University of Fort Hare

Together in Excellence

A Feasibility Study of Wireless Network Technologies for Rural Broadband Connectivity

A thesis submitted in fulfilment of the requirements for the degree of

Master of Science

in the Faculty of Science and Agriculture

Computer Science Department

At the University of Fort Hare

By

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Submission Date: 31 January 2013

Declaration

I Nombulelo Twele, declare that the work contained in this dissertation is my own and that it has not been previously submitted in any form, for any degree or any form of examination at any institution of higher learning. Information originating from other sources, published or unpublished, has been acknowledged in the text, with a list of references recorded at the end of the dissertation.

Signature…………………………………………………………

Date……………………………………………………………

Acknowledgements

First I would like to extend my gratitude to my supervisor Prof. M. Thinyane for his support and guidance during the course of this research. My sincere thanks also goes to Prof. A. Terzoli, the Siyakhula Living Lab team of researchers for their endearing support and assistance and management for facilitating and hosting this research and most importantly for the lessons learnt during this study. A journey without a beginning, destination and experience is a complete waste of time and scarce resources, but thankfully because of your willing hearts, this journey has been concluded successfully.

I would like to also extend my special thanks to the University of Fort Hare's Telkom Centre of Excellence hosted within the Computer Science Department, funded by the Department of Trade and Industry through the THRIP programme and by industry partners, for their financial support. In addition I extend by thanks to the National Research Fund for their financial, support as well, SLL and its industry partners. My gratitude is also extended to Saab Grintek for their infrastructural and special skills support without which the study would not even have been conducted. I thank the Computer Science department for accepting my application and giving me the opportunity to take a step closer to realizing my dream and their continued support.

To Prof. Jim Chadwick, in his absence, thank you for telling me what no man is always willing to tell just when it was necessary: the truth. To Dr. K. Sibanda, I always value your support throughout my study years in this institution, you have been a pillar of strength academically and a dear friend, THANK YOU.

To my colleagues, you have made our working environment our second home, for that alone I am grateful, I really appreciate and cherish all the time we spent in the lab together, because I know that during both pleasant and unpleasant experiences together, we have learnt from each other.

My undiluted thanks go to my family, my source of strength, for the love and support they gave me. I thank my wonderful friends Ms M. Makamba, Mr T. Mthoko, Mr T Bokval, Ms S. Buhlungu for their support even beyond the scope of this research, If words are more that I could give, you guys have all of what is there for me to give. I thank you guys for being there for me,

your wise words, kindness and compassion, always providing a shoulder for me to cry on, encouragement and great understanding, you are truly one in a million!

To God Jehovah almighty, can a man lie to you God? Certainly not, through you all things happen and all things are because you live, those words guarantees my sincerity when I say, Thank you Jehovah, for the beautiful gift of life and source of strength, you deserve the glory.

Dedications

This work is dedicated to my family, for their endearing support, to my mother who always reminds me "nawe uThixo akakuthiyanga mntwanam" (God love you too my child), to my brother M.M. Bayo you always encourage me to push myself to do more that I think I can do, to my cousin M.J. Twele, you always tell me that even the sky should not be the limit, only things that man cannot escape should be the limit.

Abstract

The adoption of wireless broadband technologies to provide network and Internet connectivity in rural communities has conveyed the possibility to overcome the challenges caused by marginalization and many other characteristics possessed by these rural communities. With their different capabilities, these technologies enable communication for rural communities internally within the community and externally on a global scale. Deployment of these technologies in rural areas requires consideration of different factors - these are in contrast, to those considered when deploying these technologies in non-rural, urban areas.

Numerous research show consideration of facts for deployment of broadband technologies in urban/ non-rural environments and a little has been done in considering facts for deployment in rural environments. Hence this research aims to define guidelines for selection of broadband technologies and make recommendations on which technologies are suitable for deployment in rural communities, thereby considering facts that are true only within these rural communities.

To achieve this, the research determines the metrics that are relevant and important to consider when deploying wireless broadband technology in rural communities of South Africa. It further undertakes a survey of wireless broadband technologies that are suitable for deployment in such areas. The study first profiles a list of wireless communication technologies, determines and documents characteristics of rural communities in Africa, determines metrics used to declare technologies feasible in rural areas. The metrics and rural characteristics are then used to identify technologies that are better suited than others.

Informed by this initial profiling, one technology: mobile WiMAX is then selected for deployment and further evaluation. A technical review of mobile WiMAX is then carried out by deploying it at our research site in the rural, marginalized community of Dwesa (Eastern Cape, South Africa). The final section of this research provides recommendations that mobile WiMAX, LTE and Wi-Fi are the best suitable technologies for deployment in rural marginalized environments. This has been supported by extensive research and real life deployment of both Wi-Fi and mobile WiMAX. This research also recommends consideration of the following facts when seeking deployment of these technologies in rural communities: the geographical setting of the target terrain, the distances between sources and target customers and distances between target communities, weather conditions of the area, applications to be deployed over the network, social wellbeing of the community and their financial freedom as well.

Key Words – *Rural Broadband Technology, Feasibility Metrics, ICT for Development, Siyakhula Living Lab, mobile WiMAX, Wi-Fi, LTE.*

Publications

Twele, N. Thinyane, M. 2011. *An Investigation of Mobile WiMAX Feasibility for Service Provisioning in MRA/ICT4D Contexts.* Proceedings of SATNAC 2011 Conference, ICC East London, South Africa

Twele, N. Makamba, M. Lutshete, S. Masuku, D. Sonamzi, L. and Thinyane, M. 2011. *Enhancing Information and Communication Technology Solutions for rural Communities.* Proceedings of IST-Africa, 2011 Conference, Kunduchi Beach Hotel, Dar es Salaam, Tanzania

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List of Acronyms and Abbreviations

AAA	Authentication Authorization Accounting
ALA	American Library Associations
AP	Access Points
ASN	Access Service Network
ASP	Access Service Provider
BS	Base Station
CDMA	Code Division Multiple Access
CPC	Continuous Packet Connectivity
CSN	Connectivity Service Network
DAN	Digital Access Nodes
DoC	Department of Communications
DSSS	Direct Sequence Spread Spectrum
EDGE	Enhanced Data for Global Evolution
FDMA	Frequency Division Multiple Access
FHSS	Frequency Hoping Spread Spectrum
GPRS	General Packet Radio System
GSM	Global System for Mobile Communication
HOM	Higher-order Modulation
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access

HSUPA	High Speed Uplink Packet Access
ICT	Information and Communication Technology
ICT4D	Information and Communication Technology for Development
IDU	Indoor Unit
IR	Infrared
ISP	Internet Service Provider
ISPA	Internet Service Providers' Association
LLiSA	Living Labs in South Africa
LOS	Line of Sight
LTE	Long Term Evolution
MDG	Millennium Development Goals
MIMO	Multiple Input/ Multiple Output
MS	Mobile Station
NAP	Network Access Point
NGO	Non-Governmental Organization
NLOS	Non Line of Sight
NRM	Network Reference Mode
NSP	Network Service Provider
ODU	Outdoor Unit
OFDM	Orthogonal Frequency Division Multiplexing
OFDM	Orthogonal Frequency Division Multiplexing

PAPR	peak-to-average-power ratio
PDU	Protocol Data Unit
PSK	Phase Shift Key
QoS	Quality of Service
RAFT	Réseau en Afrique Francophone pour la Télémédecine
RLC	Radio Link Control
RS	Relay Station
SABS	South African Bureau of Standards
SABS	South African Bureau of Standards
SADC	South African Development Community
SBT	Set Box Top
SCFDMA	Single-Carrier Frequency-Division Multiple Access
SLL	Siyakhula Living Lab
SS	Subscriber Station
TDMA	Time Division Multiple Access
THSS	Time Hoping Spread Spectrum
UMB	Ultra-Mobile Broadband
UMTS	Universal Mobile Telecommunications System
UN	United Nations
VHE	Virtual Home Environment
VoIP	Voice over Internet Protocol

WACs	West African Cable Systems
WAP	Wireless Access Point
WCDMA	Wideband Code Division Multiple Access
Wi-fi	Wireless Fidelity
WiMAX	Wireless Interoperable for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
WWAN	Wireless Wide Area Network

1 CHAPTER 1: INTRODUCTION

In this chapter focused is placed on providing an introduction to rural broadband connectivity in the ICT for Development (ICT4D) context, giving its background in Southern Africa and technologies used to achieve it. The research context which discusses the project under which the research is undertaken is provided herein, followed by an outline of the research problem, the motivation and a research question. This chapter also describes objectives and the methodology of the study, through which the solutions are crafted. Lastly, the chapter provides expected deliverables and defines the structure of the thesis.

1.1 Rural Broadband Connectivity

Rural broadband connectivity refers to a connection to fast Internet access available in rural communities. Internet access is defined as the provision of access to the system of interconnected computer networks referred to as the Internet. Through this connection of computers, vastly different services are provided and these services easily become part of day-to-day lives of individuals globally. The choice of services and the extent to which one makes use of depends on the person's level of computer literacy, and that is in turn influenced by the community in which she/he lives. It has been established as truth that as globalized as information is, users from rural communities still have limited use and/or knowledge of Internet services available. These limitations are largely due to low computer literacy levels, which may, in turn, be caused by a number of reasons including: marginalization from urban communities, lack infrastructure, limited financial freedom, lack of awareness, etc. This limited knowledge and consequent use of ICT then emphasises the digital divide between rural communities and what we refer to as urban communities. The digital divide is merely the difference between people with access to ICT and those who does not have such access (Parliamentary Office of Science and Technology, 2006).

In Lor (2003) digital divide is described as disparities based on economic status, gender, race, physical abilities and geographic location between those who have and those who do not have access to information, the Internet and other information technologies and services. While Mphithi (2010) defines it as the gap between individuals, households, businesses and geographic areas at different socio-economic levels with regard to both their opportunities to access information and to the use of such technologies for a wide variety of activities.

For a period exceeding a decade, Information and Communication Technologies (ICT) have been assigned a key role in the aim to reduce poverty and economic growth. These ICTs are not meant to replace real life system but rather to increase efficiency of these systems, to provide access to new market services, to create new opportunities so as to generate income and to give disadvantaged people a voice and thereby decreasing and/or eliminating the digital divide. The opportunities made possible by presence of CTs are necessary for the growth and development of these disfavoured areas and communities where they were not possible in the past.

Providing broadband connectivity in the disfavoured communities does not only mean development, it also open possibilities to achieving information globalization, opening an opportunity to the possibility that the world could be one prominent cyber community: this possibility could result in lifestyles rural communities never thought were possible for them, where technology is part of their day to day lives. This access to telecommunication could provide a platform where they voice their opinions to the government in ways faster than previous communication methods. The access to ICT will also ensure that these communities are exercising their political rights in governing their country and hence making it easy for the government to conduct assessments and improve their service delivery in sectors relevant to these communities.

1.1 ICT

Information and Communication Technology (ICT) refers to any technology that can be used to enable communication through processes of electronically capturing, retrieving, processing receiving and transmission of data (Postnote, 2006). Numerous examples of such technology exist; such as television, radio and today also include satellite, Internet and cellular and wireless networks (Postnote, 2006). The revolutionary potential of these new ICT’s lies in their capability to instantly connect immense networks composed of individual computers and organizations across very wide geographic spaces at very little cost. It is these types of ICTs that this research is focused on.

The availability of such ICTs have done more than create opportunities for their users; the World Youth Report (2003) says that "Notwithstanding the vast diversity in living environments, an unprecedented and unifying global media culture has developed. This culture challenges and usually surpasses such traditional forms of socialization as family and school". This complex cultural situation, in which young people are still at a stage where they are finding ways to survive, to improve their living conditions and to develop their identities has been identified in various ways. Some refers to it as the information or informational age, some use the term techno-culture or techno-capitalism, global media culture or globalization, virtual and cyber society (World Youth Report, 2003).

Sein *et al,* (2007) argues that it is now widely accepted that Information and Communication Technologies have an important role in national development, though the nature of the link between the two is not clear due to lack of clarity on how ICT is conceptualized in the development context.

Sein *et al,* (2007) continues to argue that although the matter has previously been discussed by numerous authors, clarity is still necessary in regards to the role of ICT in national development. Another argument is that the extent of the success of ICT interventions to enable development or lack thereof will depend on how stakeholders such as the national and local government, national and international development agencies, non-governmental organizations and public agencies conceive ICT and development (Sein and Harindranath, 2007). In continuance with the application of ICT for the purpose of developing the nation, a term associated with this has emerged: ICT4D (Information and Communication Technology for Development). The following section provides an introduction to ICT4D its relevance and application.

1.2 ICT4D

The term Information and Communication for Development (ICT4D) is motivated by and refers to the capacity of the ICT to act as a driver to human social and economic development and hence evolution of globalization culture, wherein ICT plays a major role in making it a real possibility. In our days the simplest lifestyle still admits to making use of ICTs. In a peculiar way basic ICT has become an essential part of human lives (Tilvawala, 2009; World youth Report, 2003; Twining, 2003). However the United nations Publications (2003) emphasizes the importance of having well-defined, well-accomplished and clear real world processes before deploying these ICTs over the Internet. United nations Publications (2003) argue that ICTs can be an effective “and”, rather than a substitute “or” to induce development and believe ICTs are not a panacea for development or a replacement for real-world processes, if these processes are flawed, deficient or absent, ICTs cannot make good the flaws or make up for the deficiencies.

Numerous ICT4D initiatives have been undertaken globally and they have been utilized as means to bring broadband connectivity to previously disadvantaged rural communities. Due to the evolution of ICTs over time, ICTs used in the past for this purpose had different capabilities to those currently available to date, which are more advanced than their predecessors. Below, there is an introduction to ICTs that are used to connect rural communities.

1.3 Rural Connectivity

Wireless networks have become the favoured technology for providing connectivity and hence elevating the level of Internet and phone services usage in developing and developed countries. Nonetheless, there are still other options that may be used to provide Internet connectivity to rural communities. Of course choice of technology will be influenced by a number of factors in each target community or site; for an example, factors such as the availability of electricity, the size of the area to be connected, sustainability, cost, etc. Different wireless technologies exist with dissimilar capabilities, this research will consider a number of these in the following chapter. In the ensuing section, an introduction to the research context is provided which is further discussed in the literature review chapter (chapter 2).

1.4 Research Context – Siyakhula Living Lab (SLL)

This research is undertaken in Dwesa, a rural marginalized community in the Eastern Cape province of South Africa. At this area a body called Siyakhula Living Lab (SLL) has implemented a project aiming to develop and increase the human capacity in the field of ICT, by supporting development and deployment of ICT systems in rural and marginalized communities which need them. SLL is a body that comprise of four pillars: academia, private sector, public sector and the community.

Each pillar is represented by a group of member, for example those representing academia stem from the University of Fort Hare and Rhodes University. The department of computer science from these two universities each host a Telkom Centers of Excellence and work together in application or software development, network administration and maintenance as well as any other activities in support of smooth operation of the SLL. The private sector is also well represented by a number of companies which play a major role in sponsoring the necessary equipment and sustaining of the project working hand in hand with some government departments. Finally, all of these organizations work closely with the Dwesa community, which is the center of the living lab methodology adopted by the SLL.

In line with ICT4D, SLL deployed a fixed WiMAX network with Wi-fi hotspots in each node, which this research means to experiment. This network operates over VSAT as a backhaul and initially consisted of five nodes situated in the local schools of Mbashe region.

These schools were chosen merely because they were community centers with electricity. Internet can be accessed through the labs and the hot spots, which offer coverage area of about 100m all around. These hot-spots were meant to extend the labs (DANs). This is a disadvantage to the community because it means limited access to the Internet and other e-services which are offered, in the following manner: in order for a user to be able to access the Internet they must be within the covered area. Moreover, the labs are within the school premises; this deprives the community of the freedom of using the labs during school hours. Further discussion of the research site is found in chapter 3 of this document. The ensuing section exposes the issues that are considered to be the research problem and which have motivated the course of this study.

1.5 Research Problem and Motivation

A lot has been done in South Africa and Africa as a whole in support of ICT4D. Numerous ICT4D interventions has been undertaken, some are in progress and some still to be undertaken, towards achieving reliable Internet connectivity to even the most rural and marginalized corners of the country, and thus towards achieving information globalization. Natasha Odendaal (2012) reports on Engineering News that the Department of Communications (DoC) continues to go forward with rural connectivity and in support of that she says the DoC has identified 161 areas "to focus on with the aim of bridging the urban/rural digital divide" (Odendaal, 2002) . In addition, frameworks have been modelled to define how the abovementioned goal is to be achieved in deploying ICTs in urban areas. Nonetheless, very little has been done in modelling or creating a framework that will assist in achieving the same goal: deploying ICTs in rural areas in South Africa. That then serves as a motivation towards undertaking this research. Moreover, lack of clear guidelines and/or framework or recommendations on which access technologies are feasible for deployment in rural communities and guidelines to declare their feasibility, also provides motivation for this research. This research aims to formulate the recommendations for deployment of broadband technologies in the most rural and marginalised communities.

1.6 Research Question

The following questions will drive or greatly assist in achieving the objectives of the research, the main research question is:

1. Which technologies are feasible for deployment in rural communities?

Sub-questions have been devised that will assist towards establishing an accurate response to the main question and, hence, the main research objective and these questions are structured as follows:

1. What are the factors or metrics used to evaluate the feasibility of various broadband technologies for deployment in rural communities?
2. What are the characteristics that define rurality in South Africa?
3. Which wireless technologies are evaluated for this purpose?

1.7 Objectives

The main objective of the study is to identify a suit or group of broadband technologies that are suitable for deployment in rural communities, with the aim of providing e-services to such communities, using Dwesa as a test bed. This study will serve as a prototype or a road map for deployment of wireless access technologies in rural communities, with hope that similar factor will be considered for deployment in other similar environments. Sub secondary objectives of the study are:

1. To identify feasibility factors that are important to consider in rural contexts and which will serve as a theoretical framework for rural broadband connectivity.
2. Identify and define relevant rurality characteristics or requirements.
3. Identify and undertake a theoretical evaluation of wireless broadband technologies.
4. Undertake technical evaluation of a selected technology.
5. Make recommendations regarding the most feasible technology for rural broadband connectivity.

1.8 Methodology

The methodology used for the used for the overall survey is a collection of integrated methods, each appropriate for different sections of the research. Various documentation are analysed to collect knowledge of and review various wireless broadband technologies, so as to understand and/or gain knowledge of the capabilities and analyse in terms of supporting the research objectives; such as to identify feasibility factors applicable for this research and defining a framework for rural broadband connectivity. This method is qualitative in nature and thus provides a depth understanding of each subject reviewed. Data is collected from different sources and observation is another method used for this purpose. This method is essential in collecting some of the information that is not documented or may be better understood through observation such as weather conditions, the geographical area, identify or defining relevant characteristics of rurality or requirements. And finally deployment of selected wireless technology method is used for reviewing the technology technically. The table below illustrates on how each secondary objective is tackled which method is used:

Table 1.1: Mapping objectives to relevant methods

SECONDARY OBJECTIVE	METHOD	SECTION
1. Identify feasibility factors	Literature review and analysis methods are used for this cause.	Chapter 3
2. Identify and define relevant rurality characteristics or requirements.	Observation and Literature review methods are applied.	Chapter 3
3. Identify and undertake theoretical evaluation of wireless broadband technologies.	Literature review used to identify technologies and comparison of capabilities is applied to further evaluate them.	Chapter 4
4. Undertake technical evaluation of a selected technology.	Deployment and testing of selected stated capabilities	Chapter 5
5. Make Recommendations on the most suitable technology for rural broadband connectivity	Analysis of Literature and Documentation	Chapter 6

1.9 Deliverables

This research seeks to highlight important metrics to consider during the deployment of wireless technologies in rural communities. It also offers recommendations as to which broadband technologies are most feasible in this regard.

1.10 Thesis Organisation

The remaining part of this thesis is organized as follows:

Chapter 2: Literature Review. This chapter provides an overview of literature about the use of Information and Communication technologies for rural development. It explores on the evolution of this concept, bringing forth its existence through time differences and technology changes. It then looks at its relevance in respect of solving the challenges faced by rural communities to date, by overviewing such challenges and observing some of the already existent ICT4D initiatives in Africa as a whole. The reasoning behind this is to create an understanding that as much such initiatives exists now and some have been in existence for a significant number of years, there will always be a room for improvement as long as technology advances.

Chapter 3: Methodology. This chapter discusses how the selection of the technologies occurs and the metrics under which a technology is selected are also clearly discussed herein.

Chapter 4: Profiling Of Wireless Technologies. This chapter provides an overview of different wireless technologies for review in the research. Information about their capabilities is well depicted. The aim for this is to understand the technologies and have a clear view of their capabilities and to find a basis upon which the selection of a technology is made in order to deploy the project on collective facts.

Chapter 5: Implementation. This chapter discusses the theoretical selection of these technologies and further illustrates how the selected technology is deployed. Evidence of its deployment is indicated in the process how it was carried out.

Chapter 6: General Discussion and Conclusion. This chapter provides recommendations of technologies that should be deployed in rural contexts and make conclusions on the overall performance of the research.

2 CHAPTER 2: LITERATURE REVIEW

2.1 Chapter Overview

This chapter begins with a discussion of ICT4D from different perspectives, whilst offering an overview of relevance of ICTs for rural development and an overview of telecommunications in South Africa is provided thereafter. This chapter also offers a discussion of other ICT4D interventions undertaken in Africa, by focusing on the technologies used.

2.2 ICT4D – The History

The term ICT4D merely refers to the application of information and communication technologies for international development. It has been in use for over decades and has been interpreted and pointed to a vast number of projects. This term dates back in the 1950's when the first digital computer was installed and used in a developing country; this was in Kolkata at the Indian Institute of Statistics. Even then it was only used for numeral calculations work (Heeks, 2009). From that beginning two application emphases in the use of computing for development existed. The main emphasis was on government processes and then IT processes follows, as they were initially know. During the 80's other nations and private firms joined the revolution and IT was recognized as a tool used for delivering economic growth in the private sector. In his paper in Heeks (2009) termed this stages "ICT4D 0.0" or even IT4G (information technology for government/growth).

Later in the 1990's two occurrences gave birth to what was christened as ICT4D 1.0. The first was the fact that Internet was generally moved out of its base which was military and scientific research, it was now available for the public to access, in elementary and high schools, public libraries, commercial entities (Sterling, 1993). The second was the agreement between the 191 United Nations (UN) Millennium Development Goals (MDGs). The Internet caused a global sudden rush of interests in ICTs and how it may be applied to pursue development in developing countries, business entities wanted to it to be put on a sound financial footing, where a sound business model will be used to sell access to the Internet, Government people wanted the Internet to be fully regulated and academics wanted it to be used exclusively for scholarly research (Sterling, 1993).

In 2009, Heeks (2009), said that the 1990's digital technologies were tools, still not used to their full capabilities, they were still in search for a purpose, while in the other hand development goals were new targets in search for a delivery mechanism, which then later, these two found each other in a way, matched it each other out unexpectedly and produced a baby who was called ICT4D.

In this stage of ICT4D the main actors were the international development organizations and non-Governmental Organizations (NGOs) and they based their priorities to application of ITCs on MDGs, whose central goal is to improve the lives of the three billion on the planet who live on lowest income, who sometimes does not even afford the basics (Unwin & Unwin, 2009). During this stage time was relatively shorter and with high expectations and pressure to produce tangible results, as a result the main actors looked around for quick, off the shelf solutions that could be duplicated in poor communities in developing countries, focusing especially on the needs of rural poor and attempts to provide a vision for effective rural developments (Unwin & Unwin, 2009).

Considering the fact that most communities who experience poverty are the rural communities, good off-the-shelf model was the rural telecenter which were rolled during the 1980s and the early 1990s in the North American and in the European (Heeks, 2009). Of course these telecenter were not solely the only ICT4D projects at that era but they were the pilot for this period, recognising need to diversify from agriculture projects as an important issue (Unwin & Unwin, 2009). The deployment of the telecenters stretched from the mid/late 90s to the mid/late 2000s, as a results collectively concluding that it sums up to three words; failure, restriction and "anectdote", which each directed specifically to a new watch word (Heeks, 2009);

- ✓ **Sustainability;** given the fact that many ICT4D interventions failed to deliver and/or outlast, new emphasis to ascertain longevity of such interventions was born.
- ✓ **Scalability;** considering the limited reach offered by each telecenter project, there need to be projects that go beyond that.

- ✓ **Evolution;** Given that the ICT4D 1.0 stage was often held high by hype and unsubstantiated, self-interesting stories, there is a new concern with objective evaluation impact.

2.3 ICT4D 2.0

Edgerton (2008) argues that we initially had been too obsessed with technology-as-an-invention and paid too little attention on technology-as-in-use and yet it is technology-as-in-use that made much more difference in people's lives. The initial stages of ICT4D (ICT4D 1.0) initially took the invention-down-approach bringing forward new technologies into development contexts, much more that it took use-up approach of understanding how already existing technologies were being employed with in disadvantaged communities, Heeks, 2009:

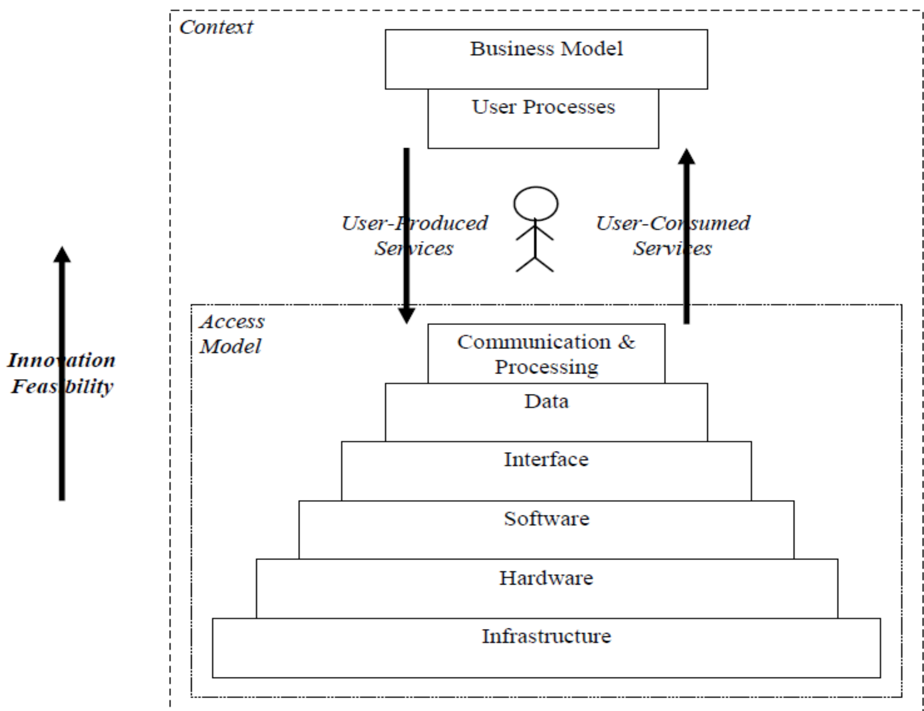


Figure 2-1: Technologies and Processes of ICT4D.

