WiMAX for rural SA: The experience of the Siyakhula Living Lab

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***Abstract*— Rural development is seen as a priority in South Africa; information and knowledge are key strategic resources for social and economic development. Information Communication Technologies (ICTs) are seen as important tools in rural development, assisting in enabling change through economic development. In rural areas where ICT infrastructure is limited wireless technologies, like WiMAX, afford an easy deployment of new technologies to these marginalised communities. The Siyakhula Living Lab, a joint venture between the Telkom Centres of Excellence at Rhodes University and the University of Fort Hare, is focused on introducing appropriate ICTs to foster development. In order to support that focus an Alvarion BreezeMAX WiMAX network was deployed to the region. This paper details the current network status and the future extensions.**[1]

***Index Terms*— WiMAX technologies, wireless networks, rural networks, rural development, Siyakhula Living Lab**

I. Introduction

There are numerous wired and wireless methods for connecting organisations or individuals throughout the world to the Internet. These technologies range from narrowband to broadband solutions at varying costs. Availability of these technologies often depends on the financial situation of a country and the priorities of that country, their history and their communications policies and regulations. South Africa finds itself in a unique situation in that it can be seen as both a first and a third world country. Large urban areas such as Johannesburg and Cape Town are very nearly, if not fully, first world living environments, while in the more rural areas of the Eastern Cape, KwaZulu-Natal, Limpopo and Northern Cape, some South Africans live well below the poverty line. This situation plays a significant role in determining what kinds of communication technologies are available in an area, if there are any at all.

This paper discusses the network configuration of the Siyakhula Living Lab (SLL); a joint venture between Rhodes University and the University of Fort Hare, focused on introducing appropriate Information Communication Technologies (ICTs) to foster development. The paper is divided into four sections. The first discusses background information and literature necessary in understanding the scope of the SLL project. The second section then presents the SLL local loop network configuration as it currently stands. The third section details the future developments and extensions that the network will undergo in the coming months, while the fourth and final section concludes the paper.

[1]This work was undertaken in the Distributed Multimedia CoE at Rhodes University, with financial support from Telkom SA, Comverse, Stortech, Tellabs, Amatole Telecommunications Services, Bright Ideas 39 and THRIP.

II. Background

This section of the paper discusses the background information and relevant literature pertaining to the SLL in the Mbashe Municipality. Firstly we look at the benefits of and need for rural development in South Africa, then looking specifically at the Dwesa region within the Mbashe Municipality. Finally we discuss the WiMAX technologies which were used to build the local loop access network within the community.

A. Rural development and the SLL

The improvement of rural areas together with poverty alleviation are priorities for development in South Africa. Information and knowledge are key strategic resources for social and economic development. Rural communities in South Africa could be empowered by participating in the knowledge society through the use of ICTs. Thus ICTs can act as tools to support existing efforts towards rural development, enabling innovative approaches. ICTs can generally be defined as tools that facilitate communication through electronic means of capturing, processing, storing, and communicating information. They are also tools in rural development, complementing ongoing investments, that assist in enabling change through economic development [1].

ICT infrastructure in rural areas is limited; the fixed-line teledensity in some rural areas of South Africa is less than 5 % [2], while a significantly large proportion (42.5 % at the time of the last census in 2001) of South Africa's population live in rural areas of the country [3]. While these areas represent a potentially large customer base, wired infrastructure is not deployed to these areas for a number of reasons, namely, the costs incurred in laying new copper and fiber plants are high, while the potential for revenue is low as people in the areas tend to be very poor. Furthermore, high copper theft and poor quality copper in rural areas make it unattractive to both telecommunications suppliers and potential customers [4], [5].

The SLL is a joint initiative by the Telkom Centres of Excellence in the Departments of Computer Science at Rhodes University and the University of Fort Hare. The SLL is currently running in the area around the Dwesa-Cwebe Nature reserve within the Mbashe municipality. Like many African rural areas, the Mbashe Municipality is characterised by endemic poverty and a lack of infrastructure and services. The project has adopted the *living lab* approach which means "an approach that deals with user driven innovation

of products and services that are introduced, tested and validated in real life environments" [6, p8].

