Field testing the Alvarion BreezeMAX as a last mile access technology

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Abstract— **With an alarmingly low teledensity of approximately 12 % in South Africa, and not much hope of further wired infrastructure at the local loop level – as the costs incurred are high compared to potential revenue – wireless connectivity could be a great asset and service in South Africa. This paper looks at how WiMAX technologies, and specifically the Alvarion BreezeMAX, could be used in providing much needed telecommunications infrastructure to both rural and urban areas in South Africa, providing broadband data throughput rates together with excellent network reliability and low latency.**[1]

I. INTRODUCTION

The total teledensity for South Africa in 2002 was just 12 %. The majority of fixed line telephones were located in urban, historically white, residential and business areas, while black rural areas continued to experience teledensities around 1 % [1]. According to the Genesis report, published in 2005 [2], of the 2.8 million lines that Telkom rolled out in compliance with its exclusivity agreement, 70 % have now been disconnected due to non-payment, leaving South Africa with approximately 5 million fixed lines for 42 million citizens.

In order for more South Africans to benefit from the Information Age and the empowerment that it provides, more wireless technologies could be employed in order to affordably connect South Africans to the Internet. Wireless technologies can be easily deployed in areas where teledensity is low and at a lower cost than wired alternatives [3], [4]. Popular wireless technologies that are being explored in order to connect more people to communication networks include WiFi (IEEE 802.11) and WiMAX (IEEE 802.16).

At the time of writing, April 2007, in South Africa, a number of telecommunications companies are involved in public hearings with the Independent Communications Authority of South Africa (ICASA) regarding the allocation of bandwidth for use in WiMAX networks as well as licensing in order to deploy such networks [5], [6], [7], [8], [9]. In addition, under-serviced area license (USAL) [10], [11] holders are also interested in deploying WiMAX networks in order to reach their clientele in rural, under-developed areas with low teledensities. One such USAL is Amatole Telecommunication services, which operates in the Amatole District of the Eastern Cape [12]. National telecommunication providers such as Telkom are already licensed and conducting field trials with WiMAX equipment. Telkom have a trial network in Pretoria and Centurion, where they have achieved throughputs of up to 4 Mbps to individual subscribers [13].

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This work was undertaken in the Distributed Multimedia CoE at Rhodes University, with financial support from Telkom SA, Business Connexion, Comverse, Verso Technologies, Tellabs, Stortech, THRIP, Mars Technologies, Amatole Telecommunications Services and Bright Ideas 39.

II. WHAT IS WIMAX?

WiMAX stands for Worldwide Interoperability for Microwave Access, and is a means of broadband wireless access (BWA) which generally refers to fixed radio systems used primarily to convey broadband services between users' premises and core networks [14]. WiMAX is based on the IEEE 802.16 specifications and was given the commercial name of WiMAX by the WiMAX Forum. (The WiMAX Forum is an industry-led, non-profit organization formed to certify and promote the interoperability of all WiMAX products.) When 802.16 based equipment conforms to the standard and pass interoperability testing they will be "WiMAX Forum Certified" and can display this mark on their products and marketing materials [15], [16].

The core 802.16 specification is an air interface standard for broadband wireless access systems using point-to-multipoint infrastructure designs, and operating at radio frequencies between 10 GHz and 66 GHz, addressing line of sight environments (LOS) [17]. According to the literature, it targets an average bandwidth of 70 Mbps with peak rates of up to 268 Mbps [18].

Wavelengths in the region 10 - 66 GHz suffer a progressive increase in attenuation of the signal when propagating through the air and are often affected by atmospheric conditions – rain in particular [19]. Trees and buildings are also problematic [19]. In cities where there are many tall buildings shading smaller buildings, LOS requirements may be a problem for service providers and thus limit their clientele. For these reasons the IEEE ratified its core standard to incorporate the 802.16a specification, which operates in the 2 - 11 GHz spectrum and thus suffers less from the above mentioned problems of attenuation and necessary LOS [19].