If this ICT4D 2.0 phase of shifts successfully the invention; use balance, this would then mean:

- ✓ Less stressing on what might be used such as the Internet and Personal Computers, and the emphasis now will be more at what is actually used such as the mobiles, radio and television.
- ✓ Less stress on key technical innovation and more emphasis on application and business model innovation.

2.4 ICT4D Movement

According to Rothenberg-Aalami, in the year 2002 ICT as a tool for enabling social and economic development was formalized at a meeting of the G-8 where major industrialized nations acknowledged that for some of the world's population, ICT is one of the most potent forces in shaping the twenty-first century, its revolutionary impact affects the way people live, learn and work, and the way government interacts with civil society (Rothenberg-Aalami *et al*, 2005).

As a result of the meeting, the Okinawa Charter on the Global Information Society created a call to bridging the international information and knowledge divide. The G-8 had also launched a Digital Opportunity Task Force (DOT Force) in 2001 in order to provide a strategic framework for both public and private stakeholders to harness ICTs for development purposes (Rothenberg-Aalami J. *et al* 2005). Extending from these efforts, the UN General Assembly held the World Summit on the Information Society (WSIS) in Geneva in December 2003, a forum for interested stakeholders from governments, international organization, nongovernmental organizations and industry (Rothenberg-Aalami J. *et al* 2005; Kleinw, 2004). The outcome of the meeting was the ICT4D Platform; a set of concrete goals associated with the strategic framework previously generated by the G8 DOT force and outlined in the Okinawa Charter (Rothenberg-Aalami J. *et al* 2005; Kleinw, 2004).

Today, the ICT4D movement involves a host of interested public and private players, including every agency of the United Nations, the World Bank Group, and the International Monetary Fund (IMF), development donor aid governmental agencies including Canada (CIDA), the Netherlands (NORAD), and the United States (USAID), governments at all levels, grassroots and international non-governmental organizations, private organizations with the express purpose of bridging the digital divides and business leaders who are increasingly acting as development agents like their partners listed above. Most of these stakeholders have committed large resources to the development of rural information kiosks as places that provide access and training to first time ICT users and a direct conduit to the Information Age" (Rothenberg-Aalami J. et al 2005).

2.5 ICTs for Rural Development

Khane *et al,* (2011) argues that Upliftment of rural areas and poverty alleviation are a priority for development in South Africa. Information and knowledge are key strategic resources for social and economic development. Rural communities in South Africa can be empowered by participating in the knowledge society through the use of Information Communication Technologies (ICTs). ICTs act as tools to support existing efforts towards rural development and to enable innovative approaches (Khane, *et al* 2011). Since the emergence of the general term ICT4D which merely referrers to the application of Information and Communication Technologies (ICT's) for socio-economic development of communities, so many initiatives have been undertaken worldwide to develop disadvantaged, rural and remote communities in developing countries (Smith *et al* 2008). Currently people in the developing countries own or have access to new, innovative and affordable information and communication technology that looking back few years ago these technologies were non-existent or were non-existent or were not possible for them to reach (CRS, 2011).

Hence the Government, big and/or small Non-Governmental Organisations (NGO's), Public and/or Private Companies have been actively making use of these technological advances to provide services to the deserving/disadvantaged communities and for managing and improve quality of services already provided (CRS, 2011). Rapid rate of data and information exchange made possible by ICT therefore acts as an advantage to facilitating these developmental initiatives (Rothenberg-Aalami J. *et al* 2005). A number of interventions have been taken in supporting of the ICT4D initiative, to ensure it continuation until to a point where its objectives have been achieved. Following is an overview of history of telecommunications in South Africa.

2.6 Telecommunications in South Africa

During the 2007 to 2010 period, the Information and Communication Technology market matured by over R131 billion to R179 billion and the estimation was that it would grow as far as R250 billion in 2020, with the growth largely driven by the speedy uptake and use of data and application driven mobile communications (South African Government Information, 2012). The telecommunications sector has grown in more than one aspect and following is a review of such:

2.6.1 Policy

The Department of Communications (DoC) has numerous efforts towards improvement of telecommunications in South Africa through development of new strategies that they believed have the ability to improve telecommunications in SA (Ranga, 2011); such strategies include a broadband policy aimed at providing reliable, accessible and cost-effective ICT broadband infrastructure (Ranga, 2011), as well as development of new policies that will support the objective of placing South Africa to be competitive in the global telecommunications economy and hence create opportunities for investors.

South African Government Information (2012), states that during 2011/2012, the DoC has made significant progress towards its mandate of implementing the Broadcasting Digital Migration Policy. Final amendments to the policy were distributed in February 2012 in the Government Gazette, so as they may be implemented by relevant role players (South African Government Information, 2012).

2.6.2 Access

The South African Bureau of Standards (SABS) launched a standard in June 2012 at the inaugural ICT. Set Box Top (SBT) manufactured locally will be built to comply with these set of standards. The DoC aims to finalize the selection of suitable STB manufacturers process, thereafter enabling job creation with an estimated value of 23 500 to be created across the value chain (South African Government Information, 2012).

The DoC has also developed the ICT Rural development Strategy to be implemented during the 2012/2013 financial year, which focuses on launching new access centers in the 161 areas that have been identified by the Department of Rural Development and Land Reform, as priority across the country (South African Government Information, 2012).

The stated strategy also confirms that the government has committed to Internet connectivity to all the schools and health centers country wide and has during the 2012/2013 financial year prioritized the broadband connectivity to 1 650 schools across the provinces, marking the initial phase to implementation of National Connectivity Plan for Schools (South African Government Information, 2012).

In May 2012, WACs (West African Cable Systems), the fifth submarine cable system to link South Africa to the rest of the world was launched and it is promising further improved bandwidth connectivity down the west coast of Africa. Infraco, a South African state company is entitled to 11,4% of the WAC system, promising country wide broadband connectivity by 2020 (South African Government Information, 2012). However MTN is the largest investor in the this 17 200 km fiber optic submarine cable system that is expected to effectively elevation the current broadband capacity in South Africa by more than 500 Gbps (IT News Africa, 2012). WACS broadband capacity is said to be necessary in South Africa to improve MTN, considering the fact that customer appetite for data grew to as much as 200% during 2011 measured on a year-to-year interval. MTN has ensured direct access to its market in west Africa through deployment of multiple (15) landing points in all countries where MTN has a presence starting at Yzerfontein near Cape Town in South Africa and ending in the United Kingdom (IT News Africa, 2012).

*Figure **2-2**: WACS Point of Presence along the West Africa.*

2.6.3 Mobile Communications and Internet

In recent years, there has been remarkable growth in South African cellphone industry with mobile penetration increased more than 10% which is declared as the highest rates in world wide. There are currently five mobile operators in SA: Vodacom, MTN, Cell C, Virgin Mobile and Telkom (South African Government Information, 2012), with an addition of the 6^{th} Neotel entering the industry as an operator extending their services from providing infrastructure to providing telecommunications services as well. From recent statistics it has been discovered that there were 8.5 million South African Internet users by the end of 2011, from which 7.9 million users access the Internet via their cellphones (South African Government Information, 2012).

2.7 ICT4D Initiatives in Rural South Africa

Many countries around the globe are faced with overwhelming problems which part of include poverty, illiteracy, malnutrition and child mortality and for years government and private agencies have been probing for ways to counteract and reduce the human suffering caused by these problems (Al-Jaghoub, 2011). Since a few years ago, when a few development agencies found a new answer to tackling these problems: Information and Communication Technologies, countries wanted to achieve socio-economic development by harnessing the advantages offered by these ICT to better people’s lives (Al-Jaghoub, 2011). South African government has prioritized rural development and alleviating of poverty for its development (Pade *et al*, 2010). Knowledge and information are key strategic resources for social and economic development, seeing that they play a major role in empowering rural communities by providing them with the ability to spread out their choices through knowing and detecting what their specific needs are as a community (Pade *et al*, 2010). Numerous organizations have intervened in the ICT4D initiative and a number of interventions have been developed throughout the world, observing South Africa in this case, in the quest to develop rural communities through use of ICT tools, connecting such communities to the global knowledge community. Following is an overview of ICT4D interventions within rural communities in Africa, starting with the Siyakhula Living Lab (SLL) initiative, under which this research is taken.

2.7.1 Siyakhula Living Lab

"SLL is a multi-stakeholder operation that consists of academia, industry, government and marginalized communities to facilitate *user-driven innovation* in the ICTD domain. This not only empowers the rural communities, but also integrates the *innovative potential* in the rural marginalized areas within the general *national system of innovation"* (SLL, 2011). SLL has all its stake holders represented by groups from respective class such as academia is well presented by the two Telkom Centres of Excellence, hosted within the department of Computer Science both in University of Fort Hare and Rhodes University. The diagram below illustrates the SLL ecosystem, indicating all aforementioned stakeholders, highlighting as well some of the activities carried out with SLL:

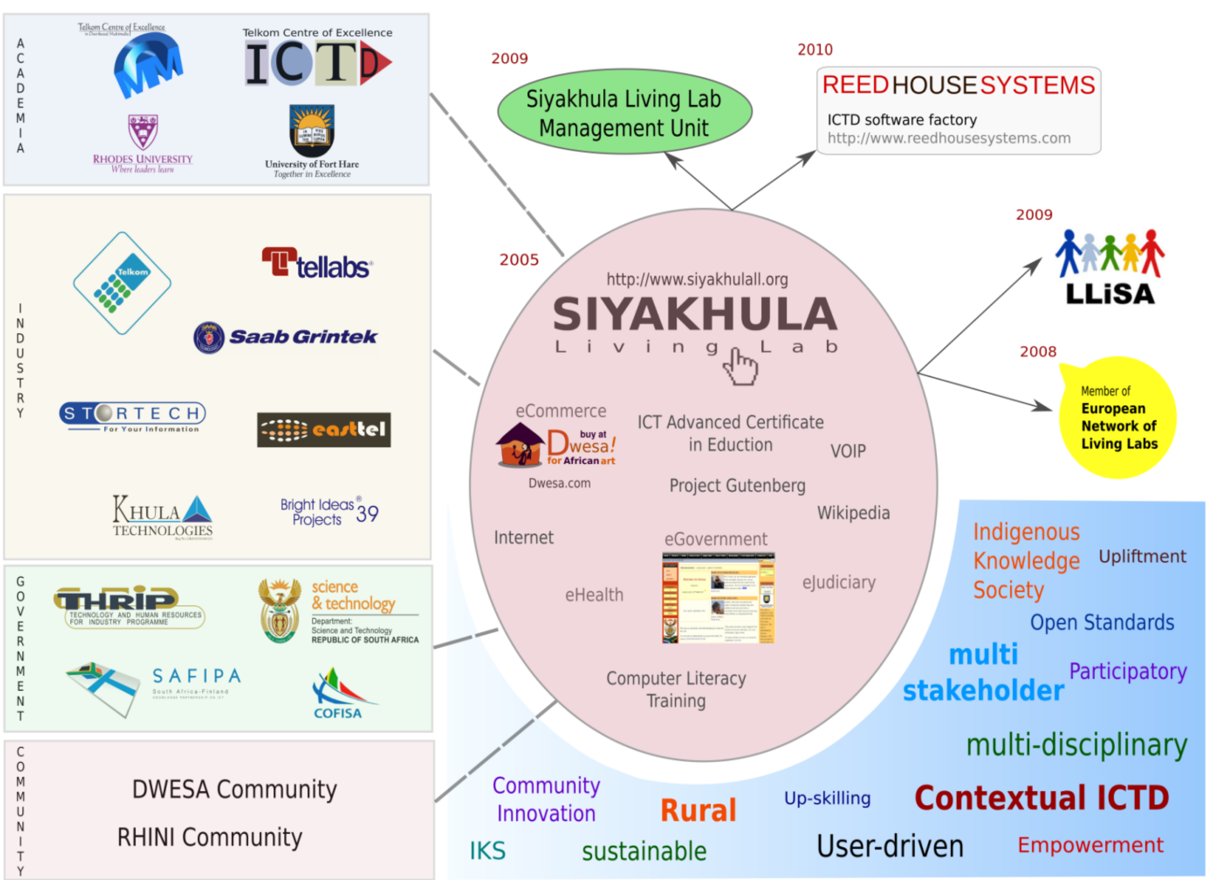


Figure 2-3: SLL Ecosystem

Some of the important highlights within the SLL ecosystem include the emergence of ReedHouseSystems, a software development and commercialisation factory within SLL in 2010, the SLL Management Unit which manages all the processes within SLL in 2009, the SLL becoming a member of European network of Living Labs in 2008 and SLL becoming a member of Living Labs in South Africa in 2009 (LLiSA) (Twele et al, 2011).

Back in 2005 Siyakhula Living Lab (SLL) took an initiative in support of the concept of using ICT4D. This initiative saw the deployment of a fixed WiMAX network comprising of five digital access nodes (DAN), each node with Wi-Fi hotspot that operates over VSAT as a backhaul (Ndlovu *et al*, 2010). Initially each of these nodes is hosted in the local schools namely Mpume, Nondobo, Nqabarha, Mtokwane and Ngwane. These schools were initially chosen purely due to the fact that they were community centres with electricity. A diagram below shows the initial network diagram built in 2005:

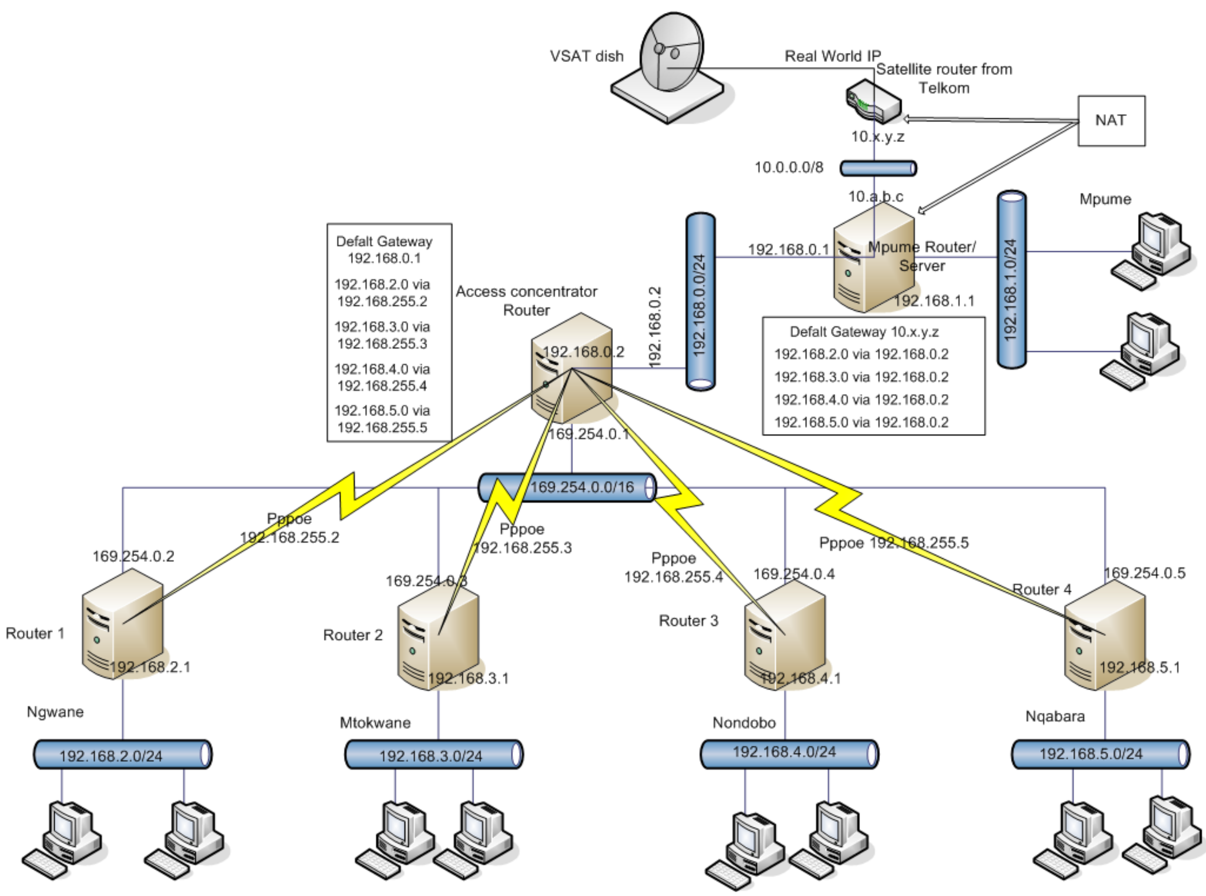


Figure 2-4: A network diagram of local loop access network in SLL

From this topology Internet can be accessed through the labs and the hot spots are deployed within each node, which offer coverage area of about 100m all around. This is a disadvantage to the community because it means limited access to the Internet and other offered e-services in the following manner; in order for a user to be able to access the Internet they must be within the covered area. Again, the labs are within the school premises, which then deprive the community the freedom of using the labs during school hours. This study then reviews a number of wireless broadband technologies that could be deployed in the area, and in similar environments, to provide Internet over a broader range and reach other areas not covered by the current network. The technology presumably would enable the spread of network to cover the Dwesa area and therefore allow access to more users.

SLL is not the only such initiative, a number of other rural communication models exist and some are success stories. Below is a continuation of such initiatives review, looking next at project targeting the rural schools.

2.7.2 Learn-O-Vision

The Learn-O-Vision was developed by D. Oosthuizen to afford schools in rural communities all the facilities available in a first-rate educational institution. The origin of the Learn-O-Vision concept was motivated solely by a television news item about a Garankuwa school lacking classrooms and lessons conducted under a tree (Herselman 2003).

This project offers a solar-powered computer system, television, video machine, writing and flannel board in a portable and secure box, for teaching purposes. This teaching unit is contained in a standard wardrobe proportioned box with wheel for ease of movement during classes and has been prepared to serve as a writing board with the television and video machine in front (Herselman 2003). The solar unit has two solar panels providing power to it and when it is fully charged the batteries can last for a full school day and it has also an option to work with electricity mains.

Herselman (2003) say that Learn-O-Vision is expected to grow and evolve as far as giving rural schools access to the Internet and hence furnish the idea of distance learning in such communities.

2.7.3 Coza Cares

CoZa Cares was originally known as the CSI arm of UniForum SA, but has gained independence in 2012 and became the CoZa Cares Foundation. CoZa Cares core focus continues being enabling sustainable ICT environments in under-resourced schools. This Foundation supplements the conventional models of teaching and learning by increasing access to ICT for under-resources schools through partnership with the following entities, the Department of Basic Education, NetDay Association (an educational technology solutions provider), Edunova (school capacity and leadership developer) and Internet Service Providers' Association's (ISPA) Teacher-Teaching initiative (CoZa Cares, 2012).

2.7.3.1 CoZa Cares Success Story

During this period starting from 2001 to date CoZa Cares has donated over R40 million to the national schools' project, with number of schools benefited from this Foundation exceeding 250 in 7 provinces (CoZa Cares, 2012). CoZa Cares installed 3000 computers in over 250 computer labs nationwide. Below is a figure that shows one of the labs built by CoZa Cares:

Figure 2-5: CoZa Cares Computer Lab

From the image shown, it is evident that these labs are open to all students, regardless of the school they go to, encouraging not only learning, but also a learning environment where sharing of ideas from students who come from different schools, giving the students the confidence in the information and training they receive (CoZa Cares, 2012).

From all these schools about 3500 teachers has been trained with basic and intermediate computer literacy skills, basic technical support skills and as well as project related to their curriculum. In addition to computer centres and other technology interventions, CoZa Cares supply an extensive Open Source digital content package (CoZa Cares, 2012).

2.7.4 The RAFT Network

The RAFT (Réseau en Afrique Francophone pour la Télémédecine) network has its origin in Africa, by a group of medical students from the Bamako University Medical School in Mali (Geissbuhle *et al*, 2007). The Bamako University is the only health care training facility in Mali, while this country is not the least in Africa, its current population according to (Index mundi, 2012) is 14.5 million which is twice the size of France. The grand idea was to make us of the Internet for the students to stay connected to each other, their lecturers and other knowledgeable specialists regardless of where they go to practice. The project was then initiated and initially named "Keneya Blown" (Geissbuhle *et al*, 2007). RAFT as it is currently known broadcasts medical education courses webcasts on weekly basis and these are followed by hundreds of health care professionals across French speaking Africans.

Since its offset, RAFT is reported to have grown to such an extent that it runs now across the continent, cultural and geographical boundaries with collaborations between Réseau informatique malien d'information et de communication médicale (Mali), Ministère de la Santé du Mali, Hôpital Universitaire du Point G (Mali), Geneva University Hospital (Switzerland), Geneva University UNESCO chair of telemedicine (Switzerland), Health-ontheNet Foundation (Switzerland and Mali), OESO Foundation (Switzerland), Ministère dela Santé de Mauritanie, Secrétariat d'Etat aux Technologies Nouvelles (Mauritania), Hôpital European Georges Pompidou (France), Réseau HOPES et Université Numérique Francophone Mondiale (France), Université de Marrakech (Morocco), Université Cheikh Anta Diop de Dakar (Senegal), Hôpital Universitaire Le Dantec (Senegal), Hôpitaux Universitaires de Ouagadougou (Burkina Faso), Association AMMIE de Ouahigouya (Burkina Faso), Institut National d'Orthopédie (Tunisie), Hôpital Central de Yaoundé (Cameroon), Centre Suisse de Recherché Scientifique d'Abidjan (Ivory Coast), Université d'Antananarivo (Madagascar), Ministère de la Santé de Madagascar, Ministère de la Santé du Niger (Geissbuhle *et al*, 2007).

In 0rder to reach as far as possible using the already available communication infrastructure, RAFT focused on low bandwidth with the assumption that growth in these two aspects would eventually simultaneously while they tackle the bigger challenge for better understanding the challenges faces by the organisation and moral needs. RAFT network offers the following activities (Geissbuhle *et al*, 2007):

- ✓ The *e-course,* which is an e-learning system offering health professionals courses and consultation services with other health professionals and information bases so as to solve difficult cases, regardless of the distance barrier. Their system was originally developed at Geneva University, specifically designed to use minimal bandwidth and still provide high quality sound and presentation of its material. This system allows student to post feedback to the teachers via instant messaging, giving them allowance to adjust quality of video of the “talking head” during vide consultation, which of course saves resources. A bandwidth of 28 kbps is sufficient for the communication, enabling participants from remote areas to make use of widely available tools, for example, a cybercafé connected to the Internet via an analogue telephone line.

- ✓ The *iPath* tele-consultation platform, which was developed by the Basel University Hospital, is an open source instrument providing a controlled environment for virtual communities of already identified health care professionals to present clinical cases for assistance from their associates. These cases are illustrated by use of images with email notifications used to facilitate rapid response mimicking the actual patient care.
- ✓ IP based visioconferencing is used to mostly point-to-point remote consultations during patient’s remote clinical examination when necessary. These processes are only limited to cases where bandwidth of more than 100 kbps is available.
- ✓ WLAN connections linking the hospitals together have been installed in few locations: Bamako (Mali), in Nouakchott (Mauritania) and in Yaoundé (Cameroon). These WLANs enable high bandwidth alliances between the health care professionals.
- ✓ Two satellite stations have been installed, one in Dimmbal in Mali another in Maata Moulaana in Mauritania (figure 7), both situated in rural areas. These satellites provide connectivity in rural areas where necessary infrastructure is inadequate, to pilot the project in delocalised primary care situations. The mini-VSAT technology was chosen due to the fact that it is largely available in Africa, its advantageous capability of resisting frequent climatological conditions, including heavy rains and winds and most importantly its affordable than VSAT technology.

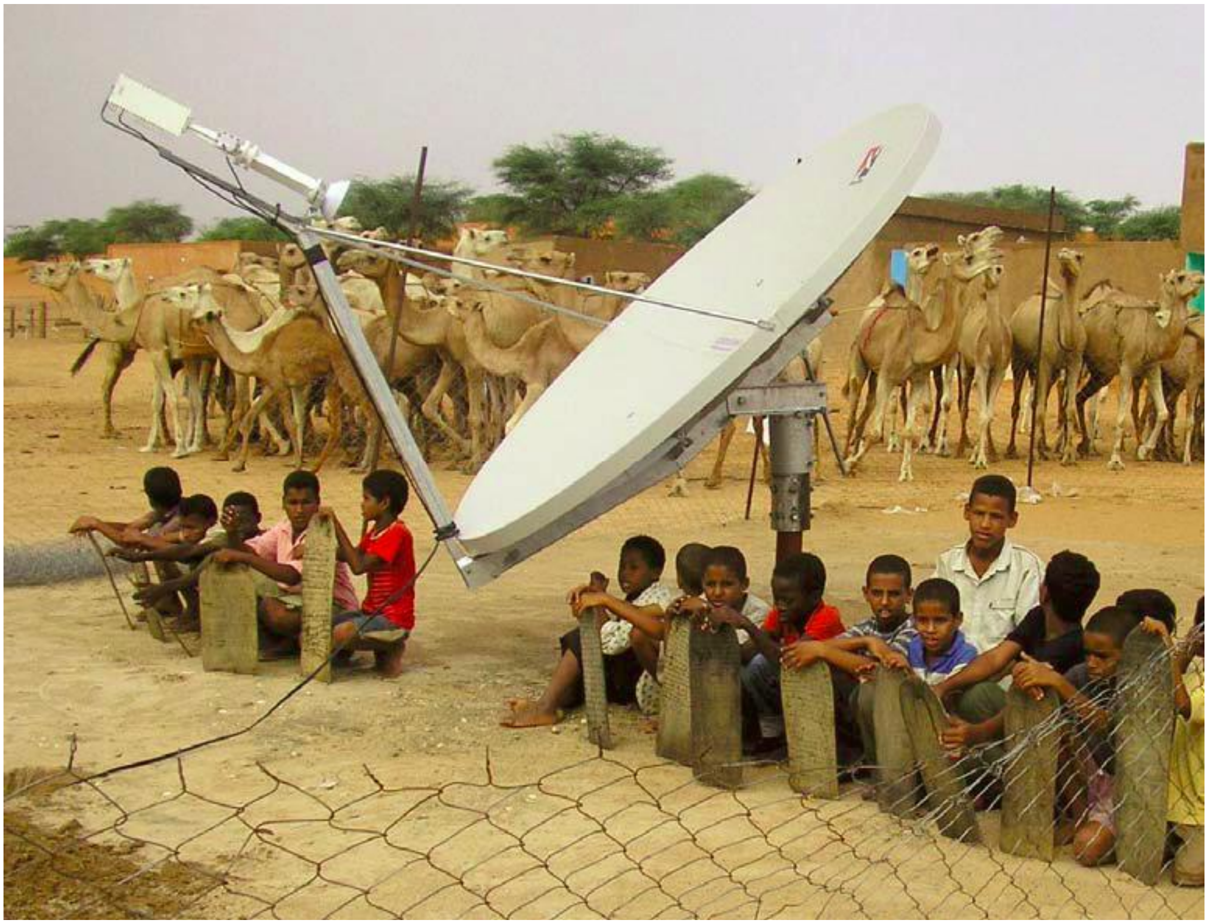


Figure 2-6: mini-VSAT technology in Maata-Moulana in Mauritania

3 CHAPTER 3: THE RESEARCH METHODOLOGY

In this chapter, the overall methodology used to conduct the research is discussed and further explained. This chapter provides further details on each method used during each step of the research, as the research comprises of different methods in separate sections all used to carry out research objectives. However the research mainly mimics and motivates the use of the living lab methodology as its overall method. This is mainly motivated by the fact that the research itself is conducted within the Siyakhula Living Lab, which then adopts, along with its day-to-day processes, the living lab methodology.

