# Models of Internet connectivity for secondary schools in the Grahamstown Circuit

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# Abstract

Information and Communication Technologies (ICTs) are becoming more pervasive in South African schools and are increasingly considered valuable tools in education, promoting the development of higher cognitive processes and allowing teachers and learners access to a plethora of information. This study investigates models of Internet connectivity for secondary schools in the Grahamstown Circuit. The various networking technologies currently available to South African schools, or likely to become available to South African schools in the future, are described along with the telecommunications legislation which governs their use in South Africa. Furthermore, current ICT in education projects taking place in South Africa are described together with current ICT in education policy in South Africa. This information forms the backdrop of a detailed schools survey that was conducted at all the 13 secondary schools in the Grahamstown Circuit and enriched with experimental work in the provision of metropolitan network links to selected schools, mostly via Wi-Fi. The result of the investigation is the proposal of a Grahamstown Circuit Metropolitan Education Network.

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# Chapter 1

# Introduction: setting the scene

## 1.1 Background

Computers are increasingly considered as valuable tools in education, not only for the purpose of administration but also for teaching and learning. Computers can aid learners in projects, both in the research, through the use of the Internet, and the actual project creation itself, through the use of software such as word processors for report production, or slideshow applications for producing presentations of their work. For the teacher, computers can aid in their administrative work as well as in lesson preparation. They can make use of software such as word processors or graphical editors to create, for example, worksheets and handouts, as well as making use of databases and spreadsheets in order to keep track of the marks and performance of their classes. “It is felt that [computers] can increase not only the effectiveness of the educational process but also its overall efficiency, whether in terms of classroom activities or administration. The possibilities they offer have the potential to transform the organisation and structure of schooling and may promote the development of higher cognitive processes” [1].

In 1996, Summerly and Marquard [2] investigated the use of the Internet in South African schools. The survey was entitled “1996 SA School Connectivity Review” and looked at school connectivity to the Internet from a technical and infrastructural point of view. The research questions that were posed were:

- how many schools have Internet access?
- what sort of access do they have?
- who are the providers of school Internet access?
- what school-related networking infrastructure is in place?

All nine provinces were included in the survey. According to Summerly and Marquard’s findings, Internet access was heavily concentrated in four of the nine provinces, namely the Western Cape, Gauteng, the Eastern Cape and KwaZulu-Natal. Only a very small percentage of South African schools had Internet connectivity – approximately 1 % of the total number of schools at that time in South Africa, of which the Western Cape accounted for 53 %, Gauteng 20 %, the Eastern Cape 18 % and KwaZulu-Natal 8 %. The remaining 1 % was divided up amongst the remaining five provinces. These disparities across the provinces were due to activities of school networking organisations in the regions; the distribution of tertiary institutions, which provided backbone connections to the schools as well as technical support, and non-ICT related problems, e.g. the relative affluence of schools in the area. They further found that, of the schools that were connected to the Internet, most had relatively poor connectivity, as they could not provide all members of the school with email facilities or access to the World Wide Web (WWW) [2].

Later, a survey published in 2000, entitled “Computers in Schools: A national survey of Information Communication Technology in South African schools”, conducted by the Education Policy Unit of the University of the Western Cape and the International Development Research Centre, showed that “the effective use of ICTs in a country impacts strongly on the competitiveness of that economy within the global marketplace as well as the ability of governments to deliver on their social goals. The development of ICTs in education are seen as an important priority by most countries [3, p2].” The survey also found that, no matter what the country’s stage of development, factors which accompany successful implementation of ICTs in schools include networks of connectivity and structured and continuous programs that work to educate and train teachers to make effective use of the technology for teaching and administrative purposes [3]. Networking and specifically connectivity to the Internet open up a world of information and opportunities for communication. In the schooling environment this means that not only are computers tools for producing reports and making presentations, but computers also facilitate research and provide access to knowledge repositories for teachers and learners.

This survey established that schools in the Western Cape and Gauteng provinces had on average a better ICT infrastructure than schools in the other seven provinces. Schools in the Free State, KwaZulu-Natal, Mpumalanga and the North West Province had an intermediate position in terms of ICT resources, while schools in the Eastern Cape, Northern Cape and the Northern Province were the worst off [4]. They noted that the connectivity to the Internet tended to mirror the ICT infrastructure found in each province. The survey also showed that email facilities were being used extensively in many schools as a management and administrative resource, as well as a teaching resource. Use of the Internet was widespread across a spectrum of schools in all the nine provinces of the country, with Gauteng and the Western Cape having the greatest access [4]. This was an improvement from the findings of Summerly and Marquard.

Further findings from the 2000 survey indicated that the number of schools in the country with at least one computer was 2311 out of a total of 21032 schools in the country (11 %). Of this number, 212 schools were within the Eastern Cape, that is 9.2 % of the total. There were 5880 schools in the Eastern Cape at the time of the 2000 survey, meaning that 3.6 % of the Eastern Cape schools had at least one computer [4].

In addition, the 2000 survey indicated that schools with ICT resources are primarily located in urban areas and that there is a stark inequality between urban and rural schools [4]. Urban schools tend to be better off than those found in the rural areas. In the Eastern Cape, the majority of schools tend to be rural and as such experience difficulty in obtaining ICT infrastructure and Internet connectivity.

A more recent survey was conducted into the number of computers available in schools for teaching and learning, the results of which were published in the e-Education White Paper published in 2004 [5]. The White Paper states that 8.8 % of schools in the Eastern Cape have computers, while only 4.5 % have computers for the use in teaching and learning [5]. This survey differs from the previous survey of 2000 because it does not just look at the total number of computers within the schools but also ascertains how many of those are available for teaching and learning. These values are an improvement on the figures found in the 2000 survey.

In summary, over the last ten years after the end of Apartheid, more and more previously disadvantaged schools seem to have acquired computers and ICT infrastructure nationally. However, there are still some schools that are unaware of how to go about acquiring ICT infrastructure and, furthermore, schools tend to be unaware of the necessary infrastructure required and complexities in having and maintaining ICT facilities. In addition, the infrastructure found in schools, can be unsuitable for teaching and learning purposes.

Thus there seems to be a general lack of understanding in both the technical aspects of ICT infrastructure necessary in schools to make facilities work best, as well as a lack of educational understanding in using it appropriately in teaching and learning. This lack of understanding is reflected in ICT education policies (or a lack thereof) that do not cover in adequate detail the steps that schools have to take in order to obtain appropriate ICT facilities. In some cases computers have been donated to schools and left there, with no thought given to proper planning in order to satisfy the teaching and learning needs of the school.

There is an urgent need in South Africa for an understanding of both the ICT educational needs of a school and the technology that could support those needs. The Grahamstown Circuit appears to be an ideal region for conducting research of this nature, for various reasons. There are 13 secondary schools in the Grahamstown Circuit, ranging from the affluent independent schools to the previously disadvantaged former Department of Education and Training (DET) schools, providing a microcosm of the schooling system in South Africa. In addition, both the Education Department and the Computer Science Department - through the auspices of the Centre of Excellence (CoE) - of Rhodes University have good relations with the majority of the schools in the Grahamstown Circuit, providing the necessary relationships on which the study is built.

The focus of this research project has been to study models of Internet connectivity to schools, looking to find the best possible solutions for schools in the Grahamstown Circuit in the Eastern Cape. Further, it includes an investigation into the networking and ICT infrastructure within the schools. This study attempts to bring the two camps of Computer Science and Education together, to understand the educational needs of the schools in the Grahamstown Circuit and then to use this information to inform the network and ICT infrastructure suggestions for the schools.

Finally, this project contributes to a wider project that is being sponsored by the National Research Foundation (NRF). The aim of the NRF project is the identification of the infrastructural, policy, pedagogical and learner-related issues that influence the integration of ICT into the curriculum in the Grahamstown Circuit. Master of Education (MEd) students Nikiwe Maholwana-Sotashe and Nombeko Mbane, who are studying methods of successful integration of ICT into the curriculum, also contributed to the wider NRF project.

## 1.2 Research design

### 1.2.1 Research aims and main outcome

This research aims to establish the most cost-effective and organisationally-sound means of networking computer facilities of schools in the Grahamstown Circuit in the Eastern Cape.

The objectives of the study were to investigate the infrastructure requirements necessary for appropriate ICT facilities in schools. Furthermore, to identify appropriate Internet connectivity methods that could be deployed by or to schools in the Grahamstown Circuit based on the schools' current situation and educational needs. Factors which affect how a school acquires and employs ICT infrastructure include the school category or type, the school's geographical situation, socio-economic status; the availability of a champion IT teacher or specialist and its intended use.

This study also draws attention to the shortfalls in policy governing various aspects of using ICT in education, namely, ICT in education policies and telecommunication policies. In terms of the ICT in education policies this study draws attention to the gaps in the policies, while in terms of the telecommunication policies the study highlights how current telecommunications policies and regulations tend to reinforce the digital divide.

The outcome of this project is to produce a practical plan that could be applied to all Grahamstown Circuit schools, tailoring a solution to the individual situation. It is hoped that it will result in schools having the best (or most appropriate) Internet connectivity and networking as well as computer facilities for their particular situation and that the maximum potential will be obtained from these facilities.

A possible solution to the problems of ICT in schools that will be proposed, is an education network that would connect all the Grahamstown schools together and to the Internet. This would allow all schools access to the resources of the Internet as well as encouraging collaboration amongst all involved. Furthermore, such an education network would need to be designed in such a way that the needs and concerns of the schools are met in full, in line with the various schools' ICT visions.

### 1.2.2 Research questions

The main research question is:

What networking technologies and models can support secondary schools in the Grahamstown Circuit in implementing their vision for integrating ICT into schools?

The subsidiary questions arising out of the main question are:

- What ICT infrastructure and computer networking technologies already exist in the schools?
- What are the infrastructural issues that the school principal, teachers, learners, parents and the state face in introducing ICT and Internet connectivity into schools?
- How can these infrastructural and connectivity challenges be overcome?
- What network technologies can be used in the Grahamstown Circuit in order to connect schools to the Internet?
- How exactly can those network technologies be used to gain maximum efficiency from them?

### 1.2.3 Methodology

This study attempts to bridge the disciplines of both Social Science and Computer Science. This is reflected in the methodology, employing a survey to gather information about the Grahamstown Circuit schools and deploying and testing real or simulated networks, within the framework of action research.

The survey involved all thirteen secondary schools in the Grahamstown Circuit and attempted to ascertain their current ICT infrastructure as well as their ICT infrastructure desires. A 'desktop survey' of the network connectivity options was undertaken concurrently. This 'desktop survey' was subsequently used to inform the deployment of various network technologies to selected schools and the characteristics of these networks were then tested.

Together, these methods are used to propose an education network in chapter 7. A complete discussion of the research methodology of this study is presented in chapter 4.

## 1.3 Structure of thesis

This thesis describes the work done in order to answer the research questions as best as possible. Its structure is depicted in Figure 1.1.

Chapter 2 is technical in orientation and presents an overview of the various networking technology solutions, both wired and wireless, that are currently available or have the highest possibility of being available in the foreseeable future in South Africa. Current and future telecommunications legislation in South Africa is also presented and the sections and gaps that are pertinent to schools adopting ICTs are highlighted.

Chapter 3 is educational in orientation and discusses the possibilities afforded by networks to schools. The chapter covers the current ICT-in-education projects taking place in South Africa, while briefly looking

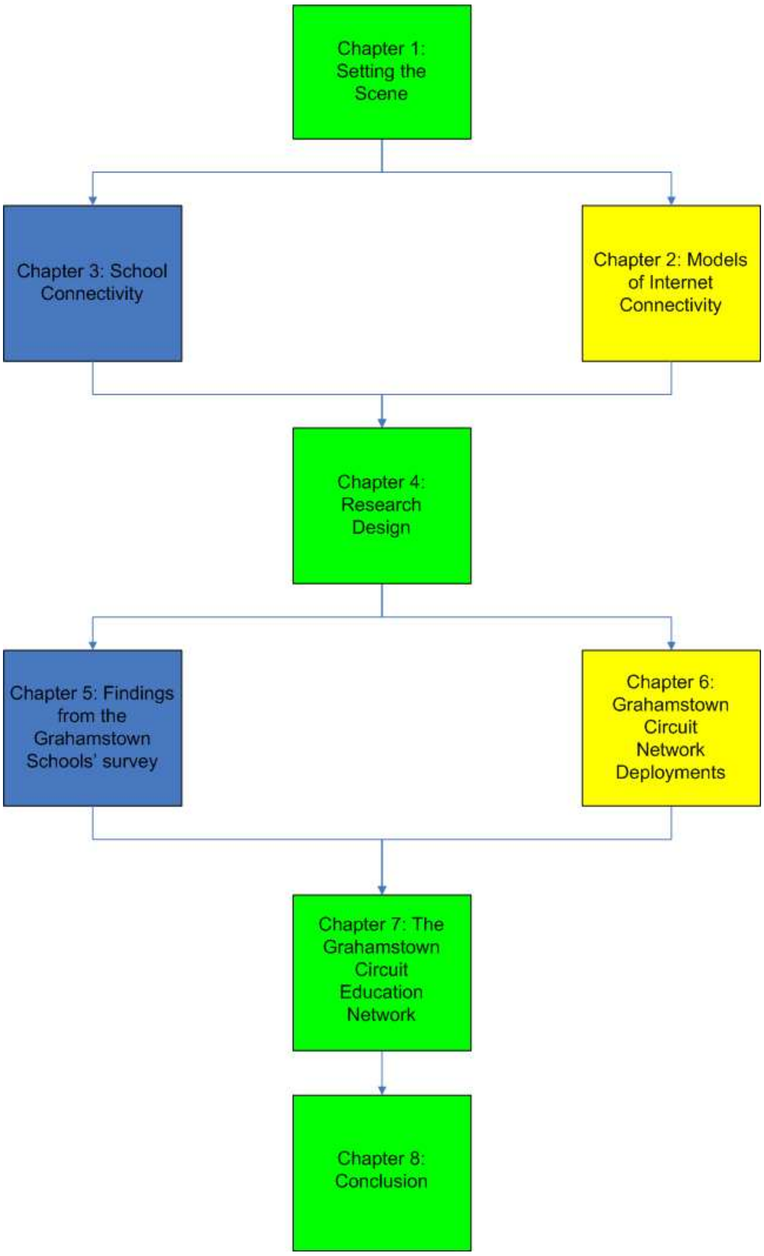


Figure 1.1: The structure of this dissertation.

The blue chapters are predominately education in orientation while the yellow chapters are computer science in orientation. The green chapters are those that attempt to bridge the two disciplines in order to draw from their specific insights into ICTs in education.

at what is happening in the international arena. The discussion also covers the current ICT-in-education policies and the perceived gaps within those policies, and suggests ways to fill them.

Chapter 4 presents the research design underpinning this study. The chapter presents the orientation of the research undertaken, introducing the research site and participants. Furthermore, it presents the research methodologies, tools and activities as well as the data analysis methods employed in this study. Chapter 4 attempts to bridge the technical and educational components of this study.

Chapter 5 is largely educational in orientation and describes the results of the survey of the Grahamstown Circuit schools. The survey employed questionnaires, semi-structured interviews and observations (in the form of an on-site audit) in order to collect the necessary data. The chapter highlights issues raised by the IT teachers/specialists at the 13 Grahamstown Circuit secondary schools in ICT infrastructure deployment and use. Issues pertaining to network connectivity are naturally of particular interest in this study.

Chapter 6 is predominantly technical in its orientation and examines the network deployments undertaken in the Grahamstown Circuit. This chapter presents the deployments and the results of network tests performed on the deployed networks. Furthermore, it entertains alternative network solutions to those currently deployed in the Circuit. This chapter highlights network lessons learnt that could be used in creating a network solution for the secondary schools in the Grahamstown Circuit.

Chapter 7 presents the proposed Internet model of connectivity for secondary schools in the Grahamstown Circuit. This chapter draws on what was learnt in Chapter 5, the schools' survey and Chapter 6, the Grahamstown Circuit network deployments. It attempts to bridge both the technical and educational components of this study and provides recommendations on how schools in this Circuit can be connected to the Internet, as well as how to go about acquiring the necessary ICT infrastructure.

Chapter 8 concludes this dissertation by re-examining the initial research questions and research objectives and discussing how these questions were answered and objectives met. In addition, it discusses future research that could be undertaken in this area.

# Chapter 2

# Technologies for achieving connectivity

## 2.1 Introduction

A computer network is a group of computers linked together to share information. Networks can consist of a number of linked computers in a specific physical location, called a Local Area Network (LAN), or they could consist of computers located at different physical sites linked together by means of phone lines and modems or other forms of long-distance communications, to form a Wider Area Network (WAN) [6]. When a wider area network spans a town/city/metropolitan, it is referred to as a Metropolitan Area Network (MAN).