The 802.16a collection of amendments took into account the emergence of licensed and license-exempt broadband wireless networks operating between 2 GHz and 11 GHz, with support for non-line-of-sight (NLOS) architectures that could not be supported in higher frequency ranges [18]. The 802.16a standard, or HiperMAN, for 2 - 11 GHz is a wireless MAN technology that provides broadband wireless connectivity to fixed, portable and nomadic users [17]. This Orthogonal Frequency Division Multiplexing (OFDM) and NLOS technology can be used to back-haul 802.11 hot-spots and WLANs to the Internet, and enable a wireless alternative to DSL for last mile broadband access [17]. It potentially provides up to 80 kilometers [20] of service area range, allows users to get broadband connectivity without needing direct line of sight with the base station, and provides total data rates of hundreds of Mbps per base station - a sufficient amount of bandwidth to simultaneously support hundreds of businesses with T1/E1-type connectivity and many hundreds of homes with DSL-type (512 Kbps) connectivity with a single base station [17], [21]. As said, support for NLOS performance was one of the primary PHY (physical layer) differences in 802.16a [17]. The OFDM format was selected in preference to competing formats, such as CDMA, due to its ability to support NLOS performance while maintaining a high level of spectral efficiency – maximising the use of available spectrum [17]. In OFDM individual transmissions are distributed across the entire available spectrum in complex inter-leavings that leave relatively little spectrum unoccupied for any length of time during periods of heavy traffic [19].

The IEEE 802.16 standards include support for various modulation schemes which can be used depending on the prevailing conditions. (Modulation is the process in which a carrier wave's amplitude, frequency or phase are altered in such a way as to carry a message or digital signal.) The use of adaptive modulation allows a wireless system to choose the highest order modulation depending on the channel conditions [22] per-subscriber basis. If the air-link degrades due to rain or other interference factors, the technology automatically reverts to less-complex schemes to allow for reliable data transfer [23]. The various modulation schemes which the standards support include, in order of increasing complexity, BPSK, QPSK, QAM16, QAM64 and QAM256 [24], [23].

QAM stands for Quadrature Amplitude Modulation and is the most complex of the modulation techniques. The number (n=16 or n=64 or n=256) denotes the size of the set of symbols that is used to modulate the signal [24], [23]. QPSK stands for Quadrature Phase Shift Keying and uses a smaller set of symbols, four [24], [23]. Finally, BPSK stands for Binary Phase Shift Keying and is the least complex of the modulation methods, employing two symbols [24]. The use of more complex modulation schemes results in higher throughput because more symbols can be sent at a time. When signals have to travel over longer distances, however, they are weakened and more susceptible to interference, which results in poorer demodulation at the receiving side. Thus in order to cover greater distances, less complicated modulation schemes must be used [22].

In 2004 the 802.16a standard was amended and replaced with the 2004 revision. Most of the original 802.16a specification was absorbed into the revision, named 802.16-2004 or 802.16d [24]. The purpose of the revision from 802.16a to 802.16d was to "align the standard with aspects of the European Telecommunications Standards Institute (ETSI) HIPERMAN standard as well as lay down conformance and test specifications [25]." The Alvarion BreezeMAX equipment discussed in this paper is pre-802.16a compliant.

IEEE 802.16 standards integrate seamlessly into most wired networks, much like 802.11 standards. For further detailed information on the IEEE 802.16 standards and specifications see for example [14], [24], [20] and [19].

III. Testing

A. Last mile access technologies

The Rhodes University Telkom Centre of Excellence in the Computer Science Department has over a number of years been conducting research into cost effective last mile Internet access solutions. One of the aims was the identification of solutions that would be affordable for previously disadvantaged schools. This research has included DSL-type connections [26], [27] and WiFi connections [27], [28], [29], both with promising results.

The WiFi last mile network had a number of benefits over the DSL: it was very quick and easy to install at the various premises and the equipment was cheap and didn't rely on any previous infrastructure such as copper in the ground [27]. However, the WiFi technology has limitations in that it was not specifically designed to connect computers at distances greater than 100 m [30], requires line of sight (LOS) in order to connect to the access point when used in wide area network (WAN) deployments and can suffer greatly from interference [27], [28].