Although the living lab method is applied throughout the research, also the research comprises of sections elaborated upon in the various chapters of this dissertation where each section may comprise of more than one method applied. These methods mentioned above are referred to as sub methods, which are applied so as to carry out each section's objective (sub objective). These sub-methods are then put under the big umbrella of the living lab methodology, governing the overall processes within SLL including this research.

This research is qualitative in nature; therefore qualitative methods are used to carry out the specific sub-objectives. In elaborating these qualitative methods we commence by discussing and reviewing the overall methodology: Living Lab Methodology and then later discussing each method used in each chapter. The first sub-method applied in this research is found in chapter 2, where literature is reviewed and discussed to understand more the ICT4D concept adopted in this research, its background and furthermore understand the relevance of this research in day-to-day lives within society. A second sub-method used is: a combination of Observation and Review of literature, applied in this chapter (chapter 3), which will be later practiced in identification of metrics as well as the identification and discussion of rurality characters. In the fourth chapter, a literature review method is applied to collect information and hence profiling of wireless broadband technologies. A combination of two methods again is applied and elaborated in chapter 5, where implementation is carried out in two steps; first analysis through comparison of literature to determine suitable technologies and deployment of a selected technology. The next and last section (chapter 6); recommendations from the author are elaborated and research is concluded.

3.1 The Living Lab Methodology

The Living Lab concept attains its relevance from the necessity of evaluation of mass deployment of potential of ICT solutions. According to the Working Group; 2008, “Living Labs represents regional innovation environments focusing on user communities embedded within real life ”. The Working Group, also state that besides the technological aspects, Living Labs pays attention to the most important aspect for successful ICT projects, the human dimension of technology (The Working Group, 2007).

The European Commission (2009), describe a Living Lab as a “user-driven open innovation ecosystem based on a business-citizens-government partnership which enables users to take an active part in the research, development and innovation process”. This European Commission (2009) states that this method then brings users early into the creative process, thereby improve chances of discovering new behaviours and user patterns; bridges the innovation gaps between development of technology and consumption of these new services by encouraging partnerships between the relevant stakeholders; and it allows for early evaluation of socio-economic implications made possible by new technology solutions by demonstrating validity of their proposed business models and new services.

The Southern Africa Development Community (SADC) innovations have made changes in their ICT provisioning scheme, from product-based to service based areas, sometimes making use of these ICT as the main driving force for growth, addressing quality of life to relevant communities (baseline, 2009). Involving users in the innovation processes is still perceived as a challenge experienced by ICT providers, most preferably, in Living Lab efforts (Pade *et al*, 2009). This perception should be totally shifted in such a way that interactions move away from users being accepted as consumers of innovations led by the industry to a perspective where users co-create and thereby develop theoretical knowledge valued by the research community (Pade *et al,* 2009). Siyakhula Living Lab values this notion to an extent of applying and extending it to their ICT4D intervention for the benefit and development of local rural communities. Below is a narration of how SLL currently puts the living lab methodology to practice.

3.2 Application of the Living Lab Method within Siyakhula

Siyakhula Living Lab has applied this methodology to its own operations to include the active participation of user communities in the innovation processes (Twele *et al*; 2011). This Living Lab methodology plays a role in promoting human empowerment within the test bed community so they may take part in solving their own problems, hence improve their quality of life thrugh the use of technology (Twele et al; 2011). The Siyakhula Living Lab (SLL) seeks to provide skills and new technology solutions to the Mbashe rural community, starting with Dwesa (Pade *et al*, 2010; Pade *et al* 2009) in support to its 4-steps mandate to ICT4D concept. The steps include provision of infrastructure, connectivity, application development and literacy to the target communities so as to catalyse the development processes. It's four tier collaboration efforts from the stated community, the government, the industry and academia ensures provision of all necessary requirements to pursue SLL's mandate. These tiers are well represented as follows: the Dwesa community are the test bed of desired type of target community to be developed, government is represented by the Department of Science and Technology including collaborations between South Africa and Finland (SAFIPA), the industry represented by companies such as Telkom and Eastel, and the last tier, academia well represented by the Telkom Centers of Excellence hosted within computer science department at the University of Fort Hare and Rhodes University. Collaboration within these stakeholders, each playing a significant role in the innovation process within Siyakhula, constitutes what Siyakhula Living Lab is about and its desire to grow in innovation and sustainability (Twele et al; 2011).

Before any application development process begins, the target community (Dwesa in this case) is always consulted by the developing team. During these consultation sessions the envisioned application or the idea is shared, explained to the representing members of the community and their input and view is required. These processes are always run as the brainstorming sessions and are run with different groups within the community. The groups usually comprise of teachers, students from local schools, the elderly within the community and the non-schooling youth. The purpose at this stage is to get their views regarding the envisioned application or any other ICT products the community requires or see necessary and/or proposed acceptance by the community. This also plays a major role as it also gives the community a chance to state their technology needs, what is relevant to them and it also assist with limiting chances of developing applications that are not culturally inclined (contains or reflect issues of cultural disobedience) or generally chances or ethical issues that may arise with the target communities. Most importantly the sessions enlightens the designing team, in the case of software development, with the community's expectations of the end product.

The development phase then begins as soon as all the necessary information is collected from the target users and after that has finished, the end product is presented to the community before its formal deployment. At this stage the community is informed of the products state, hey provide feedback, and if changes or updates are necessary from their feedback the product goes back to development and is updated. In completion of the product the community is then trained for the use of the new application or product. The below section depicts how this method is conveyed within this particular research.

3.3 Living Lab Methodology With in the Research

The Living Lab methodology is used as the overall methodology to this research, due to the fact that the research is hosted within Siyakhula and operations within Siyakhula adopting a Living Lab approach. This method is used to govern its overall processes such ensuring that the research satisfies or encourages SLL main objectives. In this research, the living lab approach is used to govern the overall processes; such as ensuring that involvement of the community throughout the project duration. Due to the nature of the research and the literacy background of the community, their involvement was only necessary on certain stages of the research, during project introduction and testing phase. In the introductory phase application of this methodology becomes evident more when the community is enlightened about the implementation of the project prior to its inception. Community meetings are called and scheduled via the project champions channels already established between SLL and the community, also via the traditional way which normally is used within this community for communications, by consent with local chief. During these meetings the communities are introduced to the project and all its stages, clearly explained what is expected from them and what they should expect at the end, the mile stones of the project and their questions and concerns tackled through devising ideas together with them as a team until meaningful and viable solutions are found.

During the testing phase, information and mile stones: which is a functional mobile network in places that were not reached before, that were presented to the community are elaborated. Evidence of the availability of the network is provided, where the users, which is the community members is in this case, interrogate themselves by connecting to the network and open web applications. After the network testing phase is complete, there still exists post project activities that are carried out in support of the living lab methodology and continuation of SLL mandate. These activities include conducting computer literacy training for the community, so as to sustain the functioning of the network, by ensuring users ability to use the facilities made available to them. The sub methods used to carry out specific research sub-objectives within sections/chapters are discussed in the following sections.

3.4 Selection of Access Technologies for Profiling and Profiling

It is clearly very necessary to review and select technologies in search for broadband technologies that may be used to deploy a network in rural communities and connect them to the Internet.

Technologies that are profiled in the technology profiling section are technologies that are known by author. These technologies are not necessarily selected from a certain pool of technologies, using a specific mechanism, rather all wireless technologies that are investigated by reviewing literature are reviewed and profiled in chapter 4 for further selection in chapter 5 of this research. Reviewing literature at this stage assists in attaining better understanding of the technology; its proposed capability, requirements and specifications. This information affords ease of determination of whether the technology qualifies to be broadband technology or not. Hence determine whether it can be included to a list of technologies to be taken for further analysis.

Reviewing literature is the best sensible option to carry out this objective, for the reason that, relying only on information known by author about these technologies may not be the best method to be used due to the fact that it may not be an expert in the field, but a researcher seeking new ways to solve society problems. There may be other means for this cause such as interviewing experts in the telecommunication field or experts in access technologies at large.

However this method is time consuming and research resources (funds) hog, due to the fact that the research in carried out in the Eastern Cape, where is not vast telecommunications skill. It is for the these reasons that literature review proved to be the best option to carry out this objective of selecting wireless access technologies to be considered for this research purposes. The following section looks at the next step taken after determining and profiling wireless access broadband technologies, which is methodology used in determining the technologies that qualify for rural broadband connectivity.

3.5 Determining Rural Broadband Technologies

This section discusses means used to further select from the profiled technology list obtained from reviewing literature, a pool of technologies that qualify for deployment in rural communities.

To select from the profiled technologies to a pool of technologies suitable for rural broadband, as indicated in the research introduction, metrics stated in section 3.6 of this chapter are be used. These metrics are determined and discussed below in this chapter. Also the rurality characters of these communities have been discussed, elaborating what rural community entails in Southern Africa. It is a fact that in different countries “rural” communities exists, but also we understand that although, there may exist similarities in what we define as “rural” communities, differences may as well exist. Hence the discussion of what “rural” community means in this research is included.

The profiled technologies are then further studied, looking for those who possess capabilities that cater for the discussed metrics and rural characteristics, providing networking through these limitations. Technologies that satisfy these metrics and nullify the limitations caused by rural characteristics are considered the best option for deploying a network and providing Internet access to rural and marginalized communities. Hence they are referred to as rural broadband technologies and it is from them that a specific technology will be selected further for technical review (deployment). The section below the further elaborates the method/s used to select a technology to be currently deployed within Siyakhula Living Lab.

3.6 Selection of Access Technologies for Technical Review

This section discusses methods that are used to decide or determine which technology will be deployed within the Siyakhula Living Lab network, as means of conducting a technical/hands-on study of the technology.

To select one technology for deployment, a method used is comparison between the selected rural broadband technologies. The comparison is achieved by tabulating technologies and their capabilities, carefully decide on eliminating those that have less favourable capabilities. In this process technology capabilities are not the only facts considered for the selection. Their deployment feasibility also depend on a number of reasons which include: financial freedom available to procure equipment and carry out this process, the state of licensing requirement for the spectrum in which the technology is expected to operate, its availability on the SA market, availability of end user equipment for interacting with the technology and applications made possible by the availability of such technology.

Information about these technologies will be tabulated and hence the capabilities compared, looking for best technology to deploy, as per expected, reasons for selection will be stated. Subsequently a technology of choice will be deployed and merged into the already existing Siyakhula Living Lab WiMAX network in Dwesa. The following section then illustrates and discusses the metrics used to declare the technologies feasible for rural connectivity.

3.7 Selection of Metrics

In this research metrics are selected; which are used as a standard of measurement for feasibility of these technologies deployment in rural communities. Selection of metrics is a very important milestone in this research and needs to be conducted carefully. This section elaborates how this process is undertaken. It is an established truth that factors affecting different types of communities largely differ. Hence is important for the community to be studied when these are a matter at hand.

In order to highlight and select facts that are of paramount importance and that are to be used as metrices we will review our test bed community Dwesa. This is necessary because Dwesa is one of the most rural communities in the Eastern Cape, also due to fact that Eastern Cape is a province well known to host most home lands in South Africa () including Dwesa. This are holds historic back ground to former Kings of the Nguni tribes, which fought civilisation in the former government of apartheid. Nonetheless through observation it is evident that Dwesa can be used as a representation of rural communities in South Africa. A target community is *profiled* collecting all the facts about this community which makes it suitable/ qualify to be classified as rural. Dwesa then provides the link between what the research utilise as metrics and the importance of use of ICTs in such rural communities.

This study then profiles its target community (Dwesa) and from its profile, a study analysis is conducted; the following are highlighted and lead to selection of metrics; limiting factor that may be eliminated by or largely reduced by the availability of a proposed ICT, which are factors that have a huge percentage of sabotaging or defecting the implementation and/or sustainability of the ICT proposed. Identifying these factors and identifying a technology with capabilities that recommends overcoming such limitations then indicates success in identification of relevant metrics for the target community.

3.8 Profiling the Research Site Dwesa

When constructing a community profile, details about the community are crafted in a manner that should enlighten and give clear picture of what the community looks like and how it may feel living in such a community. Details are drawn to give correct and true image and environmental characteristics. This section elaborates how the profile of the target community is created and paying attention to its reflectance of the above factors. The diagram below indicates the processes undertaken and the discussion below it discloses how the process what conducted:

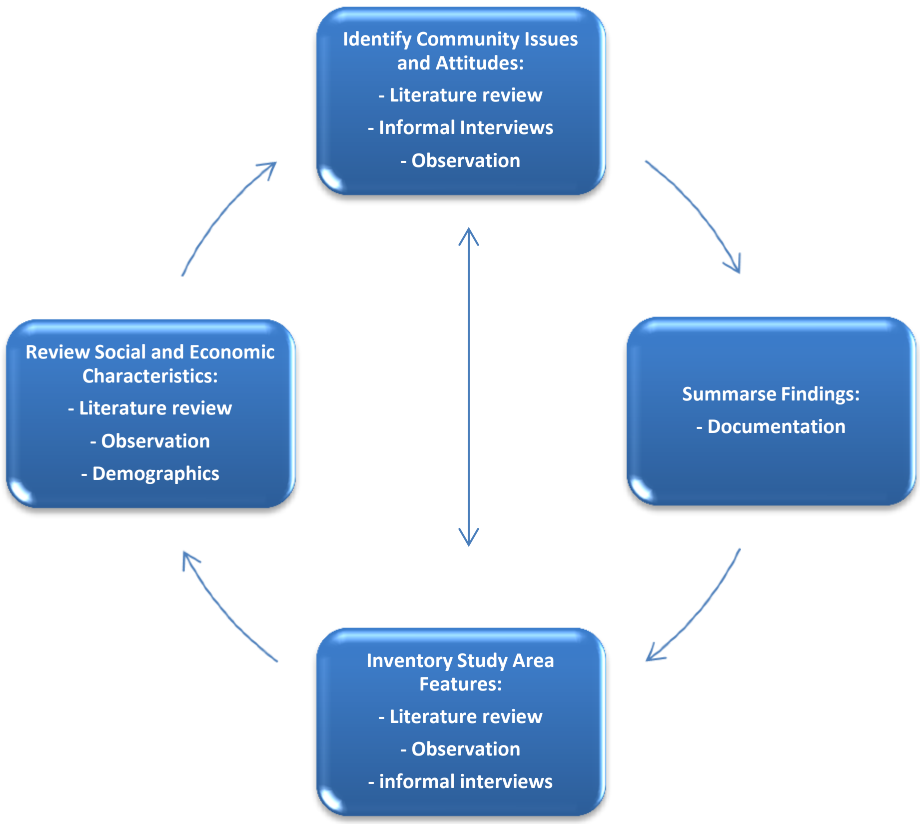


Figure 3-1: Dwesa Profiling Process

The above diagram shows steps taken to collect information for the community profile, with each step taken a number of methods are applied to complete the step. In identifying issues that affect the community and their attitudes, literature review is used as the primary method; a baseline study which was recently undertaken highlights community attitudes about the ICTs brought forth by SLL. Conducting informal interviews with some knowledgeable members of the community, observations conducted through immersing ourselves into the community during visits done in a monthly basis staying one week in about 2 months and constant communication with the project champions. Project champions are members of the community; teachers in the schools that are hosting the network equipment.

The social and economic status of the community reviews are conducted through literature reviews on the already existing study materials, observation and demographic information and creating or representation of trends within this community. Information is collected from the department of Social Development and Treasury Department. A study of the area features is also conducted through literature review, observation and informal interviews with random community members..

3.9 Desktop Analysis

This is the necessary analysis applied to the physical depiction or a map of the target area, where the aim is to set up a virtual network over the map. This network analysis is performed to develop a network topology or a diagram that mimics the actual proposed network on the ground, by feeding the analysis software the exact details and it then provides facts about the network. A network analysis tool called Radio Mobile was used in this project. This technology requires information about the proposed location of the base station and user equipment, type of channel used, amount of bandwidth to be used and a map of the desired area. Radio Mobile will then produce a schematic representation of the network indicating connections that are possible and ones that are not possible. It then becomes easier for network designers to make necessary adjustments to the values so as to ensure connectivity.

3.10 Metrics

These are the factors that are used to determine best suitable technologies for deployment in rural communities. These metrics discussed below reflect matters that are important to rural communities. Hence are to be considered when seeking deployment of access technologies in rural communities due to the areas nature and/or characteristics.

Metrics selected here are based challenges faced by rural communities, where implementation of ICT will provide an opportunity to eliminate or limit these challenges. Motala (2012) highlighted that some of the major challenges faced by rural communities are lack of, to minimal permanent employment, saying that most residents in rural communities depend on seasonal employment. Motala (2012) depicts the following as challenges as well; lack of housing, limited access to water and sanitary, alcohol and drug abuse and lack of family units.

According to Gopaul (2006) South African rural communities are some of the most impoverished societies worldwide, with limited access to employment, education, land, housing, and health services. Gopaul (2006) highlights that another persistent challenge is that of rural communities that are underdeveloped and less populated, with human settlements of numbers usually less than 10 000 persons (Avila *et al*, 2005). Avila *et al* (2005) argues that rural communities they are also dominated by forests, mountains and/or deserts and that are diverse economically. Labour from these communities usually is cheap due to the fact that gainful employment options are limited (Avila *et al*, 2005). Residents from these communities lack or have limited access to adequate basic social services caused by their low national priority status and they lack political voice, especially the poor (Avila *et al*, 2005).

Nel *et al, (*2000) highlights that some of the constraints are these communities are spatially isolated, with poor support and physical resources such as roads, etc. and infrastructure, residents lack skills capital, machinery and buying power. Rural communities primary source of income are largely from government grants and from urban areas; remittances provided by migrated family members residing in urban areas (Nel *et al*, 2000).

It has been established that some of these metrics may not necessarily be considered or paid much attention to, when seeking deployment of these access technologies in non-rural, urban communities. That may be due to the fact that these communities are expected to entail favourable conditions for deployment of such technologies; hence other factors consideration becomes more significant than others. These metrics are individually discussed below elaborating what each metric mean for this research and they include technical feasibility, physical feasibility, socio-economic feasibility, functional feasibility and a desktop analysis.

3.10.1 Technical Feasibility

Technical feasibility in our case refers to the ability or simplicity of the technologies to be deployed. It is very important also to determine what other challenges may arise during deployment of a selected technology. It is in the research's best interest to continuously investigate whether the technology will maintain carrying out the project's sub-objective of deploying a functional network. It is also very important to look at the projects manpower capacity to carry out the deployment of the technology, their level of technical skill required to carry out the deployment to its final stages and the necessary complementary equipment/machinery required other than the technology itself. These are requirements that are not necessarily communications related or even possessed by the technology, but are requirements that are very crucial to consider before the actual deployment commences. Though they are not communication technology capabilities, but they are necessary in other cases to implement a network successfully. These include the amount of electricity require to keep the network equipment up, the amount of electricity already available (in volts) in the proposed hosting centre. The amount of electricity in this case refers to the electric voltage already available at the hosting centre. These may also include height enhancing infrastructure for the base station and/or user equipment such as a mast. All of the above mentioned requirements are important to consider and are what, in this research referred to technical feasibility. These factors may not always be necessary to double check and assure pre-existence in urban communities, due to the fact that they are or may already be part of such community's basic life possession. The capabilities offered by the technology remain the core of the technology's technical feasibility hence initially theoretical review discusses these in detail.

Aspects included in this metric are:

- ✓ complementary machinery and/or equipment – these include height extenders: mast and they are important due to a fact that every so often a radio antenna requires to be lifted higher a significant height above the ground to achieve better coverage. This is done to avoid obstructing structure in the signal path most in LOS connections (Bhagwat, *et al, 2004*: Siriginidi, 2005). These are important to plan for as the cost of mast depending in its height may exceed the cost of the deployed technology (eg. In case of Wi-fi deployment) (Bhagwat, *et al, 2004*: Siriginidi, 2005)
- ✓ electricity- during network planning it is important to consider require amount of power for rural deployments, as it may be that extra effort are taken to provide for power consumption required by the network equipment and PC with the planned lab (Bhagwat, *et al, 2004*: Siriginidi, 2005).

At this stage the theoretical review has been already conducted, hence technical review by deploying a selected technology and converge it to the already existing fixed WiMAX network is also necessary. The following section discusses another metric considered; physical feasibility.

3.10.2 Physical Feasibility

This sub section provides discussion of what Physical feasibility in our case means and what features are considered important to watch when deciding on wireless network infrastructure to implement. Physical feasibility in our case means the ability of the target area's physical features, characteristics and weather conditions, to host both the networking and complimenting infrastructure. At this stage the inspection of the test bed is conducted by looking at the area on which deployment will be implemented. Areal map indicating the geographical setting of the community will be used. These photographs assist in determining areas that are uneven, with hills, trees, rivers and valleys, which are crucial to consider due to the fact that hills may pose challenges. The challenges may include obstructing desired areas for subscriber station or base station locations, communities that are situated behind hills or at deeper area near valleys, making it difficult to reach, very strong weathers such as blowing winds and heavy rains that may affect the effectiveness of the infrastructure in a long run. The constant rainy weathers are also a disadvantage due to the fact that water degrades the strength of the radio signal. The next section discusses how socio-economic status of the target community if important to consider for choice technology to be deployed.

Aspects included in this metric (Physical feature):

- ✓ Terrain and topology – the terrain of the locality is crucial as it affects the transmission paths of the wireless signal: "terrain irregularities in rural environments reflect and diffract energy in a complicated way and have significant impact on the radio path loss" (Janaswamy, *et al 2000*)
- ✓ Weather conditions – climatic conditions such as rain, snow, fog and other precipitation forms are can significantly affect the radio waves propagation in the atmosphere: communications system may experience a loss of signal caused by the effects of rain on the radio link (Crane, 1996).

3.10.3 Socio-Economic Feasibility

This section social status of the target community (Dwesa) is covered, studying also their willingness to accommodate such technology infrastructure and the improvements that may be brought by this technology. Most crucial at this stage is studying closely their level of financial freedom, whether they can afford to buy and own gadgets that are necessary in order for them to make use of the deployed technology. Socio-economic feasibility also means the business opportunities furnished by the presence of the deployed technology, how the community will financially benefit from the services made possible by this technology or availability of the technology altogether. This information has recently been collected and documented from a research carried out within Siyakhula Living Lab. Therefore it will be collected for this research through literature review. The following sub-section illustrates on what is meant by functional sustainability in this research.

Aspects included in this metric:

6. IT skills – this are important because the deployment technology needs to be maintained on a regular basis, and encouragement of resident skills come to the fore in this regard, as suggested by Huggins and Izushi (2010). They also depict use of local skills as one of good practise from a rural dimension of ICT learning, as means of generating ownership of these ICTs within the community (Huggins and Izushi, 2010).
7. Level of economic activity – communities or an individual's economic activity is closely related to income per household that is closely intertwined with level of financial freedom within the community, which will assist in determining applications and services that the community may afford to pay for and hereafter may be deployed over the network. This is a critical issue to consider according to Bhagwat, *et al*, *2004)* as it may result to a loss making-venture.
8. National GDP/ investment in community development projects – these are important to consider as the deployment of broadband in communities hosting community development project, will prove valuable as it will increase GDP as depicted by Pearce and Pagano (2009).

9. Community demographics – community demographics may not have a direct relationship with deployment of ICT, however demographics are useful in determining relevant services that may be offered over a network (Bhagwat, *et al, 2004)*, by determining community needs and challenges.
10. Community IT readiness – community IT readiness refers to the status of the community readiness for implementing IT program. According to Edwards, *et al*, (2000) Community readiness consist of stages that vary from not being aware of the proposed program to professionalization and it is important to determine as it gives insight about community support and use of proposed ICT.

3.10.4 Functional Feasibility

Functional feasibility that is considered in this research is the actual availability of the network connection between network equipment and user equipment. In order for any network to be considered functional this connection should be established without any hustles. Functional feasibility also includes the moving of the data traffic from its source to its intended destination, thereby indicating communication between the involved networked computers. Functional feasibility also means caring to determine services that will be offered over the network. These functionalities will be determined by setting up means to test for the availability traffic movement between two networked computers. This may simply be proven by opening a web page to prove connectivity to the Internet. An investigation of services deployed within the network and those that will be made possible to deploy due to implementation of that technology and thereby sustaining its full functionality, will be done through review of literature.

Aspects included in this metric:

11. IT needs in the community – IT needs in the community refers to the application and services that the community needs to overcome some of or all of the community issues and according to Bhagwat, *et al, (2004)* these applications and services are part of five very important aspects to consider in the use of ICT for connecting rural communities.

The following section discusses the characteristics entailed by rural communities which will be used along with metrics to determine a technology's feasibility for rural network deployment.