The primary objective of the SLL is to develop and field-test a distributed, multifunctional community communication platform, using localization through innovation, to deploy in marginalized rural communities in South Africa. These communities, by sheer size and because of current political dynamics, represent a strategic emergent market [1].

B. Mbashe Municipality

The Mbashe Municipality is a deep rural area situated along the Wild Coast of the Eastern Cape province of South Africa. The (initial) five villages targeted in the SLL are adjacent to the Dwesa-Cwebe area, which comprises the nature reserve and adjacent communities which are extended over a land area of approximately 153 square kilometers [7]. Both the reserve and the local communities have become involved in a development initiative as the natural environment, consisting of the nature reserve and the coast are assets for the communities. The nature reserve serves to provide income generating activities to support rural development in the area [7]. The unspoiled natural beauty and wild beaches has the potential to significantly promote eco-tourism in the region. Furthermore, the high levels of rainfall and rich soil in a typically dry area of the country, has potential for controlled agricultural intensification and commercial forestry.

The Mbashe municipality is also faced with socio-economic challenges associated with poverty and poor development. Some characteristics of poor development in the area include: severe local limitations of the regional road network, limited access to government services and delivery, inadequate education and health care facilities, lack of national grid electricity, and poor/vandalized telecommunication (land-line telephones) infrastructure in some areas. Consequently, this area has recently been the target for developmental projects. ICTs can support rural development by enabling communication which can further enable the effective operation of development activities.

In order to support the project's objectives and provide the community with access to ICTs, a local loop access network was deployed to the Dwesa-Cwebe area. WiMAX technologies were used to build the local loop while VSAT technology is used to link the community to the Internet.

C. WiMAX technologies

WiMAX stands for Worldwide Interoperability for Microwave Access, and is a means of broadband wireless access (BWA) which generally refers to fixed radio systems used primarily to convey broadband services between users' premises and core networks [8]. WiMAX is based on the IEEE 802.16 specifications and was given the commercial name of WiMAX by the WiMAX Forum. (The WiMAX Forum is an industry-led, non-profit organization formed to certify and promote the interoperability of all WiMAX products.) When 802.16 based equipment conforms to the standard and pass interoperability testing they will be "WiMAX Forum Certified" and can display this mark on their products and marketing materials [9], [10].

The core 802.16 specification is an air interface standard for broadband wireless access systems using point-to-multipoint infrastructure designs, and operating at radio frequencies between 10 GHz and 66 GHz, addressing line of sight environments (LOS) [11]. It targets an average bandwidth of 70 Mbps with peak rates of up to 268 Mbps [12]. Wavelengths in the region 10 - 66 GHz suffer a progressive increase in attenuation of the signal when propagating through the air and are often affected by atmospheric conditions – rain in particular. Trees and buildings are also problematic [13]. In cities where there are many tall buildings shading smaller buildings, LOS requirements may be a problem for service providers and thus limit their clientele. For these reasons the IEEE ratified its core standard to incorporate the 802.16a specification, which operates in the 2 - 11 GHz spectrum and thus suffers less from the above mentioned problems of attenuation and necessary LOS [13].

The 802.16a collection of amendments took into account the emergence of licensed and license-exempt broadband wireless networks operating between 2 GHz and 11 GHz, with support for non-line-of-sight (NLOS) architectures that could not be supported in higher frequency ranges [12]. The 802.16a standard, or HiperMAN, for 2 - 11 GHz is a wireless MAN technology that provides broadband wireless connectivity to fixed, portable and nomadic users [11]. This Orthogonal Frequency Division Multiplexing (OFDM) and NLOS technology can be used to back-haul 802.11 hot-spots and WLANs to the Internet, and enable a wireless alternative to DSL for last mile broadband access [11]. It potentially provides up to 80 kilometers [14] of service area range, allows users to get broadband connectivity without needing direct line of sight with the base station, and provides total data rates of hundreds of Mbps per base station – a sufficient amount of bandwidth to simultaneously support hundreds of businesses with T1/E1-type connectivity and many hundreds of homes with DSL-type (512 Kbps) connectivity with a single base station [11], [15].