There are numerous wired and wireless methods for connecting schools, and indeed any organisation or individual throughout the world, to the Internet. These technologies range from narrowband to broadband solutions at varying costs. Availability of these technologies often depends on the financial situation of a country and the priorities of that country, their history and their communications policies and regulations. South Africa finds itself in a unique situation in that it is both a first world and a third world country. Large urban areas such as Johannesburg and Cape Town are very nearly, if not, first world living environments, while in the more rural areas of the Eastern Cape, KwaZulu-Natal, Limpopo and Northern Cape, some South Africans live well below the poverty line. This situation plays a significant role in determining what kinds of communication technologies are available in an area, if there are any at all. Furthermore, restrictive regulation in the telecommunications sector limits available communications technologies. Thus when communication technologies are discussed, this work only looks at those that are readily available in South Africa - certain wired technologies - and those that have the greatest potential of becoming available - in the wireless technology arena.

This chapter will look at various communications technologies, both wired and wireless, that are currently available to South African schools or are likely to become available to South African schools in the future. Following the discussion of such technologies there will be a discussion on telecommunication policies in South Africa and how such policies affect the connectivity options of South African schools.

## 2.2 Wired communications

Wired communication technologies are those which allow for communication across a physical medium, i.e. a “wire” of some sorts. There are numerous wired communication technologies in the world today, but not all of them are available in South Africa. Currently, South Africa has only one fixed-line service provider, Telkom. Each technology will be explored individually and their advantages and disadvantages discussed.

The discussion begins with the older technologies, so-called legacy technologies, and moves onto the more recent technologies available in South Africa.

### 2.2.1 Analogue dial-up

The main (most common) form of Internet connectivity in South Africa is Analogue dial-up [7]. Analogue dial-up typically involves two modems and a telephone line. The customer of an Internet Service Provider (ISP) will use his/her modem and telephone line to reach the ISP, which in turn will terminate the Point-to-Point protocol (PPP), extract the TCP/IP (Transmission Control Protocol / Internet Protocol) packets and route them to the Internet [8, 9].

**Advantages of analogue dial-up** Firstly, analogue dial-up technology is cheap, particularly for people who only wish to read their mail and work minimally on the World Wide Web (WWW). Secondly, dial-up tends to be pervasive in urban areas and in some rural areas of South Africa [10]. Lastly, the local loop for telephone lines, i.e. the distance from the customer to the exchange, can be relatively long (although, the longer the local loop the greater the loss of information).

**Disadvantages of analogue dial-up** The main disadvantage of dial-up is that it is narrow-band, with a maximum download speed of 56 Kbps and maximum upload of 33.6 Kbps. If substantial use is made of the Internet connection, then the user will be paying more than they would with an "always on" broadband Internet connection [11]. Such a disadvantage will be noticeable to schools where, given the chance, children will make extensive use of the Internet for research and email purposes, resulting in slowed connection speeds and increased expenses (See Appendix B for a comparison of Dial-up and ADSL costs in South Africa).

Another disadvantage is that the more rural areas have limited wired telecommunications infrastructure [12], i.e. copper cable/optical fibre would have to be laid underground and exchanges built. The costs incurred in laying new copper cable/optical fibre and building such exchanges is high compared to potential revenue and is therefore unattractive to telecommunication companies. A further disadvantage of wired Internet connections in disadvantaged areas of the country is the high probability of poor quality copper cable, which results in bad data lines, as well as copper cable theft [13, 14, 15].

*In order to circumvent some of the disadvantages of dial-up, the digital version of dial-up, Integrated Services Digital Network (ISDN), was developed.*

### 2.2.2 ISDN

Integrated Services Digital Network (ISDN) is designed to support various communication functions, including voice, data and video on a single integrated network [16]. ISDN provides a method to best use the Plain Old Telephone System (POTS) by dedicating lines for pure data-centric or high-quality hybrid applications. ISDN was created to facilitate an environment to integrate voice and data traffic in the Public Switched Telephone Network (PSTN) end-to-end network [17]. ISDN works in much the same way as dial-up in that there are two ISDN interfaces on either end of an ISDN line, TCP/IP packets are encapsulated in PPP packets and transmitted over the line. At the other end the TCP/IP will be extracted and routed to the Internet. ISDN provides two types of subscriber interfaces, the basic rate interface (BRI) and the primary rate interface (PRI) [18].

ISDN BRI consists of two 64 Kbps channels, which are commonly referred to as bearer (B) channels and a 16 Kbps signalling channel, commonly referred to as a data link (D) channel. The two B channels are commonly used for the transmission of voice and/or data, while the D channel is used to control the switching of the two B channels [16].

In North America and Japan, ISDN PRI consists of twenty-three B channels and one D channel, each of which operate at 64 Kbps, which corresponds to a T1 (1.5 Mbps) connection. In all other countries offering ISDN PRI, including South Africa, there are thirty B channels and 1 D channel, also operating at 64 Kbps, which corresponds to an E1 (2 Mbps) connection. As with the case of the BRI, the B channels are for voice and/or data and the D channel for control [16, 18].

**Advantages of ISDN** The main advantage of ISDN is the improved bandwidth from regular dial-up. With entry-level ISDN BRI, speeds of up to 128 Kbps full duplex (2 x 64 Kbps channels) are possible, paying the same price per call per channel as on a normal phone line [16], but the rental will be higher than dial-up over POTS. For schools, these advantages would result in broadband access for the schools, but for those schools which would make extensive use of the connection, the price would still be higher than other "always on" broadband options.

**Disadvantages of ISDN** The disadvantages of ISDN are similar to that of regular dial-up. In addition, ISDN has a local loop limit of 6-8km [19].

*With the costs incurred in using "dial-up" technologies extensively this dissertation now looks to "always on" connectivity technologies, such as those of the Digital Subscriber Line range.*

### 2.2.3 DSL

Digital Subscriber Lines (DSL) provide high bit rate digital services over ordinary telephone lines. DSL is an evolutionary technology built on the POTS infrastructure [17, 19]. DSL is a generic term for a set of technologies that use an additional 1 MHz of bandwidth on the POTS to connect the customer's premises to that of the exchange of the telecommunication company. DSL does not affect or make use of the 3 KHz band on the POTS, which is used for transmitting voice traffic along the copper cable or shielded twisted pair (STP) [17]. Worldwide, the leading technology used for last mile broadband is DSL [20]. The last mile refers to the connection from an exchange to a private premises of a user.

With DSL, both data and analogue voice travel over the same piece of copper cable. Voice is transmitted over low bands of frequency, 0 - 4 KHz, while data is transmitted over the higher frequencies, typically 10 KHz - 1 MHz. The DSL connection enters the user's premises through a high-pass filter that recognises a high-frequency band for data traffic and bypasses a low-frequency band for voice traffic during a traditional phone call. Therefore, DSL is able to provide high speeds for Internet access (in comparison with standard dial-up) without interrupting voice calls [17, 19]. This results in speeds of 100 Kbps to 10s of Mbps [19].

The DSL Access Multiplexer (DSLAM) concentrates a number of DSL subscriber lines onto a single Asynchronous Transfer Mode (ATM) line connected via a router or switch to the provider's ATM backbone network. DSL is a relatively popular network with service providers as it allows up to 8 Mbps data access over existing copper cable infrastructure, while still supporting traditional POTS traffic [17].

There are various DSL transmission types, often denoted as xDSL, where the x represents various letters, depending, for example, on the data rates and symmetry or asymmetry of the DSL service [19]. The various types of DSL services can be categorised broadly into the following two groups:

- Symmetrical
- Asymmetrical

In symmetrical DSL the transmission speeds available for both upstream and downstream communication between source and destination nodes are the same. Examples are high-bit-rate DSL (HDSL), high-bit-rate DSL version 2 (HDSL2) and symmetrical DSL (SDSL) [17].

Asymmetrical services provide different speeds between the two ends of the network. In asymmetrical DSL (ADSL) the upstream communication is implemented on a slower speed of anywhere from 16 to 640 Kbps, while the downstream communication is implemented at higher speeds, such as 1.5 to 8 Mbps, asymmetric services are implemented because there are generally higher data transfers from the server to the client and therefore more bandwidth is needed. Examples of this category are asymmetric DSL (ADSL), rate-adaptive DSL (RADSL), G.Lite and most versions of very-high-data-rate DSL (VDSL) [17].

Currently, in South Africa, the only form of DSL available in the telecommunications market is the Telkom ADSL product, which offers speeds of 1024 Kbps, 512 Kbps, 384 Kbps and 192 Kbps [21].

**Advantages of DSL** The main advantage of DSL is that it allows for faster Internet access over existing copper cable infrastructure, while still supporting traditional voice traffic. For schools which are in urban areas or within 5 km from an exchange the "always on" Internet connection provided by DSL products, while still allowing for voice traffic, is an attractive Internet and telephone connection [22].

**Disadvantages of DSL** The disadvantages of DSL technologies are that they are confined to the local loop and thus cannot be used over distances that exceed 5km. The limitation of 5km for DSL is a major disadvantage in South Africa and rural South African schools that may wish to take advantage of DSL [17].

As with dial-up and ISDN, copper cable theft in South Africa tends to be problematic, as well as the presence of bad quality copper cable, both of which will result in poor or interrupted data transmissions for DSL technologies [17].

Furthermore, by providing DSL network technologies to their customers, telecommunication company's often need to deploy bridge taps/filters in order to service multiple customers. Such filters pose significant challenges to the deployment of xDSL, and all result in signal attenuation [17]. In addition, management, provisioning and billing are all complex issues with DSL networks [17].

*With these disadvantages to most of the telecommunication solutions to connectivity, communication through the use of Power lines is an alternative option.*

### 2.2.4 Powerline communication

Powerline communication (PLC) is a technology that enables broadband data services to be delivered over electricity lines [23] alongside the electric current. PLC is also known as broadband over powerlines and allows for rapid and potentially cheap installation of new telecommunications links through the existing powerline infrastructure [24]. The capital expenditure required to build a communication infrastructure to the end-user is one of the chief inhibitors of first/last mile access technology deployment [17], hence PLC becomes a very attractive solution.

PLC technology has been around since 1920. The early use of PLC was so that electricity companies could communicate with and monitor their power networks [25]. Early PLC allowed for simple things such as "on" or "off" messages to be passed for tasks such as the switching on or off of street lights. However, with the development of complex frequency modulation processes such as OFDM (Orthogonal Frequency Division Multiplexing) together with highly integrated and inexpensive semi-conductor chips, data transmission rates of 1 Mbps and more are possible, which makes PLC a viable option for last mile access.

PLC uses special modems at the customer's premises and at the electrical substations. The modems transmit and receive data at a higher frequency than the 50 Hz to 60 Hz used for AC power, enabling the two signals to coexist on the same line [26]. Through the demand for broadband connections to the Internet and advances in the area of digital signalling, there has been renewed interest in the research and development of PLCs. Data rates have reached up to 4.5 Mbps and 14 Mbps, with rates of 45 Mbps being quoted by some researchers [27]. There is even mention of rates as high as 100 or 200 Mbps in future systems [20].

PLC will make it possible to both phone and surf the Internet over power lines. The benefits are obvious: valuable additional uses without the need for expensive infrastructure investments. In South Africa where we have particularly low teledensities in some areas of the country [12] the option to provide these facilities and services over an already in place infrastructure, such as the electricity grid, is very attractive. Currently, in South Africa, there is a pilot project in PLC taking place in Tshwane Metropolitan area. The aim of the project is to achieve landline access to almost all of South Africa's poor at a third of current prices, delivering voice and data via existing electricity lines. It is hoped that this technology will help to bridge the digital divide in the greater Tshwane area [28, 29].

**Advantages of powerline communications** The advantage of PLC is that it makes use of existing infrastructure by using the existing powerlines. According to the October 2004 issue of the South African Survey, there were 3,4-million electricity connections made to households between 1995 and 2002. Seventy percent of South African households use electricity for lighting (by 2001) while 51 % use electricity for cooking (by 2001) [30]. Thus, potentially 70 % of South Africans could make use of their existing powerlines to their homes to provide additional telephone and data services. For schools which already have electricity, but no telecommunications infrastructure, the benefits are obvious.

**Disadvantages of powerline communications** The obvious disadvantage of PLC is that not all South Africans or South African schools have grid electricity and laying infrastructure will be costly, similar to the laying of new infrastructure by telecommunications companies mentioned earlier. Thus PLCs may not always be attractive to potential electricity providers, as the revenue generated may not cover the expense of laying the infrastructure. Furthermore, if cables will need to be put in place then it might be more worthwhile to establish telephone infrastructure, as DSL and ISDN that currently provide better and more reliable data rates [31].

Additional problems with PLC include the fact that electric powerlines frequently have significant interference caused by surges in voltage or by electrical appliances [32]; the high frequency signals needed for data transmission turn the electric grid into a giant transmitter which radiates waves that interfere with wireless communications [26]; PLC regulations need to be standardised and high bandwidth PLC is still very immature [24]. The copper cable theft problems experienced by telecommunication companies, discussed in dial-up, ISDN and DSL, are also experienced by grid electricity suppliers.

*With all the problems that are faced in acquiring connectivity via copper cable methods (through both traditional telecommunication methods and grid electricity methods) the alternative wired medium of optical fibre is considered.*

### 2.2.5 Optical fibre

A commonly used wired alternative to that of copper cable is optical fibre. Optical fibre uses light, not electricity, to transmit information. Optical fibre solves some of the limitations of using copper wire, namely that copper cable is susceptible to interference, lightning strikes and signal loss or degradation when trying to transmit data over long distances. Thus optical fibre is resistant to electrical noise, while having the capacity to transmit enormous amounts of data. For these reasons Telecommunication companies make use of optical fibre for their long-distance services [33].

Fibre optic cable is composed of three main components: the core, the cladding and a protective outer cover. The core is composed of a very pure glass or plastic material, and the cladding, which surrounds the core, is also made from glass or plastic but it is optically less dense than the core [33].

Light enters the optical fibre by being placed at one end of the fibre. This is usually a laser or a light-emitting diode (LED). Either of these devices produces a pulse of light, typically near the infrared frequency of $10^{14}$ Hz. The laser has a higher power output which allows the light to propagate further than the light produced by a LED. However, LEDs are less expensive and generally last longer. Thus, lasers are normally only used when a high data rate is needed over a long distance. The light source will emit short but rapid pulses that enter the core. The light then travels along the core by bouncing (reflecting) off the boundaries of the fibre. Eventually the light exits the core at the other end and is detected by a sensor [33].

The field of optical fibre communications is large and the research and development vast. For further information on the topic of optical fibre communications see [34, 35].

**Advantages of optical fibre** There are several advantages that optical fibre offers over copper cable and other conducting metals, namely: it can transmit data more quickly; it has very low resistance meaning that signals can travel further without the help of repeaters; it is unaffected by electromagnetic interference as signals are transmitted as light; and it has high resistance to environmental elements [33]. The advantages of optical fibre to schools include high data transmission rates and long-distance coverage.

**Disadvantages of optical fibre** Computers are currently electronic devices, which communicate using electrical signals, thus to use optical fibre requires the conversion of electrical signals to light rays and vice versa [33]. This process adds an extra level of complexity, adding to overall costs of an already expensive technology in South Africa [36], not to mention that “fibre to the home” is not implemented here as it is in some other first world countries such as Japan [37]. Furthermore, it should be noted that optical fibre can have micro irregularities from the manufacturing process which can contribute to an interference known as Polarisation Mode Dispersion (PMD) [38].

Optical fibres are also very small, thin and fragile and this makes them incredibly hard to work with and difficult to tap into or splice together [33], although optical fibre networks are becoming more cost effective.

Unfortunately, the current cost disadvantage of optical fibre solutions greatly outweighs the benefits of transmission rates and long distance coverage for South African schools. However, when considering how first world countries such as Sweden are becoming more densely covered by optical fibre, it is probably only a matter of time before South Africa sees such developments in infrastructure taking place as well.

*Due to the numerous disadvantages of wired solutions in South Africa it is worth considering the potential wireless solutions that may become available within South Africa.*

## 2.3 Wireless communications

Wireless communication is the transmission of information without wires. Wireless communication may use radio or optical transmission for communication. Currently in South Africa, wireless communication is illegal unless you are the holder of a carrier of carriers licence and own the spectrum in which you may operate [39]. However, with the pending deregulation of the sector through the pending convergence bill, wireless communications could become a reality for consumers in South Africa [40, 41]. For these reasons, the technologies discussed below are probable wireless technologies that could be beneficial within the

South African context, once regulations allow for them. The discussion covers a range of technologies starting with those that are extensively used in the world today and moving towards technologies of the future.

