University of the Witwatersrand

Faculty of Engineering and the Built Environment

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Research Project Report

WiMax – A critical view of the technology and its economics

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Declaration:

I, Kagiso Hellen Rapetswa hereby declare that the contents of this research project report are my own original work. Information extracted from other sources is acknowledged as such. This Research Project report is submitted to the Faculty of Engineering and Built Environment, University of the Witwatersrand, in part fulfilment of the requirements for the degree of Master of Science in Engineering Msc(Eng).

Signature:_______________ **Date:** 7 September 2015

Acknowledgements

I am exceedingly grateful to my supervisor, Rex Van Olst, who encouraged me to pursue this research topic and guided me through the writing of this thesis. I attribute the quality of my research to his wisdom, knowledge of various telecommunication technologies, and his ability to provide guidance while allowing me room to work in my own way.

I thank Mr Farouk Gaffour for the many insightful discussions and suggestions made during the development of the ideas in this thesis and for helping me to achieve a clearer structure.

I would like to acknowledge the support of the management at Vodacom Pty LTD. Who gave me generous access to their Network Planning and Simulation tools.

It has been a pleasure to study at the University of the Witwatersrand and I thank my fellow students for their friendship and encouragement.

Last but not least, I would like to thank my family, especially Conrad Mahonga and Tintswalo Sono, for proof reading my work at several stages of the research and for the long discussions on my research findings.

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LIST OF ABBREVIATIONS

2G	Second Generation of Mobile Telecommunications Technology
3G	Third Generation of Mobile Telecommunications Technology.
3GPP	3rd Generation Partnership Project
AeroMACS	Aeronautical Mobile Airport Communications System
AES	Advanced Encryption Standard
AMC	Adaptive Modulation and Coding
ASN	Access Service Network
ARQ	Automatic Repeat Request
BE	Best-Effort Service
BER	Bit Error Rate
BSC	Base Station Controller
BTS	Base Transceiver Station
CAPEX	Capital Expenditure
CDMA	Code Division Multiple Access
CPE	Customer Premises Equipment
CSI	Corporate Social Investment
CSN	Core Services Network
DAS	Distributed Antenna System
DSCP	Differentiated Services Code Point
DSL	Digital Subscriber Lines
ECA	Export Credit Agency
ECN	Electronic Communication Network
ECNS	Electronic Communication Network Services
ECS	Electronic Clearing Service
EDGE	Enhanced Data GSM Environment
ErtPS	Extended Real-Time Polling Service
EUL	End User Layer
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FBBS	Fast Base Station Switch Handover

FTP	File Transfer Protocol
GSM	Global System for Mobile communication
GPRS	General Packet Radio Srevice
HARQ	Hybrid Automatic Repeat Request
HHO	Hard Handover
HSDPA	High Speed Downlink Packet Access
HSPA+	Evolved High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
ICASA	The Independent Communications Authority of South Africa
ICI	Inter-Carrier Interference
ICT	Information and Communications Technologies
IMT	International Mobile Telecommunications
IPTV	Internet Proctocol Television
ISP	Internet Service Provider
Kbps	Kilobits per Second
LoS	Line of Sight
LPGSM	Low Power Global System for Mobile communication
LTE	Long Term Evolution
MAC	Media Access Control
Mbps	Megabits per Second
MDHO	Micro Diversity Handover
MIMO	Multiple Input Multiple Output
MPEG	Moving Picture Experts Group
NAP	Network Access Provider
NEs	Network Elements
NLOS	Near-Line-of-Sight
NrtPS	Non-Real-Time Packet Service
NSP	Network Service Provider
OFDMA	Orthogonal Frequency Division Multiplex
OPEX	Operational Expenditure
TDD	Test-Driven Development
PAPR	Peak-to-Average-Power-Ratio

PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RNC	Radio Network Controller
RtPS	Real-Time Packet Service
SC-FDMA	Frequency Division Multiple Access Scheme
SeGW	Security Gateway
SNR	Signal-to-Noise Ratio
SON	Self Organising Network
SVDO	Simultaneous Voice and EV-DO
SVLTE	Simultaneous Voice and Long Term Evolution
UGS	Unsolicited Grant Service
UMTS	Universal Mobile Telecommunications Services
VoIP	Voice over Internet Protocol
WCDMA	Wideband Code-Division Multiple Access
WiGRID	Wireless Grid
WiMax	Mobile Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

1. Introduction

Broadband Internet commonly refers to high-speed Internet networks based on fixed or wireless technology. The Internet is notorious for exposing people to many socially and economically transformative opportunities in the e-commerce, e-health, e-education, and e-government spheres. As such, South Africa has implemented a number of plans to increase the uptake and usage of Information and Communications Technologies (ICT), specifically Broadband Internet. However, a study conducted in 2013 by de Lanerolle [1], shows that only 34% of adults in South Africa (this is about 12.3 million adults) use the Internet and that most of these adults live in urban/semi-urban areas and access the Internet through their mobile phones, from their places of work or study, or through Internet cafes. This study suggests that Broadband Internet is not as accessible in rural areas as it is in urban/semi-urban areas.

South Africa could create a transformation opportunity for itself by extending broadband Internet to these under-served areas. However, South Africa, like many other African countries, has many people living in rural areas and villages that are remote or have uneven terrain. As explained by Cull [2], Network Operators regard these areas as commercially unattractive for investment because it is expensive for both fixed and mobile Operators to deploy and maintain fixed line access services, such as Leased lines, Digital Subscriber Lines (DSLs), and Fibre, which mobile Operators use to backhaul mobile traffice and fixed line Operators offer as primary services to their customers. Further, the likelhood that Operators will reap good returns on investment is low as the projected spend on services, especially fixed line services, is generally low. Consequently,the geographic coverage of mobile networks, far exceeds that of fixed line infrastructure.

However, there are still areas that have intermittent (if any) mobile network coverage. These areas, therefore, have limited (if any) access to broadband services. Examples of such places include:

- Magoesbaskloof, Limpopo

- Duiwelskloof, Limpopo
- Adelaide, Eastern Cape

These areas were unsystematically selected (from a list of areas that currently do not have reliable broadband coverage) to form the focal point of this study. They have the following in common:

1. They have challenging topographies for network deployment;
2. They are situated in remote locations, relatively far from other villages and towns;
3. They are sparesly populated, with low income levels, and thus a low potential spend on Mobile services.

This leads to the deduction that wireless networks are better suited for these type of areas as residents are more likely to have mobile devices than desktop computers. That is, the chances of residents accessing broadband services from their mobile phones are higher than those of access through fixed line infrasturcture. This has, amongst other factors, triggered a demand for longer range wireless networks such as Mobile Worldwide Interoperability for Microwave Access(referred to as WiMax) and Long Term Evolution (hereinafter reffered to as LTE).

In the last twenty years, the introduction of a vast number of mobile communication technologies has been witnessed - globally. Some technologies have been successful, while others were not. Some of the technologies that did not succeed did not necessarily fail because of technical flaws. The timing and manner in which the regulator of the communications sector allocates and offers spectrum, influences the Private Sector's (Technology Equipment Manaufacturers, Distributors, and Mobile Network Operators) business strategy in that it forms the basis of the decision that the private sector takes when choosing technologies to invest in. The Private Sector, in turn, influences the adoption rate of a new technology. This has played a role in some technologies being overlooked despite being technically sound.

Another contributing factor is the architecture of the new technology; it is difficult for a new technology to be adopted by Network Operators if it is unable to interoperate with existing technologies as it then competes with existing technologies for a share of the market. Operators are also reluctant to invest in new infrastructure when their existing infrastructure has not fully depreciated in value. By the same token, Operators often support the technology that yields the highest economies of scale as it results in returns on investment in the short term. What is most concerning is that technology decisions made by developed countries, in other parts of the world are adopted in developing countries, without conducting an analysis of the suitability of the technology in the given country. This has been to the detriment of the people that could theoretically benefit the most from the technology. It is for this reason that the study took a critical look at the WiMax technology and its economics, in a South African context, in order to determine if it should still be considered for deployment in rural South Africa. This was achieved by comparing the performance and economics of WiMax with that of other wireless broadband networks currently available in South Africa.

1.1 Statement of the Problem

Mobile WiMax remains a notable technology for rural connectivity in developing countries despite the increase in technological innovations within the mobile communications industry,. It is known to enable Operators to offer a uniform end-user experience irrespective of the location (rural or urban) of the end-user. This promotes the adoption of technology in rural areas. However, South Africa has not adopted Mobile WiMax as a Mobile Network solution.

1.2 Objectives of the Study

The objective of the study was to evaluate the technical capabilities of Mobile WiMax in selected areas, in South Africa, in order to determine whether Mobile WiMax is suitable for deployment in these areas. The underlying objective was to determine if WiMax can be used to deliver quality broadband services in rural South Africa, equivalent to the kind enjoyed in urban areas, but in a more economical fashion. The performance of WiMax was compared to that of other more prevalent broadband solutions, commonly found in urban parts of South Africa. These include LTE, HSPA, UMTS, EDGE, and Wi-Fi hotspots. It was not the objective of the study to determine the technology adoption rate, nor its impact on society.

1.3 Hypotheses To Be Tested

In order to address the research problem effectively it was hypothesised that:

I. The traffic mix and device type mix of the selected rural areas is representative of all the rural areas that match the definition of the rural areas being studied. This will be tested by compiling a report of the devices used in the selected areas to determine if the users in these areas already use data enabled devices and if the devices are WiMax enabled.

II. A simulation of the various mobile technologies deployed in the selected areas may be used to conduct a comparative analysis of the various mobile technologies. The comparison was based on the signal strength that can be achieved in the respective areas. This was linked back to the literature survey which shows the performance rankings of the various technologies.

III. The above-mentioned simulation provides a better understanding and knowledge of Mobile WiMax, its advantages, limitations, and its ability to compete with or complement existing broadband technologies in South Africa.

1.4 Significance of the Problem

The importance of the problem lies in taking a critical look at the economical and technical viability of a mobile technology that other developing countries, whether many or few, have stamped as a good broadband technology for deployment in rural areas, and formulating a position for South Africa, based on the factors that are relevant for South Africa specifically.

This research is centred around Mobile WiMax as it has been deployed, mainly as a fixed service, in other parts of the African continent such as Ghana, Tanzania, and Kenya. These areas are similar to South Africa in a lot of ways such as: 1) the terrain of the areas being studied; and 2) these countries have more mobile users than fixed line users as is the case in the areas identified for this research [3] WiMax has unfortunately not incited a lot of hype in South Africa. This is despite the numerous studies conducted and conferences held to deem it a suitable technology for deployment in areas better suited for wireless access media compared to fixed-line access media.

1.5 Assumptions and Delimitations

In order to address the research problem effectively it was assumed that:

- A simulation of an LTE network will yield similar performance results as Mobile WiMax would. This assumption is based on the comparative study conducted by Bhandare [4] which proved that LTE and WiMax are technically alike providing similar access technologies, radio access modes, FFT sizes, channel bandwidth, cell radius, antenna configurations, QoS, and mobility in an All-IP network. Further, [5] shows that LTE slightly outperforms WiMax when using channel bandwidth of 5 MHz for LTE and 10 MHz for Mobile WiMax.
- End-users are not concerned with the type of technology they use - provided their devices are able to support the technology. This means that the users would adopt the technology if devices are readily available and affordable even if they are required to learn a new way of using the services (e.g VoIP calls through an app vs traditional mobile calls).
- The backhaul and access to Internet infrastructure would be provided by Fixed Line network Operators, through partnership or reseller agreements with the Mobile WiMax Operators.

In order to address the research problem effectively, the following limitations were identified and assumed to not impact the study:

- In large buildings, Mobile WiMax (802.16e) provides inconsistent in-building penetration. This is not a cause for concern in rural South Africa as the buildings are small.
- Mobile WiMax (802.16e) delivers low throughput at vehicular speeds (faster than 120 km/h) as speed causes a significant reduction in bandwidth throughput. This is not a cause for concern in rural South Africa as the areas are residential with a speed limit of 60 km/h.

- Mobile WiMax equipment is not readily available in South Africa. Further, local maintenance and after sales support on the equipment is limited and likely to decrease as more and more Original Equipment Manufacturers (OEMs) choose LTE over Mobile WiMax.
- The number of certified WiMax engineers in South Africa is low and decreasing as certifications are valid only for a period of three years, after which the engineers must renew their certification. This means that the Mobile Operator may struggle to get resources and would thus also incur training costs to upskill its current engineers.
- The cost to rollout a new WiMax network is higher than the cost of upgrading or enhancing an existing data network (for instance enhancing an HSPA network to the latest HSPA release as this would be a software upgrade using the existing core network and infrastructure). However in areas where there is no broadband service, WiMax would be cheaper to deploy than UMTS as it would cover a larger area, require less infrastructure as UMTS, and provide better network speeds and better quality service. [6]
- WiMax uses the same spectrum as LTE; this spectrum is likely to be very expensive when it is finally made available in South Africa. However, this presents an opportunity for Operators to extend their 4G footprint as WiMax (802.16m) and LTE- Advanced are interoperable thus allowing each of the technologies to be deployed in areas where it would be most beneficial for the operator and the users without restricting users to a particular area to obtain good broadband services.
- The phones that are currently used in the identified areas are not WiMax enabled and there are literally only three types of WiMax enabled devices available in South Africa – all of which were launched more than a year ago and are thus outdated when compared to the phones that have recently been launched. That is, users will struggle to get WiMax enabled devices locally and would also not be able to follow mobile device trends as most devices available on the market are not WiMax enabled. Newer WiMax enabled devices can be shipped into the country, however, the users would likely have to pay a premium for them unless if the demand is high and leads to economies of scales being achieved for the devices. Note that devices

procured overseas must be tested on the South African Networks (by the Network Operators) and approved for use in the country by ICASA.

- WiMax users form the minority and thus do not benefit from economies of scale which was previously anticipated by the WiMax forum.
- Unlike 802.16m, 802.16e is not interoperable with 3GPP standards. This means that a user that subscribes to 802.16e services would not be able make voice calls to GSM users and would only have access to broadband services (VoIP, Internet, and Email) in areas where there is WiMax (802.16 e) coverage.

2. Review of Related Literature

This section aims to familiarise the reader with:

a) Important terms and principles in the Mobile Technologies area of study, and
b) Key contributions made by other learners and institutions.

2.1 Definitions of important terms and principles

This section provides an introduction of the WiMax technology in terms of its history, architecture, key features, and its competitors.

2.1.1 The history of Mobile WiMax

Mobile Worldwide Interoperability for Microwave Access ("WiMax"), commonly referred to as the 802.16e, is a technology based on the IEEE 802.16e-2005 broadband wireless access standard. It was developed in 2005 as an amendment of the 802.16-2004, commonly referred to as the 802.16d, developed by the IEEE 802.16 Task Group D for fixed line connectivity. Interestingly enough the 802.16-2005 and the 802.16e are not backward compatible. [7]

Mobile WiMax is a high-speed IP network which offers voice, data, video, and multimedia services in the form of VoIP, IPTV, Interactive gaming etc. It does so using the low frequency bands of 2 GHz to 11 GHz frequency bands. It has also been discovered that services can also be offered on the 700 – 800 MHz frequency bands [3].

Its key features include High Mobility, Security, Ability to provide QoS, and Spectral efficiency. These have been cleverly built into the design of the WiMax protocol layers. This is explained in more detail in section 2.1.3 on page 23 below. The physical layer is based on OFDMA, which is an effective technique for overcoming multipath distortion. The ability of an OFDMA signal to maintain orthogonality under multipath conditions gives an intra-cell interference-free system that is well suited to high-speed data transmission. [8] However, inter-tone interference arises (degrading performance) when there are large Doppler spreads. OFDMA signals also have a relatively large peak-to-average power ratio (PAPR), which means that for a given average power, the power amplifier must be able to handle significantly higher power peaks, while avoiding distortion of the transmitted signal. OFDMA also ensures high spectral efficiency particularly when using MIMO solutions. [9]

With a MAC layer that uses strong encrytion (AES) and error correcting codes, the transport layer is designed to ensure QoS while seeing to it that the network resources are used efficiently [10]. This technology has also been designed to offer scalability by making provision for the network to be small at the very early setup stage and easily expanded according to the operator's plan [11].

Mobile WiMax implementations can be used to deliver both fixed and mobile services. This means the Operator may deploy Mobile WiMax and use it to offer both mobile and fixed service. The Mobile service is provided as a fixed service when the Operator mounts the antennae on a fixed structure and installs routers at the customer premises. In this case, the Customer Premises Equipment (CPE) would always connect to the same base station and would thus not need to be handed over to a neighbouring base station during a session or a connection. Mobile WiMax can, as a result, be thought of as a technology that enhances the WLAN (IEEE 802.11) by extending its wireless access reach. Unlike many fixed wireless services, the Mobile WiMax technology does not require clear Line of Sight (LoS) between the user’s device and the base station.

WiMax is supported by the WiMax forum which in 2009 consisted of over 400 WiMax solution providers ranging from chipset manufacturers, applications developers, infrastructure vendors, and device manufacturers, all with a common goal of ensuring inter-vendor co-operation, and conformance to the WiMax standards. This was to translate into a competitive WiMax ecosystem that would offer Operators many solution options and also enable both Operators and end users to benefit from economies of scale that transpire as a result of being part of a global market [12].

2.1.2 Mobile WiMax network architecture

As depicted in **Error! Reference source not found.** overleaf the Mobile WiMax network architecture is made up of three main parts namely;the Mobile Stations, the Network Access Provider (NAP), and the Network Service Provider (NSP).

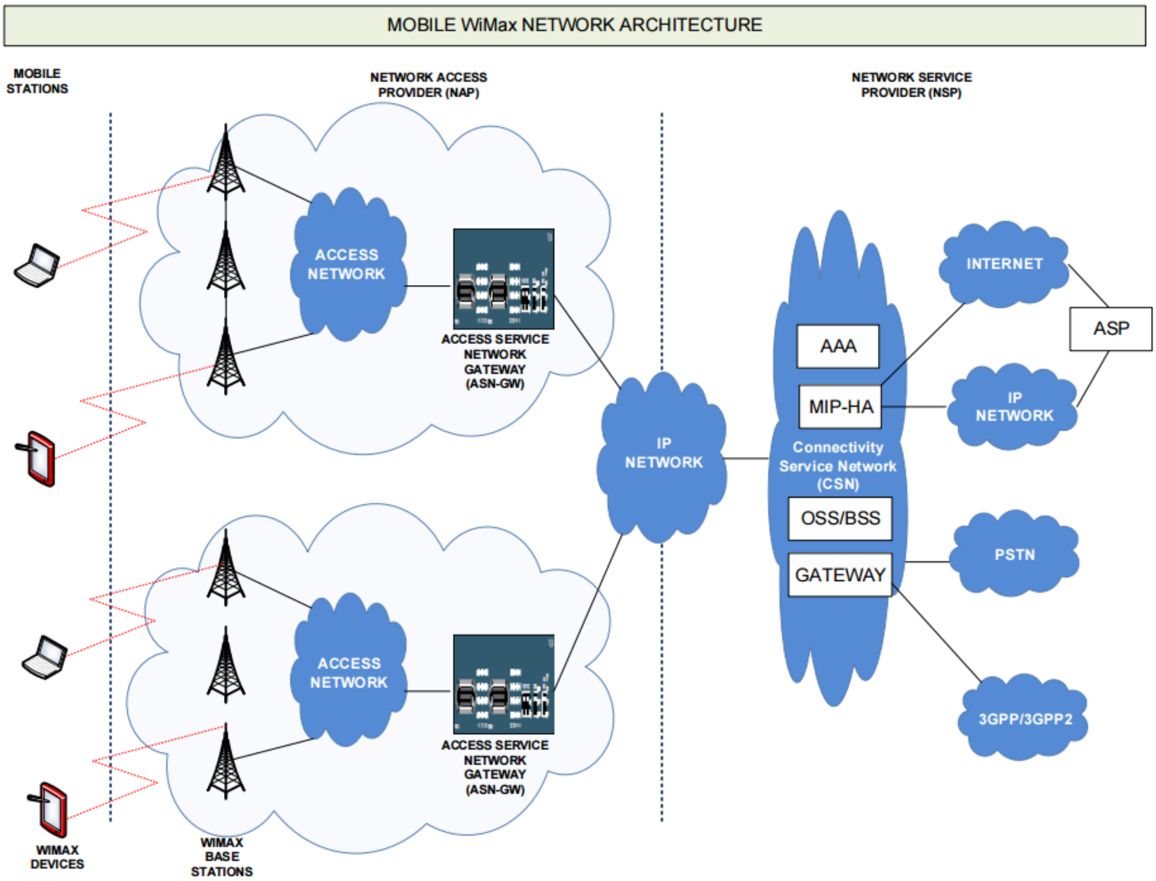

Figure 2-1: WiMax Network Architecture [63

The Mobile Stations are the WiMax enabled (mobile) devices which are used to access the network. The NAP is responsible for providing the necessary infrastructure for wireless access to one or more service suppliers. It controls one or more Access Service Networks (ASNs), which comprise of one or more base stations and one or more ASN gateways which form the radio access network at the edge. The NSP controls single or multiple Core Services Networks (CSNs) which provide subscribers with access to IP core network functions and IP network services such as the Internet, PSTN, and other IP networks [11]. The Mobile WiMax network is then integrated with an IP network for backhaul, access to the Internet, and to obtain access to services such as Voice Services, Internet, Billing services, and Security Services.

In essence, the Access Services Network (ASN) provides network connectivity. The Core Services Network (CSN) basically serves as the home network for the user/subscriber. It performs functions such as authenticating the user on the network, checking the services that the user is authorised to access, and the general administration of the account, which involves checking the prepaid/post paid services the subscriber may be on and determining if the subsciber has enough data bundles to access the network.

The latest Mobile WiMax release (802.16m) encourages the use of a number of backhaul access technologies that can be used to link the Mobile WiMax Base stations to the core IP network. These include Microwave, Fibre, Leased Lines, and Satellite.

2.1.3 Key features of Mobile WiMax

Mobile WiMax is the first broadand technology to use:

- Orthogonal Frequency Division Multiple Access (OFDMA)
- Multiple Input and Multiple Output (MIMO)
- Beam Forming
- Downlink Channel Reporting
- Space-time frequency coding
- Classes of Service (CoS)

As described by Richard and Ramjee in [13] OFDMA is a form of transmission that uses a large number of closely spaced carriers that are modulated with low rate data. OFDMA divides the channel into 1024 subcarriers for a 10 MHz channel and 512 subcarriers for a 5 MHz channel. The high-speed mobility causes a shift (Doppler shift) in the frequency of these subcarriers resulting in inter-carrier interference (ICI). Transmitting signals at a low data rate across all the carriers makes the signal immune to reflection and inter-symbol-interference. In addition, making the signals orthogonal to each other ensures that there is no mutual interference. This is achieved by having the carrier spacing equal to the reciprocal of the symbol period. This means that when the signals are demodulated, they will have a whole number of cycles in the symbol period and their contribution will sum to zero. In other words, there is no interference contribution. The data to be transmitted is split across all carriers meaning that, if some of the carriers are lost due to multipath fading then error correction techniques can be used to re-construct the data. This makes it possible for us to implement single frequency networks, where all transmitters can transmit on the same channel. In essence, OFDM is used to increase the throughput bandwidth and ensure efficient transmission of the data, while also providing a high degree of resilience to reflections and interference.

MIMO is an advanced antennae technology used to optimise the throughput using various antennae configurations and supporting spatial diversity. In rural areas, it is used to enhance the network coverage area (coverage cell radius)

Beam forming, also known as spatial filtering, focuses and concentrates the signal in the direction it is required to go in and in so doing, improves the bandwidth utilisation, signal-to-noise ratio (SNR), network range, and the quality of latency-sensitive transmissions such as VoIP, and Video streaming. Beam forming works hand in-hand with MIMO technology.

Downlink Channel Reporting provides information on the channel quality across the full downlink carrier bandwidth. This assists in optimizing the network.

Space-time Frequency coding is a method that goes hand-in-hand with OFDM and MIMO. It is used to improve the reliability of data transmission in wireless communication systems using multiple transmission antennas.

Unlike other broadband technologies, Mobile WiMax offers five classes of service to ensure the quality of service required for real-time applications such as VoIP, and Video streaming as shown on Table 2 - 1 overleaf. However, mobile WiMax can also be deployed as a best effort service.

QoS Category	Applications	QoS Specifications
UGS Unsolicited Grant Service	VoIP	• Real-time data streams including fixed-size data packets issued at periodic intervals. • Maximum Sustained Rate. • Maximum Latency Tolerance. • Jitter Tolerance. • Not implemented at 15MHz Spectrum allocation.
rtPS Real-Time Packet Service	Streaming Audio or Video (MPEG Video)	• Real-time data streams comprising variable-sized data packets that are issued at periodic intervals - reserved Rate. • Maximum Sustained Rate. • Latency Tolerance. • Traffic Priority.
ErtPS Extended Real-Time Packet Service	Voice with Activity Detection (VoIP)	• Real-time service flows that generate variable-sized data packets on a periodic basis. • Maximum Sustained Rate. • Latency Tolerance. • Jitter Tolerance. • Traffic Priority.
nrtPS Non-Real-Time Packet Service	File Transfer Protocol (FTP)	• Delay-tolerant data streams including variable-sized data packets for which minimum data rate is required. • Minimum Reserved Rate. • Maximum Sustained Rate. • Traffic Priority.
BE Best-Effort Service BROADBAND SERVICE	Data Transfer, Web Browsing, Standard grade VoIP, etc.	• No minimum service level is required, data may be handled based on available space • Maximum Sustained Rate. • Traffic Priority.

Table 2-1: Quality of Service Specifications [10]

Vishwanath, et al [13], provides insights on factors that impact the signal quality of wireless access technologies. It explains that the strength of the signal received at the Mobile Station depends on the path loss, channel condition at the Mobile Station, and multipath effects of the wireless channel. These in turn depend on the location, speed and the physical objects near the mobile station. However, the IEEE 802.16e standard supports multiple Modulation and forward error correction Coding Schemes (MCS). This means that the Base Station can choose to employ different MCSs for different mobile stations based on the channel condition experienced by the mobile station. The selected MCSs can further change dynamically across frames for the same Mobile Station. Choosing a robust MCS allows the transmission to tolerate poorer channel conditions. The high throughput offered by WiMax is attributed to the robust MCS.

A subscriber session consists of both the subscriber QoS (defines the transmission speed) and the service QoS that regulates the prioritisation of the service flow. Both QoS profiles specify the traffic flow parameters that are defined in the DSCP frame of the data packet which is passed onto and managed through, the network core. If the service flow can not be set up, due to radio resource limitations, the filter is not established and the IP flow automatically uses the default service flow. Note that the QoS Class only affects the radio scheduler in the upstream direction – in the downstream direction, each non-BE (Best Effort) flow is scheduled on the basis of its reserved traffic rate.

Scheduling is the process through which data flows are given access to system resources (communications bandwidth in this case). This is usually done to load balance a system effectively and/or achieve a target quality of service. In theory, there are three schedulers needed for IEEE 802.16, one for outbound transmission scheduling at the Base Station for downlink, another for uplink burst scheduling at the Base Station, and last is the outbound transmission scheduling at the Mobile Station [14]. The benefit of the scheduling algorithm used in WiMax is that it allows users to only compete once for the access point thus increasing the throughput, lowering latency, and improving spectral efficiency.

