Rural Internet Connectivity: A Deployment in Dwesa-Cwebe, Eastern Cape, South Africa

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by

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Declaration

I hereby declare that the contents of this research work are my original work. Information extracted from other sources is acknowledged as such.

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November 2007

Dedication

To my late grandfather Chrispen Chiraravapota Doromutoro veMutopo veDziva, who inspired me to pursue my studies, while he himself could not tolerate being surrounded by people who could not read or write.

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Abstract

This thesis presents aspects of Internet connectivity in rural South Africa. The work looks at government initiatives being undertaken to connect rural communities to up-to-date information networks. Various projects that seek to connect rural areas of South Africa, as well as other remote areas around the world, are discussed. These projects present many novel ideas that have been successfully used to link rural communities in remote areas with the information age. In particular, wired and wireless access technologies that can be implemented to connect remote communities to the Internet are discussed. A field test utilizing GPRS, VSAT and WiMAX was implemented in Dwesa-Cwebe, Eastern Cape Province, South Africa. VSAT proved to offer better Internet connectivity in terms of throughput and latency. WiMAX was then successfully implemented to relay the signal over the remote area of Dwesa-Cwebe, thus effectively providing Internet connectivity to an area with limited cell phone coverage and no telephone lines.

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List of Abbreviations and Acronyms

3DES	Triple data encryption standard
3G	Third-generation
AAS	Advanced antenna system
ADSL	Asymmetric digital subscriber line
AES	Advanced encryption standard
AP	Access point
AVU	African virtual university
AU-ODU	Access unit–outdoor unit
BEE	Black economic empowerment
BSNL	Bharat Sanchar Nigam Ltd.
BPL	Broadband power line
CDH	Community digital hubs
CDMA	Code division multiple access
CDMA2000	Code division multiple access – 2000
CSIR	Council for Scientific and Industrial Research

CRSD	Costa Rican Foundation for Sustainable Development
CPE	Customer premises equipment
DHCP	Dynamic host configuration protocol
DSLAM	Digital subscriber line access multiplexer
DSSS	Direct-sequence spread spectrum
EDGE	Enhanced data rates for GSM evolution
EMI	Electro-magnetic interference
EUL	Enhanced uplink
FCC	Federal Communications Commission
FDD	Frequency division duplex
FDMA	Frequency-division multiple access
FEC	Forward error correction
FFT	Fast Fourier transformation
FHSS	Frequency-hopping spread spectrum
FM	Frequency modulation
FOSS	Free and open-source software
GCIS	Government communication and information services
GEDA	Gauteng Economic Development Agency
GEO	Geostationary earth orbit
GPRS	General packet radio service
GSM	Global System for Mobile communications
GTS	Goal technology solutions
HAPs	High-altitude platforms
HSDPA	High-speed downlink packet access
HSUPA	High-speed uplink packet access
ICT	Information and communication technology
IDU	Indoor unit
IEEE	Institute of Electrical and Electronics Engineers
IRDS	Integrated rural development strategy
ISDN	Integrated-services digital network
ISM	Industrial scientific medical equipment

ISP	Internet service provider
ITU	International Telecommunication Union
L2	Layer 2
LAN	Local area network
LEO	Low-altitude earth orbit
LOS	Line of sight
MAC	Media access control
MAP	Mobile access point
MAC SAP	Media access control layer, service access point
MBSU	Micro base-station unit
MCS	Modulation and coding scheme
MEO	Mid-altitude earth orbit
MIMO	Multiple-input multiple-output
MPCC	Multi-purpose community centers
MPS	Mobile phone services
MTN	Mobile telephone network
NLOS	Non-line-of-sight
ODU	Outdoor unit
OFDM	Orthogonal frequency division multiplexing
PLC	Power-line communication
PPPoE	Point-to-point protocol over Ethernet
PSTN	Public switched telephone network
PTM	Point to multipoint
PTN	Private telecommunication network
PTP	Point to point
QoS	Quality of service
RUCoE	Rhodes University Centre of Excellence
RTT	Round-trip time
SDSL	Symmetrical digital subscriber line
S-IDU	Subscriber indoor unit
SMS	Short message service

SNO	Second national operator
S-ODU	Subscriber–outdoor unit
SU	Subscriber unit
TDMA	Time division multiple access
TD-SCDMA	Time division–synchronous code division multiple access
UAV	Unmanned aerial vehicle
UFHCoE	University of Fort Hare Centre of Excellence
UMTS	Universal mobile telecommunication services
UNISA	University of South Africa
URS	Urban renewal strategy
USA	Universal service agency
USAASA	Universal Service and Access Agency of South Africa
USAL	Under-serviced-area license
USF	Universal Service Fund
USP	University of the South Pacific
VANS	Value-added network services
VDSL	Very high bit rate digital subscriber line
VoIP	Voice-over Internet protocol
VPN	Virtual private network
VSAT	Very small aperture terminal
WAN	Wide area network
WAP	Wireless access protocol
WCDMA	Wideband code-division multiple-access WiFi
WIGWAM	Wireless gigabit with advanced multimedia
WiMAX	Worldwide interoperability for microwave access
WLAN	Wireless local area network
WLL	Wireless local loop
WWW	World Wide Web

Chapter 1

Introduction

This chapter provides background to the state of Internet connectivity in South Africa. I explore the background knowledge to the study of rural telecommunication in disadvantaged rural communities in South Africa. Next, I explain the project aims, particularly what the project has sought to address in regard to connecting remote or rural and disadvantaged areas. Lastly, I describe the overall structure of the thesis.

1.1 Background

Internet connectivity is a central enabling agent in building an information society (International Telecommunication Union [ITU], 2003a). South Africa is currently experiencing rapid growth in Internet connectivity (*South African Internet Connectivity*, 2004). The ITU reported that, in 2006, 10.3% of the South African population had access to the Internet. The World Wide Worx, a leading independent technology research organization, stated in *The Goldstuck Report: Internet Access in South Africa* that 3.6 million South Africans would have access to the Internet by the end of 2005. This would translate to 1 in every 12 South Africans having access to the Internet. The figure represents 7.4% of the South African population, mostly in urban centers having access to Internet (Goldstuck, 2005). According to a previous study released in 2003, 3.28 million South Africans had access to the Internet (*The Goldstuck Report: Internet Access in South Africa*, 2003). This indicates an upward trend in Internet access in South Africa and further implies an increase in technology adoption. Table 1.1 shows the intended trends in South Africa.

Table 1.1 South Africa Internet usage and marketing report (Internet World Stats)

YEAR	Users	Population	% Pen.	Usage Source
2000	2,400,000	43,690,000	5.5 %	ITU
2001	2,750,000	44,409,700	6.2 %	IWS
2002	3,100,000	45,129,400	6.8 %	ITU
2003	3,283,000	45,919,200	7.1 %	Wide World Worx
2004	3,523,000	47,556,900	7.4 %	Wide World Worx
2005	3,600,000	48,861,805	7.4 %	Wide World Worx
2006	5,100,000	49,660,502	10.3 %	I.T.U

A digital divide exists between the different populations of South Africa, however. The digital divide is defined as the gap between the information-haves and information-have-nots. This means there is a division between people who have access to information and communication technologies (ICTs) residing in the urban areas and those without in the rural areas. The World Bank defines ICTs as hardware, software, networks, media for collection, storage, the processing, transmission and the presentation of information (voice, data, text, images). To overcome the digital divide, access to ICTs must be provided to isolated rural areas and under-serviced urban areas.

Telkom South Africa was the only fixed land-line operator in South Africa before the granting of a license to Neotel, formerly the second national operator (SNO). Neotel was granted a license to commence operations on 9 December 2005 (*SNO Telecommunication Pty: A Brief History*, 2006). Neotel is a conceptualized company formed to end monopoly in the fixed telecommunication market of South Africa. Neotel has a leading edge in telecommunication networks built across the country (*SNO Telecommunication Pty: A Brief History*, 2006). Telkom has already provided various Internet products, including wholesaling and retailing to Internet service providers (ISPs) and other customers in South Africa. It has a wide range of creatively packaged products, tailored for different users, such as Home DSL, integrated services digital network (ISDN), asymmetric digital subscriber line (ADSL), leased lines, Diginet and satellite (*Telkom South Africa: Internet Services*, 2006). These have contributed heavily to the current growth of Internet connectivity in South Africa, especially in urban areas.

The year 2004 saw the launch of Internet access by the second telecommunication operator, Sentech. Sentech offers broadband wireless access, mostly in urban areas, under the brand name MyWireless. They have packaged various products that utilize wireless fidelity (WiFi). The Department of Communication expects broadband access to increase tenfold with the introduction of Sentech's wireless service network (*Business Report*: *Call tariffs likely to drop as broadband gains popularity*, 2006). This, in turn, is expected to increase Internet access in South Africa as more companies have come on board to offer such services. The government announced this major capital expenditure project on the rollout of Sentech wireless broadband network to increase access and reduce costs in April 2006 (*Business Report: Call tariffs likely to drop as broadband gains popularity*, 2006). Market analysts BMI-TechKnowledge believes that the market for Internet access service in South Africa will continue to grow. Broadband is cited as the key driver of growth in the South African Internet market, since end-user trends have been changing as users migrate from dial-up services to broadband (*Broadband Access to Drive Internet Growth in South Africa*, 2006).

The cellular phone service providers MTN, Virgin Mobile, Cell C and Vodacom are currently offering Internet connectivity through General Packet Radio Service (GPRS), Enhanced Data for GSM Evolution (EDGE) (introduced in 2005; now as country-wide backup), Third Generation (3G) and High-Speed Data Packet Access (HSDPA). Although HSDPA and 3G are available in South Africa, they can only be accessed in major metropolitan areas. However, with South Africa having approximately 90% coverage, combining the MTN and Vodacom cellular networks (Vodacom South Africa, 2005a; Mobile Telephone Networks, 2005).

GPRS can be utilized as an alternative. The reduction in Vodacom tariffs to 39 cents per megabyte made GPRS and 3G technologies more affordable. These technologies enable Internet access to all mobile subscribers (Vodacom South Africa, 2005b). This is one of the affordable Internet connectivity technologies which can be utilized for Internet access where there is coverage.

These initiatives and growth, however, as reported by Goldstuck (2005), have not been able to benefit the poor who cannot afford such services. The use of Internet connectivity through GPRS is not prevalent in the economically disadvantaged rural areas of South Africa. The major factor has been the type of phones that most of the rural community members use; most of these phones are second generation and are not equipped with GPRS capabilities.

In order to afford telecommunication services in rural communities, Vodacom has rolled out subsidized community telephones in under-serviced areas of South Africa (Vodacom South Africa, 2005c). These phones cannot be utilized for Internet access but have been able to provide other telecommunication services. The establishment of community telephones has been a government initiative to serve the marginalized rural areas of South Africa. Vodacom, with more than 5,700 base stations in the country, provides coverage to most areas, and as a result the majority of rural communities have benefited from this initiative (Vodacom South Africa, 2006). From December 2006, Vodacom had 23 million cell phone users, representing 58% of the market (Vodacom South Africa, 2007b). This implies that Vodacom remains the most utilized cellular provider in South Africa.

Other initiatives have been put in place by the government to afford rural communities' access to the Internet. The Universal Service and Access Agency of South Africa (USAASA), formerly the Universal Service Agency (USA), is one such organization, established and operating under the regulatory and policy framework enshrined in the Telecommunications Act No. 103 of 1996 (as amended in 2001). USAASA seeks to promote the goals of universal service and universal access (Republic of South Africa Telecommunications Act No. 103, 1996). They define a universal service as a reliable connection to the communication network, and which enables any form of communication to and from any part of South Africa. Universal access is defined as the ability to use the communication network at a reasonable distance and affordable price, and which provides relevant information and has the necessary capacity in under-serviced areas. 42.5% of the South African population lives in rural areas, according to the 2001 census (Statistics South Africa, 2001). The under-serviced communities comprise mainly rural and peri-urban areas. These areas are characterized by: high levels of poverty; poor infrastructure; high levels of unemployment, with only a few employment opportunities; and, limited access to important services, such as telecommunications and road infrastructure.

The USAASA is funded by the Universal Service Fund and was established by a Ministerial Policy Directive. From 2003, all telecommunications licensees, including the value-added network services (VANS), are required to contribute a percentage of their annual turnover to the Universal Service Fund. VANS refer to telecommunication service provided by a person over a telecommunication facility. The facility has been obtained by that person in accordance with the provisions of section 40(2), to one or more customers of that person concurrently, to which value is added for the benefit of the customers (Republic of South Africa Telecommunications Act No. 103, 1996). The VANS contribution should not exceed 0.5% of their annual turnover. The private telecommunication network (PTN) and the under-serviced area licensees are exempted from paying contributions to the Universal Service Fund (Department of Communications, 2001). The PTN is a telecommunication system provided by a person for purposes principally or integrally related to the operations of that person. It is installed onto two or more separate, non-contiguous premises, and where the switching systems (nodes) of at least two of these premises are interconnected to the public switched telecommunication network (PSTN), as contemplated in section 41 (Republic of South Africa Telecommunications Act No. 103, 1996). The contributions from the VANS and PTN are periodically reviewed by the Minister of Telecommunications. This means that the Universal Service Fund depends on the profitability level that the telecommunication companies achieve in a particular year.

By December 2005, the USAASA had established 133 telecenters nationwide in disadvantaged rural communities by (Universal Service Agency, 2005a). These telecenters are telecommunication access points deployed in unserviced and under-serviced rural areas to provide access to electronic communications services. The purpose of setting up these centers is to provide universal access to ICTs to communities in unserviced or under-serviced areas. Unserviced areas are defined as those that do not have telecommunications access while under-serviced areas have a teledensity less than 5%. The telecenters have enabled communities to access basic services, like computer services, telephones, data (fax, Internet, email), video, ICT training services, typing, printing and photocopying (Universal Service Agency, 2005a). In areas where formal building structures are limited, ICT telecontainers have been deployed to serve as telecenters.

Schools in under-served communities have also been used as access points to ICT, through the establishment of USAASA's Cyber Laboratories. By December 2005, 235 cyber labs had been established in schools in all of the nine provinces of South Africa (Universal Service Agency, 2005b). The laboratories provide ICT services and computer literacy training to the school community. The schools are responsible for maintenance costs, while Internet connectivity for the first 12 months is paid for by the USAASA. One cyber lab is equipped with thirty computers, one photocopying machine, and one printer; fax machines are provided when there is need. The USA provides for the setup and security of these labs (Universal Service Agency, 2005b).

The South African government introduced the *Batho Pele* project, in which it seeks to increase access to services, and has seen such initiatives as gateway, call centers and the launch of multi-purpose community centers (MPCC) (Batho Pele, 2005). The aim of such initiatives is to provide government service delivery, 24 hours a day, seven days a week, for citizens who wish to use information technology, irrespective of their geographical location. MPCCs are emerging as one-stop development service centers in many of the disadvantaged rural communities. The government has recognized the increasing need for an integrated rural development strategy (IRDS) and urban renewal strategy (URS) to meet the socio-economic needs of disadvantaged rural communities. The MPCCs are being launched in partnership with Government Communication and Information Services (GCIS) (South African Government Communications and Information Systems, 2005). The USAASA has been able to setup telecenters inside existing MPCCs as part of promoting access to technology and capacity-building. Similarly to the cyber labs, these telecenters provide several services, such as telephones, Internet, photocopying, scanning, faxing and computer training using appropriate equipment (Universal Service Agency, 2005c). The MPCCs have been able to improve government communication since at least six departments are represented in each center. The government services that are facilitated include pension payouts, healthcare, education, processing of passports and IDs, and library use.

A new concept of community centers that are to be deployed in rural areas demarcated for development is called the community digital hub (CDH) (Universal Service Agency, 2005d). The areas of the CDH are advanced ICT facilities, deployed by USAASA, to provide human capacity-building and technical support to the remote telecenters and cyber labs. The hubs are envisaged to provide support for content-development and to deliver various applications, such as e-government services, e-education, e-health, e-business development and other services (Universal Service Agency, 2005d). The CDH is made up of a combination of technology centers offering various ICT services.

The USAASA has also introduced the under-serviced area licenses (USALs) in areas with a teledensity of less than 5% (South African Consulate General, 2003) so as to provide basic telecommunication facilities. This allows small businesses to provide telecommunication services or facilities in such areas. The USALs are issued by the Minister of Telecommunications; so far, 28 areas in under-serviced areas have been identified to receive USALs. This has culminated in the USA granting license holders R5 million grants for development in the under-serviced areas. The grants will enable black economic empowerment (BEE) enterprises to kick-start the roll-out of infrastructure in those. This will also provide employment and alleviate poverty, thereby improving quality of life for the people living in some rural and remote areas of South Africa (Universal Service Agency, 2005e).

The telecenters established by the USA have been connected mostly through Telkom landlines; at the initial stage of the project, Telkom was the only fixed landline operator. The landlines are used for Internet access where this service can be provided. Benjamin (2000) noted that the use of Vodacom phones as dial-up had worked better for three reasons:

- They were more reliable;
- They were prepaid, meaning users would not accumulate crippling debt as in the case of Telkom post-billing;
- Vodacom allowed a greater profit margin since Vodacom’s charges were lower than those of Telkom’s (which had also included monthly rental charges).

The Vodacom lines however can only be utilized for voice traffic telephones and cannot support Internet connections. Thus, efforts are underway in remote areas to utilize other access technologies, such as satellite and wireless Internet access.

The USA telecenter program has had mixed results. There are cases where the local organizations could use the technologies to meet local needs; and, there are many cases where a combination of lack of technical and financial capacity limited the effectiveness of the telecenters (Benjamin, 2000). Sustainability of the telecenters has also been a major challenge. The telecenters are of limited use unless the services provided are relevant to the local community. Although telecenters have the potential to serve various aims (which include universal access to telephones, other developmental services to meet basic needs, education in information-age skills and local telephone connections), their usefulness as an effective means of addressing the issue of connectivity has still to be proven (Schofield *et al.*, 2006). Cheaper alternatives could be utilized (e.g., pay phones), while no mechanism yet exists to enable universal access. Hence, in other areas, telecenters have improved access to some extent, especially for under-serviced areas, but the model has not helped in achieving universal service and access (Barendense, 2003). *Universal service* according to the Telecommunication Act 1996 refers to the universal provision of telecommunication services as determined in terms of section 59(2) (a) (ii), while *universal access* means universal access to telecommunication services as determined in terms of section 59(2) (a) (i) (Republic of South Africa Telecommunications Act No. 103, 1996). The high rate of technical failure, especially in connectivity, has also been sited as a major problem (Universal Service Agency, 2005g). But this could be solved through the deployment of easily configurable technologies that suite people with low levels of technical skills.

Despite the effort to afford rural communities' access to ICTs many remote rural areas communities still pose challenges as they remain out of coverage. Some rural areas, in some parts of the country, still have a teledensity less than 5% (South African Government Communications and Information Systems, 2005). Other communities are very remote from existing infrastructure, making it difficult to achieve the mission of connectivity. Lack of electricity in some areas has also been a barrier to telecommunication and Internet connectivity in many rural areas. The telecommunication networks require a source of energy to power the components that make up the network. This presents a large investment for setting up the network infrastructure. In some cases, alternative sources of energy, such as solar energy and generators, have been implemented. Solar energy and generators have proved to be good alternatives in the absence of electricity. However, where solar energy has been in use the major problem has been theft of the solar panels; community awareness of the use and application of solar power seems common and has led to an actively fraudulent market for solar panels. The impact is such that some sections of the networks are permanently affected. The most successful anti-theft mechanism has been the education and involvement of local communities (Rycroft *et al*., 1997). Yet, the theft of solar panels has hampered the rate of development in these rural areas.

The cost of deploying network infrastructure is capital-intensive. This results in companies calculating the return on investment in undertaking deployment to the rural areas. Consequently, most telecommunication companies have preferred to invest in areas of brisk business, which are the urban centers. Sentech, for example, has offered wireless packages tailored mainly for users in the major metropolitan cities. This indicates that telecommunication companies continue to invest most in areas of high business — leaving rural, disadvantaged areas with little or no telecommunication service.

The mission of rural Internet connectivity continues to be hampered by various challenges. The problem that most hinders Internet access in rural or remote areas has been the initial cost of deploying network infrastructure, which remains relatively expensive. Furthermore, the return on investment on telecommunication projects in remote or rural areas has been low. This presents business in the remote/rural areas as a high-risk investment. As a result, network deployments in rural areas often have not been able to improve on the teledensity of those areas. The absence of electricity in many remote/rural areas has made the scenario more difficult as the operation of a telecommunication network requires a source of energy to power it. Even in cases where an alternative source of energy, such as solar energy, has been sought, components of the network have frequently been vandalized. This has left major breakdowns in the network, typically resulting in bad lines in areas where telecommunication services are already poor.

Thus, serving rural/remote areas remains yet to be accomplished. Certain efforts, such as the establishment of telecenters by the USA, have met with challenges that importantly affect sustainability. The obvious challenges are a combined lack of technical and financial capacity, which has limited the effectiveness of telecenters, for instance.

1.2 Statement of the problem

To date, the absence of Internet connectivity in marginalized communities in rural areas of South Africa can be largely attributed to the lack of comprehensive investigation of back-haul connectivity options. It is imperative that the appropriate technology be investigated with a view to mitigating the many drawbacks associated with a lack of Internet access for communities in these areas.

1.3 Aim of the study

The work aimed to carry out a feasibility and practical study of the various connectivity technologies available for rural connectivity, and then to identify the model that is most cost-effective, sustainable, and easily deployed (in similar or in most rural terrains). An evaluation of data throughput, reliability, and cost of deployment of such networks in rural communities has been performed. The rural, economically disadvantaged community of Dwesa-Cwebe, in the Eastern Cape, South Africa, was used as the test bed.

Dwesa-Cwebe is located in the Mbashe Municipality of the Eastern Cape. It is situated in the central Wild Coast region, bordered on the one side by the Indian Ocean and on the other by the rugged grasslands of the former Transkei homeland. The Dwesa-Cwebe community was recently granted ownership of the Dwesa-Cwebe Nature Reserve, through the Land Claims Court, as they had been forcibly removed from the area during the apartheid era. This was one of the first successful land claims completed in South Africa. At the moment there is the need to come up with solutions which can enable development in this area.

1.4 Research approach

The study looks at rural Internet connectivity in South Africa and gives an overview of the topic in the world. Numerous aspects are addressed: use of access technologies; suitable applications to be offered; community needs; planning of the Dwesa-Cwebe project, and management of the projects that have been established to deliver Internet connectivity in disadvantaged remote/rural areas. Importantly, the work also examines the challenges affecting the delivery of various applications on the established telecommunication networks, since these applications are likely be determined or affected by the medium through which they are being delivered.

The University of Fort Hare Centre of Excellence (UFHCoE) in E-Commerce and Rhodes University Centre of Excellence (RUCoE) in Distributed Multimedia are currently involved in a project called *Siyakhula* to develop and field-test a multi-purpose ICT platform for deployment in the marginalized and semi-marginalized communities of South Africa. This work would provide the back-haul connectivity of this multi-purpose ICT platform. The various access technologies available for deployment in the rural areas are to be assessed on their applicability to provide Internet connectivity. Some selected access technologies have been deployed and network parameters, such as latency and throughput, are evaluated.

1.5 Scope of the study

The study evaluates the various access technologies that are available for rural Internet connectivity in South Africa. These access technologies are assessed in terms of their availability and applicability in the disadvantaged rural areas. This would allow affordable rural Internet networks to be built so as to connect the rural communities. The study provides a report on practical experiments undertaken by the University of Fort Hare Centre Of Excellence (UFHCoE) in E-commerce and Rhodes University Centre of Excellence (RUCoE) in Distributed Multimedia in the area of Dwesa-Cwebe on the Siyakhula project. The primary objective of this joint research is to develop and field trial a robust cost-effective and localized Multi-purpose ICT platform e-commerce/communication platform for the rural community. This project therefore provides the access technology upon which this platform would be built.

The area of Dwesa-Cwebe at the moment has poor electricity supply, unreliable telephone and cell phone coverage. The presence of communication technology means connectivity in this case would be a central enabling agent in aiding economic development in this rural community which has eco-tourism potential. As a result, the need for sustainable and easily deployable, cost effective Internet connectivity necessitated this study on connectivity technologies.

1.6 Significance of the study

This study provides significant results for use in three different arenas:

1. To scientific knowledge and researcher: The study seeks to add more insight into practical deployment issues of Internet connectivity in rural, disadvantaged communities. Internet connectivity decisions are presented, taking into consideration the scenario for deployment in a remote/rural environment. The common network performance parameters (throughput, reliability and latency) for the deployed access technologies are measured, hence showing how the deployed access technologies might perform.

2. The utilization of free and open-source software (FOSS) for the establishment of networks is seen as a cost-effective way for network deployment. Furthermore, the utilization of FOSS allows localization of software that enables people in disadvantaged rural areas to easily conceptualize ICT for development. This is a way to usher people in rural, disadvantaged communities into a global information society. The model discussed can thus be used as a reference when setting up such centers countrywide.

3. To the ICT industry: The study seeks to provide information to the ICT industry about deploying telecommunication networks for rural, disadvantaged communities. This will provide more insight into approaching that market. So far, the industry has been reluctant to invest in these areas since they are viewed as areas with a low level of business and as difficult to serve. The findings of particular deployments, such as described here, can help the ICT industry to tailor future services that are relevant to this particular market as they remain skeptical of making investments there.

4. To rural disadvantaged poor communities: The deployment of Internet connectivity to rural, disadvantaged areas remains the most direct way to usher those communities into the information age. In this context, we

provide Internet connectivity to a multi-purpose ICT platform. This platform is being used to build e-commerce applications that can ultimately empower people residing in such rural communities.

1.7 Principal research results

The results give insight into various issues surrounding access technology deployment in disadvantaged rural/remote areas in developing countries. The discussion entails various Internet connectivity projects, especially how they are being deployed and what applications they plan to deliver to remote/rural areas — in South Africa and in other parts of the world. Various access technologies for deployment, specifically in Dwesa-Cwebe, South Africa, are evaluated in an attempt to provide Internet connectivity to such an area, as so to connect it to a multi-purpose ICT platform.

1.8 Thesis organization

Chapter 2 gives an overview of literature describing similar connectivity projects in rural areas, focusing on projects that have been undertaken in rural South Africa.

Chapter 3 presents an overview of the various Internet access technologies currently available in South Africa. These include the wired and wireless Internet access technologies in operation.

Chapter 4 reports on the various connectivity technologies that could be used in the Dwesa-Cwebe area. Further to that the experimental tests carried out on the access technologies which could be easily deployed with a focus to their applicability in a rural setting are also discussed.

Chapter 5 elaborates on the selected access technologies and the network architecture in operation on the e-commerce communication platform network.

Chapter 6 concludes the project showing goals achieved and future work which can be done.

1.9 Summary

This chapter has laid down the state of Internet connectivity and the various initiatives which have been undertaken to address Internet connectivity in the disadvantaged rural areas and other areas within South Africa. It further lays down what the project is all about and what it seeks to achieve.

Chapter 2

Review of Related Work

This chapter looks at the unique characteristics of rural areas — the areas that we hope to serve with telecommunication services. This chapter also gives an overview of some research projects and deployments of networks for rural Internet connectivity in South Africa and other parts of the world over.

2.1 Characteristics of rural areas

Rural areas present unique characteristics that require appropriate technology to serve the area. According to ITU-D Group 7 (2000), more than half the world's population in 2000 lived in a rural areas. Rural areas are characterized by at least one of the following characteristics (Kawasaki, 2000):

- Difficult topographical conditions, such as lakes, rivers, hills, mountains, deserts and long distances between settlement areas, which cause the construction of wired telecommunication networks to be very costly.
- Severe climatic conditions that make heavy demands on certain components of telecommunications equipment (e.g., the antenna and remote switch), thus adding to the costs of installation and maintenance.
- Lack or absence of public facilities, such as usable water, reliable electricity supply, access roads, regular transport, and an existing communication infrastructure.
- Underdeveloped social infrastructure, such as for health, education or small business, and lack of most government services.

- Low level of economic activity with few jobs opportunities; the existing economic structure may be based mainly on agriculture, fishing or handicrafts.
- Also, low per-capita income, as low-paying work leads to low family incomes. Ultimately, there is low demand for communication services.
- Low educational levels and high illiteracy rates. Thus, there is a scarcity of technical personnel who have even nominal telecommunication knowledge, and this has implications for technical maintenance and repair of equipment placed in the area.

The above characteristics make rural areas a difficult environment for any telecommunication company to provide a basic network infrastructure. In addition, rural areas typically have very high calling rates per telephone line, reflecting a scarcity of telephone services and the fact that large numbers of people must rely on a single telephone line. Therefore, telecommunications service providers find it difficult to provide potential consumers with acceptable quality at affordable prices. It seems to be ‘a worst-case scenario’ for the disadvantaged rural areas of South Africa, which have a teledensity of less than 5% (South African Consulate General, 2003).

One of the poorest provinces in South Africa is the Eastern Cape, which still has many underdeveloped rural areas. Low per-capita income, low levels of economic activity, scarce technical personnel, an underdeveloped social infrastructure, and difficult topographic conditions are characteristic of the Eastern Cape (Palmer *et al.*, 2002). Some of these, such as scarcity of technical personnel in the area, have implications for maintenance and repair of technical equipment placed in such communities. Consequently, technical personnel often have to be brought in to work on projects to deploy network infrastructure. In addition, the Eastern Cape is partly a mountainous area. The Dwesa-Cwebe terrain is hilly and incised by numerous rivers and streams (Timmermans, 2004).

This makes installing wired infrastructure both costly and sometimes infeasible. Moreover, local climatic conditions may place heavy demands on equipment deployed in the area. The constant tripping and restoration of the electricity supply may also affect the operation of the equipment. However, alternative sources of energy can be adopted.

As mentioned, the Eastern Cape rural areas have a pervasive low per capita income and low level of economic activity. The Eastern Cape Provincial Budget for 2007/8 described it as the poorest province in the country, with some 69% of the population receiving an income below the poverty datum line. The incidence of poverty is highest in the rural areas of the former Transkei and Ciskei homelands (*Eastern Cape Provincial Budget 2007/08*, 2007). This inevitably affects the rate of return on investment, such that telecommunication companies are likely to shun investing in rural areas. This area of the Eastern Cape also has a low population density, with people living in widely dispersed, small clustered settlements. The population of Dwesa-Cwebe is approximately 15000, with a land area of 42 km^2, and a population density of 96 people/km^2 (Pondocrop, 2005).