### 2.3.1 IEEE 802.11 (WiFi)

The IEEE 802.11 standard is part of a family of standards for local and metropolitan area networks. This family of standards deals with the Physical (PHY) and Data Link layers (also known as the Medium Access Control (MAC)) as defined by the International Organisation for Standardisation (ISO) Open Systems Interconnection (OSI) Basic Reference Model. This standard defines the protocol and compatible interconnection of data communication equipment via the air, radio or infrared in a local area network (LAN) using the carrier sense multiple access protocol with collision avoidance (CSMA/CA) medium sharing mechanism [42]. It defines the PHY and MAC layers so that they are compatible with the existing standards for higher layers (Logical Link Control and higher) [43] allowing stations to move and roam freely through a wireless LAN (WLAN) and still appear stationary to the Logical Link Control (LLC) sub-layer and above. This allows existing network protocols such as TCP/IP to operate transparently over IEEE 802.11 WLANs without any special considerations [44].

The IEEE 802.11 architecture consists of several components that interact to provide a wireless LAN. The coverage area (also known as the basic service set (BSS)) is the basic building block of an IEEE 802.11 LAN. Within the coverage area of BSS, stations (a station is any device that contains an IEEE 802.11 conforming MAC and PHY interface to the wireless medium) may communicate directly with other members of the BSS. Should a station leave the BSS, direct communication will cease. To become a member of a coverage area, a station is (dynamically) “associated” [42] with a single server, called an Access point (AP) [43].

The basic form of BSS is a stand-alone, however it is possible to connect many BSS to each other through a distribution system. A distribution system is defined as a system used to interconnect BSSs and integrated local area networks (LANs) to create an extended service set (ESS). The access points are the stations that provide access to the distribution system, allowing data to move from the coverage area of the AP to the distribution system, via the AP [42].

IEEE 802.11 WLANs can be integrated with a traditional wired LAN through a portal. A portal is a logical point at which packets/data from wired LANs (of some sort) can enter an IEEE 802.11 WLAN’s distribution system. Thus the portal provides logical integration between the IEEE 802.11 architecture and the existing wired LAN. A portal can also act as an AP, as is the case when the distribution system happens to be a wired LAN.

IEEE 802.11b of 1999 extends the IEEE 802.11 standard (1997) by building on the data rate capabilities to provide 5.5 Mbps and 11 Mbps payload data rates in addition to the 1 Mbps and 2 Mbps rates [45]. The IEEE 802.11g of 2003 further extends the 802.11 standard, building on the payload data rates of 1 and 2 Mbps that use direct sequence spread spectrum (DSSS) modulation and builds on the payload data rates of the 1, 2, 5.5 and 11 Mbps that use DSSS, complementary code keying (CCK) and optional packet binary convolutional coding (PBCC) modulations. The extended rates of 802.11g provide additional payload data rates of 6, 9, 12, 18, 24, 36, 48 and 54 Mbps [46].

For more in-depth detail about the IEEE 802.11 standard, and its “b” and “g” extensions, see [42, 45, 46].

**Advantages of 802.11** There are several advantages to using the IEEE 802.11 standards, namely cost, standardisation and interoperability (as with Analogue dial-up, ISDN and other wired solutions) and certain wireless advantages over wired infrastructures. Standardisation and interoperability make such networks cost-effective and easy to deploy and manage.

The advantages of wireless communications over wired communications are similar to those of standardisation and interoperability, namely cost and ease of deployment. While the infrastructural costs of wired solutions tend to be high and often not attractive when potential revenue may not be high [17], wireless technologies result in less financial pressures due to minimal infrastructural deployment when compared with wired counterparts [47].

The low cost, ease of use and ubiquitous nature of wireless technologies, and indeed of the IEEE 802.11 standard, make them attractive to schools that do not necessarily have sufficient money or expertise.

**Disadvantages of 802.11** The greatest disadvantage of 802.11 as a WAN or MAN wireless network, is that it is specifically designed to be a LAN network standard and thus not particularly suited to covering distances longer than 100 m [42]. However, the 802.11 technology can and has been stretched to cover much larger distances in the range of kilometres. In such instances it involves signal boosting to stretch beyond regulation limitations. For this reason rural schools, which are not within the access loop of an exchange, may find this problematic. WiFi is also not a good provider of long-distance back-haul and for deep rural schools it may not be a good solution. Furthermore, schools in urban areas may choose wired counterpart products, such as DSL or ISDN, as they offer better reliability within metropolitan distances when compared to WiFi.

Another important disadvantage to 802.11 is interference. Interference problems within the 802.11 radio frequency range tend to be substantial as many other household appliances operate in the same range – 2.4GHz is the Industrial, Scientific and Medical (ISM) band. This can result in an unreliable signal for a school. Common examples of equipment which use the ISM band are microwaves, electric door openers and car alarms.

In addition, wireless communication is not permitted unless you are the holder of a carrier of carriers licence [39]. Telkom and the SNO (Second Network Operator) are currently the only licences holders and are not selling any wireless services as yet. However, Sentech has an unique multimedia licence [41], which allows them to provide wireless communications. Sentech 3G wireless services are currently not available countrywide, but rather are concentrated in the major cities of South Africa.

*With the need to improve on signal strength and decrease interference as well as to cover larger distances than 100 m, and maintain regulations limitations, the newer IEEE specification for wireless transmission, 802.16, need to be considered.*

### 2.3.2 IEEE 802.16 (WiMAX)

Broadband wireless access (BWA) generally refers to fixed radio systems used primarily to convey broadband services between users' premises and core networks. IEEE 802.16, otherwise known as WiMAX, is such a method of wireless access. A typical Fixed BWA (FBWA) network supports connections to many user premises within a radio coverage area [48] of 31 - 50 miles [49] (49.9 - 80.5 kilometres). It provides a pool of bandwidth, shared automatically among the users. Such networks deliver significant bandwidth-on-demand to many users with a high level of spectrum efficiency [48]. Often significant frequency reuse is employed. The range of applications that such networks can support is wide and evolving all the time. They include voice, data, and entertainment services of many kinds. Traffic flow may be unidirectional, asymmetrical, or symmetrical, or change with time [48].

FBWA systems often employ Multipoint (MP) architectures. MP includes point-to-multipoint (PTMP) and mesh. PTMP is a topology where a base station (BS) services multiple geographically separated subscriber stations (SSs), and each SS is permanently associated with only one BS, while mesh is a wireless network topology in which a number of subscriber stations (SSs) within a geographic area are interconnected and can act as repeater stations (RSs) [48]. The IEEE 802.16 Working Group on Broadband Wireless Access has developed standards containing a fully specified air interface for PTMP (2 - 66 GHz) and mesh (2 - 11 GHz) systems. Similar standards have been developed within the HiperACCESS and HiperMAN working groups of the European Telecommunications Standards Institute (ETSI) Broadband Radio Access Networks Project. In addition, a number of proprietary FBWA systems exist for which the air interface is not standardised [48].

FBWA systems typically include at least one base station (BS), a number of subscriber stations (SSs), terminal equipment (TE), core network equipment, inter-cell links, repeater stations (RSs), and possibly other equipment [48]. The base station connects to the network backbone and uses an outdoor antenna to send and receive high-speed data and voice to subscriber equipment, thereby eliminating the need for extensive and expensive wireline infrastructure and providing a flexible and potentially cost-effective last-mile solutions [50]. In a PTMP system, RSs are generally used to improve coverage to locations where the BS(s) have no line of sight (LOS) or to extend coverage of a particular BS beyond its normal transmission range [48].

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 the line of sight environments [51]. It targets an average bandwidth performance of 70 Mbps and peak rates up to 268 Mbps [52]. Wavelengths in this region become shorter and shorter resulting in an increase in attenuation of the signal when propagated through the air and are often affected by atmospheric conditions - rain in particular [53]. Trees and buildings are also problematic and result in an increase in signal degradation [53]. In cities where there are many tall 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 which operates in the 2 - 11 GHz spectrum and thus suffers less from the above mentioned problems of attenuation and necessary LOS [53].

The 802.16a collection of amendments took into account the emergence of licensed and licence-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 [52]. 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 [51]. 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 [51]. It provides up to 50 kilometres 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 thousands of homes with DSL-type (512 Kbps) connectivity with a single base station [50, 51].

Support for NLOS performance was one of primary PHY (physical layer) differences in 802.16a as well as being able to operate in lower frequencies [51]. The OFDM signalling 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 [51]. 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 [53].

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 [48], [54], [49] and [53] amongst others.

**Advantages of 802.16** Similar advantages that were noted for the IEEE 802.11 standards can be noted here for the IEEE 802.16 standards. Additional advantages are that WiMAX is designed to be a MAN/WAN technology and as such will be better at creating WAN networks than that of WiFi. While according to [55], the main advantage of FBWA technologies over wired systems results mainly from the high costs of the labour intensive deployment of cables. “A 200-square-kilometre service area costs a DSL provider over $11 million. The same area can be served wirelessly for about $450,000 [55].”

**Disadvantages of 802.16** While the IEEE 802.16 standard for wireless communication better addresses the issues found in the IEEE 802.11 standard, such as interference and distance, these improvements are still going to be limited to some degree. As mentioned previously, transmissions become increasingly subject to atmospheric conditions and in particular rain, while other structures/obstructions found in urban areas, such as trees and buildings, attenuate the signal. Furthermore, at the higher frequencies data can only travel over very short distances, and line of sight is necessary in order for communication to take place. In the highly populated Radio Frequency (RF) spectrum, such as those of the unlicensed spectrum (i.e. 2.4 GHz ISM band and others) interference is still going to be an issue for the network. In this case operators will need to seriously consider purchasing licensed spectrum, which is often incredibly expensive [53].

Another disadvantage to 802.16 is that the data rates are not nearly as high as some of its wired-line counterparts, such as optical fibre [53]. In addition, very few WiMAX products have entered the market at this time and as such are still rather expensive when compared with WiFi technologies. While this will probably change in the foreseeable future, it will influence prices to the customers and hence to schools. Furthermore, there are currently no telecommunication companies offering WiMAX technology to the public in South Africa. This, however, could change in the near future, as Telkom is currently implementing a test phase.

*While many manufacturers conform to the WiMAX standard there are still companies that produce their own proprietary products. For example, one such product, Motorola Canopy, is being tested in a rural schools development project in the Tshwane Municipality.*

### 2.3.3 Motorola Canopy

Canopy [56] is Motorola’s wireless broadband solution. Its solution is able to deliver data communications, whether broadband Internet access, voice over Internet protocol (VoIP), video services, or security surveillance. Motorola aims to “combine carrier-grade toughness with performance, security, ease-of-use and cost effectiveness” with this technology, while seamlessly integrating with existing wired and wireless technologies [57].

The technology can be used in point-to-multipoint (PTMP) and point-to-point configurations. It is IP-based (Internet Protocol-based) and operates in the Industrial, Scientific and Medical (ISM) band of 5.725 - 5.825 GHz [57]. In PTMP mode ranges of up to 16 km in one hop and in PTP up to 55 km and data rates can be 7 Mbps or 14 Mbps can be achieved [57]. The subscriber modules (and base station Access Points) are contained in a small box that is mounted on the top or side of a building and connects to either a computer or a server, through an ordinary Ethernet cable. Line of sight (LOS) is necessary for data transmission to take place. The equipment is manufactured for an unlicensed shared frequency band in the United States of America (UNII – Unlicensed National Information Infrastructure), thus the technology is designed with the intent to make it immune to interference, with a specified carrier-to-interference ratio of 3 dB, allowing it to be used without frequency coordination (with other users) [58].

The equipment consists of the following [56]:

1. The Canopy (AP) Unit - the core of the Internet Access network
2. The Canopy (AP) Installation Kit - the 'glue' that holds the Internet access network together
3. The Canopy Subscriber Module (SM) - connects a subscriber to the Internet access network
4. The Canopy Back-haul Unit (BH) - allows for connection of the Internet access network to a remote Internet 'feed'

The Canopy platform uses Dynamic Time-Synchronised Spreading (DTSS), which is Motorola's patented high-speed wireless communications technology [59]. DTSS combines elements of Radio Frequency (RF) modulation, synchronisation and interference handling techniques [59]. The DTSS protocol allows the Access Point to transmit beacon signals on pseudo-random frames, through Transmit Frame Spreading (TFS) [59]. This enables multiple access points to address multiple receivers in the same geographical area without interfering with each other.

The DTSS also makes use of Global Positioning System (GPS) to control and coordinate transmit and receive times for all the components in the Canopy network [59]. An additional benefit of GPS is that it provides a highly accurate timing signal. DTSS uses this signal to schedule communications and determine accurately when transmitters should transmit and receivers should receive. This is made use of in Time Division Duplexing (TDD) deployments and as such outbound and inbound transmissions occur on the same frequency in an alternating fashion [59]. This allows the system to make sure that no transmitter is transmitting when it should be receiving and vice-verse, thus eliminating self-interference [59].

For more in depth detail into how Canopy works see [60], [61], and [56].

**Advantages of Motorola Canopy** The advantages of the Motorola Canopy platform are that it is able to connect people in more rural areas of the country where there are no wired-line options, such as the Ulwazi pilot project [62] in Mamelodi, Tshwane, South Africa. Such connections are broadband at distances of up to 55 km. Furthermore, it uses methods that alleviate the effects of interference, especially focusing on the unlicensed RF spectrum, which is prone to interference due to high use thereof [59, 58]. The benefits for schools can be seen in the Ulwazi project (which will be discussed in chapter 3) and include allowing for real-time teaching amongst schools and the sharing of resources and information interactively.

**Disadvantages of Motorola Canopy** The most notable disadvantage of the Motorola Canopy platform is that it is a proprietary solution. Thus it does not have the benefits of standardised solutions, such as those of the IEEE, which include cost effectiveness and prevention of vendor lock-in. In other words, the Canopy platform will not necessarily integrate with other IEEE products, such as WiMAX equipment. However, Motorola has recently joined the WiMAX forum and it is possible that their Canopy solution may be adapted to become WiMAX certifiable. A further disadvantage is that the provided bandwidth is less than some of the wired counterparts available.

*None of the technology solutions thus far have been ubiquitous in this country. A currently more ubiquitous solution within South Africa, is that of the Wireless Cellular Systems.*

### 2.3.4 Wireless cellular systems

The different cellular technologies are grouped into three separate generations of mobile standards that have evolved over the years. The first standard was known as First Generation Technologies (1G) and began to emerge in the 1940s in the USA. This was based on the Advanced Mobile Phone Service (AMPS) technology [63], which in turn, was based on Frequency Division Multiple Access (FDMA) technology. Mobile telephone services were historically concerned with providing roaming telephone services. However, data services were possible with AMPS but were limited to low data rates of less than 10 Kbps [63, 64].

The 1990s saw the birth of Second Generation Technologies, 2G, through mobile services that were based on digital mobile technologies. These technologies made use of Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA) and Global System for Mobile Communications (GSM) [63]. TDMA and CDMA were deployed in various parts of the USA, while GSM was deployed as the common standard in Europe and in South Africa as well. 2G systems are still rather limited and only offer data rates of 10 to 20 Kbps [63, 64].

An "in between" generation took place at this point (the mid to late 1990s), namely 2.5G networks. 2.5G networks were an overlay from the more voice-centric 2G networks to the converged voice- and data-centric 3G networks [63]. Technologies such as General Packet Radio Service (GPRS), Enhanced Data rates for GSM Evolution (EDGE) and CDMA are 2.5G network technologies [64].

The next generation of mobile services, 3G, supports higher bandwidth digital communications and is based on the International Telecommunications Union's (ITU) International Mobile Telecommunications-2000 (IMT-2000) umbrella of 3G standards, which include technologies such as Universal Mobile Telecommunications System (UMTS), CDMA-2000 and Time Division Synchronous Code Division Multiple Access (TD-SCDMA) [63]. 3G networks can support data rates from 384 Kbps up to 2 Mbps, although most commercial deployments offer data rates closer to 100 Kbps [63, 64]. 3G networks have only recently (2005) been launched in South Africa by two of our three cellular phone companies, Vodacom and MTN.

Driven by a need to support content-rich multimedia applications and services, fourth generation networks are envisaged. The proposed 4G network will allow for high data transfer rates in both the up- and down-links of the network connection. 4G networks are said to support global roaming and multiple classes of service with variable end-to-end Quality of Service (QoS) requirements across heterogeneous wireless systems [65]. Furthermore, 4G networks will be purely packet-switched and based on a pure-IP architecture [65].