Hybrid Automatic Repeat Request (HARQ) is a data packet retransmission mechanism which uses error control code in addition to the retransmission scheme. It differs from the Automatic Request (ARQ) scheme in that it combines the previous erounously received transmission in order to improve reliably. It requires the Physical layer to support OFDMA. HARQ parameters are specified and negotiated during the initialisation phase [15].

Mobile WiMax has three types of handover procedures in mobile WiMAX, which are Micro Diversity Handover (MDHO), Fast Base Station Switch Handover (FBBS) and the Hard Handover (HHO). The first two types are optional handover, which enable the Mobile Station to send and receive data from numerous access points simultaneously. On the other hand, the hard handover is mandatory and is therefore often considered the default handover procedure in Mobile WiMax [16]. However, Mobile WiMax currently suffers from a delayed handover process between base stations and some real-time applications cannot tolerate this delay [16].

Link adaptation techniques, frequently referred to as Adaptive Modulation and Coding (AMC) improve the spectral efficiency of time-varying wireless channels while maintaining a predictable Bit Error Rate (BER). They are designed to track channel variations, and change the modulation and coding scheme to yield a higher throughput by transmitting high information rates under favourable channel conditions and reducing the information rate in response to channel degradation. Thus, the FEC scheme is varied when adjusting the code rate to the variations in the communication channel. For example, in periods of high fade when the channel is in a poor state, i.e. low SNR, the signal constellation size is reduced in order to improve reliability, lowering the effective SNR to make transmission more robust. Conversely, in periods of low fade or high gain (high SNR); the signal constellation size is increased in order to allow higher data rate modulation schemes to be employed with low probability of error, thus instantaneously improving the SNR [17]. The mandatory modulation methods used in Mobile WiMax on the downlink include QPSK, 16QAM, and 64 QAM. The mandatory modulation methods used in Mobile WiMax on the uplink include QPSK, and 16QAM, however, the 64 QAM method may also be applied (optional). It is best practice for higher order modulations to be used when the end user device is closer to the Base Station to ensure increased throughput, while lower modulation schemes should be employed as the end users device moves further and further away from the Base Station. [10]

Mobile WiMax uses air interfaces to ensure that communication between the various components of the system takes place. Figure 2 – 2 below [10] gives a high-level overview of the points where the air interfaces are used and how these air interfaces actually glue the entire system together.

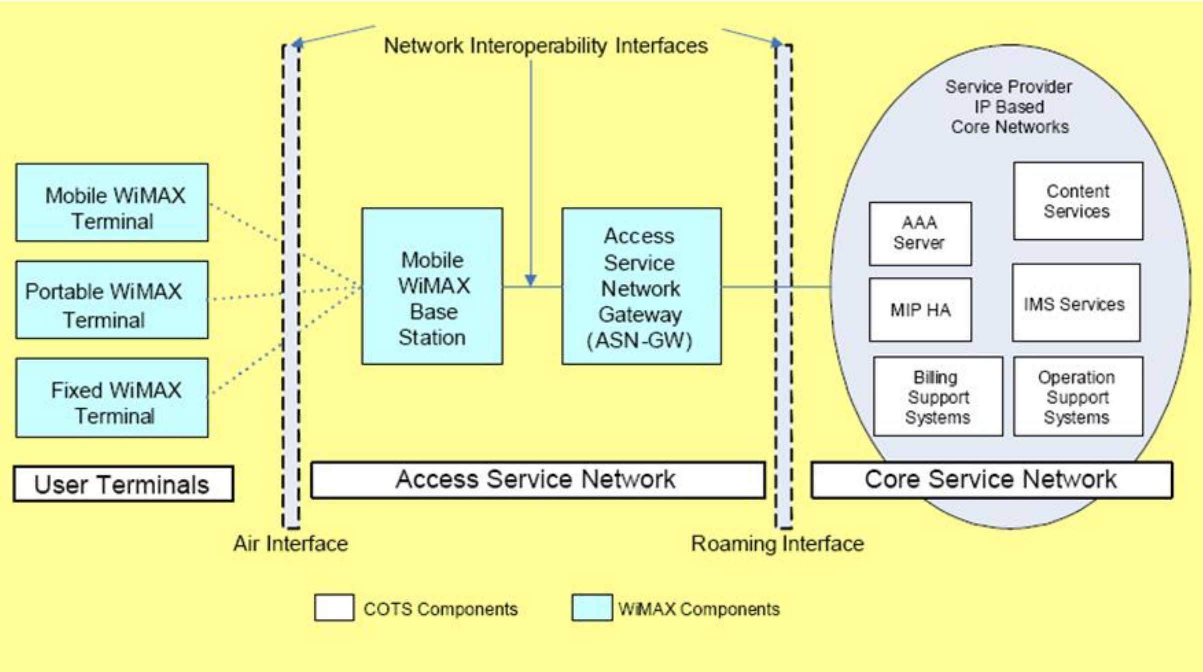

Figure 2-2: High Level Network Interoperability Interfaces Diagram [10]

Figure 2 - 3 overleaf provides a more detailed explanation of the types of air interfaces that are used [10].

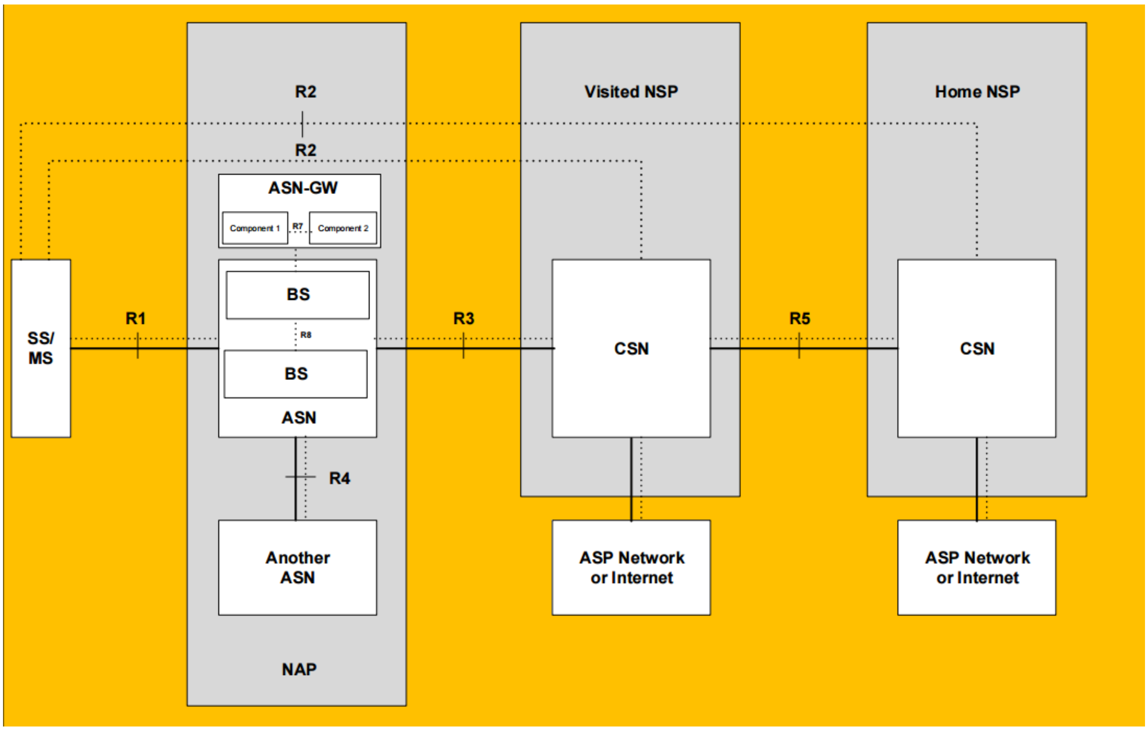

Figure 2-3: Low Level Network Interoperability Interfaces Diagram [10]

The Mobile stations (end user devices) use the R1 interface to connect to the base station. The CSN uses the R2 interface to connect to the mobile station. The R3 enables communication between the ASN and the CSN. The R4 interface connects neighbouring ASNs. The R5 interface connects neighbouring CSNs. The R6, located within the ASN, enables communication between the ASN-GW and the BS. The R7, located within the ASN-GW, enables communication between the the components of the gateway itself. The R8 interface, which is also located within the ASN, is used for inter-base station communication.

2.1.4 Other Mobile Solutions

The 3rd Generation Partnership Project (3GPP) is a collaboration that brings together a number of telecommunications standards bodies to form a single standards body that works within the scope of the ITU to develop 3rd (and future) generation wireless technologies that build upon the base provided by GSM [18]. The 3GPP was jointly formed by telecommunication associations from the US, Europe, Japan, South Korea and China. At present, it has more than 400 member companies and institutions. The 3GPP defines GSM and WCDMA specifications for a complete mobile system, including terminal aspects, radio access networks, core networks, and parts of the service network. Standardization bodies in each world region have a mandate to take the output from the 3GPP and publish it in their region as formal standards. 3GPP specifications are structured in releases. Ordinarily, discussions of 3GPP technologies refer to the functionality in one release or another. It is worth noting that all new releases are backward compatible with previous releases.

Long Term Evolution (LTE) [19] is a standard that was developed by the 3GPP; as a progression from HSPA+ and was deployed in South Africa in 2012 on the 1800MHz and 2300 MHz bands. However, Legacy LTE and LTE advanced use Licensed IMT-2000 Bands at bands like 700, 900, 1800, 2100, and 2600 MHz [20]. LTE is backward compatible with all GSM based technologies up to HSPA. LTE-Advanced is compatible with previous mobile technologies – GSM, GPRS, UMTS, EDGE, WCDMA, HSPA, CDMA-one, CDMA2000, EV-DO, EV-DV and the synchronous SC-CDMA. It was designed to provide an extremely high performance radio access technology that offers full vehicular speed mobility. LTE capabilities include:

- Downlink peak data rates up to 326 Mbps with 20 MHz bandwidth.
- Uplink peak data rates up to 86.4 Mbps with 20 MHz bandwidth.
- Operation in both TDD and FDD modes.
- Scalable channel bandwidth with high spectral efficiency.

LTE uses OFDMA multiplexing scheme in the downlink and SC-FDMA for the uplink. Mobile WiMax (802.16e), on the other hand, uses OFDMA in both the uplink and the downlink. This causes LTE enabled devices to require less battery power than WiMax enabled devices as OFDMA has a higher PARP than SC-FDMA, causing the battery of the WiMax mobile station to be depleted/exhausted quicker than the LTE device. SC-FDMA reduces Peak-to-Average-Power-Ratio (PAPR) by 3 - 5 dB giving rise to uplink improvements that can be utilised to improve coverage or throughputs of cell edge users. 802.16m uses SCFDMA for both uplink and downlink [20]. Furthermore, to ensure minimum BER, LTE uses 15 KHZ spacing while WiMax uses 10 KHz. The inter-carrier interference is thus higher in WiMax than it is in LTE.

However, LTE is still expensive to deploy due to the high infrastructure costs, spectrum licenses, and the installation costs. For these reasons LTE is currently only deployed in major cities where Operators expect to get the quickest and highest return on investment. These cities have the highest smartphone penetration in the country and relatively high disposable incomes compared to rural areas. This makes LTE in South Africa a premium service for a niche market. This For these reasons, LTE is (from a commercial perspective) better suited for urban areas, than rural areas. From [10, and 59] we learnt that the cost to deploy WiMax is cheaper than that of LTE. Further, a WiMax network requires only a few resources to cover a large area and can be deployed over licensed or unlicensed spectrum. This suggests that WiMax may be a good alternative for fast broadband access in rural South Africa.

There are other solutions that can be considered for providing Mobile connectivity. These include Macro cells, Micro cells, Pico cells and Femto cells. All cells are categorised according to the power output they transmit and the coverage area. Macro cells are cells where the base station antenna is fixed on a mast or a building above average roof top level. A GSM based macro cell is served by a macro BTS (also known as a traditional BTS) that covers a large area (approximately 20 - 35km radius) and is used to provide continuous network coverage. This type of BTS typically supports 3GPP technologies and is the most common type of BTS. It requires high OPEX, and CAPEX costs, and acquiring property to host the large site is often a very challenging and long process. A Distributed Antenna System (DAS) is a system that is often used with a macro cell to provide indoor coverage. It is the preferred solution for malls and large corporations.

Micro cells are cells whose antenna height is under average roof top level. Micro cells are served by BTSs similar to the macro BTSs and they cover a smaller radius than the macro BTS. Micro cells typically ‘fill’ areas that have no coverage using power control. They can also improve capacity in dense areas.

Pico cells are served by a small base station/radio that is used to improve coverage or capacity in a very small area. A Pico cell covers a smaller radius than a micro cell (less than 100 meters) and is often used to provide coverage indoors for example, in offices.

Another solution is the Low Power GSM (LPGSM) which was designed especially to address the need of covering indoor environment, by implementing small and low power antenna, and also providing dedicated radio coverage to ensure sufficient capacity and network in all areas such as basements, stairwells or elevators.

Femto-cells, just like Pico cells, are part of the small cells group. A femto cell is a wireless access point that improves cellular reception inside a home or office building. The device, which resembles a wireless router, essentially acts as a repeater. The device communicates with the mobile phone and converts voice calls into voice over IP (VoIP) packets. The packets are then transmitted over a broadband connection to the mobile operator's servers. Femto cells are compatible with CDMA2000, WiMAX or UMTS mobile telephony devices, using the provider's own licensed spectrum to operate. [21]

2.2 Contributions made to the Mobile Wimax literature

The basic needs of a prospective subscriber are summarised in Figure 2 - 4 overleaf, which shows that subscribers place the most value on the ability to make and receive voice calls and the least value on the ability to make video calls. This information is based on the traffic mix generated on the Vodacom network, in selected rural areas in South Africa [22]. This data was obtained using Touch point. More information on Touch point is provided in the Appendix under Section 7.1. It is assumed that other rural areas would have a similar traffic mix.

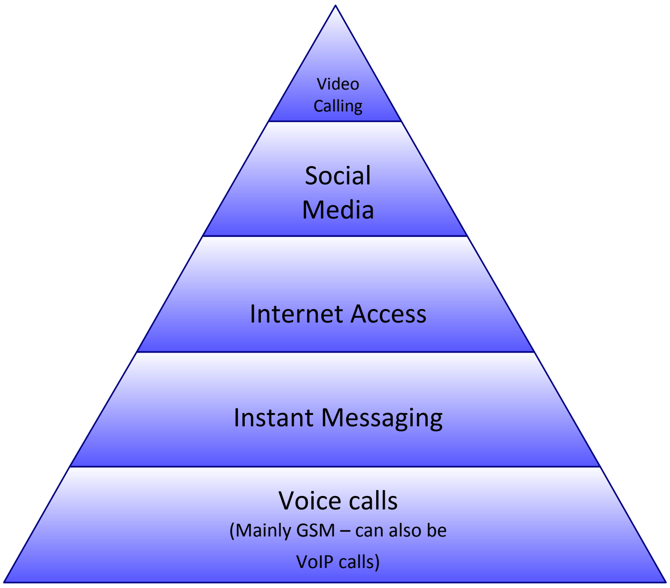

Figure 2-4: Basic Needs of the prospective customer

2.3 Current Broadband Ecosystem in Urban and Rural South Africa

The mobile broadband ecosystems in rural or remote South Africa consists mostly of 2nd generation (GPRS, EDGE) technologies as depicted in Figure 2 - 5 overleaf. The limitation of this diagram, and other such diagrams which are made available by service providers, is that it simply shows areas as "having coverage", rather than making a distinction between good and poor network signal. Nevertheless, Figure 2-5 overleaf, shows the areas that the Vodacom 2G network is designed to cover. It does not reflect the reliability of the network but it does indicate the areas where there currently is no 2G coverage. This map is also a good indication of the extent of 2G coverage in the country as Vodacom currently has the most extensive network footprint compared to other Mobile Network Operators in South Africa.

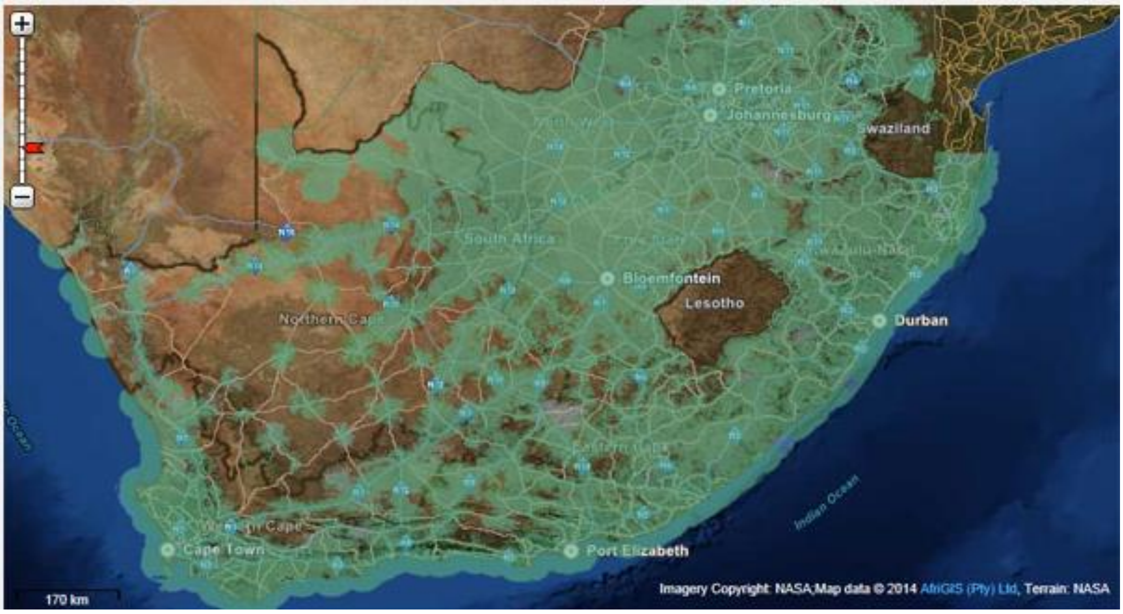

Figure 2-5: Vodacom's 2G Network Coverage Map.[62].

It is a common principle for Network providers to provide 3G and newer technologies in areas where there is already 2G coverage as it is cheaper to upgrade a network than it is to deploy new infrastructure in an area. Therefore, a map of the Vodacom 3G coverage in the country would also have the same open areas (areas without network coverage) as shown in figure 2 – 5 **Error! Reference source not found.**. The 2G coverage map is shown as it is more extensive than the 3G coverage map because 2G coverage was previously deemed as sufficient broadband coverage by the previous Department of Communications. This is no longer the case as 2G is no longer suffient to meet the bandwidth speeds required for some of the latest mobile apps and online transactions.

It is therefore reasonable to state that the communication needs of subscribers in many rural areas are not met. On the other hand, people living and working in urban and semi-urban areas are often able to choose, from a range of technologies, the type of technology they would like to use to access the Internet. They are able to access the internet through mobile technologies supported by their mobile devices or through fixed line infrastructure (ADSL, Fibre, Microwave etc) used at their homes, places of work, or at Internet cafes. The mobile broadband ecosystems in urban South Africa consists of 2nd generation (GPRS, EDGE), and 3rd generation (UMTS, HSPA+, and LTE) technologies. The 4th generation technologies (such as LTE-

Advanced and WiMax Release 2) have not been launched commercially as the spectrum required has not been made available by ICASA.

2.4 Mobile WiMax

The literature on Mobile WiMax, published between 2005 – 2009 was intended to prove that Mobile WiMax provides faster speeds and broader coverage than what cellular broadband technologies of that time, namely 2G, EDGE, and UMTS were able to provide in rural areas. In 2007 Little published a report titled HSPA and mobile WiMax for Mobile Broadband Wireless Access [23], which explains that the peak data rates that Mobile WiMax can achieve are higher than those which HSPA offers. The objective of the literature published in 2009 - 2012 was to compare the performance and viability of WiMax vs HSPA and, in most cases, LTE. In 2009 Ericsson published a white paper to discuss how the performance of HSPA and Mobile WiMax compare, in theory and in practice [6]. In this paper Ericsson proves that Mobile WiMax achieves higher spectral efficiency, and higher data peak rates than HSPA, although HSPA is better able to achieve fairly identical coverage of users over a wide area. This is important because it shows us that Mobile WiMax was deemed a technically sound and viable mobile solution by large companies and telecommunication bodies.

2.4.1 How mobile subscribers' communication needs are addressed

The GSM based technologies seem to have been designed to cater for the subscriber needs depicted in Figure 2 - 4 above in that GSM based technologies are backward compatible. This allows subscribers to be seamlessly downgraded to the next best technology available in the users vicinity, offering the best signal, and seamlessly move the user to a better technology when the signal strength possible reaches a certain minimum level again. This happens while the subscriber moves in and out of areas offering different technologies at different signal levels. This is also in line with operator's business strategy for deploying network infrastructure as Network Operators often deploy UMTS/HSPA (3G) in areas that already have 2G and LTE in areas that already have UMTS/HSPA (3G) as it is a more cost effective strategy than deploying infrastructure in an area that currently does not have infrastructure. Network Operators also deploy technologies depending on the demand for services, required capital investment, and the projected return on investment. This means that an operator can opt to have 3G in a township and 2G in the village right next to the township. The subscribers would be seamlessly handed over between base stations as they move between the areas. This strategy also assists in load balancing between base stations with different capabilities; although the user experience may be impacted at, the various technologies offer different data speeds and thus different service.

A Mobile WiMax network (which might not be as vast as the more common 3GPP based networks), is also able to address the communication needs of its subscribers as it has built in functionality that allows the operator to employ different methods to ensure that the customer still enjoys quality service while in the WiMax coverage area [24]. The operator is able to achieve this by restricting users from accessing services other than voice calls when the network is congested or when resource challenges are experienced on the network [10]. This displays the robustness of the WiMax technology, as the operator is able to prioritise voice traffic over other services (such as web browsing) [24] and therefore still meet the users' most basic requirements without downgrading users to a lesser technology. The operator does this by configuring the Classes of Services (CoS) necessary to provide the required services (sometimes only voice, depending on the demand for services and resources available). All other traffic is processed as "Best Effort" traffic. It is therefore acceptable to say that WiMax was built to provide robust, and superior services to the end user, whether it is Voice only services or Voice and Multimedia services.

It was also found that most African countries (including Cameroon, Central African Republic, Congo, Ethopia, and Ghana) that deployed Mobile WiMax used it as a fixed line network and not a mobile network this was due to regulatory restrictions, availability of spectrum, and Network Operators' technology strategy which is driven by the dominance of 3GPP networks and devices. [25] This shows that the reason Mobile WiMax was not widely adopted in Africa was not due to technical flaws, but rather the decisions made by regulators and other stakeholders from the private sector. This shows us that Mobile WiMax is a technically sound broadband technology.

2.5 The status of Mobile WiMax in South Africa

The 2500 – 2690 MHz spectrum band is the most preferred band to use for Mobile WiMax [26]. However, in [27], Zhou explains the benefits of deploying technologies in the 700 – 862 MHz range. These benefits include the benefit of a considerable range. What is important in this paper is the evidence provided to show that Mobile WiMax deployments in the 700 – 862 MHz range, over a generally flat topography are feasible depending on how the network is designed. However, in densely populated areas, Operators would need to have at least 20MHz of spectrum to take advantage of this range, whereas 6 MHz would suffice in areas with low populations. These deployments favour WiMax solutions based on TDD.

The migration to Digital Terrestrial Television is currently underway thus it is expected that the 800 MHz spectrum and the spectrum remaining on the 2.5 GHz band will be allocated in the near future. It is for this reason that Mobile WiMax (802.16e and 802.16m) and LTE-Advanced, are currently not available as commercial offerings in South Africa.

ICASA, uses ECN and ECNS licenses, in accordance with the ECA Act No. 36 of 2005, as a way to regulate the telecommunications sector, while remaining technologically neutral. Technological neutrality is aimed at encouraging innovation to meet the demands of all consumers in the country. The Class ECNS and ECS licenses are designed to increase access to telecommunication services in areas where the penetration of telecommunications services is low. These areas are typically areas that have not been served by the big operators due to the high cost of rolling out services in low-density areas inhabited by low-income populations [28]. ICASA, in preparation for the digital migration, is in the process of determining how spectrum should be allocated and the fair economic value of the 700, 800, and 2600 MHz bands [29] without showing favour to one technology over another.

ICASA’s decisions will directly impact operators’ technology strategies thus indicating whether operators (small or big) are interested in adopting Mobile WiMax - even as a technology to enhance their coverage/footprint. What’s more, ICASA needs to accomplish these tasks with the understanding that the main factor that affects capacity is the spectral width of available channels because different technologies require different allocations of spectrum on the same band in order for their service to be competitive. As an example, allocating an operator 20 MHz on the 800 MHz would be sufficient for an operator wanting to deploy WiMax, however, the same allocation allocated to an operator that wants to deploy LTE-Advanced could make their service cheaper to deploy and more competitive than Mobile WiMax (802.16e).

2.6 The history of Mobile WiMax in South Africa

In 2007 ICASA awarded Test Licenses to Operators that were interested in deploying WiMax Networks. These include [29]:

- Tshwane Metro (16 MHz trial)
- BCS NET (14 MHz trial)
- Cell C
- MWeb (15 MHz trial)
- Internet Solutions
- Altech Management Systems (10 MHz trial)
- Michelangelo Technologies
- Multisource Telecomms
- Verizon
- Origin X

None of the above mentioned companies have WiMax Networks today. They might still be waiting for ICASA to officially release the spectrum in order for them to officially deploy the network, however, this is unlikely as GSM based technologies are gaining more popularity around the world than WiMax. It would, however, have been interesting to compare the performance of each these trial networks in order to see the impact of various network choices, terrain, and environmental effects on the strength of the signal and to compare these finding to the findings in the literature survey. However, most of these companies were not at liberty to share information pertaining to the performance of their trial networks.

Some Operators, such as Vodacom, on behalf of Wireless Business Solutions (WBS), built trial Mobile WiMax (802.16e) networks, but they did not offer the services to the public as a mobile service because ICASA had not approved of this as the licence was for fixed line connectivity only. Vodacom/WBS in particular deployed the 802.16e standard, however, they offered it to customers as a fixed or a normadic network which was to serve as a replacement of DLS. Users would have antennaes on their buildings and routers on the inside of the building. However, this service offering was later discontinued. Sentech also built a WiMax network, but later shut it down. Telkom and Neotel deployed 802.16d (Fixed WiMax) networks, however Telkom has now have decommissioned its WiMax network mainly because it now has a Mobile Network based on 3GPP standards and thus prefers to expand on that model using LTE in urban areas. Neotel still offers fixed WiMax, but it has not shared its views on deploying a Mobile WiMax network. This may be because it is a fixed line operator or because it has since been bought by Vodacom which, if allowed to take over Neotel's spectrum, intends to deploy an LTE-Advanced network on the prized spectrum – this is as per the current Vodacom business Strategy.

2.7 Charateristics of competing Mobile technologies

In the work done by Little [23], network operators are urged to treat coverage and throughput as equally important factors when deciding on a technolgy to support as the financial implications of these factors, if captured, will assist Operators in making an informed decision on the suitability of a technology in a given area. This is important because if Operators do not take both of these factors into consideration when planning a network, then they may find that they have to deploy more resources than initially anticipated in order for them to provide the required coverage in the area. This may, in the end, be a costly lesson for the Operator. This notion is taken into account in Chapters 3 and 4.