Thus the logical next step in the project was to deploy WiMAX within our experimental network. According to literature sources using WiMAX would allow the circumvention of most of the problems faced when using WiFi, namely better data transmission rates, better resistance to interference, and the provision of direct connectivity to locations that do not have direct line of sight. In addition, WiMAX would cover greater distances to allow sites that are further away to connect to the network [17], [20], [24].

B. Alvarion BreezeMAX equipment

The Alvarion BreezeMAX technology was chosen for our WiMAX deployment. Alvarion's equipment was among the systems tested at the time at SAAB Grintek, a partner company within the Telkom Centre of Excellence network. So a micro base station and 10 subscriber unit (SU) kits were sourced from them. The choice of 10 units was in line with the then available budget and the experiment was carried out in Grahamstown as it is where Rhodes University is situated. The Alvarion equipment uses 256 OFDM carriers; uses the modulation schemes listed in TABLE I; supports bandwidth of up to 14MHz; operates in the 3.5GHz band, the up-link operating in 3.3995 to 3.4535GHz and the down-link in 3.4995 to 3.5535GHz; and uses Frequency Division Duplex (FDD) [31].

The base station was installed at the 1820 Settlers Monument, a prominent building in Grahamstown where Rhodes University is situated, in a ventilation shaft just 20 m below the roof. Directly above, on the roof top, the radio interface for the base station together with a 13 dBi omni-directional antenna were installed.

Tripod brackets were mounted onto walls of the test premises that faced the Settlers' Monument. To each bracket we attached an aluminium pole, held in place by two U-bolts, and the outdoor component of the SU was mounted to the top of the pole. The outdoor component consists of a radio interface with a flat panel antenna attached. This is powered by the indoor component, which is basically a power-over-Ethernet injector.

Currently a total of six subscriber units (sites A, B, C, D, E and F) have been tested in Grahamstown. For the purposes of this paper, only two of those sites will be reported on, site A and site C. The two sites were chosen as they present data for a connection that is relatively close-by to the base station and another which is a lot further away from the base station. Site A is approximately 900 m from the base station and site C, 5.1 km from the base station. Site C has a clear LOS with the base station, while site A has a partially blocked LOS with two high rise apartment blocks protruding into the LOS.

C. Experiments

According to the Alvarion BreezeMAX system manual [31], the micro base station can provide its subscribers with a burst data rate of up 12.7 Mbps. The data rates quoted in the manual are almost more than double the achievable speed on our DSL network and four times the speed achieved on our WiFi network, and hence very promising.

A series of experiments were conducted to ascertain the exact data rates achievable using the Alvarion BreezeMAX. Throughput tests were run for settings of 12, 10, 8, 7, 6, 5, 4 and 2 Mbps. These values were chosen in order to firstly determine whether or not the 12.7 Mbps data rate was achievable and, if not, what was the highest throughput we could achieve. Secondly, we wanted to know how close actual and nominal data rates were.

As said, transmission rate on the WiMAX network will be affected by the modulation scheme employed by the equipment. The Alvarion BreezeMAX base station employs a multi-rate algorithm that dynamically adapts the modulation scheme and Forward Error Correction (FEC) [24] according to link conditions between the base station and each of the subscriber units. The base station manages this algorithm and separately calculates optimal modulation scheme values for both the up-link and down-link of each of the subscriber units. If the multi-rate algorithm is disabled, communication between the base station and subscriber stations continue using the last up-link and down-link rates selected by the multi-rate algorithm. In addition, a basic rate needs to be set on the base station. The basic rate is the minimum rate to be used by the multi-rate algorithm, as well as the rate that will be used for all broadcasts and multi-casts [31].