**Advantages of wireless cellular systems** The greatest advantage of mobile/cellular telephone services is that they have a (near) ubiquitous and continuous coverage in most countries [63]. In South Africa the number of cellular phone subscribers exceeds that of the number of fixed line subscribers [66]. The ubiquitous nature of wireless and cellular technologies makes it possible to connect anyone anywhere to the Internet and to information and telecommunication services, be that data or voice. Furthermore, with "Pay-as-you-go" mobile services, cellular phone technologies are becoming more and more cost effective to the end-user and hence the high uptake amongst poor communities within the African continent [66].

For rural schools with no fixed-line infrastructure, mobile technologies offer a viable solution in terms of being able to connect them to the Internet and even more so with 3G technologies and the imminent 4G technologies. A further advantage is that the bulk of the cellular phone infrastructure has already been laid and thus not much additional work needs to be done.

**Disadvantages of wireless cellular systems** The current disadvantages of mobile telephone standards is that the rate of data transmission is still relatively low. Currently in South Africa 3G technologies provided by cellular telephone companies deliver data transfer rates of up to 384 Kbps [63], relatively small in comparison to other wireless services and certainly to other wired services. However, Sentech is able to offer up to 2 Mbps, but their services are only available in Johannesburg, Pretoria, Durban, Cape Town and Nelspruit [67].

*As satellite technologies are set to become as ubiquitous as wireless cellular systems, currently available, potential satellite technologies are worth considering.*

### 2.3.5 Satellite communications

Satellite communications offer attractive solutions due to their ability to connect widely dispersed geographical sites. Satellites offer the ability to service many users and solve the expensive 'last-mile' issue without having to dedicate to each user cable, optical fibre, switching equipment ports, and other such expensive equipment, makes satellite use attractive for broadband communication [68].

Satellite communication systems can be classified into three categories according to their orbit altitudes [69]:

- Geostationary Earth Orbiting (GEO) satellites, with approximate altitudes of 35000 km
- Medium Earth Orbiting (MEO) satellites, with approximate altitudes of 10000 km
- Low Earth Orbiting (LEO) satellites, with approximate altitudes of <1000 km

LEOs can be further sub-divided into Big LEO and Little LEO categories. The Big LEO satellites are to offer voice, fax, telex, paging and data capabilities, while the Little LEOs are to offer data capabilities only, via a 'bent-pipe' method or store-and-forward service [69]. The 'bent-pipe' method is a satellite technology that transmits data from one point on the Earth to a satellite and then from the satellite back down to another point on the Earth's surface. Pipe payloads simply receive and retransmit signals from the same beam's coverage area [70]. The name 'bent-pipe' comes from the shape of the path that the data travels to and from the satellite. As the satellite orbits get closer to the Earth, so its footprint over the Earth decreases. For this reason, lower orbiting satellites will require larger constellations than higher orbiting satellites, in order to achieve the same global coverage as their higher orbiting counterparts. Lower orbiting satellites will, however, require less energy than the higher orbiting satellites because of the shorter average distance between transmitter and satellite [69].

Until the early 1970s satellites were mainly used for international telephone trunking and TV signal transmissions and were in geostationary orbits [68]. These GEO satellites were entirely analogue and conveyed either a single TV signal or a number of telephone channels using Frequency Division Multiplexing (FDM) [68]. These satellites acted as simple 'bent-pipe' repeaters in the sky and were very limited in power and capacity [68]. The limitation of single beam satellites was low data rates. The need for higher data rates thus led to the development of multibeam satellites and methods of frequency re-use [68].

In order to avoid interference, when there are multiple users, there is a need to multiplex information so that when it is sent down from the satellite it can be properly separated by the users. For these reasons the choices of multiple access and multiplexing methods are important and will impact on the performance of the satellite network [68].

Two-way interactive data networks involve much more than the combination of two one-way channels. The two directions of communication flow in the channels of a two-way VSAT (Very Small Aperture Terminal) network with a client/server configuration and involve two fundamentally different forms of communication [71]. In the direction from the satellite to the terminals, the communication channel is one to many, or broadcast. In the direction from the terminals to the satellite, the communication channel is many to one, or multiple access [71]. Transmitting data from a single satellite station to a large number of remote terminals (the broadcast channel) is almost always configured in a simple time-division multiplexed (TDM) mode [71]. Transmitting data from large numbers of remote terminals to a single satellite (the multiple access channel) is a more challenging problem [71].

In frequency division multiple access (FDMA) each user is assigned a different frequency upon which to transmit. With FDMA many users can simultaneously share the satellite. FDMA has been used for decades in 'bent-pipe' satellites for the up- and down-links of analogue signals, such as telephone conversations. In time division multiple access (TDMA), users are assigned positions in a quickly repeating schedule for transmitting on a common frequency on the satellite [68].

FDMA is attractive for Earth stations since an amplifier in an FDMA system operates continuously, while an Earth station transmitting with TDMA requires a higher burst power and a correspondingly more expensive amplifier [68]. A drawback of the FDMA up-links is inflexibility and often the fraction of system channels actually in use is poor, since not every Earth station may have something to transmit at all times. In a TDMA system the time slot plan can be changed dynamically to accommodate such varying demands [68].

If an FDM down-link is used then several carriers must be amplified simultaneously for transmission. Often such amplifiers, when operating at their maximum, will distort the transmitted signal and waste power [68]. Thus for a FDM down-link a large amplifier must be operated at less than half the power. If time division multiplexing (TDM) is used then there is only one signal that needs to be amplified, which results in no inter-modulation products. A satellite producing a TDM down-link transmits essentially continuously. Hence, FDMA is economically preferable for up-links to reduce Earth station cost, while TDM is preferred for down-links to reduce the satellite costs [68].

Some satellite implementations have also been known to implement other multiple access techniques in various ways, see [68], [69], [72], [73] and [74].

In South Africa today there are not many satellite communications services available. From Telkom [75], one may purchase one of their SpaceStream [76] products, and from Sentech [67] one may purchase one of their VStar products [77]. Both these services make use of GEO satellites in orbit. Currently MEO services are limited to GPS, while there are no LEO services within South Africa due to the high expense of running such a network [69].

Iridium, based in the United States of America, with a constellation of 66 LEO satellites, is able to deliver communication services to and from remote areas. Iridium services cater for industries such as maritime, aviation, government/military, emergency/humanitarian services, and many others [78].

**Advantages of satellite communications** The advantages of satellite communications are much the same as the advantages of other broadband wireless communications that have been looked at. For example, they are able to connect users to other users who are geographically dispersed without the use of wired infrastructure or by integrating into wired infrastructure [68]. They are also useful in connecting users to the Internet in areas where there are no wired alternatives. Additional advantages of satellite communications for broadband inter-connectivity include [68]:

- The broadcast nature of satellites supports the transmission of the same message to a large number of stations, making satellites a good choice for point-to-multipoint transmissions

- New users can be accommodated by simply installing new Earth stations at customer premises, making such networks scalable.

**Disadvantages of satellite communications** A major disadvantage to satellite communications in the South African context is the cost of the services. Currently, VSAT offerings in South Africa are more expensive than other wired alternatives [36] and thus are less likely to be utilised by those customers or schools in the rural areas where there are no wired alternatives.

Further disadvantages of satellite communications are due to the RF spectrum shortcomings: the Ka-band, which most satellite communications use, experiences significant rain attenuation. This attenuation is due to molecular water vapour absorption resonance frequency, which is located in the Ka-band, 22.3 GHz [68].

The delay in data round-trip time for GEO satellites is very long, often affecting quality of service in real time services. While lower orbiting satellites such as MEOs and LEOs would not have this problem, they are much more expensive to deploy and several companies have gone bankrupt in attempting to do so [68, 69].

Currently in South Africa, the time delay and current expense of GEO satellites could affect schools when using interactive applications over a network, and the expenses of LEO satellites are not currently viable for schools in the South African context.

*An interesting alternative to LEO satellites, which is considered to be considerably cheaper while offering the same benefits, is that of High Altitude Platform Stations.*

### 2.3.6 High altitude platform station (HAPS)

High altitude platform station is the name of a technology for providing wireless narrowband and broadband telecommunication services as well as broadcasting services using either airships or aircraft. HAPS operate at altitudes between 17 and 22 km and should be able to service (cover) an area of up to 1000 km in diameter [79]. HAPS operate in the 47/48 GHz bands in most western countries and in the 28 GHz band in most of Asia [80]. While the term HAPS does not have a strict definition, it is generally taken to refer to solar-powered and unmanned, high-altitude platform based on lighter-than-air vehicles or conventional aircraft such as aeroplanes or airships [80], capable of long endurance (several months or more) on-station [81].

Common implementations of wireless technology to the customer are via mobile or satellite technologies, as discussed earlier. HAPS attempts to be a solution to the limitations of both those technology groups, namely providing less signal attenuation and delay than satellites, while needing less infrastructure and thus being less costly than the mobile technologies. These aerial platforms are to carry communications relay payloads and operate in a quasi-stationary position. The payloads can be a complete base-station, or simply a transparent transponder. Line-of-sight propagation paths can be provided to most users, with minimal attenuation to the signal, thus providing the best features of terrestrial and satellite communications [81], and can be thought of as either a very low satellite or a very tall cellular phone mast [80]. Another useful feature of HAPS is the fact that it is relatively easy to bring them back to Earth, unlike satellites, for service and/or replacement of any faulty parts, maintenance or upgrades [81].

Recent resurgence of interest in balloons and airships, with technology developments such as new plastic envelope materials that are strong, UV resistant and leak-proof to helium, has led to the proposed use of balloons and airships in HAPS projects [81]. The greatest challenge when using a balloon as HAPS, is being able to keep it stationary in the face of high winds. The altitude of 17 to 22 km is chosen because in most regions of the world this represents a layer of relatively mild wind and turbulence. However, wind speeds of 55 m/s have been measured in this layer [81]. Proposed implementations of airships for high-altitude deployment use very large semi-rigid or non-rigid helium-filled containers of the order of 100 m or more in length. Electric motors and propellers are used to keep these HAPS relatively stationary and for flying against prevailing winds. Power, which is necessary for propulsion, station-keeping and payload applications, is provided by lightweight solar cells in the form of large flexible sheets, which are intended to weigh 400 g/$m^2$ and cover the upper surfaces of the airship. Additional power generated during the day will be stored in regenerative fuel cells in order to provide power to the aircraft during the nights [81].

Another form of HAPS is the unmanned solar-powered plane, which needs to fly against the wind or in a roughly tight circular path in order to remain above its service area. The prime challenge in this sort of deployment will again be the power balance, the aircraft having to store sufficient power for station-keeping throughout the night [81].

A single HAPS can provide up and down-link services to user terminals, together with backhaul links into network backbones. Inter-HAPS links may also serve to connect a network of HAPS while links may be established with satellites directly from the HAPS [81].

HAPS do not require any launch vehicle and can move under their own power throughout the world or remain stationary. Furthermore, they can be brought back down to Earth, refurbished and re-deployed. Once a platform is in position it can immediately begin delivering service to its service area without the need to deploy a global infrastructure or constellation of platforms to operate, as is the case with LEO constellations. HAPS can use conventional base station technology (mobile and fixed wireless technologies) and customers will be able to make use of the same handsets, the only difference being the antennas [79]. To best exploit the given spectrum that is allocated to a service, directive antennas on the platform (as well as directive antennas at fixed ground stations and user premises) would be utilised to maximise signal-to-noise ratio (SNR) values. As the dimensions of these antenna need to be rather modest (<0.5 m aperture diameter) an array of many antenna on the HAPS has been proposed to produce a cellular architecture on the ground [80].

HAPS technology is not ubiquitous throughout the world and indeed has not currently been deployed in South Africa. However, due to its potential to increase teledensity and thus reduce the digital divide, organisations such as the Council for Scientific Research (CSIR) in South Africa are currently investigating the possibilities of such technology for use in South Africa [82].

Further reading in the field of high altitude platform stations can be found in [79], [80], [81] and [83].

**Advantages of HAPS** HAPS communications have a number of potential benefits, only some of which are mentioned here.

- Large Area Coverage [81],
- Incremental deployment; service may be provided initially with a single platform and the network expanded gradually as greater coverage and /or capacity is required [81],
- Low cost: although there is to date no direct experience of operating costs, a small cluster of HAPS should prove considerably cheaper to procure and launch than a geostationary satellite or a constellation of LEO satellites [81].

**Disadvantages of HAPS** A major problem that faces HAPS is the weather conditions in which they have to operate in the stratosphere. The biggest concern here is the high winds, reaching up to 55 m/s in some cases. Stations are required to maintain a semi-fixed location despite these high winds. There are further potential problems that face HAPS technology in the form of modulation and coding issues, resource allocation and network protocol issues, hand-off issues and fixed or steerable antenna issues [81].

*Having covered current and future technologies that may be available to schools within South Africa, the legislation which governs those technologies and what the legislation means in terms of connectivity to the schools of South Africa will be reviewed.*

## 2.4 South African telecommunications regulations

The following section begins with a brief history of telecommunications in South Africa as well as an introduction to the industry players. It then moves on to the legislation which governs telecommunications in South Africa, with a more specific focus on how these regulations affect or will probably affect ICT in Education.

### 2.4.1 Background and introduction

Historically, the South African Posts & Telecommunications (SAPT) was in most respects a classic post, telephone, and telegraph monopoly (monopolistic public corporations are known as 'parastatals'), legally monopolising postal and telecommunications services and operating a system characterised by internal cross-subsidies. The SAPT, often colloquially referred to simply as 'the Post Office,' was classified as a 'state business enterprise' and was run through the office of the Minister of Transport and Communications. The finances of the Post Office were controlled by the Treasury and as such experienced little outright corruption or gross overspending, but generally suffered from a shortage of capital inasmuch as it had to compete for funds with other central government capital projects [84].

South Africa's telecommunications structure changed in October 1991 when posts and telecommunications were separated from each other and set free from direct ministerial control. This change was due to a number of factors, which include calls from the public for better services, but most notably because the government appears to have come to the conclusion that privatising its public corporations and enterprises was a better option than operating debt-ridden ones. The SAPT's debt stemmed from its conversion from the electromechanical switching system to digital in the late 1970s [84]. South Africa's new telecommunications entity, Telkom SA, became a company formally registered in October 1991 under the South African Companies Act, with the state as the sole shareholder [84]. The old SAPT relinquished its joint role as player and regulator, and a very small Department of Posts and Telecommunications acted as interim regulator, without having its legal standing or the scope of its authority spelled out [84].

The then South African government approached Coopers & Lybrand, Deloitte, the U.K.-based international accounting firm, to conduct an independent study of the South African telecommunications sector. The report that they produced suggested protecting Telkom as the primary supplier of South Africa's telecommunications services and using a mixed set of regulatory controls to encourage the company to behave in an efficient, public-interested manner [84]. Based on this report the newly democratically elected South African government, the Government of Nation Unity, implemented the Telecommunications Act of 1996 [84].

The current players in the telecommunications industry in South Africa are:

**Telkom** is a fixed line operator in South Africa. It was previously one of the state-owned parastatals but has since been privatised with the state retaining a 38 % share, the other 62 % belongs to private investors. Telkom provides all fixed-line voice and data services in South Africa and, until the SNO's (Second Network Operator) licensing was completed, was the only entity which could provide telecommunications infrastructure between privately owned properties [85]. However, with current legislation changes that enable the mobile operators to self-provide as well as being legally allowed to resell that infrastructure to other customers, mobile operators could become fixed line competition to the incumbent Telkom and the SNO.

**The Second Network Operator (SNO Telecommunications)** The licensing of the SNO was settled upon on the 9th of December 2005. The SNO consists of Tata Africa (or VSNL) of India which has a 26 % shareholding, Nexus Connexion (19 %), Eskom-owned Transnet which owns 30 %, as well as CommuniTel and Two Consortium which hold 12.5 % each in the operator [86]. The need for the SNO is to provide much needed competition to Telkom's monopoly within the sector. It promises to roll out an alternative telecommunications network to which clients can subscribe during the course of 2006 [85, 87].

**Sentech** is a commercially-owned but government-controlled company which specialises in wireless broadcasting. It is the carrier for the broadcasting industry and carries 98 % of South Africa's terrestrial broadcasts. Sentech is a wireless service provider that is licensed as a multimedia provider as well as a provider of international access to other telecommunications licence holders [41]. Sentech is further involved in the provision of satellite services. Sentech plans to roll out a national wireless data service and claims that this service would offer an alternative to the data services offered by Telkom [85].

**Cellular operators** In South Africa there are currently three cellular operators, namely Vodacom, Mobile Telephone Networks (MTN) and Cell C. These three operators are only allowed to supply voice services to clients, in accordance with their licences. However, due to legislative loopholes they are also able to provide limited data services. These data services include wireless applications services, (WAP), GPRS and EDGE and their very recently launched 3G networks [85]. In the recent deregulations (to be discussed further in section 2.4.3) the cellular phone companies were permitted to self-provide their own fixed line telecommunication infrastructure and may sell off any spare capacity to other interested parties [88].