[30] presents how WiMax, using LOS configuration, under optimal conditions, is able to deliver 70 Mbps over 8000 square kilometers with a range of 50 kilometers in all directions for fixed stations and almost 5 kilometers for mobile stations – all using one tower. In [30], A. Nelson takes this further by proving that WiMax out performs

LTE in multi-antennae (4x4 MIMO) architectures, in rural areas. This is important to know as it shows that Mobile WiMax, applied in a rural context, can assist in bridging the digital divide by providing quality broadband coverage in rural areas. However, in densely popoulated areas, LTE is able to cover a larger cell radius and coverage area than WiMax [32].

The Non-Line-of-site WiMax configuration covers a smaller area than the LoS configuration. This is shown in Table 2-22 below [21] which is based on the results obtained by Vodacom when testing the distance that WiMax is able to cover in different locations. However, the fact that WiMax is able to provide coverage in areas where the terrain does not allow for a LoS configuration further emphasises the suitability of Mobile WiMax for rural areas.

Type of Area	Rooftop Antenna	Window/Fixed Antenna	Indoor/Portable Antenna
Rural	<20 Km using NLOS**	<8 Km	<4 Km
Suburban	N/A	<4 Km	<2 Km
Urban	N/A	<2 Km	<1 Km

Table 2-2: Size of WiMax Cell in Different Areas [24]

From [33] the conclusion that a Mobile WiMAX Base Station (BS) has the ability to support both fixed and mobile broadband wireless access is drawn. This gives Operators the added advantage of being able to deploy a fixed and a mobile network using the same main equipment. This benefit is taken further in [34] where it is announced that equipment vendors now offer integrated WiMax and LTE multi-platform base stations which simplify the process of integrating the two technologies (WiMax and LTE) into a single network.

2.8 Duplex Transmission Modes

In [35], Retnasothie explains that the way the spectrum is configured (paired or unpaired) can be used to determine if FDD or TDD WiMax should be deployed. This is because the one configuration might be better suited for the allocated spectrum, than the other configuration. The literature on TDD and FDD deployments indicates that the TDD configuration is best suited for scenarios when spectrum is limited and traffic is expected to be asymmetric because TDD has the flexibility of changing the downlink-to-uplink ratio to accommodate a variety of traffic asymmetries. However, in practice, the network operator has to either fix the downlink-to-uplink ratio system-wide or use guard bands between the different frequency bands in order to limit interference effects. Another drawback of TDD systems with a large downlink-to-uplink ratio, is that they incur a link budget penalty as the uplink average power is reduced for a given peak power. Note that a Link Budget is the maximum allowable path loss, which is derived from the loss, and gain sum of signal strength as it travels through different components in the path between a transmitter and receiver. A link budget thus determines the maximum cell radius for each base station for a given level of reliability.

In essence, the TDD configuration enables optimal spectral efficiency which results in a higher downlink capacity for the base station, and thus a more cost effective assignment even though the data density would be low. Generally, mobile data users frequently require more bandwidth on the downlink than on the uplink. This means that the TDD configuration will be able to cater for this requirement, however because of the link budget penalty, the range of the signal would be lower than if the downlink/uplink ratio were to be more balanced.

The FDD duplexing approach is better able to combat interference challenges because the uplink and the downlink sizes are fixed. The IEEE 802.16d (Fixed WiMax) specification is more suitable for FDD operations, while the IEEE 802.16e (Mobile WiMax) specification uses the TDD configuration. The Mobile WiMAX system profile, as currently defined in the WiMAX Forum, is TDD technology with just one frequency channel (10MHz for example) that is shared in the time domain between the uplink and downlink. The ratio between the uplink and downlink determines how the frequency channels are shared. A 2:1 ratio means the channels used two-thirds of the time for the downlink and one-third of the time for the uplink.

This means that the way ICASA, the regulator, allocates spectrum has a direct impact on the type of configuration that the WiMax Network Operator will be able to deploy. This in turn has a direct impact on the cost effectiveness, the expected performance that the technology configuration will yield, and thus the operator's ability to compete with other Operators operating in the same space using different technology. This is because TDD and FDD achieve different levels of spectral efficiency which informs the number of resources required to meet the data requirements of the users. Spectral efficiency is of great importance because spectrum is a scarce resource.

As discussed above, rolling out a TDD network will aid in enhancing the network footprint in a cost effective way. Other reasons are due to TDD spectrum often costing less than FDD spectrum and requiring less backhaul than FDD spectrum thus resulting in further savings. Table 2-3 below [36] compares FDD Methods with TDD Methods.

FDD AND TDD METHODS		
Characteristic	**FDD**	**TDD**
Spectrum usage	High including guard bands	Less
Complexity	High	Low but needs accurate timing
Cost	Higher	Lower
Latency	Little or none	Depends on range, TX-RX switching times
Range	Unlimited	Shorter, depends on guard time
UL/DL symmetry	Usually 50/50	Asymmetrical as required
Dynamic bandwidth allocation	None	Can be implemented
MIMO and beamforming	More difficult	Easier

Table 2-3: FDD and TDD Methods [36]

As depicted in Table 2-3 above both FDD and TDD configurations are prone to interference. TDD deployments, by definition, require network synchronization as it is not possible for one cell to be transmitting while its adjacent cell is receiving data. This may introduce problems as more Operators introduce networks in the same spectrum band. Figure 2-6 below depicts the types of intereferences encountered in the TDD and FDD deployments.

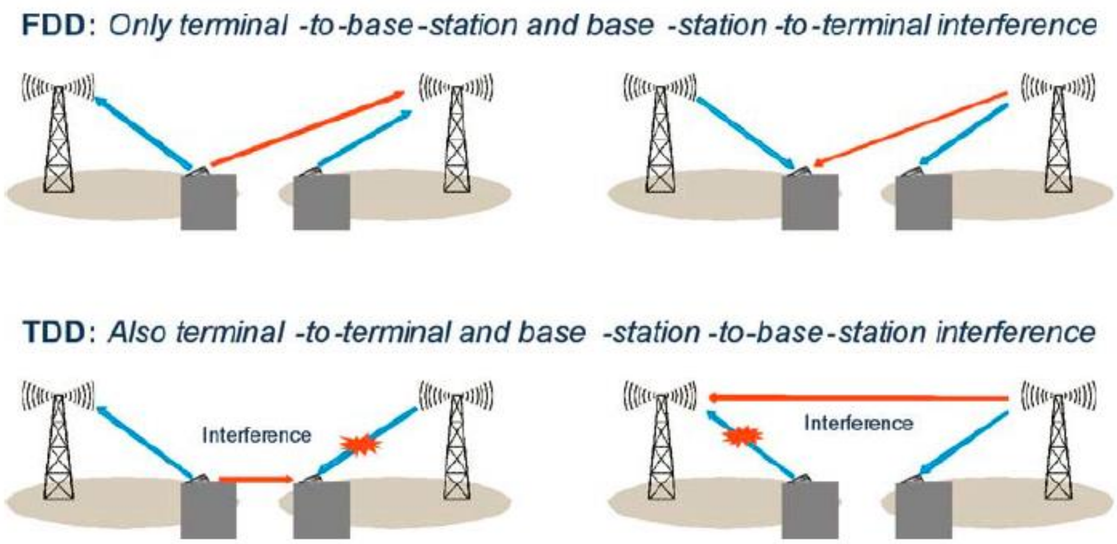

Figure 2-6: Types of Interference [6]

2.9 WiMax Deployment Models

WiMax can be deployed using a range of models; as an example, for indooor only operations using indoor CPEs, for outdoor only operations or both indoor and outdoor operations, using Smartphones, Laptops and PDA. These models are shown in Table 2 -4 overleaf.

Table 1. Types of access to a WiMAX network					
Definition	**Devices**	**Locations/ Speed**	**Handoffs**	**802.16-2004**	**802.16e**
Fixed access	Outdoor and indoor CPEs	Single/ Stationary	No	Yes	Yes
Nomadic access	Indoor CPEs, PCMCIA cards	Multiple/ Stationary	No	Yes	Yes
Portability	Laptop PCMCIA or mini cards	Multiple/ Walking speed	Hard handoffs	No	Yes
Simple mobility	Laptop PCMCIA or mini cards, PDAs or smartphones	Multiple/ Low vehicular speed	Hard handoffs	No	Yes
Full mobility	Laptop PCMCIA or mini cards, PDAs or smartphones	Multiple/ High vehicular speed	Soft handoffs	No	Yes

Table 2 -4: Types of Access to a WiMax Network [37]

WiMax can also be deployed as a hybrid Network with other technologies such as LTE, WiFi or with other 3G technologies as depicted in Figure 2-7 below [37]. The WiMax network can therefore be integrated with existing 3GPP technologies by conecting the ASN-GW to the HSS through the IP backone using the R3 interface.

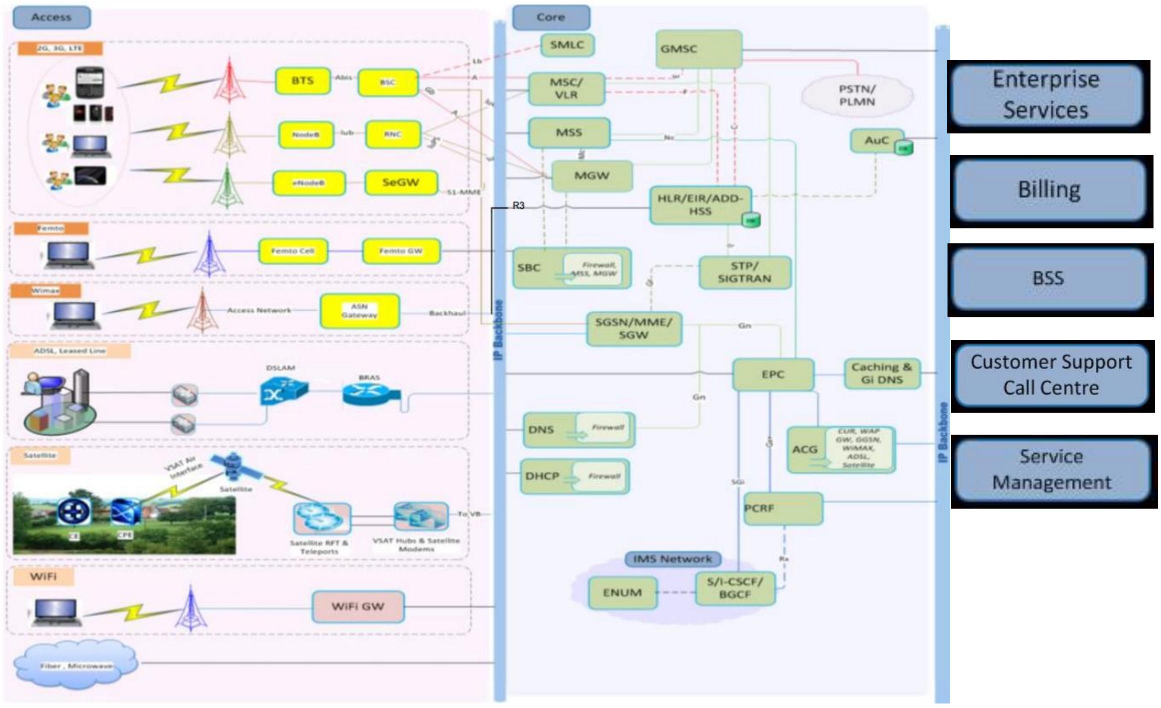

Figure 2-7: Hybrid Network Architecture [38]

In [20], Aldmour makes a significant contribution to the literature survey by providing a detailed explanation of why Mobile WiMax and LTE are competing technologies. This explanation is provided through a discussion of the technical similarities between Mobile WiMax and LTE. As an example, both technologies are fast broadband technologies based on OFDMA, and designed to deliver high throughput (wireless) data. This is important for us to understand as it helps us to appreciate where Mobile WiMax fits into the Broadband ecosystem in South Africa, and in the rest of the world. From [20] we are able to understand the reason why WiMax, like LTE, is superior to all existing 3G technologies from an architectural perspective.

2.10 Focus on WiMax and LTE: Competing Technologies

In South Africa, 3GPP technologies are the mainstream technologies – WiMax is not. The adoption of Mobile WiMax has been the highest in Japan, South Korea, and the United States [39]. In fact, Japan has seen an increase in the number of Mobile WiMax subscribers in 2013 [40]. However, LTE has been deployed in more countries globally and by more Operators than WiMax. This is supported by Figure 2-8 below [41] which shows that the number of LTE subscriptions (globally) are still on the rise.

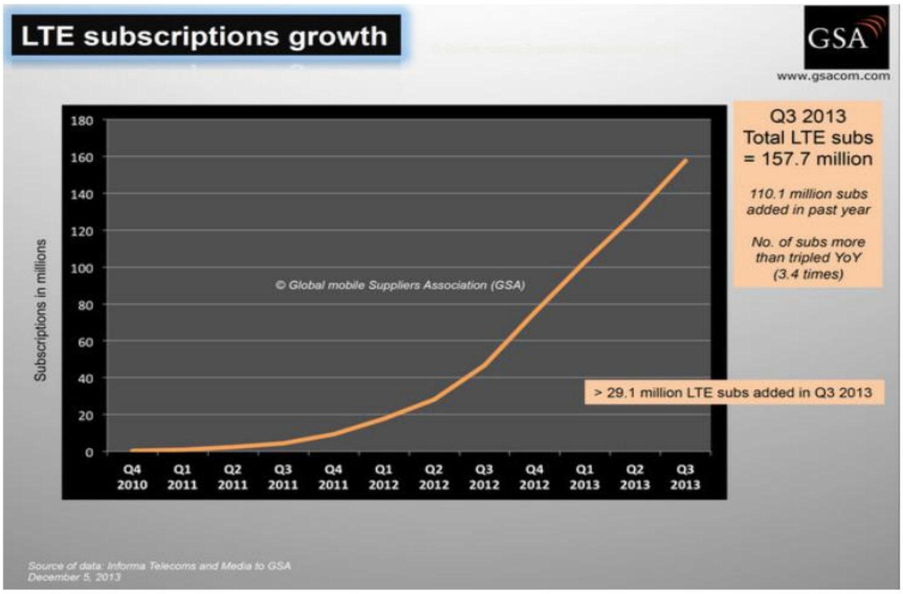

Figure 2-8: LTE Subscriptions Growth [41]

In December 2014, TheGlobal mobile Suppliers Association (GSA) represents mobile suppliers worldwide, engaged in infrastructure, semiconductors, devices, services and applications development, and support services. The GSA reported that the total number of LTE subscribers worldwide had reached the 373 million mark in Q3 of 2014. This data was supplied to the GSA by Ovum. On the other hand, in February 2014, the WiMax forum reported that the core WiMAX operator community served a customer base of a little over 30 million subscribers [42] This is interesting to note because, as explained in Section 1.6, WiMax was lauched in 2005 and therefore had the advantage of time to dominate the market for high-speed broadband services, but for various non-technical reasons was not able to. For this reason, it is unlikely that WiMax will become a mainstream technology, preferred over LTE. This does not mean that Mobile WiMax can no longer be considered as a communications technology capable of adequately satisfying the data requirements of users in remote, rural areas with challenging terrains.

2.11 Advances in WiMax and LTE

The IEEE, like the 3GPP, have begun defining their “beyond 4G standards” [20]. These are likely to be called WiMax 2.2 and LTE-Advanced +. This should give Network Operators further assurance that WiMax still has a future. Unfortunately, network Operators in South Africa might still not pursue Mobile WiMax because the spectrum is not available and because LTE promises higher economies of scale. This emphasizes the fact that end-users are fully reliant on local Network Operators for exposure to technologies that are currently being used in other parts of the world. Network Operators are fully reliant on the regulator for spectrum to deploy new technologies. The longer the regulator takes to allocate spectrum, the more difficult it becomes for a new technology to gain market share. This means that end-users adopt technologies that the Network Operators choose (or are able) to support and not necessarily the technology that would best suit their communication needs, in the most cost efficient manner.

The International Mobile Telecommunications - Advanced requirements for next generation wireless communication protocols directed the development of 802.16m (also known as Mobile WiMax Release 2) and LTE-Advanced. [43, 44] Figure 2-9 below depicts the evolution of the 3GPP and the IEEE WiMax technologies leading up to the release of 802.16m and LTE-Advanced. It also shows the roadmap for these technologies beyond 4G, leading up to WiMax Advanced 2.2 with TD-LTE.

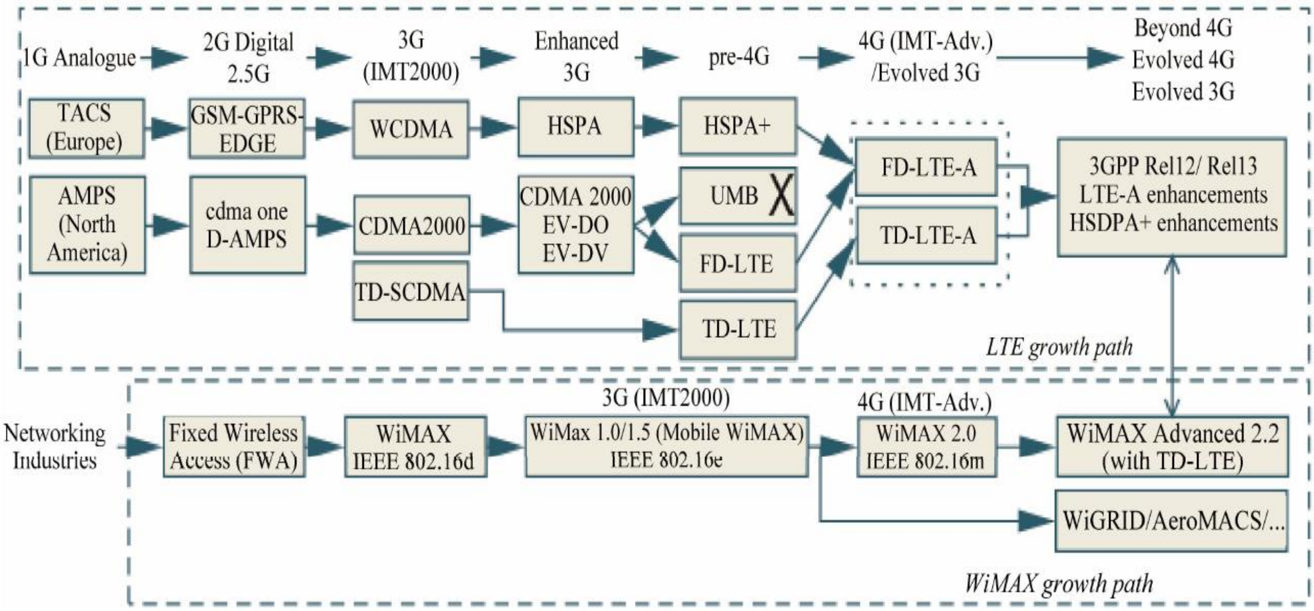

Figure 2-9: Evolution of the 3GPP and the IEEE WiMax Technologies. [20].

Figure 2-9 also illustrates the interoperability of Mobile Wimax release 2 (802.16m) and LTE-Advanced which further allows the two technologies to be deployed in hetrogenous networks. WiMax release 2 (802.16m) is more secure than 802.16e, and supports the smooth handover to/from LTE-Advanced. The appropriate authentication infrastructure between these technologies has been designed, together with a means of optimising handovers and preserving QoS between technologies, This functionality can be taken further to enable inter-operator roaming. [4] This capability can also be seen to be in support of ICASA's objectives in unbundelling the local loop.

Mobile WiMax 2, like LTE - Advanced, can also support mobility that can reach up to 350 km/h, which makes it a suitable candidate for high speed mobility environments such as high-speed express trains [45]. However, users in the identified areas are not expected to travel at high vehicular speeds because the main form of transport is not through cars, or express trains – most people walk, ride horse or donkey wagons. Further, only a few of these residents have cars, however, the quality of the roads in the areas make it extremely unsafe and improbable for users to travel at speeds higher than 120km/h.

A hetrogeneous network comprising of LTE and WiMax technologies allows the reach of the Mobile WiMax network to logically extend into the areas covered by the LTE-Advanced Network and vice versa. Thus giving the operator the freedom to choose the technology best suited for the identified area. The salient benefit of heterogeous networks lies in allowing users to communicate with each other without being concerned about the type of communications technology they are using to facilitate the communication, but rather being concerned with the quality of the service. That is, users are therefore able to roam in other areas where the primary technology in their primary location is not available. In simple terms, this means a users that uses Mobile Wimax in their own village will be able to continue accessing broadband services if they visit an area that has LTE, but does not have WiMax. The user’s mobile station will of course have to support all of these technologies.

However, the technical specification of 802.16e adequately meets the requirements of users in the rural areas which means that Operators may still opt to deploy 802.16e instead of 802.16m. The concern with this approach is obviously the risk in Operators not getting adequate support from the Original Equipment Manaufacturer (OEM) as more and more OEMs switch over to 802.16 m and LTE – with LTE getting the bigger part of the market. This risk is however a calculated risk because there are still many Mobile WiMax Network Operators, using WiMax 802.16e and as shown in [20] the WiMax Forum is designing WiMax 2.2 which indicates that the IEEE has clearly defined technology roadmap that goes beyound 802.16m. Examples of countries that are currently using WiMax include India, Japan, and Malaysia. Therefore Wimax Operators are expected to receive adequate support from the OEMs as there is still demand for WiMax products.

The WiMax forum has also developed new ways to grow the number of Mobile WiMax subscribers. It has developed Mobile WiMax solutions suitable for the aviation, and energy Firms, and other machine-to-machine (telemetry) segments.

The solutions are commonly known as WiMAX based private wireless systems. The solution for aviation is called the AeroMACS solution. It is designed to support the aviation industry in the communication infrastructure of airports. The solution for energy utilities is called the WiGRID; it is designed for the monitoring, measurement, and management of power distribution stations that use smart grid industrial applications of telemetry that are latency sensitive and require high security features. These solutions can be implemented using the frequency bands that are usually allocated to utilities, namely 1.4 GHz, 1.8 GHz, 2.3 GHz, 3.65 GHz and 5.8 GHz [46].

2.12 Other Broadband Technologies Compared to WiMax

Other technologies that have been deployed to provide broadband in rural areas include CDMA2000 and HSPA (High Speed Packet Access). These are plotted on Figure 2 - 10 below to assist us in understanding how and when the technologies evolved.

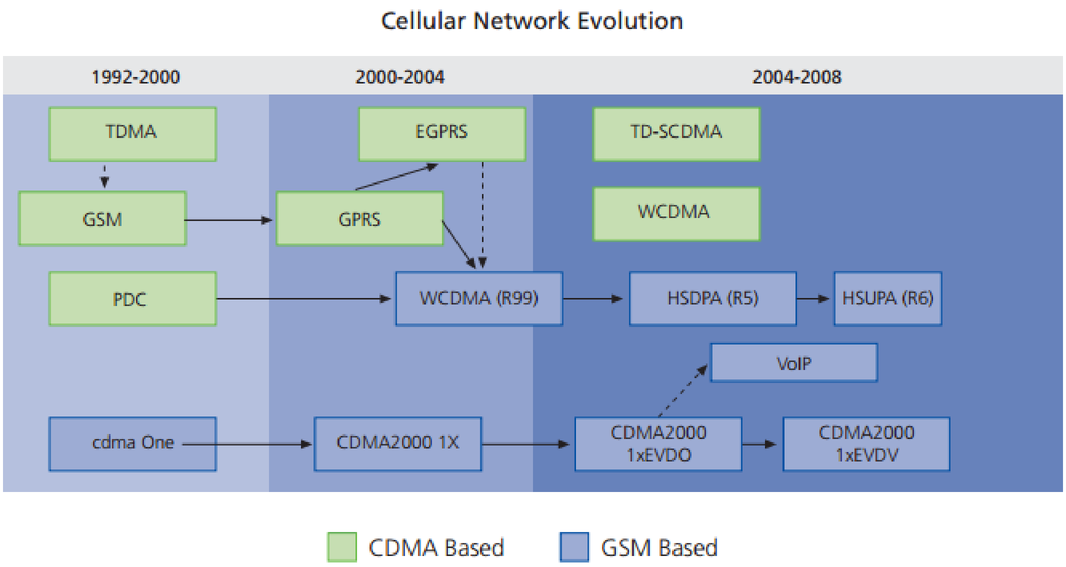

Figure 2-10: Cellular Network Evolution [47]

According to Ericson [6], provides a high-level overview of High Speed Downlink Packet Access (HSDPA), which is said to have sprouted from the evolution of WCDMA. It shows us that the key enhancement in WCDMA 3GPP Release 6 was a new transport channel in the uplink, called the enhanced uplink (EUL). The EUL is also sometimes referred to as High Speed Uplink Packet Access (HSUPA). This enhancement improved throughput, reduced latency and increased capacity of HSPA networks. The combination of HSDPA and EUL is known as HSPA. 3GPP Release 7 introduced HSPA evolution (also called HSPA+) in 2008. This technology adopted techniques that were initially brought to the surface by WiMax. These techniques include dynamic scheduling, link adaptation, HARQ with soft combining, multiple-level QoS, and advanced antenna systems (MIMO). It also applies different modulation schemes in the downlink and in the uplink namely the 64QAM in the downlink, and the 16QAM in the uplink, in order for it to further boost its peak data rate and network capacity. HSPA evolution supports data rates of up to 42 Mbps in the downlink and 11.5 Mbps in the uplink.

According to Ericson [6], also gives us a clear explanation of the similarities and differences between Mobile WiMax and HSPA+, while also highlighting the reason for their differences. HSPA and Mobile WiMAX systems use channel-dependent scheduling (which enables transmission at fading peaks) for efficient and effective use of resources for packet data. HSPA and Mobile WiMAX support dynamic selections between QPSK, 16QAM and 64QAM modulation schemes, as well as that of the channel coding rate, where the lowest coding rate without repetition is 1/2 for Mobile WiMAX and 1/3 (additional coding gain) for HSPA. HSPA currently supports frequency bands ranging from 800MHz to 2600MHz. HSPA is an FDD technology, with uplink and downlink transmission taking place in separate frequency channels (usually denoted as 2x5MHz to indicate two separate 5MHz channels, one for the uplink and one for the downlink). Mobile WiMax is mostly a TDD technology. This assits us in understanding where WiMax is ranked and the reasons why it out performs HSPA.

CDMA2000 consists mainly of One Carrier Radio Transmission Technology (1xRTT) and One Carrier-Evolved, Data-Optimized (1xEV-DO) versions. The 1xRTT is currently the most widely deployed CDMA2000 version. In June 2014, there were 112 EV-DO Rel. 0 networks, 175 EV-DO Rev. A networks, and 12 EV-DO Rev. B networks deployed worldwide EV-DO Rev. A [48] incorporates a more efficient uplink, which has spectral efficiency similar to that of HSUPA. Operators started to make EV-DO Rev. A commercially available in 2007 and EV-DO Rev. B available in 2010. EV-DO uses many of the same techniques for optimizing spectral efficiency as

HSPA, including higher-order modulation, efficient scheduling, turbo-coding, and adaptive modulation and coding. For these reasons, it achieves spectral efficiency that is virtually the same as HSPA. The 1x technologies operate in the 1.25 MHz radio channels compared with the 5 MHz channels UMTS uses, resulting in lower theoretical peak rates, although average throughputs for high-level network loading are similar. Under low- to-medium-load conditions, because of the lower peak achievable data rates, EV-DO or EV-DO Rev. A achieves a lower typical performance level than HSPA. One U.S. operator has quoted 400 to 700 kilobits per second (Kbps) average downlink throughput for EV-DO Rev. 0 and between 600 Kbps and 1.4 Mbps for EV-DO Rev. A. In the past, it was impossible to have simultaneous voice and data sessions with 1X voice and EV-DO data; however, this is now feasible via a capability called Simultaneous 1X Voice and EV-DO Data (SVDO), available in some new handset chipsets. Similarly, devices can simultaneously have 1X voice and LTE data sessions using a capability called Simultaneous Voice and LTE (SVLTE) [49]. 3GPP2 has also defined EV-DO Rev. B, which can combine up to fifteen 1.25 MHz radio channels in 20 MHz, significantly boosting peak theoretical rates to 73.5 Mbps. More likely, an operator would combine three radio channels in 5 MHz. Such an approach, by itself, does not necessarily increase overall capacity, but it does offer users higher peak-data rates. 3GPP2 has defined technical means to integrate CDMA2000 networks with LTE [48]. [6] Explicates that WiMax delivers more data, at a higher speed, and in a more spectrally efficient manner than EVDO.