In order for local ICTs to be successful, there is a need for a basic level of literacy and training. The IT literacy rate is extremely low in the Dwesa-Cwebe area, with the village school children showing little understanding of what computers are. Computer literacy and training should be tailor-made for the people residing in such an area, and the use of localized software solutions would be useful in aiding their understanding. The general consensus is that providing connectivity to residents of marginalized rural areas can be an innovative way to empower the community and individuals.

2.2 ICT rural applications

The rural areas present challenges to ICT; besides existing public and private radio broadcast programs, which are only an asymmetric type of service, various symmetric (two-way) applications can potentially be delivered to better serve people residing in remote communities. The new applications being developed by telecommunication companies are being created to meet local rural requirements and are often linked to development efforts. Such applications include telemedicine, distance education, and community and business development (ITU-D Group 7, 2000).

2.2.1 Telemedicine

Telemedicine has been described as the use of electronic information and communications technology to provide and support healthcare when distances separate the participants (Field, 2002). The delivery of medicine at a distance, using communications and information technologies, is an initiative being used in many developing countries. This approach offers individuals a wide range of health benefits, such as achievable through remote patient monitoring and diagnosis, typically through multimedia communication links between urban and remote rural facilities.

Challenges associated with utilization of telemedicine systems include high telecommunication costs, lack of physician interest, and the failure to build evaluation into the design process from the onset of the telemedicine project (Salvemini, 1999). The bandwidth requirements depend on what applications may be offered and whether those applications will be live/real-time (synchronous) or store and forward (asynchronous) interactions. When applications are done in real-time, delivery requires more bandwidth. The investment in a telemedicine system is costly, and its operational costs can also be high. Most rural areas in South Africa do not have broadband networks, and, moreover, telephones may not be available in many areas.

2.2.2 Distance education

The delivery of distance education through satellite or Internet has been found to lower the administrative costs of running distance education courses over a wide student base. The African Virtual University (AVU) and the University of the South Pacific (USPNet) are initiatives based on the concept of cross-border educational access (Kawasumi, 2000).

The delivery of high bandwidth applications utilizing voice and video capabilities has become available and integrated into online educational delivery. However, these require a bandwidth capable to deliver services to remote areas. The bandwidth requirements for distance learning have been a technical challenge, regardless of whether or not an adequate network infrastructure is available, and this depends on the services to be offered through the various technologies (Denny Lin, 2000). The telecommunication services in remote areas remain poor; and the delivery of high bandwidth applications remains a mission to be fulfilled.

2.2.3 Community and business development

The introduction of telephones, telecenters, e-mail and radio broadcasts in rural communities are promoting business development. The establishment of e-commerce programs in developing countries has allowed local artisans to directly market their products to first-world consumers. The successes of community and business development applications were found to depend on local language support and the availability of relevant content (ITU-D Group 7, 2000).

2.3 Rural Internet connectivity in developing countries

There have been various initiatives undertaken to provide Internet connectivity to the remote rural areas of developing countries. The characteristics of remote rural areas, outlined above, continue to impede the mission of rural Internet connectivity. However, projects have been tailored to suit prevailing conditions in such areas around the world. In the following, I describe various attempts to provide Internet connectivity in rural areas of South Africa, Central America and India.

2.3.1 The Gaseleka Telecentre, Northern Province, South Africa

The Gaseleka Telecentre was established in the Northern Province of South Africa through the telecenter program from the USA. This was the very first telecenter to be established by the USA in 1998. The telecenter program from the USA seeks to deploy telecommunication access points in unserved and under-serviced rural areas. Gaseleka is in a remote rural area about 80 kilometers from the nearest town, Ellisras, and about 40 kilometers from the border with Botswana. The area is very arid, nearly desert. The telecenter can be reached by a poor dirt road. According to the 1998 Census, the area’s population was 85,000, with unemployment around 60% (Benjamin, 2000). The percentage of the population that has access to the telecenter is estimated as 25% (that is, people who reside within 30 minutes walking distance from the telecenter). The active population is estimated at 80% of the total population. The percentage of active individuals is estimated by excluding children under age 4 and adults over age 65.

The Gaseleka Telecentre, like many other USA-established telecenters, started out by offering only access to equipment. Other services were brought to the telecenter later. Most people visit the telecenter to make phone calls, since this is the most usable pay phone in the area. Others use the centre for sending faxes and photocopying. The local schools have also been major users of bulk photocopying for test papers and reports and typing curricula, reports and schedules on the computers. Computer training was introduced when a full-time computer trainer was made available at the centre. Some local businesses also use the centre to produce leaflets and advertising (Latchen *et al*., 2001). Some local businesses have with their invoices and payrolls done at the telecenter (Benjamin, 2000). All this has helped it fulfill its mission to be a multipurpose centre. The telecenter also supports local students from the University of South Africa (UNISA). Other services developed through the centre include the area's first community newspaper, launched in 2000. The South African Department of Home Affairs also utilizes the centre to process applications for identity documents, birth and death registrations, passports and other services. Also in 2000, the telecenter became a postal service point, with a bank of 1,000 post boxes.

The Gaseleka Telecentre went online in May 2000; it consists of the following equipment:

- Six phone lines: 4 for telephones, 1 for fax, and 1 for Internet access.
- One Pentium computer for administration and 4 other Pentium computers for training; 4 older 386 Olivetti computers are used mainly for typing practice.
- Peer-to-peer networking allows printing from all computers on the network.
- A Cannon BJC 4200 black-and-white/color printer, color scanner (Mustek 1200 SP).
- Olivetti JP790 color printer and an Olivetti 8416 photocopier that copies in A3 and A4.

According to Latchen *et al*. (2001), the lessons learnt from this telecenter included the knowledge that:

- Embedding the project in local organizations and systems can be a time-consuming and frustrating process.
- The key factors in the success of telecenter are the energy and commitment of the local owners and managers.
- Proper training of telecenter managers is required, specifically in the areas of financial management, equipment maintenance, customer service and business skills.
- Sustainability is a challenge for most telecenter projects. Appropriate consideration should be given to issues of telecenter financial sustainability at the outset of the project, not just when government business or external donor funding has run out.
- Telecenters do not create useful and relevant information and communication — they only facilitate local access to it. National agencies need to distribute national information for centers to disseminate at the local level in order for telecenters to be vibrant and useful information hubs.
- Although centers to support learning about information access and delivery services are desperately needed in rural areas of South Africa, no model has been realized for self-sufficiency. Over half of the 60 projects initiated by USA are not functioning well — for a variety of technical managerial, competitive and financial reasons. Experience from the Gaseleka Telecentre project suggests that sustainability is more achievable when telecenter sites are based where supported infrastructure exists, such as at clinics, schools, libraries or post offices.
- Clarity is needed on what telecenters are meant to offer. If the focus is simply on providing telephones, there are many easier ways of doing this, such as installing pay phones. If the focus is on supporting information services, then investment is needed more in information than in technology. Projects to find what information is most needed and to codify this nationally, or to develop mechanisms for local content creation, are more important than getting a computer working. If the focus is on skills

development and training, then developing courses, course materials and facilitation skills are more important than the technology.

Gaseleka is one of the very few South African telecenter making an operational profit and paying half-decent wage. This shows that Gaseleka in a way has managed to sustain itself in comparison to others However it has not been able to meet its depreciation costs no repay the money invested in it by the USAASA (i4donline, 2004). The survival of Gaseleka Telecenter in the long run is doomed if funds are not injected into the telecenter.

2.3.2 Manguzi wireless

The Manguzi wireless project was established in Manguzi in 1998. This is a rural community in the Maputaland region of the KwaZulu-Natal Province of South Africa. The area is 60 km^2 with about 100,000 inhabitants (Figure 2.1). The community is made up of mainly impoverished subsistence farmers. It offers subtropical and tropical climate zones with an ecological diversity of terrestrial and marine animals. This makes it one of the most popular ecotourism destinations in South Africa. The area has remained relatively sparsely populated and unknown, and it is underdeveloped largely due to malaria in this region. The major tourist attraction is the Kosi Bay Nature Reserve, renowned for its remoteness and unspoiled beauty. Eco-cultural tourism has become a means of sustainable rural development in the area. A number of projects have been set up to promote ecotourism, and which incorporate the telecenter and the Internet connectivity in the area (Smith, 2000). The sparsely populated rural community is separated by vast distance from the nearest urban area. The telecommunication infrastructure in the area is underdeveloped, as denoted by the majority of homes and business that do not have phones. Although cellular coverage is available it is patchy and unreliable. Furthermore, high bandwidth services (such as ISDN) are not available anywhere in the area.

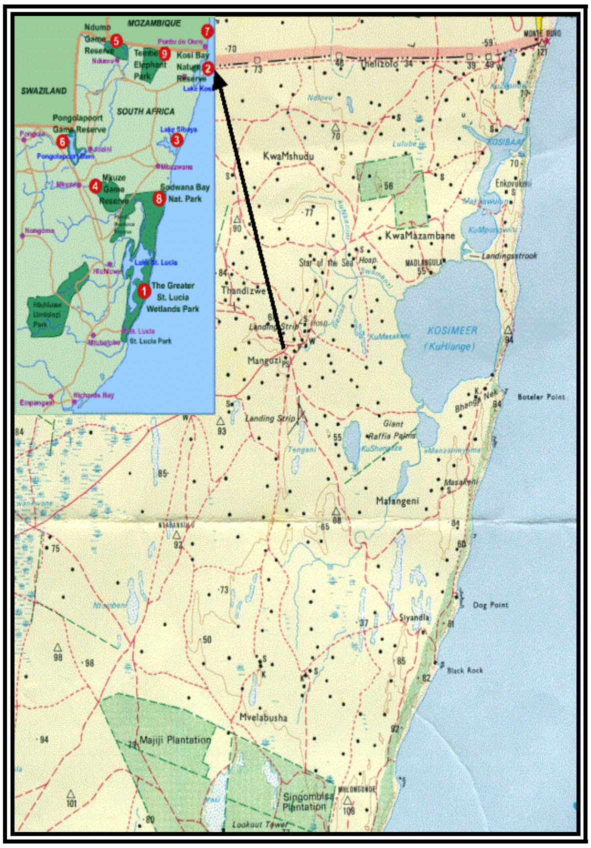


Figure 2.1: Maputaland region of the KwaZulu-Natal Province, South Africa (Smith, 2000).

The Information and Communications Unit of the Council for Scientific and Industrial Research (CSIR) had the challenge of providing this rural remote community with Internet access. Faced with such a challenge they had to design appropriate methods for serving this rural remote community.

A telecenter was established with the aid of the CSIR's Information and Communications Technology Unit (Mikomtek) and has been operational since September 1998. Most of the homes and businesses in this area did not have communication infrastructure. The telecenter sought to address the problem of complete absence of an adequate communication infrastructure. Accordingly, it sought to provide communication through the phone shop, which has five telephone booths and a fax machine. The local area network had eight personal computers running Windows 98 with a FreeBSD file server; these are connected through a dial-up analog that dials on demand. Other services provided are word processing, scanning, printing and photocopying. The telecenter has since been actively involved in servicing the community (Smith, 2000).

Smith (2000) also explains that the headmaster of one of the schools in the area realized the potential of Internet as a source of information and requested Mikomtek to connect his school. In a well-developed telecommunication infrastructure, the solution would be an easy one. However, in this remote rural area with poor telecommunication infrastructure, the request was not simple, considering other factors, such as:

- Of the schools in the vicinity of Manguzi, only three had electricity and none had telephones to connect to the Internet;
- Funds available for installation were extremely limited;
- None of the traditional telecommunication infrastructure was suitable;
- The solution necessarily had to be cheap, and preferably should not involve recurring monthly costs.

2.3.2.1 Project planning

Mikomtek sought to obtain community buy-in and cooperation for this project. It was important to get the community cooperation so that the project would be launched with the community participating. A pilot project was launched with the aim of exploring the various options available to provide Internet access to the schools. This involved identifying the schools that could be partnered for this project. Shayina Secondary School and Maputa Senior Primary were nominated to participate for the following reasons:

- Both had electricity;
- They were close enough to the telecenter (3 to 5 km), making access to both sites easier during the installation and the testing phase;
- Despite being close to the telecenter, the schools did not have a line of sight to the telecenter, which was needed to properly test what was installed.

The solution to connect the schools came from exploring various traditional methods available. The options explored were:

Table 2.1: Link options investigated to provide Internet connectivity (Smith, 2000).

Option	**Comment**
Telephone lines	Not available.
Cellular telephone	Coverage not ubiquitous; reception very unreliable.
Two-way VSAT	Installation and monthly costs too expensive.
Spread-spectrum radio solutions	Requires line-of-sight, but the two schools are not visible from the telecenter; license required.
ISDN	Not available.
Satellite Internet broadcast	High-speed Internet downloads via satellite uses a telephone line for the back channel to the Internet; no license required.
Low-frequency radios	Normally used for telemetry and limited to very low bit rates; attractive option since a partner company had a license and line of sight was not a factor.

2.3.2.2 Deployed network

The deployed network is a combination of radio and satellite Internet broadcasting. The telecenter serves as the network hub. When a user at one of the schools wants to access the Internet, a request is relayed to the telecenter via the radio link where the FreeBSD file server dials on demand to execute the request. The satellite is used to download the requested information directly to the network at the school. In other words, an information request is sent via the single telephone line allocated to the project and is received via satellite. This method makes relatively modest use of the telephone line and allows multiple users to access the Internet simultaneously (Ryan, 2000). Figure 2.2 provides a diagrammatic representation of the network deployed. Siyanda is the satellite ISP providing the satellite connection. It makes use of the PAS satellite, which has footprint coverage of the whole of southern Africa utilizing the Ku-band. The ordinary 90-cm digital broadcasting satellite dishes are used for reception. Requests from clients are sent to Siyanda via virtual private networks (VPNs) over MWeb's terrestrial infrastructure.

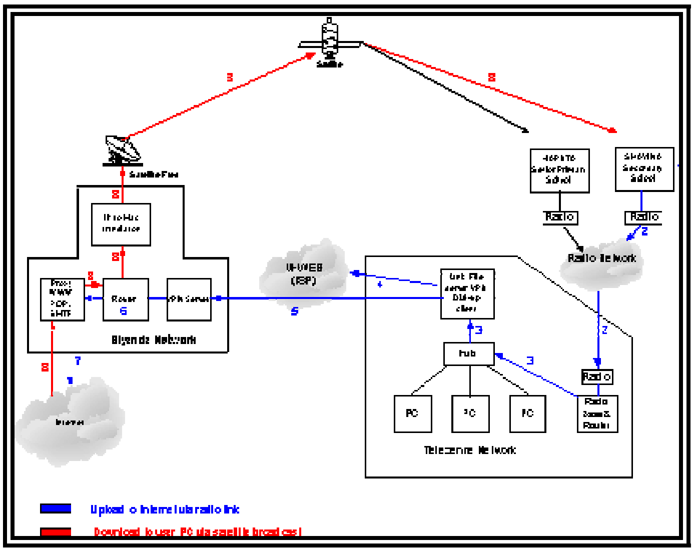


Figure 2.2: Manguzi wireless network source (Smith, 2000).

2.3.2.3 Findings

The network deployed has succeeded in the introduction of ICT to Manguzi, facilitating access to opportunities and information. The community is actively involved in the use of the facilities, such as word processing, desktop publishing, send and receive e-mail, web surfing and numerous other activities. The performance of the network can be roughly compared to the experience of an

Internet user with a 9.6 kbps dial-up connection; this is much slower than the 30 Kbit/s expected and can be attributed to the extremely slow uplink (Smith, 2000).

This wireless Internet project is helping to raise the quality of life for the people of the region. It has brought new economic opportunities to the area, helping it to realize its vast eco-tourism potential (Ryan, 2000).

However from the telephone conversation in March 2008, with Ronel Smith (Project Manager) I learnt that the project had been run as a pilot project in that area to provide rural Internet connectivity. It had been successful to integrate such technologies together and to enable them to offer Internet connectivity in Manguzi. Since it was a pilot project it is no longer in existence.

2.3.3 DakNet

DakNet involved the implementation of a very low-cost asynchronous ICT infrastructure that was developed to store and forward wireless networks for rural connectivity. The DakNet wireless network which was established in India utilizes the existing telecommunication and transport infrastructure to distribute digital connectivity to outlying villages that lack any digital communications infrastructure.

The DakNet network combines the physical means of transportation with wireless data transfer in order to extend Internet connectivity that is provided through a central link (Sandy *et al*., 2002). It avoids relaying data over wired networks, which are expensive, by transmitting data over short point-to-point links between kiosks and portable storage devices, called mobile access points (MAPs). The MAPs are mounted on and powered by vehicles that physically transport data among the public kiosks and private communications devices, such as an intranet and between kiosks and a hub for non real-time Internet access. They are low-cost WiFi radio transceivers, which are responsible for the automatic transfer of the data stored on the MAP at high bandwidth for each point-to-point connection.

The DakNet operates when the MAP-equipped vehicle comes within the range of a village where a WiFi-backed kiosk would automatically sense the wireless connection, and then uploads and downloads the tens of megabytes of data. The hub will automatically synchronize the data from all the rural kiosks using the Internet (Sandy *et al*., 2004). These steps are repeated for every vehicle, while carrying a MAP unit, thereby creating a low-cost wireless and seamless communications infrastructure.

Although the data transported by DakNet is not real-time, a significant amount of data can be moved at once. The system actually provides a higher data throughput than other low bandwidth technologies, such as the traditional analogue telephone. A significant amount of data can move at once — typically 20 Mb in each direction (Sandy *et al*., 2004, Sandy *et al*., 2002). The DakNet can be used for a variety of application that require low-cost distribution and collection of information. These include Internet/intranet messaging, information distribution and information collection.

DakNet has been fully implemented as an affordable rural Internet connectivity solution for Bhoomi. The project has seen the computerization of land records initiative pioneered by the State Government of Karnataka in India. This is one of the first national e-Government initiatives in India which has been successfully implemented at district headquarters across the state to completely replace the physical land-records system (Sandy *et al*., 2004).

DakNet has enabled Bhoomi to decentralize its land-records database up to 40 km away from its district headquarters. The project took advantage of the existing transportation infrastructure by outfitting a public government bus with a DakNet

MAP to transport record requests from each village kiosk to the Taluka server (the bus passes by and stops at each village six times per day). The server is responsible for processing requests and outputs records, which are then delivered back to each village kiosk for payment and for the land record. The MAP on the bus will transfer data when the bus comes within the range of the kiosk. The average session is 2:34 (minutes: seconds) during which time an average of 20.9 MB can be transferred uni-directionally, and up to twice that amount bidirectionally. The average throughput for a session during which the MAP and Kiosk go in and out of connection due to mobility and obstructions, is 2.47 Mb/sec. The Bhoomi application would not exploit the broadband capacity of the DakNet network since the land-records requests are only 2 KB and electronic land records are approximately 20 KB.

2.3.4 Long-distance (LD) WiFi Aravind Eye Hospital

Long-distance WiFi is a fixed point-to-point wireless technology, like microwave links, that has enabled organizations to develop their own wireless network in a remote rural area (Intel, 2006a). The Aravind Eye Hospital project is a collaboration involving researchers from Intel and the University of California at Berkeley, with support from the National Science Foundation. They have helped the Aravind Eye Care System, a network of five hospitals in South India, in its quest to deliver affordable, quality eye-care services to the rural poor. Their contribution was a custom-built long-distance, high-bandwidth and point-to-point WiFi network that connects rural vision centers to Aravind hospitals. The network has enabled rural residents to have video consultations with doctors, eliminating the need for patients to travel to the hospital for routine eye care. This has provided a cost-effective communication link to the rural residents in this remote part of the country.

In developing their custom networking technology, a key challenge for the researchers was that WiFi was designed for short-distance communication. To make it work over the long distances between rural vision centers and the Aravind hospitals, they modified the software, specifically the WiFi media access control (MAC) protocol. The combination of the modified WiFi software, with directional antennas and routers, is able to send, receive and relay signals. The research team so far has been able to obtain network speeds of up to 6 Mbps, at distances up to 40 miles. This was validated at another project in Ghana, West Africa, in which the University of California at Berkeley was also involved (*Technology and Infrastructure for Emerging Regions*, 2006). These speeds are about 10 times faster than dial-up speeds and carry 100 times as fast as standard WiFi technology. The result was a unique wireless network that can handle high-speed communications over distances as far as 40 miles (Intel, 2006a).

This project was seventeen months old as of June 2006 and had proved successful; it has therefore been expanded in the state to include five hospitals linked to 50 clinics, to provide a service to half a million patients each year. The technology developed was a simple, inexpensive software and hardware system that can provide villages with a high bandwidth connection to computer networks in cities as far as 50 miles away (Greensfelder, 2006). This has been a cost-effective communication service linking the clinics and hospitals in this region.

2.3.5 Mobile telephony in rural areas

In the rural West Bengal region of India, Grameen Sanchar Society has been formed with the aim of providing access to telephones through the wireless local loop (WLL) phones of Bharat Sanchar Nigam Ltd (BSNL) (*WiLL CDMA PCO Phones*, 2006). It is hoped to provide 3 to 5 phones in each of the states. The phones cost about Rs17,000 (US$ 340) and are funded by banks and small refinance institutions with the support of the society, which identifies enterprising unemployed youth to become the village phone owners (Best, 2003). The rates for incoming and outgoing phone calls are fixed by the society. It proved to be an economically viable service-provider model for the youth and villagers alike. It also demonstrates the pent-up demand for phone services in Indian villages, and demonstrates that, at the right price, services can offer reasonable returns to telecommunication service providers. The Grameen Sanchar Society now plans to expand the scope of the project by setting up Internet kiosks (*WiLL CDMA PCO Phones*, 2006).

Another innovation to bring telephones to the villages has been to let the postmen carry mobile phones with them as they make rounds to deliver mail. Over 7,000 villages now have access to telephone service through the WLL phones provided by BSNL. The service is operated by the Department of Posts, since the postmen are their employees. As an incentive, the postmen, called Grameen Sanchar Sewaks, are allowed to keep a percentage of the call charges collected from the villagers who use the phones (Ministry of Communications and Information Technology, 2003).

A project called e-Post, aimed at Indian residents abroad, allows hard copies of e-mail sent by them to be delivered to the destination in rural areas by the postmen at Rs10 each. The service combines the speed of e-mail with the reach of ‘snail mail.’ India’s postal service operates 154,000 post offices, and employs 60,000 postmen, who deliver 5 million pieces of mail everyday (Kamesh, 2004).

The WLL phones of BSL have been able to deliver an economically viable service to the people in this rural area. This has been demonstrated through the utilization of this service — because it was being offered at the right price.

2.3.6 The village area network (VAN)

This is a mobile and fixed ICT service implemented in the rural community of Bohechio, The Dominican Republic. The aim was to provide services and capabilities that could enhance the economic development of local rural communities, hence raising the living, medical and educational standards (Best, 2003).

The VAN network deployed provides coverage of 1 km^2. This operates with a set of outdoor antennas and routers on a wireless network with IEEE 802.11b standards. The VAN is able to extend facilities for the multipurpose community telecenter (MCT) throughout the village via mobile and fixed wireless devices and services. The telecenter is part of an initiative by the Costa Rican Foundation for Sustainable Development (CRSD). It consists of a recycled steel shipping container with six computers, two telephones, scanner/fax/copier/printer machine, cash machine, a soil and environmental testing lab, broadcast equipment for a frequency modulation (FM) radio station, big-screen television, and a telemedicine unit. The telecenter uses a very small aperture terminal (VSAT) satellite link and a fixed wireless telephone connection.

The VAN architecture consists of external radios and antennas mounted on a mast tower, with radio links providing connection to the telecenter unit. This ultimately links to the VSAT, which connects to the Internet. The link to the VSAT is made through a point-to-point antenna that communicates with the antenna on the radio mast tower on top of a municipal building. A cable connects these through an outdoor router located on the top floor of the building. The router then connects via cable, amplifier and splitter to four 90-degree, point-to-multipoint antennas. The antennas create a wireless VAN throughout the entire village. The network has coverage of 1-km radius, at speeds of 11 Mbps shared (Best, 2003).

2.3.6.1 The village area network (VAN) topology

The established VAN provides network access to the community's school and medical clinic. This platform has been able to increase telephone service penetration rapidly in this town. A voice-over Internet protocol call-processing unit and IP telephones have been deployed throughout the village. A commercial handheld appliance running Windows CE has been deployed with a WiFi network card, which interfaces with the handheld's PC card slot. The handheld device has an integrated full-duplex sound card with a speaker and microphone, making it suitable for communication experiments.

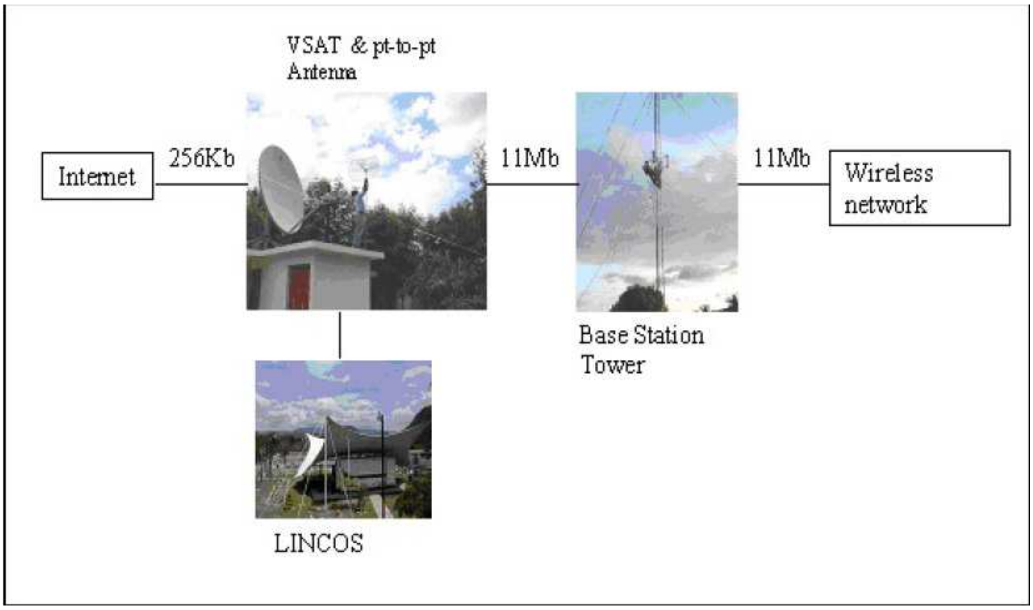


Figure 2.3: Village Area Network Topology (Best, 2003).

The project has been able to attract other service providers (Best, 2003) (at the start of the project, there was only one service provider offering phone and cable television). The cost of an outgoing call has dropped from 30 cents to 18 cents. Furthermore, various applications have been deployed to assist schools, a medical clinic and agriculture (Best, 2003). The VAN demonstrates that areas where service providers ‘shun to serve’ can be serviced only when other service providers start offering services. This can result in affordable services being delivered in the area, since the different providers will compete for the market and lower their prices.

2.3.7 Peer-to-peer wireless networking

This system was developed by the Media Lab Asia research lab at IIT Madras; the system has sought to service rural communities in India. Most of these communities are within 25 km of fiber landing points; the key challenge is to provide low-cost, high bandwidth, wireless connectivity at distances up to 25 km. The system has been designed to interconnect a village with three other neighboring villages, forming a mesh network (*Peer to Peer Wireless Mesh Networks for Rural Community*, 2005).

The project aims to develop 802.11b/g-based mesh networks for rural communities. The design emphasizes the development of stand-alone 802.11b/g router cards and planning of an effective mesh network using these cards. Each of the router cards has three 802.11b/g-based wireless cards and an Ethernet port for linking to backhaul. The directional antennas connected to the wireless cards facilitate long links, of a few kilometers, while the Ethernet provides the link to the fiber backbone. The stand-alone router cards can be localized in each village node to route packets in all directions. The Ethernet port may connect to the fiber backbone or any of the Internet kiosks in the villages. Directional antennas connected to each of the WLAN cards provide the 120° sectoral coverage in each direction (*Peer to Peer Wireless Mesh Networks for Rural Community*, 2005).

This is a cost-effective connectivity system developed with off-shelf components, which is able to service neighboring villages. This network can be easily deployable in remote/rural areas to service community needs.

2.4 Conclusions

This chapter has presented the characteristics of rural areas and various applications being delivered to achieve rural connectivity. There are various rural connectivity projects being carried out in South Africa and throughout the world. These projects seek to promote Internet connectivity to marginalized rural areas. The chapter has pointed out the contributions that various case studies have made concerning rural Internet connectivity. Major successes have been reported from using wireless access technologies for providing connectivity to rural areas. The major failures have been reported in the management of telecenters. However, some projects have involved development of special applications for use in rural areas. The case-focus of this research involves deploying cost-effective and sustainable technology to deliver Internet connectivity in a marginalized rural area. This will include the wired and wireless access technologies for Internet connectivity, which are discussed in the next chapter.

Chapter 3

Access Technologies

This chapter provides a review of the last-mile access technologies. These include wired and wireless technologies currently available for the last-mile connection for Internet access in a remote/rural area. The technologies range from narrowband to broadband, with variations in cost.

3.1 Wired media access technologies

The wired media access technologies are those that allow communication through a physical medium (a ‘wire’ of some sort). These are the most common media access technologies available for Internet access in South Africa. It is important that factors such as broadband/narrowband, throughput, cost, reliability and maintenance are considered with regard to user-application requirements when evaluating which media access technology can be utilized for network deployment. The following are discussed in relation to wired media access technologies:

- Broad/narrow band: Broadband is defined by the International Telecommunication Union (ITU) Telecommunication Standardization Sector (ITU-T), in their recommendation I.113, as transmission capacity that is faster than primary-rate integrated services digital network (ISDN) at 1.5 or 2.0 megabits per second (Mbps) (ITU, 2003b). Broadband connection supports a very high bit rate, as opposed to narrowband, which supports a lower bit rate. The higher the bit rate, which is a measure of speed of transmission of bits per second (bps), the faster the transmission will occur in a given period of time to transfer data. Broadband Internet can exchange more data per second than a narrowband connection. PSTN offers bandwidth in the range of 28.8 Kbps to 57.6 Kbps, while basic-rate interface ISDN offers 64 to 128 Kbps for data. Narrowband signals occupy a small amount of space on the frequency spectrum. Broadband can carry multiple signals by dividing the total capacity of the medium into multiple, independent bandwidth channels, where each channel operates only on a specific range of frequencies. The need for Internet access and data connectivity in rural areas poses several challenges.