As said, support for NLOS performance was one of the primary differences at the physical layer in 802.16a [11]. The OFDM format was selected in preference to competing formats, such as CDMA, due to its ability to support NLOS performance while maintaining a high level of spectral efficiency – maximising the use of available spectrum [11]. In OFDM individual transmissions are distributed across the entire available spectrum in complex inter-leavings that leave relatively little spectrum unoccupied for any length of time during periods of heavy traffic [13]. The IEEE 802.16 standards include support for various modulation schemes which can be used depending on the prevailing conditions. The use of adaptive modulation allows a wireless system to choose the highest order modulation depending on the channel conditions [16] per-subscriber basis. If the air-link degrades due to rain or other interference factors, the technology automatically reverts to less-complex schemes to allow for reliable data transfer [17]. The various modulation schemes which the standards support include, in order of increasing complexity, BPSK, QPSK, QAM16, QAM64 and QAM256 [18], [17]. The use of more complex modulation schemes results in higher throughput because more symbols can be sent at a time. When signals have to travel over longer distances, however, they are weakened and more susceptible to interference, which results in poorer demodulation at the

receiving side. Thus in order to cover greater distances, less complicated modulation schemes must be used [16].

In 2004 the 802.16a standard was amended and replaced with the 2004 revision. Most of the original 802.16a specification was absorbed into the revision, named 802.16-2004 or 802.16d [18]. The purpose of the revision from 802.16a to 802.16d was to "align the standard with aspects of the European Telecommunications Standards Institute (ETSI) HIPERMAN standard as well as lay down conformance and test specifications" [19]. For further detailed information on the IEEE 802.16 standards and specifications see for example [8], [18], [14] and [13].

The Alvarion BreezeMAX equipment in the SLL is 802.16a compliant. IEEE 802.16 standards integrate seamlessly into most wired networks, much like 802.11 standards.

III. The Siyakhula living lab network configuration

In order to provide a distributed, multifunctional community communication platform in the SLL a reliable local loop access network was required. This section describes the configuration of the WiMAX local loop access network. This section is divided into two parts. Firstly, we discuss the Distributed Access Nodes (DANs) which are located in five schools in the area and provide access to the SLL infrastructure to the schools and their local communities. Secondly, we look at the network configuration and implementation.

A. The Distributed Access Nodes

The community accesses the SLL infrastructure and communications platform via the distributed access nodes (DANs) at the schools where the DANs are hosted. Currently five schools house DANs, namely, Mpume JSS, Ngwane School (both a primary and a secondary school), Mthokwane JSS, Nondobo JSS and Nqabara SS.

Each DAN is equipped with a thin client computer lab running Edubuntu Linux and approximately 5 to 20 thin clients, depending on the size of the school's computer labs and the level of security available. At each DAN there is a community access point (CAP) which provides access to the local loop WiMAX network for all the clients at each site. The CAP is a FreeBSD router that is configured to manage and monitor the DAN through a number of services such as SMTP and Netflow to name a few.

The CAP acts as a gateway between the local area networks (LAN) within each school and the bigger local loop access network. The CAP runs a Point-to-Point Protocol (PPP) client, specifically PPP over Ethernet (PPPoE), which contains the school's username and password for authenticating with the access concentrator housed at Mpume. Once authenticated and the link has been established the router will route all outgoing traffic, intended for one of the other schools (such as local VoIP traffic) or the Internet, onto the next hop which is the access concentrator.