3.11 Characteristics of Rural Areas in South Africa

Views on what comprises rural areas vary, the demarcation of where exactly "rural" ends and urban begins differs from one economy status to another. The South African Department of Human Settlements (2009) contributes that there is no a single universally accepted definition and that they have adopted the UN Habitat which views "urban and rural as a continuum of settlements and emphasises the linkages between urban areas and rural areas".
The Human Settlement Department (2009) claims that these linkages often take deferent or a collection of factors, such as flow of capital, labour and goods between these two types of areas: rural and urban.

Buxon as cited in JSDA, (2003) defines a rural area as an area "that lags behind in population per square mile, in education, a variety of experiences and finally, in power to control its own destiny, compared to more urban areas".

Rural areas are often those areas outside the city or urban boundary where populations or inhabitants are usually spatially dispersed. Usually such communities rely on agriculture as their main source of sustenance and as main economic activity providing job opportunities. These areas are also often affected by the limited socio-economic development leading to migration of, usually, young capacitated individuals to bright city lights leaving a remainder of aged, illiterate or under educated, very young and generally vulnerable population. Such household are frequently dependent on social grants, remittances from their relatives living in the cities and incomes not allowing much of financial freedom.

Many other rural communities in South Africa still have a high percentage of traditions dwellings which in some quarters are still preferred than modern dwelling such as RDP houses and more. Individuals residing in rural areas often come across very specific social, economic and ICT development issues. These communities compete with urban areas for scarce resources and their disseminated manner of dwellings requires an increase in development costs hence restrains the capacity to provide efficient and effective rural development.

Rural areas are also often politically marginalised, hereby causing limitations in opportunity for the poor to influence government policies and development priorities. In 2009 SA Human Settlement Department (2009, vol 5) estimated that approximately 70 % of South African poor live in rural areas, and also about 70% of the rural inhabitants are poor. 85% of them reside in the former homelands and the 15% shared amongst those who live in commercial farms and in the small towns (SA Human Settlement Department, 2009, vol 5). Their income is limited due to the fact that the rural economy is not adequately vibrant to make provisions such as well-paying jobs or even sufficient self-employment.

3.12 The Research Site Profile: Dwesa-Cwebe

Conducting a study of the research test bed before initiating any project requiring long term use of or development of community using Information and Communication Technology (ICT) is critically crucial for a sustainable project. Also it is important as it plays a role in determining and identifying relevant ICT programs and technologies that will support local development necessities or requirements (Pade *et al*, 2009).

With regards to this concept, when initiating an ICT project, Siyakhula Living Lab conducted a Baseline study from March 2008 to April 2009 period. This study, along with other relevant documentation, comprise of details about the status of Siyakhula Living Lab test site, the Dwesa-Cwebe region and about the initiation of the project itself. This section the comprise facts collected from these documents as well as other documents and observation, which are relevant for this research. In the baseline study the Mpume community situated within the region was then selected as a representative rural community for analysis purposes and the following sections discusses the nature or points of interests about the Dwesa community that are considered relevant to this research. As indicated in the above methodology, the initial step is to review the socio-economic characteristics of the area.

3.12.1 Dwesa-Cwebe Socio-economic Review

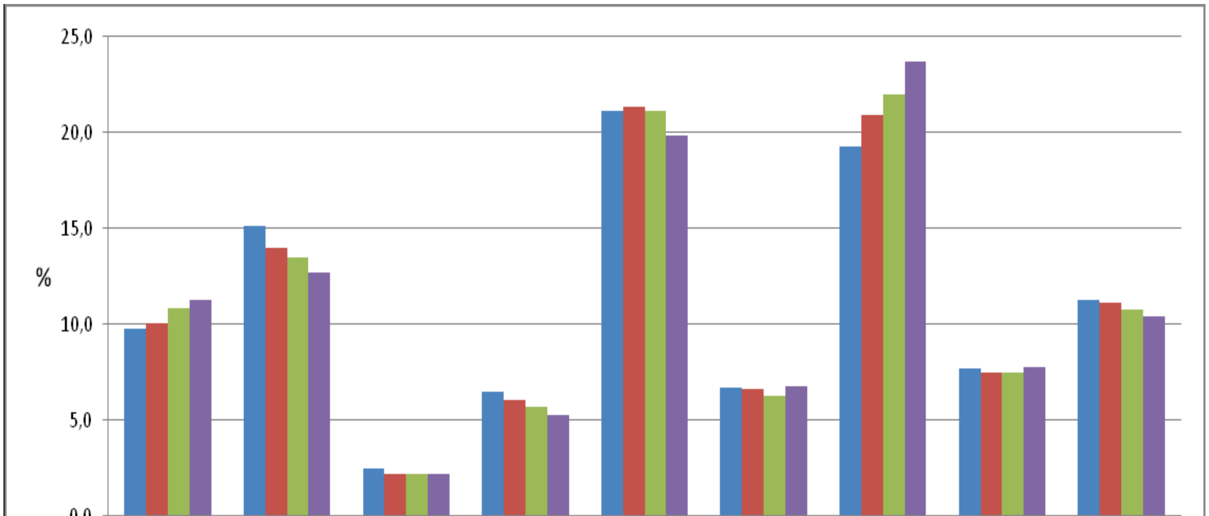
3.12.1.1 Geographical Orientation

The Dwesa-Cwebe villages are situated right next to, in the land side of, the Dwesa-Cwebe Nature and Marine reserve, which extends to about 6000 hectares of native forest, grassland and shoreline (baseline, 2009), in the former Transkei region in the Eastern Cape (Mandioma et al, 2006; Palmer et al, 2002). The area is in current land demarcation, under the jurisdiction of Mbashe local Municipality a sub-district of a bigger Amatole district Municipality. Dwesa is characterised by high hills separating community sections, with their houses behind these hills and some built exactly on the hills. The area lies between the indigenous Nqabara and Ntlonyana rivers with the famous Mbashe River intersecting and dividing the Dwesa area from the Cwebe side. Seven community sections make up the Dwesa region, namely Mpume, Nqabarha, Kunene, Ngoma, Bhadi, Mevane and Ntubeni.

These communities sections are characterised by an average distance of about 3 kilo metres as the crow flies, distance between each other, making it a longer distance on the road, which community members walk on frequent occasions. According to local residents, climate conditions in Dwesa change frequently and drastically sometimes. The area demonstrates with its always green vegetation, the frequency of rainfall, even during dry seasons such as winter and autumn. The figures below show the uneven, hilly terrain of Dwesa, with the famous ancient Mbashe River intersecting and forming a border between Dwesa and Cwebe regions. Such a terrain as Dwesa's causes difficulty during implementation of telecommunications network. The following section then reviews population dynamics of this area, which is also an important fact to consider, as it is closely coupled/ closely tied with social and economic statuses of the community.

3.12.1.2 Population Overview: Eastern Cape and Dwesa

Current population status show that population the Eastern Cape Province is the third biggest population with 12,7% following Gauteng (23,7%) in the first position and KwaZulu Natal (19,8%) in the second position (statssa, 2011), from the table below:



	Western Cape	Eastern Cape	Northern Cape	Free State	KwaZulu Natal	North West	Gauteng	Mpumalanga	Limpopo
1996	9,7	15,1	2,5	6,5	21,1	6,7	19,3	7,7	11,3
2001	10,1	14,0	2,2	6,0	21,4	6,7	20,9	7,5	11,1
2007	10,9	13,5	2,2	5,7	21,2	6,3	22,0	7,5	10,8
2011	11,2	12,7	2,2	5,3	19,8	6,8	23,7	7,8	10,4

Figure 3-2: Population Statistics in South Africa

Demography in 2009 indicate that there were about 15 000 individuals in the Dwesa area, and an estimation of 200 households, separated amongst these seven communities (Matwayi, 2011). A household study conducted in 2008 indicated the gender imbalances that exist within the Wild Coast: women taking a bigger percentage than male figures; statistical imbalance of age groups among the residents, where you find mostly elderly people at about 65 years of age and teenagers and younger people (Pade *et al*, 2009). These facts already establish bases of social and economic concern about the community with the lack of or limitation in number of mid aged youth who are usually the most active participants in the country’s economy. The following section reviews the socio-economic statuses of the Dwesa community.

3.12.1.3 Economic Status

The middle aged generation in Dwesa shows that is the one that has been affected mostly by urbanisation, leaving their kids with their parents (kid's grandparents) until senior high school (Baseline, 2009). This generation is then, in other households in Dwesa serve as the family bread winners.

The majority of residents in Dwesa are underprivileged and they rely on grants and food package donations from the Government. Another significant group of people are sustenance farmers who depend primarily on farming (baseline study, 2009: Palmer et al., 2002).

From observation it was discovered as well that another minor group of residents' income is comprised of government workers such as teachers and nurses, although some of these come from different town in the Eastern Cape, they have immersed themselves into the Dwesa community. A very limited group have another source of income from their small businesses that range from local taxi business, car mechanics and retail shops or "spaza" shops as the community refers to them. Some of the families also rely on supplementary income such as those who are in the crafting business and those who receive some financial assistance from their family members in the big cities.

The Dwesa-Cwebe nature reserve situated along the coast; a tourists attraction that usually has its business solely during school holidays from tourists visits South Africa during that time (Matwayi, 2011), provides other means of income for a limited number of community members who work at the nature reserve. Moreover, the community is characterised by its limited infrastructure. The following section elaborates on these infrastructural constraints.

The Mbashe Annual Report (2010) indicates that the majority of this municipality's residents live in poverty line, with high percentages of unemployment rate. Most households are very underprivileged to such an extent that 96% of their income is less than R 1601 per. The above given value also comprises of 43 % of the population under the age of 15 who are not active participants in economy exchanges Stats SA Community Survey (2007) . The figure below depicts the income range of Mbashe community from a survey conducted by statssa in 2007:

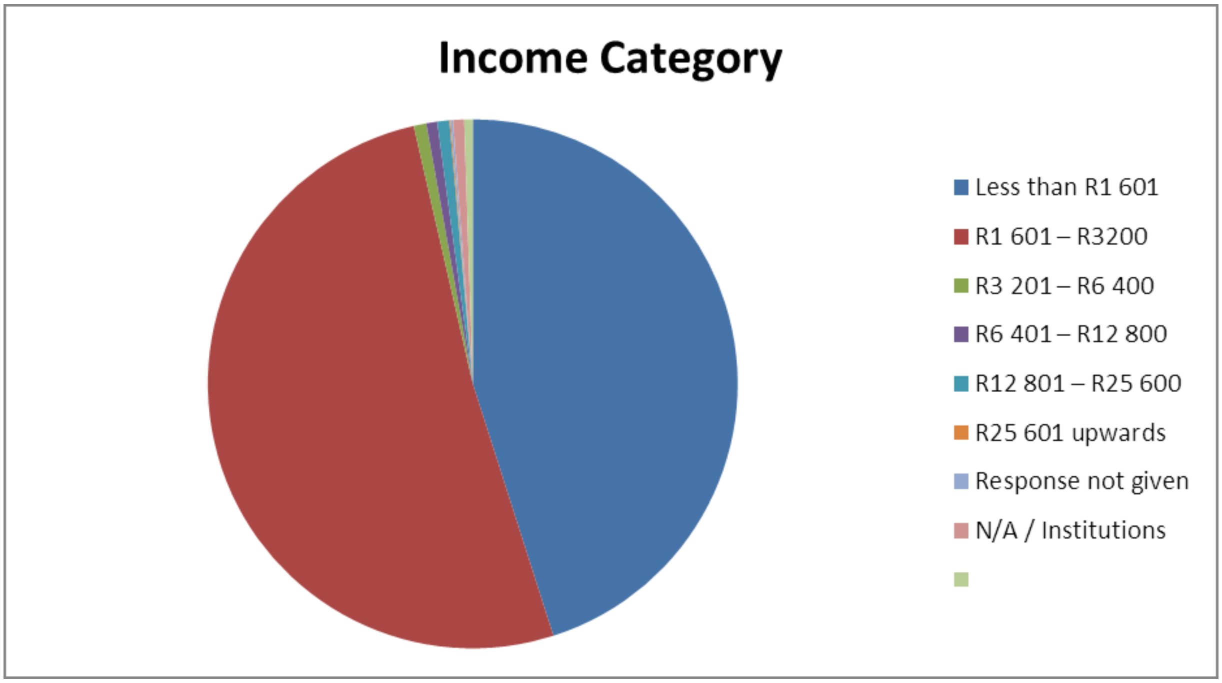


Figure 3-3:Stats SA Community Survey in 2007

While Pade (2009), from a study conducted in one of the Mbashe villages called Mpume that 88% of its residents are not employed. From the 88%, 42 indicated that they have given up in the job seeking quest and the 46 % is still searching for employment. This fact is encouraged by the issue of very limited job opportunities moreover amongst those that are available are informal jobs that pay an average income of R940 per month.

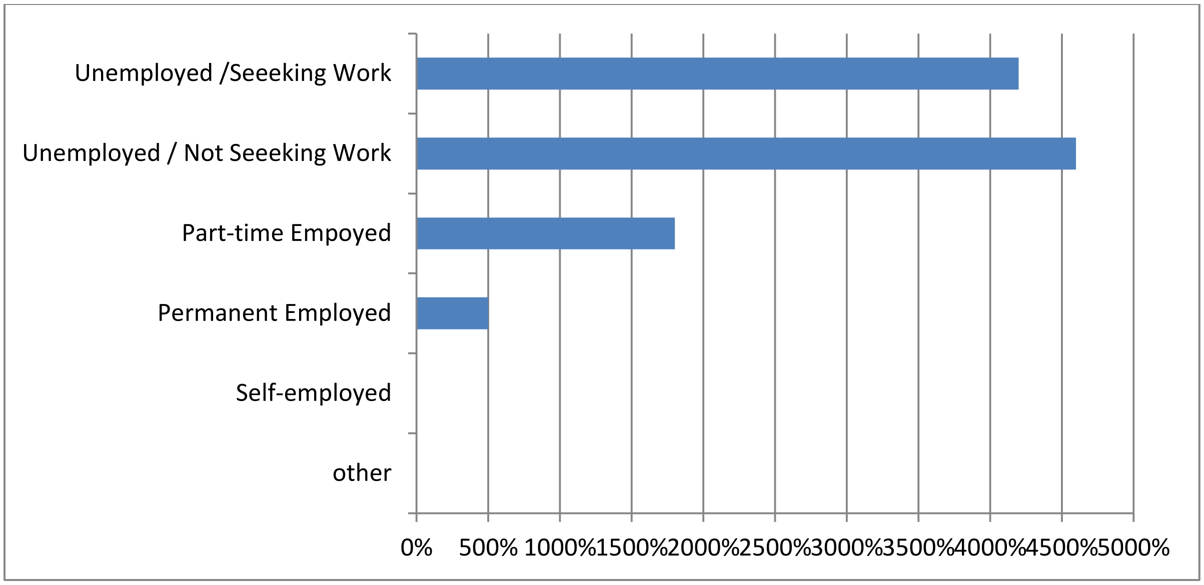


Figure 3-4: Employment status Reflected by Mpume Residents

3.12.2 Inventory Study: Area Features and Infrastructural Constraints in Dwesa

As could be expected for any other rural community, Dwesa does not consist of many community facilities. Currently as been stated before that the area is partitioned to 7 semi settlements, with each comprising of a primary school and all these areas depend on one high school in Nqabara. That concludes that there are 8 schools in total, from which & are primary schools and only ne high school to serve the area. There are only two health care facilities that are available in this area; a clinic in Mpume another one in Nqabara. The clinics offer services such as family planning, voluntary counselling (HIV/AIDS), treating minor illnesses, recently integrated infant delivery and chronic illnesses depending on the skill of available nurses. Some patients who require serious medical care are transferred to a hospital in Willovale, a journey that could take from 35 minutes to more than an hour depending on the conditions of their untarred road. This area has neither a library nor a public hall, the schools are utilised by the community when in need of a bigger shelter for their activities.

Similar to other rural communities, Dwesa have very limited infrastructure to support services provisioning to its community members. Services such as, the network of roads, leading to

Dwesa, from Willowvale and within the Dwesa community are all gravel and dusty roads (Ndlovu, 2011). These roads are maintained from time to time, but the fact still remains that they are, gravel, rocky not tarred roads and are dusty. From Dwesa, nearest administrative town is Willowvale, which is 52km away, and costing a drive that lasts an hour, on local transport services (Ndlovu, 2011). Transport system in this area is also a scarce resource, government hired bus transport service provider (Mayibuye Transport co-op) supported by local taxi businessmen with their bakkies and usually Hyundai vans (locally referred to as bhoka-bhoka) are the only transport providers in this area, excluding a very limited few with private transport.

According to Ndlovu (2011) the area had no electricity until early in 2009, where only certain villages had electricity. Recently in 2011, some areas such as Ngoma, Zwelidumile, Lurwayizo, etc. were also included into the electricity grid pursuing Eskom's rural electrification scheme's objective (Ndlovu, 2011). The schools clinics, locals shops and few homesteads were the only ones with electricity prior 2009, and these (except for the few homesteads) were considers the community centres and hence a business model was developed, for those who had no electricity to make use of it from the centres. The model allowed arrangements such as allowing people to go charge their phones for a specified small fee. However, since 2009 and extensively in 2011, improvement has been made and hence most households in Dwesa have electricity and only a few villages are not yet electrified. Unlike before, majority of households in Dwesa now owns at least one cell phone, ranging from low cost cellular to very affordable smart phones.

The community has also very few telephone lines with few public pay phones which are at this stage vandalised and not operational. Vodacom and MTN have deployed a GSM network in the community (Ndlovu, 2011), nevertheless, although the GPRS and EDGE technologies are available in the domain, their connectivity is highly unpredictable and scarce according to Ndlovu (et al, 2010). The lack of infrastructure in this domain, similarly to other rural communities also serves as a source of many socio-economic limitations experienced in the area, meaning that, provision of telecommunications and any other necessary infrastructure in the area entails a possibility of beyond just availability of infrastructure. It will furnish the opportunities made possible by the availability of such infrastructure to the dissimilar environments, the urban/non-rural environments.

3.12.3 Identify Community Issues and Attitudes

Community impact assessment that may be conducted in the future require a detailed understanding of the probably affected community, comprising of the community values, issues or attitudes applicable (Chapter 4,).

Community values are perceived as those morals/ ethics that are openly known and practised by the individuals constructing a group. These values may be expressed in written, spoke or in terms of rituals performed, communicating these to others. The Dwesa community like any other has expressed their own values and matters that are of concern to them.

Encouraged by their economic status, residents in this area performs a lot of sustenance farming, this is one of the most treasured rituals of this community. Through observation, it is clear that this considered a one of the community values, making use of their rich soils and feed their families in return. This is something that even the families considered as those whom can afford themselves still perform.

One of this community's value as expressed in their mother tongue is *Ubuntu (*humanity. This is one of the findings from a baseline study conducted in 2008, with its results concluded from interviews with different age groups within a representative community. This community has expressed the importance of staying with family, where some members of the community only seek employment close to home so as to pursue this goal. This has been the mostly expressed value from this community; from the group interviews that were conducted for the base study, all of these highlighted mostly the importance of being closer to family for moral support.

The Dwesa community has also expressed cohesion amongst residents as one of its values. This has become evident from several activities that the community has initiated and pursue throughout the year. These activities include crafting, which also serves as a source of income as they also sell their products. Other activities include traditional dancing groups, which are organised locally and supported by the church and cultivating. There is also an agricultural project called Siyazondla, where members grow crops besides the farming one grow independently in their own gardens.

There were also some issues that were expressed by this community members; these groups some common issues and some deferent. These issues include poor roads, the bridge they use to access each sub settlements is low and dangerous when it has rained, lack of a police station, lack of a community hall, limited medical services, limited transport means, transport is expensive, there are few local jobs, poor service delivery and crime. The youth in the community has also expressed the limitation in access of the computers in Mpume, due to the fact that they are located in the school stuff room.

Some of the issues expressed by this community may not be solved by provision of ICT's nonetheless their availability will make means of communication faster and provide other options for the community to deal with their issues.

This chapter defined methodology and methods used to complete this research, metrics that are used to declare technologies feasible are discussed along with rural characteristics in this research contexts have been defined. The following chapter is profiles wireless technologies through literature review.

This chapter has elaborated a number of pressing issues, such as the methods used to carry the entire research, the means used to select technologies and declare them feasible in rural communities, characterisation of rural communities in SA and profiling of the research test bed. Hence all this progress brings matters to the carrying out of the next session; profiling wireless technology.

4 CHAPTER 4: WIRELESS TECHNOLOGY PROFILING

Wireless technologies have been operational since the first century, in differential to what exists today of course, but they have been in the market and providing connectivity to ad hoc networks. To date they have grown not only in numbers but in capabilities as well as in production and dissemination (Mudit_Ratana, ND). For service providers, wireless technologies have proven a lucrative cost effective solution in many ways that one; they do not require right-or-way across a private or public property for service delivery to customers. Many businesses cannot receive broadband data services as there is no fiber optic running to their buildings (Ohrtman, 2001). Wireless technologies also are ideal for providing these services to rural and marginalized communities where running a fiber optic would be very expensive due to the fact that they are too far from industrial buildings or where the cables are mostly situated (Ohrtman, 2001).

This chapter (4) provides a comprehensive wireless communications technology guide/profile review, which is useful for variety of groups of users such as beginners in the network and telecom industry and professionals. Wireless communication refers to as a transfer of data over a distance without the use of enhanced electrical conductors or wires (Mudit_Ratana, ND). We have a higher class of wireless techs that are grouped according to their purpose, use and the kind on networks they build, the cellular network and data (communication) network technologies. Wireless communication technologies divided and subdivided into a series of groups according to their form/anatomy/phase/nature, capabilities, use and instance. Other instances of their categorizing is according to their nomadism; the categories are known as *fixed wireless technologies, mobile wireless technologies, portable wireless technologies and IR wireless technologies* (Kaustubh, 2011).

Fixed wireless technologies are usually wireless device/system operating in contained environments such as homes and offices, particularly the equipment connected to the internet via specialized modems (Kaustubh, 2011). Type of devices connected over these technologies usually source their power form main and not batteries like mobile devices do (Pong *et al,* 2003). These types of wireless technologies operate over a point-to-point signal transmission that occurs over a terrestrial microwave platform rather than through copper or fiber cables, they then do not require the use of satellite or local phone service (Pong *et al,* 2003). *Mobile wireless* *technologies* allow connection between devices or systems aboard motorized, moving vehicles such as automotive cell phones and personal communication services (Kaustubh, 2011). Another type are *portable wireless devices*, which refers to the operation of autonomous, battery powered wireless devices or those systems that operate outside the office, home or even vehicle, some of the example include handheld cell phones and PCS units (Kaustubh, 2011).

IR (infrared) wireless is the use of devices that convey data through IR radiation and these are employed in certain limited range communications and control system (Kaustubh, 2011). These technologies are all referred to as wireless technologies and the distinction between the types is not always significant, sometimes even ignored and just known as close-range and long-range wireless technologies. The distance factor in wireless technologies is further classified or allows further classification of these to what is known as wireless local area networks (WLAN), wireless (WPAN), wireless metropolitan area networks (WMAN) and wireless wide area networks (WWAN). Technologies from the previously mentioned groups are used to create these WLANs, WPANs, WMANs and WWANs.

Below is a review of technologies used to deploy the different types of networks and profiling of these technologies known by author and available to date. First the definition and limitation to what broadband means is established, then follows a discussion of wireless local area networks. Finally numerous wireless access technologies are reviewed and profiled beginning with Wi-fi, WiMAX, LTE, CDMA, HSPA, microwave links, GSM, GPRS, EDGE and UMTS.

4.1 Broadband

Broadband has initially has been introduced as merely the next step in technology advance in the Internet evolution. According to (Ream M., Beales A., 2003) of BCC in a report compiled, Broadband refers to a range of technologies that enables always-on, high speed access to the Internet and other electronic services (Pong *et al*, 2003; Abbasi,2009). While (OECD, 2007) describes broadband as typically a term used to refer to an Internet connection with a download speed that is faster than traditional dial-up connections (at 64 Kbit/s) (Kim, *et al*, 2009), while Bouvard and Kurtzman agrees to the notion also stating/highlighting the fact that traditional dial-up connections are limited to a maximum of 56kbps, they claim that most classify Internet connection speed of 100 kbps or higher as broadband (Abbasi, 2009).

While FCC states that broadband speeds may vary significantly, depending on a number of factors that may include, the type of service offered and level of service ordered, the range may be as low as 200 Kbps to 30 Mbps (Bhalla, 2010). Also some recent broadband speeds offering also include 50 to 100 Mbps. Broadband services for residential consumers usually allow faster download speeds than upload speeds (Bhalla, 2010). Broadband provides users with access to Information over the Internet with different types of high-speed technologies. The transmission of data over these technologies is digital, it therefore means that the information is transmitted as bits data, being it images, text, sound or video (Bhalla, 2010). Broadband provides its users with an advantage of services that are not convenient or available to use in dial-up Internet connections (Bhalla, 2010).

It is evident that several definitions of what broadband is exists, but there as well exists a common understanding that "broadband" offers high data rates and its' threshold speed is always greater that the speed offered by dial-up services. For this research purposes we will use Bouvard and Kurtzman threshold speed of 100 kilobytes per second. This speed threshold/value is sensible in this research when considering the fact that, the broadband access is considered for deployment in rural communities where Internet access and connectivity at large is at its infant stages. That then means Internet traffic will not necessarily be high, depending on the services provided, and it is safe to consider a technology offering a minimum speed equal or greater 100 kbps as broadband.

In the following session in this chapter, we then review all connectivity technologies available and known to author that are considered as broadband under the fore stipulated condition. These technologies will be reviewed specifically with an intention to find/propose technologies selected from the literature survey for further technical survey, looking at those that will further support Siyakhula Living Lab's objective and hence the objective of this research, which is provision of Internet connectivity and necessary broadband services in rural communities.

4.2 WLAN

In this new century, we have gone as far as a decade and yet it is more evident that wireless communications have become and are becoming the new popular standard for personal and business users where customers are leading the way towards this evolution. For a, to date rapidly growing number of users, wireless broadband devices such as tablets, laptops and smartphones have taken over their communications and essentially are changing the way people communicate with options advancing beyond voice and texting, but also include electronic mails (email), facebook, twitter and video (Motorola, 2011).

An eMarketer analyst Noah Elkin notes in iMediaConnecion.com that "at the end of 2009 there were about 40 million Smartphone users in the U.S. representing about 13 percent of the mobile market". Furthermore at the end of 2010, the numbers had grown to an approximately 60 million or 31 percent of users with mobile phones. Moreover it was expected that by the end of 2011 smartphones will account for more than half of mobile phones in use and also wireless systems are surely beginning to replace wired systems (Motorola, 2011).