The base station used during the experiments was set to use the multi-rate algorithm, while the basic rate was initially set to the lowest modulation scheme available, BPSK 1/2 . After the initial tests at 12, 10, 8, 7, 6, 5, 4, and 2 Mbps were conducted, another series of tests were done with the data limit set to 6 Mbps while altering the modulation scheme in order to test if higher throughput results were obtainable. Tests were run for every modulation scheme available on the Alvarion platform. In addition, basic tests were conducted in order to ascertain the reliability and latency of the network. The results of these experiments are discussed in the next section.

Modulation Schemes	
BPSK 1/2	QAM16 1/2
BPSK 3/4	QAM16 3/4
QPSK 1/2	QAM64 2/3
QPSK 3/4	QAM64 3/4

TABLE I
ALVARION BREEZEMAX MODULATION SCHEMES

IV. RESULTS AND DISCUSSION

The initial throughput results, for tests conducted at 12, 10, 8, 7, 6, 5, 4, and 2 Mbps, with the basic rate of the multi-rate modulation algorithm set to BPSK 1/2, showed that the data rate limit of 6 Mbps resulted in the highest overall average throughput of 5.12 Mbps. The results from the two sites, A and C, were averaged and the combined average was taken. The difference in results between sites A and C was mostly negligible, 0.03 to 0.1 Mbps, and thus the difference in distance between the two sites with the basic modulation at BPSK 1/2 didn't appear to have any effect.

The results obtained for the other data rate limits can be seen in Fig. 1. From the results in Fig. 1 it would appear that there is an optimum data rate limit setting (peaking around 6 and 7 Mbps) in order to achieve the best data rates to subscribers. (The difference between the results at 6 and 7 Mbps are so small that they could be a result of experimental error.) The reason for this might be that when a limit is set, the base station will choose a modulation scheme that allows data to be transmitted at the specified rate. However, because of the nature of the connection from the subscribers to the base station and the environment through which connections take place, together with the distance to the subscriber station, the data rates taper off at more complex modulation schemes. As explained in section II, higher modulation schemes employ more symbols, which are harder to demodulate after a signal has traveled long distances and is exposed to interference. Thus the peak of data rate transmission (seen in Fig. 1) is approximately 6 or 7 Mbps.

While 6 Mbps gave the highest average data rate to the subscriber units, the 4 Mbps data rate limit gave the best result in terms of actual vs nominal data rate. This was calculated by comparing the average throughput to that of the limited throughput. Thus the ratio of achieved average data rate to the data rate limit at 4 Mbps was 93.34 %. The lowest ratio achieved during the experiments was at 12 Mbps, with a ratio of 37.65 %. The remaining ratios can be seen in Fig. 1 by comparing the configured limit to the measured throughput.

In order to determine if increasing the modulation rate would result in an increase in throughput, tests were run at 6 Mbps (the optimum data rate limit) while increasing the modulation schemes from BPSK 1/2 through to QAM64 3/4 – the modulation scheme options available on the Alvarion BreezeMAX base station can be seen in TABLE I.

It was found that as modulation steadily increases, the average data rate increases (for the rate limit set to 6 Mbps) until the modulation scheme passes QPSK 1/2 or QPSK 3/4