- Throughput: The wired media offers superior performance in terms of data throughput. The Ethernet connections offer up to 10/100 Mbps bandwidth. The connection should be sufficient for home file-sharing, gaming, and high-speed Internet access. This is sufficient to offer access in the case of rural areas. The wired LAN's utilizing hubs can suffer performance slowdown if computers heavily utilize the network simultaneously. The use of Ethernet switches instead of hubs avoids this problem, however: a 24-port switch costs R815, which is more expensive than a 24-port hub at a cost of R320 (Pinnacle Micro, 2006). Utilizing ADSL and ISDN for Internet access, Telkom South Africa does not guarantee throughput. However, in the case of Diginet, Telkom guarantees the Diginet throughput speed, but does not guarantee any throughput speeds of the Internet. The Diginet line guaranteed speed stops once the data enters the Internet (Telkom South Africa, 2006a).

- Cost: The cost of wired access media technologies depends on the expected speed and the equipment required to make it operational. The cost also includes installation to allow the technology to be operational. Technologies that employ a low throughput speed are cheaper than those offering high throughput. Depending on what type of line is being utilized for connection, the costs differ. In the case of an ISDN connection the requirements are a normal PC, public switched telephone network (PSTN)

ISDN line, ISDN modem and connection fees. As of May 2006 the cost for monthly rental was R220.50, and installation cost R558.20 on Telkom tariffs. XDSL costs also vary, with Home DSL 192 having a monthly rental fee of R270 and installation cost of R404, while analogue cost R79 (Telkom South Africa, 2006b).

- Reliability: Reliability refers to the access technology being fault-tolerant while giving enough performance and capacity to deliver data. The fault-tolerance aspect means that the technology does not succumb to break downs. Performance and capacity refer to the support of peal loads requirements on the network (Dooley, 2001). Ethernet cables, hubs and switches are extremely reliable, mainly because manufacturers have continually improved the Ethernet technology.

- Maintenance: Maintenance of wired access technologies varies depending on the mix of devices, the type of Internet connection, and whether internal or external modems are used. However, none of these options poses any special difficulty to maintain. The devices do require a power supply to function; cases of power outages will affect the functioning of the devices.

The ISDN, PSTN, and XDSL have support from the various service providers, making maintenance problems easier to confront, wherever the devices may be situated.

Various wired media access technologies currently exist, however these have disadvantages for use at the access layer where teledensity is less than 5%. This situation would require rolling out copper/fiber networks to link these areas, thus escalating the cost of deploying such networks. South Africa has had only one fixed-line service provider, with the long-awaited second national operator (SNO) only recently licensed (*SNO Telecommunication Pty: A brief history*, 2006).

3.1.1 Analog dial-up

This is the most common wired media access technology available for Internet connectivity in South Africa (Jenson, 2002). This service works on a regular telephone line with a modem. The modem and the telephone line allow the customer of an Internet service provider (ISP) to connect to the Internet. However, this is being phased out in first-world countries that are ushering in broadband technologies.

Advantages

The analog dial-up access technology remains the cheapest technology, especially for e-mail retrieval and minimal work on the World Wide Web (WWW). Currently, Telkom rates are R79 for the monthly rental (Telkom South Africa, 2006). Dial-up is available in most urban areas and some rural areas of South Africa. In the case of Europe, dial-up is readily available in both urban and rural areas, which thus presents several options for Internet access.

Disadvantages

The analog dial-up offers narrowband, thus the system slows down traffic. The maximum download speed of 56 Kbps, and maximum upload of 33.6 Kbps, results in users demanding faster transmission of data and easy accessibility at affordable rates. But the disadvantaged rural areas have limited wired telecommunication infrastructure (Lowe *et al.*, 2000), posing a problem since the copper cable/optical fiber have to be laid underground and exchanges must be built to cater for this. The costs incurred in laying new copper cables/optical fiber and building such exchanges is high compared to the potential revenue. This leaves this option relatively unattractive to telecommunication companies, especially for rural areas. Another major issue relating to wired technologies in remote/rural areas is the high probability of poor-quality copper cables (which results in bad lines) and the prevalence of copper cable theft in disadvantaged areas (Lowe *et al.*, 2000; *Daily Dispatch*, 2005).

3.1.2 Integrated-services digital network (ISDN)

ISDN is designed to support various communication functions, including voice, data, and video on a single integrated network (DeMartino, 1999). ISDN was designed to overcome problems associated with the analogue dial-up. It provides a method to best use the ‘plain old telephone system’ (POTS) by dedicating lines for pure data-centric or high-quality hybrid applications. ISDN was created to facilitate an environment that can integrate voice and data traffic in the PSTN end-to-end network (Gumatse *et al*., 2004). ISDN operates the same way as analogue dial-up in the sense that there are two ISDN interfaces on either end of an ISDN line. The transmission control protocol (TCP)/Internet protocol (IP) are extracted and routed to the Internet.

ISDN provides two types of subscriber interfaces: basic-rate interface (BRI) and the primary-rate interface (PRI). The ISDN BRI consists of two 64-Kbps channels that are commonly referred to as bearer (B) channels and a 16K-bps signaling channel, commonly referred to as the data-link (D) channel. The two B-channels are commonly used for the transmission of voice and/or data, while the D-channel is used to control the switching of the two B-channels (DeMartino, 1999). In South Africa, the ISDN PRI has 30 B-channels and one D-channel operating at 64 Kbps. The B-channels are for voice while the D-channel is for control (Gumatse *et al*., 2004).

Telkom does guarantee any throughput speeds up to the connection point (i.e. 64 Kbps for one B–channel; 128 Kbps for two B-channels). However, Telkom does not guarantee any speeds over the Internet. The customer is billed for the connection time when making use of Telkom’s ISDN service to surf the Internet.

Essentially, an ISDN connection consists of three components: the ISDN line itself, the equipment, and the ISP fees. As of May 2006, the Telkom ISDN line rates were R114 on 64 kb and R198 on 128 kb (Telkom South Africa, 2006).

Advantages

ISDN offers improved bandwidth from regular dial- up. The ISDN BRI has speeds of up to 128 Kbps full duplex (2 * 64 Kbps channels). The cost is the same price per call per channel as on a normal phone line. However, rentals are higher than dial-up over POTS. This, however, offers the benefits of broadband Internet access.

Disadvantages

Disadvantaged rural areas have limited wired telecommunication infrastructure (Lowe *et al.*, 2000); this means that ISDN cannot be offered in such places. The laying of underground copper cables or optical fiber and then building exchanges for this can only rectify this. The costs incurred in laying new copper cable or optical fiber is high compared to the potential revenue. The cost of copper cables per 100 kg stands at 444 Euros. This represents quite a high figure in comparison to 100 kg for 163 Euros in 2004 (Drakact Comteq, 2006). A further disadvantage, in the case of DSL, is that it has a maximum reach of approximately only 5 km, which limits its use in either urban or rural areas that are not close to an exchange (DeMartino, 1999). Most exchanges in rural areas are located in the nearest town, therefore affecting the implementation of DSL in rural areas. ISDN is now being replaced by digital subscriber line (DSL) technology in some areas.

3.1.3 Digital subscriber line (DSL)

DSL is a wired access technology that uses regular telephone lines, or POTS, to bring access to homes or businesses. In actuality, DSL offers upload speeds of up to 128 Kbps and download speeds of 1.5 Mbps for individual connections

(Mervana *et al*., 2001). The DSL modem utilizes a highly sophisticated modulation process (like FDM, Echo cancellation, AMI coding) and is well suited for high-speed transmission of audio and video. Thus, with DSL, both data and analogue voice travel over the same piece of copper cable. Voice is transmitted over low bands of frequency, 0 to 4 KHz, while data is transmitted over the higher frequencies, typically 10 Hz to 1 MHz. The performance of DSL also depends on the type of wire and the DSL technology used (Mervana *et al*., 2001).

There are many related technologies, such as asymmetrical DSL (ADSL), symmetrical DSL (SDSL), very high bit rate DSL (VDSL), and many others that are referred to as xDSL technologies.

3.1.3.1 Asymmetrical DSL (ADSL)

ADSL is a wired access communication that can dramatically increase speeds of data communications over typical copper wires, and uses analog signaling and one copper pair. Asymmetrical services provide different speeds between the two ends of the network. In ADSL, the upstream communication is implemented at higher speeds (e.g. 1.5 to 8 Mbps), and asymmetric services are implemented when there are higher data transfers from the server to the client and therefore more bandwidth is needed (Gumatse *et al*., 2004). This makes ADSL particularly suitable for Internet-related communications since it has high speeds. DSL has a local access loop of up to 5.5 km and is therefore not suitable for disadvantaged rural areas. For loops beyond 5.5 km the signal loss at frequencies above 1 KHz is excessive, making voice transmission unacceptable.

ADSL technology can coexist in the same line with normal analogue telephone lines (PSTN) for POTS (0-4 kHz) and ISDN (4-80 kHz). This is done by implementing filters between the line and PSTN devices that filter out the ADSL high-frequency signals from entering those devices.

3.1.3.2 Symmetrical DSL (SDSL and HDSL)

Single-line DSL (SDSL) transports fast digital signals through telephone lines using one copper pair. The transmission speeds for the upstream and downstream communication are the same (symmetry). High data-rate DSL (HDSL) uses two copper pairs.

3.1.3.3 Very high bit rate DSL (VDSL and HDSL)

VDSL provides more bandwidth, with downstream speeds up to 13 to 52 Mbps and upstream speeds of 1.5 to 2.3 Mbps. It is seen as the next step in providing a complete home-communications or entertainment package (Stallings, 2004). VDSL can only operate over the copper pair for a short distance, about 1,200 meters.

In South Africa, the only form of DSL is available from Telkom. The Telkom ADSL product offers speeds of 1024 Kbps, 512 Kbps, 384 Kbps and 192 Kbps (Telkom South Africa Limited, 2005a). This product has seen an increase in demand since customers are demanding speedy and always-available Internet access (Telkom South Africa Limited, 2005b).

Advantages of DSL

DSL allows faster connection to the Internet while utilizing the existing copper cable infrastructure, and still supporting the voice traffic on the same cables. Customers within 5 km of the exchange can enjoy always-on Internet connection provided by DSL products.

Disadvantages of DSL

A major disadvantage of DSL is distance limitation. The 5-km limitation prohibits its use for Internet connectivity in areas outside its coverage. This limits the use of DSL to the areas confined to the local loop. Major problems accompanying use of copper cable in South Africa are theft and bad-quality cables that adversely affect data transmission for the DSL technologies (*Daily Dispatch*, 2005; DeMartino, 1999). The provision of DSL network technologies means that telecommunication companies would need to deploy bridge filters in order to service multiple customers. The filters pose significant challenges to the deployment of xDSL as they result in signal attenuation (Gumatse *et al.*, 2004). This also indicates a making a significant investment to deploy the bridge filters on the network.

DSL is a distance-sensitive technology: as the connection length increases, the signal quality and connection speed decreases. ADSL service has a maximum distance of 5,460 meters between the DSL modem and the DSLAM; though for reasons of speed and quality of service, many ADSL providers place an even lower limit on the distance.

3.1.4 Broadband powerline (BPL)

Modern powerline communication (PLC), also referred to as broadband over power lines, is the process of transmitting a data signal through existing low-voltage (110-240V) or medium-voltage power lines (Mandioma *et al.*, 2004). Medium- and high-voltage PLC have been long-used for point-to-point data communication in power utility industry, offering 64 Kbps, within a distance of up to 400 km. Utilizing the power line as a communication medium is a cost-effective method as it utilizes the existing power line infrastructure. This presents a potential cost-effective method for the last-mile access. However, the major difficulty is the inexistence of the power-line grid in some disadvantaged rural areas of South Africa.

The technologies utilizing this concept differ, and currently the highest deliver speeds of up to 200 Mb/s at the physical layer and 130 Mb/s at the application layer. HomePlug AV standard, which is interoperable with HomePlug 1.0 or Intellon proprietary 85 Mbps Turbo mode is available on the proprietary DS2 technology, based on OFDM modulation with 1,536 carriers and TDD or FDD channel-access method. DS2 technology may operate between 1 and 34 MHz. It provides a high dynamic range (90 dB) and offers frequency division and time-division repeating capabilities. These characteristics allow implementation of quality-of-service (QoS) and class-of-service (CoS) capabilities (*Electrifying the Broadband*, 2005)

There are a variety of end-user modems (customer premise equipments: CPEs) on the market, for example data-only modems, modems with an integrated IP telephone, and modems with a socket into which a normal telephone handset can be plugged. The characteristics of modern PLC modems are very similar to those of DSL modems (Europa Rapid Press Release, 2005).

The lack of reliability of PLC equipment has been the weakest link of the home-controls industry. Nevertheless, manufacturers have moved on to produce better chips, facilitating a better modulation technique. UPB, the next generation of power-line carrier technology, will provide increased functionality and dramatically improved reliability. The aspect of increased reliability is especially important to the sophisticated technologies (Mann, 2004).

PLC is an alternative to Ethernet cable networks and DSL services for supplying broadband to the end-user. The physical coverage of PLC coverage depends on the carrier frequencies in which they operate, as in the case of ASCOM equipment. A distance of 150 to 250 m can be achieved at 2.4 MHz, and at 8.4 MHx the typical distance is in the range of 100 to 200 m. Repeaters can be utilized to extend the system's coverage (ASCOM Powerline Communications

System Manual, 2002). Typically, the commercial offerings are competitive and cheaper than DSL. PLC is not more expensive than other broadband offerings over DSL or cable. In Germany, for instance, PLC is generally offered at the cost of 15 Euro per month — a price below that of the DSL service, which is 17 Euro (Europa Rapid Press Release, 2005).

In South Africa, particularly in places where there is low teledensity, PLC offers the opportunity to deliver telecommunication services to remote areas. According to MyADSL (2006), a pilot project deploying PLC in the Tshwane Metropolitan Area is underway. Goal Technology Solutions (GTS) had finalized its trials in the Tshwane region; they are now ready to roll out commercial services to residential users utilizing the current power grid as an access medium to consumer's homes. The initial service offering will be equivalent to DSL 512, with a 5-GB usage allowance, at an all-inclusive cost of R479 (R420 ex VAT). This is cheaper than the comparable ADSL offering, which costs over R700. Telephone services can also be offered on top of the broadband offering. This will cost the consumer a basic monthly telephony cost of just under R100, while the call costs will be on average around 15% cheaper than Telkom rates (MyADSL, 2006). This signifies yet another large milestone to offer broadband for residential homes in South Africa.

Advantages of BPL

Despite the success of other broadband access methods in South Africa, rolling out BPL can still attain some advantages. Since it uses the existing infrastructure, BPL could mean that low-cost broadband could become a reality in areas that cannot get DSL, cable or wireless broadband; as of 2001, 70% of South African households used electricity for lighting, while 51% used it for cooking (*The Star*, 2004). Even in extremely remote rural areas, one can now potentially get broadband without having to resort to the high-latency satellite broadband, as long as the area is on a power-line grid. The power-distribution grid may be thought of as a PLC LAN; powerline connecting points to the backhaul may use an existing optical fiber network of power utilities or any wireless backbone, for instance worldwide interoperability for microwave access (WiMAX).

A major selling point for the development of BPL for utility companies is that most of the necessary infrastructure is already in place because the technology relies on the existing power grid. This enhances the cost-effectiveness of rolling out BPL. Only the power substation server equipment and customer-conditioning service units need to be installed in order to establish a digital power-line network.

The fact that BPL equipment uses existing power outlets in the home makes it easy and simple to set-up as it is plug-and-play. There is no need for complicated wiring and additional installations, so it is possible to move one’s computer and appliances wherever you want them within a home.

Another potential benefit of BPL is the possibility of its use for smart appliances (Powerline Communications, 2004). The idea behind this is that you can control appliances with your PC. While these devices could potentially be connected with Ethernet to a DSL connection, BPL offers a much neater solution, since a single plug acquires both the device’s electricity and its data. Some have proposed this as an aid for people with mobility problems (*Electrifying the Broadband*, 2005).

Users in rural areas, who cannot receive DSL or cable modem services, can finally look forward to BPL. BPL can be used to provide an all-in-one service that provides telephone, cable television and high-speed data transfer. With such advantages BPL could offer broadband Internet access to remote/rural areas that are on the power-line grid but still lack telephone lines.

Disadvantages of BPL

BPL has some drawbacks. According to NER (2002) 32.1% of the disadvantaged rural areas of South Africa remain outside an electricity grid line. This means BPL will be impossible to implement in these areas. Like all broadband technologies that require the use of high-capacity backbones, there is a large investment involved in providing these high-capacity connections. The capacities provided to each sub-station should be individually considered, depending on the number of potential customers and the levels of broadband uptake in the area. BPL can be implemented in disadvantaged areas once the rural electrification is fully fledged.

The operational condition of the power-line grid places limitations on the performance of BPL (Dornan, 2000). Each substation will require a backbone connection to provide customers with significant bandwidth. However, the amount of bandwidth available between a substation and the homes or premises connected to it must be shared, which may bring contention. Like DSL, BPL will be contention-based, though the level of contention will depend on how many customers are connected to one substation and also on how many of the customers are benefiting from the service. Likewise, subscriber bandwidth will be determined by the number of customers connected to the substation (Flood *et al*., 2005).

The designers and consumers may have concerns over the security provided when using BPL. The power cables are not twisted and use no shielding, which means power lines produce a fair amount of electro-magnetic interference (EMI). Such EMI can, with little work, be received via radio receivers (Flood *et al.*, 2005). Thus, encryption must used to prevent the interception of sensitive data by unauthorized personnel.

3.1.5 Optical fiber

An optical fiber is a plastic or glass (silicon dioxide) fiber designed to transmit information using infra-red or even visible light as the carrier (usually a laser). The light beam is an electromagnetic signal with a frequency in the range of 10^14 to 10^15 Hz. There are two basic types of fiber: single fiber (5 to 10 micrometers) and multimode fiber (50 to 100 micrometers) (Shay, 1990).

Optical fiber is composed of three main components: the core, the cladding, and a buffer layer. The core is composed of glass (silicone dioxide) or plastic, and the cladding material that surrounds the core is also made from glass or plastic but is optically less dense than the core. The buffer layer protects the cladding and core against ultraviolet light and gives the cable rigidity (SiewHung Tee, 2002).

Light travels through the fiber through a process called total internal reflection (TIR); this is made possible by using two types of glass which have different refractive indexes. The inner core has a high refractive index and the outer cladding has a lower index. TIR states that when the angle of incidence exceeds a critical value, light cannot get out of the glass: instead, the light bounces back inside (ARC Electronics, 2001). This principle allows information to be transmitted down fiber lines in the form of light pulses.

Optical fiber cables can be divided into two classes based on their modal properties: single-mode fiber or multi-mode fiber. Single-mode fiber has a smaller core than multi-mode fiber. This allows only one mono-frequency signal to be transmitted at a time. Multi-mode fiber has a larger core, which allows hundreds of signals to pass through the fiber simultaneously. The single mode can keep every light pulse over a longer distance, since its degradation is very small, allowing it to have a very tuned bandwidth (Arumugam, 2001), and this allows high throughput. These features make the single-mode fiber an ideal source for transmission for any long-distance applications, and multi-mode is preferred for communication over short distances (e.g. within buildings). Continuous developments are still occurring in the development of optic fibers with higher data rates.

Advantages of optical fiber

Optical fiber solves some of the limitations otherwise inherent with copper cables, including copper cables' susceptibility to external noise, lightning strikes, and signal loss when transmitting data over long distances. Thus, optical fiber is resistant to electrical noise, while having the capacity to transmit enormous amounts of data. Furthermore, optical fiber is also difficult to tamper with, making it appropriate for more secure communications. These features have contributed to telecommunication companies' use of optical fibers for their backbone networks (Shay, 1990).

The bandwidth of a fiber optics cable is 100 to 1000 MHz, as compared to a copper wire, which can handle only 3 to 20 MHz. This relatively large bandwidth allows many applications and uses (SiewHung Tee, 2002). For example, a video signal has a bandwidth of 5 MHz; therefore it is possible to send 20 to 200 video signals on a signal fiber optics cable, which is impossible with copper wire. In fact, by using digital compression techniques it is possible to modulate 500 to 1000 video signals on a single fiber optics cable.

Their light weight and small size also make optic fiber cables ideal for applications where running copper cables would be impractical; and by using multiplexers one optic fiber cable could replace hundreds of copper cables (Arumugam, 2001). This is impressive for a tiny glass filament, but the real benefits in the data industry are the fiber's immunity to EMI, and the fact that glass is not an electrical conductor. Since the fiber is non-conductive, it can be used where electrical isolation is needed, for instance between buildings where copper cables would require cross bonding to eliminate differences in earth potentials.

Increasing the transmission capacity of wire cables generally makes them thicker and more rigid. Such thick cables can be difficult to install in existing buildings where they must go through walls and cable ducts. Fiber cables are easier to install since they are smaller and more flexible; they can also run along the same routes as electric cables without picking up excessive noise.

One way to simplify installation in existing buildings is to run fiber cables through ventilation ducts. However, fire codes require that such plenum cables be made of costly fire-retardant materials that emit little smoke. The advantage of the fiber types is that they are smaller and hence require less of the costly fire-retardant materials. The small size, lightweight and flexibility of fiber optic cables also make them easier to use in temporary or portable installations.

Disadvantages of optical fiber

Optical fiber is renowned for its efficiencies, yet it has drawbacks in terms of system configuration. Converting existing hardware and software for the use of optical fiber takes substantial time and money, which in turn will reduce the turnover for any profit-making firm in the market.

The use of optical fiber in LANs is not widely done because implementation would require many changes in the current networks and systems. The cost of the change in the hardware and software technology to make the LAN run efficiently would add up to an expensive package. As can be seen, optical fiber costs more than ordinary wires, making ordinary wires a cheaper alternative for rolling out networks in rural areas (Shay, 1990). Still, the current cost of optical fiber outweighs the transmission rates and distance coverage into the disadvantaged rural areas.

3.2 Wireless media access technologies

This section considers alternative technologies, namely wireless media access technologies. These utilize electromagnetic waves to carry the signal. Wireless technologies represent a rapidly emerging area for providing Internet connectivity where there is lack of fixed infrastructure or where there is a need for mobility. These technologies can often provide support to the institution mission and provide cost-effective solutions. Important factors to consider are throughput, cost, reliability and maintenance when evaluating wireless media access technologies for deployment in rural areas:

- Throughput: The actual throughput in wireless access technology is product- and set-up dependent. Factors that affect throughput include the number of users, propagation factors such as physical range and multi-path, the type of wireless system used, as well as the latency and bottlenecks on the wired portions of the LAN. In the case of rural areas, throughput should be able to allow for web browsing, e-mail and other minimal applications, such as voice-over Internet protocol (VoIP).

- Cost: Wireless gear costs more than the equivalent wired Ethernet products. At full retail prices, wireless adapters and access points may cost three or four times as much as Ethernet cable adapters and hubs/switches, respectively. IEEE802.11b products have dropped in price considerably with the release of IEEE802.11g, and bargain sales can be found if shoppers are persistent. Mobile cellular phones also offer alternative access to the Internet. In South Africa, Vodacom, MTN and Cell C have 90% coverage of the country (Vodacom South Africa, 2005a). This allows for easy access through mobile phones that have GPRS, EDGE, and WAP technologies embedded in them. The cost of data per megabyte remains R2 from both networks (Vodacom South Africa, 2007a; Mobile Telephone Network, 2007). The use of WiMAX as an access technology remains expensive. The technology was adopted in 2001, and prices have remained high, but should drop as more vendors begin to manufacture these products. The adoption of wireless technologies would depend on the prevailing circumstances in a rural area so as to be considered as an alternative access technology.

- Reliability: Reliability refers to the ability of a network to provide a consistent level of service (Castaneda *et al.*, 2006). In wireless access technologies, reliability is a major challenge since the physical medium is often unpredictable (Van Rensburg, 2007). This makes wireless access technologies more susceptible to problems than are wired LANs. The IEEE802.11b and IEEE802.11g wireless signals are subject to interference from other home appliances, including microwave ovens, cordless telephones, and garage door systems. With careful installation, the likelihood of interference can be minimized. Wireless networking products, particularly those that implement IEEE802.11g, are comparatively new. As with any new technology, we can expect it will take more time for these products to mature.

- Maintenance: Maintenance of wireless access technologies is mostly done with the aid of software that monitors the state of the access point. The software is also useful for trouble-shooting, thus making it easier to diagnose problems within the network. The wireless local area network (WLAN) would require low maintenance and simple configuration. The addition of basic security WLAN, such as wireless encryption protocol (WEP), would prevent unauthorized access. This is the case with the small home/office environment (Van Rensburg, 2007). In large organizations the deployment of other security tools, such as RADIUS server, would prevent unauthorized access.

3.2.1 IEEE 802.11 wireless fidelity (WiFi)

This is a family for wireless LAN (WLAN) standards developed by a working group of the Institute of Electrical and Electronics Engineers (IEEE) LAN/MAN Standards Committee (IEEE 802). These standards define an over-the-air interface between a wireless client and a base station (or access point), or between two or more wireless clients. The specifications in the family utilize CSMA/CA As a path-sharing mechanism (Belloti *et al*., 2001).

The IEEE 802.11 architecture consists of several components that interact to provide a wireless LAN. The coverage area (also known as the basic service set [BSS]) is the basic building block of an IEEE 802.11 LAN. Within coverage area of the BSS, stations (i.e. a station is any device that contains an IEEE 802.11-conforming MAC and PHY interface to the wireless medium) may communicate directly with other members of the BSS. If a station leaves the BSS, communication between the two will cease to exist. Members in the coverage area are associated with an access point (AP) (Belloti *et al*., 2001); the APs are the stations that provide access to the distribution system, allowing data to move from the coverage area of the AP to the distribution system, via the AP (Baghaei *et al*., 2004).

The IEEE 802.11 standard was designed to address wireless local area coverage. The standards developed are differentiated by an alphabetic suffix. These are 802.11, 802.11a, 802.11b, and 802.11g, each operating on different frequency bands, with devices that do not interfere with one another.

802.11 – This is the basic standard that applies to wireless LANs; it provides 1 or 2 Mbps transmission in the 2.4 GHz band (the same used by many cordless phones), using either frequency-hopping spread spectrum (FHSS) or direct-sequence spread spectrum (DSSS). FHSS is a technique that uses a time-varying narrowband signal to spread a radio frequency signal over a wide band, while DSSS is a transmission technique that spreads a signal over a wide-frequency band. At the receiver, the widespread signal is correlated into a stronger signal; meanwhile any narrowband noise is spread widely (CyberScience, 2003).

802.11a – This is an extension to 802.11, which applies to wireless LANs, and provides up to 54 Mbps in the 5 GHz band (IEEE Standard for Information Technology, 2003). The standard 802.11a uses an orthogonal frequency division multiplexing (OFDM) encoding scheme rather than FHSS or DSSS. OFDM technology uses sub-carrier optimization, which assigns small sub-carriers to users based on radio frequency conditions. Orthogonal means that the frequencies into which the carrier is divided are chosen such that the peak of one frequency coincides with the nulls of the adjacent frequency (Intel, 2005).

802.11b – This is another extension to 802.11 and applies to wireless LANS and provides 11 Mbps transmission (with a fallback to 5.5, 2 and 1 Mbps) in the unlicensed industrial scientific medical (ISM) equipment frequency at the 2.4 GHz band. This is an unregulated frequency band, such that there are interferences from appliances utilizing the same range. The standard 802.11b uses only DSSS. In 1999, the standard 802.11b was ratified to the original 802.11 standard, allowing wireless functionality comparable to Ethernet.

802.11g – This further extends 802.11, combining the best of both 802.11a and 802.11b; it utilizes OFDM as the modulation technology. 802.11g provides additional payload data rates 6, 9, 12, 18, 24, 36, 48 and 54 Mbps, and it uses the 2.4 GHz frequency for greater range (IEEE Standard for Information Technology, 2003). The 802.11g is backwards-compatible with 802.11b. This allows 802.11g-access points to work incompatible with 802.11b wireless network adapters without causing problems.

802.11n – This is a high throughput standard currently under development by the IEEE. 802.11n builds upon previous 802.11 standards by adding multiple-input multiple-output (MIMO). MIMO uses multiple transmitter and receiver antennas to allow for increased data throughput. The scope of IEEE 802.11 Task Group n (802.11 TGn) is to define modifications to the physical layer and medium access control layer (PHY/MAC) that deliver a minimum of 100 Mbps throughput at the media access control layer/service access point (MAC SAP) (Wilson, 2004). In May 2007, draft 2.02 was accepted.

Gigabit WLAN – These seek to provide the same throughput and quality of service (QoS) as wired LANs. This is because WLAN data performance has lagged behind. The project Wireless Gigabit with Advanced Multimedia (WIGWAM) aims to close the gap between WLANs and wired LANs with a heterogeneous 1 Gb/s fourth-generation system based on high data-rate orthogonal frequency-division multiplexing (OFDM) transmission, MIMO, and efficient MAC protocol techniques. This project was started in 2004 and is expected to finish in 2007 (Ebert *et al*., 2005).

