are modeled using Application Configuration and Profile Configuration objects. Application configuration definitions are used to define the properties of all applications on the network (Database, email, web browsing, file transfer etc.) and Profile configuration definitions define the application usage pattern for each category of user (secretary, manager, point-of-sale etc.). Applications configured were web browsing and database access, as these are the services currently implemented in the TanSSe-L servers. Usage profiles were configured as heavy web browsing as well as heavy load database access. Thereafter, the specified types of application were also configured in the server. This configuration will associate the server with the corresponding applications. For example, all database requests and web page requests be directed to this server, the TanSSe-L server. This server is configured to support all services specified earlier; i.e. database access and web browsing. Just like the server is associated with applications, the same applies to workstations. Client computers were also configured to support the specified applications, web browsing and database access. A heavy usage pattern is configured to both database and web servers assuming that 45 students in the computer laboratory will send heavy traffic to the servers.

After a complete network creation, traffic and usage pattern configuration, parameters are specified where statistics will be collected and viewed as simulation results. Statistics can be collected from individual nodes in the network (object statistics) or from the entire network (global statistics). Server loads, link utilization and end to end delay were specified as global statistics in order to gather information about the network as a whole. Server load is a key statistic that reflects the performance of the entire network. This is the rate at which requests arrive at the server. Note that these requests could belong to different sessions maintained at the server. Link utilization (Ethernet link from LAN switch to the TanSSe-L Server) represents the percentage of consumption of the available channel bandwidth, where a value of 100 indicates a full usage. The delay for the entire network is determined by collecting the global delay statistic. This statistics represent the end to end delay of all packets received by all stations. Thereafter the simulation was configured to run for two (2) hours as this is the same time for one class period in most of the secondary schools.

Simulation results for end to end delay, link utilization and server loads are as shown in figure 4.5, 4.6 and 4.7 respectively. The end to end delay is around 32 micro seconds, link utilization is download = 1.05, upload = 0.05 and server loads are 4.5 requests/sec for web browsing and 3.5 requests/sec for database access.



Figure 4.5: Scenario 1- End to End Delay



Figure 4.6: Scenario 1- Link Utilization



Figure 4.7: Scenario 1- Server Load

The end to end delay is low about 32 micro seconds; this network can satisfy QoS for multimedia services that need an end to end delay of at most 2 seconds. Link from LAN switch to the TanSSe-L servers is not fully utilized, so there is still a room for this network to accommodate more traffic (computers). The load on the server appears to be leveling off (not increasing), indicating a stable network. This simulation results answer questions i – iii. The simulation scenario 2 is conducted to answer the remaining question number iv which states *"How does increasing number of computers affect performance of the network? And therefore what is the maximum number of computers to be connected that satisfies the QoS?"*

4.3.2 Connectivity Configuration with Local Servers - Scenario 2

The following assumptions are made in order to find number of computers that connect to the local server simultaneously while satisfying QoS for e-learning services: A school has two computer laboratories each with 45 computers. Classes in these computer laboratories are run simultaneously. Therefore the TanSSe-L local servers are receiving traffic from 90 computers. The rationale for specifying two (2) computer laboratories per school is based on the fact that a rural secondary school in Tanzania can at most own one computer laboratory. So having a school with two computer laboratories and a total of ninety (90) computers is the highest assumption.

Assume that LANs in the two computer laboratories are made up of forty five (45) personal computers each connected to a switch with a 100BaseT Ethernet. The two LANs are connected by a router through their switches. The TanSSe-L server and the router are located in one of the computer laboratories. The simulated network topology of two computer laboratories with a total of 90 PCs is as shown in figure 4.8.



Figure 4.8: Scenario 2- Network Topology Simulation Model

Application configuration and usage profile were configured as in the first scenario. Ethernet end-to-end delay is configured to identify delay experienced by end users over the whole network. Statistics were also specified to collect utilization of links between router and the TanSSe-L server. The interest is to find out link utilization status, is it fully utilized or is there room for more traffic (computers)? Statistics for web and database servers loads are collected to identify the total traffic/load sent to the server per second.