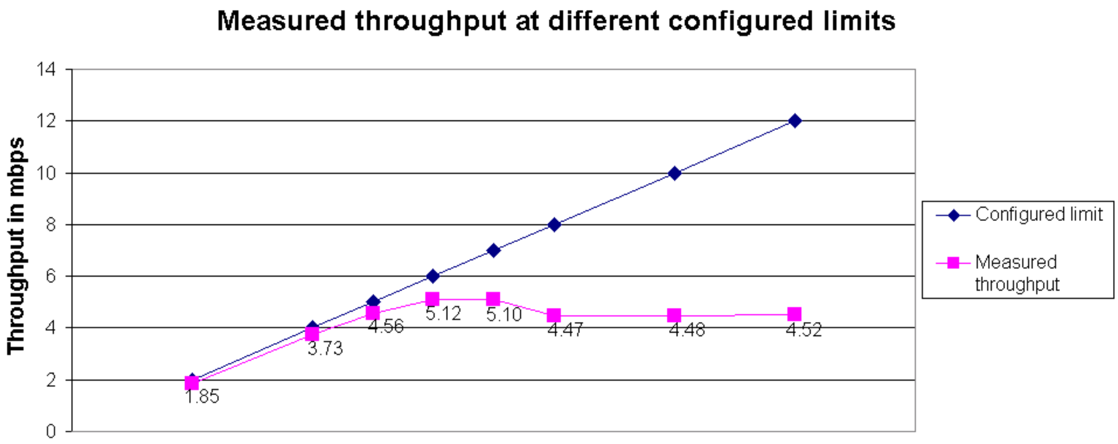

Fig. 1. Measured throughput at different configured limits. Modulation scheme is BPSK 1/2.

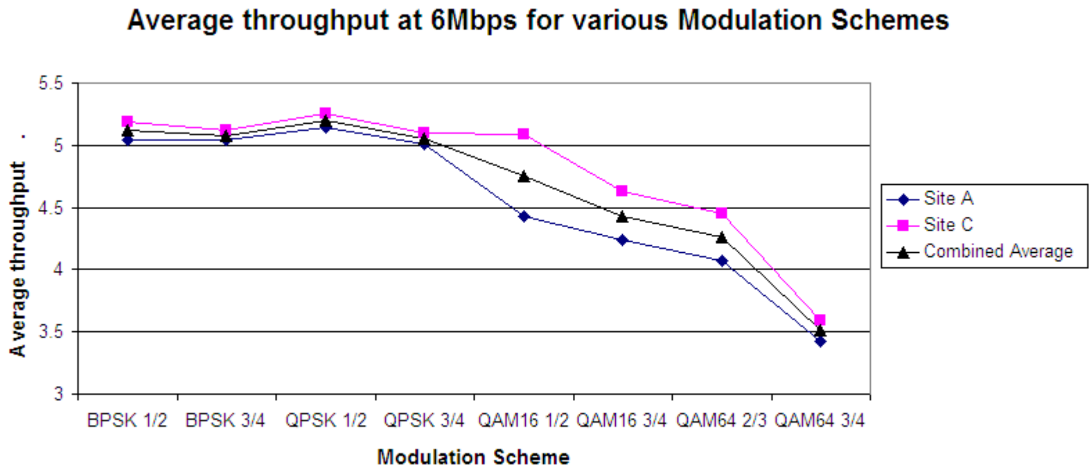

Fig. 2. Average throughput of sites A and C vs the basic modulation scheme

after which data rates begin to decrease (see Fig. 2). In Fig. 2 we can see that the first four modulation schemes throughputs are very close, the following three show a greater difference and the final ones are very close again. The difference in throughput between the two sites is believed to be as a result of heavy rainfall during the QAM16 1/2 to QAM64 2/3 tests. During the test for QAM64 3/4, the rain had once again stopped. The maximum average data throughput rate achieved was 5.2 Mbps. While the increase in the average data rates for sites A and C are not very much, between 0.1 and 0.2 Mbps, some of the individual burst speeds of traffic are much higher, at 5.4, 5.5 and 5.6 Mbps. In Fig. 3 we can see some of these bursts for site C (circled on the graph), while another site – not specifically included in this paper (site D) – showed traffic bursts of up 700 KBps, which translates to 5.6 Mbps (see Fig. 4). In Figure 2 the results for site C are greater than site A, even though A is closer than C. We assume that this uncharacteristic result is because the LOS from A to the base station is not as clear as it is from C to the base station.