2.13 Performance Comparisson of HSPA and EVDO to WiMax

From the literature discussed above, it is clear that there are a number of 3G mobile standards, defined by different bodies, that yield performance results that should be sufficient in a rural environment where the contention ratio may be low for various reasons, one such reason being the low population. It is also clear that EVDO and HSPA are the leading technologies outside of LTE and WiMax. However, these technologies only offer best effort services, which mean that they cannot guarantee the quality of the service that the user will experience. They also do not use spectrum efficiently, and cover a smaller geographic area than WiMax and LTE.

More importantly, WiMax was designed to be a data network while CDMA and HSPA evolved incrementally over the years from being voice centric to incorporating data services. This is evident in WiMax's ability to:

1. Tolerate multipath distortion while ensuring spectral efficiency using OFDM
2. Yield high data rates by using an all IP network
3. Ensure low latency rates (using advanced QoS) for real-time applications.

These features are illustrated in Figure 2-11, Figure 2-12, Figure 2-13, and Figure 2-14 provided below and overleaf.

[47] Explains that WiMax experiences the least latency when compared to GPRS, EDGE, WCDMA, EVDO, and HSPA. This is illustrated in Figure 2-11 below.

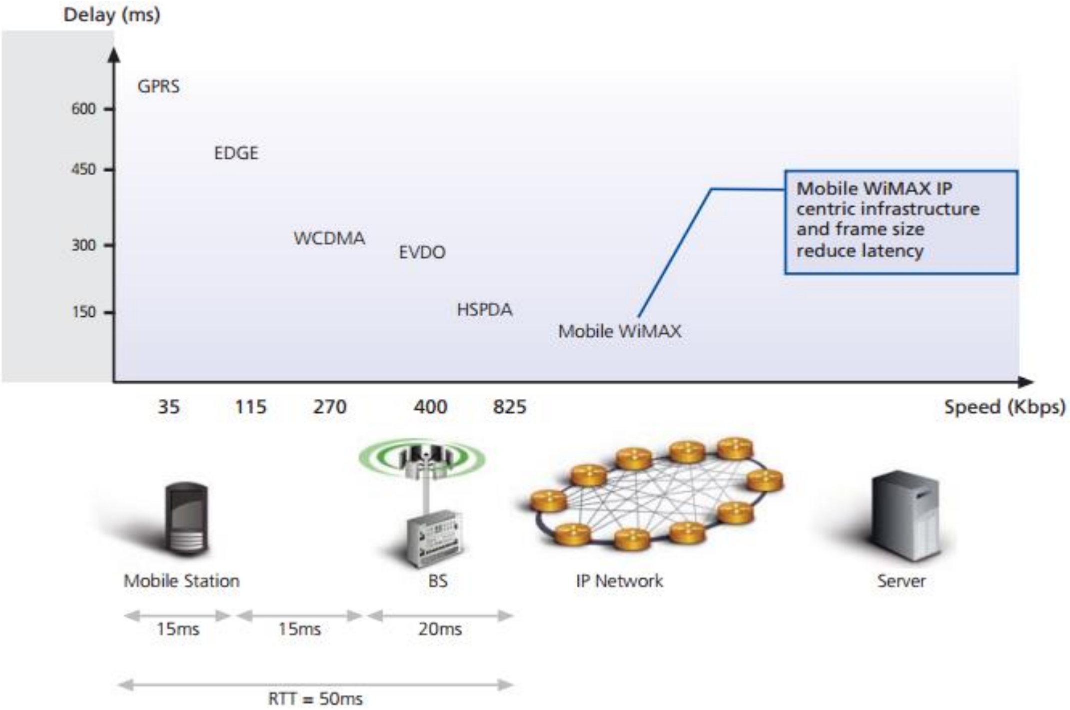

Figure 2-11: WiMax Latency [47]

The performance results of the experiments conducting in [46] also show us that WiMax is more spectrally efficient than EVDO and HSPA. This is illustrated in Figure 2-12 overleaf.

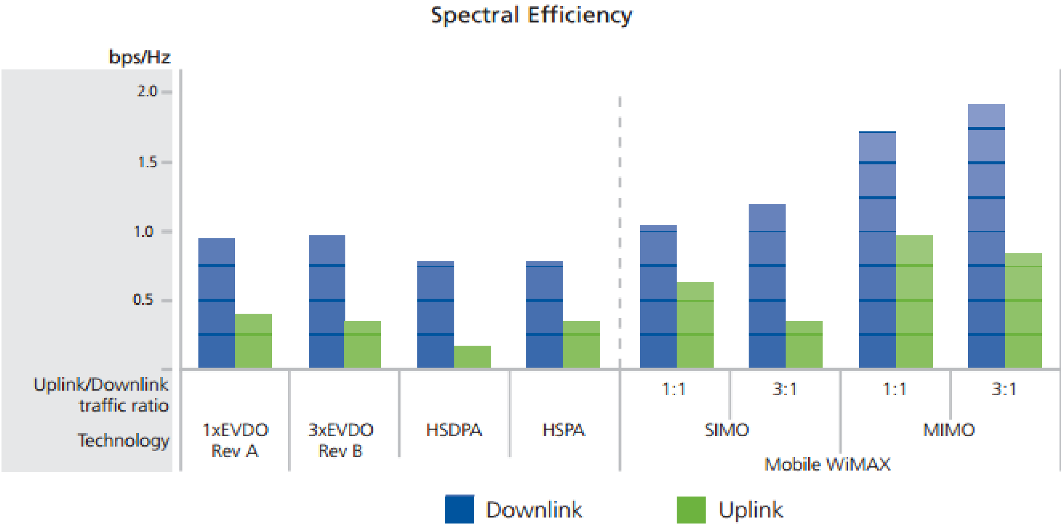

Figure 2-12: WiMax Spectral Efficiency [47]

From the tests conducted in [47], it is shown that the net data throughput (per channel or sector) achieved when using WiMax was higher than in EVDO and HSPA and that WiMax achieves the highest data Peak rates when compared to HSPA and EVDO. This is illustrated in Figure 2-13 and Figure 2-14 respectively.

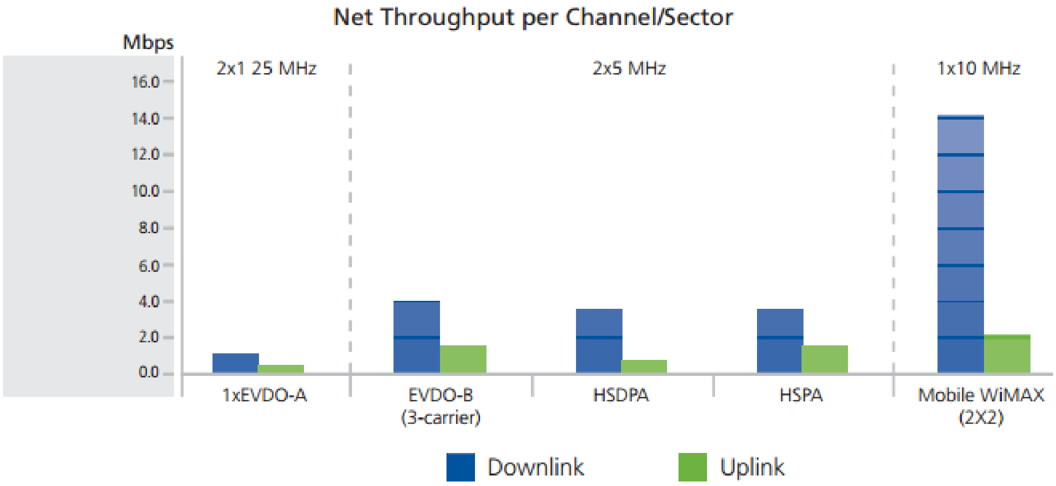

Figure 2-13: Net Throughput per Channel for Various Technologies [47]

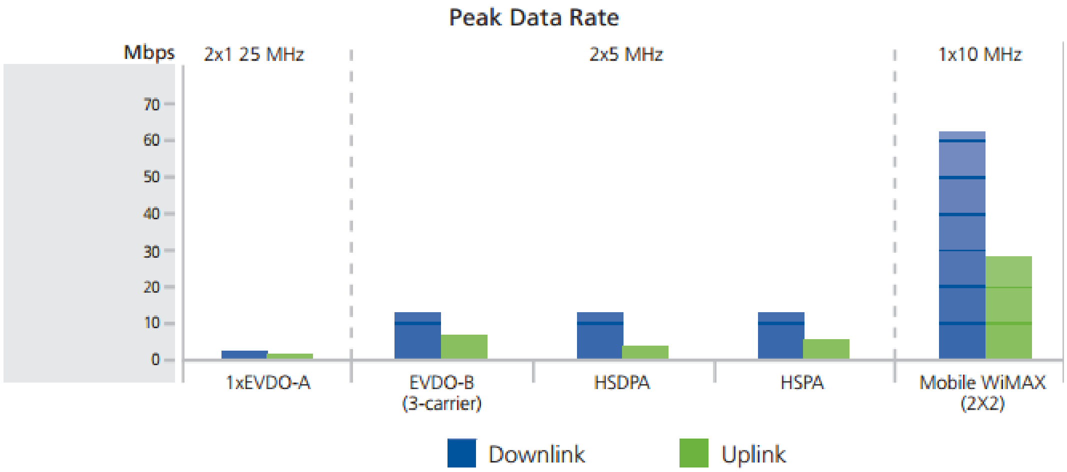

Figure 2-14: Data Rates for Various Technologies [47]

In [6], it is explained that the differences in the physical layer, signal format, duplex scheme, handover mechanism, and operating frequency bands impact the performance of a wireless technology. An overview of the WiMax Duplex scheme, frequency bands, and signal format is provided in sections 1.6, and 2.2. The impact of these are not categorically shown as the above comparisons, however it can be deduced that WiMax supersedes the other technologies because its physical layer is based on OFDMA and thus has small frame sizes which makes it more efficient and it uses low frequency bands which enhances the data throughput a technology is able to achieve. From this, it is clear to see that lower frequency bands cover larger cell areas. It is for this reason that Mobile WiMax would be suitable for deployment in rural areas.

2.14 Wi-Fi vs. WiMax

Another technology that is gaining popularity in rural areas and other remote locations (such as airports) is Wi-Fi. Wi-Fi, like WiMax, is a wireless solution based on IEEE standards; however, it is not designed for the same application as WiMax. WiMax is a long-range system. Wi-Fi is a shorter-range system, typically hundreds of meters with speeds of 54 Mbps, which uses unlicensed spectrum to provide access to a network. Wi-Fi is intended for LAN applications, it can scale from one to tens of subscribers, for each Access point (CPE) device. WiMAX can efficiently support from one to hundreds of Consumer Premises Equipment (CPE), with the unlimited subscribers behind each consumer premises equipment (CPE). Wi-Fi uses fixed channel sizes of 20 MHz while WiMax uses flexible channel sizes ranging from 1.5MHz to 20MHz [47]. Moreover, Wi-Max and Wi-Fi employ different Quality of Service (QoS) mechanisms. As previously discussed, Wi-Max uses a mechanism based on setting up connections between the Base Station and the user device. Each connection is based on specific scheduling algorithms, which means that QoS parameters can be guaranteed for each flow. Wi-Fi on the other hand has introduced a QoS mechanism similar to fixed Ethernet, where packets can receive different priorities based on their tags. This means that QoS is relative between packets/flows, as opposed to guaranteed [49]. Therefore, the two technologies can be deployed in one heterogeneous network with the Wi-Fi addressing the LAN bandwidth requirements, and WiMax addressing the backhaul and connection to other data services such as the Internet, VoIP platform etc. However, Wi-Fi is not able to meet all the data (speed, throughput, QoS) and mobility requirements that Mobile WiMax was designed to address.

From the literature survey, it is clear that Mobile WiMax is a technically sound technology with a flexible physical layer, and a resilient architecture. In South Africa, the fact that 802.16e is not backward compatible with 802.16d has no bearing on the study because in South Africa the only fixed line Operators that existed prior to the launch of 802.16e were Neotel and Telkom and their licences would not permit them to rollout a mobile network so backward compatibility was not a challenge. Secondly the only fixed WiMax access links that are still operational in the country are built as part of privately owned closed networks (Virtual Private Networks) for a particular corporate (e.g. Transnet) and will thus not be integrated with networks used by the general public. As stated above Telkom has opted to replace its fixed WiMax network with an LTE network, which will be used by Telkom Mobile in order to enable Telkom Mobile to compete with other Mobile Network Operators in South Africa. For this reason, backward compatibility between 802.16e and 802.16d (in South Africa) is not a limitation to this study. This would only be a limitation if Operators has already invested extensively in 802.16d and now wanted to add mobility to their infrastructure.

2.15 Summary of Literature Surveyed

Mobile WiMAX was the first mobile broadband technology to offer speeds similar to fixed line solutions. It was launched in 2005, but has never been deployed as a commercial offering in South Africa. Table 2-5 below provides a summary of how WiMax compares to EVDO, and HSUPA in less urban environments such as in Kenya. This is according to Alvarion [50]

Technology	Peak Data Rate		Throughput per sector/per channel	
	downlink	uplink	downlink	uplink
1XEVDO rev A 2.5 MHz	3.8 Mbps	1.8 Mbps	0.9 Mbps	0.5 Mbps
HSUPA 10 MHz	14 Mbps	2 Mbps	2.4 Mbps	1.5 Mbps
Mobile WiMAX (SISO) 10 MHz	36 Mbps combined		10 Mbps combined	
Mobile WiMAX (MIMO) 10 MHz	72 Mbps combined		20 Mbps combined	

Table 2-5: Types of Access to a WiMax Network [50]

LTE was designed to compete with Mobile WiMax and was launched in South Africa in 2012. These two technologies, commonly known as pre-4G technologies, are from a technical perspective, very similar and achieve similar performance standards. Figure 2-15 below summarises the comparison of the two technologies

LTE and Wimax Technical Specification

	LTE (3GPP R8)	LTE- Advanced (3GPP R10)	WiMAX 802.16e (R1.0)	WiMAX 802.16m (R2.0)
Physical layer	DL: OFDMA UL : SC-FDMA	DL: OFDMA UL: SC-FDMA	DL : OFDMA UL : OFDMA	DL: OFDMA UL: OFDMA
Duplex mode	FDD and TDD	FDD and TDD	TDD	FDD and TDD
User Mobility	350 km/h	350 km/h	60 to 120 km/h	350 km/h
Channel Bandwidth	1.4, 3, 5, 10, 15,20 MHZ	Aggregates components of R8	3.5, 5, 7, 8.75, 10 MHZ	5,10,20, 40 MHZ
Peak Data Rates	DL: 302 Mbps UL: 75 Mbps	DL: 1 Gbps UL: 300 Mbps	DL: 46 Mbps UL: 4 Mbps	DL: 350 Mbps UL: 200 Mbps
Spectral Efficiency	DL: 1.91bps/Hz UL: 0.72 bps/Hz	DL: 30 bps/Hz UL: 15 bps/Hz	DL: 1.91bps/Hz UL: 0.84 bps/Hz	DL: 2.6 bps/Hz UL: 1.3 bps/Hz
Latency	Link Layer < 5 ms Handoff < 50ms	Link Layer < 5 ms Handoff < 50ms	Link Layer = 20 ms Handoff =35 to 50ms	Link Layer< 10ms Handoff < 30ms
VOIP Capacity	80 users per sector/MHz (FDD)	>80 users per sector/MHz (FDD)	20 users per sector/MHz (TDD)	>30 users per sector/MHz (TDD)

Figure 2-15: Summary of the comparison of WiMax and LTE [51]

From the literature surveyed, one is able to:

1. Acquire a better understanding and knowledge of Mobile WiMax, its advantages, limitations, and its performance in comparison to other broadband technologies.
2. Study the simplicity and relevance of Mobile WiMax in the world today, and to the advances made on the standard.
3. Appreciate that WiMax, although not as popular as 3GPP technologies, is rich in capabilities and it is suitable for implementation in various industries and geographies.

The literature further expanded on the fact that WiMax can also be implemented on the 700- 800 MHz band which is fantastic spectrum for rural coverage. It also introduces Mobile WiMax release 2, also known as the 802.16m standard, which is interoperable with LTE-Advanced and can thus be implemented as an innovative technical and business model if integrated with LTE Advanced. This network design is depicted in figure 2-16 below. [53]

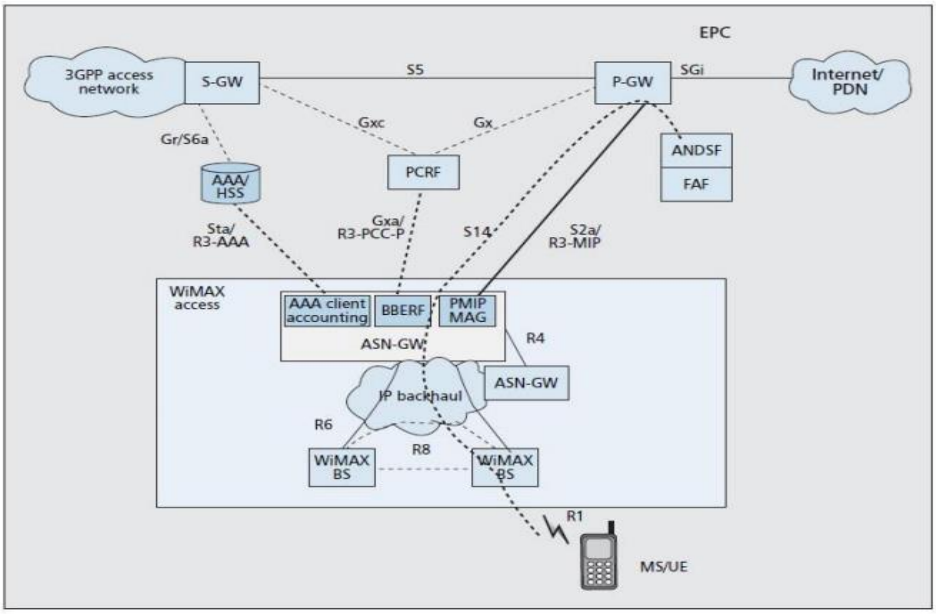

Figure 2-16: Architecture For Integrating WiMax Network with 3GPP EPC [53]

Figure 2 - 12 overleaf shows the theoretical and real world data rates that can be achieved provided the Mobile station is within range of the Base Station. Kindly refer to table 2-5 on page 56 for the coverage range possible with each technology.

WiMax is the only technology that can still be used even when there is no LOS between the Mobile Station and the Base Station.

		Real World (avg)		Theoretical (max)	
		Download	Upload	Download	Upload
2.5G	GPRS	32-48Kbps	15Kbps	114Kbps	20Kbps
2.75G	EDGE	175Kbps	30Kbps	384Kbps	60Kbps
3G	UMTS	226Kbps	30Kbps	384Kbps	64Kbps
	W-CDMA	800Kbps	60Kbps	2Mbps	153Kbps
	EV-DO Rev. A	1Mbps	500Kbps	3.1Mbps	1.8Mbps
	HSPA 3.6	650Kbps	260Kbps	3.6Mbps	348Kbps
	HSPA 7.2	1.4Mbps	700Kbps	7.2Mbps	2Mbps
Pre-4G	WiMAX	3-6Mbps	1Mbps	100Mbps+	56Mbps
	LTE	5-12Mbps	2-5Mbps	100Mbps+	50Mbps
	HSPA+	-	-	56Mbps	22Mbps
	HSPA 14	2Mbps	700Kbps	14Mbps	5.7Mbps
4G	WiMAX 2 (802.16m)	-	-	100Mbps mobile / 1Gbps fixed	60Mbps
	LTE Advanced	-	-	100Mbps mobile / 1Gbps fixed	-

Table 2-6: Peak Data rate achievable with various technologies [36]

3. Design of the Study

The literature review showed that Mobile WiMax was developed long before LTE. It is the first technology to use enablers such as OFDMA, Advanced Antennae systems (MIMO), and Beamforming. LTE was also designed to use these enablers and to operarate on (mostly) the same spectrum as Mobile WiMax. This made the two high-speed broadband technologies direct competitors. However, LTE had the advantage of history because LTE, being a product of the 3GPP, is backward compatible with the GSM based technologies which make it an evolutionary technology for Network Operators with UMTS or HSPA+ networks who want to provide faster broadband and gear up for 4^{th} generation technologies. Further, LTE can also be deployed on the 1800 MHz band currently used for 3G technologies such as UMTS. WiMax cannot be deployed in this band and the bands suitable for Mobile WiMax have not yet been allocated to Mobile Network Operators. These are some of the factors that have contributed to WiMax not being able to be the mainstream Mobile broadband technology in South Africa. However, the battle for Mobile WiMax is not yet over because IMT Advanced standards require 4G technologies to be interoperable. This requirement has directed the design of LTE-Advanced and the Mobile WiMax release 2 (802.16m) technologies which can be deployed as hybrid networks.

It was also found that there are currently a number of Mobile Operators that are migrating their WiMax networks to LTE. This presents an opportunity to procure Mobile WiMax equipment at a lower price as a reduction in the demand for a technology causes a reduction in the price. Moreover, the launch of a new technology (E.g. Mobile WiMax release 2) causes the prices of the previous models to be reduced while, the cost of used network equipment is less than that of new equipment (excluding delivery and installation costs). This phenomenon is also explained in [55] where technology innovation caused a reduction in pricing.

3.1 Areas of Focus

Section 2.9 explained that Broadband (3G) coverage is much more extensive in urban and semi-urban areas than it is in rural areas. However, from Figure 3-1 below which shows the 3G (UMTS) coverage outside the main city centers across the Gauteng province, and parts of Mpumalanga and the North West provinces, it is clear that 3G coverage even in these areas could be enhanced. This should give the reader a sense of the accessibility of broadband services in South Africa as the 3G coverage map of remote rural areas covers an even smaller area.

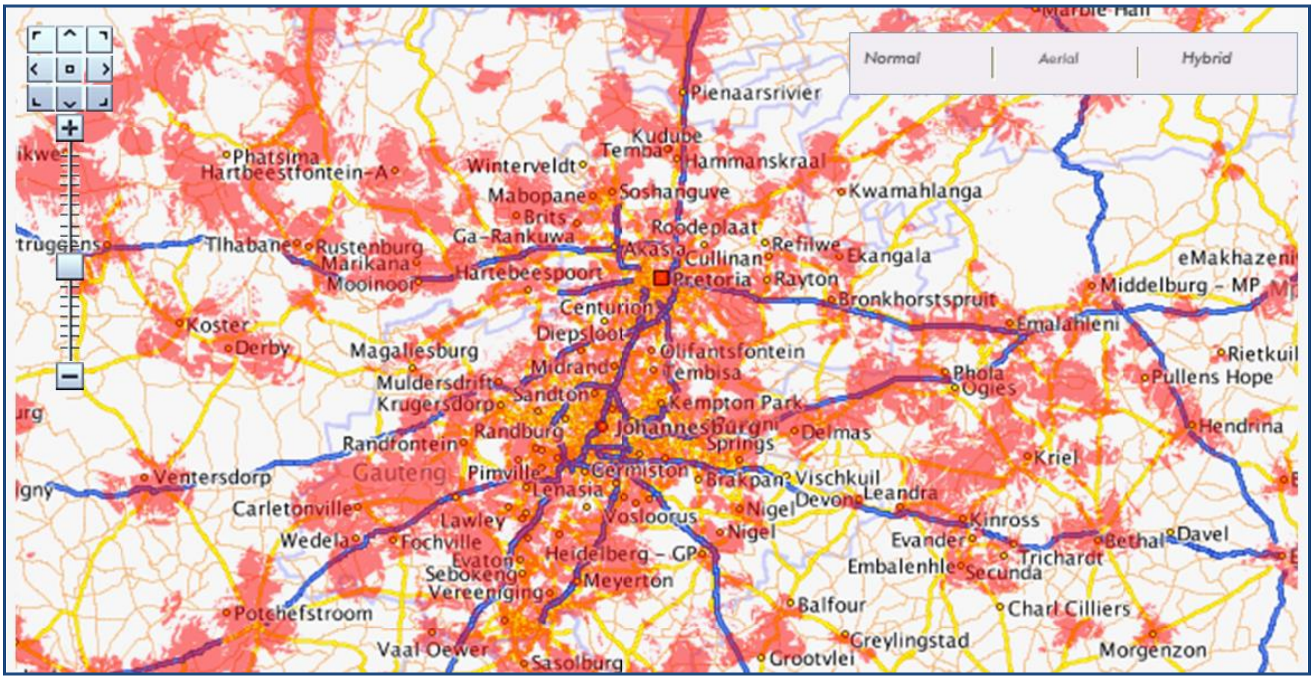

Figure 3-1: UMTS (3G) Coverage Map outside the main city centres in Gauteng [56]

The areas that do not have coverage often also do not have high volumes of cellular phones. In Fact, according to a report published by Statistics South Africa [56] the provinces with the least number of cell phones are:

1. Northern Cape,
2. Eastern Cape, and
3. North West.

This means that the people in these areas are at a disadvantage because they are not as exposed to technology as the people in urban areas. This is in line with the findings from [1]. The report also indicates that the areas with the least access to the internet are:

1. Northern Cape,
2. Eastern Cape, and
3. Limpopo

This means that the people in these areas are currently excluded from the knowledge economy, as they do not have access to ICT infrastructure.

These provinces are known to have a large number of rural areas with difficult terrain, which makes it difficult and expensive to deploy fixed line infrastructure. This makes wireless broadband services more suitable for these areas than fixed line infrastructure. What's more, when one looks at the coverage maps from various Network Operators in South Africa (available on each operator's website) one realises that these three provinces are indeed the provinces with the least mobile broadband coverage compared to the rest of the country, as stated in [56].

According to Price Waterhouse Coopers [57], the speed that the data network is capable of determines the services that can be run over the network and can influence the types of devices used in an area. The data collected on the number and types of mobile devices used in South Africa shows there has been a massive growth in the demand by users, for data services. For starters, during the time period August 2007 to February 2012, the total number of devices used on the Vodacom Network increased by over 71%, the total Network traffic increased by 1104%, while Smartphone growth was 613%. Smartphones are also expected to increase to 22.8 million in South Africa by 2015. However, users will only be able to use the features of these smartphones if there is a (fast) data network in their areas without which people will be excluded from the benefits brought on by access to the Internet and thus to Information.