B. The network

The Alvarion BreezeMAX technology was chosen for our WiMAX deployment. Alvarion's equipment was among the systems tested at the time (2005) by SAAB Grintek, a partner in the Telkom Centre of Excellence at the University of Fort Hare. So a micro base station and five subscriber unit (SU) kits were sourced from them in 2006. The Alvarion equipment uses 256 OFDM carriers; the modulation schemes discussed in section II-C; supports bandwidth of up to 14MHz; operates in the 3.5GHz band, the up-link operating in 3.3995 to 3.4535 GHz and the down-link in 3.4995 to 3.5535 GHz; and uses Frequency Division Duplex (FDD) [20]. In South Africa this frequency requires a license. Amatole Telecommunications, a USAL in South Africa and a partner in the CoE project owns the frequency license for that spectrum in the Mbashe Municipality and we have been given permission to operate the network in collaboration with them.

The WiMAX micro base station is housed at the Ngwane school as it is the school in the project which is situated at highest point within the geographical area (as can be seen in the topographical map in Figure 1, created using Radio Mobile [21]). WiMAX technologies do not require a clear line of sight (LOS) like WiFi, however large obstructions will still affect the signal path and either disrupt or prevent communication. Thus a high site is still required so that the best possible path is available for wireless communication between the micro base station and the customer premises equipment (CPE) at the various DANs. At Mpume, Mthokwane, Nondobo and Nqabara there is a CPE unit that connects back to the micro base station at Ngwane to allow traffic to be transported between the schools.

The local loop access network connects to the Internet via a Telkom VSAT connection. This equipment is however not housed at the Ngwane school (where the micro base station is installed). The VSAT unit was installed at the Mpume school. The reasons for this are both historical and strategic. The Mpume school was the first school to join the SLL project and so was the logical location (at the time) for VSAT installation. The Ngwane school only joined the project a year after the VSAT link had been installed and so its status as the geographically highest school in the SLL was only determined post VSAT installation. However, it was decided that the VSAT unit should not be moved retrospectively to the Ngwane school in order to ensure that no one school was responsible for all the network facilities. Rather, the schools and communities need to work together, pooling their resources and collective capacities to jointly run and operate the network for the benefit of all.

Mpume thus houses the Access Concentrator (AC) which terminates all incoming PPPoE connections from the school sites in the SLL local loop access network. Traffic from the other schools is switched at the micro base station and sent to the Mpume school where the AC terminates the PPPoE sessions; each router at each of the other schools runs a PPPoE client and authenticates with a PPPoE service running on the AC. These four schools (Ngwane, Mthokwane, Nondobo and Nqabara) are reliant on the AC being up in order to reach the Internet, while Mpume are reliant on access to the base station in order to make use of other local services such as VoIP and access to shared resources (off-line content) that are housed at the other schools.

The local loop access network facilitated the strategic pooling of resources (specifically Internet access) across the schools and communities. In addition, the local loop network allows us to provide local services to the schools, such as telephony (via VoIP), email, and content sharing (sharing