Table 3.1: Wireless LAN Standards Chart

802.11	The original WLAN standard; supports 1 to 2 Mbps.
802.11a	High-speed WLAN standard for 5 GHz band; supports 54 Mbps.
802.11b	WLAN standard for 2.4 GHz band; supports 11 Mbps.
802.11d	International roaming: automatically configures devices to meet local RF regulations.
802.11e	Addresses quality-of-service requirements for all IEEE WLAN radio interfaces.
802.11f	Defines inter-access-point communications to facilitate multiple-vendor-distributed WLAN networks.
802.11g	Establishes an additional modulation technique for the 2.4 GHz band; supports speeds up to 54 Mbps.
802.11h	Defines the spectrum management of the 5 GHz band.
802.11i	Addresses the current security weaknesses for both authentication and encryption protocols; the standard encompasses 802.1X, TKIP, and AES protocols.
802.11n	Provides higher throughput improvements; intended to provide speeds up to 500 Mbps.

Advantages of WiFi

The use of IEEE 802.11standards comes with several advantages in the mission of providing Internet connectivity. These include such issues as cost, interoperability and standardization. Deployment without cables potentially reduces the costs of network deployment and expansion. Areas where cables cannot be run, such as outdoor areas can host wireless LANs thereby aiding in our goal for connectivity in every space. Further to that is the cost of WiFi adapters has been lowered down considerably since their inception because of competition between vendors.

WiFi is a set of global standards allowing interoperability between different brands of access points and client network interfaces at a basic level of service (Baghaei *et al.*, 2004). This makes deployment of such networks cost effective and easy to deploy. Where the infrastructural costs of deployment of wired connectivity tend to be high and the potential revenue is low, wireless has been the best solution (Gumatse *et al*., 2004). This is mostly the case with connectivity in disadvantaged rural areas.

Disadvantages of WiFi

IEEE 802.11 has drawbacks associated with the use of this technology. Because this is WLAN technology, it is not particularly suitable for covering distances longer than 100 m (LAN/MAN Standards Committee of the IEEE Computer Society, 1999). However, WiFi is still not good enough to offer backhaul connectivity. This becomes a problem particularly with our mission for connectivity of a disadvantaged rural area. DSL or ISDN becomes a better alternative since these offer better reliability.

The issue of licensing in South Africa affects the use of IEEE 802.11. This is only permitted when you are a holder of a carriers' license (Republic of South Africa Telecommunications Act No. 103, 1996). Currently, Telkom and SNO are the only holders of such a license, but there are no products on offer at the moment. Sentech has a unique multimedia license that has allowed it to offer wireless

Internet connectivity. Sentech offers wireless Internet packages that are available only in the major cities in South Africa (Sentech, 2005).

Interference on the industrial scientific and medical (ISM) band is a major factor affecting the deliverance of IEEE 802.11. Interference tends to be substantial in this band, as household appliances operate in the 2.4 GHz band. Further to that, WiFi was designed for short-range operations and is basically an indoor technology. Thus, it is not a suitable technology for long ranges.

3.2.2 IEEE 802.16

IEEE 802.16 is a standards-based wireless technology that provides high-throughput broadband connections over long distances of up to 50 km (Gabriel, 2003; LAN/MAN Standards Committee of the IEEE Computer Society, 2004; Intel, 2006). It can be used for a number of applications, including last-mile broadband connections, hotspots, cellular backhaul and high-speed enterprise connectivity for business. This has certain conformity and interoperability tests for the IEEE 802.16 family standards.

The IEEE 802.16 specification was the first interface standard for broadband wireless access systems, approved in 2001. This utilizes point-to-multipoint (PMP) infrastructure designs operating at radio frequencies between 10 and 66 GHz addressing issues in the line-of-sight (LOS) environment (Worldwide Interoperability for Microwave Access Forum, 2003). The WiMAX base stations (BS) can offer greater wireless coverage of about 5 miles with LOS transmission, within a bandwidth of up to 70 Mbps (Wei *et al*., 2005). When the signal is propagated through the air there is an increase in attenuation; this occurs due to the amplitude of the wave changes. Trees and buildings are also problematic, contributing to signal degradation (Sweeny, 2004), but the IEEE 802.16 addressed the LOS environment. This led to the amendment of 802.16

(extension 802.16a) standards for use between 2 and 11 GHz, which provides support for non-line-of-sight (NLOS) operation at the lower frequencies, which is not possible in higher bands (Anderson, 2001).

HiperMAN is the ETSI standard-based equivalent of WiMAX (802.16.a) and it provides broadband wireless MAN connectivity to fixed, portable and nomadic users (Intel, 2006). This was achieved through the introduction of three new PHY layer specifications (i.e. new single-carrier PHY, a 256-point fast Fourier transformation [FFT] OFDM PHY and a 2048-point FFT OFDMA PHY). The orthogonal frequency division multiplexing (OFDM) signaling format has the ability to support NLOS performance while maintaining a high level of spectral efficiency, maximizing the use of available spectrum (Nuaymi, 2007). The other attributes of the PHY-layer features of 802.16a that enable the technology to deliver robust performance in a broad range of channel environments are: flexible channel widths, adaptive burst profiles forward error correction, with concatenated Reed-Solomon and convolutional encoding. The optional advanced antenna system (AAS) is responsible for the improvement in regard to range/capacity. Dynamic frequency selection helps in minimizing interference while space-time coding enhances performance in fading environments through spatial diversity (Wei *et al*., 2005).

The WiMAX-based solution is set up and deployed like cellular systems, using base stations that service a radius of several miles/kilometers. The most typical WiMAX-based architecture includes a base station mounted on a building, and it is responsible for communicating on a point-to-multipoint basis, with subscriber stations (the customer premise equipment CPE) located in business offices and homes. Voice and data from CPE are then routed through standard Ethernet cable, either directly to a single computer, or to an 802.11 hot-spot or a wired Ethernet LAN (Burrows *et al.*, 2005). As noted above, the IEEE 802.16 can easily be integrated into most networks.

The 802.16d is the fixed WiMAX standard IEEE 802.16-2004, approved by the IEEE in June 2004. It provides fixed, point-to-multipoint, broadband wireless access service, and its product-profile utilizes the OFDM 256-FFT system profile (IEEE 802.16d, 2004).

In December 2005, the IEEE approved the mobile WiMAX standard, the 802.16-2005 (also known as 802.16e). The IEEE 802.16e is based on the early WiMAX standard 802.16a, adds mobility features to WiMAX in the 2 to 11 GHz-licensed bands. 802.16e allows for fixed wireless and mobile NLOS applications, primarily by enhancing the orthogonal frequency-division multiple access (OFDMA).

IEEE 802.16f – Management Information Base for Fixed Services is an amendment to IEEE Standard 802.16-2004 which provides enhancements to IEEE Standard 802.16-2004. It defines a management information base (MIB) for the MAC and PHY and associated management procedures (IEEE 802.16f, 2005).

IEEE 802.16g – Management Plane Procedures and Services (amendment under development). This is an amendment to IEEE Standard 802.16-2004, which provides enhancements to the MAC and PHY management entities of IEEE Standard 802.16-2004, as amended by P802.16e, to create standardized procedures and interfaces for the management of conformant 802.16-devices (IEEE 802.16g, 2005).

Advantages of IEEE 802.16

The IEEE 802.16 has several advantages, especially in our mission of offering backhaul connectivity for a rural area outside PSTN coverage.

- The WiMAX standard recovers from many of the limitations of WiFi, thus providing increased shared bandwidth, larger coverage, and stronger encryption (triple-data-encryption standard [3DES] or advanced encryption standard [AES]), and it aims to provide connectivity between the endpoints of a network without the necessity of direct LOS (*Airband*: *WiMAX: Navigating Between Hype and Reality,* 2007). This makes WiMAX an enhanced wireless technology.

- Continuous quality of service (QoS): This is built into the WiMAX MAC layer (WiMAX Forum, 2004). It provides essential support for applications such as voice-over IP (VoIP), which requires QoS for effective operation. This was found to be lacking in the earlier 802.11 standards (IEEE Std 802.11, 1999), and it has only been recently added to the 802.11e amendment (IEEE Std 802.11e, 2005).
- WiMAX is a WAN/MAN technology designed to provide up to 50 km of coverage with a throughput of 70 Mbps, making it the most ideal access technology for rural Internet connectivity (Wei *et al.,* 2005; Sweeny, 2004).
- Throughput and performance are optimal within the typical cell radius of up to 10 km (Intel IEEE 802.16 and WiMAX).
- WiMAX will be able to connect to IEEE 802.11 (WiFi) hotspots to the Internet and provide a wireless extension to cable and DSL for last-mile broadband access. Also, a high tower is not needed for achieving adequate 5-km coverage in rural settings; and a single sector (Tx/Rx radio pair) of 20 MHz of a BS may simultaneously connect more than 60 businesses with T1-level connectivity and hundreds of homes with DSL-rate connectivity (Intel, 2005).
- The ability to quickly offer service, even in areas that are hard for wired infrastructure to reach, helps operators to overcome problems associated with connectivity in remote, disadvantaged areas (Burrows *et al.*, 2005). This is one major advantage, especially in our mission of providing rural connectivity.
- Greater reliability, since the technology is more robust and will improve network performance. The WiMAX equipment is able to manage spectrum

much more efficiently in a more automated fashion to eliminate potential interference issues (*Airband*: *WiMAX: Navigating Between Hype and Reality,* 2007).

The advantages of IEEE 802.11 are similar to those of WiMAX. But one other advantage associated with fixed broadband wireless access over wired access technologies is the cost. The high costs from cables and the labor-intensive deployment of cables makes fixed broadband wireless access technology a cheaper option. WiMAX is also able to offer cost-efficient service supply in areas where traditional xDSL is not suitable due to a small number of customers per digital subscriber-line access multiplexer (DSLAM). These merits make WiMAX an access technology that can offer FBW services to disadvantaged rural areas in South Africa.

Limitations of IEEE 802.16

- IEEE 802.16 can offer Internet connectivity for long distances up to 50 km; however, there are drawbacks associated with the technology. Other wireless technologies operating in the vicinity can interfere with the WiMAX connection and cause a reduction in data throughput (*WiMAX Technology Brief*, 2005). The issue of transmission being affected by atmospheric conditions, such as rain, affects WiMAX performance. Buildings and trees attenuate the signal, contributing to signal degradation (Sweeny, 2004). This affects the performance of WiMAX technology overall.
- LOS is required for long-distance connection (5 to 30 miles) (*WiMAX Technology Brief*, 2005). Without LOS backhaul, connectivity is not possible for such long distances.
- The data rates being offered by WiMAX are not as high as some wired access counterparts, such as optical fiber (Sweeny, 2004).

- Currently, pre-WiMAX products are available on the market. This means time is needed for WiMAX to mature and offer products that offer long-distance connectivity.
- In South Africa, at present, few companies offer WiMAX products. Rather, they must be shipped from outside the country. Although the cost is still high, this should come down once these products are manufactured locally.

3.2.3 Mobile **wireless cellular systems**

Various wireless cellular technologies have been and are in use for data transfer in cellular systems. The main difference between the mobile wireless cellular systems and the IEEE 802-based technologies can be found in the extent of coverage, services, and therefore users and scale of mobility (Lahti, 2000). Currently, third-generation (3G) mobile wireless technology is in use. The 3G, as the name suggests, has evolved from first generation (1G) to second-generation (2G) wireless mobile phone service (MPS) technology. This progression has been based on frequency-division multiple access (FDMA) technology, allowing telephone-roaming services in USA (Dornan, 2002). The FCC licensed two operators in each market to offer AMPS services, in the 800 to 900 MHz band. However, the data rates provided were limited to less than 10 Kbps (Lehr *et al.*, 2003).

The 1990s saw the beginning of mobile services based on digital mobile technologies, the 2G. These were referred to as personal communication systems (PCS) in the United States. The technologies made use of time-division multiple access (TDMA), code-division multiple access (CDMA), and the global system for mobile communications (GSM) (Rhyn, 2005). CDMA and TDMA were deployed in the United States, while GSM was deployed in Europe and in South Africa. The data rates offered by these technologies are limited to between 10 and 20 Kbps (Lehr *et al.*, 2003).

The 2.5G networks are an extension of the 2G system. The 2.5G radio transmission technology is radically different from 2G technology as it uses packet-switched connection and enhanced data rates. The 2.5G includes general packet radio service (GPRS), enhanced data rates for GSM evolution (EDGE) and CDMA (Anderson, 2001). In GSM operation it became evident that the circuit-switched bearer services were not particularly well suited for certain types of applications with a bursty nature. Furthermore, the circuit switched connection has a long access time to the network, with calls based on connection time. The GPRS system, which is a packet-switched network, does not reserve resources permanently, but makes use of a common pool, highly efficient in applications of a bursty nature (Halonen *et al.*, 2003).

The GPRS system brings the packet-switched bearer services to the existing GSM system. In the GPRS system, the user can access the public networks directly, using their standard protocol addresses (IP, X.25), which can be activated when the mobile station is attached to the GPRS network. The GPRS mobile station can use up to eight channels, which are dynamically allocated when the mobile station has packets sent or received. The uplink and downlink channels are reserved separately, making it possible to have a mobile station with various uplink and downlink capabilities. Resource allocation is dynamic and dependent on demand and resource availability. Packets can also be sent on idle time between speech calls. It is possible to communicate point to point (PTP) or point to multipoint (PTM). The system also supports the SMS and anonymous access to the network. Theoretical maximum throughput is 160 Kbps, utilizing all eight channels, without error correction (Anderson, 2001).

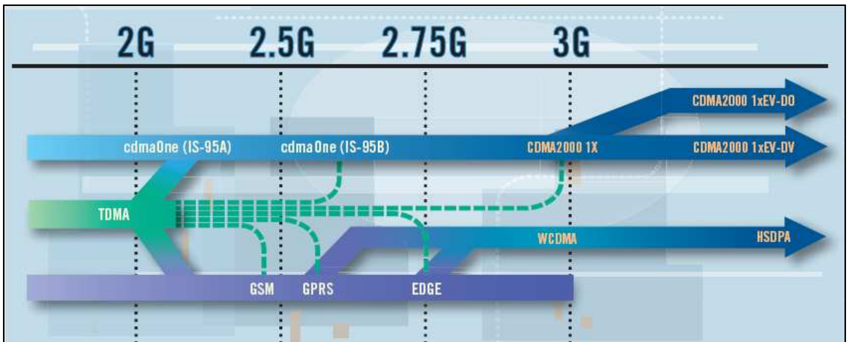
EDGE is a major enhancement of the GSM data rates. It is a superset to GPRS and can function on any network that has GPRS deployed on it, provided the carrier implements the necessary upgrades. EDGE provides enhanced GPRS

(EGPRS), which can be used for any packet-switched applications, such as high-speed Internet connection. High-speed data applications, such as video services and other multimedia benefits, from EGPRS-increased data capacity. The introduction of the octagonal-phase shift-keying (8PSK) allows the tripling of data rates on the existing Gaussian minimum shift keying. EDGE produces a 3-bit word for every change in carrier phase. This effectively triples the gross data rate offered by GSM. EDGE, like GPRS, uses an adaptation algorithm that adapts the modulation and coding scheme (MCS) according to the quality of the radio channel, and thus the bit rate and robustness of data transmission. Incremental redundancy is a technology that, instead of retransmitting disturbed packets, sends more redundancy information to be combined in the receiver in use in EDGE. This increases the probability of correct decoding (Halonen *et al.*, 2003).

The 3G of mobile services is based on the International Telecommunication Union (ITU) International Mobile Telecommunications' (IMT, 2000) family of 3G mobile standards. The aim of IMT-2000 is to harmonize worldwide 3G systems to provide global roaming. The 3G standards include: time-division synchronous code-division multiple access (TD-SCDMA), code-division multiple access 2000 (CDMA2000), and wideband code-division multiple access (WCDMA)/universal mobile telecommunication services (UMTS). The 3G systems can achieve high data rates of up to 2 Mbps in indoor environments and pico-cellular environments, and about 144 Kbps in macro-cellular environments (Chitamu *et al.*, 2006).

High-speed downlink packet access (HSDPA) is a protocol for mobile telephone data transmission. It is a packet-based technology for WCDMA downlink, with data transmission of 4 to 5 times that of 3G networks (UMTS), and 15-times faster than GPRS, over a 5 MHz bandwidth (Kolding *et al.*, 2003). The HSDPA concept is applicable to a transport channel, which is intended to carry interactive, background and optionally streaming traffic. The system utilizes advanced technologies, such as adaptive modulation and coding (AMC), hybrid automatic request (HARQ), fast-packet scheduling, and advanced receiver design (Jose, 2003).

CDMA2000 is a family of 3G mobile standards that offers enhanced voice and data capacity higher than the 2G. The family includes CDMA2000 1x and CDMA200 1xEvolution–Data Optimized (CDMA2000 1xEV-DO). CDMA2000 1X delivers a system capacity of 26 Erlangs (of voice traffic per sector in a 1.25 MHz channel), and this capacity is expected to double with the inclusion of the selectable-mode vocoders (SMV) and dual-receive diversity techniques (Halonen *et al*., 2003). CDMA2000 1xEV-DO offers broadband data speeds to support applications such as VPN access, video downloads and large file transfers. The CDMA2000 1xEV-DO network can deliver average download data rates between 600 K and 1200 Kbps, with peak data rates of 2.4 Mbps (Chitamu *et al.*, 2006). Figure 3.1 depicts the generations of mobile wireless technologies and how they have evolved over time.



[1] "Spectrum" is a continuous range of frequencies. Frequencies are usually referenced as hertz [Hz], kilohertz [kHz] or megahertz [MHz]. For example, 30-300 Hz is a range of frequencies. And 30-300 Hz, 300-3000 Hz, 3-30 kHz, 30-300 kHz and 300-3000 kHz make up a spectrum.

Figure 3.1: Mobile cellular systems (source: Halonen et al., 2003).

High-speed uplink packet-access (HSUPA) is a data access next-step evolution for UMTS networks. The technology, which is also known as FDD enhanced uplink (EUL), has been introduced in release 6 of 3GPP standards. The purpose of HSUPA is to enhance uplink-packet data transmission by achieving data rates of up to 5.76 Mbps. Moreover, HSUPA will increase uplink capacity and reduce latency. A combination of HSDPA and HSUPA is especially beneficial, since it will allow optimized packet data transfer in downlink and uplink.

Advantages of mobile wireless cellular systems

The mobile wireless cellular systems have 90% coverage in South Africa from the three mobile cellular companies (Vodacom, Cell C and MTN) (Vodacom South Africa 2005a; Mobile Telephone Networks, 2005). This makes it an access technology that is readily available and which can be utilized for rural connectivity. Also, considering that there are more mobile cell phone subscribers than fixed-land-line subscribers in South Africa, this makes mobile cellular an ideal access technology (Jensen, 2001).

The key architectural features of the 3G standards (which includes converged network for voice and data using multimedia services) overcome problems of using separate networks for different services (Anderson, 2001). This allows for the provision of one network that is able to deliver a bundle of telecommunication services in rural area. The bulk of the mobile cell phone infrastructure already exists in these areas. Regarding rural connectivity in disadvantaged rural areas of South Africa, with the merits of mobile cellular systems, this is a technology that should to be utilized.

Disadvantages of mobile wireless cellular systems

The inexistence of some technologies in the network coverage in rural areas makes it difficult to get high data rates. In South Africa, 3G coverage is only available in major cities (e.g. Johannesburg, Sandton, Pretoria, Durban, Cape Town, Sun City, Midrand, Port Elizabeth and Bloemfontein) (Mobile Africa, 2005), from two cellular phone network service providers (MTN and Vodacom). In wireless technologies offering connectivity in areas where 3G is not available, the data rates remain relatively low. GPRS offers data rates of 384 Kbps, which is quite low, compared to some of the wireless and wired technologies. The small screens on mobile phones are not user friendly; they make content viewing difficult. This presents a challenge for Internet access to rural residents. However, the question of availability of this access technology in the rural areas remains.

3.2.4 Satellite communication

Satellite technology has become a flexible and cost-effective solution for domestic and international networks, irrespective of geographic location. Satellites offer the ability to service many users and the means to solve the issue of expensive last-mile connectivity. Satellite technology can be an access technology for connecting some of the most complicated access problems (Hadjitheodosiou *et al.*, 1999). Satellite systems can be classified according to orbit altitude, as follows (Meldrum, 2003):

- GEO or geostationary earth orbit, approximates an altitude of 35,000 km;
- MEO or mid-altitude earth orbit, approximates an altitude of 10,000 km;
- LEO or low-altitude earth orbit, approximates an altitude of less than 1,000 km.

LEOs can be further subdivided into Big LEO and Little LEO. The Big LEOs offer voice, fax, telex, paging and data capability, while the Little LEOs offer data capability only, either on a real-time direct readout basis, or as a store and forward service.

The size of the satellite footprint decreases as the orbit gets lower. The footprint is the geographical area that the satellite can transmit to, or receive from. The LEO and MEO systems require larger constellations than do GEO satellites in order to achieve global coverage and avoid data delays. Less energy is required for LEO and MEO satellite communication, however, because of shorter average distance between transmitter and satellite (Meldrum, 2003). The GEO and MEO systems are best suited for wide area networks (WANs).

Satellites are essentially space-based, receiving and transmitting radio signals. It sends electromagnetic waves, carrying information over great distances, without using wires. An orbiting satellite receives radio-frequency signals from a satellite dish on earth. It then amplifies the signal, changes the frequency, and re-transmits them on a downlink frequency to one or more earth stations.

The satellite architecture allows communication data to pass through the satellite using a signal path known as a transponder. Satellites have between 24 and 72 transponders. These transponders are shared between customers in a demand access environment, or segments of capacity may be dedicated to an individual customer, depending on customer application. This allows satellites to transmit any kind of content, from simple voice or data, to the most complex and bandwidth-intensive video, audio or Internet content (Rhyn, 2005).

Satellite capacity is a combination of bandwidth and power and is measured in units of Hertz (cycles per second). There is a relationship between the amount of bandwidth and the amount of power available from the satellite. Each transponder has a maximum amount of power and a maximum amount of bandwidth available to it. Conversely, a customer with a large antenna may use all the bandwidth available but still have power available. There is a need for service providers to work with their customers to design a transmission plan that optimizes the power and bandwidth required (Hadjitheodosiou *et al.*, 1999).

Satellite capacity can be shared among multiple users or can be dedicated to individual customers. There are methods of transmission which offer different capacity. In frequency-division multiple access (FDMA) each user is assigned a different frequency upon which to transmit. Many users can simultaneously share the satellite. FDMA has been use in ‘bent-pipe’ satellites for the up-and-down links of analogue signals, such as generated by telephone conversations. Time-division multiple access (TDMA) users are assigned positions in a quickly repeating schedule for transmitting on a common frequency on the satellite (Meldrum, 2003). FDMA is attractive for earth stations since an amplifier in an FDMA system operates continuously, while an earth station transmitting with TDMA requires a higher burst power and a correspondingly more expensive amplifier (Milas, 2004). In a TDMA system the time-slot plan can be changed dynamically to accommodate varying demands (Rhyn, 2005).

If time-division multiplexing (TDM) is used then there is only one signal that needs to be amplified, which results in no inter-modulation products. A satellite producing a TDM downlink transmits essentially continuously. FDMA is then economically preferable for uplinks to reduce earth-station cost, while TDM is preferred for downlinks to reduce satellite costs (Hadjitheodosiou *et al.*, 1999).

All satellite communications are sent to, and received from, the satellite using earth stations or antennas. The earth stations range in size from large telecommunication carrier dishes to very small aperture terminals (VSAT) (Rhyn, 2005).

3.2.4.1 VSAT

VSAT (very small aperture terminal) refers to a small earth-fixed earth station (typically 0.75 to 2.4 m), which provides the vital communication link required to set up a satellite-based communication network. The small earth station operates in conjunction with a larger hub (typically 6 to 9 m) earth station acting as the network management centre. The VSAT station is made up of two separate sets of equipment: the outdoor unit (ODU) and the indoor unit (IDU). The outdoor unit is the VSAT interface to the satellite, while the IDU is the interface to the customer's terminal or local area network (LAN) (Maral, 2003).

The ODU consists of the antenna system and the electronics package containing the transmitting amplifier, the low noise receiver, the up-and-down converters, and the frequency synthesizer. Figure 3.2 illustrates the electronics container.

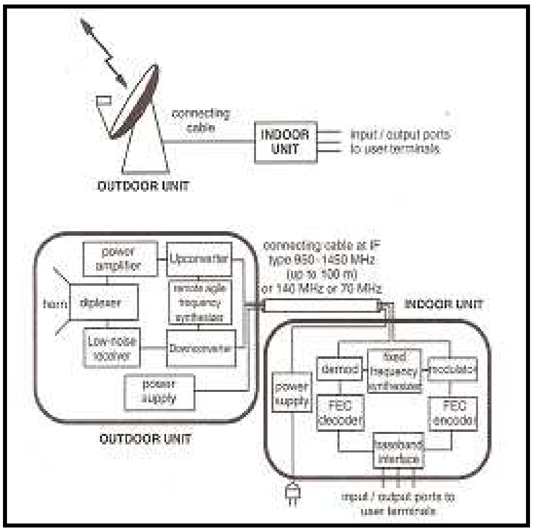


Figure 3.2: VSAT station equipment (Maral, 2003).

VSAT technology represents a cost-effective solution for users seeking an independent communications network connecting a large number of dispersed sites. The network is capable of offering satellite-based services capable of supporting the Internet, data, LAN, and voice/fax communications (Rhyn, 2005). Some of the telecommunication applications in which VSAT is being used include: Internet/Intranet access, corporate networks, SCADA/ine monitoring, rural telecoms, environmental monitoring, distance learning, seismic monitoring, telemedicine, utility monitoring and various other applications.

Advantages of VSAT technology

The cost and security advantages of satellite bandwidths compared with terrestrial networks will cause the number and diversity of VSAT networks to continue to grow. The mining, construction and oil and gas industries are typical examples of applications that have found the advantages of utilizing the VSAT. Advantages from the use of VSAT technology are:

- One single network to all sites, allowing cost-sharing in the maintenance of the network within different sites, making the load lighter.
- Full availability of all sites on the same networking, allowing resources to be shared within the same network.
- Flexible network topology that is easy to add or relocate to other sites.
- Transmission costs are not distance dependent as with terrestrial networks.
- Predictable costs in the deployment and maintenance of the system.
- One point-of-contact for all network issues. The scarcity of technical personnel in rural areas would be easily solved since few personnel are required to maintain the network.
- More cost-effective than leased or dedicated phone lines to remote locations, thereby making it an ideal access technology for deployment in rural areas.
- More robust data networks as compared to standard telephone lines.

Disadvantages of VSAT technology

- High initial equipment/installation costs; this hinders the deployment of such networks in rural remote areas.
- Latency can impact some application performance, thus resulting in delay.
- Requires a clear line of sight between dish and satellite.
- Dish installation requires site planning and about 30 days of overall installation time (*VSAT Pros & Cons*, 2004).

3.2.5 High-altitude platforms (HAPs)

HAPs are stratospheric platforms, recently being investigated for broadband wireless telecommunication services, and utilizing airships or aircrafts (Grace *et* *al.*, 2001; Milas, 2004). These combine the features of satellite and fixed wireless access (FWA) services. HAPs appear are a potential wireless telecommunication alternative to terrestrial and satellite systems, preserving the advantages of these systems and providing their own. The features that make HAPs attractive include: high data rates, high mobility, large coverage, payload reconfigurability, possibility for frequent take-off and landing for maintenance and upgrading (Milas *et al.*, 2004). HAPs operate at an altitude between 17 and 22 km, with coverage of 400-km diameter. The choice of that altitude is two-fold: at that altitude the average wind speeds are minimal and the high altitude means that the coverage of the antennas can cater for a significant number of users. The frequency allocated for this is the 47/48 GHz bands in most Western countries and the 28 GHz band in Asia (Thornton *et al.*, 2001).

HAPs technology consists of airships, aeroplanes, unmanned aerial vehicles (UAVs) and tethered aerostat. Airship HAPs use very large semi-rigid or non-rigid helium-filled containers of the order of 199 m or more. Electric motors and propellers are used for keeping the station while the airship flies against the prevailing wind. Prime power is used for propulsion and station-keeping. This is provided from lightweight solar cells that cover the upper surfaces of the airship; these typically weigh under 400 g/m^2. During the day, power is stored in the regenerative fuel cells, to provide power at night. The ageing of cells will determine the period of operation of the airship HAPs; however, it is easy to bring this down and carry out repairs (Milas *et al.*, 2004).

An aeroplane HAP is an unmanned solar-powered plane that flies against wind or in a tight circular path. The major challenge is power balance and the craft being able to store sufficient energy for station-keeping during the night. AeroVironment in the United States has such highly developed crafts. Several other projects are underway as part of the HeliNet project is a collaboration of European countries to offer broadband telecommunication services, environmental monitoring and vehicle localization (Thornton *et al.*, 2001).

Unmanned aerial vehicle HAPs refer to small, fuelled, unmanned aircraft having short mission durations and operating at generally modest altitudes. This type is mainly used in military surveillance. The use of UAV as the communication relay node is limited due to short endurance. A tethered aerostat is an airship on a cable, whose length may reach 5 km or more. Tethering helps in station-keeping, although the platform movement is still in use. The tether can also be used as a communication backhaul and power to the aircraft. A major challenge is the hazard presented to air traffic, although most are deployed in aircraft exclusion zones (Grace *et al.*, 2001).

HAP technology is currently undergoing technical feasibility study. Several projects have been launched in Europe; worldwide, the HeliNet project, SkyLARC Technologies, Japanese National Aerospace Laboratory, AeroVironment/SkyTower USA are some of the major players with projects in progress. In South Africa, CSIR and Gauteng Economic Development Agency (GEDA) had formed a partnership to explore the technical feasibility of HAPs (Council for Scientific and Industrial Research, 2005). This was seen as a way to explore and promote effective communication infrastructure in the region. However, this project did not produce results, according to correspondence with the project manager Ronel Smith.

Advantages of HAPs communication

HAPs have a number of potential benefits in the overall mission of connectivity. These replace extreme ground based infrastructure. One HAP provides multi-cellular services over a large area, helping to do away with a local terrestrial backbone. Backhaul connectivity can be provided to places where fiber optics are available.

HAPs can be built at a low cost. The procurement of a cluster of HAPs should prove cheaper than a geostationary satellite or a constellation of LEO satellite. HAP networks would also prove to be cheaper than terrestrial networks with a large number of base stations (Grace *et al.*, 2001).