**Value-added network Services (VANS)** A value-added network service (VANS) is a telecommunications service provided to customers in order to add value to the customer's current communications connection [85]. These services are provided over a telecommunication facility which has been obtained by the VANS licensee in accordance with the provisions of section 40(2) of the Telecommunications Act of 1996 [39]. The services may consist of: any kind of technological intervention that would act on the content, format or protocol or similar aspects of the signals transmitted or received by the customer in order to provide these customers with additional, different or restructured information; the provision of authorised access to and interaction with processes for storing and retrieval of text and data; and managed data network services [85]. Examples of services that would be of benefit to schools include: web hosting, providing email facilities, support and maintenance.

### 2.4.2 The South African Telecommunications Act of 1996

In the mid-1990s Telkom faced a difficult future. On the one hand, the end of apartheid imposed new equity-based demands on it to expand the basic telephone network to populations and areas historically denied access. On the other hand, South Africa's businesses, feeling themselves restricted under a traditional, monopolistic telecommunications structure, wanted enhanced and value-added services to be liberalised. In 1994, a time when Telkom had a monopoly in South Africa's various service areas, the most significant of which was the running of the public switched telephone network, the ANC-led Government of National Unity inherited the issues left unresolved since the commercialisation of the Telecommunications industry. This left the new government with a choice between social responsibility and fiscal responsibility. Responding to political pressure from business, consumer groups and labour, the ANC attempted to pursue both objectives [84].

In July 1995 the Green Paper on telecommunications was published in several languages and made available on the World Wide Web. By October, when the period for submissions finally closed, 131 submissions had been made, amounting to over 4000 pages of commentary. There were many points of consensus, including the need to expand the sector through new sources of investment; on the need for operators, service providers, and equipment manufacturers to commit to retraining and redeployment of staff; that universal access is a reasonable step on the way to the goal of universal service; and that an independent regulator should supervise the system. On the major questions of market structure and ownership, there was a wide range of opinion, from the maintenance of state control to full competition and privatisation [84].

Much debate ensued but eventually parties reached consensus and the White Paper was published in early 1996. The paper articulated a scenario that gave Telkom essential exclusivity for five years, after which parts of the network would be opened up to phased competition. The specific timetable included [84]:

- In year four, Telkom's tariffs were to remove cross-subsidies; allowing resale of excess capacity by private network carriers through interconnection with Telkom's network. All competitors would contribute to a 'Universal Service Fund" which would be used to fund network expansion.

- In year six, allowing development of local loop service by local providers in cooperation with Telkom; liberalising the long-distance market; and allowing 'metropolitan area networks,' or networks of private networks providing service to major cities.

- In year seven, licensing a second network provider; and liberalising the international call market.

The White Paper essentially provided the public telecommunications operator a period of time to expand even as it facilitated the growth of value-added and private network entrants, and phased in regulated competition. The White Paper proposed the creation of a Universal Service Agency (USA) alongside a Regulator. The job of the USA was to ensure that universal service remained a central focus in the telecommunications industry and the job of the Regulator was to oversee many complicated processes and resolve a great number of technically intricate disputes [84]. In addition, the Regulator was to guide the sector into a competitive market structure [84].

The policy was that of managed liberalisation and had two underlying sets of objectives from the outset, which in many ways were contradictory. On the one hand, managed liberalisation was based on the premise that it was no longer reasonable for the state to own and operate huge telecommunications and broadcasting infrastructures, but on the other hand it needed to foster economic growth and development. In order to do that, the telecoms and broadcasting infrastructures needed to be opened up to greater ownership and usage by the private sector to drive technological innovation and bring South Africa on a par with its global peers [84]. However, on the other hand, the telecoms and broadcasting infrastructure was seen as key to the development of previously disadvantaged areas within the country [84]. It could be used to stimulate development and bridge the digital divide. The state felt that the private sector could not be trusted to put this critical need high enough on its corporate agenda and thus it needed to maintain adequate control over the infrastructure to ensure the needs of all South Africans were equitably met [41].

In November 1996 the Telecommunications Act, no. 103 of that year, was passed by Parliament [84]. The Act provided Telkom with exclusivity until the 7th May 2002 [39]. As a result of this exclusivity, Telkom had a number of social responsibilities that it had to meet in accordance with the PSTN licence that it was issued [89]. The licence had to fulfil the policy intentions of achieving universal service without compromising the more sophisticated requirements of the established business and residential market. What was captured in the licence was that the network had to be doubled within five years and Telkom was to prepare for competition. However, the company was not permitted to double the network only where it was most profitable, but rather it had to provide services to priority customers such as schools, hospitals, libraries and local authorities. In addition, they were required over the five years of their exclusivity to ensure that over 3000 villages without service were serviced [89]. Failure to meet these targets would result in Telkom incurring substantial penalties, but it also had the incentive of a sixth year of exclusivity if it exceeded its targets. Additionally, they had pay telephone obligations, which included provisioning for free emergency services and special services to people with special needs, such as the blind or hard of hearing. Telkom also had to meet certain service targets, which included efficient response times to customer complaints, efficient turn-around times to faults, directory obligations, voice directory services in all official languages and many others [89].

The Telecommunications Act of 1996 was written is such a way that on a given date the Minister of Communications could determine a more liberalised market. The Act allowed for dates to be set by the Minister at which time certain sections of the Act would come into affect. Some of these include [39]:

- VANS licence holders to self-provide;
- Mobile operators to self-provide;
- All state schools to pay only half price for telecommunications;
- A national public school network to be established;
- Liberalisation of public telephones;
- Provision of voice by VANS licence-holders.

### 2.4.3 Ministerial determinations 2 September 2004

On the 2nd of September 2004 the then Minister of Communications, Dr Ivy Matsepe-Casaburri, made a policy announcement on a number of determinations [88] from which various provisions of the Telecommunications Act could be activated in order to stimulate sector growth. Dr Matsepe-Casaburri's announcement came as a result of a call from the President of South Africa, Mr Thabo Mbeki, in his state of the nation address in May 2004, where he emphasised the need to lower the cost of doing business in South Africa [88]. He further charged the Department of Communications with creating a globally competitive telecommunications sector which was to address the challenges of the 2nd economy [88]. According to Dr Matsepe-Casaburri's announcement, in order of the South African ICT sector to meet these challenges the following changes needed to take place:

- A more competitive ICT environment.
- Improved access to ICT infrastructure and services.
- Affordable telecommunications services.
- A variety of choice in services being provided by the ICT sector to meet both economic social needs of our society.

As such the decision was taken to further liberalise the sector as well as amend various of the existing laws within the Telecommunications Act of 1996. Thus the Minister announced a number of policy decisions and a date on which those decisions would come into effect, as provided for in the Telecommunications Act. These provisions were supposed to be the first of a number of policy interventions designed to further accelerate growth in the sector, reduce the cost of telecommunications and facilitate appropriate interventions in the 2nd economy [88].

The provisions covered the following areas:

- Self-provision and greater choice for mobile operators
- Provision of public pay phones
- Provision of voice by Value Added Network Service (VANS) providers
- **Choice in the provision, including self-provision, of VANS**
- Cession of telecommunications services by VANS
- Optimising the use of Private Telecommunications Network (PTN) facilities
- **Preparing our youth for the knowledge economy**

The first six points were to come into affect on the 1st of February 2005, while the last was to come into affect on the 18th of January 2005 – the start of the school year [88].

Of these provisions, the most noteworthy for this project are the two highlighted points on self-provision for VANS licensees and the youth knowledge economy, as both have a direct effect on the provision of ICT in schools. Self-provision for VANS licensees may result in them being able to provide cheaper access to schools within the community of the VANS business, with the possibility that such VANS would be able to provide infrastructure in rural areas where there has been none in the past. Furthermore, the e-rate, provided for by the youth knowledge economy, would assist schools that lacked sufficient funds to be able to purchase Internet connectivity and those that already had Internet connectivity to double their bandwidth for the same price.

Within the Telecommunications Act there was also provision made for a national education network, in Chapter 5, section 41(10). Unfortunately no announcements were made regarding this section in the Ministerial determinations.

### 2.4.4 The ICASAs interpretations, 22nd November 2004, and the ministerial clarification, 31st January 2005

The Independent Communications Authority of South Africa (ICASA) is the regulatory board set up to regulate communication in South Africa. ICASA is responsible for the management of radio frequencies and other communication mechanisms (i.e. all fixed and wireless methods for conveying communications, be it voice, data or video) in South Africa. ICASA also plays a role in ensuring that the Department of Communications and industry players operate within legal boundaries [85].

Following the Minister's announcement in the Government Gazette 26763 Notice 1924 of 2004, ICASA held a two-day colloquium on the 20th and 21st of October 2004 to engage the sector on the ambit and scope of the determinations and to gauge industry's views on their impact from a regulatory point of view [90]. In addition to the colloquium, over 30 written submissions were received from licensees and interested parties documenting their views on the impact of the Ministerial Determinations [90].

The Authority undertook an audit of regulations, embarked on further research and considered the public submissions made. Based on these steps the Authority made clear its understanding of the Ministerial Determinations and announced the programme schedule to be followed in an attempt to comply with 1 February 2005 and 18 January 2005 in the case of the e-rate [90].

ICASA's interpretations of the two determinations which have a direct bearing on the use of ICT in schools include [90]:

- Choice in the provision of VANS: VANS may self-provide facilities from 1 February 2005. Self-provision considers the procurement of telecommunication facilities by a VANS licensee from any telecommunication facility supplier and the use of them under and in accordance with its licence to provide telecommunication services. NOTE: The Determinations do not in any way affect the current restrictions in relation to the ISM band.

- Preparing our youth for the knowledge economy: The e-Rate was to be applicable from 18 January 2005 to all public schools as defined in the South African Schools Act of 1996 and all public further education and training institutions as defined in the Further Education and Training Act of 1998.

These interpretations were intended to result in cheaper Internet access for schools. For details on the other determinations see [90].

On the 31st of January 2005, Dr Ivy Matsepe-Casaburri, released a press statement [91] in order to clarify some of her determinations. She felt that she needed to make a public statement clarifying the state's intentions and outlining the envisaged state policy. This was apparently in order to avoid any delays with implementation of the Determinations and the speedy introduction of competition and the lowering of prices to the end consumer, as well as to avoid having to amend the Telecommunications Act [91].

The Minister went on further to clarify one point of ICASA's interpretation of her determinations, which was the issues of VANS self-provision. The Minister announced that the issue of self-provisioning was issued in the state's policy determinations only in relation to mobile cellular operators in terms of fixed links, to give greater meaning to the intention to reduce the costs of telecommunication services in South Africa [91]. It was the intention that value-added network operators would obtain facilities from any licensed operator and as specified in the determinations [91]. As a result VANs licensees may not (to date, January 2006) self-provide any infrastructure. Moreover, the schools' e-rate is yet to be honoured by telecommunication companies.

### 2.4.5 The convergence bill

Convergence is the concept that all modern information technologies, once based on very disparate technological paradigms and systems, are becoming digital in nature. At present a person might receive information by telephone, television, radio, newspaper and the Internet. In the future these different information delivery systems may be replaced by a unified system based wholly on digital technology [92]. Convergence has emerged as a global phenomenon as a result of digitisation which has allowed traditionally distinct services to be offered across interchangeable platforms. These technological trends have been accelerated by the liberalisation of markets allowing for the development of global digital communication networks offering multiple services across national borders [93]. In the past, while television broadcasts used analogue radio channels, voice calls used dedicated circuits and data used packet-switched networks. There is now no longer a practical distinction in terms of transmission infrastructure between these different types of data. Increasingly they are carried on high speed, packet-switched networks much like the Internet's transmission protocols. Thus convergence is simply the coming together of formerly distinct technologies [41].

Convergence in South Africa has been hampered by disabling legislation [41]. The Telecommunication act of 1996 and the amendments of 2001 are highly specific in terms of which technologies are to be used to deliver which services. This turned converged services from a mere technical evolution into an illegal activity [41]. Fortunately, South Africa is currently in the process of drafting its Convergence bill. Interestingly, there was never a green and white paper process for the convergence bill process, which some believe has been to the detriment of the process as there is a lack of consensus about exactly what convergence means [94]. The proposed Convergence Bill is welcomed as the realisation by the state that convergence has been hampered in the past by telecoms law and as such the new Convergence Bill will replace that of the Telecommunications Act of 1996 [41]. However, the Convergence Bill will not be replacing the Broadcasting Act as a proper understanding of the nature of convergence would suggest [41]. Not incorporating broadcasting into the convergence process could negatively affect companies such as Sentech whose businesses are in the realms of both telecommunications and broadcasting, and could stand to face contradictory legislation [41]. The first draft of the convergence bill was released in 2003 [95], Government Gazette number 3382, while the second draft was released in 2005 [96].

According to the second draft Convergence Bill, published in the Government Gazette No. 27294 of the 16th of February 2005, the aim of the bill is to promote convergence in the broadcasting, broadcasting signal distribution and telecommunications sectors and to provide the legal framework for convergence of these sectors [40]. Furthermore, it is to make provision for the regulation of communications and network services, provide for granting of new licences and new social obligations, provide for control of radio frequency spectrum, and provide for the establishment of the Universal Service Agency (USA) [40].

The Convergence bill provides for four new categories of licence. Individual Communications Network Service Licences (CNSLs) are to be issued to the current holders of both PSTN and mobile operator licences. This licence would cover Telkom, the SNO and the three cellular phone providers, MTN, Vodacom and Cell C and it may also cover Sentech and WBS (Wireless Business Solutions) [41]. These licences will probably contain specific provisions and obligations set by the regulator for each licensee. Obligations could include universal service levies or roll-out targets. The new Communications Service Licence (CSL) is to be issued as a class licence to providers of services that use communications networks as their means of delivery [41]. There are two additional categories of service: applications services and content services. According to the latest draft of the convergence bill providers of the latter will not require an explicit licence. If they were, then all web site owners – schools, business, individuals – would be required to pay licencing fees [41]. It is not clear from the Bill whether current holders of VANS licences will need an applications services licence or a communications services licence [41].

It is hoped that a Convergence Bill would remove monopolistic practices which have contributed to high costs as well as remove antiquated laws and protectionist polices that have restricted the roll-out of more efficient technologies [41]. Positive changes such as these would bring down prices and make available new technologies to schools in South Africa allowing the many that are not part of the 'Information Society' to join it and reap the benefits thereof.

However, it is important to note that there are no provisions for an e-rate or a national education network within the Convergence bill as there were in the Telecommunications Act of 1996. The only provision for schools is that there will be some funds available to the Universal Service Agency for use by schools [40]. It is doubtful, however, that there will enough money for the Universal Agency to subsidise Internet connectivity for every single state school in the country, which in effect is what the proposed e-rate would have done for all South African state schools. There have however been talks between the Department of Education (DoE) and Telkom to continue with the e-rate regardless of lack of legislation [97]. It is not clear how the DoE is going to convince Telkom to implement the e-rate as it would mean a loss in their revenue. However, there may be hope for schools in other areas of the Convergence Bill (to be called the Electronic Communications Act when it is passed), namely that local governments are allowed to apply for PTN (Private Telecommunication network) licences which will allow them to self-provide their own networks and resell any spare capacity on those networks [98].

In a recent international peer group comparison of telecommunication prices in South Africa [99], South Africa's telecommunication pricing was compared to overall best practice countries in the world and also best practice countries with similar characteristics, including input costs, geographical dispersion of population, income dispersion and level of development. Findings from this comparison include:

- South Africa was the most expensive broadband of all fifteen countries sampled, and was in fact more than nine times as expensive as the cheapest country surveyed [99].
- On domestic leased lines, South Africa was the most expensive of 12 countries surveyed, 100% more expensive than the average price sampled, and almost fifteen times more expensive than the cheapest country surveyed [99].
- For international leased lines, South African prices are almost three times as high as the next most expensive country sampled and 31 times more expensive than the cheapest country [99].
- South Africa's monthly ISP fees are 4th most expensive of the fifteen countries surveyed [99].
- Peak local calls in South Africa were the most expensive of the fifteen countries sampled and almost 200% more expensive than the average price [99].