It is for this reason that the SONAR Analysis tool was used to overlay the 2G network over the 3G (UMTS, HSPA, etc.) network to identify the areas that have limited 2G coverage and little or no 3G coverage in the above-mentioned provinces. The Atoll tool was used to study the terrain of the areas to identify areas that have the characteristics of the type of areas that the study was to focus on. More information on these tools is provided in the Appendix under Section 7.1. From this exercise, three areas, with the least broadband coverage, were randomly selected to form the focus of the study. These are:

1. Magoesbaskloof, Limpopo
2. Duiwelskloof, Limpopo
3. Adelaide, Eastern Cape

Each of these areas lie in remote mountaineous areas, that have intermittent broadband coverage, and a fairly small population. These areas are the type of areas that are unattractive to Mobile Operators. The chapters that follow display the economic and technical suitability of Mobile WiMax in the above listed areas.

3.2 Conceptual Design

A high-level WiMax network architecture suitable for each of the three areas that form the focus of the study, was designed, and is presented in Figure 3-2 overleaf. This architecture provides an overview of the end-to-end connection path and thus shows how users would connect to a base station to access various network services, including the Internet. This architecture also illustrates how a base station would connect to the rest of the network and the projected amount of bandwidth required to backhaul the traffic from a base station in the identified areas. The projected bandwidth is dependent on the amount of traffic traversing the base station. This WiMax network architecture is also designed to be easily scalable because it is understood that the number of resources (Base Stations, Backhaul links, etc.) required will differ from area to area depending on the size of the population, demand for data services, device penetration, and other environmental factors such as the terrain. Further, more resources will be required as the population grows and as the penetration of smart devices increases as this would cause an increase in the amount of traffic traversing the network.

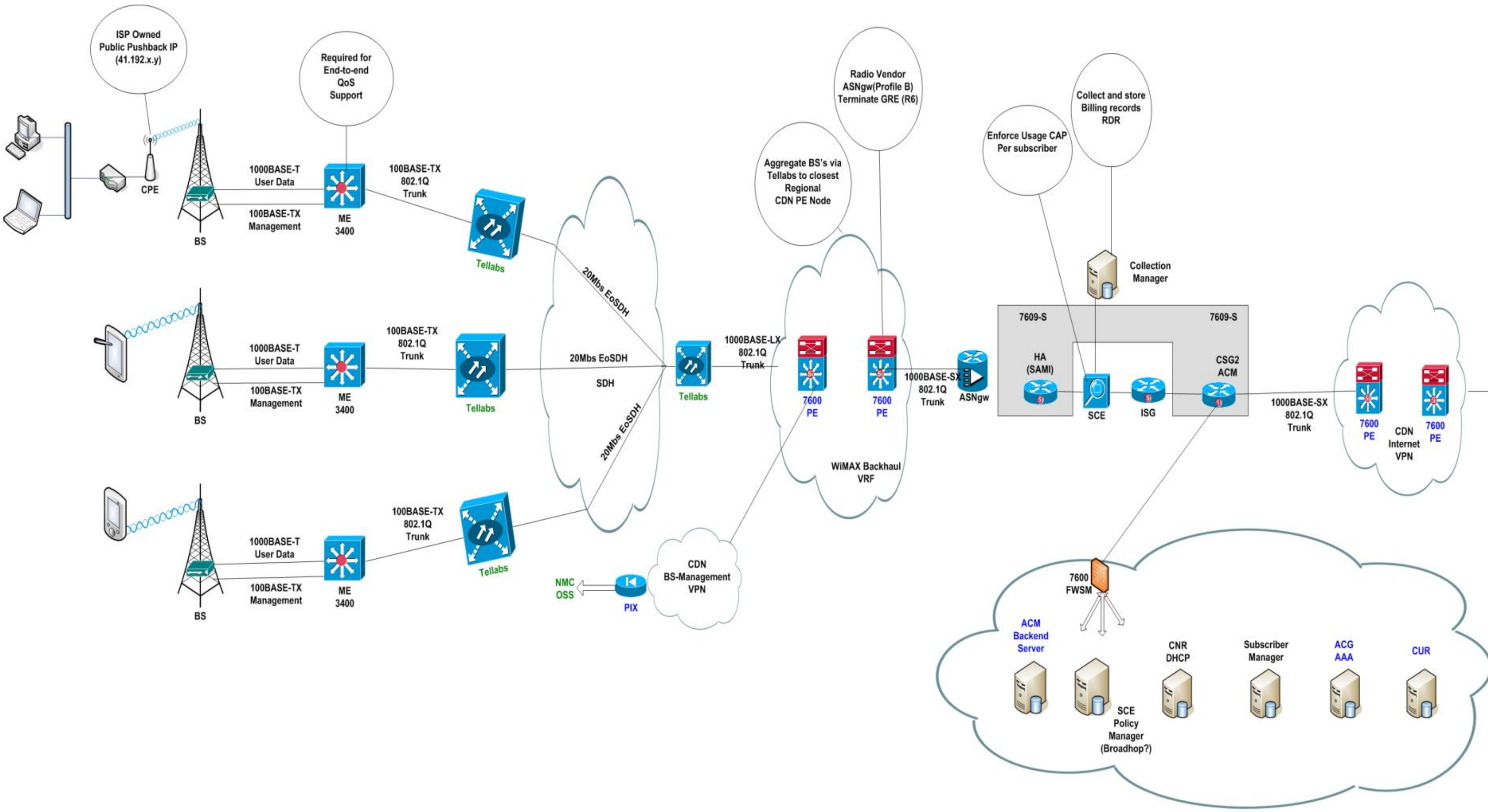

Figure 3-2: Mobile WiMax Network Architecture for each of the Identified Area

Figure 3-2 above provides a good starting point for one to understand how WiMax can be deployed in rural South Africa, before a comparisson of the performance of WiMax and other broadband technologies (EDGE,UMTS, and LTE) is made.

The experimental study in essence compared the network coverage area attainable with the architecture illustrated in Figure 3-2 above with the coverage areas possible through EDGE,UMTS, and LTE. This was done in order to determine if Mobile Wimax is a suitable broadband technology for deployment in the three areas listed in Section 3.1. This process is outlined in detail below. This is how the research questions were investigated.

The steps of the conceptual design were:

1. Use the research tools (Atoll, Touchpoint, and the SONAR Analysis tool) described in Chapter 7.1 (the Appendix) to identify three areas that currently have little or no 3G coverage. The areas are required to be remote, sparesly populated, and commercially unattractive to Operators due to the low projected earnings. More importantly, these areas are to have difficult and uneven terrain. The selected areas are listed in Section 3.1.
2. Research the population size, average income per household, and device types in the areas. In order to determine the economics related to deploying WiMax
3. Use the Atoll tool, to calculate a link budget to determine the quantities of resources (Base stations) required in order to deploy EDGE,UMTS, or LTE. Refer to Chapter 7.1 for further information on Atoll.
4. Compare the findings from point 3 to the number of resources required to rollout a Mobile Wimax network. Do this by simulating an LTE network then apply the WiMax theory in order to determine the number of WiMax resources required.
5. Repeat steps 2 to 4 for each of the identified areas.
6. Compare the simulated signal strength attainable, the size of the cells, and the peaks data rates attainable using UMTS, LTE, and WiMax.
7. Use the findings to recommend the most suitable technology for deployment in each specific area.

3.3 Techniques of Data Collection

The method of research that was selected to guide the approach of this research is the Qualitative Research method as the reseach aimed to test a theory and generate a hypothesis. Moreover, the main means of collecting evidence for and against the hyothesis is through the measurement and observation of network parameters, thus making this research approach the most suitable approach to accomplishing the research objectives.

The project involved a lot of experimental work. An experiment is defined as a situation in which the independent variable (also known as the exposure, the intervention, the experimental or predictor variable) is carefully manipulated by the investigator under known, tightly defined and controlled conditions, or by natural occurrence. At its most basic, the experiment consists of an experimental group which is exposed to the intervention under investigation and a control group which is not exposed. The experimental and control groups should be equivalent, and investigated systematically under conditions that are identical (apart from the exposure of the experimental group), in order to minimise variation between them. [58] In this study, the experimental group is the group of areas identified according to the conceptual design, which currently have limited or no network coverage. The predictor variable is the Mobile Wimax technology. The control group is the same group of identified areas using the access technlogy that they are currently using (which is not WiMax). A comparrisson of the peak data rates, latency, and cell sizes achieved with each technology was then compared to determine whether Mobile WiMax should still be considered for rural broadband connectivity.

As stated in Section 1.6, WiMax may be deployed on licensed and on unlicensed spectrum. This is makes it possible for Operatotors that currently do not have the required spectrum license to deploy a WiMax network using the license exempt spectrum bands. The challenge with this approach is that the quality of the service experienced by the user is highest when the user is stationary and deteriorates as the user moves around at increasing speeds up to 120 km/h, at which point the user is unlikely to be able to get any service at all. Further, Operators are not able to gaurantee quality of service (QoS) for services accessed such as voice calls which may experience high latency, jitter, and packet loss due to interference with traffic from other Operators using the same band or due to the increased competition for spectrum between the Operators. This is due to there being no restriction on the number of Operators that may operate on the license exempt band and so the service offered by an Operator may be degraded as more and more Operators use the same spectrum. Further, Operators using license exempt spectrum to deploy the WiMax networks have to deploy LOS WiMax in order for them to provide an acceptable service. This may lead to the Operator having to employ MIMO solutions in order to curb the cost of having to install a lot of antennae in order to maintain LOS and provide coverage to the entire village. In this case, the Operator has to consider the cost of skilled resources to deploy the MIMO solutions, which if not installed properly, will be wasted expenditure. The experimental work conducted in this study was conducted by simulating a network over licensed spectrum. Therefore the study does not consider the spectrum channel limitations described above.

3.4 Description of Techniques Used

In preparation for the experimental work, a pilot study was conducted as a fore-runner to the actual experimental in order to:

- Ensure there are areas that fit the definition provided herein for a rural, remote area.
- Identify all the challenges with the conceptual design.
- Re-design the conceptual design if required until a clear framework for the study is developed and understood.
- Test the completeness of the conceputal design and ensure that all steps have been explained under the conceptual design.
- Ensure the results of the pilot study are able to answer the research questions - although this will be high-level and will address only the pilot area.

The pilot study was conducted with the understanding that a good mobile broadband solution must provide high data rates, high capacity, low cost per bit, low latency, good quality of service (QoS), and good coverage. Spectrum efficiency, defined as the optimised use of spectrum or bandwidth, is a measure of the maximum amount of data that can be transmitted with the fewest transmission errors. [21] In a wireless network, spectrum efficiency equates to the maximum number of users per cell that can be provided while maintaining an acceptable quality of service (QoS). For this reason, it is advantageous for a good mobile technology to also use spectrum efficiently as this increases capacity and thus allows for services to be offered to a significantly increased user population. Several techniques can be used to meet these criteria in a wireless system. Examples of such techniques are now provided.

For higher data rates and capacity:

- Higher-order modulation schemes, such as 16 quadrature amplitude modulation (16QAM) and 64QAM multiple-input, multiple-output (MIMO).
- Advanced antenna systems that rely on multiple antennas at both the transmitter and receiver, effectively multiplying the peak rate for improved QoS and low latency.
- Dynamic scheduling, with end-user traffic streams prioritised according to service agreements.
- Short transmission time intervals (TTI), allowing for round-trip times approaching wired equivalents (such as DSL).
- Shared-channel transmission to make efficient use of available time/frequency/ codes and power resources link adaptation to dynamically optimise transmission parameters, depending on actual radio conditions.
- channel-dependent scheduling to assign radio resources to users with the most favourable radio conditions.
- Hybrid automatic repeat request (H-ARQ) to enable rapid retransmission of missing data, and soft combining to improve performance and robustness.

For greater coverage:

- Advanced antenna systems and advanced receivers to enhance the radio link and improve cell range.

Mobile WiMax was selected as the technology that could be considered for deployment in Makotopong and other areas similar to Makotopong because of the “WiMax Promise” which as outlined in [10] is to offer:

- Lower cost CPE, due to greater economies of scale as the same chipsets were to be embedded in a base of consumer products, as well as on indoor and outdoor fixed customer premises equipment.
- Scalable system bandwidth.
- Quality performance of Real-time applications (Quality of Service).
- Improved Spectral efficiencies.
- Power Reduction –Sleep and Idle mode power management.
- No cell shrinkage as more users are connected to the network.
- Deep indoor penetration.
- Efficiently (cost and performance) provide coverage and capacity while avoiding build-out of a large number of new Base Stations.
- Mobility: 70 Mbps throughput when travelling at 120km/h.

The “WiMax Promise” therefore classifies WiMax as a good broadband technology which meets the criteria of a good broadband technology as described above. It was for this reason that the Pilot study could be conducted in an attempt to determine if the planned research techniques and methods would successfully address the research questions. The pilot study was therefore an opportunity to modify the design of the study in areas where it was necessary.

3.5 The Pilot Study

The pilot study was conducted on the Makotopong Village, using Atoll, Touchpoint, and SONAR analysis tools. The village is situated 25 kms east of Polokwane in Limpopo. It covers an area of 5.69 km^2 and has a population of 8163 (1434.12 per km^2) people which make up the 2159 (379.30 per km^2) households found in this village [56].

As shown in Figure 3-3 below, the area has intermittent UMTS network coverage which generally has very low signal levels. The estimated number of Vodacom Subscribers in Makotopong is 2730. The challenge encountered by these subscribers is that they often are not able to connect to the network due to 1) The inability to achieve LOS with the serving Base Station, 2) The users closest to the Base Station get first preference to connect during periods of high utilisation (due to cell shrinkage). This is because the serving Base Station was not primarily designed to serve the users in Makotopong, but rather to serve the users in the neighbouring village (Sebayeng). This means that the users in Makotopong are relatively far from the Base Station -some may even be at the edge of the cell.

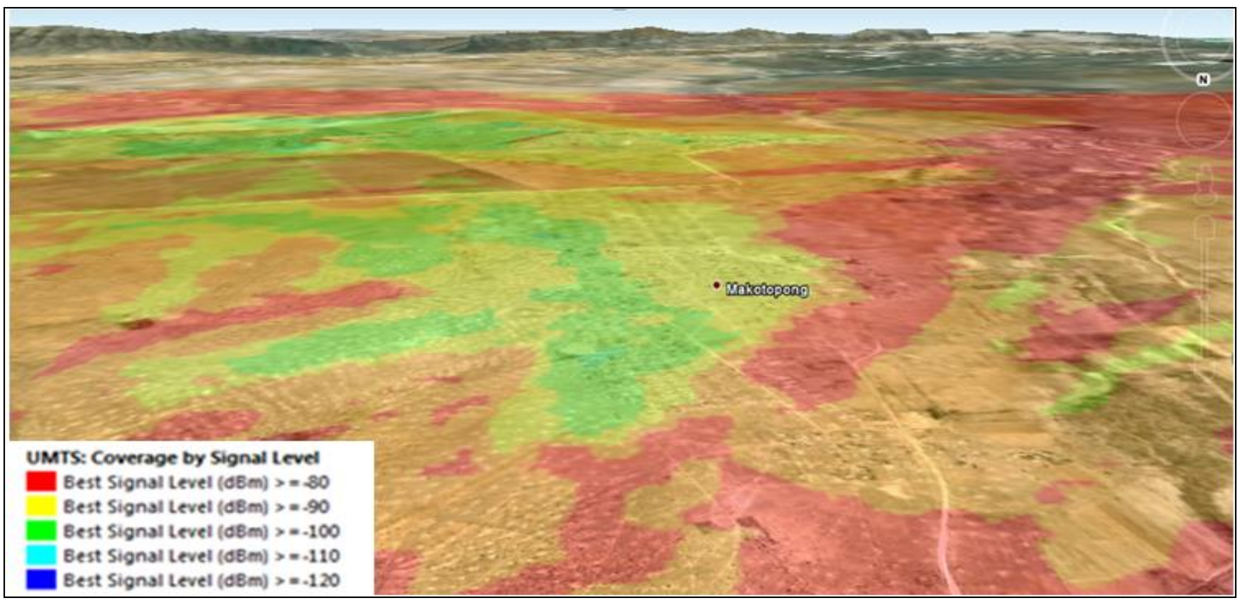

Figure 3-3: Simulated coverage map. *This map illustrates the signal strength of the Vodacom network in Makotopong*

A different (zoomed out) representation of the above figure is shown in Figure 3-4 below with the black triangular symbols representing the simulated Base Stations for the area. This gives us a sense of the terrain surrounding Makotopong. For instance, the base stations labelled Makotopng and Base Station X are macro base stations and should (as explained in Section 1.6) cover a large area, however the simulation run on Atoll shows that Line of Sight to the Base Station is broken by mountains and forest-like areas.

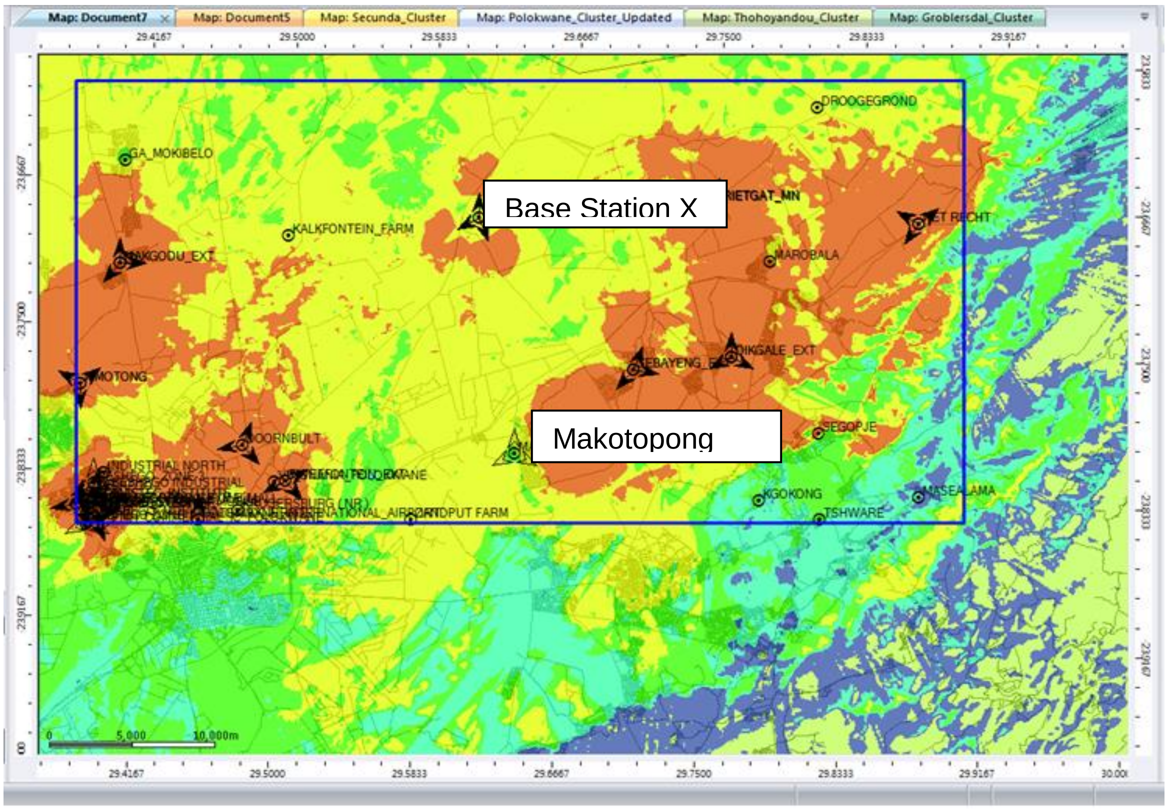

Figure 3-4: Makotopong and surrounding areas simulated coverage map. *This map illustrates the position of the Base Stations and the signal coverage area*

Figure 3-4 therefore shows the impact of the terrain on the quality of signal that a single base station is able to attain. Atoll does this by calculating the link budget and allowing the researcher to simulate a network by choosing suitable locations for Base Stations and measuring the coverage area that can be attained. This is also how the researcher is able to identify and bridge coverage gaps. Figure 3-5 overleaf shows the terrain in the Makotopong area. From this figure, one can see that Makotpong is a fairly flat area, surrounded by patches of forrest, open fields, hills, and mountains which obstruct the line of sight to the Base Station.

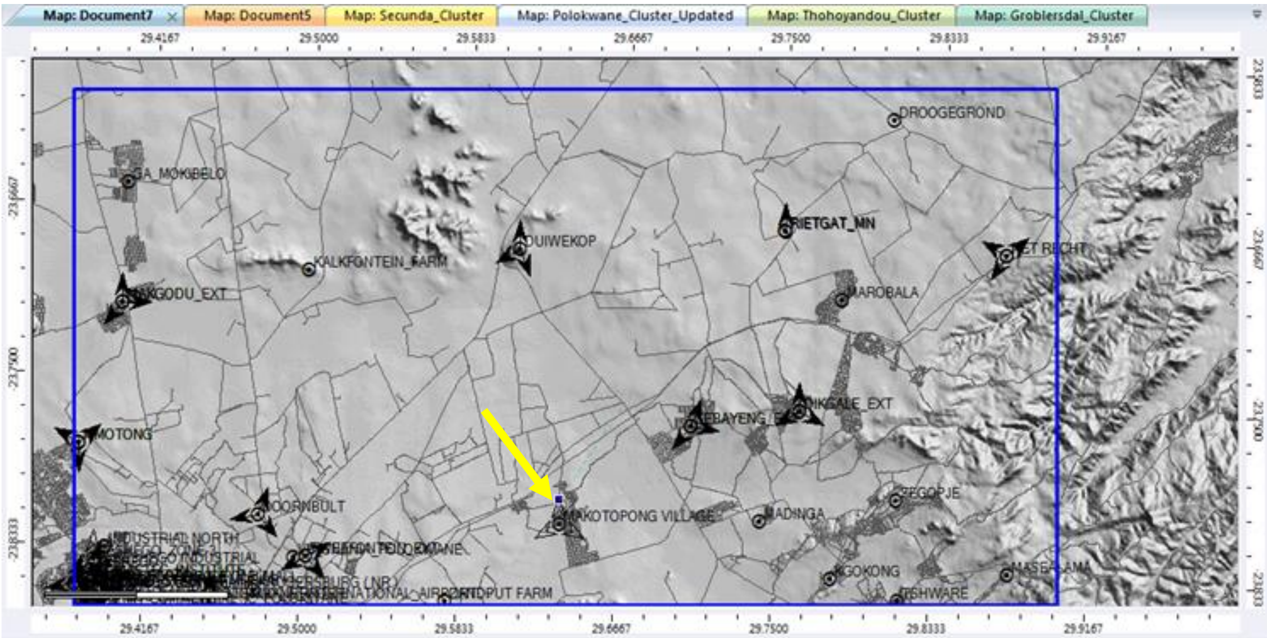

Figure 3-5: Topographical Layout of the Makotopong Area. *This map illustrates the terrain of the Makotpong area to illustrate the reason for the poor signal despite the numerous Base Stations*

Figure 3-4, Figure 3-5, and Figure 3-6 together show that a single UMTS base station would not be able to provide coverage right round the Makotopong village, although the area where the population resides would be (largely) covered by the network. Figure 3-6 also shows the forest areas and mountains that obstruct the Line of Sight between the Base Station and the user device. It also shows that Makotopong lies at the bottom of a valley and therefore struggles to get service from neighbouring Base Stations.

Figure 3-6: Terrain Profile

Based on Chapter 2, which explains the distances that NLOS WiMax networks are able to achieve, it is evident that Mobile WiMax would provide greater coverage and quality service in this area than UMTS. It is also evident that it would be cheaper to deploy NLOS WiMax in this area, as less Base Stations would be required than in the case of the UMTS simulation.

Other factors that generally influence wireless signal quality include physical obstructions like tall buildings, poorly deployed antennae solutions, the distance between mobile devices and the Base Station, and the number of users using the network concurrently. As shown above, these factors would not be applicable in Makotopong if a single WiMax base Station were to be deployed in the place of the simulated UMTS base station labelled Makotopong Village on Figure 3-5 above which lies at 23°49'6.54"S, 29°38'33.69"E. However, based on the analysis of the area, it would be advantageous for the antennae for the NLOS Mobile Wimax configuration to have a height of 15m above the closest building in order for the Base station to be configured to provide coverage to the entire village.

The WiMax Base station site for Makotopong was designed to use the Tellabs 8605 Access switch located at each BS site and backhaul traffic to the regional ASN-GW. The Tellabs switch was configured to map the air interface QoS to 802.1p markings on the transmission side to ensure that the traffic prioritisation is carried up until the core network. A 100 Base-T copper connection would be used between the Base Station and the Tellabs 8605 while a point-to-point 2 Mbps circuit would be used between the Tellabs 8605 and the ASN-GW. This equipment is shown in Figure 3-7 overleaf

Please note that the pilot study does not include the costing exercise to determine the property costs, costs of the Base Stations, device penetration, nor integration of the Base Station with the existing network i.e. backhaul costs. The pilot study focused on planning the network for an area and determining the number of resources that would be required to make the technology a feasible solution.

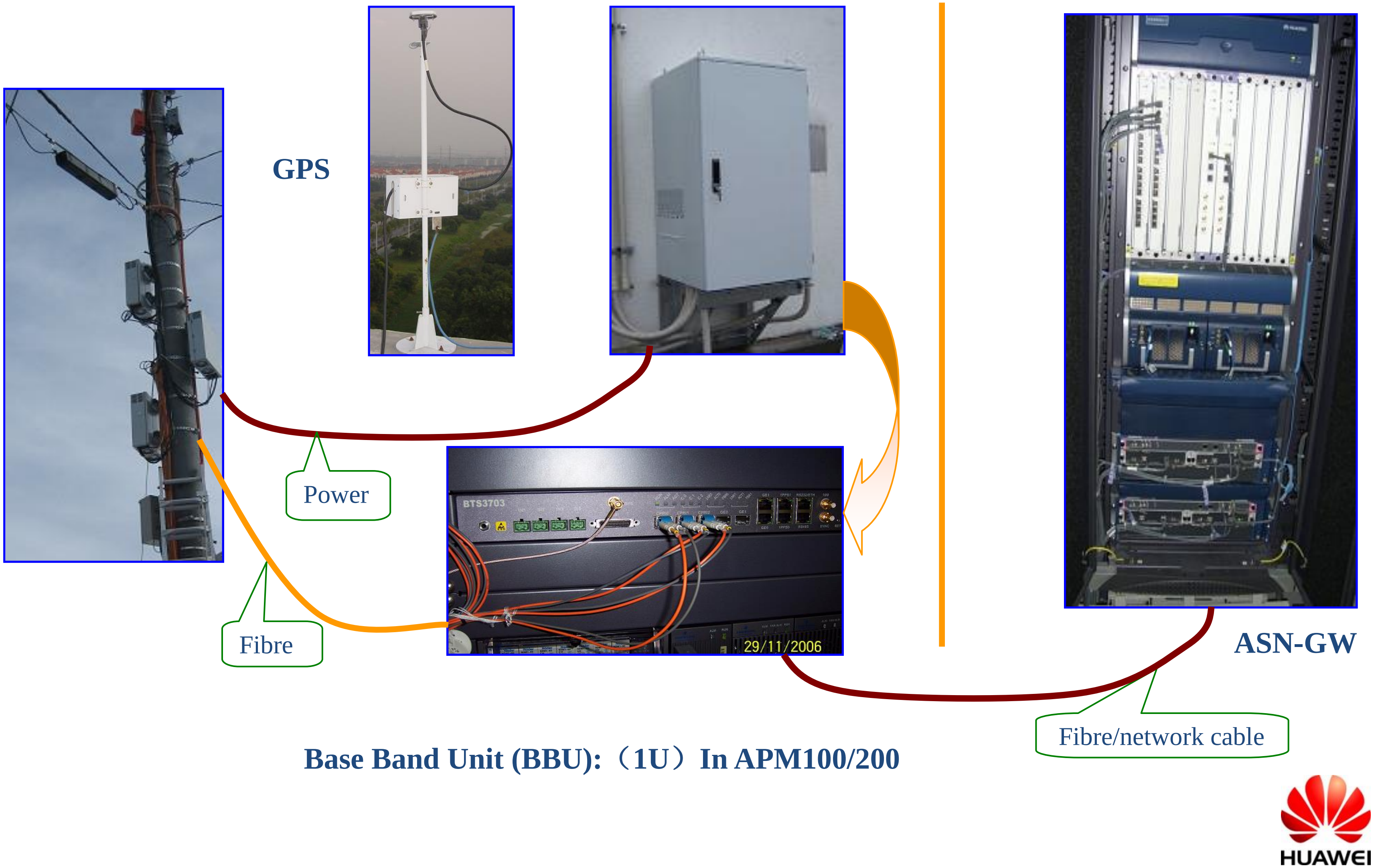

Figure 3-7: WiMax Equipment

A study of the traffic patterns of the area was done as follows: One Erlang is equivalent to one telephone line being permanently used, for an hour. If it is assumed that there are 2730 people making calls for (on average) 1.5 minutes, then it would mean that approximately 68.25 Erlangs of traffic could be expected at any point in time. That is (90 seconds * 2730 concurrent users)/3600 seconds. This calculation will differ from one area to another as it is based on the number of subscribers in the area. The traffic at the Base Station determines the number of TRXs required. Using Erlang's model and a chosen Grade of service, it was found that the BTS would require 97 speech channels and thus 13 TRXs. Each required TRX requires two time slots of 64Kbps and one signalling channel of 16Kbps. One TRX typically has a handling capacity of 12 transceivers, depending on the equipment used. Therefore backhaul of 2 Mbps will suffice. This bandwidth also caters for future growth in bandwidth requirements.