Service may be provided initially on a single platform. This can be expanded as and when there is need for greater coverage. This is different from the case of a LEO satellite network, which requires several satellites for continuous coverage. Terrestrial networks would also require a number of base stations to offer connectivity for the whole coverage (Milas *et al.*, 2004). It should be possible to rapidly deploy another HAP given the availability of suitable platforms. A new HAP service can be easily designed, implemented and deployed as quickly as possible. In the case of satellites this takes several years from initial procurement through to the launch. This is also the same case with terrestrial networks, which involve time-consuming planning to create the network. HAPs can offer a rapid roll-out of services by service providers who are keen to go into business before their competitors (Thornton *et al.*, 2001).

HAPs rely on solar energy power. This represents an environmentally friendly technology that can be easily deployed in the atmosphere.

Disadvantages of HAPs communication

HAPs can offer connectivity, but the technology has drawbacks. The ITU has allocated HAP frequencies in bands 47/48 GHz and 28 GHz in Asia. Propagation from HAPs is not fully developed at these high frequencies. Rain attenuation has effect on these bands, and therefore there is a need to develop rainfall attenuation and scattering statistics; this would allow appropriate margins to be included and highlight any problems with frequency reuse plans developed at the system level (Grace *et al.*, 2001).

There is need to optimize network capacity, suitable modulation, and coding schemes to serve broadband telecommunication service with quality of service and bit-error-rate requirements, applicable under different link conditions. Adaptive techniques will provide overall optimum performance, using low-rate schemes with powerful forward-error-correction coding when attenuation is severe (Thornton *et al.*, 2001). Wind speeds of 55 m/s are a major challenge to maintain the position of a HAP. Stability of the platform is critical. There may be roll, pitch and yaw of the platform due to turbulence in the stratosphere. Large aircrafts will exhibit greater stability (Grace *et al.*, 2001).

Table 3.2: Access technologies with key features for rural applications.

Technology	**Key features**
Analog dial-up	Only feasible where telephone lines exist; still the most economic access technology.
ISDN	Offers more bandwidth than analog dial-up.
DSL	Limited to areas near the telephone exchange.
ADSL	The short, local access loop affects its implementation in remote areas.
VDSL	Operates on copper cables for a short distance.
BPL	Dependent on the existence of electric cables in the area.
Optical fiber	Has the capacity to transport enormous amounts of data without susceptibility to noise.
WiFi	Provides a cost-effective and fairly acceptable network in terms of reliability, throughput and latency.
IEEE 802.16	Able to connect distant areas (50 km) with a throughput of 70 Mb/s; the cost of acquiring this remains high.
Mobile cellular systems	Have wide coverage, making them readily available.
Satellite communication	Can be deployed anywhere as long as there is satellite footprint coverage.
VSAT	Can bring Internet connectivity to any place, but needs another technology to serve the end-users directly.
HAP	Low building costs, although no direct experience of operating them yet reported.

3.3 Technology Performance Basis

Having taken a review of the various access technologies which can be implemented for rural connectivity. It is also imperative that there be basis upon which the technology can be analyzed according to their performance.

Parameters such as round trip time, download time/latency and throughput can be used to measure the performance of a technology.

- Round Trip Time (RTT): Round Trip Time is a measure of the time it takes for a packet to travel from a computer, across a network to another computer, and back. RTT is computed by the sending side recording the clock when it transmits a packet, and then records the clock again when an acknowledgment or a reply arrives. Subtracting the two values, yields a single estimate of the round trip time. A collection of these values for a set period of time give the average RTT. RTT shows the IP network total path delay that can be caused by many factors such as; packet capturing delay, queuing delay, switching/routing delay and light-speed propagation delay.

  Packet capture delay is the time required to receive the entire packet before processing and forwarding it through the router. This delay is determined by the packet length and transmission speed. Using short packets over high-speed trunks can easily shorten the delay but potentially decreases network efficiency.

  Latency is normally composed of queue delay, path delay and transmission delay. Path delay is the delay in transmitting frames between end nodes. Queue delay is delay required at the input and output ports of a packet switch due to the statistical multiplexing nature of IP networks and to the asynchronous nature of packet arrivals. This delay is a function of the traffic load on a packet switch, the length of the packets, and the statistical distribution over the ports. Designing very large router and link capacities can reduce but not completely eliminate this delay. Switching/routing delay is the time the router takes to switch the packet. This time is needed to analyze the packet header, check the routing table, and route the packet to the output port. This delay depends on the architecture of the route engine and the size of the routing table. Hence additional headers increase this type of delay. New IP switches can significantly speed up the routing process by making routing decisions and forwarding the traffic via hardware as opposed to software processing (International Engineering Consortium, 2005).

Propagation delay is the time required for a digital signal to travel from one point to another, usually from source node to the destination node in a computer network. It largely depends on the underlying network topology. Increased RTT induced by additional overhead due to more processing time and larger frame sizes affects the QoS of the network, especially in real-time applications such as video conferencing and voice over IP (VoIP). Transmission delay is the time it takes for the TCP Layer to transmit the segment onto the communications link. This is determined purely by the TCP segment's size and the bandwidth of the link.

$$\text{Average RTT} = \frac{1}{n}\sum_{i=1}^{n} t_i \qquad (3.1)$$

Where t = return trip time of i

n = be the number of trips recorded

Adopted from Mujinga, 2005

- Download Time: Download Time is the time it takes to download a file or a webpage from the remote server or computer to the local computer. This can be calculated by subtracting the time the first frame of the downloaded file is received from the server and the time that last frame is received.

$$\text{Download time} = \frac{1}{n}\sum_{i=1}^{n}(t_{r_i} - t_{s_i}) \qquad (3.2)$$

Where t_s the request for a web page is sent from the client computer to the web server

t_r the time the last fragment is received on the client from the web server

n the number of times the process is performed

Adopted from Mujinga, 2005

- Throughput: Throughput is the amount of digital data per time unit that is delivered over a physical or logical link, or that is passing through a certain network node. This can be taken as the amount of data that is delivered to a certain network terminal or host computer, or between two specific computers. Throughput is measured in bits per second (bits/s or bps), occasionally in data packets per second or data packets per timeslot.

$$\text{Throughput} = \frac{File\ Size}{Transfer\ Time} \qquad (3.3)$$

- Ping: Ping is an application that tests host responses over a network connection. Ping uses the network layer to send packets to a remote address. If there are network connectivity problems or the host has problems, the ping will fail, indicating a problem exists. Additional tests may be needed at that point to determine the cause of the problem.

  The Ping is an application on OSI layer 7 designed to use echo request and echo reply to calculate and display round trip times for each request/reply pair to a host over a network. Ping utilizes raw ICMP sockets to send packets to a remote host, calculates the difference in time between transmission and receipt of the packet and 10 8 produces printed, human-readable results of these measurements in milliseconds for each request/reply pair. Any delay anywhere in the chain will create what is referred to as propagation delay or more simply latency.

3.4 Conclusions

Table 3.2 provides a summary of access technologies with their key features for rural applications. In this chapter I discussed the various access technologies currently available and others planned for future Internet connectivity in South Africa. Some of the technologies are able to deliver the mission of rural Internet connectivity. With Neotel set to be the second network operator there is hope coverage will soon improve in remote disadvantage areas of South Africa. It is important that we test these technologies for rural deployment, especially in terms of their applicability in rural areas taking into consideration the performance parameters.

Chapter 4

Experimental Network Deployments

In this chapter I draw on the experiments carried out in Dwesa-Cwebe to evaluate a backhaul connectivity technology for the implementation of field testing of an e-commerce/communication platform. The findings from the various access technologies are also discussed. This aids in determining the best access technology for deployment for the network in operation.

4.1 Introduction

In order to find the ideal backhaul connectivity access technology, it was imperative to assess the technologies that could possibly be deployed in Dwesa-Cwebe. This entailed doing an evaluation on the technologies suitable for last-mile deployment in this area. Chapter 3 discussed various access technology options for rural Internet connectivity; but, the ultimate choice depends on the pros and cons of the particular access technology. Factors such as throughput, cost, reliability, broadband and maintenance have to be considered in order to satisfy the mission of connectivity without compromising the quality of delivery.

4.2 Research environment

4.2.1 Dwesa-Cwebe

Dwesa (32°17'60"S, 28°49'60"E) and Cwebe (32°13'0"S , 28°55'0"E) are the focus points of a rural community area (Dwesa-Cwebe) of about 15,254 hectares, located in the Mbashe Municipality of the Eastern Cape Province, South Africa. The area is situated on the Wild Coast and bordered by the Indian Ocean and the rugged grasslands of the former Transkei homeland. The area extends inland for approximately eight kilometers, and has a dispersed population of about 15,000 people, whose active (employed) members are estimated to be less than 5,000. Characteristics of the Dwesa-Cwebe area (Rao *et al*., 2006) are:

- A scarcity or absence of regular public transport (e.g. the 50 km gravel from Willowvale to Dwesa-Cwebe Nature Reserve has no regular bus servicing that route).
- A shortage of technical personnel; technical support in telecommunications is essentially absent.
- A low level of economic activity based mainly on agriculture or handicrafts. There are four primary schools of an average of 200 pupils each and one high school of about 250 pupils, plus three clinics and one mobile clinic serving an estimated population of 15 000 people.
- Low per capita income (9,800 Rand/year on average) [this sounds high!] (ADRI, 2001).
- Absence of electricity in many parts of the area (connected to one house in 100 on average); alternative power supply are solar and diesel.
- No telephone landlines and poor cell phone coverage (three MTN towers reach 60% of the area).
- Difficult topographical conditions (semi-mountainous) (which renders the construction of wire networks costly).
- Low-density population widely scattered over plateaus and hills.

4.2.2 Networking deployments

In the following sections the feasibility of deploying the available access technologies is discussed. These include telephone-associated technologies, powerline communication, fiber optics, WiFi, HAPS, VSAT, GPRS, 3G and WiMAX.

4.2.2.1 Telephone-associated technologies

Despite the telephone being one of the most common wired connectivity technologies in South Africa, telephones are not common in the Dwesa-Cwebe area (Jenson, 2002) and Telkom does not have any land lines there. This means access technologies such as analogue dial-up, ISDN and DSL, are not deployable there. The unavailability of the telephone exchanges, within 5.5 km radius is completely rules out the use of ADSL.

4.2.2.2 Powerline communication

Dwesa-Cwebe has no complete electrification coverage; Eskom has not completed its rural electrification program in this area. Electricity is only found at Mpume Clinic, Mpume Junior Secondary School, Ngwane Primary School, Nondobo Primary School, and Ngwane Junior Secondary School. This makes it difficult to implement broadband powerline communication. Interconnecting homes along the main power lines would create opportunity to deploy PLC access, however. The current situation would first require Internet signal-coupling on the high-voltage lines running from Telkom telephone land lines at Willowvale, about 50 km from Dwesa-Cwebe. Then this would also need to be done on the low-voltage lines, where the cabling has been completed to supply basic service. The signal would need to go through the high-voltage lines with PLC repeaters installed. But this would raise the cost of deploying the network. The traditional PLC used by power utilities, which offers up to 64 Kbps, would technically be too difficult to install, due to line configuration. Moreover, there were not many access points at this stage. Another limitation included the limit with which the

BPL can provide in terms of signal coverage. These issues concerning the operation of broadband powerline communication to offer backhaul connectivity for the e-commerce communication platform, from a Telkom exchange at 10 Mbps at Willowvale, limited its potential operation. Thus, the BPL implementation in this area was suspended.

4.2.2.3 Fiber optics

Fiber optics is an ideal technology for offering backhaul connectivity for Internet connectivity. This offers larger bandwidths than the copper-based media. The large bandwidths would allow several applications to be run through such a network. The mission of backhaul connectivity for an e-commerce communication platform would be easily completed if such technologies were available in Dwesa-Cwebe.

The major limiting factor is the cost of optical fiber, namely excavating trenches and laying down or deploying the fiber overhead would require funding from sponsors. This would be a major capital investment project. Telecommunication companies are not eager to invest in such projects due to lack of return on investment: Dwesa-Cwebe, a remote disadvantaged community, would not offer a lucrative business. Thus, generally, no major investments in telecommunications are made in such areas. It is imperative to devise cost-effective ways of linking remote/rural areas. We concluded that using fiber optics as the backhaul access technology would not offer a cost-effective way of linking Dwesa-Cwebe.

4.2.2.4 Wireless fidelity (WiFi)

Wireless Fidelity can be built at a very little cost compared to traditional wired-media alternatives. WiFi has the 802.11 family of protocols used for building low-cost wireless networks. The deployment of wireless networks is not only a cost-effective deployment method, but they are able to provide rural communities with cheaper and easier access to information. Rural communities have been able to enjoy the power of Internet access through the various information services it has to offer. Communities that are connected to high-speed Internet access have a voice in the global marketplace.

The mission of backhaul connectivity in Dwesa-Cwebe would have been favorable and possible for the implementation of WiFi networks. However, there are no Telkom landlines running through this area to be used as the backhaul connectivity. WiFi is also not a good provider of long-distance backhaul.

4.2.2.5 High-altitude platforms (HAPs)

The use of stratospheric platforms for broadband wireless telecommunication utilizing airships or aircrafts presents an ideal access technology for use as backhaul connectivity. HAPs have the potential to exploit many of the best aspects of terrestrial and satellite-based systems, which enables them to offer advantageous propagation characteristics. HAPs are able to include services such as high data rates, high mobility, large coverage, payload re-configurability, possibility for frequent take-off and landing for maintenance and upgrading (Milas *et al*., 2004). These make HAP technology easily deployable in rural areas.

Considering that there is a serious absence of telecommunication facilities in Dwesa-Cwebe, HAP technology could be implemented to deliver telecommunication services. HAPs have a low cost, although to date there has not been direct experience of operating costs (Grace *et al*., 2001). This present HAPs technology as an alternative to deliver telecommunication services in Dwesa-Cwebe. However, the implementation of HAPs in Dwesa meant recruiting personnel who had experience in this technology. Also, depending on the infrastructure used, HAPS would be cost-effective for much wider areas than for only the Dwesa-Cwebe area alone. A CSIR/GEDA partnership had been working on such a project. However, according to Ronel Smith, the project manager, the project had since been suspended. Therefore, alternatives to implement telecommunication services in this area needed to be found.

4.2.2.6 Very small aperture terminal (VSAT)

VSAT refers to a small earth-fixed station (typically 0.75-2.4 m), which provides the vital communication link required to set up a satellite-based communication network. The small earth station operates in conjunction with a larger hub (typically 6-9 m) earth station acting as the network management center (Everett, 1992). The VSAT has been used for delivering Internet access to remote rural areas across the world. Other uses include the use of VSAT rural telephones in remote parts of the country. Banks have also utilized VSAT for providing connectivity between the various ATMs they host in different areas.

Currently, in South Africa, Telkom South Africa and Sentech are the major VSAT providers. Telkom provides coverage to those areas falling outside its ADSL footprint. This is being sold under SpaceStream brand-name products. The SpaceStream Express and SpaceStream Office were introduced to South Africa in October 2003 (*Telkom Wires Africa via Satellite*, 2003). SpaceStream Express offers download speeds in four packages, from 64 Kbps to 512 Kbps, while SpaceStream Office provides Internet access at a download speed of 64 Kbps, plus up to four telephone connections. Both products provide always-available access to the Internet and e-mail services, with no call charges (Telkom South Africa, 2005a). Table 4.1 shows the pricing on Telkom Internet through satellite. The satellite being utilized in this case is on the C-band satellite infrastructure. The C-band has the advantage of being more stable, but with the disadvantage of requiring bigger remote satellite antennae. This also has extensive coverage and reliability in Africa (Mandioma, 2006). Sentech offers a similar service named Sentech VStar 128, which offers 128 Kbps downstream and 128 Kbps upstream. The Internet access in this case is not limited. The cost of installation is R3, 990 and there is a monthly rental fee of R5, 186 (Sentech, 2005).

The options being offered by Telkom South Africa through their Internet by satellite seemed the most favorable option (considering Sentech's charges). We decided to have it deployed in Dwesa-Cwebe given the characteristics of the area (Rao *et al.*, 2006). This required setting up the VSAT in a secure area. We therefore undertook a survey of the existing facilities that might be used to house the equipment. The idea was to find an easily accessible area; this would help to access the site during visits to the deployment site. Furthermore, security was paramount. Mpume Junior Secondary School in the Mpume area was chosen as the host site. The school had electricity and room that could be used to house the computers. After an initial discussion with the principal, Mr Pakati, permission was granted to utilize Mpume as our host site for the VSAT.

It was necessary to apply to Telkom to request the VSAT installation at the school. Although the instructions on the Telkom website make the process look simple, it actually took many days, and then months to have the VSAT installed at the school. We opted for SpaceStream Express, with downloads speeds of 512 Kbps and 128 Kbps upload, and a monthly volume cap of 3Gbytes. This was assumed to suit diverse and mixed user applications, especially as demand at the proposed multi-purpose platform in Dwesa is expected to grow (possibly incorporating distance education, telemedicine, and community and business development initiatives).

Table 4.1: Telkom satellite Internet access (source: Telkom South Africa, 2005c).

TELKOM USER PACKAGES							
Users will have a choice of one of the following five access packages:							
Access Medium	Receive Data Rate (kbps)	Transmit Data Rate (kbps)	Monthly Volume Caps	No. of IP Address	Internet /Data	Voice Lines	Access Price
Space Stream Express	64	16	500 MByte	4	Yes	None	R998
Space Stream Express	128	32	1 GByte	4	Yes	None	R1,244
Space Stream Express	256	64	2 GByte	8	Yes	None	R1,824
Space Stream Express	512	128	3 GByte	8	Yes	None	R3,019
Space Stream Office	64	16	500 MByte	4	Yes	Up to 4	R1,500
Standard Installation							R3,100

VSAT is a proven technology for delivering Internet access in remote/rural areas, yet its performance in the context of rural South Africa remained to be tested. It was imperative that performance of the VSAT be measured. Throughput, reliability, and quality of data transfer on the VSAT network would need to be evaluated, and then the network could be set up. The intention was to establish a least-cost network, in this case a network hosting a server and thin clients. The server would handle all the processing for the clients. This project was being implemented utilizing free and open-source software to meet the goals of the project. Ubuntu Breezy Badger was chosen as the operating system to be implemented.

VSAT experimental tests

The next stage was to conduct experimental tests on the VSAT technology in Dwesa-Cwebe. The quality of a network and data transfer is based on the assessment of the throughput, reliability and latency. One method of testing network reliability is to send large data volumes over the network, then assess how many packets are being dropped on the network. Throughput refers to how much data can be transferred from one location to another in a given amount of time.

Another important tool is the ping test, which would measure the round trip latency. This involved running a script that would 'ping' another machine on the network. This enabled the calculation of minimum, maximum, average and standard deviation of the round-trip time from a remote machine. Ping is a computer network tool used to test whether a particular host is reachable across an IP Network. It utilizes ICMP packets to the target host and involves listening for ICMP replies (Foldoc, 2005).

The ping test allowed for testing network reliability as well as latency. The values returned by the script allowed for the determination of latency experienced on the network while the number of packets that are returned indicates the reliability of the networks. The Fort Hare University Web server was one machine that could be easily reached from outside the university network. Figure 4.1 shows the ping tests conducted on the VSAT network with a fully-fledged established network in operation. The results were computed from equation 3.1 this was then used to draw up the graph on Figure 4.1.

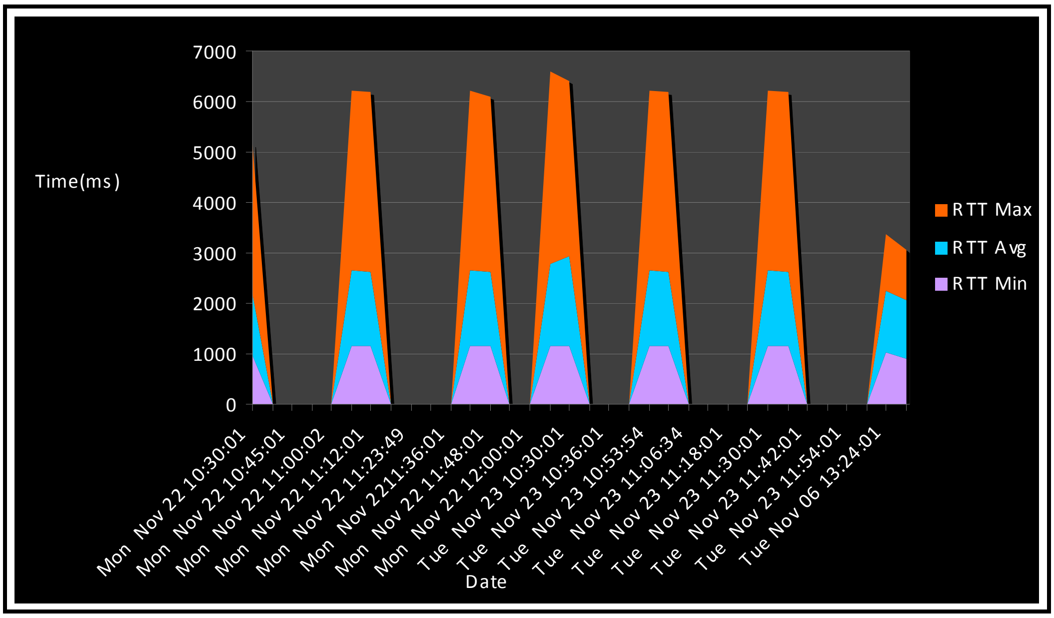


Figure 4.1: Ping on VSAT Network; this shows a ping test carried out from a computer connected on the VSAT network to the University of Fort Hare Web server.

The average round trip time (RTT) was approximately two seconds, with peaks at six seconds. This indicates high latency such that the delivery of real applications over VSAT does face problems. However, where there are no alternatives, the VSAT retained the advantage of offering an Internet connection from anywhere you are located.

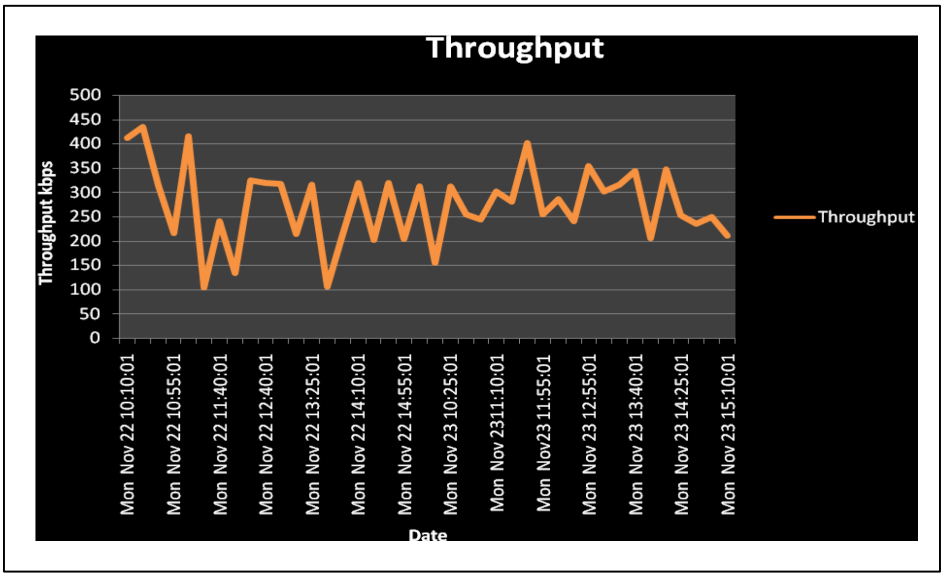


Figure 4.2: Throughput measured over the VSAT network, showing the amount of digital data per time delivered over the VSAT network.

Figure 4.2 depicts throughput on the VSAT network on the server machine connected to the VSAT indoor unit. Utilizing equation 3.3 the throughput of the network was computed which was then graphed on Figure 4.2. The throughput on the network can be seen to vary over the day. In the earlier hours of the day the throughput was high; this can be attributed to the number of users accessing the Telkom network. Later, it subsided since many users results in the fall of the throughput. There is also a general fluctuation in throughput over the network, which can be attributed to the position of the satellite's constant constellation.

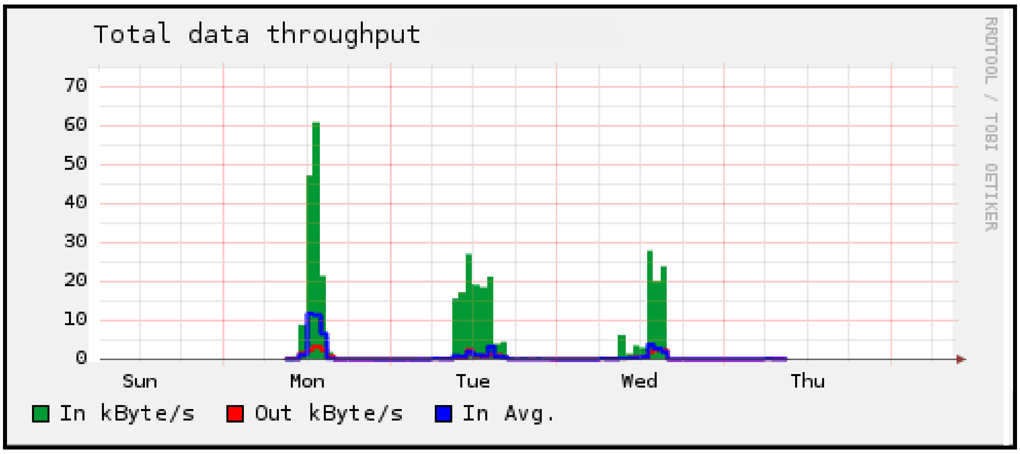


Figure 4.3: Throughput over one week, showing a sample of the system throughput measured over the VSAT network.

Figure 4.3 shows graphs of measured system throughput on the VSAT network sampled over one week, in which the network was in operation for more than two days in the week. IPTOTAL which was used to generate the graphs measures IP traffic monitor. It listens to a network interface in a non-promiscuous mode, and measures IP bandwidth usage. After specific number of seconds, the average throughput is printed at total, input and output usage. System throughput is the sum of the data rates that are delivered to all terminals in a network. Figure 4.4 shows the throughput on a monthly basis. (There are gaps in between the various graphs, because the VSAT is only functional during the day when the schools are open.) On the monthly graph the VSAT is operation during the weekdays when schools are open. During the weekend the machines are shut down to economize on power usage.

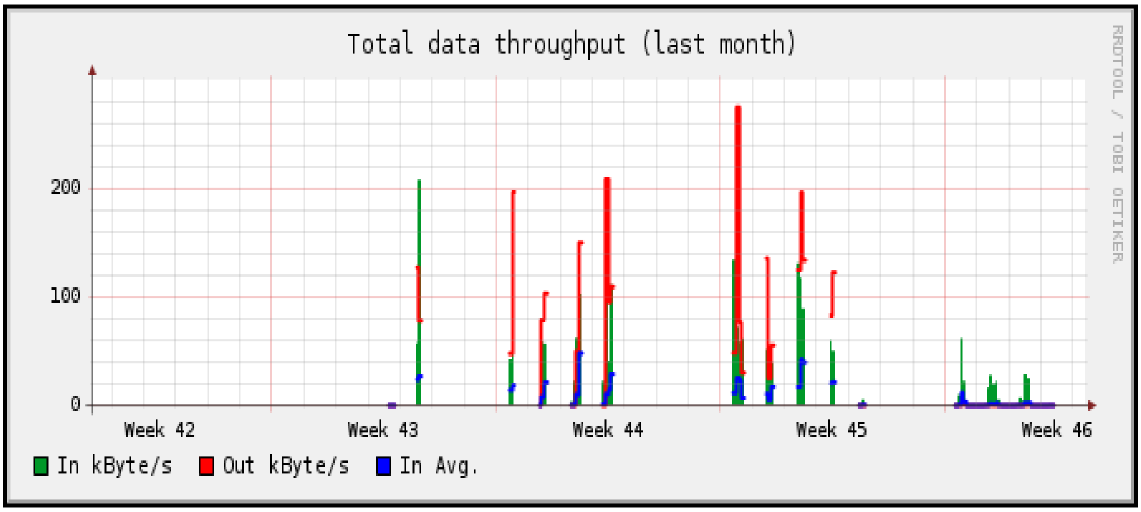


Figure 4.4: VSAT throughput measured over one year.

The different values of throughput (Figure 4.2, 4.3 & 4.4) are related to the amount of data packets transmitted and to their latency. In all, the network is fairly consistent. The latency displayed by the network is expected, and this is due to the nature of operations on satellite networks. Also, after the elapse of 24 hours the connection drops out, therefore it is necessary to log in again. This means it is not an ‘always-on’ product as advertised. Considering deployment in a remote area, there was need to solve this problem.

The VSAT at the school is maintained by Telkom as per a service agreement contract. When the VSAT broke down during the project, Telkom was in the process of changing its satellite. A month passed before they visited the site; this demonstrates that rural areas remain neglected in terms of service provision. Moreover, the cost of VSAT remains expensive (Abramson, 2000). The cost to institutions is around US$2 per kb/s (half-duplex) per month, plus the cost of a satellite dish (Martin, 2005). The industry expects prices to decrease, yet this will take time. In the case of rural deployment we suggest a cost-sharing scheme where a number of users are connected on one VSAT. The cost can then be apportioned to users based on usage. Thus, in such a case, there is need to utilize a wireless access technology to offer signals to other access points. Therefore, we still needed to explore another access technology. Since GPRS was available in the area, we intended to explore on how much it could deliver.

4.2.2.7 GPRS and 3G technologies

GPRS and 3G serve similar functions in delivering data connectivity. 3G data services are the next step from GPRS. The main difference between these technologies is that 3G is able to achieve significantly faster data transfer rates. GPRS delivers a theoretical limit for packet-switched data rates of 171.2 kbit/s utilizing the eight slots and CS-4 coding. A realistic bit rate is 30 to 80 kbit/s, since it is only possible to use a maximum of four time slots for downlink. The GPRS provides about 93% coverage in South Africa. The two major cellular phone service providers, Vodacom and MTN, provide such combined coverage (Vodacom South Africa, 2005a; Mobile Telephone Network, 2005a). Of the 30 million subscribers in South Africa, Vodacom has the larger subscriber base: approximately 16 million as of October 2005 (Mzolo, 2005), while MTN has 10.2 million subscribers (Mobile Telephone Network, 2005b). The subscriber base will fluctuate with the introduction of number portability, which came into effect in South Africa on 10 November 2006 (*Cellular Number Porting*, 2006).