The business world is reacting positively to the inception of these technologies, they are embracing the evolution of wire systems to a large extent. The benefits of these high-speed broadband WLAN technologies for the delivery of right information, to the right people, at the right time, in the right place are enormous (Motorola, 2011).

It is from these benefits that remote and rural communities should also take delight, hence the use of these technologies to connect these communities and bring them closer to the information circulation circles is a necessity. There exist a vast number of wireless technologies to date, particularly from which users/companies have an variety of choice to choose from, according to their needs. Below is a table reflecting most of facts to consider when choosing/ considering a wireless network solution:

Table 4-1: facts considered when choosing a wireless network

	1	2	3	4	5

Reliability	77%	19%	4%	0%	0%
Security	85%	11%	3%	1%	0%
Cost of Deployment	60%	35%	4%	1%	0%
On-going system management costs	48%	43%	6%	2%	1%
Speed throughput	44%	45%	9%	2%	0%
Ease of Deployment	35%	50%	10%	4%	1%
Reputation of Vendors	27%	53%	16%	3%	1%
Recommendation of Peers	17%	38%	28%	14%	3%

Note: 1 = Extremely Important, 5 = Not Important At All

These factors are considered to be the most important but are not limited to consider when seeking deploying wireless LAN.

4.2.1 WLAN Technical Overview

A WLAN usually uses one or more access points which are usually dedicated standalone hardware with powerful antenna that are connected via Ethernet cable to a router or feed to a wired network (Nghi *et al*,2000). WLANs make use of radio, microwave and infrared transmittance to broadcast data form a point of transmission to a receiver without a use of cables (Nghi *et al*,2000).

These WLANs can then be attached to a network that already exists such as the Internet or campus network (Nghi *et al*,2000). WLANs are composed of access points and nodes. Access points serve as transmitters and receivers amongst the nodes and or amongst the nodes and another network (Nghi *et al*,2000). Nodes are computers or any other network peripherals that are imbedded with a network adapter.

Different types of technologies/techniques are used to implement transmission of data in WLANs, these are: *Frequency Hoping Spread Spectrum* (FHSS), *Direct Sequence Spread Spectrum* (DSSS), *Time Hopping Spread Spectrum* (THSS) and *Hybrid* (FS/DS) *Spread Spectrum* (Nghi *et al,* 2000*; Kopp, 2005)*. These *Spread Spectrum Signal Communications* techniques are used for variety of application such as in cases where channels have power constraints, channels with severe levels of interference weather by other applications or self-interference due to data propagation to multiple paths and in channels with possible interception (Chen, 2012; ICE, 2012). These techniques includes features that corrects constraints such as the redundant codes to reduce and eliminate interference (anti-interference) and pseudo-randomness (anti-interception) that reduce and eliminate interception from jammers (Chen, 2012; ICE, 2012). Other advantageous capabilities include resistance to multi-path fading, frequency sharing, channel sharing, soft capacity, soft blocking and soft hand off (ICE, 2012). Also spread spectrum communications have disadvantages that include self-jamming, near-far problem and their implementation is more complex (ICE, 2012).

In Frequency Hoping Spread Spectrum, the carrier frequency shifts in discrete increments in a pattern generated by a code sequence. The shifts occur in different (fast-hop and slow-hop) manners: fast-hop is when frequency hops at a rate that is greater than the message bit rate, and slow-hop, which is when the hop rate is less than the message bit rate (ICE, 2012). Frequency hopping is shown on the diagram below.

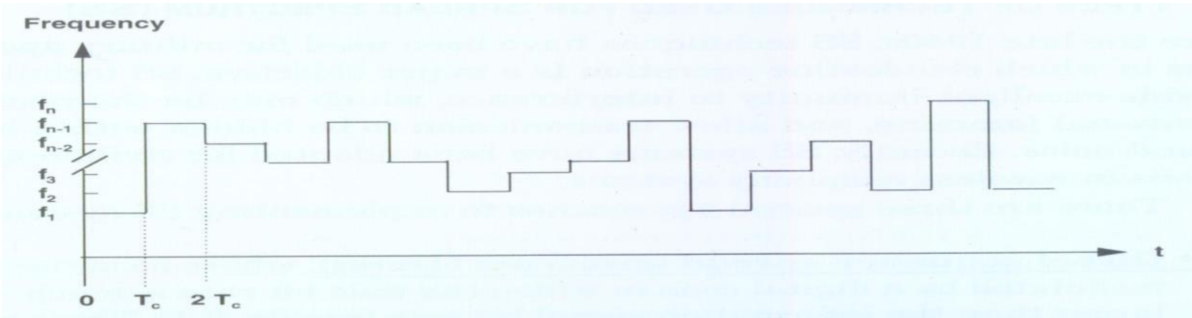


Figure 4-1: FHSS Time modulation

Frequency Hoppers (FH) are more sophisticated and considered as better family of spread spectrum techniques than systems using Direct Sequence, with however an expensive price tag. The central idea behind FH systems is to return the transmitter RF carrier frequency to a frequency value that is determined pseudo randomly. This mechanism then prevents eavesdropping in these systems such that unless the PN code is known, there is no way to determine where the next carrier wave is likely to pop up from (Kopp, 2005).

However Direct Sequence Spread Spectrum (DSSS) methods are most frequently used techniques and are easier to understand than FH systems. In DSSS, a carrier is modulated by a digital code in which the code bit rate is much larger than the information signal bit rate and such systems are also called pseudo-noise (PN) systems (ICE, 2012). A single bit time period in the PN code is called a chip and the bit rate of this code is called the chi rate (Kopp, 2005). Spread Spectrum systems using a unencrypted/ cryptographically insecure code remains vulnerable to eavesdroppers who can synchronize on to the signals should be able to eventually crack it and have access to the data (Kopp, 2005).

In Time Hopping Spread Spectrum systems the transmission time is further divided into intervals referred to as frames, which in turn each frame s also divided into time slots. In the course of each frame, exactly only one time slot is modulated with a message (ICE, 2012). Below is a diagram indicating a frame and time slots.

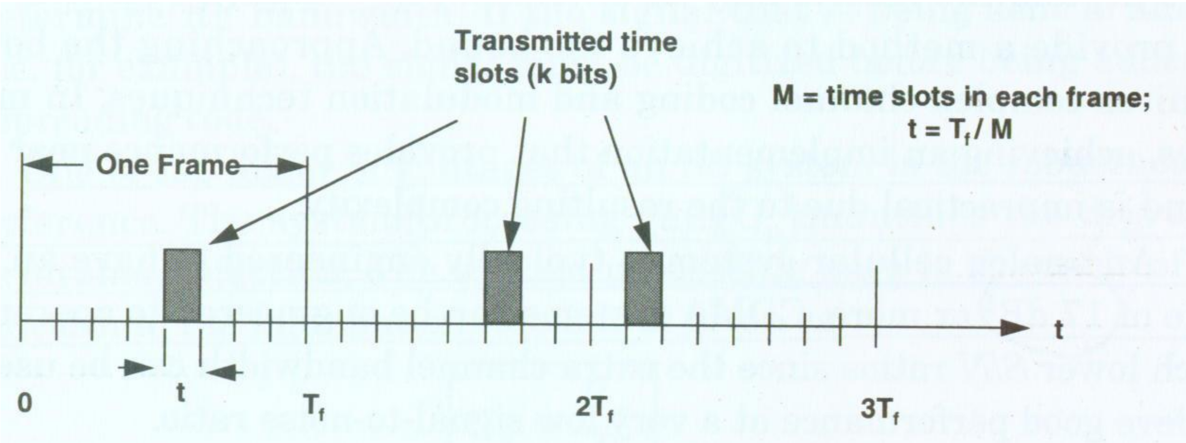


Figure 4-2: THSS time frame and slots

Other systems, usually, that prevention of eavesdroppers is high priority are referred to as Hybrid Spread Spectrum systems where commonly both FH and DS techniques are used. Such scheme typically employs frequency hopping of the carrier wave, while at the same time using a DS technique to modulate the data upon the carrier (Kopp, 2005). Such scheme, along with encryption of data streams before they are subjected to DS modulator, is usually used in JTIDS/Link 1 data link in military communications (Kopp, 2005). This section will then next discuss a particularized review of numerous wireless technologies used to create WLANs and broadband wireless technologies. List will be reviewed in the order stated and includes the following:

- ✓ Wifi
- ✓ WiMAX
- ✓ Microwave
- ✓ GPRS
- ✓ GSM
- ✓ LTE
- ✓ UMTS
- ✓ EDGE
- ✓ HSDPA
- ✓ LTE (4G)

4.3 Wi-fi

Wi-fi hotspots have played a major role by dramatically increasing productivity and convenience in Internet access provision from fixed broadband connections such as cable, Digital Subscriber Line and many other (Abbasi, 2009). Market reviews expect venue growth of Wi-fi hotspots to reach over 11 billion by year 2014. 2 billion connects were expected by the end of 2010 and by 2012 handheld devices would be used to access Wi-fi networks half the time (Lehr, 2003).

Abbasi Quratulian in 2009 said that more than 223 million homes had Wi-fi connections around the world, and there were over 127 million hotspots (Abbasi, 2009). He said that adoption of Wi-fi was accelerated by its integration into over 97% of notebooks and many other handheld devices (Abbasi, 2009).

Wi-fi an acronym for Wireless Fidelity is the popular name for the Ethernet 802.11x standard for WLANs. Over the years IEEE approved a succession of Ethernet standards to support higher capacity LANs over a diverse array of media. The 802.11x Ethernet standards are specifically for wireless LANs (Lehr, 2003) and have been modified over the years with the letter at the end (a, b, g, n, e) representing modifications made by the IEEE forum.

Wi-fi operates using an unlicensed spectrum in the 2.4 GHz frequency band and it supports up to 11 Mbps data rate at a limited radius of 100m from the access point (Bhalla, 2010). Flickenger (2001) states although the standard is originally defined for home and office use that usually are well covered by the 100m radius, with use of special antennas extended radius can be achieved outdoors, up to a maximum range of approximately 15 km in line of sight (Flickenger, 2001).

The 802.11x family was developed by modifying the standard over the years and representing the modifications with the letter at the end (a, b, n, g, e). The modifications include the unlicensed frequency band that the technology uses a channel for communication. The 802.11x family includes The 802.11a which offers the highest data rate of up to 54 Mbps in the 5 GHz unlicensed frequency band, the 802.11b which operates at 5GHz Mbps unlicensed frequency band, The 802.11g the most popular standard to date which is expected to offer from 22-54 Mbps in the 2.4 GHz unlicensed band, the draft 802.11n which is a high throughput enhancement design and the 802.11e which support more in its family such as Quality-of-Service (QoS) mechanism to manage latency (Lehr, 2003). The QoS support is very important for voice telephony provision over the Wifi technology and security measures (Lehr, 2003). Due to the fact that Wi-fi operates in the unlicensed spectrum band, interference from other sources cannot be controlled or limited, and that results to the fact that services requiring QoS Such as VoIP, are possible but can be problematic outdoors.

Wifi is used to offer the last mile connection to a wired LAN and it is used to provide connectivity to wireless devices within that same network. Wifi can be deployed to form a wireless point-to-point network in a scattered settlements environment or can be implemented a part of a private network (Lehr, 2003). This technology allows mobility to end user devices moving at a low speed. Deploying wifi requires a use of over the counter equipment that are easy to install and its ‘plug and play’ equipment that does not require intense skills to configure.

The business model applied in Wi-fi networks is basically that of equipment makers who sell to their customers whom at the end of the day do not pay for the services provided by the equipment (Lehr, 2003). Typically, wifi end users are not charged directly when accessing the network, the services are usually provided at no cost for the closed community such as students in the university, employees at a certain company (Lehr, 2003).

One of the key characteristics of wifi is that it uses unlicensed shares spectrum. This has important implications for (1) cost of services; (2) quality of services (QoS) and congestion management; and (3) industry structure. Because wifi uses the unlicensed spectrum, wifi network deployment cuts down the cost of buying a spectrum license and hence avoid the rigid licensing rules that impede the license owners to innovate flexibly with respect to the technologies used, the services offered or even their mode of operation (Lehr, 2003). In this technology era where innovation is key, changing supply and demand dynamics, the lack of flexibility increases costs and reduces the efficiency of spectrum utilization (Lehr, 2003).

Wi-fi is a technology that has been optimized for very high speed broadband WLAN connectivity models and it uses OFDM and advances antenna innovations to accomplish high-broadband data rates and improved signal reception. It implements Multiple Input/Multiple Output (MIMO) in IEEE 802.11n to improve data rates and Wi-fi networks provide connection to the Internet by leveraging IP based technologies. This IP-based network approach of connecting to the Internet, the 802.11 standard including the certification of equipment by the Wi-fi Alliance furnishes then benefits to different stake holders in the network stack comprised of users, network service providers, network infrastructure and network management.

These benefits include:

- ✓ An open network doctrine where any Wi-fi enabled device certified is able to connect to the any Wi-fi network that supports the same certification profile, in that way improving today's business models for delivering mobile broadband services
- ✓ Vendor agreed upon certification profiles, alleviating intense production of certified Wi-fi devices and global economies of scale, thereby enabling competition between vendors and building of multi-vendor networks
- ✓ Wireless client and network equipment submitted to extensive interoperability and conformance testing, enabling an open and competitive multi-vendor network environment
- ✓ An all-IP based network infrastructure, enabling cost-effective deployments for operators and Internet services for users
- ✓ And a common user experience for wireless broadband services, which is a critical enabler in accomplishing rapid user adoption.

4.4 WiMAX

New wireless broadband technologies with high bandwidth capacities and that operates on high frequency band have been developed since 2004. These are referred to as 4th Generation cellular technologies and they will dramatically change the communications landscape, changing the way people interact with each other and how they access information (Becker *et al, 2009*). These 4th Generation technologies will not only cater for cellular phones, but also for many other new types of communication systems such as broadband wireless access systems, millimetre-wave LANs, intelligent transport systems and high altitude stratospheric platform station systems (Ohmori, *et al,* 2002). WiMAX is a high performance technology, considered as one of the 4th

Generation wireless technology solution which is based on the IEEE 802.16 standard (WiMAX Forrum, *2008*).

“WiMAX technology is a wireless metropolitan area network (WMAN) communications technology that is largely based on the wireless interface defined in the IEEE 802.16 standard”(Scarfone *el at*, 2010). WiMAX was originally an acronym for Worldwide Interoperable for Microwave Access that employs a proven OFDM-MIMO (multiple input multiple output) based solution (WiMAX Forrum, *2008*), however WiMAX in longer considered as an acronym (Scarfone *el at*, 2010). WiMAX is supported by an ecosystem consisting of more than 530 member companies forming a broad, open and innovative group known as the WiMAX Forum. WiMAX Forum is responsible for maintaining and updating the 802.16 WiMAX standards for any amendments and enhancements (WiMAX Forrum, *2008*) with last revision of the standard (IEEE 802.16 e) finished in December 2005 and it predecessor (802.16d) completed in 2004. There exist two versions of WiMAX to date: the mobile WiMAX (IEEE 802.16e 2005) and fixed WiMAX (IEEE 802.16d-2004). The name WiMAX was awarded to the 802.16 standard by the WiMAX Forum.

They describe WiMAX as “a standard based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL” (Scarfone *el at*, 2010).This Forum constitutes of more than 300 companies in the telecommunication industry also promotes conformity of the standard and manifests interoperability of WiMAX products that are produced by deferent vendors (Zakhla, *et al*, 2010). The WiMAX Forum has been working on a pursuit to globally secure spectrum for WiMAX deployments.

The mobile version of WiMAX was introduced so that the technology may support mobility amongst other things (Woollard, 2006).WiMAX addresses an array of lucrative business models with very much lower cost per bit when compared with a range of other technologies, thus makes it the suited option for connectivity to remote communities (WiMAX Forum, *2003*).

Over a count of 407 commercial WiMAX networks have been launched in over 133 countries by the end of year 2010 (Zakhla, *et al*, 2010). In the United States (US) Clearwire has deployed large WiMAX networks and already offer WiMAX services on different parts of the US such as Philadelphia, Chicago and Las Vegas with another operator known as Xanado also offer services in few but significant markets in the US (Zakhla, *et al*, 2010). Other high-tech companies and wireless service providers in deferent parts of the world are taking profound interest on WiMAX technology due to a number of reasons that include its cost advantage and its capability to provide last-mile connectivity to those parts of the world that were previously too expensive serve with wired technologies (Zakhla, *et al*, 2010). In Africa (South) MTN Group has signed a collaboration agreement with Intel for these companies to co-deploy WiMAX networks in Africa and in the Middle East (Balancingact, nd), and AirTel in 2008 announced a deployment of approximately 100 WiMAX base stations in Cameroon (Balancing-act-Africa, 2003). WiMAX addresses such above mentioned limitations and enables everything from basic high-speed access for homes to voice over IP services broadband Internet and cable television or video-on-demand, business connectivity and support for schools and government offices at large (Zakhla, *et al*, 2010). According to Sean Maloney, an Intel executive vice president and a general manager of the Intel Mobility Group, “WiMAX certified systems will provide the building blocks to connect the next five billion users to the Internet and truly usher in the broadband wireless revolution” (Zakhla, *et al*, 2010).

WiMAX caters for both fixed point to point, fixed point to fixed multi-point and fixed point to mobile multi-point and it also covers operating powers, modulation techniques to support mobility (Zakhla, *et al*, 2010). WiMAX covers a connectivity range of up to 30 miles (50 km) for the fixed point to point stations, with the mobile stations covering a range of 3 to 10 miles (5 to 15 km) depending on other factors such disturbances that may impede the connection. This WiMAX technology operates over a licensed and unlicensed spectrum with currently available solutions using the 2.3 GHz band, 2.5 GHz band and 3.5 GHz band (Motorola, 2007).

WiMAX adopts business models that are equally about innovative ways of cost management as well as are about driving revenue, paying special attention to these challenging economic environments. Its network architecture is simple and inherently cost-effective because of its flat, all IP architecture also with the possibility of further trimming costs. It is a protocol that enables for a more efficient use of bandwidth, avoiding interference and it is proposed to enable higher data rates over greater distances. This section looks at fixed and mobile WiMAX as connectivity technologies, reviewing their capabilities with interest to their abilities to connect rural and marginalised communities. As described by the IEEE 802.16 standards we will pay attention to the technical characteristics of WiMAX communication protocol for both fixed and mobile WiMAX.

4.4.1 WiMAX Fundamental Components

WiMAX network consists of five fundamental architectural components, these components may all be available on a specific network topology or one may be omitted depending on the type/purpose of a network. These five components include:

4.4.1.1 The Base Station (BS):

This is the node that connects the wireless subscriber stations and/ or devices together and logically to the operator network (Scarfone, 2010). It is facilitates communication to the network subscriber stations through use of infrastructure such as antenna, transceiver, etc, and controls all access to the operator network. BS are typically fixed and outdoor installations that may server as a backhaul to other networks (Scarfone, 2010), but also may be implemented on moving vehicles to provide access to nearer WiMAX enabled devices (Scarfone, 2010). BS are responsible for a number of functions that include: handling of interface (e.g. PHY, MAC, CS Scheduler) and processes as handover (horizontally: between two BS for mobility), power control and network entry; Quality of Service PEP for traffic via air interface; micro mobility hand over triggering for establishment of mobility tunnels; radio resource management update; mobility stations activity status update; supporting tunnelling protocol towards ASN Gateway EP; traffic classification; DHCP Proxy; key management, ie key generation and delivering to the BS/MS; session management and managing multicast group association (IGMP proxy) (Scarfone, 2010).

4.4.1.2 Subscriber Stations (SS):

SS are WiMAX connectivity devices that deployed in customer premises for connectivity to a WiMAX network through a WiMAX BS. These are fixed stations that may connect a single user to the network or multiple users playing an Access Point (AP) role for a local area network or wireless area network (Riegal, 2005).

4.4.1.3 Mobile Station (MS):

This is a subscriber station that has ability to be used or connect to the network while on the move at approximately vehicular speed (Scarfone, 2010). These are typically SS that are battery powered and therefore make use of improved mechanisms for managing power. Examples include smart phones, laptops embedded with WiMAX radios (Scarfone, 2010).

4.4.1.4 Relay Stations (RSs):

are typical in multi-hop network architectures or topologies and these are configured to forward traffic to other Relay Stations. These may be stationary in a fixed location or mobile be placed on a moving vehicle (Scarfone, 2010).

4.4.1.5 Operator Network:

consists of infrastructure network functions providing radio access and IP connectivity services to WiMAX networks subscribers being the SS and/or MS (Scarfone, 2010).

All these above mentioned components are arranged in different manners forming sections of WiMAX network architecture. There exists several architecture models that are also known as Network Reference Model (NRM) which may be adopted during deployment of a WiMAX network. These reference models are the arrangements of WiMAX network components and the user applications (or equipment) in a manner that allows, manages and controls communication over the network and over the Internet. These WiMAX network components are assigned to further grouping according to their functionality for networking purposes thereby allowing use of infrastructure from deferent vendors. Such grouping include the *mobile station* as described above, the *network access point (NAP)*, the *network service provider (NSP)* and *connectivity service network (CSN)* as described by Riegel (2005).

4.4.1.6 Network Access Provider (NAP):

comprises of the business entity which provides the access infrastructure to the Network Service Provider/s (NPSs). This is achieved by setting up a one or more Access Service Networks (ASN) (Riegel, 2005).

4.4.1.7 A Network Service Provider (NSP):

is a business entity which provides IP connectivity and WiMAX services to the network subscribers in compliant with the Service Level Agreement established with the target Network Access Providers (Riegel, 2005). There may also exist some roaming agreements between 2 or more Network Service Providers (Scarfone, 2010).

4.4.1.8 Connectivity Service Network (SCN):

SCN manages connectivity to the Internet, Access Service Network including other corporate networks to be joined to the newly deployed network. CSN component is also responsible for user equipment and services Authentication, Authorisation and Accounting (AAA). It controls and manages roaming between Network Services providers, manages IP address allocation based on PoA management, manages location, mobility and roaming between ASNs also included there is management of connectivity and transport amongst a number of ASN coverage zones (Riegel, 2005).

These groups of/components make up a WiMAX Network depending following a chosen reference model. The Network Reference Model (NRM) available will be discussed further during the overview of each version of WiMAX, fixed and mobile. Below is a discussion or overview each version of WiMAX in consideration to ICT4D contexts, looking also at architecture models of both fixed and mobile WiMAX versions:

4.4.2 Fixed WiMAX

The very first version of fixed WiMAX was developed in year 2001, the IEEE 802.16-2001 standard targeted mainly the last-mile wireless broadband access and it was approved in December same year. This very first version operated over the 10-66 GHz range of frequency providing connectivity only in line of sight (LOS) fixed point-to-point and point-to-multipoint communications at maximum data rate of approximately 70 Mbps (Scarfone, 2010).

Unfortunately implementation of this standard was limited due to its necessity to provide LOS type of communications and lack of availability to its required spectrum. In 2003 amendments were made to this standard (IEEE 802.16a) which provided interoperability, quality of standards (QoS), and performance of data, propagation of data signals from one active device to another ability and allowing non line of sight (NLOS) communications (Scarfone, 2010).

Later in 2004 the amendments and the standard were aggregated to form a new single standard IEEE 801.16-2004 which also improved interoperability and hence prior versions are no longer supported by product vendors. This new standard combined and comprised of all the amended functionalities and improved interoperability specifications. The IEEE 802.16-2004 standard supports communication in the 2-66 GHz frequency range for LOS communications and 2-11 GHz range for NLOS communications (Scarfone, 2010; Riegel, 2005).

At each frequency range a different modulation technique is employed to ensure communication between the network devices depending on their communication requirements and both point-to-point and point-to-multipoint network topologies are supported. Following is a diagram that shows both types of topologies:

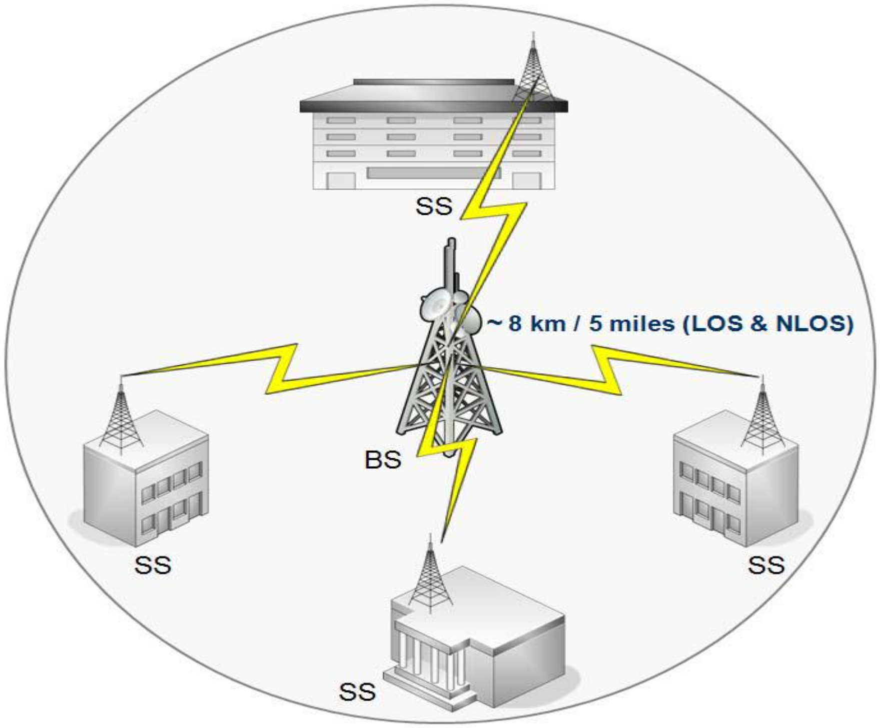


Figure 4-3 Point-to-Multipoint Topology

In point-to-multipoint (PMP) WiMAX network topologies a central Base Station (BS) supports a number of Subscriber Stations (SSs) by providing network connectivity from a single location to many locations usually used for last-mile broadband connectivity (Scarfone, 2010). Its other uses include connecting private enterprise to its offices located remotely to one another, long-range wireless backhaul services for multiple sites and fixed WIMAX can connect both LOS and NLOS of these topologies (Scarfone, 2010). Each PMP Base Station can offer a range of about 8 km maximum depending on its configurations and other factors such as served communality density.