The increase, followed by decrease, in data rates as we changed the modulation scheme confirms our theory that as we increase the data rate limit, more complex modulation schemes are employed in order to attempt to increase the data rates to the individual subscriber units but this results in lower data rate throughputs. Thus, for each environment there will be a ”sweet spot” at which maximum throughput is achieved for a particular data rate limit and basic modulation scheme. It is also important to note that at the time of conducting the tests the base station was servicing six subscriber stations, none of which seemed to suffer any adverse effects from the bandwidth usage of the other subscribers. This is a definite improvement over Wi-Fi (802.11) networks, where if one subscriber is making extensive use of the shared medium all other subscribers experience a marked decrease in throughput, reliability and latency. (The main reason for this is that the WiMAX base station polls the subscriber units and each has specific time slots for transmitting, while a Wi-Fi client will attempt to send data when it thinks the shared medium is free, and this can result in crippling interference and degradation of the network when hidden nodes are present [32], [33].)

In addition to ascertaining data rates, reliability and latency were tested. It was found that on average, at both site A and site C we measured a reliability of 99.79 %. This was determined using ICMP packets: 10 packets were sent out every minute and the number of packets returned were recorded over a three month period. ICMP packets were also used to determine the overall latency on the two links, recording the round-trip time for the packets to traverse to the subscriber units and back again. On average this was found to be approximately 43 ms, well under the 150 ms required

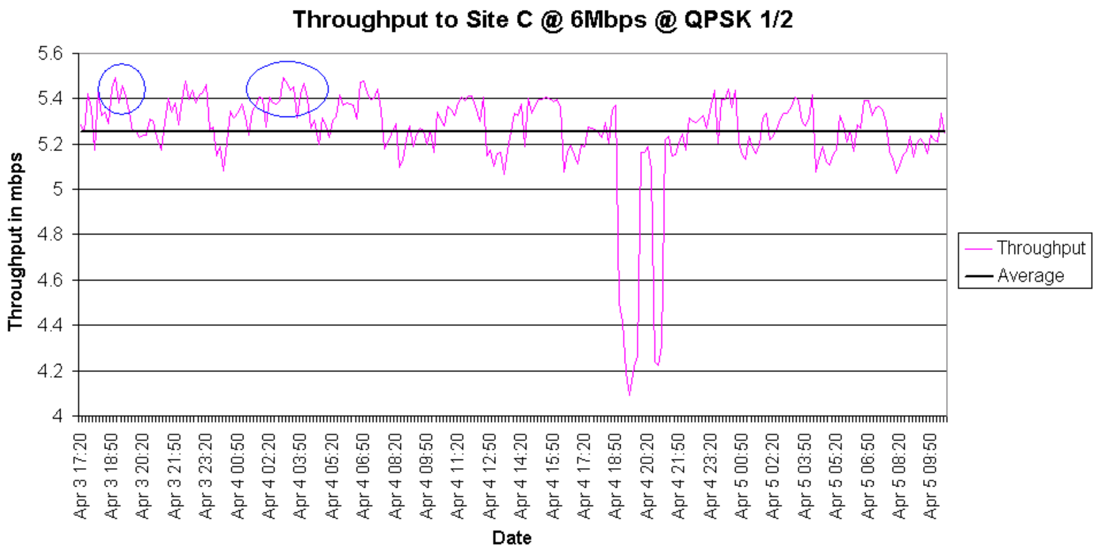

Fig. 3. Throughput to site C at 6 Mbps data rate limit and basic modulation scheme at QPSK 1/2

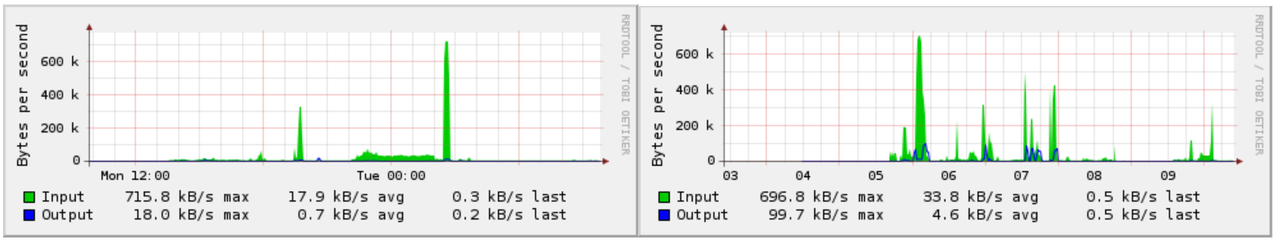

Fig. 4. Traffic bursts on the Alvarion network with QPSK 1/2 and QPSK 3/4 at the additional site D on the network, on 24-hour and 7-day timescales. Graphs show total traffic over the link