The next step was to determine the throughput of each technology based on the configuration. At this point, it was found that the Atoll software that was being used did not have the WiMax module and thus the researcher would not be able to simulate the WiMax network using the same tool as for the 3G network. As previously discussed, the next best option was to simulate an LTE network for the area and apply the WiMax theory to determine the possible throughput for the area. This option was better than resorting to open source software as it would be difficult to verify the results and to also be certain that the simulator was able to pick-up the traits of the specific terrain and how it impacted the results of the simulation. It was also decided that this approach was better as it is better to compare results generated from the same simulator than from different simulators as you are then able to be sure that the same technical or goegraphic considerations were applied to both technologies.

From the pilot study it became clear that using the Vodacom licences for the Atoll tool would result in the study producing results which are based on Vodacom's current network footprint as the tool it designed also indicates where the service provider has (and does not have) infrastructure. As an example, when one is planning a network for an area, one can use the tool to identify the current technology in use in that area and the possible signal strength. This information is produced by the tool checking which infrastructure has already been deployed in the area and works out the radius that the equipment (BTS or BSC) is able to cover. The user would then be able to identify the gaps in coverage and plan coverage through new Base Stations, Femto Cells, or Pico cells etc. It has been decided that this is not a limitation of the study as the focus of the study is the areas where there is currently poor 2G or 3G coverage, or no coverage at all. However, this does not necessarily mean that other network service providers also do not have good network coverage in the identified areas. As explained in Section 2.9, the coverage maps obtained from the websites of Mobile Network Operators show the areas their network is intended to cover, but they do not show the best signal level that a user is able to attain in each area. This however did not take away from the objective of the study which was to determine whether Mobile WiMax can be considered for deployment in rural South Africa.

3.6 Proposed Approach to Data Analysis

Further, the study assumes that licensed spectrum would be used for the actual rollout, therefore the study does not consider spectrum channel limitations.
After planning the network, the coverage maps were plotted and analysed. The analysis covered:

1. A description and the associated quantities of the resources that would be required in order to physically rollout the network. In the case of a 2G network, the resources that would make up the base station, the capacity required at a connecting BSC, as well as the backhaul that will be required. When planning a UMTS and an LTE network, the reader must keep in mind that the Node B for UMTS and an eNode B for LTE connect to an RNC and an SeGW respectively, as depicted in Figure 2-7 above. A BSC/RNC/SeGW each support a number of BTSes/Node Bs/eNodeB's respectively, therefore it is important to determine the BSC/RNC/SeGW that a BTS/Node B/eNode B would connect to, and to ensure that the BSC/RNC/SeGW has enough capacity to support the new infrastructure. Other solutions considered in this Section include the Femto and the Pico cells.

2. An analysis of the area that the simulated network would be able to cover and the reasons why this is the case. This section also compares the findings to the theory.
3. An analysis of the number of subscribers that can be supported before the quality of service or user experience starts to deteriorate.
4. A cost analysis of a WiMax vs 3G Network at one of the identified areas.

3.7 Findings From the Pilot Study

The experimental work began with designing a Mobile Wimax network for the identified areas. This was followed by simulations of a UMTS and an LTE radio frequency network, in each of the three identified areas. A pilot study was done on the Makotopong area to test the conceptual design of the study to determine if it would be possible to obtain answers to the research questions by following the conceptual design of the study and following the ethical guidelines of the university. The Makotopong village was selected for the pilot study because it has the traits of the type of areas that form the focus of this study. That is, uneven terrain with obstructions, low population size, low spend on ICT services, and poor network coverage or poor network signal strength.

From the Pilot study, it was found that Vodacom has a number of 2G Macro Base Stations relatively close (on average about 7km) to the village. These Base Stations are designed to cover a radius of 20-35km and they, according to the SONAR analysis tool, are not being fully utilised by the users in the areas they were designed to cover. That is, the amount of traffic that traverses the Base Stations is lower than the Base Station’s carrying capacity. This did not make sense from a theoretical perspective because the current Base Stations were supposed to be sufficent to cover the entire area. The pilot study revealed that these Base Stations could not service the Makotopong village because the village is situated at the bottom of a valley and thus cannot establish LOS between the mobile device and the Base Station. This therefore made Makotopong an ideal area for the deployment of NLOS Mobile WiMax.

4. Analysis and Presentation of Data

In Section 3.1, three remote areas with difficult terrain and low population sizes were identified to form the focus areas of this research. For this reason, this chapter focuses on the findings from network simulations of these areas with the aim of answering the main research question: Is Mobile WiMax suitable for deployment in rural South Africa.

These simulations were prepared using network planning and analysis tools that are widely used to emulate the terrain of a geographic area, and determine the signal strength of various mobile broadband technologies in a specific area. With this information in hand, the process of determining the infrastructure (e.g. number of Base Stations) required to provide sufficient broadband coverage to the population of the area being studied is simplified . Information on these tools is provided in Chapter 7.1. on page 110.

The focus of the analysis of the simulations was on:

1. The technological capabilities of WiMax in the selected areas;
2. The infrastructure requirements (equipment and backhaul required); and
3. The cost to deploy WiMax.

These findings were compared to the findings on various 2G and 3G technologies, commonly used in urban areas in South Africa

Section 3.5 presented the pilot study, which was run as a forerunner to the actual experimental work, in order to show the impact that the terrain can have on the signal strength of a wireless technology and to highlight the opportunity that this creates for WiMax. This was evident in the results of the pilot study, which favoured the deployment of Mobile WiMax in Makotopong. It was for this reason that the simulations were expected to yield results that illustrated that Mobile WiMax could be used to cost effectively deliver quality broadband services in rural South Africa, equivalent to the kind enjoyed in urban areas.

4.1 Duiwelskloof

Duiwelskloof lies 24 km north of Tzaneen in Limpopo. It covers an area of 2.91 km^2. A simulation of a 2G and a UMTS network in the area is presented Figure 4-1 and Figure 4-2 respectively. The population size is 1 815 people. The 2G coverage map is depicted as mainly red and orange, representing good 2G signal coverage. In Figure 4-1, each cell (served by a single base station) has a radius of 0.9 km. This means therefore that the area requires more than three Base Stations, which makes it a costly solution. Further, the concurrent users in each cell would share the transfer speed of almost 1 Mbps, which means that the likelihood that users will not be satisfied with the speed of the network, are high. This is because most web based applications accessed are interactive and data intensive and therefore work best on high-speed networks.

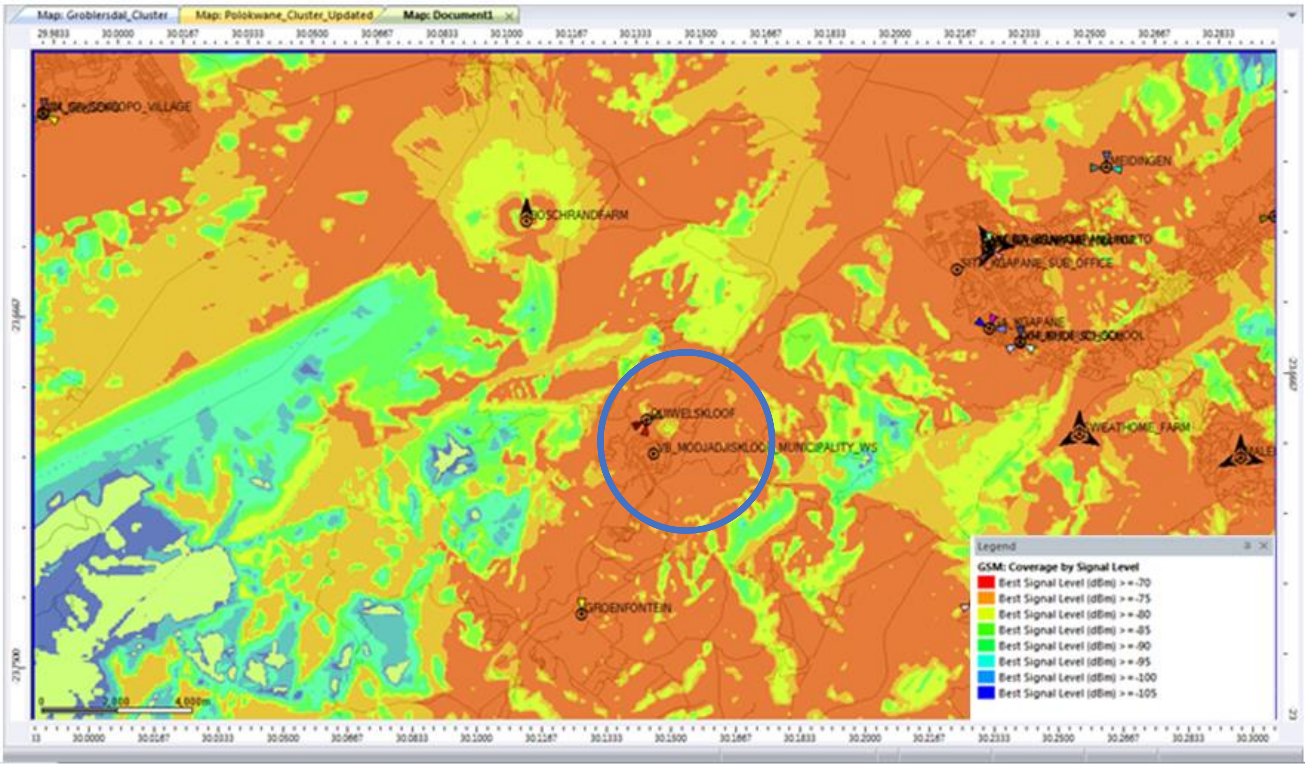

Figure 4-1: 2G Simulated coverage map of the Duiwelskloof area. *This map illustrates the proposed positions of the base stations and the strength of the signal strength they are able to provide.*

The UMTS coverage plot in the area is shown in Figure 4-2 overleaf:

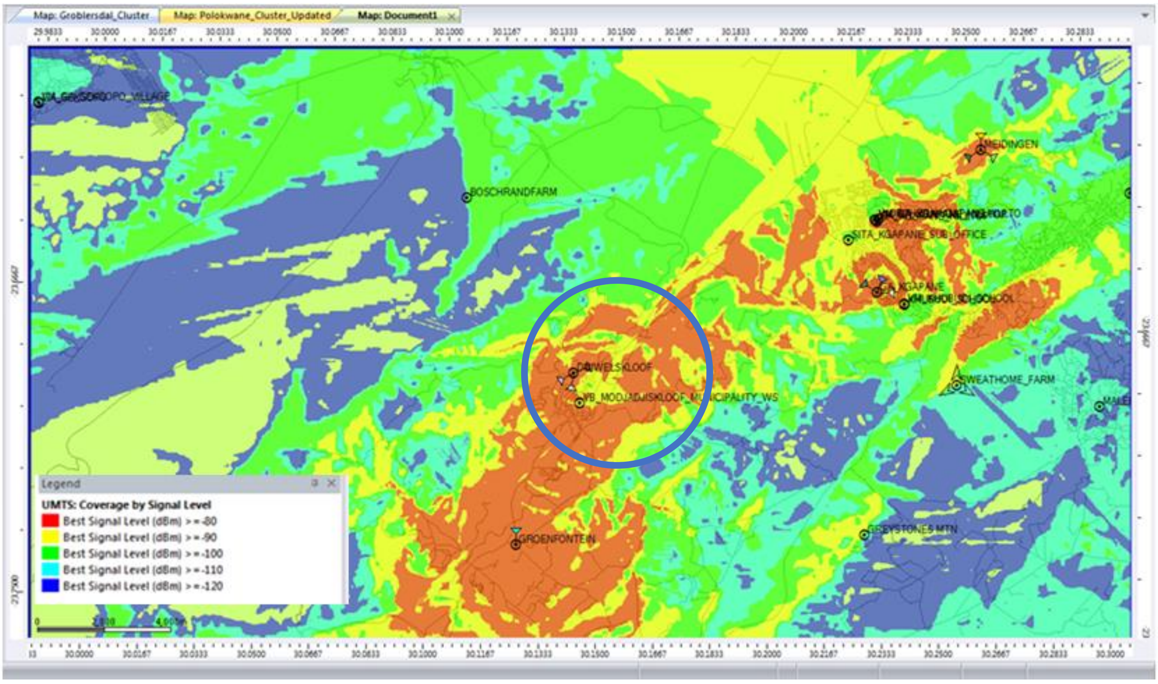

Figure 4-2: Simulated UMTS coverage map in the Duiwelskloof area. *This map illustrates the strength of the signal provided by the various Base Stations*

The signal strength of the UMTS network is not as strong as that of the 2G network because the UMTS simulation was conducted using only three Base Stations, deployed at strategic locations, for the main area. The signal strength can be improved by deploying additional Base Stations; however, this would be costly and would not make a very big difference because the signal strength is severely impacted by the mountains, forests, and dams in the area. As shown in Figure 4-1 above, the 2G network offers coverage at a signal level of -70 dB, while the UMTS network's best signal level is -80 dB.

As depicted in Figure 4-3 overleaf, the terrain of the area is mountainous. The darker grey in the top block shows the higher elevation of the terrain. This shows how difficult it is for mobile station to have Line of Sight with the Base station.

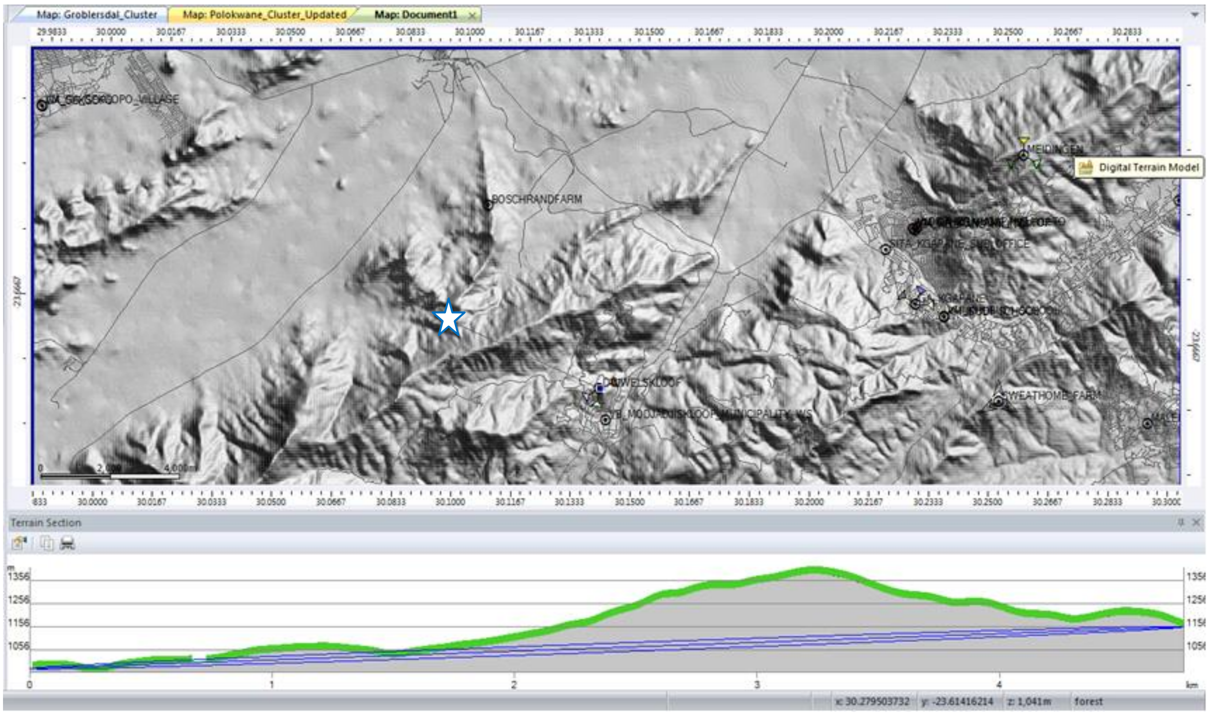

Figure 4-3: Duiwelskloof Terrain. ***This illustrates the impact of the terrain on the line of sight between the Base Station (marked with a blue star) and the point marked with the orange star.***

Figure 4-4 overleaf shows a list of the Top 10 devices used in the area. Most of these devices have internet, instant messaging, and email capabilities which contributes to the traffic generated on the network (by the users in this area) being increasingly data centric. This information is based on the traffic mix generated on the Vodacom network, in Duiwelskloof. This data was obtained using Touch point. More information on Touch point is provided in the Appendix under Section 7.1. From this, it can be seen that the users in this area are aware of trends in technology and they adopt these trends. It can therefore be said that the users in this area would purchase phones that also have WiMax capabilities if a WiMax network were to be deployed in the area.

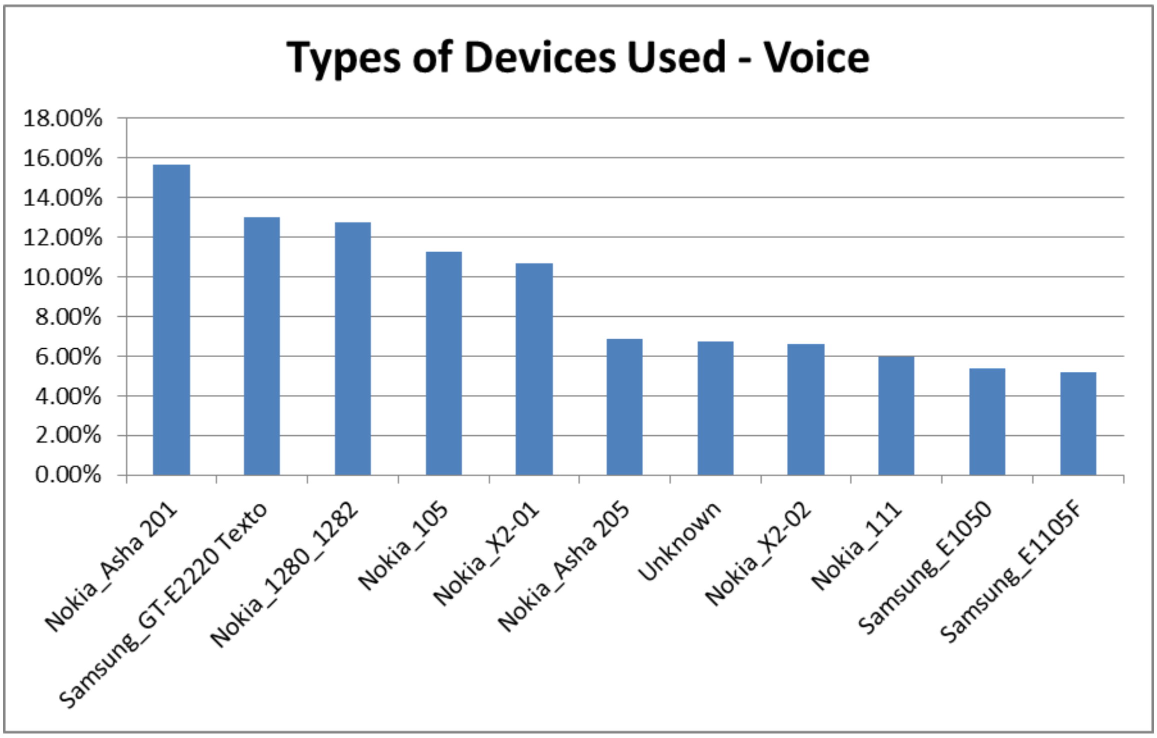

Figure 4-4: Types of Devices Used in Duiwelskloof

A simulation of an LTE network is shown in Figure 4-5 below. This shows that the signal level will be heavily impacted by the forest trees, uneven terrain, and surrounding dams. However, the area covered by the LTE cell with only a single base station is about 4.8 km. This area is illustrated with th colour purple on the picture. This is interesting as it is comparable to the WiMax cell sizes depicted in Table 2-2 on page 39.

Figure 4-5: Simulation an LTE Network in Duiwelskloof, ***This illustrates that a single base station would be sufficient to cover the depicted area***

4.2 Magoebaskloof

Magoebaskloof lies 11 km north of Tzaneen and covers an area of 1.35 km^2. Simulations of a 2G and a UMTS network in the area are presented in Figure 4-6 and Figure 4-7 respectively. The population size is estimated at 500 people. The signal strength of the 2G (EDGE) network is depicted as mainly red and orange, which represents good 2G signal coverage with a coverage radius of 0.7 km. However the signal is intermittent due to mountains and forests breaking Line of Sight between mobile stations and the simulated base stations.

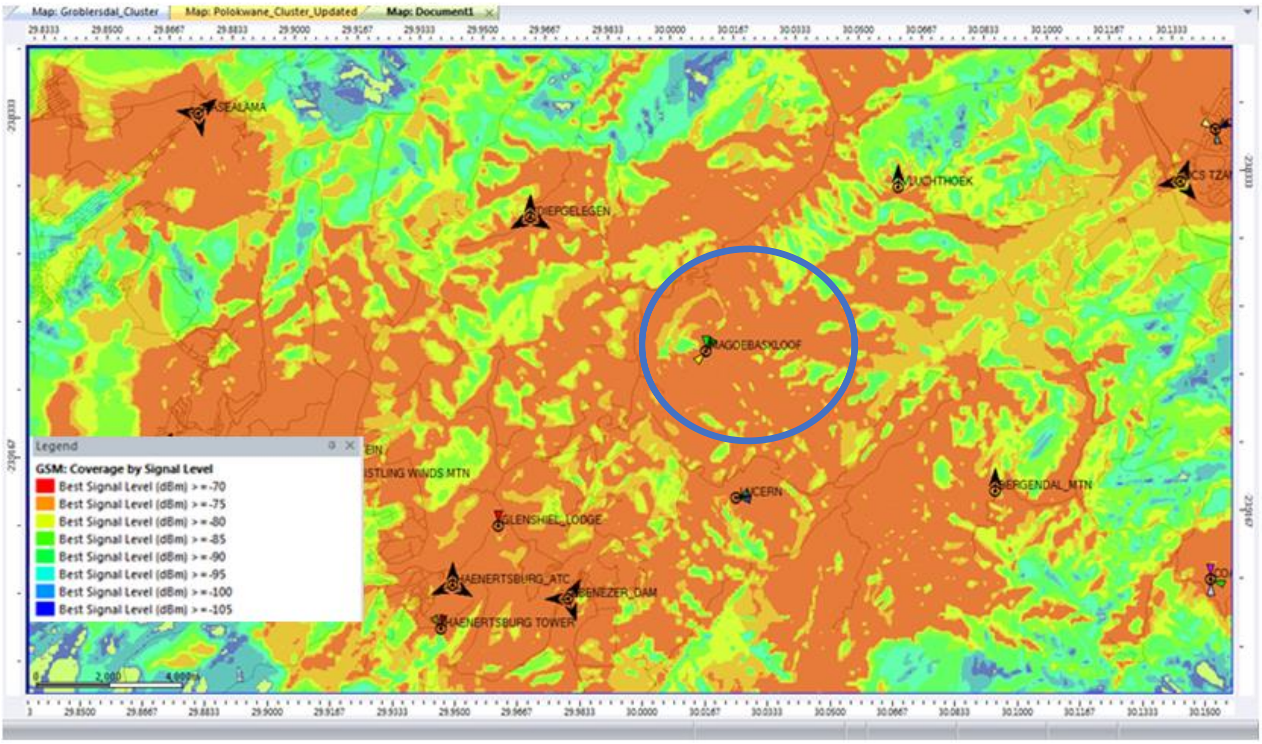

Figure 4-6: 2G Coverage Map for the Magoebaskloof Area

The simulated 3G (UMTS) coverage map is shown in Figure 4-7 below:

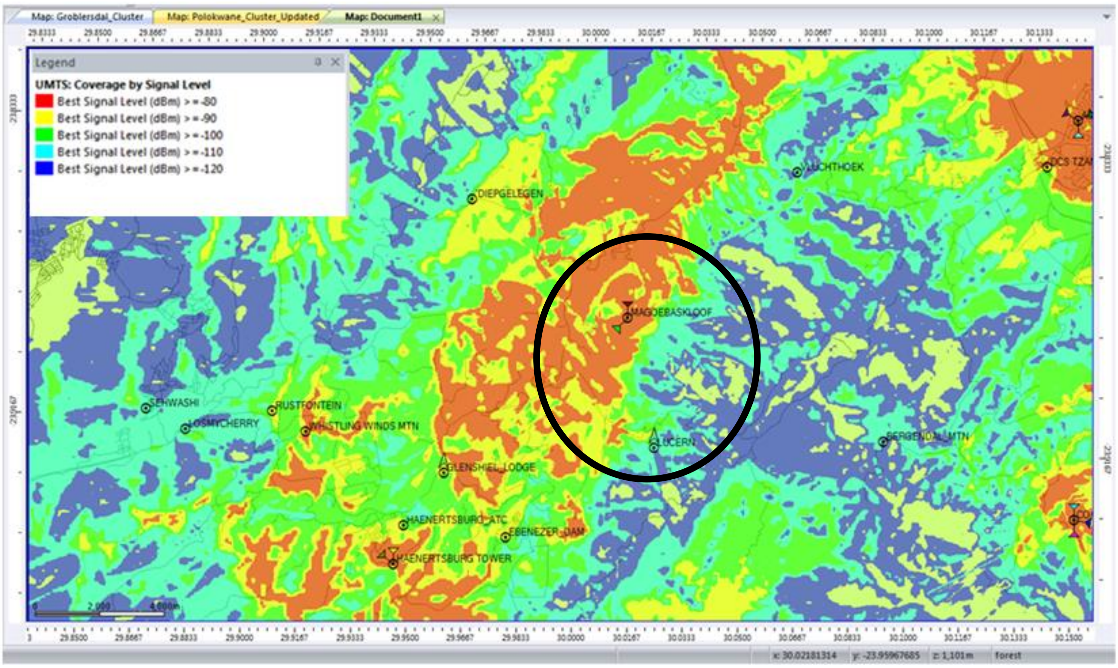

Figure 4-7: 3G Coverage in Magoebaskloof

It is possible to provide decent 3G signal coverage in the red-orange coloured areas, however the coverage map is also interspersed with a number of green and blue areas which will have poor coverage due to path loss caused by the scattering, refraction, etc. of the signal as it propagates past the forest, dams, and the mountain peaks. Good coverage is obtained closest to the Base Station and so the above coverage map could be improved by adding more Base Stations, however, this would be a costly exercise, as with the previous coverage maps. Moreover, a Network Operator would struggle to justify the cost of the Base Stations because the Base Stations would not have reached full carrying capacity.