GPRS is a packet-switched technology, which means that multiple users share the same transmission. Transmission will only occur when there is a need to send data. Thus, the total bandwidth is dedicated to those users who are sending data at a particular time. GPRS connectivity is billed per kilobytes transceived. The 3G mobile technologies offer momentous and broadband capabilities to support greater numbers of voice and data customers with high data rates. These offer higher data rates for transmission than GPRS, with 384 Kbps for mobile systems and 2 Mbps for stationary systems. Vodacom currently offers a high-speed downlink packet access (HSDPA) card that can be used for Internet access on the move. HSPDA is a technology that has empowered Universal Mobile Telecommunication Service (UMTS networks by providing higher data rates and lower latency to end-users. The three essential pillars of UMTS are: 2G/3G continuity of service, multimedia support by enabling the support of voice and data applications at the same time, and high data rates. HSDPA goes beyond providing the average throughput of 800 Kbps and even 1.5 Mbps (Nortel, 2006). These speeds are comparable to those offered by fixed-line broadband.

The Vodafone Mobile Connect card utilizes HSDPA, 3G, EDGE, and GPRS as technologies to access the Internet. These have varying speeds, with HSDPA providing the highest speed, followed by 3G, then EDGE, and lastly GPRS. This requires the recipient/receiver be within the coverage area of the Vodacom network (Vodafone, 2005). HSDPA and 3G have coverage limited to the major urban areas. So in the context of Dwesa-Cwebe, with its laid-down characteristics, HSDPA, 3G and EDGE are not available. This meant the card could only be used on a GPRS-enabled device to provide connectivity. GPRS coverage is available wherever there is Vodacom network coverage in South Africa. With such attributes, tests with GPRS were implemented in Dwesa-Cwebe.

Vodafone Mobile Connect Card

The Vodafone Mobile Connect Card is currently distributed only with drivers for operating systems running Microsoft Windows 2000 or Windows XP (Vodafone, 2005). The Windows' drivers are fairly easy to install on Windows 2000 and Windows XP. This makes it also fairly easy to utilize the Vodafone software for connecting to the Internet. However, the project was implemented utilizing a variant of a Linux-operating system, called Ubuntu.

In addition, the Vodafone Mobile Connect card is designed only for laptops. In this case the machines being utilized in the project were desktop computers. This necessitated getting the card to work on the desktop; this was possible by acquiring a PCI to PCMCIA card, which allowed us to plug the Vodafone Mobile Connect Card to the motherboard, allowing communication within the computer.

The machines being used had also been operating with Ubuntu Breezy Badger. We tried the point-to-point (PPP) connection approach to get the card to work — not an easy task on Ubuntu Breezy Badger. The various available literature/information about its support did not give concrete answers to allow the card to operate. Eventually, we tried Ubuntu Dapper, where the kernel had been built with the drivers, which were compatible with the Vodafone Mobile Connect Card. This meant that the system could identify the card upon plugging it into the system.

The PPP configuration process has been added to the appendix, showing the process of configuring the PPP connection. The initial tests done at the University of Fort Hare Computer Science Laboratory under the 3G coverage had shown good results. Initial tests, such as browsing Web pages that had less content (such as Google), proved quite fast to access. But when testing it on Web pages that have more content (such as CNN), the browsing speed slowed down. This was attributed to the Web pages having several pictures embedded in them, resulting in more content being downloaded. That is, more bandwidth would be required to have the page downloaded quickly.

Figure 4.5 shows a ping test done on the University of Fort Hare Web server from a machine connected to the Vodafone card. The ping test measures the round-trip time, which provides latency on the Internet sites. The RTT graph depicts saw-shaped curves showing how the RTT rises and falls. This reveals some inconsistency in the 3G-link over this area. High speeds, such as 492 Kbps, were achievable on the 3G network.

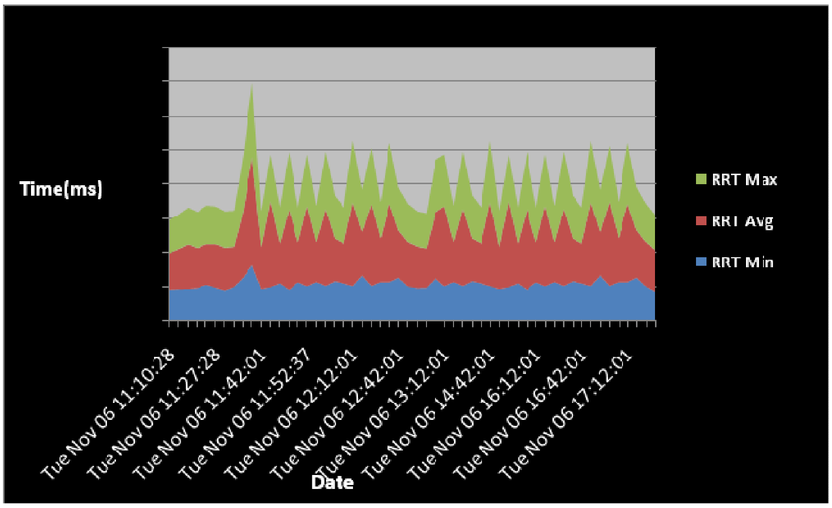


Figure 4.5: 3G ping test, showing a ping test conducted over the 3G network at the University of Fort Hare to the university's Web server.

Figure 4.5 depicts the speeds achieved when connected to the 3G network. These have been computed from equation 3.3 which is used to calculate throughput. Such throughput speeds are favorable for a number of applications which can be delivered over such a network. This makes it favorable to deploy applications which require less bandwidth. However, these were not matching the high speeds of 1.8 Mbps, the gazetted rates of the card. The 3G was expected to deliver more that it was offering.

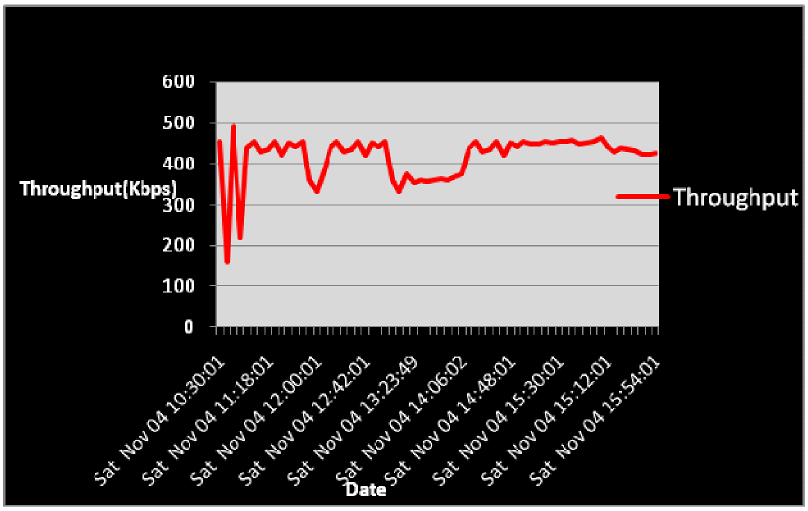


Figure 4.6: 3G throughput, showing throughput measured when connected on the 3G network around the University of Fort Hare on the Vodafone Mobile Connect Card.

Having done the initial tests at the University of Fort Hare Computer Science lab, the next stage was the deployment of the Vodafone Mobile Connect Card in Dwesa-Cwebe. From the initial results (Figure 4.6), throughput from the Vodafone Mobile Connect Card appears to deliver reasonable data rates for accessing Internet access in rural South Africa. However, the problem remained that HSDPA, 3G, and EDGE would not be available for the project area.

A 3G evaluation at Fort Hare prompted the evaluation of GPRS over the area, since this could be utilized as an alternative considering the absence of 3G in most of the rural areas. GPRS technology is prevalent wherever there is network coverage; this could be used as an alternative for Internet access in the rural areas where there is coverage. This involved setting up the same experiment, but this time considering access through GPRS. Figure 4.7 depicts the round-trip time computed from equation 3.1 for the GPRS network around the University of Fort Hare.

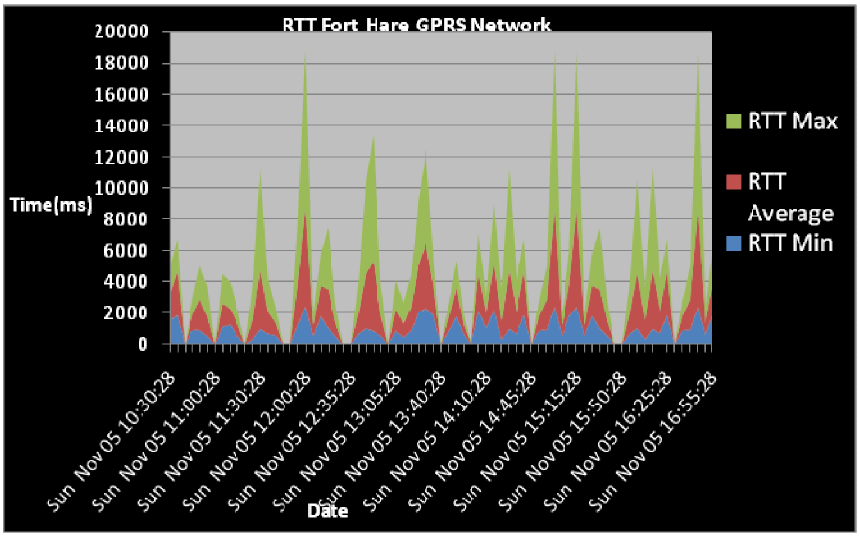


Figure 4.7: Ping test over the Fort Hare GPRS network from a computer connected to the Vodafone Mobile Connect Card.

The round-trip time on the GPRS network over Fort Hare shows high- and low-dipping figures. This shows that sometimes there is a loss of connection on the network. However, this is quite a different case when you look at the signal over the Vodacom cell phone network. The network signal seems to be always there, when actually there is a loss of signal over the network. This is the behavior of the network, however, when you evaluate the round trip time.

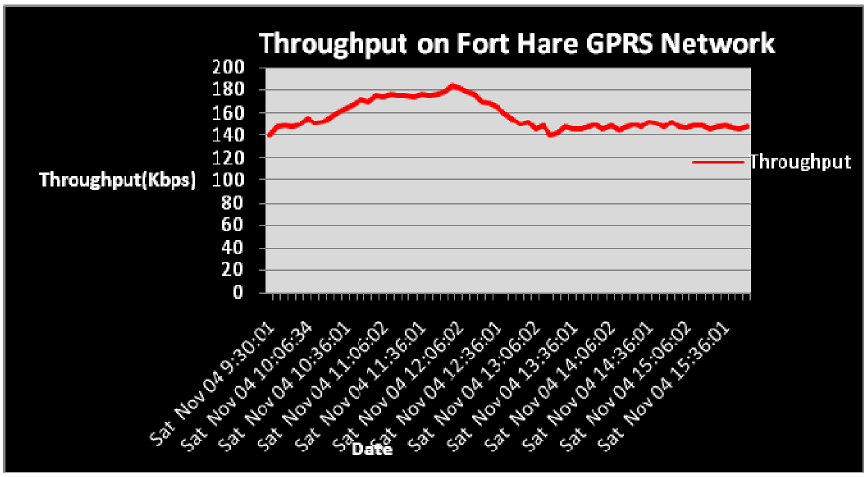


Figure 4.8: Throughput measured over the GPRS network at Fort Hare with a computer connected to the Vodafone Mobile Connect Card.

The throughput over the GPRS network varied over one day (Figure 4.8). During the earlier hours of the day, between 09:30am and 12 pm, the throughput rises to a maximum of 184 Kbps. This can be attributed to the network being not as busy as in the afternoon when the throughput drops during midday to 140 Kbps. This shows that there is an increase in the traffic on network, resulting in decreased throughput since more people are accessing the network.

3G and GPRS network evaluations at the University of Fort Hare prompted the performance evaluation of a GPRS network so that it could be evaluated for deployment in Dwesa-Cwebe. Tests similar to ones done on campus were repeated in Dwesa-Cwebe.

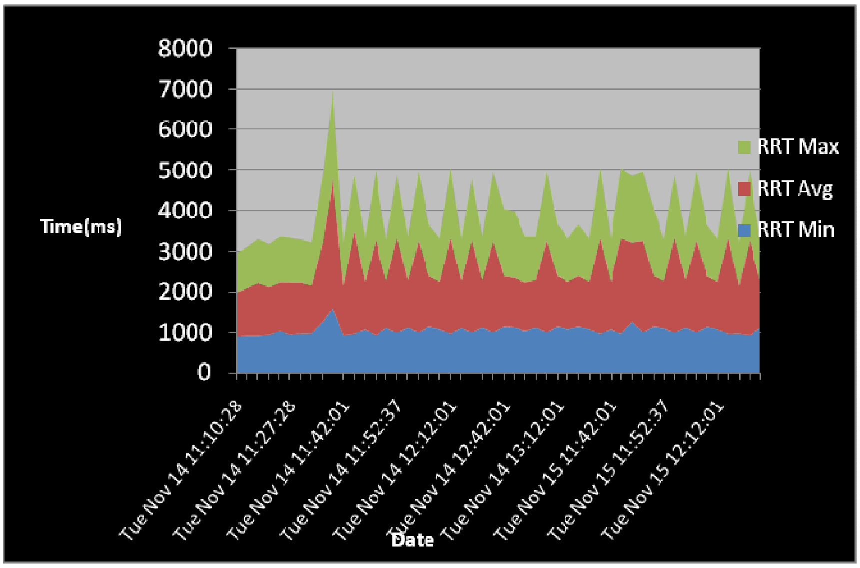


Figure 4.9: Ping test over the GPRS network at Dwesa to the University of Fort Hare Web server.

Figure 4.9 shows the round-trip time figures from the ping to the University of Fort Hare Web server. This provides an idea on the latency on the Internet sites. The saw-shaped figure shows how the round-trip time dips low and high. Thus, at one time the latency goes up and then down. This site is located about 1.5 km (in a direct line) from the nearest base station at Ngwane Junior Secondary School. Such latency values seemed not possible, but the poor coverage in this area confirms this. Also considering that distance from Dwesa to University of Fort Hare Web server is great. The round trip time figure would exhibit such a performance. Figure 4.10 provides the throughput on the network. These have been computed utilizing equation 3.3. The highest speed achievable on the network was 48 Kbps. The speeds were between 39 Kbps and 50 Kbps. The throughput speeds achieved were low considering the location of the test site from the Vodacom tower. This demonstrates poor cell phone coverage in this area; since several tests conducted average these speeds. However, speeds can be used to deliver applications that require less bandwidth.

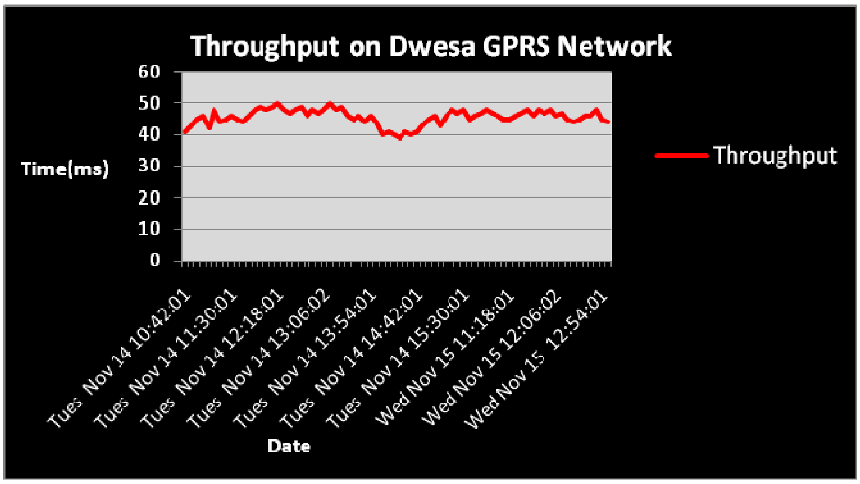


Figure 4.10: Throughput test on the Dwesa-Cwebe GPRS network. A data file was transferred from the Web server on the Fort Hare University network over the GPRS network.

A comparison of the GPRS tests in Dwesa and Fort Hare shows a remarkable difference in terms of throughput. The throughput around Fort Hare was between 184 and 140 Kbps. This varied over the day, where in the morning there was high throughput, while in the afternoon there was a decrease. This can be attributed to the number of users on the network (fewer users in the morning). In the case of Dwesa, the throughput averaged 48 Kbps. This figure is quite low compared to the throughput around Fort Hare since the network has a poor coverage in this area.

4.2.2.8 WiMAX

WiMAX is a standards-based wireless technology that provides high-throughput broadband connections over long distances of up to 50 km (Intel 2006, Gabriel, 2003). Like most wireless technologies it is considered a viable technology for rural connectivity over rugged terrain. WiMAX can be used as a backhaul connectivity technology to the other access points within an area. Dwesa-Cwebe with its characteristics (Rao *et al,* 2006) would require an access technology that can be quickly and easily deployable. WiMAX was one such technology that could satisfy the mission. This led to the carrying out of deployments in Dwesa-Cwebe to evaluate how it could deliver connectivity. Throughput, reliability and latency of the technology were measured on a deployed network.

Alvarion's BreezeMAX 3500 was the only WiMAX technology available in South Africa as of November 2005, and Saab Grintek was the only agent supplying the technology in South Africa. The BreezeMAX 3500 is designed specifically to meet the unique requirements of wireless networks. According to the Alvarion BreezeMAX system manual, the micro base station can provide its subscribers with a burst data rate of up to 12.7 Mbps. It is able to deliver broadband access service to a wide range of customers, and supports a bandwidth of up to 14 MHz; operates in the 3.5 GHz band, the uplink operating in 3.4995 to 3.4535 GHz and the downlink in 3.4995 to 3.5535 GHz, and it uses frequency division duplex (FDD). The 3.5 GHz band, which it operates in, is a regulated band in South Africa. The utilization of this equipment requires a license to operate it. We sought a license, normally a cumbersome task, but Amatole Telecommunication Services, one of our sponsors, was a holder of the USALs. The license for the operation of WiMAX provides coverage for the Amatola region, which includes the towns of Alice, Idutywa, Willowvale, East London and Dwesa-Cwebe, the project deployment site.

4.2.2.8.1 BreezeMAX System

The BreezeMAX 3500 WiMAX system deployed for backhaul wireless connectivity consists of a micro base station unit (MBSU) and a set of subscriber units (SU) as described in the following section:

micro base station: This is the access and management point of the BreezeMAX 3500 system. It caters for places where the number of subscribers is limited, typically 20 CPEs. This is targeted for deployment in low density rural areas. The micro base station equipment is composed of an indoor micro base station unit and an outdoor radio unit (AU-ODU):

- micro base station Indoor Unit: This provides full base station functionality. This includes the backbone Ethernet connectivity via a 10/100 Base-T network interface, traffic classification and connection establishment initiation, policy-based data-switching and the centralized agent management of the micro base station unit and all registered subscriber units. There are two different models: one is powered from the AC mains (110 or 220 VAC), and the other is powered from a 48 VDC power source. It has a maximum power consumption of 104W.
- Access Unit - Outdoor Unit (AU-ODU): This is a full-duplex multi-carrier radio unit that connects to an external antenna. It is designed to provide high system gain and interference robustness utilizing high transmit power and low noise figure. It supports a bandwidth of up to 14 MHz. The AU-ODU connects to the micro base station via an Intermediate frequency (IF) cable. The IF cable carries full-duplex data, control and management signals between the micro base station and the AU-ODU, as well as power (48 VDC) and a 64 MHz synchronization reference clock from the micro base station IDU. It is responsible for converting the indoor digital signal into outdoor analogue signal. It has a power consumption of 32 W when fully functional and a minimum of 27 W for a typical operation.
- Antenna: This is an omni-directional antenna of 13 dBbi, which can provide signals to the subscriber units attached to the network (Alvarion BreezeMAX 3500). Optional directional antenna can be provided.

subscriber units: These are installed at the customer premises to provide data connections to the access units. The subscriber unit is comprised of an indoor unit (IDU) and an outdoor unit (ODU)

- Subscriber Outdoor Unit (S-ODU): This contains the modem, radio, data-processing and management components of the subscriber units. The radio unit performs the conversion and amplification of the signal. It is also responsible for the connection and negotiation with the base station. The ODU is connected to the IDU via a category-5 Ethernet baseband cable. This cable carries the Ethernet data and power between the two units. The power consumption of the S-ODU is 41 W.

- Subscriber Indoor Unit (S-IDU): This acts as a power over Ethernet injector carrying data and power to the S-ODU via a category-5 Ethernet cable. This consists of three connectors and three LEDs. The Ethernet connector is for connection to a hub/pc/switch/router. The radio connector enables the connection to the ODU. The mains power connection powers the whole system. The power LEDs show if the unit is on or off. The Ethernet link status shows connectivity between the outdoor unit and the device and is connected to the outdoor unit. Lastly, the wireless link shows the connection with the AU (Alvarion BreezeMAX 3500).

These are the components that make up the BreezeMAX System that we deployed. Having considered other issues affecting deployment of the system (such as licensing) we moved on to consider the access points. In this case the access points were schools in Dwesa-Cwebe, which we had surveyed for the presence of security and electricity to power the system. However, the electricity in this area is not reliable and there are constant breakdowns. This could be attributed to the fact that the electricity supplier Eskom was constantly carrying deployments to provide coverage to the other areas.

Installation of the micro base station

After going through the BreezeMAX 3500 system and studying how the system would operate, the micro base station was deployed at Ngwane Junior Secondary School in Dwesa-Cwebe. This was the central deployment area, chosen for the following reasons:

1. This school has a lab, recently established by The Ngwane School Development Committee, with twenty computers.
2. The deployment of the WiMAX technology would go a long way in bringing Internet connectivity to this school.
3. Available LOS to the other expected CPEs access points where connectivity was to be provided, especially with Mpume Junior Secondary School hosting the VSAT.
4. Ngwane School was secure and could safely house all the equipment.

The installation involved mounting a cabinet in the computer laboratory, which would house a 24-port switch and micro base station indoor unit. The AU-ODU and the omni-directional antenna were mounted outside the building. These were mounted using a tripod stand with a clear LOS to remote access points. In this case we targeted deployment on three access points.

Deployment of subscriber units

The management of BreezeMAX 3500 System is done on the micro base station. This is one of the security features within this system, as it prevents any changes being carried out from anywhere except from the micro base station. Additions of subscriber units can only be done when you are at the micro base station. This meant adding the subscriber units on the micro base station before moving on to deploy these on the access points. The micro base station was connected through the management port, thus enabling subscriber unit’s MAC address to be added to the subscriber unit database, allowing the subscriber unit to be connected permanently to the micro base station. This process enabled the setting up of a specific subscriber profile for communication between the micro base station and the subscriber unit. After adding the subscriber unit, MAC address showed a 9/9 signal level. This showed that the subscriber unit was now connected to the base station with full coverage. The three deployments of the subscriber units were then done separately, one by one, in phases. This involved mounting the subscriber units on the various access points that had been designated.

- Mpume Junior Secondary School (MJSC): This was the first school where the first subscriber unit was mounted. The school is about 1.5 km with LOS from Ngwane Junior Secondary School, which is the micro base station host site. The subscriber unit was mounted outdoor on the wall. From the switching on of the subscriber unit it was able to pick up signals from the base station. During the mounting, caution was used to avoid having the link quality LEDs all on, as this would indicate a signal level that was too high. This had to be avoided according to the BreezeMAX system manual (Alvarion BreezeMAX 3500).
- Mtokwane Junior Secondary School (MJSC): Having added the subscriber unit to the micro base station, the next stage was to find a suitable place to mount the subscriber unit. Mtokwane is located about 750 m from the micro base station. Since the roof is high we resorted to finding a place indoors where the subscriber unit could be mounted. The best place, which had 6/9 on the Link quality LEDs, was inside the building in an office. The subscriber unit was mounted there on a tripod stand.
- Nondobo Junior Secondary School (NJSC): The school is located about 600 m from the base station. The short distance and the LOS allowed a good signal from this site, with link quality LEDs at 9\9. Because of issues of over saturation of the signal we could not mount it on this angle; we found an angle where the signal had 8/9 link quality. The subscriber unit was then permanently mounted outdoors on a tripod.

A network had now been established where tests could be carried out on the BreezeMAX 3500 System. As with our previous access technologies, network tests were done to evaluate performance.

The base station uses two types of connections to communicate with the subscriber units: Point to Point Protocol over Ethernet (PPPoE) and Layer 2 (L2) connections. PPPoE access service provides connectivity between PPPoE-enabled devices at the subscriber's site and a PPPoE aware access concentrator behind the base station. The frames are forwarded only between the subscribers' PCs and the PPPoE access concentrator. The frames that are not PPPoE type are discarded. In the uplink, frames are never relayed but only forwarded to the access concentrator. In the downlink, broadcasts are allowed only in cases of unknown addresses. L2 service transports layer 2 (Ethernet) frames between the subscriber's site, and the network resource located behind the provider's backbone either supports encapsulation of the layer 2 frames (e.g. over ATM) or else routes the frames according to the applicable layer 3 protocol, which might be different from IP. The network resource is assumed to be a corporate network (Alvarion BreezeMAX 3500).

The BreezeMAX 3500 System comes with FreeBSD version 6.1 installed. This allowed PPPoE security functions to be implemented within the network, which include data encryption. The FreeBSD router was used to carry out tests without interfering with the user. This involved running scripts on the routers. A Perl script on the router at Ngwane School would send out 10 ping packets to all the subscribers and it records the results. The other script, which carried out file transfers, was running at each client and copies a file from the Ngwane router and records the time taken to make such a transfer. The scripts were running in crontab, allowing them to automate these processes. The ping script ran every five minutes, while the transfer script ran every 10 minutes. Results of both were written to a CSV file. These were later copied into Excel to create graphs to be used for analysis.

Having managed to make the scripts operate within the established network, the next stage was getting the data on the performance of the technology. A particular subscriber unit has profiles, which defines how it interacts with the whole BreezeMAX system. Such profiles include the QoS profile, which defines the upper limit for transmission. This allows controlling the upper bounds for transmission in both the uplink and downlink transmission. The transmission rate of the BreezeMAX system is also affected by the modulation scheme employed by the equipment (IEEE Computer Society and the IEEE Microwave Theory and Techniques Society 2004). The Alvarion BreezeMAX base station employs a multi-rate algorithm that dynamically adapts the modulation scheme and forward error correction (FEC) according to the link conditions between the base station and each of the subscriber units (Alvarion BreezeMAX 3500).

Mpume Junior Secondary School

This site is located 1500 m from Ngwane Junior Secondary School, our host of the micro base station. The site has a direct LOS from the omni-directional antenna; this makes it reasonable enough to expect a relatively low RRT. The preliminary test involved switching-on the subscriber unit and evaluating the minimum signal level at which the subscriber unit is able to function. The minimum signal level available from this site was 4/9. This occurred when the subscriber unit was held about 1.5 m high. The average round-trip time from the initial ping test was 33.4125 ms, and throughput was 956 Kbps. We then proceeded to permanently mount the subscriber unit on the tripod stand, showing a signal level of 7/9, bearing in mind signal saturation, which could occur if left on 9/9. This was the best signal level that we could get from this site. Setting the Alvarion BreezeMAX base station to utilize a multi-rate algorithm that allows it to adapt to the different modulation scheme, the following results were computed from equation 3.1 and 3.3

Minimum RTT: 27.25 msec;

Average RTT: 31.46 msec;

Maximum RTT: 36.96 msec;

Average Throughput: 3.25 Mbps.

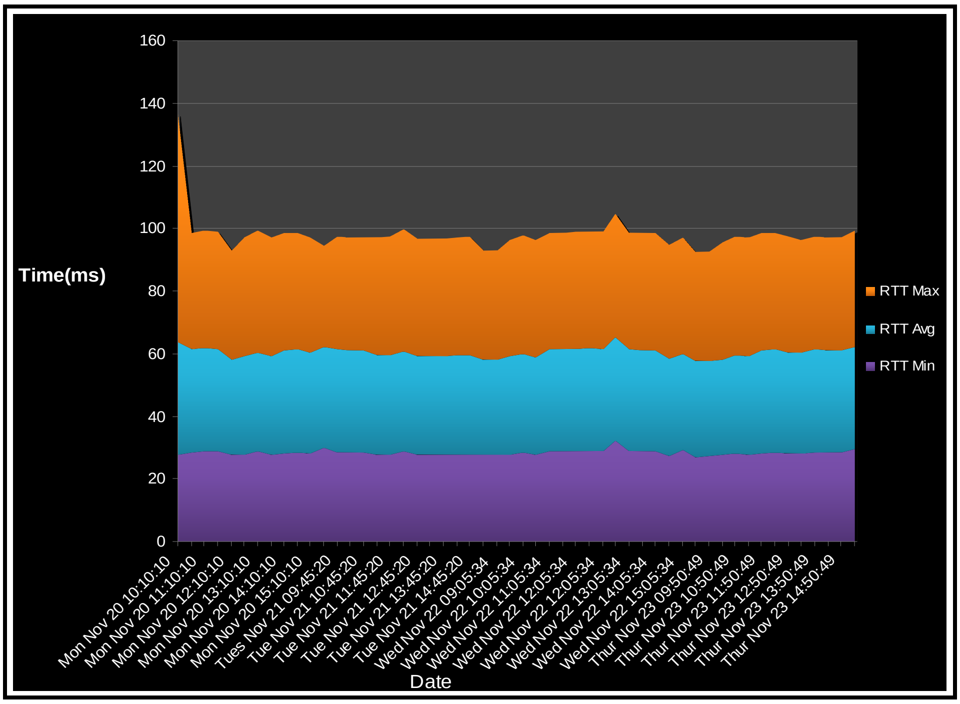


Figure 4.11: Ping test to the Mpume subscriber unit from a machine connected to the base station at Ngwane Junior Secondary School.

The results show no great difference between the average round-trip times. However, there was a significant difference in the throughput measured from the different signal levels showing that throughput varies with signal levels.