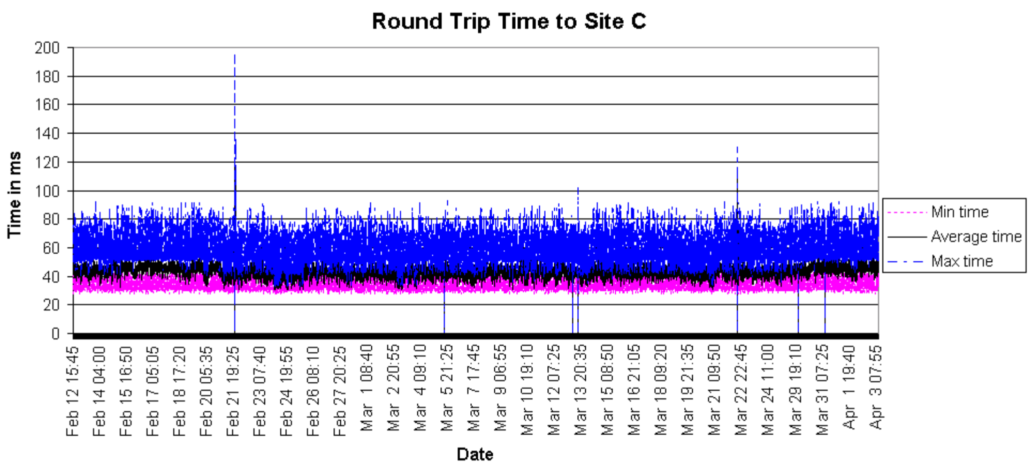

Fig. 5. Round trip time to site C

for voice conversations (see Fig. 5). More extensive research has been conducted last year by the authors [34], [35] into the quality of service (QoS) that the Alvarion BreezeMAX offers to latency and reliability sensitive services. It was found that ”Alvarion’s implementation of handling quality of service proved to be robust. There was a definite improvement on the performance of all application classes when quality of service was in play. This was evident in the in the individual application tests as well as on the triple-play feasibility test [35]”.

While we could not obtain data rates greater than 6 Mbps using the Alvarion BreezeMAX in real life settings, we were able to obtain data rates that are higher than any other broadband product currently on offer in the South African market. Furthermore, the high reliability and low latency lend the technology to supporting real-time interactive services such as Voice over IP, Video streaming and on-line gaming, important services for broadband.

V. Conclusion

From the experiments conducted using the Alvarion BreezeMAX we found that while we were unable to achieve data throughput rates of 12.7 Mbps in the field, as specified in the Alvarion BreezeMAX systems manual, we were able to achieve throughput burst speeds of up to 5.6 Mbps, with overall average speeds of 5.2 Mbps. These data throughput rates were achieved with the data rate limit set to 6 Mbps and the basic modulation scheme at QSPK 1/2.

In addition, at the time of testing, the base station had six subscriber units associated, each with the same subscriber profile. None of the subscribers seemed to experience any negative side effects from the extensive bandwidth use of other clients. Finally, the reliability and latency of the Alvarion BreezeMAX network clearly lends itself to use in providing services such as VoIP, video streaming and on-line gaming. Together with sufficient broadband data rates and the capability of servicing multiple clients the Alvarion BreezeMAX technology would provide a suitable telecommunications network both within urban and rural environments in South Africa.

VI. Acknowledgments

We thank Peter Beyleveld and Warren Tendaupenyu who, as Computer Science Honours students at Rhodes University in 2006, lay the ground work for this research and did a number of physical equipment installations as well as software settings as part of their Honours project work.

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