Simulation results for end to end delay, link utilization and server loads are as shown in figures 4.9, 4.10 and 4.11 respectively. The end to end delay is around 17 micro seconds, link utilization is download = 2.11, upload = 0.11 and server loads are 9.0 request/sec for web browsing and 7.5 requests/sec for database access.

School_ILAN	-90PCs_Scho	ool_LANs-D	ES-1: averag	e (in Eth	
0.00020-	8	iverage (in E	thernet Delay	(sec))	
0.00018 -					
0.00016-					
0.00014-					
0.00012-					
0.00010 -					
0.00008 -					
0.00006 -					
0.00004 -					
0.00002 -					
0.00000-1	0h 30m	1h Om	1h 30m	2h 0m	2h 30m

Figure 4.9: Scenario 2- End to End Delay

School_	ILAN-90PCs_	School_LANs	-DES-1: avera	ge (in poi				
	Object: TanSSeL Web Server <-> node_45[0] of Office Network> Object: TanSSeL Web Server <-> node_45[0] of Office Network <							
		average (in po	pint-to-point.util	zation)				
2.4-								
2.2-								
2-								
1.8-								
1.6-								
14-								
1.2-								
1-								
0.8 -								
0.6 -								
0.4 -								
0.2-								
					_			
0-1 0h.0m	0h 30m	1h 0m	1h 30m	2h Om	2h 30m			

Figure 4.10: Scenario 2 - Link Utilization



Figure 4.11: Scenario 2 - Server Loads

4.4 Results Discussion

Connectivity cost calculation of the pilot rural secondary school has been made possible by the connectivity cost calculator software. The software provides an insight to the cost variation between technologies as well as variation of cost with respect to operators. The calculator also provides cost analysis of different technologies with respect to a selected school. The calculator is a web based software; it can be made available to as many end users as possible, which means connectivity cost information of different technologies and different operators can be made available at the end users' finger tips.

Cost analysis reveals that VSAT technology is unattractive (expensive) both in initial cost and its recurrent costs for all the surveyed schools. On the other hand, fiber optic technology emerged to be a cost effective technology among the three surveyed technologies. At the time of writing this report, the fiber optic coverage was limited to
regional levels; however the plan was to install the fiber optic backbone in the country down to district levels. Therefore, in order to reach rural areas that are far from the district fiber termination premises, the fiber optic network needs an extension to cover the last mile connectivity to the end user. With this limitation of fiber optic coverage; the next cost effective candidate is the cellular networks. Cellular infrastructure is further backed up by its ease of last mile implementation (deployment) to the end user, direct access to the internet and the fact that the backbone is widely accessible in the country. Cellular mobile network's CAPEX is dominated by equipment cost, since there is no installation costs to the end user. Users in the pilot schools were trained in ICT literacy in order to provide project sustainability once deployed. The training, on the other hand, will remove support and maintenance cost components from OPEX, since it will be done by the trained staff. Therefore OPEX is made up by only recurrent costs (bandwidth/capacity costs). This research has realized that there is no general cost effective connectivity solution for all schools. The overall result of this research reveals that the cost of connectivity depends on the type of technology, operator's costing structure and basic ICT infrastructure available to the client/area (in this case, secondary schools) to be connected. A cheap technology for one school might be too expensive for another school. Therefore addition criteria have been used to identify the cost-effective connectivity solution, where the 3G wireless technology emerged to be the most cost effective solution.

Furthermore, the research demonstrated two strategies for connectivity configuration for rural secondary schools in order to get access to e-learning resources. Thereafter a performance evaluation study through simulation modeling for two different scenarios was done to the first configuration strategy. In all scenarios, the end-to-end delays were quite satisfactory, lower than the maximum threshold. In scenario 2 server loads and link utilization showed a slight increase, which is due to increase in number of computers but they are not fully utilized, which means there is room to accommodate some more traffic (more computers). This suggests that a school can have more than one computer laboratory with at least forty five (45) computers and still be served by the local servers with the guaranteed QoS. Conclusively, local server's configuration managed to meet the QoS for e-Learning service. The configuration also served adequately even when there are two computer laboratories.