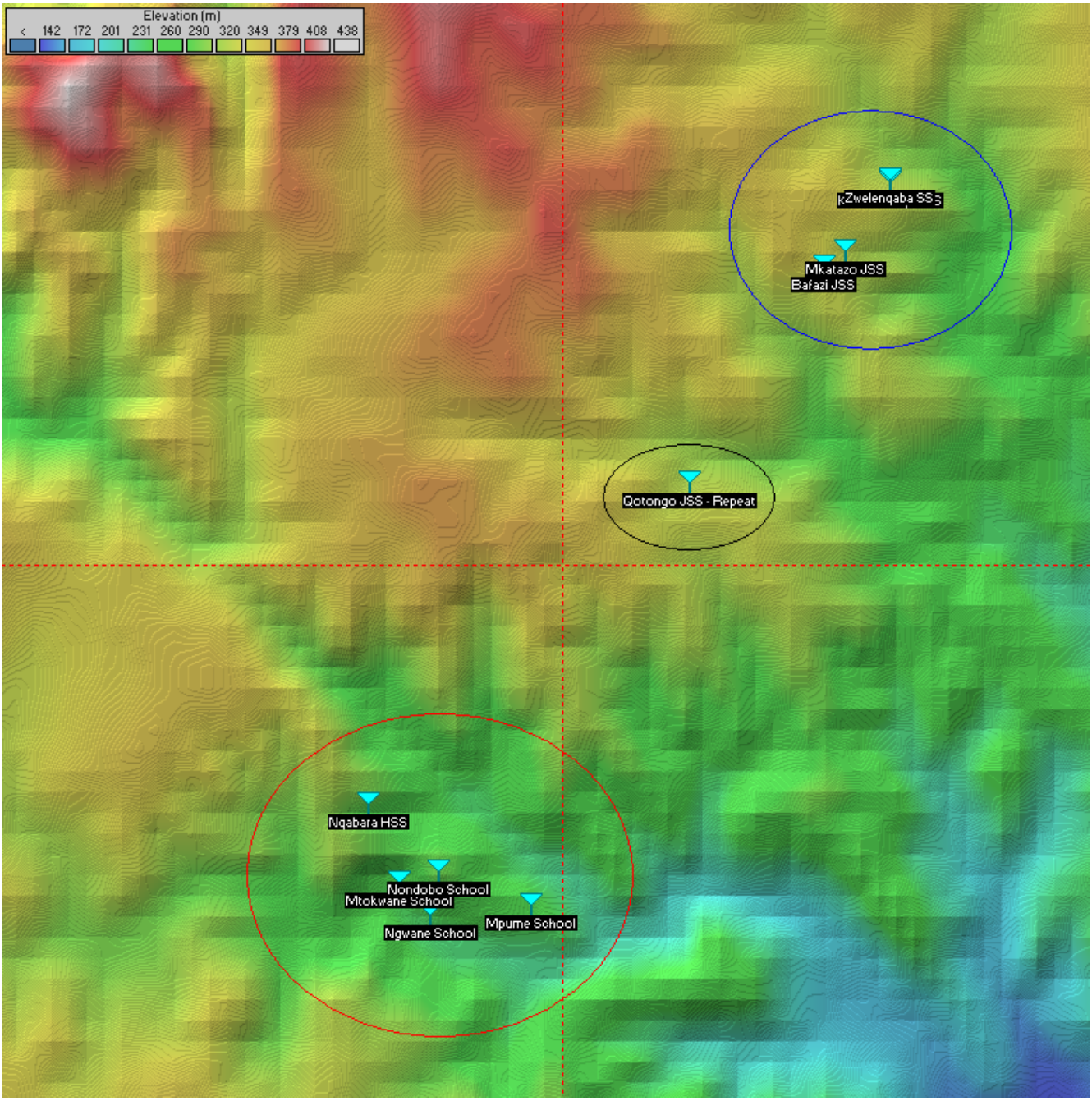


Fig. 1. Topographical map of the SLL in the Mbashe Municipality

information, lesson plans, rubrics, etc). The network has made it possible for there to be convenient communication channels between the schools and their local communities. A diagram of the logical network can be seen in Figure 2, while the schools in the red circle in Figure 1 are the schools in the Dwesa-Cwebe area of the SLL network.

IV. Future network expansions

With assistance from SAAB Grintek we plan to extend, during 2010, the local loop access network footprint to include five more schools in the Dwesa-Cwebe area, taking it to a total of ten schools. In addition, we also plan to extend the reach of the network to another area, some 30 km away, within the municipal boundaries. The area is known as Nkwalini and a further four schools will be connected in the area, using a repeater station between the two network segments. This section discusses the proposed network extensions.

A. *Five new Dwesa-Cwebe schools*

The schools to be added in Dwesa-Cwebe will be chosen together with assistance from the local government Department of Education (DoE). The local DoE has agreed to provide a list of "e-ready" schools within the area. From there a site survey will need to be conducted in order to determine each school's location in relation to the micro base station at Ngwane; feasibility in terms of distance and LOS will need to be considered.