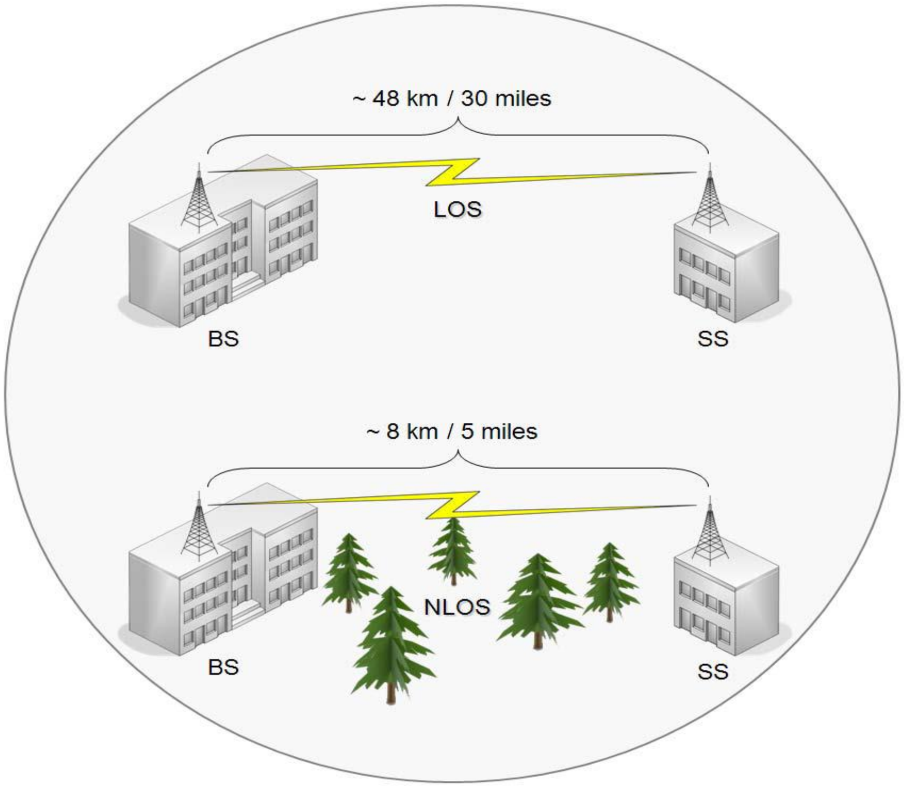


Figure 4-4: Point-to-point Topology in both LOS and NLOS Communications

A point-to-point (P2P) topology comprises of a dedicated link between a Base Station and a Subscriber Station (SS) as shown above. The BS will control the communications and necessary security parameters to establish a connection with its SS.

This type of communication is ideal for high-bandwidth wireless backhaul services with a maximum theoretical range of about 48 km when LOS is achieved and about 8km when in NLOS signal forwarding (Scarfone, 2010). The major difference between the two versions of WiMAX is that fixed WiMAX standard uses, for its physical layer, OFDM 256 technology. This technology allows a single channel for receiving and sending data, which means only a single transmission at a given time, unless additional supporting technology is implemented (Etemad, 2008). This in turn means that the technology is vulnerable to a number of anomalies and/ or attacks such as packet jamming.

Discussed below is a mobile variation of WiMAX, taking interest to its abilities for service provisioning in the marginalised and rural communities.

4.4.3 Mobile WiMAX

Mobile WiMAX is an advance from its preceding version fixed WiMAX, and there exists differences between Fixed WiMAX and Mobile WiMAX that are important to highlight. One of the differences is that the mobile WiMAX standard unlike fixed WiMAX allows multiple transmissions and multiple data exchange to co-exist over a single channel of communication at the same time. As a result mobile WiMAX technologies are not backwardly compatible with Fixed WiMAX (Etemad, 2008). Specifically Scalable OFDMA, a key signaling technique behind mobile WiMAX, supports scalable channel bandwidths from 1.25 to 20 MHz (WiMAX Forum, 2006) and is widely regarded as an enabling technology for future broadband wireless protocols that includes the 3GPP and 3GPP2 LTE standards (Altera, 207). It enables faster propagation through the communication media and therefore enhances bandwidth efficiency than its variant OFDM used in fixed version of WiMAX. This technique can be utilized for acceleration of mobile broadband wireless networks development with its capability of ensuring less fading and interference due to location and propagation problems.

The mobile version of WiMAX therefore provides mobility support for the subscriber stations and the above mentioned signalling technique that also provides the capability of providing new services such as Voice over the Internet Protocol (VoIP), multimedia broadcasting, etc. (Scarfone, 2010; Etemad, 2007).

Further enhancements made to the previous version include that of its QoS, which makes the 802.16e resilient against communications jitters and latency that result to extremely fast application response to user request, increased delivery reliability and scalable bandwidth (Scarfone, 2010; Etemad, 2007). New security measures are also introduced (Scarfone, 2010; Etemad, 2007).

Mobile WiMAX 802.16e limits its frequency range for mobile operations to 6 GHz or below and it enables a cellular like structure for its network architectures (Scarfone, 2010). Since the 802.16e standard support mobility which is not catered for in its predefined standard, this suggested that new processes for SSs management be devised. 802.16e- 2005 introduces dynamic roaming and other new methods for the management of communication handoffs between prospective base stations and subscriber stations (Scarfone, 2010). The IEEE 802.16 standards define two basics security services: authentication and confidentiality security. Authentication refers to the process where the identity claimed by the WiMAX device is verified and confidentiality then assures that the protected contents of WiMAX data is only viewed by the authorised device (Riegel, 2005). The mobile WiMAX systems provide scalability in both the radio access technology and the network architecture, therefore offering a great deal of flexibility in the range of network topology deployment options and services that could be offered within the deployed network (Sabhurati, 2008). Following are diagrams showing network topologies that are adopted by mobile WiMAX networks: the multi-hop relay and mobile topologies.

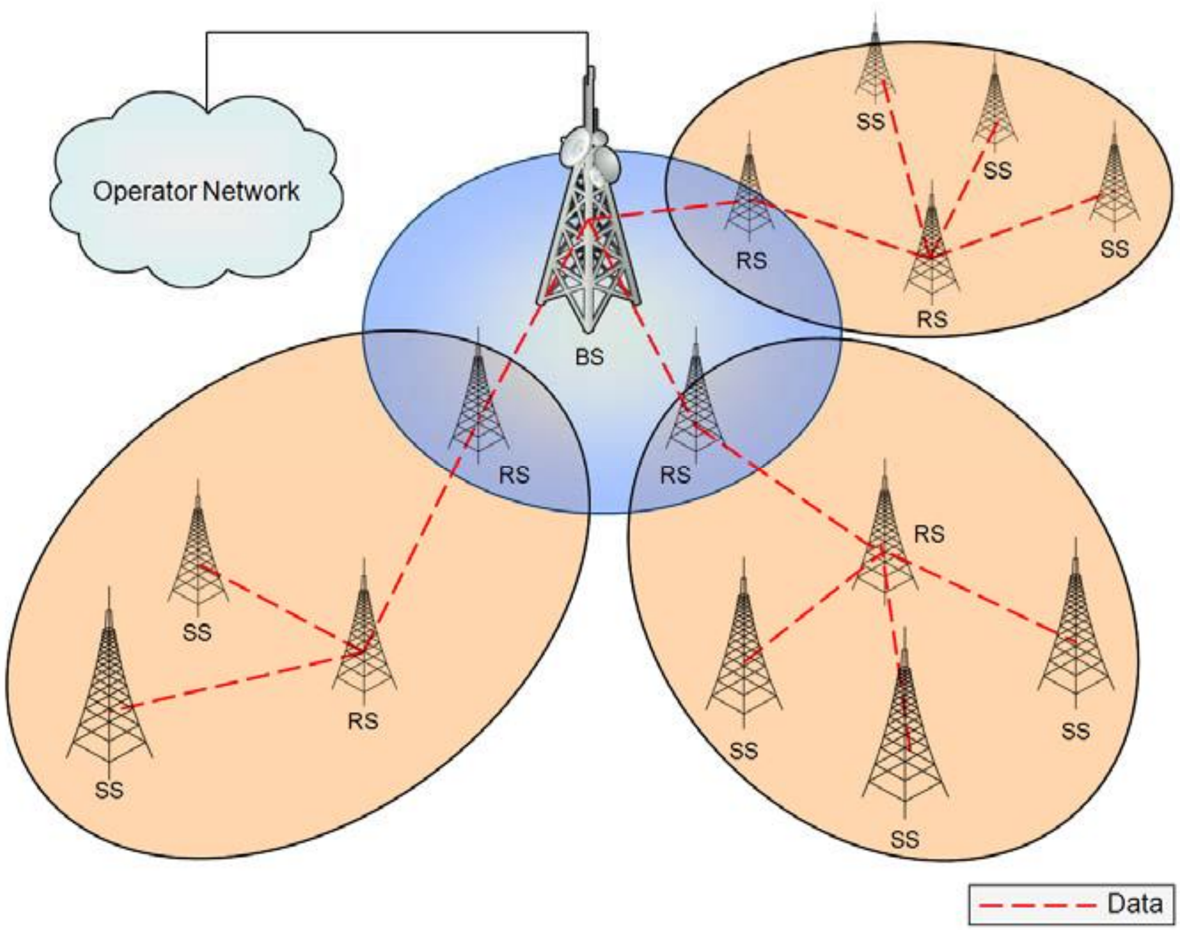


Figure 4-5: Multi-Hop

A multi-hop relay topology, which is defined in the IEEE 802.16-j 2009 version extends the network's coverage by allowing the subscriber stations or mobile stations to relay traffic, acting as a relay station (Scarfone, 2010). Data intended for a subscriber station or mobile station outside the BS's range is relayed through the use of adjacent Relay Stations (RS) and these can only relay traffic to other RSs/SSs that are within its security zone (Scarfone, 2010).

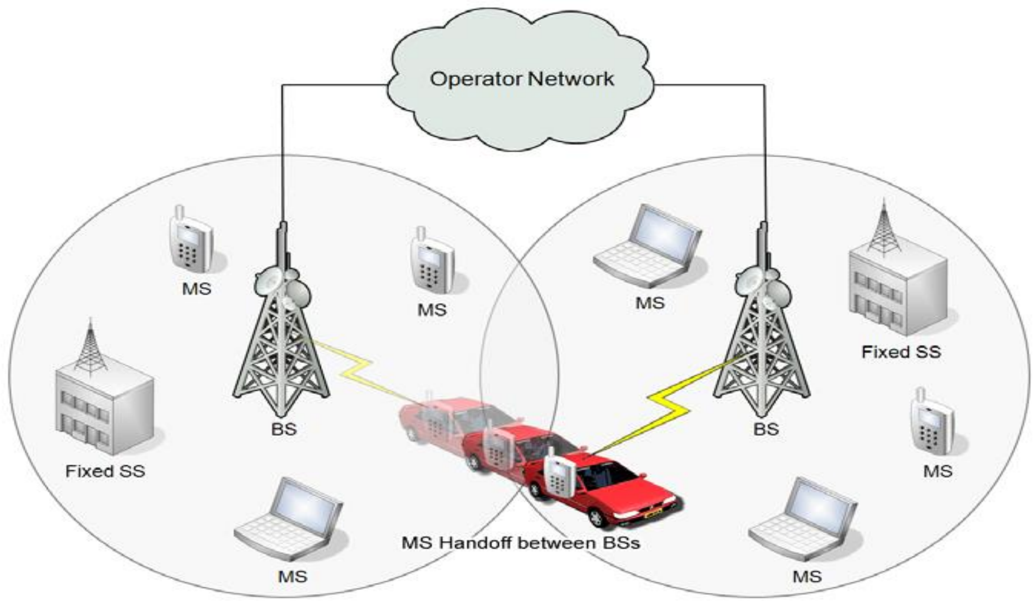


Figure 4-6: Mobile Topology .

A mobile topology is similar to a cellular network topology in such a way that numerous of Base Stations work in collaboration with each other in the quest to provide seamless communications to numerous client equipment, both mobile and nomadic (Scarfone, 2010). This topology then facilitates the major capability offered by the IEEE 802.16e standard, mobility, where measure to facilitate handoffs of mobile stations between different base station coverage areas, as shown above (Scarfone, 2010).

Some of the capabilities offered by mobile WiMAX that qualifies it to be reviewed for marginalised area deployments include its capability to offer *high data rates* which is supported or made possible by the use of MIMO antenna technique, sub-channelization schemes, Advanced

Coding and Modulation (Sabhurati, 2008). The MIMO antenna technique also enables mobile WiMAX technology to offer peak Down-Link rates of up to 63Mbps in each sector and peak Up-Link rates of up to 23 Mbps in each sector in a 10 MHz channel (Sabhurati, 2008).

Another one is *scalability*, where despite of increased globalization of economy, spectrum is still a desperate resource for allocation in wireless broadband worldwide. Mobile WiMAX therefore is designed to have the ability to scale and work in different numerous channels ranging from 1.25 to 20 MHz to abide by diverged worldwide requirements and efforts as efforts are continuously made to achieve spectrum harmonization in the longer term (Sabhurati, 2008).

The benefits also include the ability for diverse economies to realize the miscellaneous benefits of the mobile WiMAX technology for their specific geographic needs that could be providing access to rural settings versus enhancing mobile broadband access capacity in metro and suburban settings (Sabhurati, 2008).

To offer *mobility*, mobile WiMAX supports optimized handover schemes with latencies less than 50 milliseconds, ensuring high performance of real time applications such as VoIP execute without service degradation, with also flexible key management schemes assuring security during these handovers (Sabhurati, 2008).

All of these capabilities mentioned above have inevitable applicability for rural connectivity hence their consideration for deployment within SLL to improve the network services and offer cutting edge reliable connectivity to the internet. In the next session we are continuing with the WiMAX (broadband) technology reviews, looking next at LTE (Long Term Evolution).

4.5 LTE

Wireless telephony technology evolution can be distinctly categorised into various generations, based on the underlying technology's the level of maturity. The categorization into these various generations is standardised according to any generally known metrics or parameters and therefore does not constitute a strict demarcation (Sabhurati, 2008). Nevertheless, there exists a commonly agreed upon perspective, both by academia and industry and hence conceptualised as an unwritten standard (Sabhurati, 2008). The high level requirements for a 4G technology are identified as: high spectral efficiency; reduces cost per bit; increased service provisioning by lowering the cost and efficiency and experience; open interfaces as against closed technologies of the past; power consumption efficiency; scalable and flexible usage of frequency bands (Sabhurati, 2008). In accordance to these "unwritten standards", there are efforts taken towards the development of the next Generation, Fourth Generation (4G) wireless access technology (Sabhurati, 2008). WiMAX and Long Term Evolution (LTE) are both claimed to be the future of wireless broadband, the 4th Generation (4G), and these two technologies share a number of key characteristics, but there are differences in their respective implementation (Myung, 2009).

LTE is a brand name given to the efforts of 3GPP 4th Generation technology development, which are mostly in Europe and UMB (Ultra-Mobile Broadband) is the name for similar efforts by 3GPP2 in the North of America (Sabhurati, 2008; Myung, 2008). The 3GPP's LTE standard evolved from the High Speed Packet Access cellular (HSPA) standards with 3GPP comprising of several international standardization groups from several countries such as the US, Europe, Japan, South Korea and China (Abichar, 2010). The following diagram shows the evolution of LTE from HSPA to 3GPP developed by the 3GPP working group.

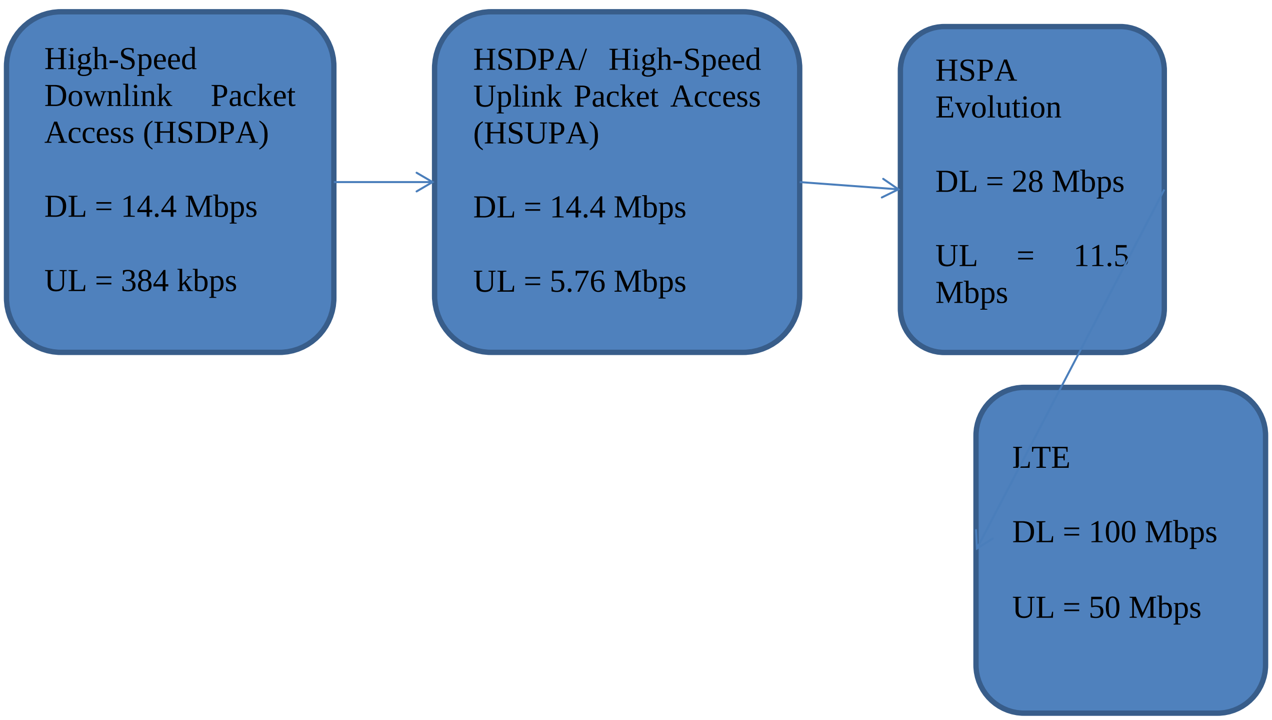


Figure 4-7: 3GPP's LTE evolution

LTE represents the next generation cellular phone technology that is intended to achieve high peak downlink and uplink data rate, low latency, scalable channel bandwidth from as low as 1.4 MHz moving up to 20 MHz in both uplink and downlink, co-existence with legacy standards while evolving to all-IP network and high radio efficiency in addition to low cost and sufficiently high mobility characteristics (Murayama, 2008). LTE data spectral efficiency is more than 2 times compared to that of WiMAX also LTE provides much more superior mobility service in terms of seamless handoffs, adaptive interference management and robust frequency re-use in comparison to mobile WiMAX (Sabhurati, 2008). That could be entitled by the fact that LTE was originally developed from its infant with mobility in mind while WiMAX in contrary was developed for fixed wireless access and its mobility aspect was developed and integrated later (Sabhurati, 2008; Myung, 2007). LTE mobility is supported for high speed (up to 500km/h) but optimized for lower speeds (from 0 to 15 km/h), increased coverage from 5 to 100 km and QoS allowing different class of services to be prioritised according to their class (Motorola, 2007).

LTE similarly to mobile WiMAX uses orthogonal frequency-division multiple access (OFDMA) in the downlink for traffic moving from the base station to the end user devices and uses a technique called Single-Carrier Frequency-Division Multiple Access (SCFDMA) (Becker, 2009; Motorola, 2007). Hence therefore this technique caters very well for mobile devices which are usually battery powered during the uplink transmission through a technique proposed by the 3GPP specifications with reduced peak-to-average-power ratio (PAPR) transmission scheme (Becker, 2009; Motorola, 2007). Hence maintaining highly efficient signal transmission becomes easier for the end user mobile device, making use of its power amplifier and power is saved without degrading system flexibility and system performance (Becker, 2009; Motorola, 2007).

LTE's evolution for cellular standards, its QoS based approach was natural and necessary, because fox an example a voice conversation over a network demands sufficient resource allocated to it. LTE uses reservation-based access meaning that time frames for reservation of resource for connection with each frame lasting a duration of 10 ms which are further subdivided into 10 sub frames of 1ms each (Becker, 2009; Motorola, 2007). It also uses what is known as switch-point concept, which indicates when the transmission will switch between the uplink and downlink. The switch point method is inspired by its cellular background because a cell phone conversation is likely to have an equal amount of traffic travelling between connected ends (Becker, 2009; Motorola, 2007).

4.6 CDMA

Code Division Multiple Access (CDMA) is a method used during radio wave propagation, to disseminate waves carrying data and header through the air channel.

Currently more that 84% of all reported cellular subscribers globally, make calls via radio access technology specified by the Third Generation Partnership Project. That fact means that WCDMA predominates in the 3G radio network technologies (Bergman *et al*, 2008). This technique is adopted by many technologies such as UMTS, WiMAX, and basis for LTE data transitions as well.

4.7 HSPA

High-Speed Packet Access evolution (HSPA), standardised by the 3GPP in release 7 and 8 of its WCDMA specification is a communications standard mainly developed to further improve the performance of WCDMA systems. The first step is an introduction of High Speed Downlink Packet Access (HSDPA) to improve performance of traffic moving downlink and secondly the uplink through introduction of Enhanced Uplink. When these technologies are combined they are known as HSPA (Bergman *et* al, 2008). These system improvements are made through providing high data bit rates of up to 14Mbits/s in the downlink (HSDPA) and up to 5.8 Mbit/s in the uplink (High Speed Uplink Packet Access (HSUPA)), lower latency, greater capacity of about five times more in the downlink and 2 times more in the uplink, improved support for VoIP and improved multicast/broadcast and advanced receivers (Bergman *et* al, 2008).

This inception of HSPA has given rise to a large increase in packet data traffic, meaning now that data has taken over as the main type of packets transported over the 3G networks. Much of these advances will benefit both the operators by furnishing higher performance and the users through providing improved end-user experience for accessing the web, file downloads and uploads, VoIP and live video streaming services (Bergman *et* al, 2008). This means that users will experience shorter download and upload periods, resulting from the higher bit-rates and cut down latency compared to that of WCDMA. Operators will benefit from the reduced production cost resulting from the higher system capacity, which then allow for more users to be serviced with higher bit rates at a cut down production cost (Bergman *et* al, 2008).

Later release (7) of the HSPD specifications introduces the following further advances of this technology (Bergman *et* al, 2008);

- ✓ *Higher-order modulation (HOM)*: digital modulation schemes are used for determining how bits are represented to the phase and amplitude of carried signals. Thus higher modulation order means higher peak data rate could be achieved for a given symbol rate. As advance to its predecessor release 7 introduces high order modulation which increase the data bit rate by using, 64QAM in the downlink increasing peak data bit rate by 50% for 14Mbps to 21 Mbps. In the uplink introducing 16QAM, which then doubles the peak data bit rate from 5.7Mbps to 11Mbps.

- ✓ *Multiple input, multiple output (MIMO)*: this technique also encourages increase in data bit rate by transmitting to a single user multiple transport blocks in parallel through multiple antennas. This is also often referred to as multiplexing.

- ✓ *Continuous Packet Connectivity (CPC)*: From an end-user's point of view, it is. The HSPA working group (3GPP) has made efforts in improving the dedicated connection for packet data user efficiency in its release. The products of the above mentioned efforts are referred to as *continuous packet connectivity (CPC)* and it comprise of two main features referred to as UE DTX/DRX (discontinued transmission from the user equipment) and HS-SCCH-less operations.

- ✓ *Layer-2 enhancements:* A new MAC protocol called MAC-ehs, is introduced. This protocol enables flexible radio link control (RLC) protocol data unit (PDU) sizes and partitioning of LRC PDUs. Additionally, multiplexing capabilities of the MAC layer have been amended, allowing RLC PDUs carrying the data from unlike radio access bearers to now be multiplexed into a single MAC-ehs PDU. This flexibility then improves uplink coverage and assists with the reduction of level-2 overhead and hence processing of packets.

- ✓ *Enhanced CELL_FACH:* HSPA is becoming a better alternative to or even a replace ADSL for connection of personal computers to the Internet. Hence change in traffic load and network characteristics. PCs run a series of applications that may run in the background without end-user interaction, such as keep-alive messages, software updates, and presence signaling. For efficient support of such traffic movement HSDPA CELL_FACH state has been activated and the uplink is improved through activation of E-DCH in CELL_FACH and hence user perception of performance is improved.

- ✓ *Advanced receivers:* receivers structures in UEs are improved continuously with product evolution and more complex features are added to HSPA, resulting to improved system performance and increased user data bit rate.

HSPA is also considered advantageous because it is an inherent part of WCDMA, where HSPA can provide mobility in a wide area network with no necessity of providing any additional spectrum or carriers. This means that just as currently WCDMA has the ability to provide simultaneously voice and data services to its users via the same carrier, the same is true for HSPA, therefore concluding that spectrum use is efficient (Bergman *et* al, 2008).

4.8 Microwave Links

Microwave has been around for a very long time, before the term wireless broadband evolved. Microwave offer point-to-point, line of sight (LOS) wireless communication method, with speed of up to 155 Mbps and a range of maximum of 5km. Single channel microwave are cost effective and simple to install and are favourable in mountainous or difficult terrain or areas with high population density where costs of installing cable is prohibitively high. However, these microwave links have a disadvantage of having a very limited data rate, consequentially they are no use for building networks that are for high capacity use. Microwave capacity can be improved by increasing the number of links installed, although deployment of supplementary links could push the price of overall network deployment to a point where it surpasses the price of a higher bandwidth technology. Microwave is ideal however for networks predicted for low capacity use, nevertheless it will inhibit significant capacity expansion and may result in loss of business for network providers in a long term (Kaustub, 2011). Microwave operates in long range of frequencies from 6 GHz to 86 GHz with today's majority of point-point links

4.9 GSM

The evolution of the modern telecommunication technologies available today dates back to the development of Global System Mobile Communications (GSM). GSM is a cellular network technology initially developed in the 2G technology era (Kaustub, 2011) with its then standard services offering voice and data very low data rates. GSM networks are circuit switched and both the TDMA (Time Division Multiple Access) and FDMA (frequency division Multiple Access) standards data to facilitate data transfer rates of up to 14.4kbps (Kaustub, 2011). GSM was initially deployed in Europe and it operates over 3 set of spectrum bands; 900 MHz, 1800 MHz and the 1900 MHz (Kaustub, 2011). Its advantages include facts such as; SSM networks have international wide coverage. Using SIM (Subscriber Identity Module) card in user access equipment provides the luxury of being able to switch from different handsets and enjoy quick and easy import of data such as contacts.