High Internet and telephone prices prevent poor schools from being able to afford these communication necessities. ISP prices are high due to the high prices that they pay to Telkom: broadband ISP fees, typically are in the region of R250 per month and of this an estimated R190 is paid to Telkom for the bandwidth acquired by the ISP [99]. The Genesis report [99] found that Telkom's pricing structure, when contrasted to an appropriate peer group of international competitors, is towards the top of the pricing spectrum. It is hoped that Convergence will bring much needed competition to the industry and thus drive prices down. However, this process may take time before we see the benefits of competition, during which schools will be subjected to high prices – furthering the digital divide – if there was to be no subsidies for them through initiatives such as the e-rate.

## 2.5 Conclusion

There are a number of possible telecommunication technology solutions available in South Africa, both currently and planned for the future. With decreased prices through competition and less antiquated telecommunications laws as well as the cheap provision for schools in terms of Internet costs, it is likely that more schools will be able to connect to the Internet. However, it is important to know and understand what the needs of the schools are. This will be discussed in Chapter 3.

# Chapter 3

# School connectivity

## 3.1 Introduction

There are many possible methods of connecting schools to the Internet, but in order to choose appropriately it is important to know what schools want and need, so that their Internet connection will be useful to them. Furthermore, it is important to understand why schools want or need the Internet, as well as what the possible benefits could be.

In this chapter the broad possibilities afforded by networks in society are presented; the effects of a networked society and the changes that it could lead to in how our society operates and how we teach and learn. The focus is then narrowed to the use of networks within schools and definitions of what is meant by networks in schools. The chapter then presents projects that are taking place in international and South African schools. The chapter then focuses on the policies that govern the use and adoption of ICTs in education, broadly on an international scale in order to be able to see the trends and then provide a more detailed look at the policies in South Africa. The conclusion discusses how policies or the lack thereof affects the installation of the infrastructure in schools across the country, as well as the use of ICTs for teaching and learning.

## 3.2 Possibilities afforded by networking

The use of computers in education has been studied by researchers for a number of years, who have debated the influences of computers on education, teaching and learning. Computers have been considered as powerful tools, which are able to enrich the resources available for teaching and to improve teaching and learning through computer-aided devices, appropriate software and a more individualised way of learning [100]. However, the developments of Information and Communication Technologies (ICTs) and the convergence of such technologies is continuing to bring about profound changes across the whole of society and education. Furthermore, the digitisation of information, text, sound and video allows for easy access to multimedia content as well as easy communication with others from all of the world and easy access to information from anywhere in the world at any time of the day from any place. From this Information Society we see two ideas emerging, that of the networked society and the networked collective intelligence [100]. These two are ideas are closely linked and will have an effect on education by how we teach and learn [100].

### 3.2.1 The network society

The first of these ideas is that of the networked society; the development of networks and the structuring of networks within society. Networks are also bringing considerable change in education and to the role of the teacher [100]. In the past society has been organised in a hierarchical or tree structure - a pyramidal structure [100]. However, a network consists of a set of interlinked points or nodes [100] - what I would term a mesh structure. Thus in a network there are generally many possible paths from one node to another, whereas in a hierarchical structure there is one unique path. Furthermore, networks can include sub-networks and thus creates new proximities and new hierarchies. In this networked society people and information are connected in a networked form, which results in a change in the relationships between people and between people and information [100]. This kind of society means that people are able to communicate with each other whether they know each other or not. Previously a person could communicate with someone with whom they were not familiar through channels of people that they had in common [100]. Today a grade 3 child can email the Premier of her province in order to ask questions about provincial government for an assignment she has from school. We live in "a new era of communication between people: networked communication [100, p41]." Even the way we are able to search through books and texts has changed from a hierarchical tree search of looking through contents or glossary, but with the Internet we are able to access the same data in new ways. We are able to go directly to a word or piece of information without even having to know the author's name or the title of the book; we are able to search for information in a networked fashion [100].

The world of tree structure hierarchy in institutions is going to have to change, "they will have to evolve, adapt and take a networked form, more compatible with the networked form, more compatible with the network environment. The case of education is particularly important. Since society is more and more networked, schools must prepare the learners for this networked society [100, p42]." Such network structures will create new links between the different components within an institution and will enable them to solve new and different kinds of problems. With knowledge now available and distributed in networks "schools must use the networks, be part of the networks and teach [the learners how to use] the networks [100, p42]." Cornu maintains that networking within the school will result in a change from the old form where knowledge circulated only from the teacher to the learners, to a networked form where both learners and teachers are involved in the knowledge process and work together to generate knowledge and ideas via access to different resources such as libraries and the Internet [100]. Schools will need to be re-organised into a more network-compatible form where learners, teachers and school administration workers are all more networked, within each of those groups, inter-groups and to other schools and organisations all over the world [100].

### 3.2.2 Collective intelligence

The second of these ideas is "the emergence and the development of a more collective form of intelligence [100]." Traditionally, intelligence has been thought of as an individual and personal quality. Cornu says that schools have aimed at developing the individual intelligence of its learners. However, he suggests that society needs a form of collective intelligence, which he defines as not only the addition of intelligence from various people, but also the juxtaposition of those intelligences [100].

It is the creation of this network society that we discussed above that makes the idea of a collective intelligence possible. Through the traditional tree structure hierarchies people are only able to form part of a collective intelligence through co-operation, transmission and hierarchy. But the new information and communication technologies make new networks and new ways of communicating with people and with groups available. They create the possibility of a new form of collective intelligence, which Cornu believes "may in turn substantially increase the collective capacity and competence of human beings [100, p43]." He goes further to say, "This collective intelligence is made of a network of individual intelligences. Individual intelligences are not only juxtaposed, but linked and interrelated in ways which make them complementary, which enrich them, in order to solve problems and address questions that need a collective form of intelligence [100, p43]." He continues to say that the intelligence of human beings is complex and takes many different forms, including collective knowledge, co-operation, collective work, collective thinking, group activities, enrichment and capitalisation of knowledge and intelligence, and collective training [100]. Furthermore, he discusses how citizenship in a networked society will become more and more collective and based on collective intelligence. Science and technology will demand more and more collective intelligence, as will industry, business and work in general. He sees the way that people work as evolving to work as a collective [100]. No longer will there be generalists, but rather lots of specialists working together, networking and pooling their knowledge and intelligence to solve problems. Cornu feels that "preparing students for collective intelligence and related competencies will be a necessity in the networked society [100, p44]." In South Africa the new Outcomes Based Education (OBE) policies provide opportunities to develop collective intelligence and learning through group tasks and activities that develop not only the individual but also collective knowledge and collective abilities. The development of collective intelligence in the Information Society can be facilitated through the inclusion of computer networks in schools.

## 3.3 Networking in schools

### 3.3.1 Networking

There are several advantages to schools having a connection of some sort to the Internet: interactivity, immediacy, accessibility, targeting, reach and versatility [101]. Internet connections allow schools to have access to a wealth of information that they otherwise might not be able to access [102].

Due to the legacies of Apartheid many of our schools severely lack basic infrastructure and available and sufficient resources. There are several thousand schools in the country without electricity [103] and telephone lines [12], as well as buildings and space [104].

While having an Internet connection will not alleviate problems of space and building infrastructure, it may help schools where up-to-date texts are not available due to the expenses of these texts. There are many schools which do not have libraries and as such there is no means for them to access information [105]. The Internet can allow learners and teachers to access various sources of information such as on-line encyclopedias, on-line newspapers and the latest research being undertaken in a variety of different areas. The Internet also provides children with the opportunity to learn collaboratively with other children all over the world, through email [106], and through videoconferencing [107].

In this section key advantages of networking in schools and some of the technical details of local area network (LAN) and wider area network (WAN) and their benefits in the schooling environment will be identified. This is followed by an exploration of some of the projects that are taking place within the international arena (at a broad level for comparative purposes) and within South Africa in provisioning ICTs in schools.

#### Schools and LANs

Local area networks tend to be privately-owned networks within a single building or a campus – the connection of all the computers of an organisation, institution or business, in order to share resources and exchange information. They tend to be at most a few kilometres in size and at least a couple of metres. LANs run at speeds of 10 to 1000 Mbps and have low delay/latency, usually tens of microseconds. They also tend to have low error rates, so data is seldom corrupted during transmission [108].

The majority of LANs today use networks based on the IEEE 802.3 standard, known as "Ethernet", in star topologies. Ethernet allows machines to transmit whenever they want to; if two or more packets collide then each computer will wait for an allotted time and then try again later [108]. Alternatively, computers on a LAN can be connected wirelessly using radio communication, with technologies such as 802.11 ("WiFi") [109, 110, 111] or Bluetooth [112].

A school-wide LAN would allow all computers within the school building or the school campus to be connected to one another. The benefits of this are that limited resources can be shared amongst all the computers on the network. For example, a limited number of printers, servers or scanners on the network will serve every computer on the campus.

Having a LAN in a school makes it easy for all the computers in the building to have the same "look and feel" and means that all learners can log on to the network from any machine on the LAN. Also, if the school had a file server on their network to which learners could save their work, then they would be able to access that work from any computer in the school.

Computers that are networked are also able to communicate with one another by virtue of the fact that they are all linked together [113]. This allows the people using the computers on the network to communicate with each other, through sending email messages to one another or using chat software such as *MSN Messenger* [114], *ICQ* [115] or *Internet Relay Chat (IRC)* [116].

### Schools and WANs

A wide area network can be defined as "a network with a backbone that spans a relatively large geographical area, usually consisting of two or more LANs. The largest WAN in existence is the Internet [117]." WANs span a large geographical area such as a country or a continent, or in fact the entire globe in the case of the Internet. WANs contain a collection of machines, called hosts. Computers and LANs connected to WANs can be connected via telephone lines, fibre optic cables [108] or wirelessly via satellites [71] and 802.16 [118, 119].

A school with a LAN, or even just one machine, could be connected to a WAN by having one of the machines act as a router. The advantages of a LAN, i.e. being able to share resources, are also applicable here. A WAN connection allows the computers at school to communicate with all other computers on the WAN and exchange information and share resources with them. Such WANs could connect schools to other machines within their town or province, or to the entire Internet.

Apart from being able to browse the World Wide Web on the Internet and access information that way, learners and teachers would also be able to make use of other services such as email allowing them to "talk" to anyone who is also connected to the Internet, all over the world. In this way the communication advantages that were mentioned previously are even more apparent in that learners are able to communicate with others all over the world, through facilities like email and messaging products. Services such as videoconferencing are also now possible allowing classes to interact with others from anywhere in the world so, for example, a class in South Africa could collaborate on a lesson with another one in England. The Internet allows a teacher to bring their class to the world [106].

### 3.3.2 International perspective

There are many researchers all over the world who are investigating the use of ICT in schools and the effects, positive or negative of ICTs in education. First world countries such as the United States of America (USA) [120] and the United Kingdom (UK) [121, 122] tend to be well resourced in terms of ICTs available in schools, while third world countries such as the Philippines [123] or South Africa [124] tend to be under-resourced and more so in the public schools than the independent schools.

As a result, first world research seems to focus on the effects of ICTs in education and how the available ICTs can be used effectively for teaching and learning in schools in those countries [120, 125, 126, 127, 128, 129]. Research in third world countries tends to focus on how can such infrastructure can be acquired in schools and how best it should be implemented to aid in teaching and learning [123, 130].

As South Africa has features of both first and third world countries, this means that we need to be investigating both how to procure ICT infrastructure for our schools as well as how to make effective use of it for teaching and learning. In order to learn more about ICT infrastructure procurement a brief introduction to what others have done around the world is presented here.

The UNESCO report [130] provides an overview of the technology infrastructure and connectivity of Indonesia, Malaysia, Philippines, Singapore, South Korea and Thailand. The types and standards of infrastructure as well as the affordability of connectivity varies across these six countries extensively. At the top end of the spectrum is Singapore where there is 100 percent connectivity to schools – linked both to each other and the Internet. Schools in Indonesia are connected in a citywide wireless WAN through an intercity backbone connection using fibre optic and satellite connections. Malaysia has connected 187 schools using ISDN, while Thailand and the Philippines make use of dial-up access [130]. The report [130] maintains that the limited availability of ICT resources is a major obstacle in classroom management and organisation of resources, as learners tend to lose concentration when groups working on a computer are too big. Furthermore, when peripherals such as earphones and microphones and copies of learning software are insufficient, teachers have great difficulty in planning and conducting lessons even if there are sufficient computers [130].

A worldwide survey of schools in 26 countries [131] was conducted and aimed at identifying the perceived obstacles of realising ICT objectives in those schools. It was found that the top ten obstacles included both material and non-material conditions. The major obstacles listed were lack of computers and a lack of knowledge among teachers [131]. Pelgrum found that there were strong positive associations between the complaints of educational practitioners and the availability of hardware in a country. Even under very favourable conditions 40% of the educational practitioners indicated that a lack of hardware was a major obstacle [131]. Pelgrum suggested that such findings needed to lead to further investments in hardware acquisition or to optimising the use of the available equipment [131], which is also recommended by Cawthera in his analysis of computer costs in the developing world [132]. Pelgrum also noted that insufficient peripherals and learning software is one of the ten major problems related to ICT integration in schools [131], while a further obstacle was the teacher's lack of ICT knowledge and skills [131]. Furthermore, it was found that ICT support staff in the schools were beneficial to the ICT skills development of teachers [131].

Whether from first or third world countries, the messages tend to be similar. The most pertinent of these is that in order for ICTs to be effectively used in teaching and learning the most important issue is that of teacher training and teacher buy-in. To quote from [133] "the ultimate success of our schools still remains in training and supporting quality, irreplaceable front-line teachers."

### 3.3.3 South African perspective

Computers were first introduced in South African schools in the 1980s, primarily in the well resourced independent/private schools and some well resourced (white) state schools [124]. These initial computers were used for school administrative tasks such as reports, timetables and student records. As education software, hardware and teacher computer literacy skills improved, so more and more schools employed computers in teaching and learning [124].

According to the school register of needs survey as reported by Howie, Muller and Paterson [124] there are 2311 schools with access to one or more computer. However Howie et al [124] estimate that the number of schools with access to one or more computers is closer to 10% of the 28000 schools in South Africa. In an attempt to improve the ICT access in schools, provincial education departments budget for acquiring different technologies, but simply cannot afford to purchase computers for all schools when there are so many who lack basic facilities such as running water, electricity and basic sanitary infrastructure. Consequently, many schools find alternative methods for funding computer acquisition, either by fundraising or becoming involved in ICT in education projects [124].

There are numerous unrelated ICT in education projects taking place all over South Africa. In this next section we look at some of these projects for which documentation and information are readily available. When documentation is available it tends to be about the project, i.e. what the project is doing or attempting to do. Rarely does one find research on the impact of these projects on education in the country. In this next section a report on the documentation provided about the projects and where applicable a report on any research about the merits of the project and the impact on education in South Africa is presented.

The largest of the projects that work at a national level in all or almost all of the provinces in the country is presented first, followed by projects that take place within specific provinces only and then finally at projects which are being implemented at more local levels.

#### World Links projects

**Description:** "The World Links for Development (WorLD) programme is one of the World Bank's education projects. It focuses on the promotion of new and better ways of achieving effective learning through the use of technology. The programme started as a four-year (1997-2000) pilot initiative of the World Bank in developing countries. The programme came into effect in response to widespread requests from developing countries to assist them in preparing their youth to participate effectively in the global information economy [134]."

The WorLD project began in South Africa in 1997 with a total of 19 schools participating in the WorLD programme from three different provinces, namely, the Eastern Cape, North-Western Province and KwaZulu-Natal. It was hoped that the project would expand the national utilisation of ICT in South African schools where it was needed most [134]. The WorLD programme sought to resource, network and train teachers in selected schools in developing countries, which includes South Africa. The project seeks to transform not only the curriculum in project countries, but also the purpose of education globally [134]. The programme further seeks to network developing countries with developed and industrialized countries for collaborative distance education [134].

**Research:** There is some research being conducted on the WorLD links project. Gbagidi Hillar Komla Addo for his Doctorate of Philosophy in Information Science at the University of Pretoria, completed a study entitled "Utilisation of Information and Communication Technology (ICT) for education in South Africa: An examination of the World Links for Development (WorLD) programme [134]." The study investigated concerns of WorLD project teachers in KwaZulu-Natal regarding the lack of achievement in project outcomes, and hence ICT impact in project schools in South Africa. "The study found that though educators in the WorLD schools in South Africa were adequately trained in computer application programmes and collaborative school projects, learners were not provided with computer skills due to educators not having time to do so. Lack of technical training also inhibited computer access, hence the project from proceeding to the levels of integrating ICT into the curriculum [134]." Furthermore, this study established that, WorLD school project teachers in South Africa were not familiar with, trained in and do not use most teaching methods that support integration of ICT in education. However, it did find a strong correlation between ICT and other information resources, such as libraries, for teaching and learning.