As shown in Figure 4-8 overleaf, the terrain in the area is mountainous; this is the reason why it is difficult to provide decent network signal in the area. A number of techniques such as using different modulation schemes, antennae schemes, and path loss algorithms can be used when planning the network, more specifically the coverage sector, to ensure the best possible network plan for the area; however, the results of the simulation are due to the technology requiring LOS between the end user device and the Base Station.

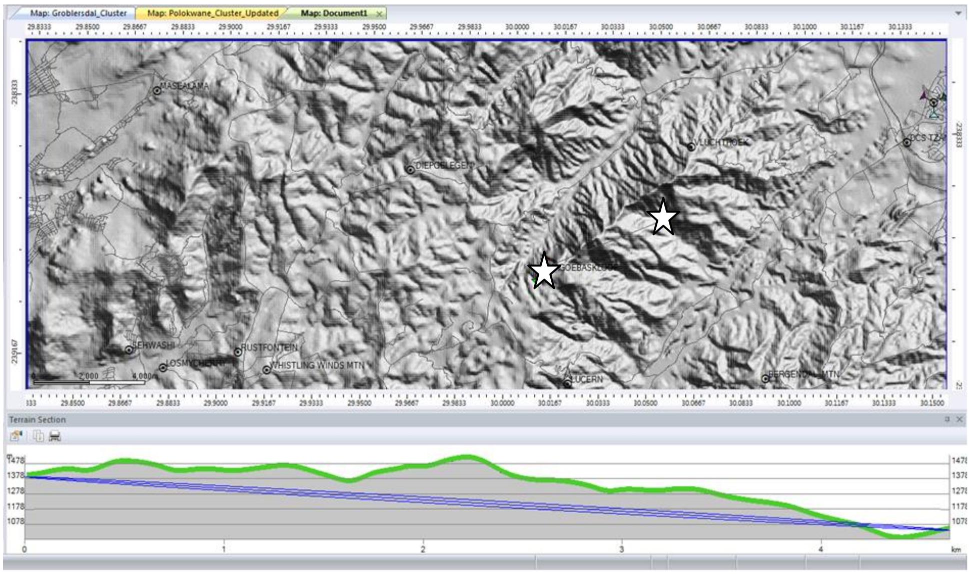

Figure 4-8: Coverage Map of the Magoebaskloof Terrain. *This illustrates the impact of the terrain between the base station (star 10 and a random second point (star two) where a mobile station could be situated*

As shown in Figure 4-9 below, the people in the area use a good mix of feature, and smartphones. In fact, the devices in this area are more advanced than the devices used in the Duiwelskloof area, although the users in this area would experience poorer network coverage than the users living in Duiwelskloof. Therefore, there is a demand in this area, for a reliable data network that offers decent broadband speeds. This information is based on the traffic mix generated on the Vodacom network, in Magoebaskloof. This data was obtained using Touch point. More information on Touch point is provided in the Appendix under Section 7.1.

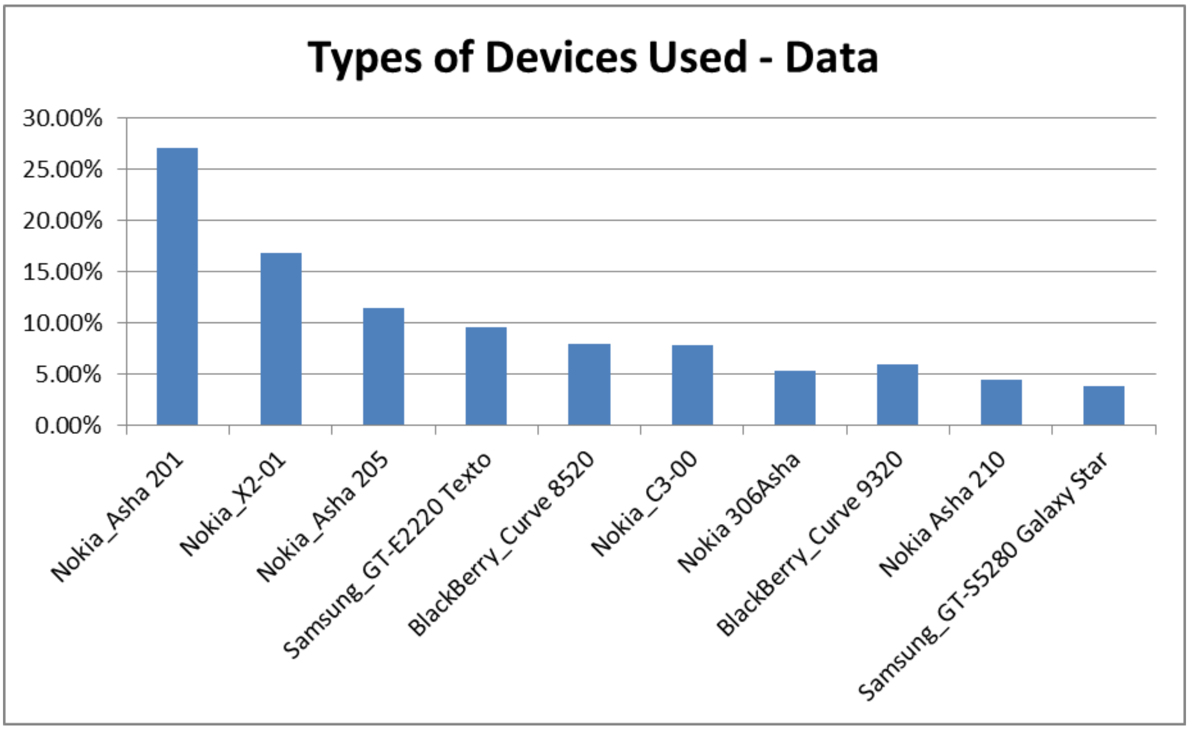

Figure 4-9: Types of Devices Used in the Magoebaskloof Area

Figure 4-10 below shows a simulation of an LTE network in the area. This is depicted by the area covered in purple. In this coverage plot, it is clear that the entire area, in the absence of objects to interrupt LOS, could be covered by a single LTE cell, with a single LTE base station. However, there are many natural objects such as water, tall forests, and uneven terrain which interfere with the propagation of the signal between a transmitter and a receiver. For this reason, more Base stations would have to be deployed to ensure LOS across the entire area. This would increase the deployment costs, making them unjustifiable given the low population. Mobile WiMax (NLOS version) is an alternative option; however, as indicated in the literature, the radius covered would be smaller than a typical LTE or WiMax LOS configuration in a flat area.

Figure 4-10: Simulated LTE Network in Magoebaskloof. *This shows the area that a singl LTE cell would be able to cover in the absence of objects that interfere with the LOS from the base station to any mobile station*

4.3 Adelaide

Adelaide is a small town in the Eastern Cape Province, situated near the Great Winterberg Mountain range. It is situated 22km east of Bedford with a population of 12 191 people, covering an area of 40 km^2. The coverage plot shown in Figure 4-11 below is for the 2G network simulation. It shows where the planned Base Stations are and area that these base stations will be able to cover. From this, it is evident that the coverage would be intermittent in some areas unless additional Base Stations were added. However, the position of these Base Stations was selected in order to ensure the biggest population area is covered using the least number of resources. The mountain peaks in the area cause the gaps in coverage.

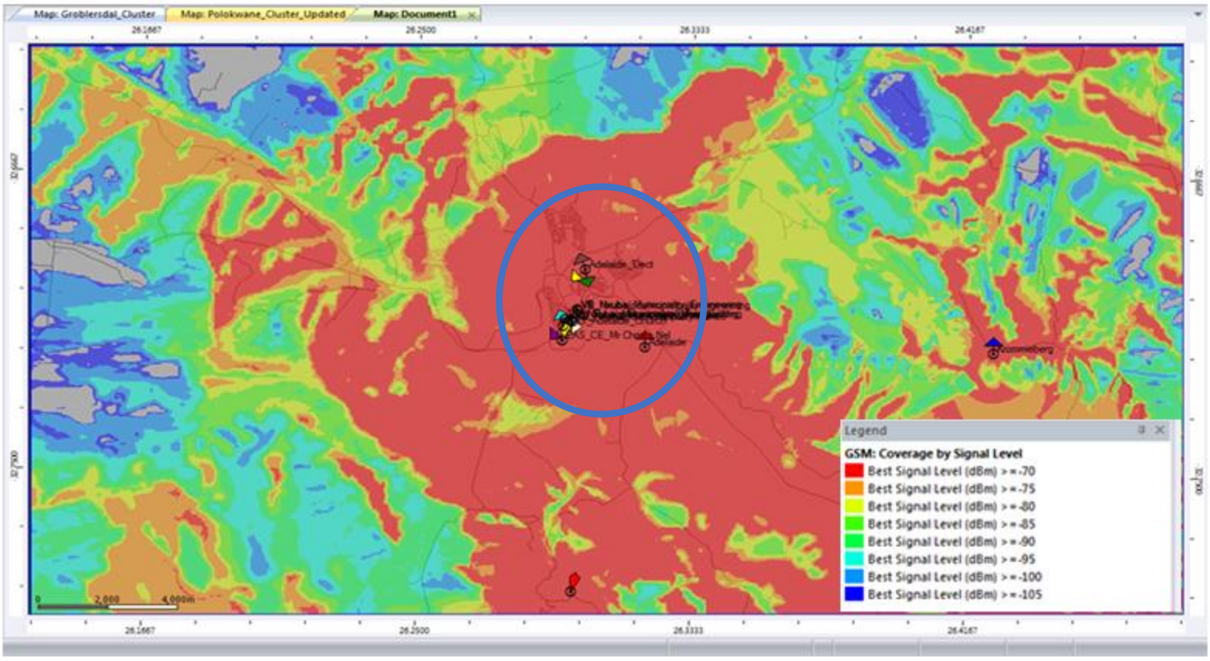

Figure 4-11: 2G Adelaide Coverage Map

Figure 4-12 below shows how the coverage gaps would be even bigger if a UMTS network were to be deployed in the area again because of the number of Base Stations planned for the area. That is, the cost of 3G equipment is more expensive than 2G equipment, which is why Base Stations have to be carefully planned for the areas where there are people and where there is demand for smart devices. This is the reason why the simulated signal strength is poor as you move to the outskirts of Adelaide. From the above, it is plain to see that it would be challenging to deploy access links to backhaul the broadband traffic generated in the area due to the terrain surrounding Adelaide. Therefore, a long distance wireless solution such as licensed Microwave, Fixed WiMax, and as last resorts, LTE or NLOS Mobile WiMax (deployed as a fixed line solution) would have to be considered.

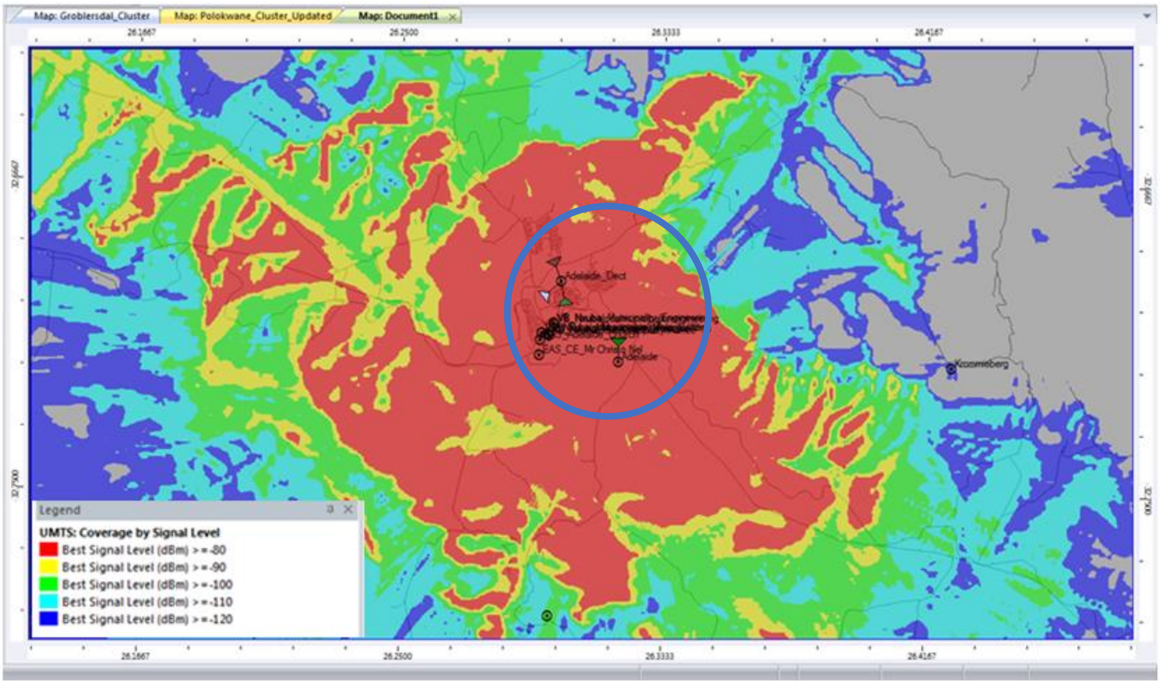

Figure 4-12: UMTS Network Coverage Plot

The terrain profile shown in Figure 4-13 below illustrates the reason the signal strength is not uniform throughout the area.

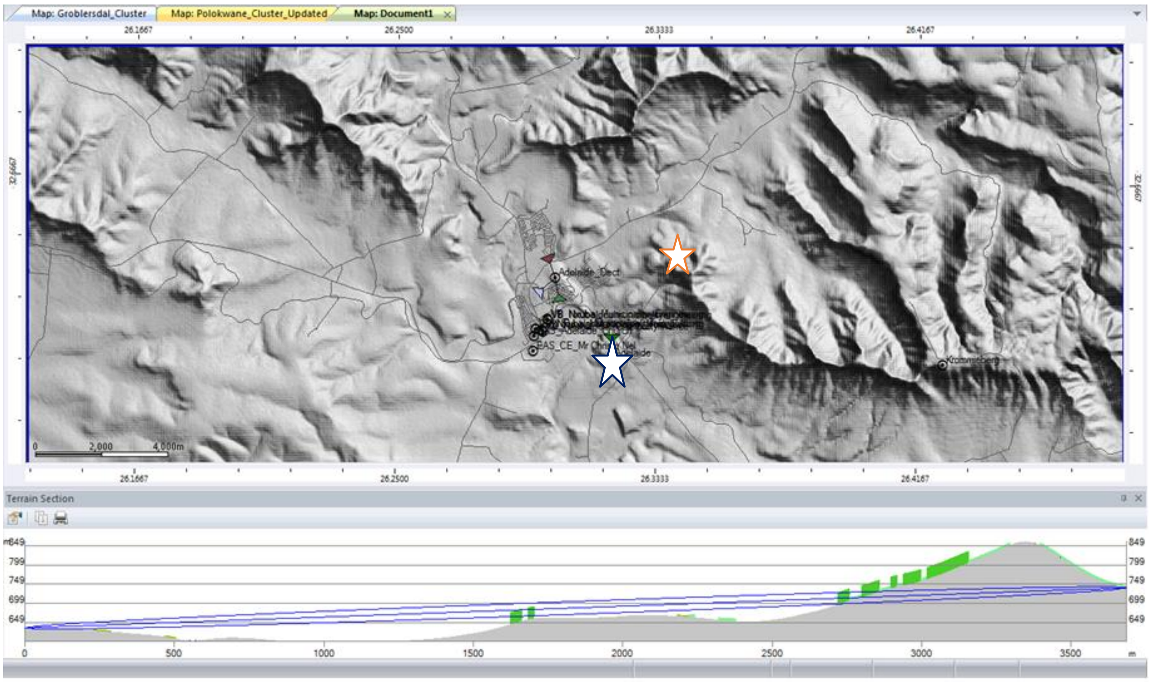

Figure 4-13: Adelaide Terrain Profile. *The LOS analysis was conducted between the Base station (marked with blue star) and a second point (marked with orange star)*

Figure 4-14 below shows that there is a good mix of feature and smartphones in the area. The “unknown” phones are phones that are brought in from other countries and are thus unidentifiable on the networks as they might not be ICASA approved. This information is based on the traffic mix generated on the Vodacom network, in Adelaide. This data was obtained using Touch point. More information on Touch point is provided in the Appendix under Section 7.1.

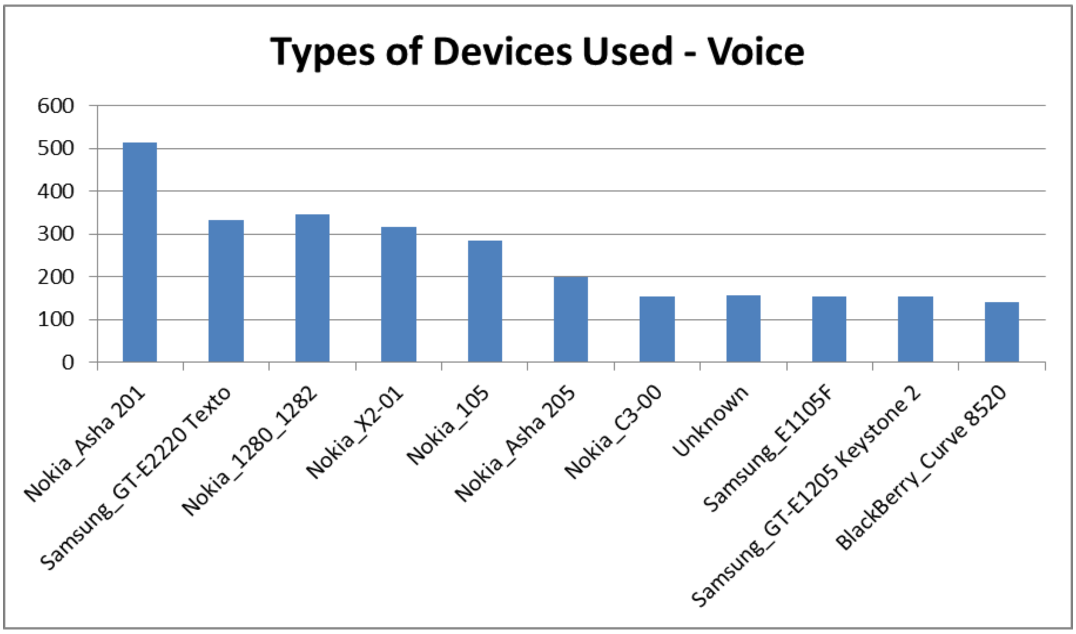

Figure 4-14: Devices used in Adelaide

The coverage plot shown in Figure 4-15 overleaf shows the LTE coverage plot for the area. This is shown by the area covered in green. It also shows that Adelaide has a terrain similar to Makotopong; flat area surrounded by a mountain range. The area has a population size bigger than an average remote village, but it is not as densely populated as an average urban area. This makes it unlikely that a business case for LTE would be approved for this area in the short term, however, it also means WiMax would more likely than not make for a good business case in the area because of the populations size, flat terrain, and current use of smart devices.

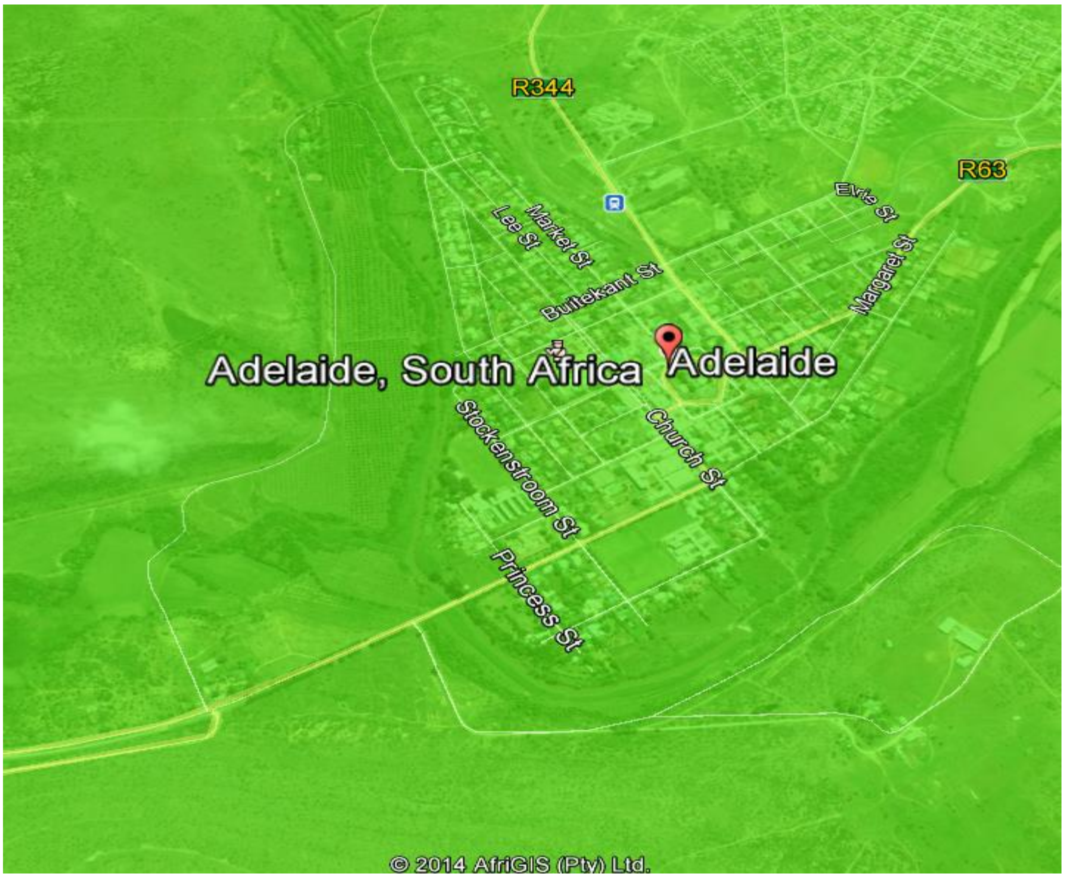

Figure 4-15: A simulated LTE Network Coverage in Adelaide

All this means Mobile (LOS) WiMax could be used to cover this relatively large area using fewer resources than required in the case of UMTS and thus reducing the amount of time, it would take the operator to realise return on investment. Further, by looking at the types of devices used in the area, one is able to forecast the growth in demand for data, as these devices (and newer models) are data intensive and designed mainly to support web based and interactive applications.

By applying the WiMax theory to the LTE simulation, (i.e. the performance of LTE is 17% higher than that of WiMax [5]), it is clear that Mobile WiMax would be suitable for this area.

4.4 Summary of the Analysis

From the analysis provided in sections 4.1 – 4.3, it was found that rural, remote areas have two main types of challenges relating to communications networks.

1. Achieving Line of Sight in mountainous areas especially in areas such as Duiwelskloof and Magoesbaskloof, which are not only mountainous, but also have forests and dams. This was found to be the main reason why there is currently intermittent network coverage although the carrying capacity of the existing 3G Base Stations has not been reached. This reason also contributed to the area not being commercially attractive to operators as more base stations are required in order to provide full 3G network coverage in the area.
2. Backhaul infrastructures such as Fibre or leased lines (Copper) is expensive to deploy and maintain in remote areas, where the traffic generated does not justify the cost of the infrastructure or where the cost to deploy the infrastructure increases due to factors such as uneven terrain. Further, the risk of Copper theft is high, and the cost to lay fibre is generally high as well. A long distance, high-speed, wireless access solution, which supports QoS and requires a low capital investment, would be suited for areas such as Adelaide and Makotopong; Flat areas that are surrounded by mountains and are therefore lying at the bottom of a valley.

Based on the simulations conducted and the WiMax theory obtained in Chapter 2, it can be said that NLOS Mobile WiMax is best suited for deployment in areas such as Duiwelskloof and Magoebaskloof. It was also found that Mobile WiMax can be used to backhaul voice traffic as WiMax, under optimal conditions, is able to deliver 70Mbps over 8000 square kilometers with a range of 50 kilometers in all directions for fixed stations, using one tower.[31]. A salient benefit of using WiMax for backhaul is that it is more cost effective and easier to maintain than terrestrial solutions (e.g. Fibre) deployed in areas such as Adelaide.

Further, from [5 and 4] we can see that in terms of performance, LTE supersedes WiMax, which supersedes all other 3G technologies. In [52] we learnt that LTE and WiMax both offer faster speeds than Wi-Fi and cover a wider area as well.

4.5 Results of the Vodacom WiMax Trial Network

Vodacom, on behalf of Wireless Business Solutions (WBS), deployed a trial WiMax network based on the 802.16e standard, but deployed it as a fixed network due to licensing restrictions. Please refer to Section 2.9 on page 42 above to understand how Mobile WiMax can be deployed as Fixed WiMax. In order to substantiate the findings outlined in Section 4.4 above, the performance results yielded by the Trial Mobile WiMax Network are presented in Table 4 1 below. Although this trial network was deployed as a fixed network in urban and sub-urban South Africa, it provides a good indication of the performance of Mobile WiMax over South African terrain. The network used 10 MHz spectrum and a TDD ratio of 1:1 (number of timeslots to uplink time slots). [24].

Description	Performance of ErtPS CoS	Performance of BE CoS
Service Availability	100%	100%
Session Set-up Success Rate (Network Entry)	99.4%	99.7%
HTTP session success rate	100%	100%
Mean Uplink data rate per timeslot	211.2 Kbps	927.5 Kbps
Mean Downlink data Rate per timeslot	249.0 Kbps	978.6 Kbps
Downlink Peak Data Rate per timeslot	557.6 Kbps	1789.7 Kbps
Uplink Peak Data Rate per timeslot	424.3 Kbps	1469.3 Kbps

Table 4-1: Network Performance Results [24]

The research group that tested the WiMax network described above found that the signal strength of the base station was weak for users further than 1.7 km from the Base Stations in NLOS configurations [24]. Therefore, the strength of the WiMax signal, as with other wireless technologies, gets weaker the further away the Mobile station is from the Base Station, in both LOS and NLOS configurations. This means that more Base Stations may be required to cover an area due to the impact that the mountainous terrain has on the signal. However, the size of the cell does not shrink as more users connect to the network because WiMax is based on OFDMA [9].

4.6 Cost comparison of Broadband Solutions

In order for a technology to be adopted, it has to attract the support of both vendors and users. One way to accomplish this is by making the cost to acquire and maintain the technology competitive relative to the cost of other competing technologies. This Section provides a comparison of the deployment and maintenance costs of various Broadband Solutions. These costs are based on a single Base Station and not the total number of base stations required in an area as the number of Base Stations required is dependent on the topography, traffic requirements, and population sizes.