4.10 GPRS

General Packet Radio Service (GPRS) is a cellular technology, acting as an supplementary technology functioning as an overlay on GSM networks. GPRS technology facilitates higher data rates of up to 170 kbps and also facilitates transportation of larger data files over the GSM networks. GPRS is responsible for introduction of packet switching and IP to mobile networks (Kaustub, 2011), therefore it plays a role of being an interim step for GSM to fully function 3G services. GPRS technology allows simultaneous data and voice transmission over the network with its users benefiting from always-on internet connectivity, high speed delivery of emails even with large data attachments, surfing the net via WAP (Wireless Access Point) and access to their corporate LANs (Kaustub, 2011).

4.11 EDGE

Enhanced Data for Global Evolution (EDGE) is a 2.5G cellular technology that is perceived by other companies as an interim step taking the cellular society in the passage trail from GPRS and GSM to 3G just a step away. EDGE, like GPRS and GSM employs the blend of the two FDMA and TDMA techniques for multiple access however EDGE employs additionally a new modulation scheme known as 8-phase shift key (PSK), therefore enabling a more resourceful use of bandwidth resulting to data rates of up to 384 kbps (Coring, 2005;Communications Commission of Kenya, 2012).

4.12 UMTS

The Universal Mobile Telecommunications System (UMTS), as specified by the 3GPP's formal implementation by the ITU as a constituent of its IMT-2000 family Third Generation Mobile Communication standards in November 1999 (Richards, 2000). The MTS technology belongs into the 3G era of mobile communication systems and its primary goal is the delivery of multimedia services to its mobile users (Richards, 2000). This requires provision of significantly higher data rate, compared to those provided by 2G mobile communication technologies. In UMTS systems users have the benefit of data rates of up to 144 kbps in macro-cellular environment (satellite and rural outdoor), up to 384 in kbps in microcellular (urban outdoor) environments and up to 2Mbps in indoor or pico-cellular environments (Richards, 2000; UMTS World, 2012).

UMTS adopted the Wideband Code Division Multiple Access (WCDMA) to broadcast its radio transmissions (Cisco, 2012). The CDMA technology then encourages the availability of high throughput, real-time services, end-to-end quality of service, and transmits pictures, graphics, video communications and other multimedia communications including data to its mobile wireless network subscribers (Cisco, 2012).

UMTS have what is referred to as Virtual Home Environment (VHE) which is a model for allowing portability to personal service environment across network boundaries and between terminals (UMTS World, 2012). Although it uses a different air interface from that of 2G and 2.5

G GPRS and EDGE, core network elements have been slowly drifting towards the UMTS requirement with their introduction. Therefore basic UMTS Core Network architecture has its foundation on GSM with GPRS technology (UMTS World, 2012).

Conclusion

This chapter has collected data about wireless broadband technologies and profiled them successfully. The following chapter takes the information collected to the next step towards achieving the objectives of this research; implementing the relevant methodologies and coming up with the results.

5 CHAPTER 5: IMPLEMENTATION: A COMPARISON BETWEEN SELECTED TECHNOLOGIES

This section discusses the implementation phase of the research; first it determines the suitbiity of broadband technologies by mapping the technologies profiled previously in chapter 4 against the metrics in 3.9, rural characteristics in 3.10 and broadband delimiters discussed in 4.1. The aim is to find those technologies that comply the most to the given delimiters. Following after that is a comparison of the technologies that are declared feasible for rural communities from the above exercise, applying the method explained in section 3.5. Finally, comes a technical deployment of a selected technology. The section below shows the mapping of technologies for rural broadband selection:

5.1 Various Technologies Combined

In carrying out the method stated, the technologies are compared with each other. When comparing, the technology are selected randomly, there is no particular matrix used to select them. The comparison is carried out by tabulating the highlight capabilities in respect to rural community needs: which prioritise in range covered by a technology, bandwidth offered, speed and their uses. The following table below shows Jupiter Networks' synthesis of comparison between WiMAX and Wi-fi:

Table 5-1: table of profiled access technologies: determining rural broadband technologies.

Technology	Standard	Frequency	Data rate	Maximum range	Typical usage
WiMAX	IEEE 802.16 IEEE 802.16-2 IEEE 802.16e (mobile)	2.4, 2.5, 3.5 & 5.5 GHz	Base station up to 75Mbit/s in a 20MHz wide channel	max 30..50 km to next base station	voice, data, multimedia services

			User: 15Mbit/s max. 52kbit/s to 5Mbit/s typically		
HSDPA	3GPP	0.9/1.8/1,9 GHz	Base station: 8 to 10Mbit/s in a 5MHz wide channel User: 3.6Mbit/s max. 400 to 700kbit/s typically	max 30..50 km to next base station Depends on the number of users in a cell	Voice, data, multimedia services
GSM	ETSI SMG	0.9/1.8/1,9 GHz	13 Kbit/s for voice, 9.6 Kbit/s for data	max 30..50 km to next base station	Voice and data, WAP
GPRS	ETSI SMG	0.9/1.8/1,9 GHz	171 Kbit/s	max 30..50 km to next base station	Data services, WAP
EDGE	3GPP GERAN	0.9/1.8/1,9 GHz	384 Kbit/s	max 30..50 km to next base station	Data services, 3G systems

UMTS (WCDMA, TD-CDMA	3GPP	1.90..1.98, 2.01..2.025 2.11..2.17 GHz	144, 384 Kbit/s, 2 Mbit/s (max.)	Depends on the number of users in a cell	Voice, data, multimedia services
802.11a,b,g (Wi-fi)	IEEE	5.15, 2.4 GHz	11, 54 Mbit/s	100 m indoor 15 km with use of specialized antenna	WLAN

From the above table, various technology characteristics which are considered relevant for rural use are tabulated. Each character depicted serves to eliminate limitations posed by rurality characteristics, such as dispersed settlement with significant distances from one community to a neighbouring community. The data depicted above is the matched with the delimiters in following table and then highlights the relationship between them.

Table 5-2: Mapping of Wireless technologies to Delimiters

Technologies	**Rural Characteristics**	**Metrics**	**Broadband (100 Kbit/s)**
WiMAX	WiMAX shows that it has ability to cater for rural communities with its 50 km connectivity range: which will eliminate the limitation posed by the distances between and amongst such areas. Its high speed data transitions	As per expected from an ICT high level skill is required to carry out this technology deployment. Depending on the hosting building, but use of supplementary equipment is necessary, such as height extender/ mast. WiMAX has a disadvantage, like any radio	WiMAX offer speed of up to 75 Mbit/s which is greater than the threshold of 100 Kbit/s. Therefore it is a broadband technology.

	and multimedia capabilities at high speeds pose as proof of its readiness for future apps such as digital TV. It is a 4G technology and is license exempt.	technology; radio waves are degraded by water, which means rainy conditions are unfavorable.	
LTE	LTE literature has also provided satisfying theories about its ability to cater for rural communities with its even wider area coverage of 100 km per cell. Like WiMAX, LTE has QoS, which ensure reliable connection and services. It offers very high speed mobility, allowing the users the free to change location while connecting. It is a 4G technology optimized to efficient use of current and future apps and is it license exempt.	LTE has a power saving technique which switches power off when there is no data transition at that time. LTE deployment requires specialized technical skills and end user devices are not yet popular in South Africa. Their limited availability then means they are expensive to buy, cost more than most families' monthly income in rural areas.	LTE can reach up to 302 Mbit/s DL and 75 Mbit/s UL, while LTE Advanced offer speed of up to 1G/s DL and 300 Mbit/s UL, which are greater than the threshold of 100 Kbit/s. Hence it is a broadband technology.
Wi-fi	Wi-fi connectivity range of 100m max. is optimized for indoor use. Wi-fi is ideal for indoor	Wi-fi equipment is very affordable, costs a minimum of R400 and access point. End-user devices that are Wi-	Wi-fi offer speed of up to 54Mbit/s which is greater than the threshold of 100 Kbit/s. Therefore it is a

	office connections or to create hotspots around community centers. With help of specialized antenna its range can be extended to a max. of 15 km, which makes it usable for outdoor connectivity over a big distance. Wi-fi is ideal for last mile connection meaning it needs to be connected to a core network. No license required to operate.	fi enabled are not too expensive nowadays and Wi-fi has become a standard feature in ICTs. Wi-fi can also, like LTE and WiMAX allow efficient use of multimedia applications, but with significant jitters during live video streaming.	broadband technology.
GSM	GSM is a 2G cellular technology. It has been improved over the years with new techniques and developed with new capabilities.	GSM technologies network operators are available all over the globe, meaning GSM enabled user devices are not popular and very affordable to buy.	GSM offer speed of up to 14Kbit/s which is less than the threshold of 100 Kbit/s. Therefore it is not a broadband technology.
GPRS	GPRS is an overlay to GSM, enabling it ability to offer 3G services.	GPRS technology operators are the same as GSM. Due to the fact that is it not a standalone technology, it is overlaid to GSM for its 3G functionalities. Allows applications such as surfing the net, etc.	WiMAX offer speed of up to 170 Kbit/s which is greater than the threshold of 100 Kbit/s. therefore it qualifies to be a broadband technology.

EDGE	EDGE is a 2.5G cellular technology. Like GPRS is it a supplement to GSM. Some corporate companies see it as an interim step moving from GSM and GPRS to 3G.	EDGE is an advance from its bases, GSM and GPRS. It allows use of efficient bandwidth that its predecessors.	WiMAX offer speed of up to 384 Kbit/s which is greater than the threshold of 100 Kbit/s
UMTS	UMTS is a 3G technology, with its primary goal of enabling multimedia to its users.	UMTS is a mobile communication technology, meaning it is not limited to use on cellular phones only, but also on laptops via USB modems.	UMTS offer speed of up to 384 Kbit/s in microcellular environment which is greater than the threshold of 100 Kbit/s
Microwave Link	Microwave links offer a connectivity range of up to 5 km in line of sight point to point connections. They are idea for mountainous uneven terrains as an alternative to cabling.	Microwave is ideal for low capacity use networks.	Microwave offer speed of up to 155 Mbit/s which is greater than the threshold of 100 Kbit/s
HSPA	HSPA is a 3GPP effort, developed to benefit both end user experience and operator through reduced production costs.	HSPA enable multimedia services and has improved support of VoIP services.	WiMAX offer speed of up to 14 Mbit/s downlink and 5.8 Mbps uplink which is greater than the threshold of 100 Kbit/s

From the above table, the comparison and results produces have indicated a few points about the technologies. One of the interesting points is that cellular technologies such as GPRS, offer speeds that are higher than what is expected to be a broadband speed. That fact then raises a question: are they considered for deployment in rural communities, as broadband? Technologies that have made it to the final stage, and are declared feasible for rural broadband and from which the next step will be applied to are as follows: LTE, WiMAX, Wi-fi, Microwave, GPRS, EDGE and UMTS. From the given list the 3 most qualifying technologies in order of precedence are LTE, WiMAX and Wi-fi, because they offer the biggest range plus highest high data transmission rate. There are, of course other factors to consider when selecting a technology to deploy, such as the types of services that will be offered over the network any and more as explained in section 3.6. The section below then shows the process used to select a technology for deployment, from the 3 most qualifying technologies; first Wi-fi and WiMAX and later WiMAX and LTE.

5.2 WiMAX and Wi-fi

Table 5-1: WiMAX – Wi-fi comparison

	Wi-fi 802.11g	WiMAX 802.16-2004*	WiMAX 802.16e
Approximate maximum reach	100 metres	8km	50kms
Approximate maximum throughput	54 Mbps	75 Mbps (20 MHz band)	30 Mbps (10 MHz band)
Typical Frequency bands	2.4 GHz	2-11 GHz	2-6 GHz
Availability	Currently available	Currently available (not widely available	Currently available (not widely available
Applications	Wireless LAN	Fixed Wireless Broadband (eg- DSL	Mobile Wireless Broadband

These two technologies are to some extent incomparable, due to the fact that they have been optimized for dissimilar usage scenarios: Wi-fi has been optimized for very high speed wireless local area networks and WiMAX optimized for high speed wireless wide area networks (Motorola, 2007). The table above shows their capabilities in quantified manner, which highlight the difference of their usage models in distance deviation offered by these technologies. Combining these two technologies result in more complete broadband services suite. The following table shows Motorola (2007) and Intel's (2009) comparison of the two technologies:

Table 5-2: WiMAX – Wi-fi comparison

	Wi-fi (IEEE 802.11 a/g/n)	WiMAX (IEEE 802.16e-2005)
Market	Deployed in local coverage areas, such as public hotspots, homes, and businesses.	Deployed in wide coverage areas, including metropolitan areas for mobile broadband wire- less as well as rural or remote areas for last- mile connectivity and portable service.
	Products certified by the Wi-fi Alliance.	Products certified by the WiMAX Forum.
	Embedded in 97% of laptops and many handheld and Customer Equipment devices.	Customer Premise Equipment (CPE) and PC cards available today; embedded in laptops and handheld devices since 2008 in the US.
Characteristics	Provides fixed and portable solutions.	Provides fixed and portable solutions.

	Operates in unlicensed spectrum. Current solutions use the 2.4 and 5 GHz bands.	Operates in licensed spectrum. Current solutions use the 2.3, 2.5, and 3.5 GHz bands.
	Short range with up to 100 meters for a single access point. Recent developments of equipment allowing range 0f up to 15 km	Metropolitan area mobile coverage of up to 15 km. Longer range (up to 50 km) for fixed & lower-density deployments.
	OFDM air interface, as defined in IEEE 802.11a/g/n.	Scalable OFDMA air interface, as defined in IEEE 802.16e-2005
	Devices connect via a Wi-fi access point to the operator's IP network and to the Internet.	Devices connect via a base station to the operator's IP network and to the Internet.
	Implementing Multiple Input/Multiple Output (MIMO) in IEEE 802.11n to achieve higher data rates.	Certified WiMAX Release 1, Wave 2 clients support both MIMO and beam forming
	Uses WEP or WPA encryption, suffers from interference especially in metropolitan areas where there are many users.	Symmetrical bandwidth over numerous kilometres, with stronger encryption (TDES or AES) and usually less interference.
Options	Evolution to mesh networks in metropolitan areas.	Evolution to multi-hop relay to improve range and data

		rates
	Access points that include Wi-fi for access and WiMAX for network connectivity.	Leverages digital advances so that the entire base station can now be mounted on tower tops.
	Voice over Internet Protocol (VoIP) is supported with enhancements IEEE 802.11e, k, and r.	VoIP is supported by the extended real-time polling class of service.
	IEEE 802.11n high throughput will support digital home applications, such as Video over IP.	WiMAX provides high data (up to 63Mbps in Down-Link, up to 23 Mbps Up-Link in a 10 MHz channel) rates and QoS classes to support broadcast and multi-cast video.

Unlike Wi-fi, WiMAX technologies do not require a clear line of sight, nevertheless their signal is still affected by large obstruction, which may either disrupt the signal path or prevent communication altogether.

Both these standards: Wi-fi and WiMAX leverages similar technologies such OFDM and advanced antenna inventions in order to obtain high broadband data services hence improved signal reception (Motorola, 2007). These advantages extend to an endless list and they include the following(Motorola, 2007; Abbasi, 2009):

- ✓ "Best-Connected" model: where users connect to either technology (Wifi or WiMAX) depending a number of factors such as their location, coverage strength and Quality of Services requests.

- ✓ Interoperable clients and access points permit global roaming and multi-vendor competition.
- ✓ Integration of these technologies into devices is likely to reduce device subsidies and hence lower Cost per Gross Add (CPGA).
- ✓ Full range of services regardless of the user's location: home, office and even on the road and service providers could leverage both types of Spectrum; the unlicensed for LAN traffic and licensed for WAN.
- ✓ Common IP network and antenna components may be implemented, such as authentication servers, service platforms and access gateways therefore that assist in reducing the cost of amalgamated devices.
- ✓ The ability of further providing extended coverage and services cost-effectively grows in time and deployment expenditure is expected to continue decreasing steadily.
- ✓ And both of these technologies support VoIP services, nevertheless operations in unlicensed spectrum limit Quality of Services assertion.

The above compared technologies have indicated their similarities in technologies leveraged and dissimilarities in models they are optimised for; hence that brings us to the conclusion about their comparison. Considering the metrics stated of the rural communities, first and foremost, the distance in between the settlements, WiMAX would be the solution. This conclusion is best when considering also the fact that for Wi-fi to be the best option, it means households would have to be used as the DANs, providing access for community members within the range. This could in turn, cause a significant amount of inconvenience to the social stature of the community, along with other implications that include security, availability and the household owners developing a sense of single ownership over the network equipment. Alternatively implementing WiMAX for wider range provision would eliminate such challenges, as it will be deployed in a common community centre and provide connectivity for everyone within a range. Although the fact that at the end deployment of these two, integrated would extend the services offered within in the network, is not discarded at all. Therefore this drives to conclude that amalgamation of these technologies, instead of comparison against each other, for a fully-fledged network, catering for all type of devices is a sensible and better option. The above mentioned option means that implementation of such, would be through installation of Wi-fi equipment in the community centers, such as schools, clinics, shops etc. than in the users households, while

WiMAX provides connectivity to the backbone of the network. WiMAX and LTE comparison follows and a highlight of their capabilities with respect to the stated metrics.

5.3 WiMAX and LTE

Table 5-3: LTE-WiMAX comparison

Aspect	LTE	WiMAX
Access Technology (DL)	OFDMA	OFDMA
Access Technology (UL)	OFDMA	OFDMA
Capable Speeds	100 Mb/s DL 50 Mb/s UL	75 Mb/s 25 Mb/s
Channel BW	1.25 to 20 MHz	5 to 20 MHz
Spectral Efficiency	5 bits/sec/Hz	3.25 bits/sec/Hz
Time to market	2010	2008
Legacy	GSM/UMTS	WIFI

Table 5-4: WIMAX-LTE comparison

	LTE (3GPP R8)	LTE-Advanced (3GPP R10)	WiMAX 802.16e (R1.0	WiMAX 802.16m (R2.0)
Physical layer	DL:* OFDMA† UL :* SC-FDMA	DL: OFDMA UL : SC-FDMA	DL: OFDMA UL : OFDMA	DL: OFDMA UL : OFDMA
Duplex mode	FDD and TDD§	FDD and TDD	TDD	FDD and TDD
User mobility	217 mph (350 km/h)	217 mph (350 km/h)	37 to 74 mph (60 to 120 km/h)	217 mph (350 km/h)
Channel bandwidth	1.4, 3, 5, 10, 15, 20 MHz	1.25, 2.5, 5, 10, 15, and 20MHz	3.5, 5, 7, 8.75, 10 MHz	5, 10, 20, 40 MHz
Peak data rates	DL: 302 Mbps (4 × 4 antennae) UL : 75 Mbps (2 × 4) at 20 MHz FDD	DL: 1 Gbps UL : 300 Mbps	DL: 46 Mbps (2 × 2) UL : 4 Mbps (1 × 2) at 10 MHz TDD 3:1 (DL/UL ratio)	DL > 350 Mbps (4 × 4) UL > 200 Mbps (2 × 4) at 20 MHz FDD
Spectral efficiency	DL: 1.91 bps/Hz (2 × 2)	DL: 30 bps/Hz UL : 15 bps/Hz	DL: 1.91 bps/Hz (2 × 2)	DL > 2.6 bps/Hz (4 × 2)

	UL : 0.72 bps/Hz (1 × 2)		UL : 0.84 bps/Hz (1 × 2)	UL > 1.3 bps/Hz (2 × 4)
Latency	Link layer < 5 ms Handoff < 50 ms	Link layer < 5 ms Handoff < 50 ms	Link layer ~ 20 ms Handoff ~ 35 to 50 ms	Link layer < 10 ms Handoff < 30 ms
VoIP capacity	80 users per sector/ MHz (FDD)	>80 users per sector/ MHz (FDD)	20 users per sector/ MHz (TDD)	>30 users per sector/ MHz (TDD
*Downlink/uplink, †Orthogonal frequency-division multiple access, ‡Single-carrier frequency-division multiple access, §Frequency-division duplexing and time-division duplexing				

From the above tables, WiMAX and LTE comparison shows that the two technologies are more technically different, than in their capabilities; hence their comparison is more evident in their technicalities. As shown from the above table, LTE has a bit more advantages than WiMAX; LTE offers mobility up to a rate of 500 km/h theoretically, and WiMAX can only offer mobility rate of up to 350 km/h (Abichar et al, 2010). Also LTE has an advantage of accommodating more (80) users using VoIP services at the same time than WiMAX which offers a maximum of 20 to 30 users at the same time (Abichar et al, 2010). These LTE advantages are inspiring, nevertheless consideration of their necessity for this particular purpose had to be gravely measured and the outcome is that it is greatly disadvantaged by a number of factors such as:

- ✓ First and foremost the unavailability of Spectrum license to host LTE network on. This is a very important consideration given a fact that LTE operates on licensed spectrum, which its attainment is still currently an issue in Africa as a whole. Telecommunications companies are still competing for this scarce resource. Siyakhula Living Lab including industry and government partners are not yet in possession of this license, hence this serves as a detour to even further consider LTE for deployment.

- ✓ LTE is still at its infant phase, where telecommunication companies only have it trial bases, although it is gaining its popularity very fast, there are no user equipment available commercially yet in Southern Africa, that fact then also discourages its selection for deployment.
- ✓ Contrary, WiMAX is a sensible choice between these 2 due to the fact that Easttel, Siyakhula Living Lab industry partner holds a WIMAX license on 3.5 GHz frequency spectrum and microwave back haul within the 13 GHz and 23 GHz spectrum (Easttel, 2012), within which SLL has been given the opportunity to operate under.
- ✓ Moreover, Saab Grintek, another SLL's industry partner which offers a range of telecommunications services, that range from turnkey infrastructure, consulting, engineering, implementation and rollout, etc. has provided the whole infrastructure necessary to carry out the deployment to its final stage, including the end user devices (mobile wimax dongles) to make use of the deployed network.

It then becomes clear that considering these facts and more WiMAX is currently a sensible choice for further technical review. It is also advantageous due to the fact that WiMAX, just like LTE allows mobility even for users moving at high vehicular speed, offers a wide network coverage range, offers VoIP services and also opens up opportunity of a lot more services that could be provided in the target area. It may also be important to note the fact that high speed mobility offered by WiMAX is enough for a current situation, considering the fact that the roads in the area are not tarred, hence means that it is not possible for a vehicle to move at high speeds. The fastest moving vehicle could not exceed 80 km/h and this fact is well supported by the reality that it is a residential area therefore vehicles are not expected to be moving in high speeds, higher than 80km/h in South African residential areas. The following section then discusses the deployment process of the selected WiMAX technology.

5.4 WiMAX Deployment

This section narrates the process undertaken when deploying mobile WiMAX network and converge it into already functional fixed WiMAX network. WiMAX has been selected from the previous sections depictions and it has been decided that a mobile version (802.16e) of WiMAX will be deployed, to upgrade to SLL network and extend the capabilities available by including mobility. In carrying out this task it is divided into sub tasks: beginning with a desktop analysis, configuring a switch, customer premises equipment (CPE) and the Base Station (BS).

5.4.1 Previous Network Status

The Original Siyakhula Living Lab network consisted of 5 nodes situated in schools within the Dwesa community. The schools forming the original network are Mpume JSS, Mthokwane JSS, Nondobo JSS, Nqabarha SS and Ngwane JSP. The local loop access network consisted of a single broadband Island, within which the schools were interconnected and hence were able to shared resources. Each node consisted of the following equipment: a thin client computer lab running EduBuntu Linuxon the server and about 5 to 20 thin clients. The number of computers each lab received depended on the size of the room available and its security level and a community access point (CAP) providing connectivity to the core network (the WiMAX local loop network) for the clients. The CAP was FreeSDB router managing the LANs in each school, acting as a gateway for traffic, between them and the WiMAX local loop network.

In the initial setup the WiMAX micro base station was hosted at Ngwane and other four schools each had a CPE to allow connection to the micro base station and hence follow of traffic between the schools. A Telkom VSAT hosted at Mpume was then used to connected the WiMAX network to the Internet. This choice of setup was supported by historical reason; that Mpume was the first school to join the project and was a logic solution for the VSAT installation. Mpume hosted also the Access Concentrator (AC), to which all the traffic from other schools was sent, meaning these schools relied on Mpume for Internet connection. However Mpume relied on the base station at Ngwane in order to access local services house at other schools.