The future work to be done is to simulate the connectivity configuration for e-learning accesses through central servers that are located far from school premises. The proposed technology to provide connectivity solution to access centralized e-learning resources is the 3G UMTS wireless technology. The objective of this simulation modeling is to study performance of 3G UMTS network in delivering e-learning services.

Chapter Five CONCLUDING DISCUSSIONS

5.1 Work Done So Far

The research conducted two surveys: a survey for ICT readiness of the pilot schools and a survey of networking infrastructures from the internet service providers. The surveys aimed at identifying the availability of basic ICT infrastructure to support connectivity establishment for e-learning services. Results from pilot schools survey reveal that, schools have limited basic ICT infrastructures. However there are initiatives underway from the Government and/or donor projects to equip secondary schools with basic ICT infrastructures like computers. Networking infrastructures survey reveals that Tanzania has 12 registered operators (as of September 2009) who can provide connectivity technologies ranging from wired to wireless that support fixed to mobile services. However, coverage and data capacity of the available networking technologies that can support multimedia services like e-learning is limited.

From the survey, it has been identified that cost of establishing connectivity varies from one technology to the other as well as from one operator to another. Given a particular rural school, it was problematic to know the required cost of connectivity establishment. So the research ventured into developing a software system, which calculates the cost of internet connectivity implementation to the pilot schools. The software is called "Connectivity Cost Calculator". The calculator provides cost from different technologies as well as from different operators. By using the connectivity cost calculator, it was possible to identify a technology with its respective operator that is relatively cheap for connectivity solution compared to all available technologies.

The research has prepared strategies for connectivity performance evaluation. The research opted for a user–centric QoS evaluation based on simulation modeling. The simulation modeling for performance evaluation done so far has revealed that the connectivity configuration with local servers can provide access to e-learning resources with guaranteed QoS.

5.2 Original Contributions

So far, the research has provided the following scientific papers as academic contribution to the body of knowledge. The papers have been orally presented at the International Conferences and thereafter published in the conference proceedings:

Paper I: Simba, F and Mwase, C. *"Secure Virtual Private Network Implementation Using Open Source Software"*. Published in the Proceedings of the IST-Africa Conference and Exhibitions – 2008, ISBN: 978-1-905824-07-6, Pp 1 -10. The paper was presented at IST-Africa 2008 Conference & Exhibition, held in Windhoek, Namibia, 07 – 09 May 2008.

This paper aims to show the potential of open source software in providing cost effective connectivity solution. It presents a novel approach of how open source software has been used to implement a secure Virtual Private Network (IPSec-VPN). A pilot study interconnecting two distant institutions is presented. The Linux Operating System and the FreeS/WAN open source software were used to implement the IPSec protocol in the VPN. Results show that open source software can be used to provide secure, yet cost-effective connectivity for remote institutions.

Paper II: Simba, F., Trojer, T., Mvungi, N.H., Mwinyiwiwa, B.M. and Mjema, E.M. "Strategies for Connectivity Configuration to Access e-Learning Resources: Case of Rural Secondary Schools in Tanzania". Published in the Proceedings of World Academy of Science, Engineering and Technology, Vol. 54, Pp 789 – 794. The paper was presented in ICOLDE 2009: "International Conference on Open Learning and Distance Education ", held in Paris, France on 24 – 26, June, 2009.

Tanzania has a challenge to have a well educated and learning society by the year 2025. This paper presents an earmarked strategy to address the challenge. The strategy is to integrate ICT in education through e-learning. However, e-learning initiatives are also challenged by limited or totally lacking connectivity to majority of secondary schools, especially those in rural and remote areas. This paper explores the possibility of rural secondary schools to access online e-Learning resources from a centralized e-Learning Management System (e-LMS). Different connectivity configurations have been proposed according to the ICT infrastructure status of the respective schools.

Paper III: Simba, F., Trojer, T., Mvungi, N.H., Mwinyiwiwa, B.M. and Mjema, E.M. *"Rural Connectivity Technologies Cost Analysis"*. Published in the Proceedings of World Academy of Science, Engineering and Technology, ISSN 2070-3724, Vol. 59, Pp 125 – 131. The paper was presented in ICCNMC 2009: "International Conference on Communications, Networking and Mobile Computing", held in Bali, Indonesia on 25 – 27, Nov, 2009.