As depicted in Figure 4-16 overleaf, the investment required to deploy a Wi-Fi hotspot is significantly lower than that of a 3G, WiMax, and LTE Base Stations respectively. However, as stipulated in Chapter 2 on page 53, Wi-Fi was designed to be a short-range solution used to provide access to a network (e.g. LAN or the Public Internet) and thus should not be deployed on its own. WiMax, on the other hand, not only covers a larger area than 3G, but it is also able to support more concurrent sessions than a 3G Base Station. This makes WiMax a more appealing offering than a 3G (UMTS) Base Station, even though the capital outlay required for WiMax is higher than that of a 3G Base Station.

From Figure 4-16 overleaf we can see that the investment required to deploy and maintain an LTE network is higher than that of WiMax. Although an LTE base Station can support more users than a WiMax base station, from [30] it is clear that the coverage area of LTE is less than that of a WiMax Base Station which indicates that only the users in close proximity to the Base Station would have access to the high-speed network. This adds to the argument that it would be challenging for operators to achieve a return on investment if they were to deploy LTE in areas such as Magoebaskloof and Duiwelskloof, which have dispersed populations as multiple LTE Base Stations, would be required to provide full coverage in the area. As explained in Section 1.6, on page 30, LTE is better suited for densely populated areas as the traffic generated can be used to motivate for the deployment of LTE as it means there can be a quicker return on investment.

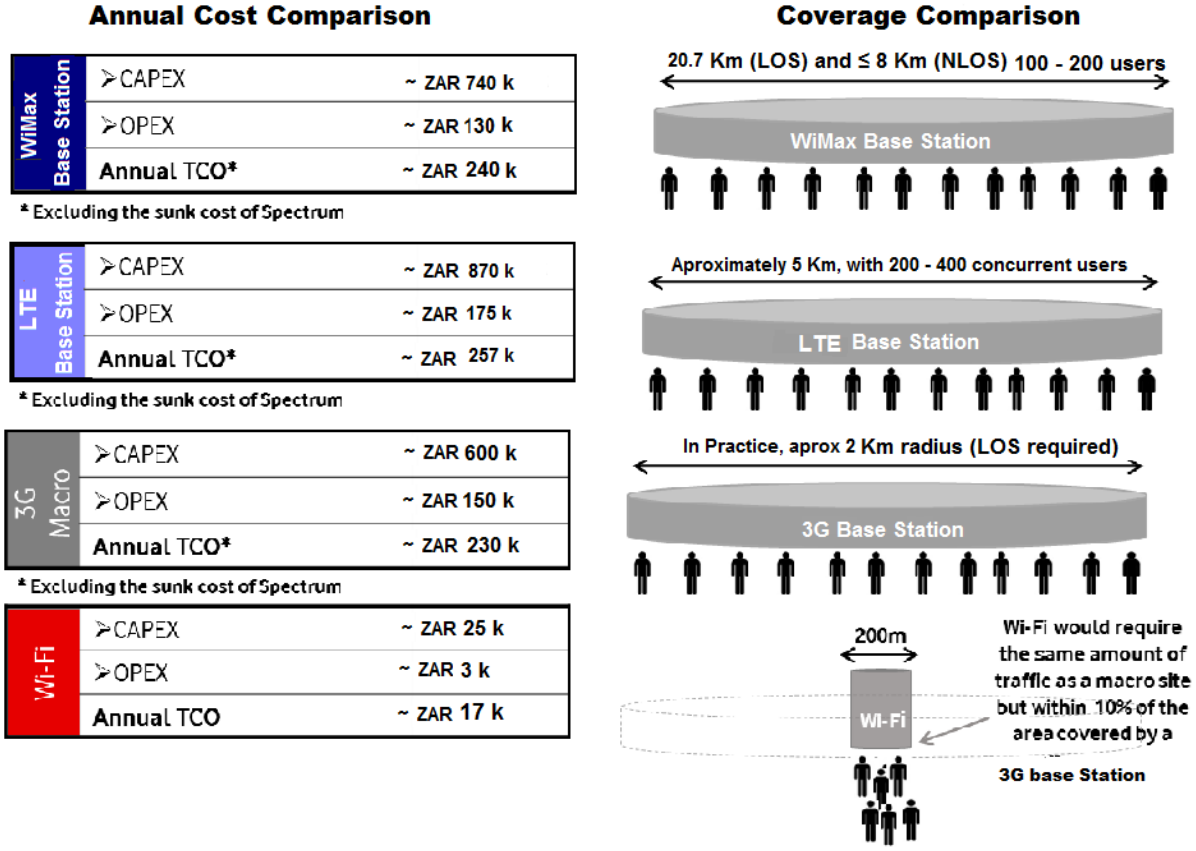

Figure 4-16: Broadband Solutions Annual Cost and Coverage Comparison

The information used to compile Figure 4.16 above was obtained from [4 and 62]. The costs associated with WiMax can be reduced by deploying WiMax over unlicensed spectrum.

This Section indicates that WiMax is a cost effective Broadband Solution that can be implemented to:

1. Bridge the digital divide in areas where it is difficult to obtain LOS .
2. Contain costs by minimising the number of Base Stations deployed.

5. Conclusions

The research was an exploratory project that seeked to propose an economically and technically viable solution for wireless broadband in under-served areas, based on Mobile WiMax. The problem was identified through the increasing digital divide and the direction that the regulator is looking to take in allocating the digital dividend, in support of the National Broadband Policy, the National Development Policy, and the South Africa Connect Policy. The Qualitative research methodology was followed in researching the main research question: Is Mobile WiMax a suitable, cost effective, and sustainable solution for rural broadband connectivity in South Africa. The research includes experimental work to compare the performance of 2G, UMTS, and LTE vs Mobile WiMax in various areas. This work was conducted by simulating the technologies in three randomly selected areas, selected from a list of areas that have challenging terrains, low income levels, and very little (if any) ICT infrastructure. These areas are Duiwelskloof, Magoebaskloof, and Adelaide.

As stated in Section 3.4, on page 65, Mobile WiMax was selected as the technology that could be considered for deployment in these areas because of the "WiMax Promise" which is to offer:

- Lower cost CPE, due to greater economies of scale as the same chipsets were to be embedded in a base of consumer products
- Scalable system bandwidth.
- Quality performance of Real-time applications (Quality of Service).
- Improved Spectral efficiencies.
- Power Reduction –Sleep and Idle mode power management.
- No cell shrinkage as more users are connected to the network.
- Efficiently (cost and performance) provide coverage and capacity while avoiding build-out of a large number of new Base Stations.
- The ability for users to move around without losing connectivity. Speeds supported are from 0 – 120 km/h.

From the literature survey, the experimental work done, and the cost analysis conducted, it is clear that WiMax is able to deliver on this promise. For this reason, the study recommends Mobile WiMax for deployment in rural areas in South Africa, similar to the areas studied.

From the study, the following points about WiMax were brought to light:

1. Mobile WiMax is a suitable technology for deployment in rural South Africa as it will grant subscribers affordable access to the internet and thus to a world that they currently are not exposed to. However, there may be limited availability of mobile stations (end-user devices) that are WiMax enabled. There may also be limited availability of network equipment and WiMax engineers that can maintain and support the network locally.
2. There are a number of changes on which the users will need to be educated. These include learning how to make use of the services. That is, how to download or access applications, and thereafter make VoIP calls. The Network Operator will also be required to provide end-user support in the form of a contact centre. This may be impractical for a Class ECN licence holder as it may be too costly.
3. Mobile WiMax is a last mile access link which connects a mobile station to a BTS. It can also be used as a fixed network in the place of fibre or leased lines, to connect the BTSes to the core network. While users in an area may be able to make calls to each other, they will not be able to access the Internet if the ISP does not have an Internet breakout point, and backhual or backhaul agreements in place.
4. While users in the area will have access to the Internet through Mobile WiMax as a last mile access link, they will not be able to roam outside their area unless the WiMax network is integrated with an LTE network or if the Network Operator is able to secure roaming partnerships with other WiMax ISPs.
5. Mobile WiMax is a technically sound technology that offers better performance in the identified areas, than UMTS or HSPA.

5.1 Discussion of results

The three areas that were studied generate similar traffic mix and use similar device types. They also have challenging terrain and low population sizes. This makes these areas most suitable for the deployment of a Mobile (Wireless) solution. However, wireless solutions are known to have a number of shortfalls due to environmental factors such as the terrain and the weather. While WiMax is not immune to signal degradation caused by the environment such as mountain peaks, forests, and dams, it experiences the least path loss in NLOS configurations. That is, coverage and throughput of WiMax reduces due to the lack of LOS, however, WiMax, generally, still performs better in these areas than all the LTE predecessors (e.g. HSPA, EDGE etc.). WiMax is also impacted by bad weather (heavy rains, strong wind, and storms). However, path loss in WiMax is reduced by using various path loss models, with the Stanford University Interim model [48] being the most suitable for the type of terrain that was considered. As in the case of LTE, the percentage coverage at the lower frequency levels (700 – 850 MHz) is higher by an average of 17% more than at the higher frequencies due to loss in signal strength. Path loss also increases at higher frequency bands, that is , the higher the frequency band, the more path loss will be experienced. The same applies for simulations done at a 2.3 GHz band and a 3.5GHz band – path loss is lower at the 2.3GHz band. In NLOS conditions – the area covered by a WiMax Base Station was limited to about 2kms. Therefore, LOS is needed for longer connections in the identified areas.

Further, applications tend to work differently on different technologies based on the classes of services that the technology support. This is the reason why Wimax, wich offers QoS, provides better user experience than 3G solutions such as UMTS, which do not gaurantee the quality of service. Another benefit of WiMax is that it allows the Network operator to decide which classes of service to provision and which applications to map to each class of service.

The disadvantage of WiMax Base Stations is that they are power (electricity) intensive which may be a problem if there is no electricity in the area, as is often the case in remote rural areas. This requirement can be mitigated using solar power. Further, widespread coverage of WiMax requires 20MHz of TDD spectrum; however, LTE would cover a larger area with the same amount of spectrum making LTE a more enticing solution for Operators.

5.2 Main Findings and inferences

WiMax has made a major contribution to the development of wireless broadband access services such as LTE, even though it is not a mainstream technology. As an example, WiMax is the first technology to use OFDM, which is now used in LTE as well in order for it to provide high data rates, which are transmitted efficiently, while also providing a high degree of resilience to reflections and interference. However, it was found that LTE is more flexible than WiMax. To ensure minimum BER, LTE uses 15 KHz spacing while WiMax uses 10 KHz. Thus, the inter-carrier- interference is higher in WiMax than it is in LTE. This is another example of an improvement that was made to the GSM based technology after realising the challenges with WiMax. Therefore, one can say LTE is a more scalable, faster, and flexible technology than Mobile WiMax because it was developed long after WiMax thus allowing the 3GPP to learn from its shortfalls when designing the technology to compete with WiMax. With that said, it is clear from the literature and the experimental work done that Mobile WiMax is a better technology than Mobile Broadband technologies deployed prior to LTE. This includes the latest version of HSPA, which competes very well with WiMax – although this enhancement was developed after the launch of LTE. One WiMax Base Station covers a wider area than is possible with the LTE predecessors. It offers faster RTT, throughput, and lower latency. However, the challenge in South Africa is that many Operators that have existing GSM/GPRS/EDGE/UMTS/HSPA networks see LTE as a natural progressive technology for their network and have therefore not considered Mobile WiMax.

The main findings of the study were:

- LTE has considerably less overhead than WiMAX thus providing roughly 17% higher throughput for high SNIR (Signal to Noise Plus Interference Ratio) than WiMax[3]. However LTE is a long way off in rural South Africa due to the cost of deployment and the last of 3G infrastructure in rural areas. This could present an opportunity for mobile WiMax, which could fast track the time it takes to deliver high-speed quality broadband services in areas where there is currently little (if any) broadband coverage.

- Mobile WiMax over unlicensed spectrum would be the cheapest alternative
- Mobile WiMax is a suitable technology for deployment in rural South Africa from a technical perspective as it offers high uplink and downlink data rates, supports NLOS configurations, offers spectral efficiencies, can accommodate up to concurrent 100 users per base station before the signal strength start to deteriorate due to contention, offers security over the air, covers a wider area than UMTS networks, offers QoS and thus can offer VoIP services. [30]

Over and above technical capability, market volume also plays an important role because economies of scale reduce costs. The 3GPP continued to enhance HSPA and Operators accelerated their LTE deployments. This means that LTE subscribers will benefit more from economies of scale than WiMax users. The number of Networks based on a type of technology as well as the projected increase in these networks influences the number devices that mobile device manufacturers manufacture. Further, WiMax is losing a lot of the vendor support it had to LTE. Examples include Nokia Siemens, Motorola, Intel, YOTA, and Alvarion. Large American Network Service providers AT&T, Sprint and Clearwire no longer offer WiMax. However, for a technology to flourish and grow, competing companies have to adopt it and an ecosystem of vendors, suppliers, and manufacturers must come into being.

5.3 Implication of the findings and limitations

The digital divide persists due to the cost of deployment of infrastructure. This is worsened by the fact that service providers in South Africa basically are required to deploy a full network for each technology that they introduce. As an example, Wi-Fi, DSL, GSM, ISDN are different technologies and thus are deployed according to the service provider’s strategy. However, South Africa could benefit from Network Operators entering into agreements to share network resources as is being tried in Kenya. With this in mind and knowing that LTE Advanced and Mobile WiMax

(802.16m) allow for interoperability with existing networks via internet working functions that is the unbundling of the access, core, and application service networks, then South Africa should redefine how it can close the digital divide. In essence, unbundling reduces barriers to entry. Although there is no compelling business case for WiMax, if equipment were to be donated (because it is not being bought) to ECN and ECNS class license holders, and if the Operators could enter into agreements to use the big operator's core network, then the recommendation would be for WiMax to be considered for a little while longer while the cost of HSPA or even LTE comes down, thus making it feasible for rollout nationally. Therefore, in such a case, WiMax could be considered to increase the country's overall broadband coverage. This would be good for South Africa as WiMax networks in Japan, Korea, and Malaysia are expected to continue to grow therefore South Africa would not be the only country still considering WiMax.

In closing, a country's ability to choose the right technology path depends on each operator's individual business strategy. It has been shown that WiMax is a sound technology for deployment in rural South Africa, but this alone cannot lead to it being the mainstream technology as there are other factors that have to be considered. These include:

1. Regulatory constraints: Available spectrum, Cost of Spectrum, Standards to be complied with.
2. Operator Strategy: Legacy networks, competitive situation, technology evolution path, investment protection.
3. Regional Constraints: Demand for services, population density, availability of devices.

Therefore, technological capabilities (Data rates, Capacity, Latency, Mobility, etc.) are just one part of the story.

5.4 Suggestions for further studies.

As the demand for data increases, so does the demand for high bandwidth, latency intolerant applications, and faster support or response times from the network operator. For this reason, network Operators are required to expand the reach and increase the capacity of their network, increase their technical support staff, or implement Self-Organising Networks (SON) in order for them to meet these requirements. The benefit of the SON is the ability to curb the costs of operating and maintaining a network in a remote location, reduce human error, increase operational efficiencies, and thus increase the end user's user experience. A SON is defined as a process that involves Network Elements (NEs) in Radio Access Networks (RAN) and Core Networks that enables the networks to automatically configure, measure or analyse performance data, and to fine-tune network attributes in order to achieve optimal performance while reducing impact on the end-users and significantly reducing maintenance costs. SONs have the following attributes:

- **Self-healing**
  The network's ability to detect, mitigate or resolve any problems encountered on the network.
- **Self-configuration**
  The network's ability to configure its settings automatically, making it a plug and play network.
- **Self-optimisation**
  The network's ability to re-configure its settings while in operation with the aim of ensuring that the network operates optimally at all times. An example is the ability to save energy by automatically switching off cells when the capacity is not required.

Mobile WiMax is unlikely to be the flagship Mobile Broadband technology. Therefore, it is expected that the number of qualified/certified WiMax engineers will decrease. The number of WiMax enabled devices are also expected to decline. However, those that have already implemented Mobile WiMax networks, as well as those that have benefitted from buying equipment from Operators that decided to shut down their networks should still be supported until the equipment reaches end-of-life. Achieving SONs in Mobile WiMax Networks is one of the best ways that network Operators can maintain their investments. It would be interesting to determine if self-organisation can be achieved in WiMax using the centralised, distributed, or the hybrid architecture. The simulations should consider three input metrics 1) Terrain, 2) Coverage radius, 3) Traffic Load.

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7. Appendix

7.1 Tools of research and sources of data

It is understood that Simulation is a powerful tool for analysis and improvement of networking technologies. It enables users to take risks, play with the different technologies in different areas and find the best fitting technology in an area. Network simulatons are obviously more cost effective than the actual rollout, but their real value, for Network Operators, lies in reducing the risk of incurring fruitless expenditure. There are many simulation packages available – some with more features than others. Atoll is a Radio planning and optimisation tool developed by Forsk. Forsk is an independent company providing radio planning and optimisation software products since 1987. Atoll has more than 6000 active licenses and 450 customers in 115 countries. Forsk's market share in Europe exceeds 50%, making it the leading Radio Planning and Optimisation Software Products Provider. In fact, on 13 August 2014, Forsk announced that there were 51 Mobile Operators in Europe that use Atoll for radio, frequency, and site planning as well as for network optimisation. Forsk also reported that it noticed a high increase in the number of Mobile Network Operators using Atoll from the year 2009, which is the time when LTE was introduced. This gives us an idea of how reputable the product is and how aligned it is to the latest technologies. Atoll is also used locally, in practice, by big Operators such as Vodacom. What is truly beneficial is Atoll's ability to simulate the South African terrain and thus enable you to simulate a real-life network. The above mentioned reasons are the reason Atoll was selected as the tool to use in this study in order to simulate the respective networks.

SONAR is a capacity management tool used for optimising and monitoring sites (BTSes) effectiveness. It is also used to create and maintain a detailed inventory database of the network. In this study, it was used to identify areas that fit the definition of the focus areas of this study and also identify areas where there is intermittent, unreliable 2G and 3G coverage mainly due to a site ineffectiveness. That is, identify the reasons why coverage is not reliable as it is often due to Network

Operators not deploying sufficient resources to cover the area and not because the technology is technically flawed. It was also used to analyse of the reasons why 3G has not been deployed in the areas that were found to not have 3G infrastructure. Netscope software can be used to monitor the IP backbone and ensure that there aren't any bottle necks on the network. The focus of this study was was on the last mile access. For this reason,the netscope tool is not discussed in detail.

In essence, Atoll was selected as a tool to use for the radio, frequency, and site planning and simulation as it enables one to plan networks for the identified areas using industry best practices embedded in the software. SONAR was selected as a tool to drill into the network to determine the effectiveness of the existing base stations that have been deployed and thus understand why coverage is poor in some of the areas where there is infrastructure. The base station is considered effective if it is able to serve the maximun (or close to the maximum) number of mobile stations it was designed to serve in that particular area as the cost of the infrastructure, and the maintenance thereof, are then justifiable. Therefore the effectiveness of a base station is measured by the availabilty, reliability, and the Base Station's ability to cover a reasonably sized area. This gives an indication of whether or not the Base Station is adding value to the people in the area and if the Network operator is able to get a decent return on investment.

The drawback with using Atoll in this study is that the licensing belongs to Vodacom and so the tool has been overlaid over the Vodacom Network thus the results of the simulation are based on the infrastructure and coverage gaps that exist on the Vodacom Network. Further, it was later found that Vodacom no longer has the Atoll license for the WiMax module as it replaced the Wimax module with the LTE module as its technology roadmap is aligned with that of LTE and not of WiMax. This was discovered after the conceptual design had been finalised. However, this challenge was mitigated using the Tu Wiens Institue of Telecommunications recommendation to simulate an LTE network instead of a WiMax network as will be explained in the sections that follow.

Touch point is another tool that was used. It was developed by Tektronix. Its main purpose was to provide insight into subscriber activity on the network. That is, obtain information on the type of devices being used in an area, the applications being accessed, and the network services being accessed. This information was required to assist in determining the basic needs of users in the identified areas. This information was intended to assist in providing an understanding of the market that the WiMax solution was intended for. This analysis was not conducted to determine the technology adoption rate or the amount of time it would take an operator to realise a return on investment. Rather, it was intended to determine if WiMax would would meet their immediate needs or if it would be a technology that could be deployed in the area, but not ignite any interest in the user simply because it is not something they need or want as an example the Khoi San people might not want cellphones to be introduced in their areas because they feel it would deter them from preserving their culture.

7.2 Other tools that are available

A number of Operators still use in-house radio planning and optimisation tools. These are often based on Java or C++ programming languages. These were however not considered for this project because they have not been extensively tried and tested by different Operators, operating in different areas (terrains) and are thus prone to having bugs that might only be identified after the actual rollout has been done thus causing fruitless expenditure. Further, Network Operators often aren't specialists in software development therefore support on the use of the software may be limited causing the user to have to resort to traditional, paper-based, network planning techniques.

Open Source Simulators also were not selected for the purposes of this study for reasons similar to the ones stated above. That is, although there is Open Source Software available which of course does not require license fees, but requires a lot of time to set-up, uses a lot of disk space, and requires the user to write scripts to run on the simulator. Further, it can be difficult to determine if the results of the simulation are accurate as the user is responsible for verifying that the results are not invalidated by bugs in the software. These simulators include Network Simulator version 2 and version 3 (NS-2, NS-3), and the WiMax Network simulator developed by the TU Wiens Institute of Telecommunication, using Matlab. The NS-3 simulator is the successor of the NS-2 and has gained popularity over the years. In fact a number of papers have been written confirming the NS-2 and NS-3 simulators' ability to simulate a WiMax network. The TU Wiens Institute of Telecommunication's WiMax Network Simulator is no longer supported, however, the TU Wiens Institute of Telecommunications recommends running their LTE simulator as LTE and WiMax, in theory, yield similar results. Their recommendation is for the user to simulate an LTE network then apply the WiMax theory to the result to deduce the results that a WiMax simulator would have yielded. This simulator is also based on Matlab.

The EDX Signal Pro wireless planning and design tool was also considered as it is also one of the most widely used engineering software products currently being used across the globe. It can be used to design a number of wireless networks such as WiMax, LTE, and WiFi by simply adding on the relevant modules for each of the wireless networks that one wishes to simulate or plan. This product is a commercial product and thus has associated license fees. This tool was not selected as the researcher already had access to Atoll and thus would not be liable for additional license fees.

7.3 Examples of simulations using Atoll

A simulation of UMTS coverage in the Koedoespoort area, in Mpumalanga, is now shown to provide an explanation of the Atoll plot to follow.

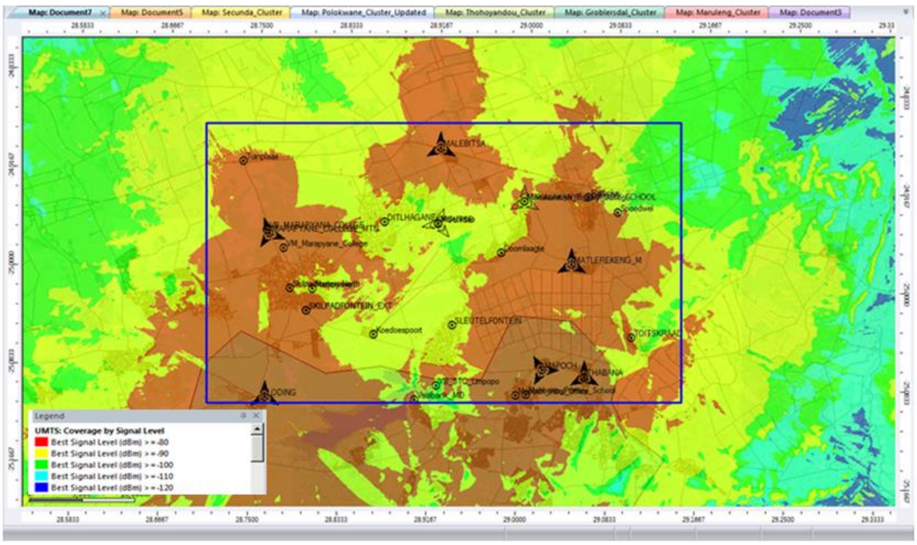

Figure 7-1: Koedoespoort Coverage Map

The signal level in the area is shown using the different colours to represent different dBm levels; the lower the dBm value, the weaker the signal in the area. The red colour represents a good signal level (less than -80dBm), the yellow colour shows the areas where the connectivity may be achieved (between -80 and -90dBm), but the connection may be unreliable. This challenge is more obvious when usage (number of active connections/subscribers) goes up as the area covered by each base station shrinks. The areas with the green and the blue colours have the least, if any, coverage (between -90 and -120 dBm). This particular area requires at least -95 dBm in order for a user to connect to the network. The terrain of the Koedoespoort area is shown below.

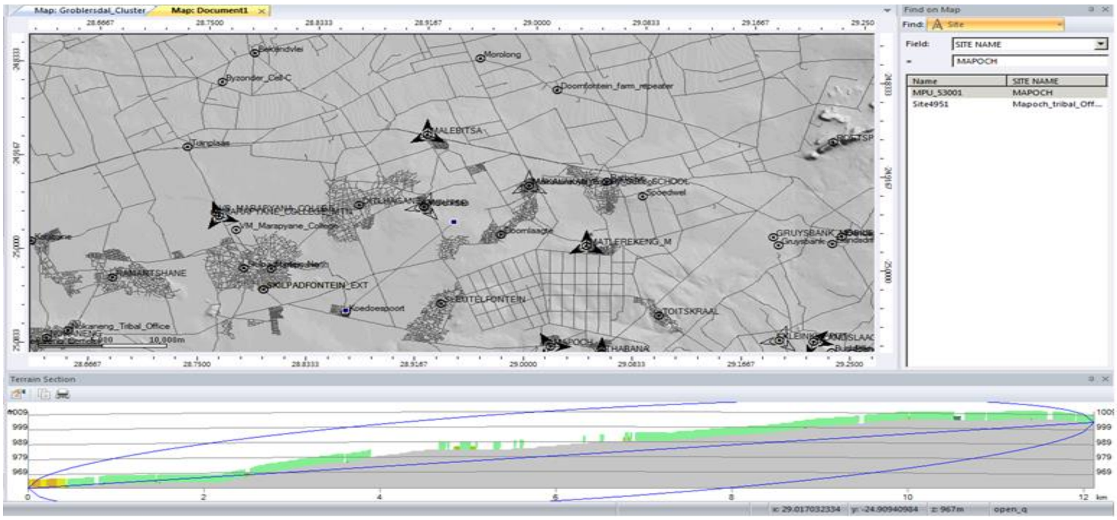

Figure 7-2: Koedoespoort Terrain Coverage Map

The first plot shows the elevation of an area. The size of the areas where there are people is shown by the grid of squares. The smaller the squares in the grid, the more densely populated the area. Koedoespoort has a small population. The second plot illustrates the clutter profile of the area which highlights the obstacles in the area that could negatively impact the signal strength. It also shows the line-of-sight profile of the area to the closest UMTS Base Station. These plots assist in providing an understanding of why certain areas have poor signal strength despite there being a number of Base Stations in close proximity to the area being studied. From the above it can be concluded that the Koedoespoort area is located on a forest-like hill, making it difficult to provide coverage in the area as it is difficult to obtain clear line-of-sight to the closest neighbouring Base Station.