Mtokwane Junior Secondary School

This site is located about 750 m from the micro base station. The site has a LOS from the omni-directional antenna, although there is vegetation and the walls of the building of the subscriber unit lay within the path of transmission. The initial tests conducted at this school were done inside the building, mainly because it was difficult to find a place to mount it outside the main office. The ping tests conducted with the subscriber unit held about 1.2 m, with a signal level of 4/9. They revealed an average of round-trip time of 33.20, and transfer results were 838 Kbps. These were computed utilizing equation 3.1 and 3.3. The subscriber unit was then permanently mounted within the building since the most ideal place was found inside one of the offices, where the signal level was 6/9.

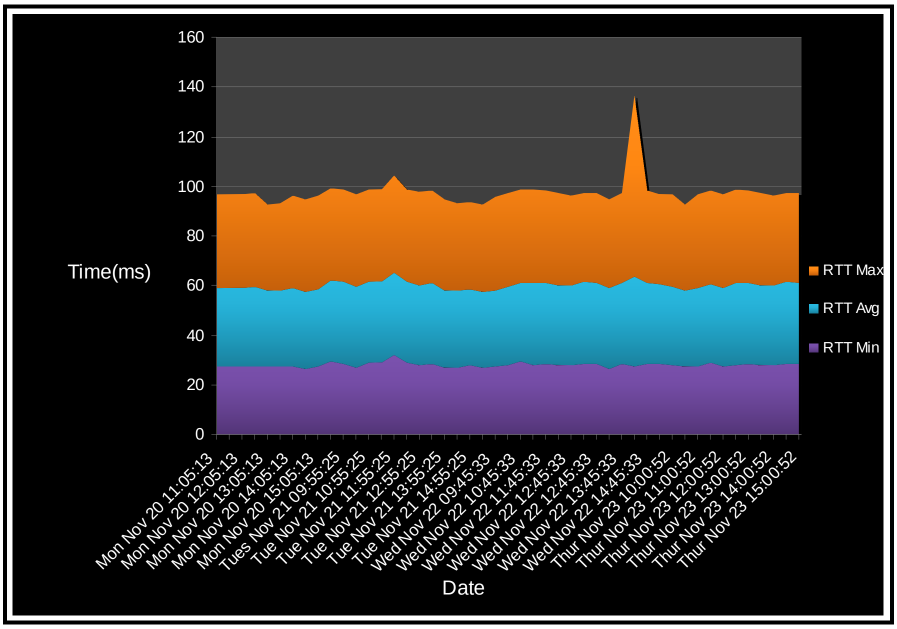


Figure 4.12: Ping test to the Mtokwane subscriber unit from a computer connected to the base station at Ngwane Junior Secondary School.

The data gathered from the site was computed utilizing equation 3.1 and 3.3 to enable the graphing it on Figure 4.12. The following were the minimum, average, maximum round-trip times and the average throughput;

Minimum RTT: 28.10 msec;

Average RTT: 32.10 msec;

Maximum RTT: 37.62 msec;

Average Throughput: 3.85 Mbps.

The results from this site show a high throughput of 3.85 Mbps, and this could be attributed to the distance between Mtokwane and Ngwane, the site where the micro base station is situated. This revealed that this site was the best-performing in terms of throughput.

Nondobo Junior Secondary School

This site is located approximately 650 m from Ngwane Junior Secondary School, the host site for the WiMAX micro base station. The site has a LOS from the omni-directional antenna deployed at Ngwane Junior Secondary School. The tests conducted here were in two phases. In the first case, an evaluation was done to find the signal level, with the subscriber unit held above the ground at approximately 1.5 m. We managed to get a signal level of 6/9 by letting the subscriber unit face the micro base station. From the ping tests we recorded an average of 33 ms and a transfer result of 928 Kbps. An ideal position was found on the gable of the building. The subscriber unit was then mounted outside the building, setting a signal level of 7/9. It was possible to get a signal level of 9/9; however, this was avoided as this resulted in signal saturation. The data gathered from this site was computed using equation 3.1 and 3.3. This provided the following results.

Minimum RTT: 27.28 msec;

Average RTT: 32.49 msec;

Maximum RTT: 37.94 msec;

Average Throughput: 3.58 Mbps.

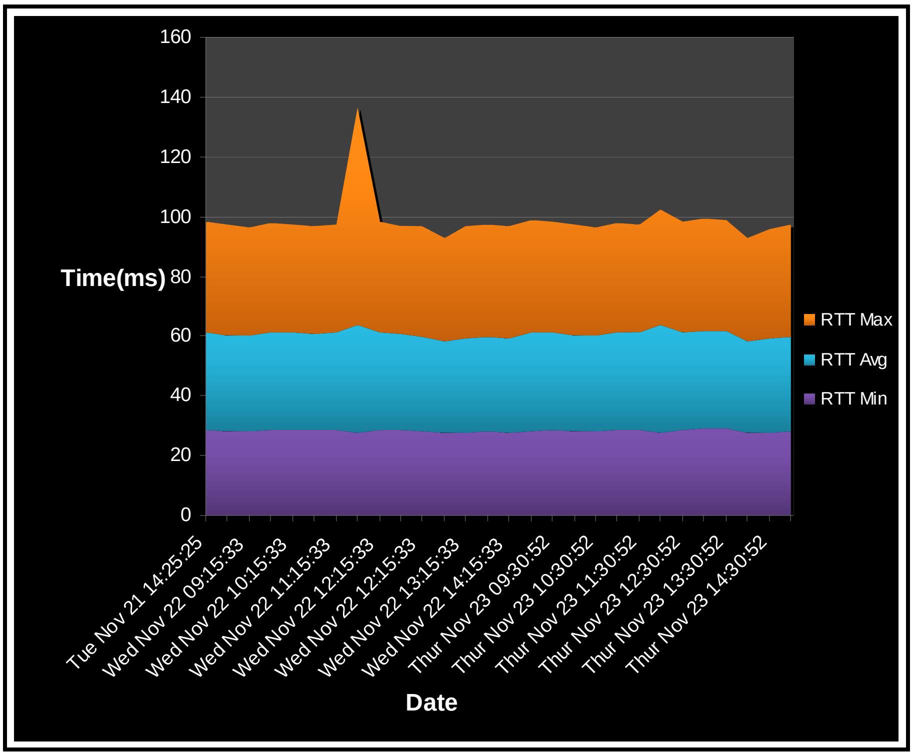


Figure 4.13: Ping test to the Nondobo subscriber unit from a computer connected to the base station at Ngwane Junior Secondary School.

The results shown in Figure 4.13 show a throughput of 3.58 Mbps, with a distance of 650 m apart. A comparison with the other sites shows this distance is shorter. This meant the throughput on this site was expected to be high; however, there was a high latency, which contributed to the decrease in throughput.

4.2.3 Evaluating file size versus throughput

To better investigate and understand how the WiMAX network performed in terms of throughput and latency an evaluation was done. This consisted of creating file sizes that were transferred over the network. Equation 3.2 and 3.3 was then used to compute the results. These results were then graphed. The graphs created illustrate two types of results; one set depicts throughput and the other latency for each file. Throughput is recorded in megabits per second (Mbps) and file size is shown in megabytes (MB). A total of eleven files were transferred across the network, varying from 500 B to 6 MB. Figure 4.14 shows the latency measured on the network between Ngwane and Mpume. The results show a positive relationship between file size and the latency experienced on the WiMAX network. The behavior of some files, from the 500 B to 1 MB file mark, have latency that is below two seconds, meaning that the smaller the file the faster the transfer. The reason may be that at low file loads the WiMAX network was not yet filled to its capacity. This means less congestion for the WiMAX network, thus explaining why the latency was low for small files.

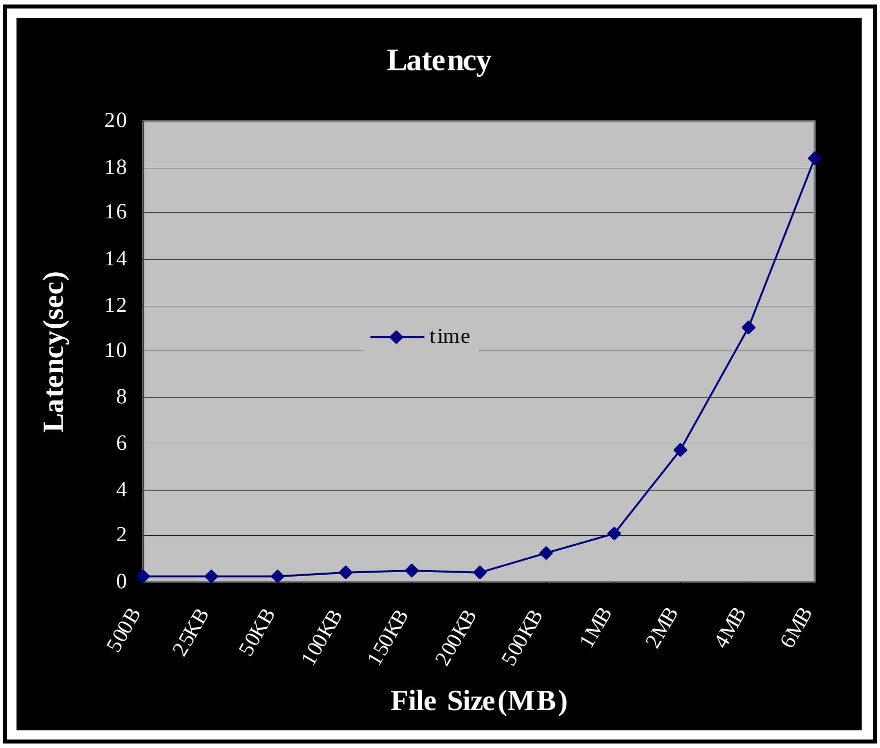


Figure 4.14: Latency plotted against file size. Shows latency on the vertical axis (seconds) plotted against file size (MB) on the horizontal axis.

The study found that as the file to be transferred becomes larger, more latency is experienced on the network. Latency increased gradually, but as file size increased from 1 MB to 6 MB, it took longer for the WiMAX network to transfer the file. The reason might be attributed to how the transfer script works. The transfer script first has to read the contents into the buffer, then fetch the content from the buffer, then write to disk, and then verify that the whole data in the buffer has been written, and then give a ‘success’ message. The verification is not part of writing to a disk, but during disk-writing, verification is considered not yet done. Verification in this case consumes extra time. Thus the study found that, in some instances, throughput was far less than expected because of high transfer time.

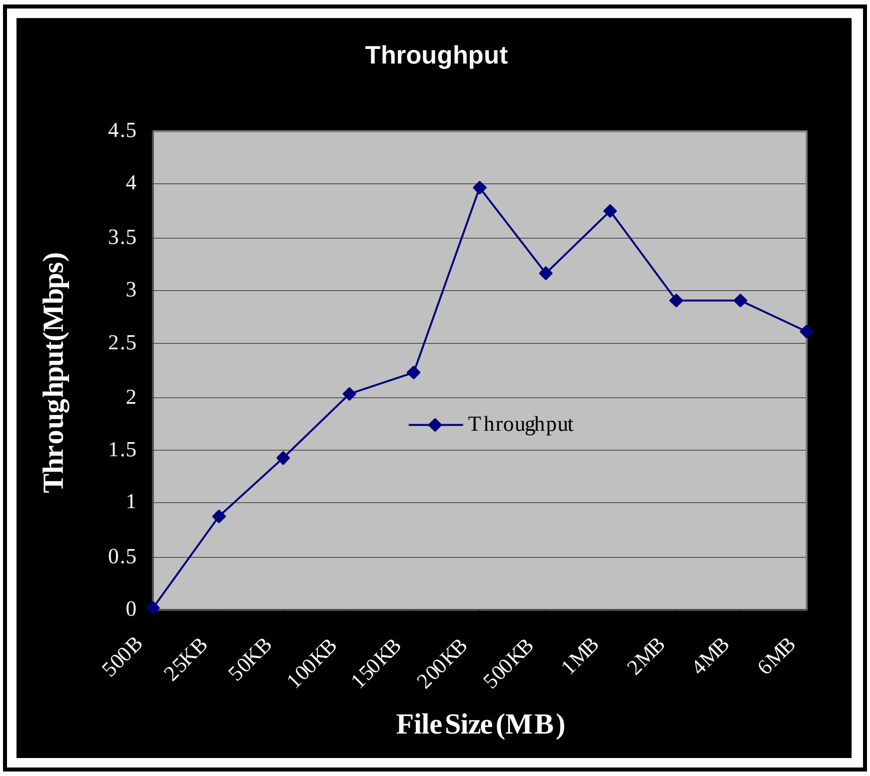


Figure 4.15: Throughput measured against file size. Shows throughput (Mbps) on the vertical axis plotted against file size (MB) on the horizontal axis.

Figure 4.15 illustrates the throughput over the WiMAX network with file variations from 500 B to 6 MB. The graph shows that there is a gradual increase in throughput between 500 B and 100 KB. This shows that as the file size increases the throughput also increases. The throughput reaches saturation (peak throughput) between 200 KB and 1 MB. On reaching that saturation region, throughput starts to decline as the file size is increased. The decline consists of a rise and fall, and eventually a decline.

The reasons for this throughput behavior could be that at small file sizes the loads on the WiMAX pipe have not yet utilized all of its capacity and so some bandwidth is still unused; thus small loads means low congestion. The WiMAX throughput increases as the file loads increase, until it uses all of the available capacity; from then on, throughput will start to drop with increasing file size.

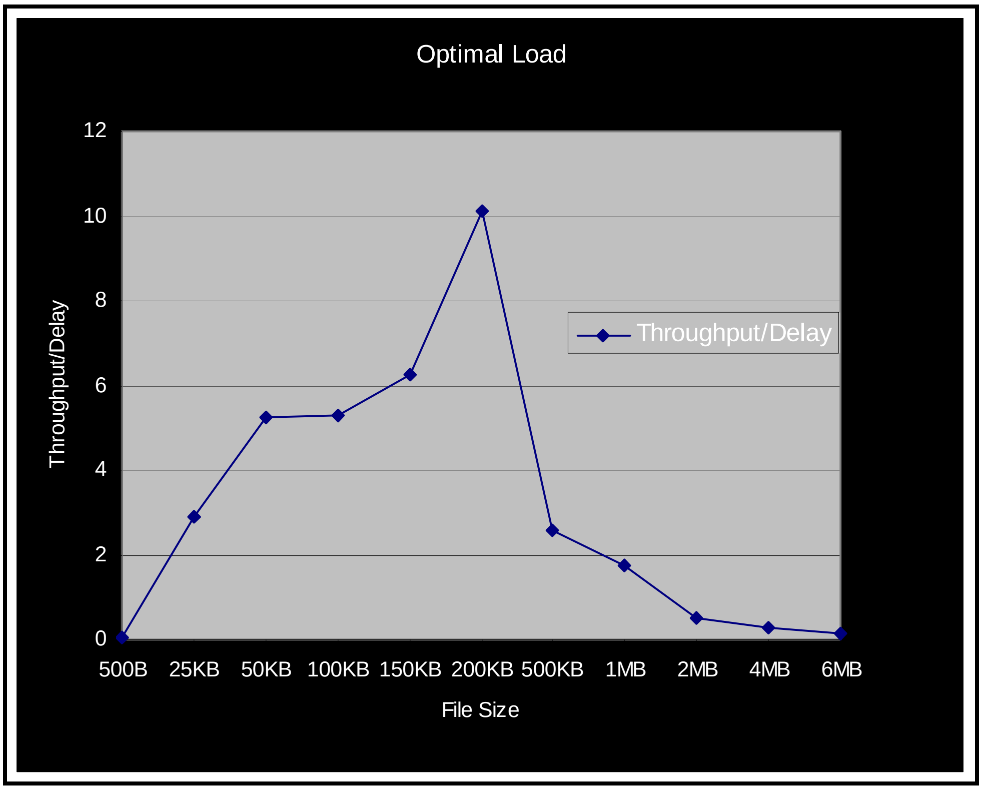


Figure 4.16: Optimal link load of the WiMAX network.

Figure 4.16 shows the optimal link of the WiMAX network at 200 KB. The optimal link of the WiMAX is computed utilizing this equation.

$$\text{Power} = \frac{(Throughput)\alpha}{Delay}$$

Where α network factor is set to 1 in this case

The graph shows a sharp increase between 500 B and 50 KB, and thereafter it gradually rose until reaching the optimal link load at 200 KB. It then declined with the increase in file size with graph falling; thus, the large files had smaller throughput/delay.

4.2.3 Conclusions

Various experiments with the possible access technologies for deployment in Dwesa-Cwebe were carried out. The various access technologies have different performance in terms of offering the backhaul connectivity to the e-commerce telecommunication platform. Table 4.2 summarizes the access technologies evaluated for Dwesa-Cwebe.

Table 4.2: Access technologies evaluated in the research.

Access Technology	**Applicability to Dwesa-Cwebe**
Telephone-associated	Complete absence of telephone lines.
Powerline communication	The absence of telephone lines rules out its integration into PLC.
Fiber optics	Expensive to deploy fiber optics up to Dwesa-Cwebe.
WiFi	Can be deployed to offer connectivity however they is need of a backhaul connectivity technology to be implemented.
High-altitude platform	Lack of technical expertise to implement and its high cost.
VSAT	Offers ideal back haul connectivity. However the costs are high.
GPRS	The data rates are very low in this area since there is poor cell phone coverage.
3G	Complete absence of 3G coverage in this area.
WiMAX	Offers the ability to extend signal over an area.

The experiments enabled a decision on the best available access technologies to be utilized in Dwesa-Cwebe to provide backhaul connectivity. This led to the development of a network now in operation for the e-commerce telecommunication platform.

Chapter 5

The Deployed Distributed Local Loop WiMAX Network

Chapter 4 dealt with the various access technologies tested and used for network deployment in the rural community of Dwesa-Cwebe. This chapter illustrates how the network was established and the various operations to serve the e-commerce telecommunication platform being established.

5.1 Background to the study area

Dwesa (32°17' 60"S, 28° 49' 60"E) -Cwebe (32°13'0"S , 28°55'0"E) is a rural community area located in the Mbashe Municipality of the Eastern Cape Province of South Africa. It has an estimated population of 15,000 people living in about 2,000 households. The inhabitants of Dwesa-Cwebe are traditionally subsistence farmers who depend on their crops for their livelihood (Palmer *et al.* 2002). Figure 5.1 shows the Dwesa-Cwebe project area.

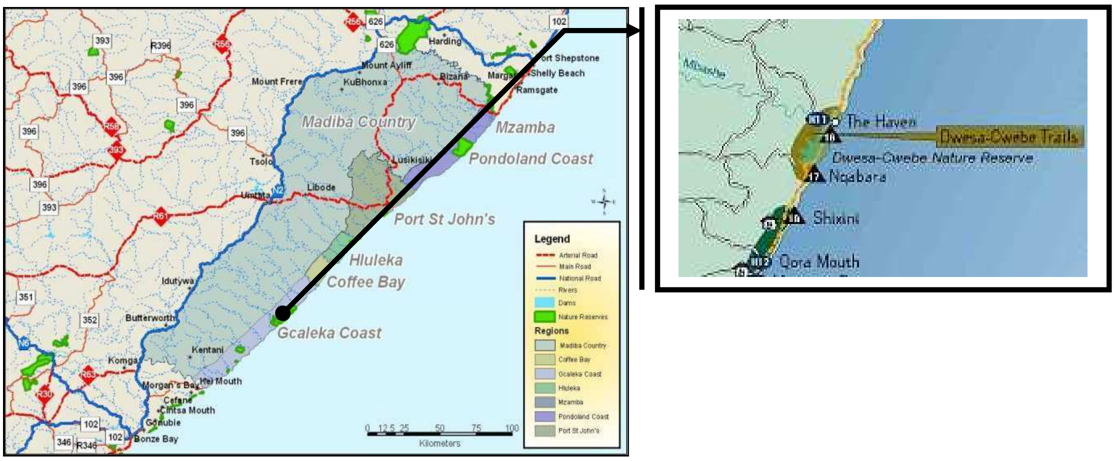


Figure 5.1: Dwesa-Cwebe maps (The Wild Coast region, Eastern Cape, South Africa).

The region features a coastal nature conservation reserve that is owned by the community around the Dwesa Nature Reserve and the Haven Hotel. The region has high potential for eco-tourism and cultural tourism due to the rich cultural heritage of the Xhosa people in this area and the marine conservation project being undertaken at the nature reserve. This makes Dwesa-Cwebe a region which is ideal to take advantage of the global upsurge in eco-tourism activities. This would promote the livelihoods of the rural community who otherwise depend on subsistence farming.

5.2 Problems and requirements specifications

Dwesa-Cwebe is characterized by lack of sufficient infrastructure in terms of roads, electricity, widespread poverty, lack of services and isolation (Human Sciences Research Council, 2005). Isolation is probably the main reason for young people leaving Dwesa for the cities, a typical phenomenon in rural areas (Salt, 1992). This deprives the community of young people who are a primary force for change and innovation. This is even worse than the physical isolation which is isolation in terms of knowledge and information. Flor (2001) discussed and highlighted the centrality of the link between access to information (or lack of it) and poverty. Access to relevant information has become one of the discriminating factors between the rich and the poor communities in the world.

Like most marginalized communities, Dwesa-Cwebe suffers from major infrastructure problems such as limited electricity availability and connectivity, minimal telecommunication infrastructure, poor quality of the transport infrastructure, and most importantly, sub-standard education facilities. The schools that do exist are also under-funded, under-equipped, and under-staffed. According to Palmer et al (2002) the Haven hotel's sporadically operational radio phone was the only communication link in this area. The conventional telephones were once operational but these have since fell into disrepair. The major problem which has affected the provision of telephone services to the rural areas in Transkei has been the theft of copper telephone cables. It was of importance that this had also to be taken into consideration during the deployment of the network in this area. This would help in safeguard the network and minimize vandalism of the equipment on the deployed network.

Dwesa-Cwebe is one of the first successful land restitution in South Africa, such that it represents a turning point for the communities residing in these disadvantaged rural areas. Problem such as telecommunication services which have affected the area in a long time can be attempted to be redressed given such a scenario. Further to that there is need to consider the opportunities for growth, including eco-tourism and cultural tourism. The establishment of such services would aid development in this area.

The process of establishing an integrated e-commerce/telecommunication platform was the primary objective of this project. The work sought to develop and field-test the prototype of a simple, cost-effective and robust, integrated e-commerce/telecommunication platform, suitable for deployment in marginalized and semi-marginalized communities in South Africa, where 42.5% of the South African population live (Statistics South Africa, 2001). These communities, by their sheer size and because of current political dynamics, represent a strategic emergent market. The results of this research may be applicable to other developing countries, where approximately 675 million people live in similar marginalized communities (Bage, 2004). In this context, an attempt has been made to bring connectivity to a particular disadvantaged rural area in the process of setting up the integrated e-commerce/telecommunication platform.

5.3 Planning

The first stage involved a survey of the region of Dwesa-Cwebe in order to identify access points where the network equipment could be easily set up. This followed several meetings with the Dwesa-Cwebe Land Trust who heard our proposal to set up the e-commerce/telecommunication platform in that area. We were working with the management of the trust to pursue area-development within their newly acquired territory. After been granted the right to deploy the field testing of the e-commerce/telecommunication platform, the next stage was to survey where this could be hosted within that area.

Dwesa-Cwebe consists of some spot areas where electricity has been deployed; these areas include Mpume, Mtokwane, Ngwane and Nondobo, whilet in other areas plans were still in progress to have Eskom deploy electricity. These areas include Mendwane, Ntlangano and Ngoma. This meant focusing on the areas where electricity was readily available before further expansion into the other areas. In these areas we concluded that the schools were the access points which could be easily set up for network deployment. We managed to liaise with the principals within these schools about the project.

The principal of Mpume Junior Secondary School our main area of presence in this area was delighted with such a proposal coming to a remote disadvantaged rural area. This signified a change in the perception of researchers to empower the rural remote areas. The principal managed to organize meetings with the community so that we could easily obtain community buy in and cooperation from the Mpume community. Together with the community we managed to cooperate and launch the project. Although they were other accessible points such as clinics in this area the schools remained the best option for various reasons which will be explained.

5.3.1 Identify possible solutions

During the planning for a network considerations have to be made in terms of the present user requirements. The fact that computer literacy was very low at the time of introducing computers in Dwesa-Cwebe it meant the requirements were not demanding. However this would change in as time goes on hopefully as users become more computer literate. Applications types needed at the inception included web browsing, email and document downloads and uploads. Green (2007) made recommendations for typical data bandwidth requirements for establishment of telecenters in rural areas. These are illustrated in Table 5.1

Table 5.1: Data transfer (shows data transfer rate required for average-sized applications).

Application\Content	Average Transaction Size (KB)	Data Transfer Rate (Kbps)
Documents/government forms	50	40
Formatted e-mail text	2	1.6
Web-browsing	62.5	50

Considering the future growth in demand of these applications assuming that they would be an increase of users on the network and therefore an increase in service demand in the coming years will not require major update of the network since the network is very scalable and upgradeable.

In deciding the appropriate access technology which could be utilized in this area various options were put under consideration as discussed in chapter 4. In an area such as Dwesa-Cwebe, a dial up link would have been an easy option to provide connectivity to this area. However the prevalent absence of the traditional phone lines in this whole area meant that other access technologies had to be explored. The presence of the telephone would have allowed easy set up for most of the telephone associated technologies.

Technology options investigated were discussed in Chapter 4 include Telephone Associated Technologies, Powerline Communication, Fiber Optics, Wireless Fidelity, High Altitude Platforms, VSAT, WiMAX, GPRS and 3G technologies with their performance results from their operation in Dwesa-Cwebe. In this section there are presented with the comments showing their inapplicability or their applicability in Dwesa-Cwebe.

Table 5.2: Linking investigated options to provide Internet connectivity.

Option	Availability	Licensing need	Costs	Flexibility
Telephone Associated Technologies	Not available	Proprietary based (Telkom)	Installation costs, monthly rental	Dependant on the existence of telephone lines
Powerline Communication	Coverage not available and absence of telephone lines	Proprietary based (Eskom)	Acquisition, installation & maintenance costs	Depends on the existence of power cables
Fibre Optics	Not available	No licensing required	Acquisition, installation & maintenance costs	Not flexible
Wireless Fidelity	Dependent on the presence of telephone lines to offer backhaul connectivity	Licensing required for its operation outside premises	Cost of equipment, installation & maintenance	Highly flexible
High Altitude Platforms	Not available	Not regulated	Cost of aeroplanes for deployment, installation & maintenance	Flexible within a certain geographic area
VSAT	Available wherever there is a clear line of sight to the sky	Proprietary based (Telkom)	Installation costs, monthly rental	Highly flexible
GPRS and 3G technologies	Available but without complete coverage not reliable	Proprietary based (MTN, Vodacom, Cell C)	Acquisition & data bundles costs	Highly flexible
WiMAX	Made available	Licensing provided by Amatola Telecommunications	Cost of equipment, installation & maintenance	Highly flexible

5.4 Implementation

Telephone-associated technologies and other prevalent technologies were not applicable to Dwesa-Cwebe, thus the chosen solution was satellite technology. The VSAT could offer backhaul connectivity in this rural remote disadvantage area. The SpaceStream Access chosen for deployment (from Telkom South Africa) uses the C-band coverage of the IS 901 satellite. The C-band has the advantage of being more stable, with the disadvantage of requiring a remote satellite antenna of 1.8 m. The SpaceStream Express VSAT was then able to offer the backhaul connectivity to this area, with download speeds of 512 Kbps and 128 Kbps upload.

The schools within Dwesa-Cwebe had to be connected in such a way that they could access the Internet on demand. This meant implementing a wireless technology to link the schools. In this case WiMAX was adopted since we had already experimented with it within the schools. WiMAX operating in the 3.5 GHz frequency band requires licensing in South Africa. The UFHCoE has a relationship with one of the under-serviced area license holders in the Amatola region, namely Amatola Telecommunications, one of the sponsors of the UFHCoE, was able to provide us with the licensing required to operate.

The current deployment of the network infrastructure in Dwesa-Cwebe has been concentrated around schools due to such factors as provision of a centralized location and accessibility to many villages. This allows us to share the existing societal structures that facilitate community acceptance, buy-in, and eventual ownership of the infrastructure, and which also insures a certain level of physical security. Another important benefit of locating our network infrastructure in schools is that they are already fitted with a source of powering the equipment. All this made setting up the network manageable as several of the requirements were in existence.

Figure 5.2 depicts the current Dwesa-Cwebe network set-up. The VSAT is located at Mpume Junior Secondary School. This provides the backhaul Internet connectivity to the Dwesa-Cwebe network. The VSAT has an indoor unit connected to the Mpume Router/Server. The indoor unit has a DHCP server that was built and installed by Telkom. The Mpume Server/Router provides server capabilities within the network in the school; it also allocates DHCP addresses within the Mpume School Lab. This server is connected to the local (Mpume

Junior Secondary School) network through a D-Link DES-1008D, which is a dual-speed 8-port 10/100 Mb Ethernet/Fast Ethernet NWay auto-negotiating switch. This provides Internet connectivity to the Mpume Junior Secondary School Lab.

The VSAT is designed in such a way that it requires login after every 24 hours. This means every 24 hours it will lose its connection and there is need to login again. Considering that this can be complicated process in a disadvantaged rural environment, we designed a script that would automatically login after 24 hours. Thus, when the connection expires it now redials, restoring the connection. The script also enables a reverse connection into the Rhodes University network, allowing for remote trouble-shooting on the Dwesa-Cwebe network.