In addition to the five new fixed wireless points added to the network, SAAB Grintek have agreed to supply us with nomadic units so that the SLL can experiment with partially mobile units in the Dwesa-Cwebe segment of the

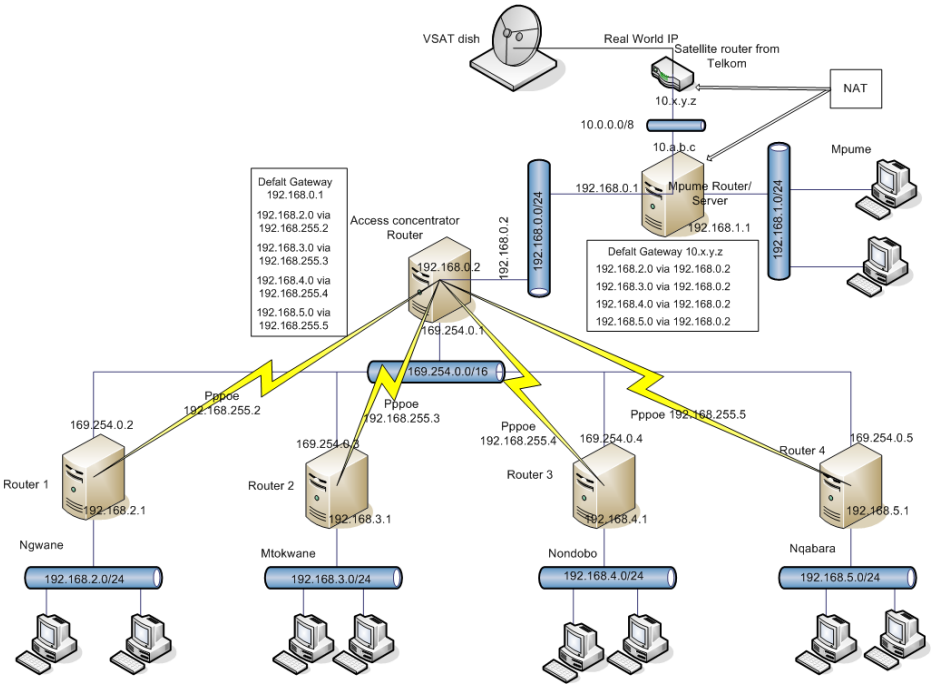


Fig. 2. Logical network diagram of the local loop access network in the SLL

SLL network. The Ngwane micro base station is a fixed mobile base station and so can not support truly mobile units, however, nomadic units are possible, where the unit can be moved from one location to another and re-establish the link with the base station once stationary again.

B. Nkwalini schools

Currently the four schools in Nkwalini are linked to one another via WiFi and share a GPRS connection to the Internet. With the help of SAAB Grintek another micro base station will be housed at Zwelenqaba SS to which the other three schools (Mkatazo JSS, Bafazi JSS and Kwantshunqe JSS) will connect. In addition, we propose that another VSAT unit be installed at the site of the new micro base station in order to link the four schools in that network segment to the Internet as well as act as a back-up link to the Internet for the schools on the Dwesa-Cwebe segment of the network. The four schools in the Nkwalini area can be seen in the blue circle in Figure 1.

The micro base station proposed for the Nkwalini network segment of the SLL will support mobile WiMAX. This would allow the SLL to experiment with both WiMAX network types, providing valuable information back to the suppliers, government departments such as education and social services and the broader research community. A mobile unit will allow the SLL to experiment with services that could be run on WiMAX enabled handsets/mobile phones. Mobile phones (although not WiMAX enabled) are reasonably common (in comparison with any other communication technology) in the area; every household in the area has access to at least one mobile phone [22], thus potentially a wider community audience could be reached using mobile handsets.