Additional research has been conducted by Andy Cawthera on "Computers in secondary schools in developing countries: An analysis of costs [132]." This paper is mainly concerned with the costs of computers in schools in developing countries. The paper works from information provided from the World Bank, from its WorLD links project in both South Africa and Zimbabwe. From this it suggests appropriate methods for infrastructure provision in developing countries. Some of the more pertinent recommendations from this project were [132]:

- policy makers should be aware of a broad range of computer provisions; brand new state-of-the-art equipment is not essential for good educational outcomes
- high levels of usage of computer facilities is key to reducing unit costs and ensuring a more cost-effective use of computers in education
- a minimum of 20 computers per lab is necessary to ensure high levels of usage and lower costs
- adequate training of teachers
- partnerships between schools and communities in computer services and provision help community relationships and have an encouraging impact on schools

**Grahamstown involvement:** One of the former Department of Education and Training (FDET4) schools participated in the WorLD links project during the late 1990s. Through their participation the school was able to acquire computers for a computer lab at the school as well as teacher training for some of the members of the teaching staff at that time.

### SchoolNet

**Description:** SchoolNet SA was established in November 1997 as a non-profit educational organisation. The vision was to create learning communities of teachers and learners who use information and communication technologies (ICTs) to enhance education in South Africa [135]. The organisation arose from the work of provincial schools networks, non-profit collaborative entities formed by networks of schools to assist each other in gaining access to and using the Internet and computers [135].

SchoolNet SA was formed with the assistance of the Centre for Educational Technology and Distance Education in the Department of Education [135]. It has operated as an NGO with core funding from the international donor sector, and expanded its work substantially through project funding from the South African corporate sector. SchoolNet SA is a Section 21 company and manages a variety of projects covering all aspects of the use of ICTs, directed mainly at historically disadvantaged schools in South Africa [135]. Furthermore, SchoolNet SA has designed, managed and implemented projects in educational ICTs on behalf of large international and national organisations, including the World Bank, Open Society Foundation, Telkom SA, Thintana Communications, Intel and Nortel Networks [135]. Some of the main focuses of SchoolNet SA are to train teachers in the use of ICT and the integration of ICT in teaching; create awareness of the use of ICT in education through publications, conferences and seminars; and establish meaningful partnerships with state departments, business and schools [135].

SchoolNet SA has been involved in on-line, mentor-based in-service training for teachers, which covers the introduction of ICTs into the curriculum and has facilitated and helped co-ordinate other projects such as Intel's "Teach to the Future" teacher development programme and Telkom Supercentres and 1000 schools projects [136, 135].

**Research:** Some research has been conducted on the work being done by SchoolNet South Africa. Such research is designed to evaluate the effectiveness of the organisation and whether or not the work and projects in which they are involved are of benefit to education and the teachers that they train. Some of the research that has been conducted includes the effectiveness of The Global Teenager project [137, 138], Intel's Teach to the Future project [139, 140], and the Educators' network [141]. Additional reports and papers evaluating the work done by SchoolNet South Africa can be found at [142].

**Grahamstown involvement:** SchoolNet South Africa has been involved with one of the former Department of Education and Training (FDET3) schools in Grahamstown. The school has participated in such projects as the Global Teenager project and the Intel Teach to the Future programmes. The school has benefited greatly from its participation in both projects, having acquired computers through the Global Teenager project and teachers have acquired skills through the Intel Teach to the Future programme.

#### CSIR projects

**Description:** The Council for Scientific and Industrial Research (CSIR) of South Africa is one of the largest R&D, technology and innovation institutions in Africa [143]. The CSIR co-ordinates and is involved in a number of research projects in the areas of ICT for rural and educational development. One of its main research areas, titled "Enabling education for all" spans four projects taking place at various places around the country [143]. These four projects are: The Digital Doorway project; Providing opportunities in a rural environment through Internet connectivity; Creating new frontiers in education through an international Internet studio initiative; and Robotics in Education. All projects make use of open source software in order to generate local content for ICT use by schools and to further encourage ownership in schools and by local developers in the use of ICTs [143].

In mid-2005 the CSIR in partnership with the South African government and the New Partnership for Africa's Development (NEPAD) have formed the Meraka Institute [144]. The Meraka Institute derives its mandate as a national strategic initiative from President Mbeki's 2002 State of the Nation Address. The major objective of the Meraka Institute is to facilitate national economic and social development through human capital development and needs-based research and innovation, leading to products and services based on ICT [144]. These will include work and research into the field of ICT in education.

For further information on the CSIR projects see [145], [146] and [147].

**Research:** In my review of the literature I did not come across any publicly available research publications.

**Telkom Foundation projects**

**Description:** Telkom 1000 Internet Schools Project (otherwise known as the Telkom Supercentres project), which began in 1998, was a commitment to provide 1000 Internet access points for schools in South Africa [148]. The Telkom 1000 Internet Schools project was completed in 2000, with a contract for training and site visits completed by SchoolNet SA between October 1999 and June 2000. Each of the 1000 schools was given at least one computer with Internet access [148]. Of these 1000 schools, 100 of them were established as "Supercentres" [148].

The purpose of the Supercentres project was to improve the quality of teaching and learning in the selected schools through the use of information and communication technologies (ICTs), and increase the number of learners who are proficient ICT users. In order to achieve these purposes, Telkom donated computer networks of 21 PCs with a server and dial-up Internet connectivity to the Supercentre schools. They further provided teacher training and technical support over a period of 20 months [148].

The Telkom Supercentres and the Thintana i-Learn projects have been implemented in a wide range of disadvantaged schools in all nine provinces. Many school locations were in deep rural areas characterised by logistical and socio-economic difficulties. The scope and purpose of the project was to [149]:

- Install new and refurbished Internet-connected computers in 200 high schools (Thintana i-Learn Project) and new Internet-connected computers in former Telkom 1000 Schools Project schools nationwide (Telkom Supercentres Project);
- Provide an teacher development programme aimed at effective educational use of ICT to 3000 teachers; and
- Provide technical training and support to 600 teachers in the schools.

Both of the projects fell under the responsibility of SchoolNet SA and were conducted between August of 2000 and December of 2003 [149].

**Research:** I have not been able to find in depth research into the educational effects, be they benefits or negative aspects, of either the Telkom Supercentres Project or the Thintana i-Learn Project. However, a report was complied for SchoolNet, Telkom and Thintana in order to evaluate the two projects. The evaluation was based on the implementation of placing the computers in the schools as well as training of teachers. Problems that were identified in the evaluation were that face-to-face teacher training was not long enough and that some schools were concerned about the sustainability of the computers once the sponsors pulled out [149].

**Grahamstown involvement:** While neither the Telkom Supercentre Project nor the Thintana i-Learn Project were implemented in Grahamstown, Telkom is involved through the auspices of the Telkom Centre of Excellence (CoE) in the Rhodes University Computer Science Department. The CoE has been instrumental in helping certain schools, namely FDET3, FDET4, FHOR, Good Shepard Primary and George Dickerson Primary, in the town acquire Internet connectivity as well as providing funding for the maintenance and replacement of hardware within the schools. Furthermore, the CoE, together with the local student computer society (RUCUS), has been involved in organising computer literacy courses at the schools for both learners and teachers.

### Shuttleworth tuXlabs project

**Description:** A Shuttleworth tuXlab [150] is a partnership between the Shuttleworth Foundation and South African schools to provide learners access to information, knowledge and education. This is carried out through the establishment of open source computer centres in the schools. Open source (non-proprietary) software is installed on these computers as an economical and sustainable way to bring the power of computing to the learners [150]. The tuXlab programme has several formal processes that define the model. These include education, application, installation, support and training processes [150]. One of the primary objectives of the partnership between the Shuttleworth Foundation and the school is to build an ICT model that can be replicated in any school or organisation [150].

In 2002, the Shuttleworth Foundation realised that it could work towards its goals of promoting both education and open source software in one project. This project was initiated to actively promote the use of open source software as a computer lab solution for schools [150].

The project began in the Western Cape in August 2003 and used Linux thin-client technology to establish a viable economical solution for South African schools [150]. Most tuXlabs use a combination of a new server, networking equipment and diskless refurbished computers. The decision to use thin client technology is purely cost driven, but also recognises the benefits of centralised software, data and support [150]. Projects involve both the teachers' and the learners' participation in establishing the labs, which range from initial infrastructure planning to installing networking cables and setting up of computer hardware and the open source software [150]. This skills transfer methodology creates a level of self-sustainability and internal capacity for on-site support. During installations, volunteers, from outside the school, are also invited to assist with the skills transfer process as well as creating an informal support structure for schools [150].

Since August 2003 tuXlabs have been installed at 110 schools in the Western Cape. At the beginning of 2005 the tuXlab project spread into the Eastern Cape and Limpopo, installing computers at 25 and 19 schools respectively [150].

In order for a school to become part of the project, they are required to commit to the following [150]:

- Submit a business plan including its initial plans to introduce the tuXlab into school activities
- Establish a computer committee
- Establish an appropriate venue for the tuXlab within the school
- Aid (volunteer) in the installation of at least two other tuXlabs
- Ensure that the appropriate infrastructure is available in that room, i.e., electricity, security, desks, trunking, network cabinet, etc
- Attend a monthly tuXlab school meeting

These, and other criteria that the school must commit to, are essential in ensuring ownership of the project within the school and providing skills to the schools as well as to support groups amongst the local community.

**Research:** In my review of the literature I did not come across any publicly available research publications.

**Grahamstown involvement:** Currently, tuXlabs are involved with one of the secondary schools in the Grahamstown circuit. The school, a former House of Representative (FHOR), would not have had the necessary funds to acquire computers on their own and as such the involvement of the tuXlab project has brought much-needed computers to a school that otherwise would not have had access to such facilities.

### The Universal Service Agency

**Description:** The Universal Service Agency was established and operates under the regulatory and policy framework enshrined in the Telecommunications Act No. 103 of 1996 as amended in 2001, and Ministerial Policy Directives issued during the same year [151, 39]. The mandate of the Universal Service Agency (USA) is to promote the goals of universal service and access in under-serviced areas where over 60 % of the South African population reside [151]. In accordance with this mandate the USA has made provision for public telecentres and Cyberlabs in rural and peri-urban areas [151].

There are five different types of telecentres, but the one of greatest interest is that of the E-School Cyberlabs. These are computer laboratories located in schools, providing computer and Internet services [151]. Cyberlabs are established in previously disadvantaged areas, particularly rural, peri-urban, or undeveloped townships, where science teachers are trained in basic computing. The teachers in turn impart these skills to learners within selected communities. Cyberlabs comprise 21 workstations, a server and printer. All workstations have Internet access. There are 16 Cyberlabs in seven provinces, equipping the schools with Information and Communications Technology (ICT) services. In the Eastern Cape there are 5 schools with Cyberlabs and one university [151].

**Research:** In my review of the literature I did not come across any publicly available research publications.

**Grahamstown involvement:** Currently there are no Universal Service telecentres in any of the schools in Grahamstown.

### Gauteng On-line

**Description:** Gauteng On-line, started in 2001, is a programme of the Gauteng Provincial Government through its Department of Education. Its main aim is to build a province-wide schools' computer network, and thereby contribute towards building the human resources capacity of the province and the country through the provision of quality education [152]. According to their website [152] each public school in the province is to be issued with a 25-workstation computer laboratory, with Internet and email, to be used for curriculum delivery. Their goal is that this will be achieved by 2013 in accordance with the White Paper on e-Education [136].

By July 2005 they had installed laboratories in 1 100 schools, trained over 22 000 teachers in the use of ICT and almost 1 million learners now have access to ICTs [152].

**Research:** I have not been able to find extensive research being conducted on the Gauteng on-line project. A brief overview of the project was provided in the Goldstuck report: Internet Access in South Africa, 2004 [153]. According to the Goldstuck report, the initiative was intended to provide an average of 25 computers per school in the Gauteng province, on condition that the school had security measures in place to protect the equipment. It is planned that by 2006 every learner in public schools (approximately 2500 schools) will have their own personal email address. Furthermore, the Gauteng Department of Education will provide software and teacher training to those schools. In total R500 million was allocated to the programme to serve 1.5 million learners in the province [153]. However, the project has been dogged by delays, obstacles and maladministration [153], and with more than 1400 schools left in which to install computers and train teachers, it seems unlikely that they will meet their goals by 2006.

### The Khanya project

**Description:** The word Khanya has been derived from the Xhosa word "ukukhanya", which means "enlightenment". This is an initiative of the Western Cape Education Department (WCED), started in April 2001 [154]. The very ambitious goal of Khanya is: "By the start of the 2012 academic year, every teacher in every school of the Western Cape will be empowered to use appropriate and available technology to deliver curriculum to each and every learner in the province" [154].

Khanya is a multi-faceted project, dealing with diverse issues. It focuses on curriculum delivery; has to fit into an existing educational system; remodels classrooms for the use of technology; installs technology; researches new trends in the use of technology in education; trains teachers and forges public-private partnerships [154]. As a result of the multi-disciplinary approach of the Khanya project, it can be thought of as a programme of projects, rather than a project [154].

The Western Cape Education Department (WCED) directs the activities of the Khanya project through a governance structure consisting of a Steering Committee, an Executive Committee and Internal Project Management [154].

The achievements of the project to date (December 2005) are [154]:

- 468 schools have been helped to use technology effectively
- Another 155 schools are in various stages of preparation for the next wave of implementation
- A total of 17034 computers are currently used in Khanya schools. Of these, 9943 have been funded by Khanya or its donor partners, and 7091 have been procured by the schools themselves
- 12440 teachers are being empowered to use technology optimally for curriculum delivery
- 412524 learners are already reaping the benefits of the project

**Research:** Research into the impact of the Khanya project is being conducted by the University of Cape Town and two papers were written for the 8th IFIP World Conference in Education (WCCE), held in Stellenbosch in 2005. These two research papers [155, 156] detailed the achievements and findings of the project. These included the importance of treating each school as an individual unit and thus an individualised project plan is prepared for every school to meet its particular needs [156]. Furthermore, the researchers [156] found that it was very important to the success of the project if each school and its local community adopted ownership of the project. This meant that schools are encouraged to participate in the process and the surrounding community is invited to do likewise. The Khanya project believes that it is through these partnerships between the school, community, donor organisation and the Western Cape Department of Education that the project is feasible and sustainable [156]. Their findings indicated that projects have a high failure rate when there is poor planning and management, inadequate skills, inappropriate technology and insufficient consultation with stakeholders [155]. Thus the Khanya project strives to avoid such mistakes [155]. Above all the Khanya project has found that the project co-ordinators must always maintain the project's vision which is that the technology be used for its intended purpose of curriculum delivery [155, 156].

### The e-LAPA project

**Description:** The e-LAPA project is an initiative of the Department of Education in the Free State in partnership with MirandaNet. MirandaNet is an international e-community of practice which was established in 1992. The aim of the fellowship is to raise the self esteem of teachers and create a confident voice for the profession [157]. The word 'lapa' means gathering place, so E-Lapa is the electronic gathering place and the project aims to demonstrate best practice for the implementation of e-Education in the province [158]. Ten schools across the province were selected to form part of a pilot project from October 2004 to March 2005. Insights gained by the Free State will be applied to the wider project, which is set to embed e-learning in all schools in the Province by 2010 [158].

The e-LAPA Project plans to contribute to the implementation of e-Education, and e-Learning in particular, in the following ways: training of school teachers and principals, making available web-based learning and teaching lesson plans, roll out of hardware and software, ensuring sure that Internet and email connections are in place thus ensuring that the local community has access to the Free State DoE ICT resources, conducting research and development, and reviewing implementations of e-learning in classroom practice [159].

**Research:** In my review of the literature I did not come across any publicly available research publications.

#### The Ulwazi project

**Description:** The Ulwazi project [62], which was initiated in early 2003, is a partnership of five schools situated in the Tshwane metropolitan area. Four of the schools are situated in the township of Mamelodi and one is situated in the Lynnwood Glen suburb, in Pretoria. The project came into being as a result of the need for the schools to share in each others' learning, cultural experiences and knowledge, interactively and in real-time [62]. The project grew out of the Connected Learning Community that St. Alban's College developed. It hopes to determine to what extent the curriculum needs can be met electronically and to explore how e-learning can be advanced by means of modern technologies, such as wireless broadband technologies [62]. The concept of the pilot project includes having, at all five schools, computer laboratories with interactive whiteboards (more particularly SMART Boards), webcams and facilities for transmitting audio information, the latter mainly for verbal communication [62]. Most of this has been placed in two of the five schools - St Albans and Gatang High School. The other three schools in Mamelodi, Tshwane Northern College, Mamelodi High School and Modiri Technical High School, still need to be equipped with most of the computer laboratory facilities, including the SMART Boards, which will hopefully happen during the second phase of the project [160]. The second phase is to incorporate all five of the schools in the project, while the first phase only involved two. It would appear that the second phase is awaiting to be approved by ICASA before it can continue.