One of the limitations for connectivity problems in rural areas of Tanzania is the high cost of establishing infrastructures for IP-based services. This paper presents development of software system to calculate cost of connectivity to rural areas of Tanzania. The system is developed to provide easy access to connectivity costs from different technologies and different operators. This is due to the fact that the cost of connectivity varies from one technology to the other and at the same time the cost is also different from one operator (service provider) to another within the same country. Development of the calculator follows the V-model software development lifecycle. The calculator is used to evaluate the economic viability of different technologies considered as being potential candidates to provide rural connectivity.

Up to the point of writing this licentiate thesis; the following contributions are considered to be new in the Tanzanian context:

(i). A practical/action oriented (Mode 2) research methodological approach

A traditional and widely used research methodology in Tanzania is for a researcher to identify a problem, collect the necessary tools or resources and knowledge to tackle the problem. Thereafter a researcher will work within the academic spheres to find a solution for the problem. The context from where the problems originate (community, location) is rarely involved in the course of conducting a research. Most of the time the problem context is involved in only data collection process of the research methodology. As a consequence, results of such research take longer to be conceptualized by the intended community as well as its implementation is also challenged by the literacy and acceptance level of the beneficiaries. This research adopted mode 2 type of knowledge production inspired by participatory action research. It is purposely to involve the final consumer of the research results right from the beginning in order to facilitate conceptualization, fine-tune the solution according to their context as well as provide ownership of the solution.

(ii). A software system for Connectivity Cost Calculation

The current status of obtaining information on cost of connectivity in Tanzania is by consulting an operator or the available documentation like web site or company brochures. This approach provides limited information as it does not show the cost of the other available technologies and their respective operators. This research has developed a prototype of a web based software system that can calculate the cost of connectivity for a specific operator and a specific technology. It can also calculate the cost of other available options (technologies and their respective operators) in Tanzania. Full implementation of the Connectivity Cost Calculator is envisioned to close the connectivity cost information gap.

5.3 Concluding Remarks

Rural secondary schools in Tanzania conduct teaching-learning processes with shortage of teachers and limited and/or outdated resources like books, laboratory chemicals etc. If the rural schools continue to provide education in this situation, it will be impossible to meet the attribute number four (4) of the National Development Vision by the year 2025; that is "to attain a well educated and learning society". The ICT for e-learning is considered as an enabler in attaining this goal. However e-learning has a prerequisite of existence of connectivity to support e-learning services. Connectivity to rural areas of Tanzania is challenged by the limited coverage, data capacity of the available technologies and the high cost of connectivity implementation. This research provides a software system that can show indicative costs to establish connectivity to the pilot schools. The software can be used by the Government, school management or donor projects to get an insight on the required cost of establishing connectivity to a particular rural school.

ICT readiness (availability of ICT infrastructures and ICT literacy) of the rural secondary schools differs among schools. This research proposes two options for connectivity configuration for the rural schools according to their ICT readiness; e-learning access through local servers and e-learning access through centralized servers. The local server configuration is a tentative solution subject to upgrade for online access. Performance evaluation through simulation modeling has been conducted on the first connectivity option. Results show that the connectivity configuration with local servers can adequately provide e-learning service within the required QoS. The remaining task which is to be carried out in the near future is to conduct performance evaluation of the online access connectivity configuration. The final product of the research is to present an optimal connectivity solution for e-learning to the rural schools in the Tanzanian context in terms of cost and performance. This means utilizing what we already have in terms of basic ICT infrastructures to provide connectivity solutions that are affordable and efficient.

5.4 Work To Be Done

The objective of this research is twofold: to find an optimal connectivity solution for e-learning in rural secondary schools in terms of cost and performance. As far as this licentiate thesis is concerned, the cost component of the connectivity solution is already done. The other component on performance evaluation which consists of: (i) Evaluate performance of the cellular network (3G UMTS technology) for e-learning and (ii) Models Validation, are to be done in order to complete the PhD work.

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