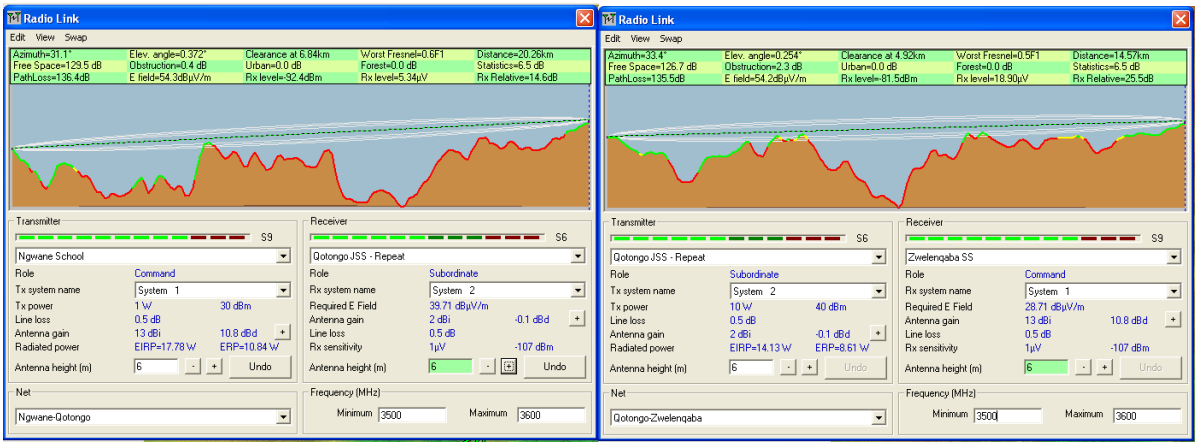
Communication between the two network segments will be through the use of a proposed repeater station.

C. The repeater station

The repeater station is to be housed at Qotongo JSS, which can be seen on the map in Figure 1 inside the black circle. As a result, Qotongo will also be connected to the SLL network, effectively adding another school in the Mbashe municipal area to the SLL project.

The two schools hosting WiMAX base stations, Ngwane and Zwelenqaba, cannot link to one another directly as they have no clear view of each other without elevating both sides by a minimum of 18 m as a result of the mountainous terrain in the area. Using radio mobile we have been able to determine that we should have a clear line of sight from Ngwane to Qotongo and again from the Qotongo to Zwelenqaba in Nkwalini. Figure 3 shows the two cross sectional views, (a) from Ngwane to Qotongo, and (b) from Qotongo to Zwelenqaba. In each we can see that we need to elevate the antennas by 6 m from ground level in order to clear the mountainous terrain, however, they are well within reasonable limits and can be attached to the tops of the school buildings. The first hop, from Ngwane to the proposed repeater station at Qotongo covers a distance of 20 km, while the second hop, to Zwelenqaba covers a distance of 14 km. A site survey needs to be conducted in order to determine true feasibility of the link as well as establish required antenna gain necessary in order to achieve link status.

The repeater station will facilitate communication amongst the schools and communities in the two areas via local services such as VoIP and email, but will also provide each network segment with access to a redundant Internet connection should their local VSAT unit or routing equipment become faulty for any reason. A redundant route to the Internet would improve the reliability and fault tolerance of the network, which would in turn provide a better user experience to the community members in the SLL project.



(a) (b)

Fig. 3. Cross sectional views of the link from (a) Ngwane to Qotongo and from (b) Qotongo to Zwelenqaba

V. Conclusion

The SLL aims to develop and field-test a distributed, multifunctional community communication platform, using localization through innovation, to deploy in marginalized communities in South Africa, where a large number of the South African population live. The development of rural areas in South Africa is a governmental priority and a strategic emergent market for industry. In order to support the SLL project objectives a local loop access network is necessary. This paper describes the WiMAX network that has been deployed since 2006 in the area in order to support the project, as well as the planned future extensions of the network. The use of wireless technologies in this 'green field' environment makes network deployment and configuration relatively simple, while tools like radio mobile support network planning and design.

The environment in which the SLL operates presents a valuable opportunity for the partnership between academic institutions, industry partners and government to work together with the local community in providing needed communication technologies that contribute to a deeper understanding of the intricacies of building rural networks and could hopefully lead to other similar networks in rural areas across the country.

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