5.4.2 Performing a Desktop Analysis

A desktop analysis is a mechanism used to simulate network connections on a computer before any actually deployed on the ground. This exercise is essential for determining connections that are possible or not from a given point. For this research we used an application called Radio Mobile to perform this task. Radio mobile is available for free download online. In order to determine this desktop analysis was used to identify schools that are possible to connect when a base station is situated at Ngwane. With Radio mobile and Google Earth, a graphical representation of schools on a topographical map, based on the complete list of possible schools in the area and their GPS coordinates. The list of schools to be connected had to be limited to 10 school, due to limitations in funds available for deployment and the schools had to be within 20 km radius to Ngwane. The fact was so to gain assurance that the base station at Ngwane (mobile WiMAX) and the fixed base station at its new location, would be able to pair and also this area (Dwesa) was mountainous, therefor it was necessary to ensure that the schools were not on regions that are hidden behind the mountains’ shadow. The figure below shows a topographic map output showing possible connection from Ngwane:

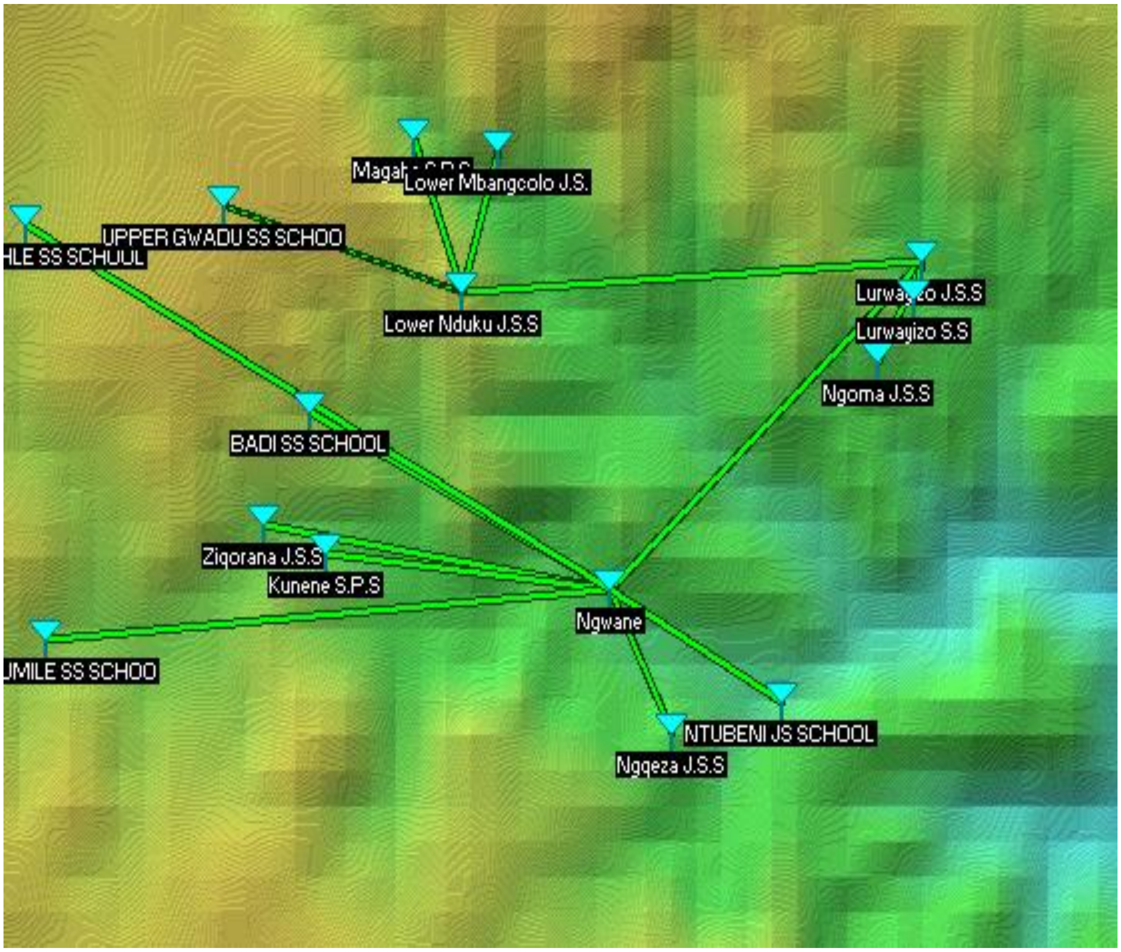


Figure 5-1: Possible connections to Ngwane

After factors in the application have been changed around to look for a better connectivity option, it was concluded that a 12 m mast to enhance the height of a base station radio antenna would achieve connectivity to more schools that would be reached without a use of mast. Badi SS was then chosen to host the second base station (fixed WiMAX) which was initial hosted at Ngwane in the original network. This school has its undeniable advantages compared to the others: it is part of the Dinaledi initiative run by the Department of Education; hence its infrastructure has been recently renovated and has secured a fully furnished 30-seater computer lab. Badi is approximately 10 km to Ngwane which is within the desired range to ensure quality pairing. Badi also has a relatively good line of sight with the schools in its own surroundings, schools that do not have line of sight with Ngwane so as to extend link to the network. It became easy and clear which schools were possible to connect to which base station.

While the desktop survey had its own advantages in identifying possible connections and hence narrowing down the list of possible schools, it was still necessary to conduct a physical site survey in order to confirm that the schools could in fact connect to the base stations at either of the two schools (Badi or Ngwane) and to ensure that the school had no physical constraints, such as a lack of power, preventing the chance to be included in the network expansion. Combining the findings from the desktop and site surveys we found that the following five new schools could be connected to Ngwane: Lurwayizo JSS, Lurwayizo SS, Ngoma JSS, Ntubeni JSS and Ngqeza JSS. While, the following five schools can be connected to Badi: Kunene SPS, Zwelidumile SS, Nquba JSS, Hlabizulu JSS and Mevana JSS.

It was then also concluded that better coverage will be achieved when a 12m mast is utilised to lift the base station’s radio antennas at both base locations. Hence first a trench was dug and a mast firmly installed by a technical team from Grintek special projects group. After the mast has been successful installed, the CPE, base station and switch were configured in preparation for installation. The following section discusses the configurations overview and hence connections that were made in building the network.

The network is designed to consist of 2 broadband Islands; Ngwane and Badi Islands. The term Islands are named after each school hosting the base station. Ngawe Island consists of all the schools that connect to the mobile WiMAX base station at Ngwane and Badi Island consists of all the schools connecting to its base station.

5.4.3 New mobile WiMAX Island Connections

The equipment used to build the new Ngwane mobile WiMAX core network (Ngwane island) include: 10 X BreezeMAX PRO 3000 CPEs, 1 X BreezeMAX Micro BST unit (includes an outside unit: Radio antenna and inside unit: ASN Gateway), Satellite compact from Internet Solutions (I Direct Satellite Router and a Dish), A Cisco Trunk Port Switch to connect the network equipment together, a Router and a Switch connecting the lab together and with the broadband Island.

The network equipment connection is different for two sets of schools: Badi and Ngwane (the schools hosting base stations) as well as the rest of other schools; hosting the CPEs. The older CPE and separate routers at the initial schools were replaced with the new mobile WiMAX CPE, but those schools that will connect to Badi, which uses the older fixed WiMAX base station, will require both the CPE and separate routers. The diagrams bellow shows the network equipment connections first for both Ngwane and Badi and next for all the CPE hosting schools. The setup is the same:

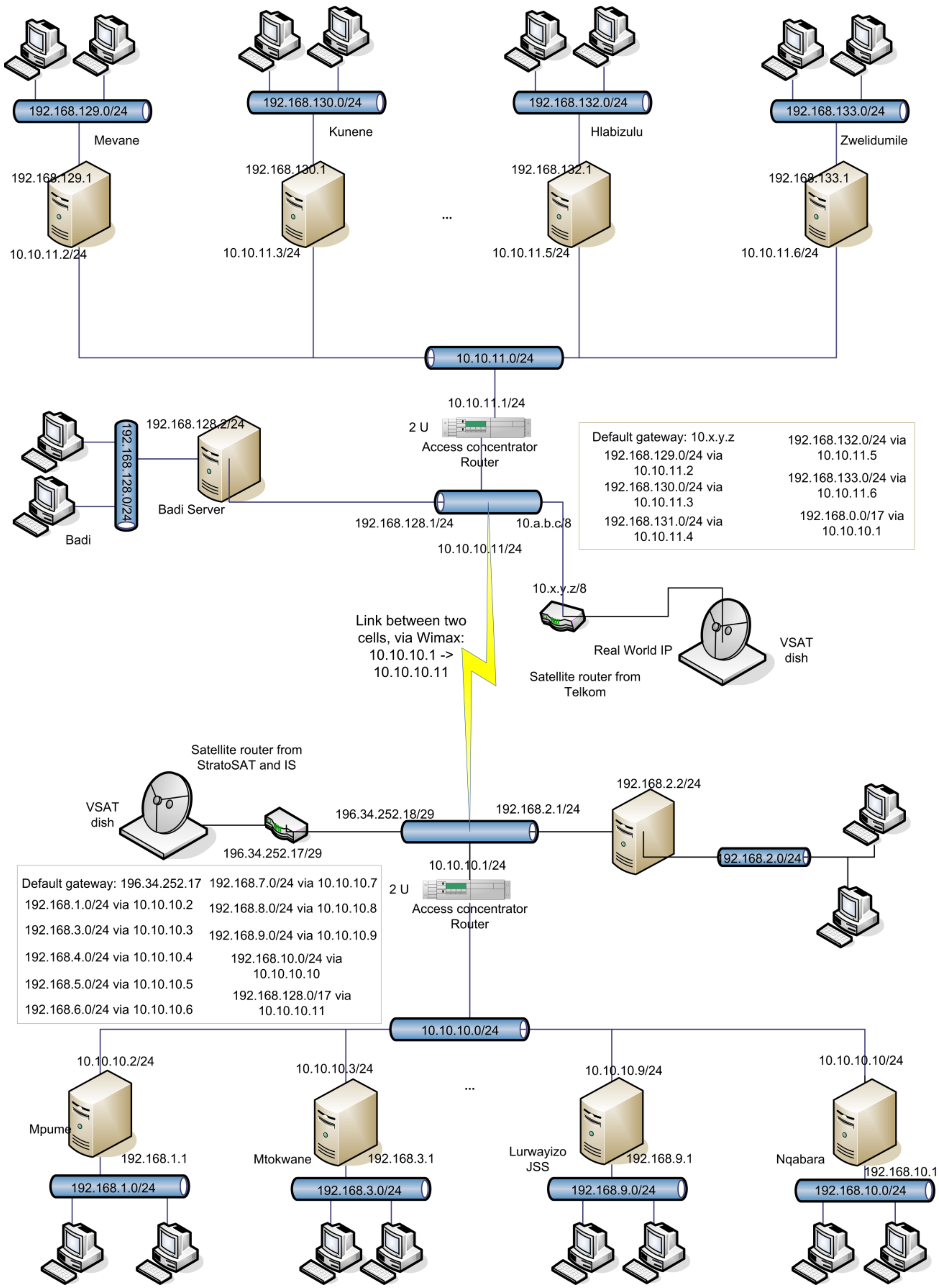

192.168.129.0/24
Mevane
192.168.129.1
10.10.11.2/24
192.168.130.0/24
Kunene
192.168.130.1
10.10.11.3/24
192.168.132.0/24
Hlabizulu
192.168.132.1
10.10.11.5/24
192.168.133.0/24
Zwelidumile
192.168.133.1
10.10.11.6/24
...
10.10.11.0/24
10.10.11.1/24
2 U
Access concentrator Router
192.168.128.2/24
192.168.128.0/24
Badi Server
Badi
192.168.128.1/24
10.a.b.c/8
10.10.10.11/24
Default gateway: 10.x.y.z
192.168.129.0/24 via 10.10.11.2
192.168.130.0/24 via 10.10.11.3
192.168.131.0/24 via 10.10.11.4
192.168.132.0/24 via 10.10.11.5
192.168.133.0/24 via 10.10.11.6
192.168.0.0/17 via 10.10.10.1
10.x.y.z/8
Link between two cells, via Wimax: 10.10.10.1 -> 10.10.10.11
Real World IP
VSAT dish
Satellite router from Telkom
Satellite router from StratoSAT and IS
VSAT dish
196.34.252.18/29
196.34.252.17/29
192.168.2.1/24
192.168.2.2/24
192.168.2.0/24
10.10.10.1/24
2 U
Access concentrator Router
Default gateway: 196.34.252.17
192.168.1.0/24 via 10.10.10.2
192.168.3.0/24 via 10.10.10.3
192.168.4.0/24 via 10.10.10.4
192.168.5.0/24 via 10.10.10.5
192.168.6.0/24 via 10.10.10.6
192.168.7.0/24 via 10.10.10.7
192.168.8.0/24 via 10.10.10.8
192.168.9.0/24 via 10.10.10.9
192.168.10.0/24 via 10.10.10.10
192.168.128.0/17 via 10.10.10.11
10.10.10.0/24
10.10.10.2/24
Mpume
192.168.1.1
192.168.1.0/24
10.10.10.3/24
Mtokwane
192.168.3.1
192.168.3.0/24
...
10.10.10.9/24
Lurwayizo JSS
192.168.9.1
192.168.9.0/24
10.10.10.10/24
Nqabara
192.168.10.1
192.168.10.0/24

Figure 5-2: SLL Network Topology showing LAN and their configuration

The above diagram shows the connections formed within the entire network, elaborating the LANs and their configurations. The following diagram shows the network topology, highlighting both the broadband islands (the base station hosting schools and their prospective clients).

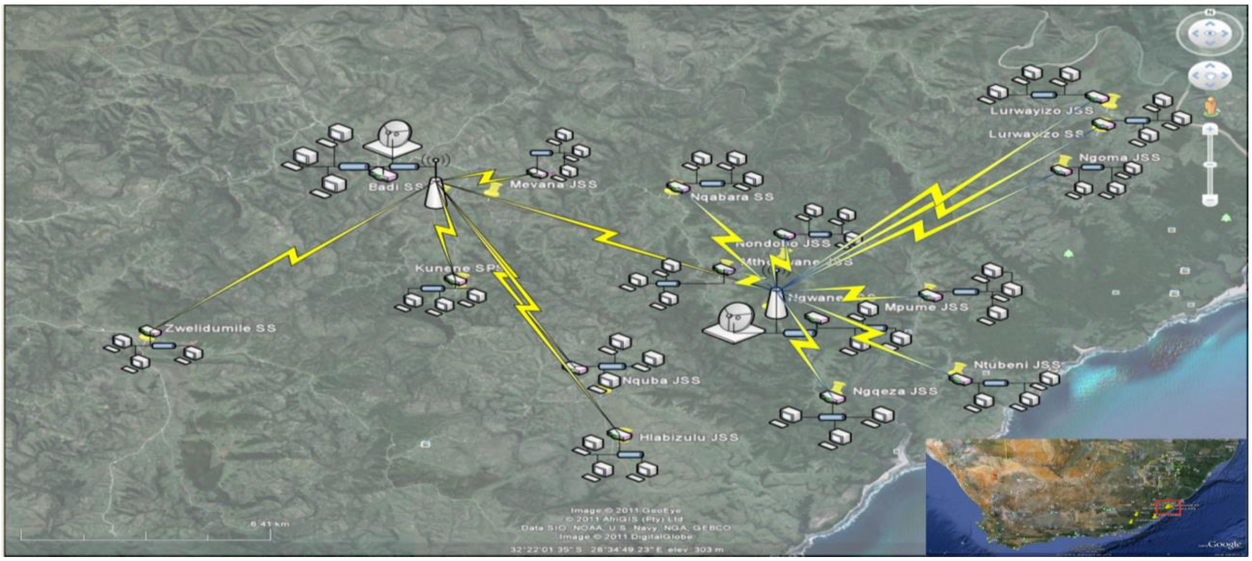


Figure 5-3: Network Topology Showing Broadband Islands

5.4.4 Equipment Configuration

The new Alvarion mobile WiMAX base station CPEs can acts a router for each local school and the new mobile WiMAX base station makes provision for client (site) authentication via a radius service, which is a security feature yet to be implemented in the expanded network. However, the older CPE with the routers still need to employ the use of PPPoE in order to provide site authentication levels of security. Via either CPEs alone or combination of CPEs together with 5 routers, schools connect back to their root node (Badi or Ngwane), routing traffic intended for the Internet or another school via their next hop at one of those two schools. Each of the schools that house a base station, Ngwane and Badi, have a core router which is responsible for routing traffic from the outlying schools to one another or the Internet. Both Ngwane and Badi schools have a VSAT connection to the Internet; the connection at Mpume having been moved to a school with a base station in order to support a simpler and logical network design. In addition, the two schools housing the base stations are connected to one another in order to allow traffic to flow from the one broadband island to the other for internal communication and to act as a redundant link to the Internet. This connection is establishes over the new network link (mobile WiMAX), with a CPE at Badi connected and serving as a client to the base station at Ngwane.

The redundant link will provide connectivity in a case where the other connection fails then access to the Internet should be accessed via the other and it allows more schools and communities within the area to communicate with one another and share resources and services. The Internet is a critical resource to maintain, thus maintaining a constant connection is very important.

6 CHAPTER 6: RECOMMENDATIONS AND CONCLUSION

This chapter discusses recommendations made from conclusions drawn on the information provided in the previous chapters. It provides recommendations on WiMAX deployment elaborated in chapter 5, and recommendations made on technologies to be deployed in rural communities. The chapter highlights challenges experienced during the research and finally concludes the dissertation.

6.1 Recommendations on mobile WiMAX:

From the results obtained in this research as shown in chapter 5, where a successful deployment of mobile WiMAX has been elaborated and hereafter the following recommendations are made regarding WiMAX;

- ✓ That the technology should also be deployed in environments.
- ✓ Mobile WiMAX has not only been proven feasible, but also it has capabilities that a favourable to current technology (end user devices) requirements.
- ✓ The newly deployed mobile WiMAX now extends the coverage to a large area, hence it means more people can make use of the services from their homes. It is our recommendation then that more relevant/ local application be deployed and made available to the community to sustain the functionality of the network.
- ✓ One of the challenges met during the deployment of mobile WiMAX is that, the local (students from the 2 varsities) members of the team responsible for this process did not have the expertise in mobile WiMAX deployment. Hence the team relied on external support which proved expensive as a result, a proactive training action to the team members to lessen the hidden expenses is recommended.
- ✓ The limitation in network coverage initially experienced within the SLL network hosting community had an impact in the use of Internet services and local services.

6.2 Recommended Technologies for Rural Connectivity

In this section, recommended technologies for deployment in rural communities are discussed and the applications that may be deployed over these networks are highlighted including their relevance to rural communities. Commencing with discussing preferred access technologies for deployment in rural communities in order of precedence; they are as follows:

- ✓ Long Term Evolution (LTE) has by far proved to be the best wireless broadband technology that should be implemented in rural communities as well, like it is in urban communities. Its capabilities which are ideal for eliminating or limiting the challenges faced by rural communities include its maximum connectivity range of approximately 100 km, its high speed data relay of up to 302 Mbit/s down link and 75Mbit/s uplink. However, this technology operates over a licensed spectrum in the range of 1.25 to 20 MHz, which is currently a very scarce resource in Africa, currently only external companies are in possession of license to the required spectrum. To date, in South Africa only Vodacom has announced LTE rollout, 8ta has announced launching LTE in the near future and MTN has announced trials in selected parts of Johannesburg. Considering that LTE is a 4G technology, its deployment in rural communities will ensure the closure of digital divide; rural communities will have the same access to technology at similar high speeds to those provided in urban communities. Thus these communities would stand a better chance at participation in the information community and be part of global society.

- ✓ WiMAX, similarly to LTE, also possess impressive capabilities that qualify it as an ideal broadband technology for rural deployment. Similarly WiMAX has high range of connectivity of 50 km per cell, with a highest speed of approximately 75 Mbit/s downlink and 25 Mbit/s uplink, allowing mobility to a maximum speed of 120 km and latency of at most 20 milliseconds. WiMAX also requires use of licensed spectrum, hence its deployment will be limited to countable operators. Currently in South Africa Siyakhula Living Lab deployed the first rural community WiMAX network. Alvarion’s MD in Southern Africa, Winston Smith, said at a Watt Communications’ press release, WiMAX is the best solution for an emerging market such as South Africa (ITweb, 2010). WiMAX is a low risk opportunity for South Africa due to the fact that its wired infrastructure is not fully developed. It offers fast and cost effective broadband solution through its quick deployment time and sustainability for both fixed and mobile deployments.

- ✓ Wi-fi is also one of the technologies that this research recommends for rural broadband connectivity. Originally Wi-fi was developed to connect end-user devices over a short distance of about 100 m maximum depending on the antenna used. Currently there are Wi-fi antennas that have the ability to disperse the signal to a maximum distance of 15 km on an unobstructed plane. Hence Wi-fi also qualifies for rural broadband connectivity. Wi-fi also has an advantage that its equipment (Access point and antenna) are over the shelf packages, thus they are not expensive to procure and exclude the shipment costs. Moreover Wi-fi does not operate on licensed spectrum, hence its equipment are plug-and-play type; they are easy to setup and the configuration does not require high expertise. Its maximum speed is at 54 Mbit/s allows live multimedia data transfers including live video streaming.

6.3 Challenges

This section contains some of the challenges experienced during the course of the research. These are important to highlight as they provide an understanding of some of the issues that could be expected from a similar project. Some of these challenges have not been due to deployment itself, however they remain issues experienced and may have prohibited or detoured the efficient use of the network. Some of these issues were computer hardware and software related such as:

- ✓ Malfunctioning of the server in Mpume, when after all network changes have occurred (installations and configurations), including configuring the server to the updated proxy address, the clients at Mpume could not login to the network: their username and passwords were not recognised. After investigation through troubleshooting it was discovered that the server required the SHH keys and edubuntu image to be updated.
- ✓ This issue the led to another, hence the community could not access the services for a period of 2 weeks. This fact highlights the dependence of this community on the network

team which only comprise of students from the two partner Universities for network administration. This issue's severity lies with the fact that there is no administrative skill within the local community. Hence sometimes even when the issue can be solved by the network admin, assistance in terms troubleshooting the problem is required from the visiting team members.

- ✓ Some of the problems experienced were with regards to the hardware computer RAMs in numerous DANs. These include problems such as computers failing to finish booting up and some failing to recognise the network booting settings and showing problems associated with MAC addresses.
- ✓ The limited literacy to the users caused their inability to understand which computer settings they should deal with and which they should not. One of the users by mistake, made changes to the BOIS settings, which resulted to disruption of usage of the computers.
- ✓ Some of the computers would lose bios settings and would require change in CMOS battery.

Some of the challenges experienced involve end users, the community members in this case and they include;

- ✓ Due to moving of the main equipment (VSAT) from Mpume to Ngwane, Mpume staff members felt that they are now inferior to the new main equipment hosts and they felt deprived of the constantly available Internet access, as it is always the case with the main equipment hosts. It was then necessary to explain and remind them what the extension plans are and how the network will operate highlighting clearly what the difference from the old settings and the new settings are and most importantly highlight the benefits of mobility and extended range, which are provided by this new network deployment. It was also explained that the aim is to be able to connect as many schools as possible and due to the terrain in Dwesa; Mpume's location does not allow many possible connections compared to the new hosting school Ngwane.
- ✓ One of the challenges experienced by Dwesa community and rural communities at large is the inability to afford the end user devices (smartphones, mobile computers, etc.) that are used to make use of the mobile WiMAX or any other 4G technology. This fact then

combats the point of providing mobility in this community due to a fact that end users would still access the network from the DANs as it may take time (years) for the network to be significantly populated by nomadic and/or mobile users.

- ✓ One of the challenges met during the deployment of mobile WiMAX is that, the local members of the team responsible for this process did not have the expertise in mobile WiMAX deployment.

Another challenge originates from the fact that network administration is handled by personnel from the SLL (from the 2 varsities) who are not Dwesa residents, whom visit the site one week each month and in cases of emergencies. This is a problem occasionally due to a fact that some issues that may not be regarded as emergencies would have to be fixed only on their arrival. Such issues include printer not functioning over the network, Wi-fi connection unavailable (usually due to mistakenly disconnecting power supply) and inability to use VoIP services. These issues then lead to number of services that would then not be available for a significant amount of time or even loss of Internet connection. Hence they deter some of SLL objectives; providing reliable network and Internet connection to the Dwesa community. Suggested solution for this would be to increase frequency of visits to the test site and training of local teachers and/or members of the community, preferably youth, for basic troubleshooting skills. That would assist the network administrator to understand the severity of an issue if it could not be identified nor solved from basic troubleshooting. It will also mean that only issues that require advanced skill would be delayed.

6.4 Addressing the research objectives

The main objective of the research was to investigate broadband technologies that are feasible to deploy in rural communities. This objective was sub divided and to be carried out is sequence of sub objectives. This section then concludes on the activities undertaken to complete each sub objective, Commencing with:

1. *Identifying feasibility metrics that are important to consider in rural contexts and which will serve as a theoretical framework for rural broadband connectivity.*

This sub-objective has been achieved through review of and analysis literature; challenges that are highlighted by a number of authors are identified as factors that should always be taken to consideration, as issues to be resolved. Hence technologies that pose a chance of eliminating or limiting these challenges are considered as viable options and the issues then regarded as viable metrics. These have been show in chapter 3, section 3.9 of this research.

The second sub-objective was to:

2. *Identify or define relevant rurality characteristics or requirements.*

The relevant characteristics include: low population density, partially dispersed inhabitants, low flow of income, poor infrastructure, low level of literacy, usually rely on agriculture / farming as main source of sustenance, poor or limited socio-economic development, usually have high percentage of traditional dwellings, they are politically marginalised and do not participate in the information generation.

This sub-objective has been also achieved through review of literature and observation. Characteristics of rural communities in South Africa has been drawn in chapter 3, section 3.11.

The third sub-objective entails:

3. *Identifying and undertaking theoretical evaluation of wireless broadband technologies.*

This objective was also performed and achieved successfully through evaluation of literature; technologies such as WiMAX, Wi-fi, LTE, CDMA, HSPA, Microwave, GSM, GPRS, EDGE and UMTS have been identified and were further reviewed for this research purposes in chapter 4 of this document.

The fourth objective includes:

4. *Undertaking a technical evaluation of a selected technology (WiMAX).*

This objective has also been achieved through deployment of the mobile version of WiMAX and amalgamation of Wi-fi into the network and hence extending nomadism and mobility in the network. The deployment and its end results are depicted in chapter 5, section 5.5 and the operation of the network in Dwesa.

The final sub-objective of this research was to:

5. *Make recommendations on the most feasible technology for rural broadband connectivity and applications that may be used over these networks.*

Recommendations on technologies that may be deployed in rural settings have been given and are elaborated and recorded above in section 6.2 of this chapter.

It has been discovered from this research that there exists several technologies which are feasible to deploy in rural communities. However the choice of technology to deploy is determined a series of factors as stated and discussed as metrics in section 3.9. The deployment of mobile WiMAX and amalgamation of this technology to an already existent fixed WiMAX network has proven the feasibility of the network in a practical level.

6.5 Future Work

Deployment of mobile WiMAX has already proven feasible in rural contexts from this research, therefore future work should include making use of this technology's capabilities and populate the network with more services that are relevant to rural communities, which will assist in eliminating the issues facing this community and eliminate the digital divide. The future phases of research can therefor explore in further detail, the type of services that enabled by the deployment of mobile WiMAX technology and also to monitor the long term impact of such a technology in a rural marginalized community.

6.6 Conclusion

This research has taken the investigation of various wireless networking technologies for the provisioning of broadband connectivity for marginalized rural communities. This has been with the view to inform subsequent and future deployment of such technologies in rural marginalized communities. The key findings from this research, which are supported by the real-life observations of such deployed technologies include: the fact that LTE, mobile WiMAX and Wi-Fi form a suit of suitable technologies for providing end-to-end broadband connectivity in rural communities. This is taking into consideration the identified matrices that are relevant for the evaluation of effectiveness of such technologies, but more importantly taking into consideration the profile of these communities, which set them apart from their urban counterparts. This research makes a contribution to the larger goal of addressing the digital devide by making particular recommendations for the network connectivity and by providing evidence to the effectiveness of the said technologies.

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