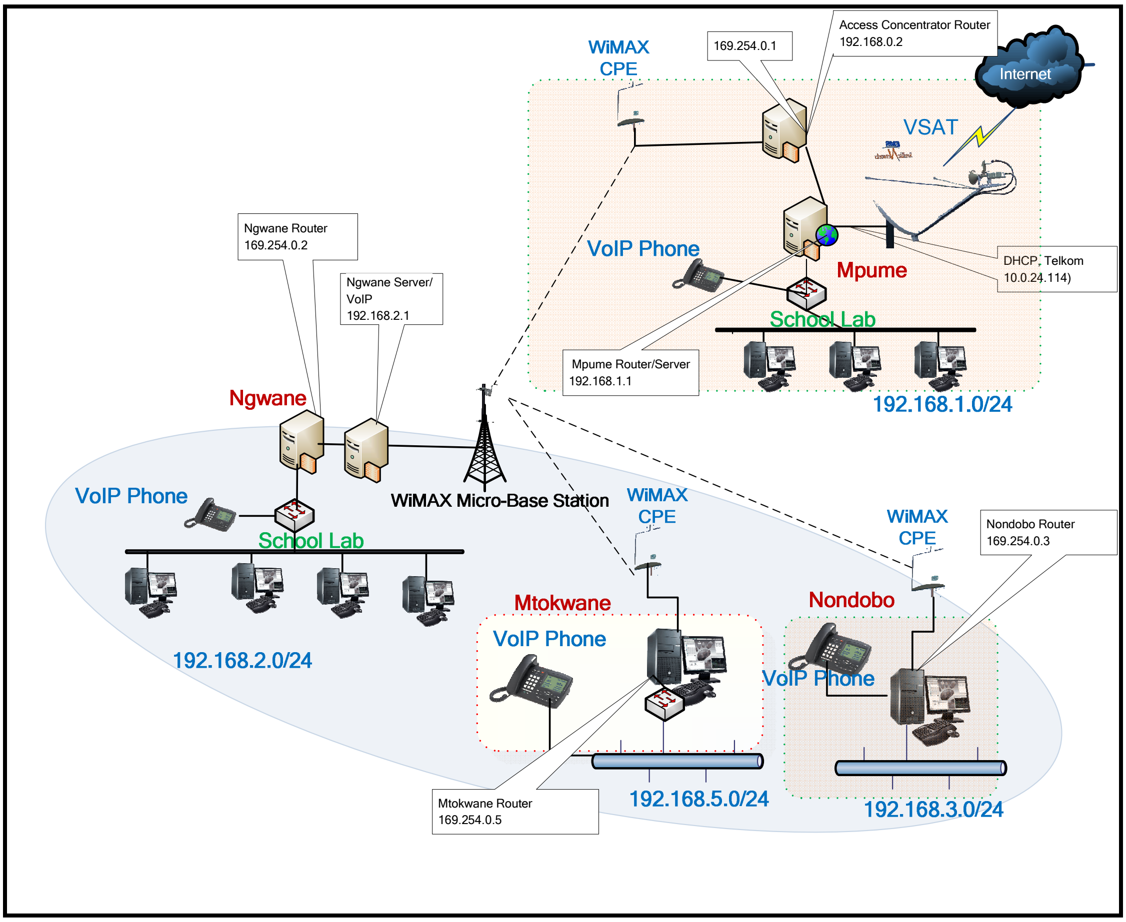


Figure 5.2: Dwesa-Cwebe network set-up.

The access concentrator router establishes communication tunnels on the WiMAX and is connected to the Mpume Router/Server where it forwards all Internet requests coming from the other clients located within the network of schools connected to this network. The WiMAX subscriber unit located at Mpume Junior Secondary School is linked to the indoor data module that is connected to the Mpume Router/Server. This is the link that enables the signal to reach the WiMAX system. The WiMAX micro base station, located at Ngwane Junior Secondary School, has an omni-directional antenna of 13 dBbi, which provides the signal to the other subscriber units attached to the network.

Figure 5.3 illustrates how the routing process is occurring on the Dwesa-Cwebe network. The access concentrator router is central in operation of this network.

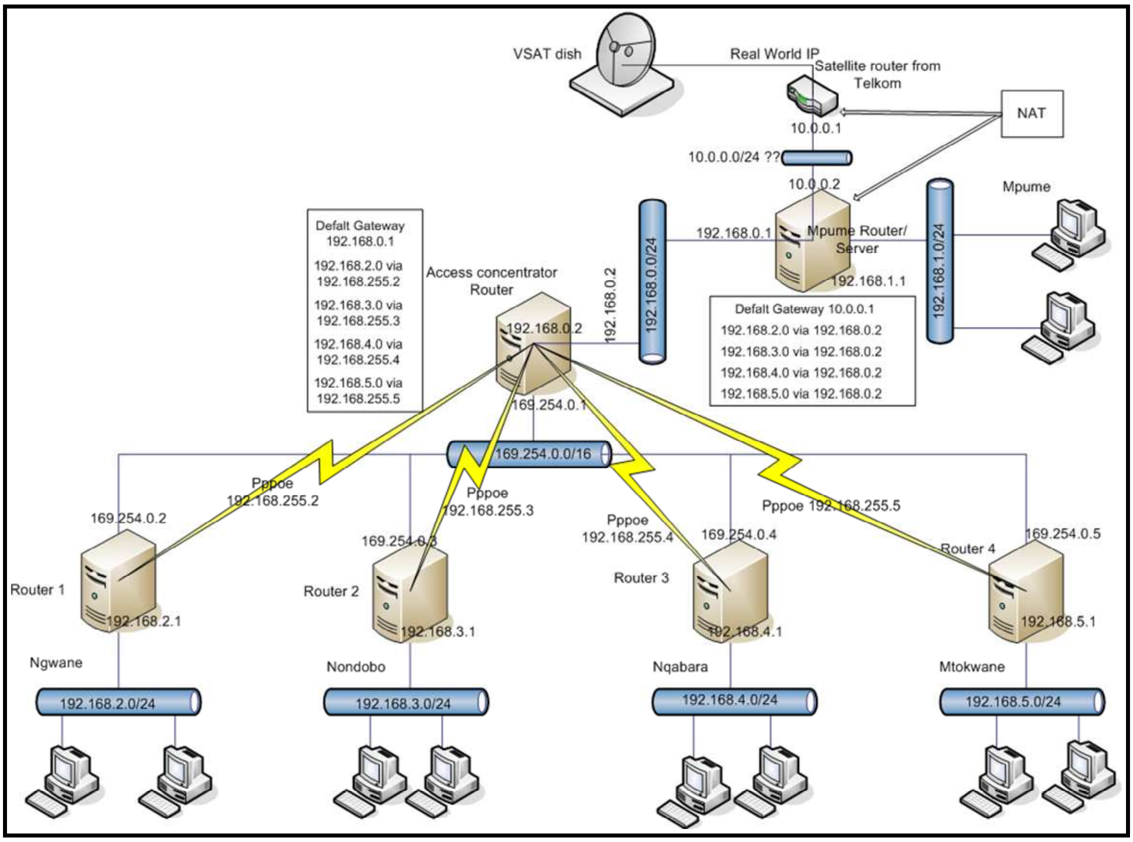


Figure 5.3: Dwesa-Cwebe network routing map.

In the diagram, four schools are connected to the access concentrator via PPPoE tunnels. The access concentrator uses the Mpume Router Server as its default gateway. It has a routing table that is used to route traffic between these different networks. For example all traffic from Mtokwane (192.168.5.0 network) is sent via the PPPoE tunnel 192.168.255.5.

The Mpume Router Server acts as the default gateway for all the networks. All traffic for the internal network is sent to the access concentrator, which then routes to the respective network. All traffic that references other networks, for example the Internet, is sent via the default gateway 10.0.0.1. Table 5.3 shows the equipment used to build up the network.

Table 5.3: Equipment in the Dwesa-Cwebe network.

Equipment	**Characteristics**
VSAT dish	1.8-m diameter, supplied by Gilat.
Satellite router	Gilat Skystar 360E 100-240V 50-60hz 0.4A.
Routers	Mpume Router/Server HP Proliant ML150 4 Intel Pentium III running FreeBSD 6.1.
Switches	Net Gear ProSafe, 24 ports with 2-gigabit ports, 100-240V 50-60Hz 0.4A, 24-port Cisco catalyst 2950.
Computers	12 Intel Celeron D processor computers running as thin clients; 20 generic computers with different specifications.
BreezeMAX 3500 WiMAX system	1 micro base-station indoor unit, 1 access unit outdoor unit; 13 dBbi omni-directional antennae, 3 subscriber outdoor units, 3 subscriber indoor units.

The following is an explanation about how the system operates when an application runs on the network. A user at Ngwane wants to access a Web page. His PC forwards the request to the router located at Ngwane. The Ngwane router forwards this request to the access concentrator in Mpume Junior Secondary School. Utilizing PPPoE, a connection is created between the two routers. The Access Concentrator Router in Mpume will then route through the Mpume Router Server which is connected to the indoor module unit of the VSAT. Thus anything with Internet is sent via the default gateway, allowing it then to fetch the requested Web page from the World Wide Web.

The same scenario also occurs when a user at Mtokwane sends an email to a user in Ngwane. His PC forwards the request to the Mtokwane router which establishes a connection with the access concentrator at Mpume. Since in this case there is no mail server dedicated for the mail service on this network we utilize other mail server on the Internet. Thus this request will be sent to the Mpume Router Server which is connected to the indoor module unit of the VSAT, allowing it to connect to the servers on the World Wide Web (WWW).

An issue of VoIP call destined for Nondobo from Mtokwane is handled by the Access Concentrator thereby forwarding it to its destination Mtokwane. The VoIP server located at Ngwane would handle the management of this call. This means this application is handled within this network without contacting the outside network (WWW). Annexure 1 document serves to describe and explain the network, servers and services on the Dwesa-Cwebe Network

5.5 Findings

The Dwesa-Cwebe network has been able to offer Internet connectivity within the schools in this area. The community has welcomed the arrival of computers in their community and has been attending computer literacy training. There has been an uptake in the use of computers seen by the preparation of various documents from the schools and the community. The schools are able to make registers, timetables, mark sheets, letters and other various documents on demand. On the part of the schools this has shown an improvement in their recording keeping. The Internet and other offline data repositories have been able to offer the teachers more resources which they can utilize in their lesson planning pupils can access Internet for assignment works. The use of the VoIP phone has also aided in communication within the schools since there were no landlines available for communication within the schools. The schools are able to access a free phone service allowing them to share any information which might be necessary. This has greatly improved the communication between the schools.

The community has also been able to markets their arts and craft through the e-shopping mall created by Sicelo Njenje (MSc, December 2007). The project entitled An Online Shopping mall for Dwesa-Cwebe was been designed to allow online shopping of the arts and crafts made in Dwesa-Cwebe. Customers worldwide are able to view arts and craft in Dwesa-Cwebe and are able to make payments online. This has greatly improved the market for their wares making them realize an increase in sales.

The project needed to be sustainable to maintain the network in the network in operation. Paul Tarwireyi designed a cost-sharing billing system (MSC-December 2007, UFH thesis to be published). The billing system allows cost of the VSAT monthly subscription to be shared among the users.

5.6 Conclusions

This chapter provided the background to the deployment area Dwesa-Cwebe. It also laid down the problems and requirements specifications for the deployment of the network. This led to the implementation of the Dwesa-Cwebe network which is serving the community and the schools. The operation of the network is then laid down leading to the benefits derived from the establishment of this network. In the next chapter we discuss work carried out and the goals achieved in this project.

Chapter Six

Conclusions and Future Work

This chapter presents the summary of the findings from the project. This includes the current initiatives which are being done to link rural remote disadvantaged communities, the access technologies which can be deployed in these rural remote areas and the goals achieved in this project. Further to that the future work which can be pursued in this study is laid down.

6.1 Overview of the thesis

The main goal of this project was to establish an Internet connectivity solution that is to be used as the backhaul connectivity to the integrated e-commerce / telecommunication platform, to be deployed in marginalized and semi-marginalized communities in South Africa. In this case Dwesa-Cwebe was utilized as the test bed of deployment. The connectivity solution was to be cheaper, cost effective, easily to configure, deploy and maintain. The connectivity solution was to be sustainable in the rural areas through the community being able to handle and associate with it. This was carried out through a practical study of the various connectivity technologies that are available for rural Internet connectivity in South Africa.

Rural Internet connectivity has been an ongoing concern in South Africa and the world over. The unique characteristics of the marginalized rural areas have proven to be a challenge. However despite these unique characteristics of the rural areas, various initiatives have been done to deliver Internet to the marginalized rural areas. The projects which have been deployed have shown several innovative ways of delivering Internet connectivity to the rural marginalized areas. This has been done through a combination of various access technologies. Several rural applications can be delivered to the marginalized rural areas through thanks to projects which were launched in various places; telemedicine, distance education and community and business development initiatives are a few. Thus the Internet has been able to somehow uplift the standard of living in places where people have been able to embrace and utilize benefits derived from its use.

In South Africa there are various access technologies which are available to deliver the mission of Internet connectivity. These include the wired and wireless technologies. The wired access technologies include DSL, ADSL, Diginet, Analog Dial Up, ISDN, PLC and Optical Fiber. Whilst the wireless access technologies are WiFi, WiMAX, Mobile Cellular Systems, Satellites, VSAT and HAPS. However these technologies are not always available in every environment. Moreover the technologies vary on their applicability in terms of cost, where they can be deployed, what they can be able to deliver in terms of throughput, reliability and latency of the technologies. The access technologies also have their advantages and disadvantages within their application domain. The technologies would need to be evaluated based on the area which deployment is occurring.

A number of technologies were evaluated for their applicability to offer backhaul connectivity. These included telephone associated technologies, optic fiber, PLC, HAPS, VSAT, Wi-Fi, WiMAX, GPRS and 3G. Telephone associated technologies, optic fibre, PLC, Wi-Fi and HAPS were not implemented in Dwesa-Cwebe area. These technologies were evaluated in terms of their deployment cost. This resulted in them being overruled for deployment in Dwesa-Cwebe area because of the costs associated with their deployment and the inability to offer backhaul connectivity in such an area. VSAT, GPRS, 3G and WiMAX were actually deployed and evaluated for reliability, latency and throughput in Dwesa-Cwebe. The results provided then the appropriate technology to deploy in the rural Dwesa-Cwebe taking into consideration of their latency and throughput. This enabled the decision to deploy VSAT and WiMAX for setting up Dwesa-Cwebe network which is in operation.

The network is built up of VSAT which provides the backhaul Internet connectivity to the network. The VSAT is a product of Telkom South Africa which operates on the C-band satellite infrastructure. It provides downloads speed of 512Kbps, and upload speed of 128kbps. The WiMAX technology has been deployed to relay signal to the other access points which in this case are schools. The WiMAX technology deployed in this case is BreezeMAX 3500 manufactured by Alvarion. The schools were chosen network easier. The deployment of the network infrastructure in Dwesa-Cwebe is concentrated around schools since they offer minimal infrastructure which made the setting up of the network easier, and factors such as provision of a centralized location, and accessibility to the community members. This allowed us to piggy back on existing societal structures which facilitate community acceptance, buy-in, and eventual ownership of the infrastructure e.g. by giving computer literacy training. This resulted in the protection of the equipment within the community.

6.2 Goals achieved

The study has provided insight into practical deployment issues of Internet connectivity in rural disadvantaged communities. In this case VSAT technology has proven to offer backhaul Internet connectivity in a Dwesa-Cwebe a rural remote disadvantaged area with most of the prevalent characteristics found in rural areas. WiMAX has proven to be able to relay this signal over the established Dwesa-Cwebe Siyakhula network. The common network performance parameters: throughput, reliability and latency for the deployed access technologies were measured. These have shown how the throughput and latency of VSAT behave over this area. The speed is able to handle web browsing and emails over the satellite network. The average round trip time of approximately 2 seconds with peak such as 6 seconds makes the delivery of real applications face problems. However where the other alternatives can not match it, VSAT remains with that advantage of offering Internet connectivity from anywhere. WiMAX can be used to distribute signal over an area without compromising on the throughput of the network. In this case an average of approximately 3.2Mbps was recorded over the connected sites. This shows WiMAX being able to distribute signal without compromising the throughput of the network.

The utilization of Free and Open Source Software (FOSS) for the establishment of networks has been seen as a cost effective way for network deployment. The deployed network has been built on FOSS, thereby reducing the cost of deployment. The utilization of FOSS has also allowed the localization of software in Dwesa enabling the people to easily conceptualize ICT for development through use of Open Office which is customizable in Xhosa. This has proven useful in ushering the rural people of Dwesa-Cwebe community into the information society since rural communities find it difficult to read the English language.

The cost of rental of VSAT service has always been viewed as too expensive. The idea of establishing a way of sharing the costs of the VSAT as has been done in this projects can be seen as a way of making the cost of VSAT becoming manageable. The fact that users contribute to the payment of the usage to the network means the cost is lowered as many users join the network the costs decreases. This therefore shows that VSAT can be implemented and costs shared between users therefore becoming manageable.

The study has also provided information to the ICT Industry sponsors about deploying telecommunication networks for rural disadvantaged communities. This will provide more insight into the rural market. The industry has been reluctant to invest in this market since they view the disadvantaged rural areas as areas of low business and difficult to serve. This research will enable the ICT industry to tailor services which are relevant to the rural market.

The deployment of Internet connectivity in Dwesa-Cwebe area has been a step to usher the people residing in this area into the information age. They can utilize the Internet for the various benefits which it offers. Further to that the e-commerce platform would empower them through the trading of arts and crafts. This will increase the levels of disposal income within the Dwesa- Cwebe community thereby enabling thereby uplifting their standard of living.

6.3 Limitations

The study covered broad issues surrounding access technologies for providing backhaul Internet connectivity for the establishment of an e-commerce/telecommunication platform. The purpose was to come up with an access technology or a mix of them which could be implemented to provide backhaul connectivity. Due to this the project does not provide an in depth analysis of BreezeMAX WiMAX technology. It gives an insight into the latency, reliability and throughput of the established network.

6.4 Future work

From this research a number of potential areas for further research can be identified. Considering that a technology such as WiMAX is still maturing such that full benefits still need to be derived from it. Besides current work being done by some other researchers like the deployment of an online shopping to promote the trading of arts and craft made in Dwesa-Cwebe. For the future work the following proposals can be considered:

1. An in depth analysis of the traffic being routed on the extended version of this WiMAX network can be done on an expanded network covering other access points which are within the reach of the network
2. The deployment of new GSM towers in Dwesa-Cwebe shall give an opportunity of through comparison with GPRS/GSM as alternative spare solutions.
3. Investigation of fully meshed wireless solution among villages can be done around using converged technologies GSM/WiMAX for voice

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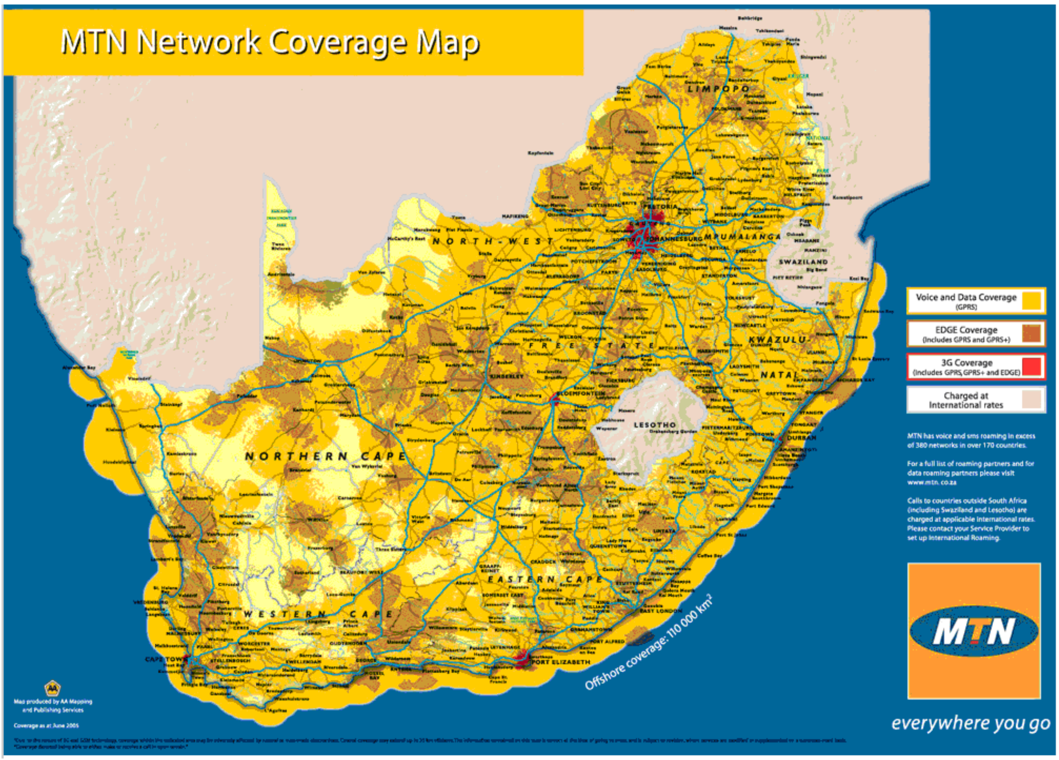
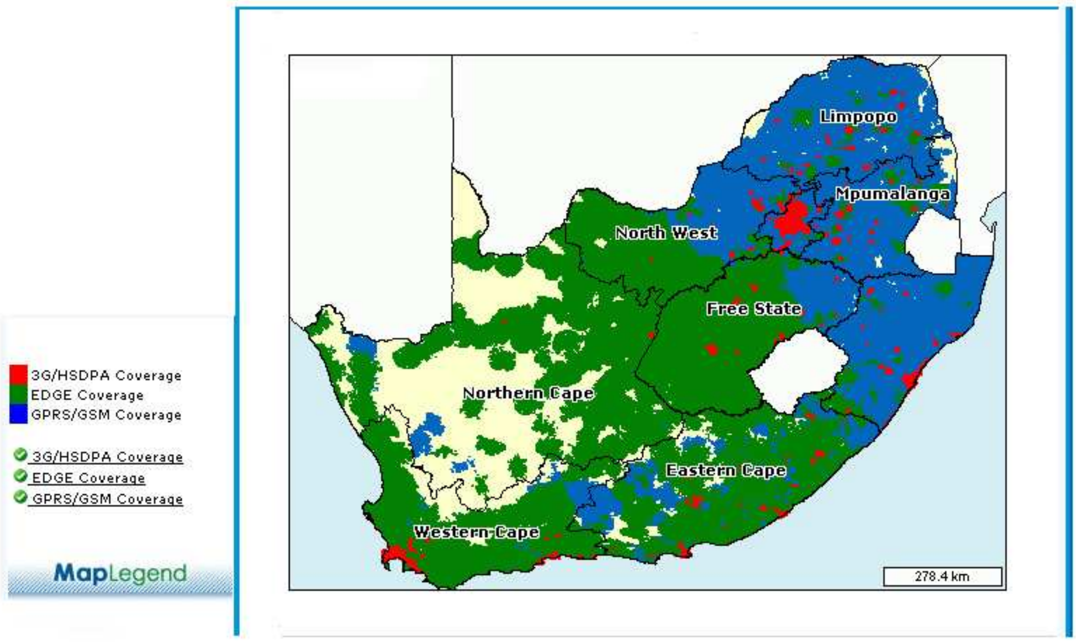
Appendices

Annexure 1



Annexure 2

VODACOM Network Coverage Map



Annexure 3

Dwesa Networking Document
Ingrid Siebörger, Barry Irwin
October 22, 2007
Document Version 1.0
1 Introduction
This document serves to describe and explain the network, servers and services at the Dwesa Siyakhula project, jointly run by the University of Fort Hare and Rhodes University. It is hoped that this document will assist any new administrators or service providers within the project to understand the current configuration within the network.

2 Dwesa Routers

At each of the schools, currently Ngwane, Mtokwane and Nondobo (with Nqabara to come on board in the next phase) there is a FreeBSD 6.1 computer acting as a router. They are all low end Intel Pentium III systems

- The current router at Ngwane is an asset number 18182
- The router at Mtokwane has an asset number of 13485
- The Nondobo router had no asset number, but again the machine is of a similar kind

3 Dwesa Access Concentrator

The Dwesa access concentrator which establishes communication tunnels on the WiMAX network with the other routers at each of the schools. This system is a Pentium III 500MHz processor, whose asset number is 15739. This server is the router for the WiMAX test bed network in Dwesa. It runs a pppoed service for the clients on the network. This allows for authentication and encryption preventing non-authorized access and securing traffic. The router runs FreeBSD 6.2.

4 The network

At each of the schools there is a local area network (LAN) allowing the local lab and school computers to communicate with the school's server and also the school's router which will route them to the Internet. The schools and their subnets are as follows:

- Ngwane 192.168.2.0/24 (ie the subnet mask is 255.255.255.0)
- Mtokwane 192.168.3.0/24
- Nondobo 192.168.4.0/24
- Nqabara 192.168.5.0/24

Each school router has two network cards: an internal network interface and an external network interface. The internal interface, called int0, has an IP address within the range of the LAN. Physically int0 is connected to the switch at the school. The external interface, called dcw0, binds an IP address on the “raw” WiMAX IP network. This “raw” network operates in 169.254.0.0/16 (ie the subnet mask is 255.255.0.0). Physically dcw0 is connected to the WiMAX network. This means at Mpume, Mtokwane, Nondobo and eventually Nqabara their network is connected to the WiMAX CPE, while at Ngwane it is connected to the base station. Each of the routers binds an IP on this network as follows:

- Ngwane 169.254.0.2
- Mtokwane 169.254.0.3
- Nondobo 169.254.0.4
- Nqabara 169.254.0.5

This “raw” network allows these machines to communicate with the Access concentrator, located at Mpume, which binds the IP of 169.254.0.1 on the network interface (network card) that is connected to the WiMAX network. The other network interface is connected into a backbone network with the Mpume server. This network block is 192.168.0.0/24 and the network interface on the Access concentrator binds the IP address 192.168.0.2. Currently this network interface is plugged into a network interface on the Mpume server directly, instead of going through another switch, using a cross-over network cable.

Each of the routers at the schools are configured such that when they receive packets from within their LAN that are meant for computers on another networks, including the Internet, they will forward them on to the next known network/router that they are connected to. In FreeBSD this is easy to configure, during installation you set the machine up to be a gateway, otherwise if you wish to configure it post installation then its a matter of setting the variable of “gateway_enable” to true in /etc/rc.conf then reboot.

Since the WiMAX network is not encrypted, virtual network links are created from each of the routers to the access concentrator across the “raw” network. The PPPoE protocol (with MPPE encryption) is used to establish these virtual links. The reason behind doing this is that the traffic will be encapsulated within an authenticated, encrypted pipe protecting the content of the traffic from man in the middle attacks or traffic sniffing (which is easier to perform on wireless network than a wired network). In addition, it increases the security in terms of only allowing authenticated users to join the network and it reflects real world network service providers.

The access concentrator runs a PPPoE service. Each of the routers will then use the “raw” network to establish a PPPoE session, authenticating itself with a username and password to the access concentrator, which then checks the credentials (against a plain-text password list) and establishes the PPPoE session. All traffic then from the school's LAN to the rest of the network or the Internet is routed via that tunnel. The access concentrator provides each of the school routers with a PPPoE IP address in the range of 192.168.255.0/24, as follows:

- Ngwane 192.168.255.2
- Mtokwane 192.168.255.3
- Nondobo 192.168.255.4
- Nqabara 192.168.255.5

The far end of the PPP session is the access concentrator's IP address on the backbone network, 192.168.0.2. This means that each of the routers is able to forward traffic from the local network intended for the rest of the network or the Internet securely to the access concentrator which will then route it onto the correct network, either to another school in Dwesa or to the Mpume router to be sent on to the Internet. The access concentrator will pass on all Internet traffic and traffic for the Mpume local network to the Mpume server.

The Mpume server contains three network cards. One of which connects to the backbone network with the access concentrator and binds the IP address 192.168.0.1. Another network interface binds an IP address on the 2 local networks at Mpume, allowing the school's local computers (thin clients) to communicate with the server. This IP address is 192.168.1.1. The local IP block for the LAN at Mpume is 192.168.1.0/24. The third and final network interface connects to the VSAT. This network interface binds an IP within the 10.0.0.0/8 range (configured via DHCP) and will change constantly as part of how Telkom seem to run their network.

Incoming network traffic will be either intended for other computers on the LAN, or the Internet, or needs to be sent to one of the other school networks. If traffic is for the LAN then the server will route it locally, if it is intended for the Internet then it will route the traffic out over the VSAT connection and if it is intended for one of the other school networks then it will forward it on to the access concentrator. Thus the Mpume server is configured such that its default gateway is the VSAT connection (10.x.y.z) with static routes so that it can reach the LANs of the other schools via the access concentrator:

- 192.168.2.0/24 via 192.168.0.2
- 192.168.3.0/24 via 192.168.0.2
- 192.168.4.0/24 via 192.168.0.2
- 192.168.5.0/24 via 192.168.0.2

Similarly the access concentrator will have static routes configured for the school LANs via the PPPoE sessions that have been created between it and each school router.

- 192.168.2.0/24 via 192.168.255.2
- 192.168.3.0/24 via 192.168.255.3
- 192.168.4.0/24 via 192.168.255.4
- 192.168.5.0/24 via 192.168.255.5

While the default gateway for the access concentrator is the IP address of the Mpume server on the backbone network, 192.168.0.1.

5 Adding new subscribers

To add new subscribers to the system is very easy. All you need to do is edit the subscribers file in /root/admin. You will see from the headings in the file that you need to provide the following details
for the new subscriber:

- username
- password
- router ip address
- point to point protocol ip address
- subnet
- network address

Once those have been added to the file, save it and run make from within the /root/admin directory. This will create the PPP account for you and put in place the necessary variables for creating routing tables when the subscribers log onto the system. In addition, it also puts into place the ability to graph the traffic generated by each of the subscribers.

6 Traffic graphing and statistics

Traffic graphing and statistics is handled by firewall rules and a statistics gathering system, which stores the statistics using rrdtool. The firewall rules count the traffic generated for each PPP connection to the local network within Dwesa and then also the traffic that they generate for the Internet. These values are then passed onto rrdtools which stores the values over time. More precise data is kept for the most recent traffic and as we go back in time the data are less accurate as they are averaged over the time passed. The Dwesa Access concentrator runs an Apache web server which serves CGI scripts which use rrdtool to draw graphs based on the data in the RRD databases. The graphs can be accessed at http://dwesaac.dwesa.org.za/~stats from within the Dwesa network.

Annexure 3


The Haven
Nondobo School
Mthokwane School
Mpume School
Ngwane School
Dwesa Nature Reserve Gate
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