A Motorola Canopy network is key to the execution of the project [62]. It is a high-speed data network, capable of data rates of several megabits/second and operates in the 5.725 - 5.825 GHz band [57]. The network comprises radio terminals at each of the schools, plus radio terminals at a relay station midway between St. Alban's and Mamelodi [62]. The network was put into place in August 2003 after ICASA awarded them a temporary licence in order to preform the experiments [160].

The word "Ulwazi" means "knowledge" in Zulu. The motto of the project, "connected we learn", stems from the project partners' beliefs that being connected on the human level as well as electronically over large distances is key to successful learning in the modern world [160].

**Research:** Currently the publicly available research into the Ulwazi pilot project is in the form of two reports; a project progress report and a technical progress report [160, 161]. The project progress report covers the progress to the end of the first phase. The report is more in the form of what was done and how, and contains less about the consequences of the project and the effects on learning and teaching. Granted, the project report reports on phase one which only lasted three months and the project needs more time (hopefully with phase two) in order to ascertain the educational merit of the work. However, there are some initial remarks and conclusions that they have found. Firstly, the technical report [161] discussed a network teething phase that unfortunately lasted almost the three months of the first phase of the project. They were, however, able to solve numerous problems and devise strategic plans and ideas on how to tackle those that remain. It was found that available bandwidth and latency in signal are very important in the transmission of educational content. The authors found that a minimum of 1.8 Mbps in any direction as well as the minimum possible latency were necessary and the Canopy network was able to provide that for the teachers [160, 161]. With these configurations the transmission of data files, video, voice and the Smartboard images were all satisfactory. The teachers were all able to work interactively with classes over distances of several kilometres with relative ease [161].

Secondly, in terms of the project progress report [160]: the project partners felt that the initial results were very encouraging and there was a strong call for the implementation of phase two of the project so that the educational benefits of the project could be investigated. The project partners felt strongly that such a project had the ability to be of help in bridging the digital divide and aiding in the backlog in education [160]. Furthermore, the project partners believed that broadband off-the-shelf technologies could be of tremendous value in education in possibly being able to provide learners with access to a National Grid of learning and thus better equip them to cope with life in a technology-driven world [160]. The project partners further stressed that access to such a grid should be free of charge so that learners in South Africa are not marginalised [160]. They felt that this would need to involve an urgent address of policy on the cost of broadband connectivity to schools [160].

**Summary**

The projects and programmes discussed above are not the only ones of such a nature. There are others, such as the social responsibility projects of the various cellular phone providers (stipulated within their licences) as well as social responsibility requirements of International corporations operating within South Africa. However, there is little if any published research on such social responsibility initiatives.

It is important to note that all of these projects do not take place in a collaborative fashion. Thus projects are not learning from each other and there is the possibility that they will all make similar mistakes instead of learning from others and improving upon the work already begun.

## 3.4 ICT in education policy

### 3.4.1 Policy

Loosely defined, a policy can be considered as a plan of action that will be adopted to realise some eventual goal. As such ICT in education policies can be considered to be a set of plans that education departments and schools will follow in acquiring and maintaining ICT infrastructure as well as a plan for teacher training, appropriate use of the ICT infrastructure and financing ICT initiatives.

The following section considers what ICT in education policies are available to guide the Department of Education and schools in the provision and use of ICTs in education. First it briefly considers policies from an international perspective and then secondly it reviews the policies that are available in South Africa.

### 3.4.2 International perspective

ICT policies tend to vary from country to country; most notably first world countries tend to have detailed ICT in education policies that govern the use and growth of ICTs in education, while third world countries tend to have few policies in place.

The most notable first world ICT in education policy is that of the British National Grid for Learning (NGfL). The NGfL has been described as "the Labour government's commitment to integrating information and communications technology into [United Kingdom (UK)] schools, colleges and libraries" [162, p63] and involves a public-private partnership between the UK government and the IT industry [162]. The policy attempts to provide a co-ordinated, nation-wide drive towards widespread, Internet-based ICT use [162]. Details of the policy include an investment of 700 million pounds in order to connect all of the 30 000 schools in the UK by 2002 as well as a further 230 million pounds to train teachers to use the new technologies that their schools will be receiving. A further 50 million pounds will be made available in order to digitise and provide on-line access to every major historical artifact in the country's museums as well as the free provision of laptop computers to nearly 10000 teachers and principals [162].

While the UK has a detailed, if somewhat extravagant ICT in education policy, conditions in third world countries are in stark contrast. For example, while the Ugandan government is committed to integrating ICT in formal and informal education systems, it has yet to come up with a national ICT policy and clearly detailed strategies for achieving these goals [163].

The development of well-elaborated national policies on ICT in education in the African context still seems to be in the making. Butcher, as quoted in [124, p4] observes that despite the range of approaches used to establish education-specific ICT policies, there is an overwhelming sense within the Southern African countries that very few policies exist. Butcher goes further to say that where the policies do exist they tend to be vague and make little reference to implementation [124].

### 3.4.3 South African perspective

**The National Curriculum Statements for schools**

In South Africa the National Department of Education (DoE) has developed a number of policy documents that govern the use of computers and other ICTs in teaching and learning. These policy statements provide the framework within which schools, teachers and learners are expected to operate. These documents include the White Paper on e-Education [5], the Revised National Curriculum Statement documents for Grades R-9 for the General Education and Training (GET) band [164], the National Curriculum Statement for Grades 10-12 (schools): Computer Application Technology [165] and the National Curriculum Statement for Grades 10-12 (schools): Information Technology [166]. (Grades 10-12 fall within the Further Education and Training (FET) band.)

At the level of national curriculum policy, the Revised National Curriculum Statement (RNCS) stipulates the inclusion of computer use for grades R - 9 in a new learning area called Technology. Technology is a stand-alone subject in the senior phase of GET (grades 7 - 9) while in the intermediate phase (grades 4 - 6) it is combined with Science. There is no direct inclusion of Technology in the foundation phase of R - 3. ICT comprises one of the three strands in the Technology learning area and the RNCS states that the computer skills needed to be developed in Technology will be applicable to other learning areas as well [167].

The National Curriculum statement for the Further Education and Training (FET) phase for grades 10 - 12 provides details of the framework for the two computer-related subjects: Computer Applications Technology (CAT) and Information Technology (IT). CAT is a new subject within the FET phase and is a hybrid of the old Typing curriculum and the old Computer Science (Standard Grade) curriculum. The aim or outcome of this learning area is to allow learners to develop medium- to high-level end-user computer skills in order that they may be able to work in areas of office administration, industry, business and commerce, amongst others, or that they may be able to create employment for themselves and for others [167]. The new Information Technology curriculum is in essence the old Computer Science (higher grade) curriculum.

The aim of this learning area is to enable learners to use information and communication technologies, more specifically computers, in social and economic applications, systems analysis, problem-solving, logical thinking, information management and communication [167]. The FET phase does not specify how computers should be used across learning areas other than for IT and CAT [167].

### The White Paper on e-Education

The White Paper on e-Education of 2004[5], as mentioned earlier, is one of the framework documents that govern how computers and more generally ICTs are to used in schools throughout the country. It provides a framework for the collaboration between the the Department of Education and the private sector in providing ICT in education [167].

The prime goal of the White Paper is that "Every South African learner in the general and further education and training bands will be ICT capable (that is, use ICTs confidently and creatively to help develop the skills and knowledge they need to achieve personal goals and to be full participants in the global community) by 2013" [5].

The White Paper provides a framework of how the Department of Education intends that ICTs should be implemented in schools. It covers background information on why it believes computers and ICT are beneficial to the society at large in South Africa as well as how they are beneficial in schools and education in particular. The White Paper provides a policy framework for funding and resourcing, strategic objectives and finally implementation strategies that will hopefully see its prime goal delivered by the date of 2013 [5].

In terms of this research, the most interesting points that the White Paper raises are those which are to govern infrastructure and connectivity. In terms of connectivity the White Paper states that "Every teacher and learner in the General and Further Education and Training must have access to an educational network and the Internet [5]."

The White Paper [5] specifically refers to the Telecommunications Act 103 of 1996, Chapter V, section 41(10), where it states that the Communications "Minister shall, with the concurrence of the Minister of Education, establish an entity to construct and operate an educational network" [39]. The White Paper states that the "Departments of Education and Communications will initiate the development of a national education network in collaboration with other relevant government departments" [5]. Such a network will be designed to serve the goal of universal access for every e-school and it will provide high-speed access for learning, teaching and administration [5]. The White Paper does not cover what high-speed access methods will be used, bar mentioning that it realises that there are alternative methods to that of dial-up, which by most classifications [48] is not broadband. Furthermore, the White Paper provides no clarification on how and when this network will be established. Moreover, in the deregulation announcement [88] of September 2004, the Minister of Communications made no mention of an Education Network. The White Paper also states that it will develop adequate security measures, such as firewalls and virus protection software for the protection of these networks and their users, as well as establish standards and develop guidelines for the use of networks and rights management [5].

The White Paper also refers to section 45(3) of the Telecommunication Act 103 of 1996 where it states that "From a date to be determined by the Minister, all public schools as defined in the South African Schools Act, 1996 (Act No. 84 of 1996), and all public further education and training institutions as defined in the Further Education and Training Act, 1998 (Act No. 98 of 1998), shall be entitled to a 50% discount on:

- all telecommunication calls to an Internet service provider; and

- any connection or similar fees or charges levied by an Internet service provider for accessing the Internet or transmitting and receiving any signals via the Internet or for such access and transmission and reception [39]."

This legislated e-rate is a discounted connectivity rate that is designed to ensure that the cost of basic connectivity is affordable [5]. This e-rate was indeed announced during the deregulation announcement by the Minister of Communications in September 2004 [88] (as was discussed in Chapter 2).

However, even though it is now legislation that state schools be given the e-rate, most are not receiving it and the E-School's Network (ESN) in the Western Cape is taking the matter to the Independent Communications Authority of South Africa (ICASA) for review [168].

The White Paper further makes mention of the social responsibility activities that all Fixed-line Telecommunications and Mobile Telecommunication Service providers are required to offer as part of the conditions of licencing. It also determines the social responsibility projects in which international corporations are obligated to participate in order to be permitted to operate in South Africa. The Department of Education feels that much of the funding for infrastructure will come through these of social responsibility projects [5].

**Managing ICTs in South African schools**

During 2002 and 2003 the South African Institute for Distance Education (SAIDE) undertook an extensive research project to investigate the use of computers for teaching and learning in South African schools. The research showed that one of the reasons why information and communication technology (ICT) projects in schools do not succeed is that principals are often not properly informed about what ICT can or cannot do [169]. This often hampers their ability to manage the introduction of ICTs into their schools. These findings confirmed a need to support the principals and school management in the integration of computers and related resources into teaching and learning activities in their schools [169].

For this reason the Principals' guide to managing ICTs in South African schools was drafted. The purpose of this guide is to "give principals and senior management information on using and managing ICT resources so that they can provide leadership in their schools [169]." It is hoped that the guide will be a valuable resource for school management and school Governing Bodies. Furthermore, the guide also considers some of the implications of using computers and related resources for teaching and learning [169].

The guide attempts to highlight the importance of a more realistic approach to what computers can do, namely that computers will not solve all educational problems. It emphasises the need to assist teachers with relevant professional development and support in using computers for teaching and learning, while acknowledging the important role of the teacher as a mediator. Finally the guide stresses the importance of using computers to learn how to learn and work better, rather than just using them to become computer literate: the basic computer skills are not enough [169]. Thus it is necessary to learn how to use computers as a tool for learning and working more efficiently, stressing that all training should be contextualised and skills taught should be related to particular work or particular learning areas [169].

The guide is broken down into seven chapters. The last chapter in the guide which looks at computer and network acquisition will be concentrated upon here. Chapter seven discusses budgeting for computer infrastructure, highlighting how much the various components will cost, while emphasising that the initial costs of purchasing computers is not the total cost of ownership [169]. It stresses it is very important for schools to realise that computers will require maintenance, repairs and replacement, all of which will need to be budgeted for in order to achieve sustainability. The chapter then goes on to discuss where computers should be placed within the school. The recommendations are based on the amount and type of computer infrastructure in the school. Next it looks at buying computers, peripherals and networking technologies for use within the school. The guide encourages schools to purchase equipment which is reliable, standardised and includes good basic services at reasonable prices [169]. The guide provides some information about new and refurbished computers, printers, CD-ROM drives, scanners and data projectors [169]. Furthermore, it provides a brief introduction to LANs, email and Internet access, with reference to five methods of Internet connectivity. The guide then moves onto the security of the computers, namely physical security as well as the importance of insuring the computers and then discusses Acceptable User Policies [169]. At no point does it appear to address the issues of software security of the computers, which is important should the school have Internet access. There is also a noticeable lack of information with regard to software and appropriate choices thereof and the implied costs. While schools can save money from the South African School Agreement for Microsoft Software [170] (hereafter referred to as the Microsoft school agreement), which provides them with free operating systems upgrades, *Microsoft Office* and *Encarta*, not all software will necessarily be free. Furthermore, there is a lack of discussion about proprietary software as opposed to open source software. Schools need to be made aware of open source software for the reason that the software is free of charge in most cases and is easy to acquire and redistribute without fear of licence infringement. Numerous teachers consulted during this research project were unaware of what open source software is. Schools also need to be made aware of good educational software, much as the state decides on good educational content in terms of text books, the state needs to recommend good educational software, in both the proprietary and open source arenas.

The guide further does not attempt to provide any advice as to which of these various products, hardware and software, schools should be looking at depending on their financial, geographical and historical background. Schools are expected to use the document as a rough guide and research all options to see what configuration of infrastructure would suit them. Furthermore, there seem to be some misconceptions about certain hardware suggestions. For example, the disadvantages of LANs mentioned, are not quite as clear cut they are made out to be. Despite the expense, installing a LAN would naturally incur, the overall costs saved through resource sharing on a LAN outweighs the initial expense of infrastructure. Instead of having to have a number of printers on stand-alone machines, one printer can be shared over the network. A further perceived misconception would seem to be with regard to ”Wireless access and satellite connection” for of Internet connections. The guide refers to these methods of Internet access as prohibitively high for schools. While, satellite access is currently expensive, wireless access should not be. Currently, wireless access in South Africa is not legal unless provided by Telkom, the SNO, Sentech or WBS. The services from Sentech and WBS are only available in certain metropolitan areas and are not prohibitively expensive, while at the time of writing this dissertation, there are no wireless offerings from Telkom or the SNO. Wireless access has a strong potential to be very cheap in comparison with fixed line access due to the minimal infrastructure needs as discussed in Chapter 2.

Arguably the most useful portion of the entire guide can be found in Appendix 2 [169] and deals with eight scenarios of ICT in school use, from purely for school administration use to a scenario that is beyond ICT integration, but envisages learners using ICTs to do subject related work in non-IT subject lessons in a sustained and well-integrated manner [169]. Each scenario tries to provide information on what ICT resources would be necessary for implementation, where computers should be located, what kind of software would be necessary (high level overview), what ICT training and professional development for teachers would need to take place, what necessary tasks an IT teacher would need to perform and what necessary tasks a technical support person would need to perform [169].

The guide begins to provide a much-needed guide for schools and school principals in implementing ICT in schools and in teaching and learning. However, there are still issues of possible confusion that the guide does not answer and levels of detail that are missing.

#### Eastern Cape's provincial policies on e-Education

While the White Paper on e-Education governs the framework for the implementation of ICTs in schools nationally, each province is expected to draft their own implementation strategy for Information and Communication Technology in Education. As this research study was undertaken in Grahamstown in the Eastern Cape the Provincial strategy for ICT in Education of the Eastern Cape Department of Education is now examined.

In its educational development and implementation programme, the Eastern Cape Department of Education considers ICT an integral part of the education and training system and has developed an ICT strategy in an effort to ensure that ICT supports education, training and development. The goals of its proposed strategy are to [171]:

- Accelerate the implementation of ICT in schools and Further Education and Training institutions;
- Minimise duplication of efforts between Education and other Departments, as well as other organizations and service providers;
- Co-ordinate private sector-led ICT investment in the education and training sector,;and
- Ensure that the ICT investment in education contributes to the broader goals of the Tirisano (an initiative of the South African Education Department to work together to build a South African education and training system for the 21st century [172]) programme of action.

The following objectives of the ICT strategy for the Eastern Cape schools are also outlined in this document [171]:

- To accelerate the introduction of ICT in its schools;
- To mobilise resources and establish partnerships to increase the implementation of ICT in schools;
- To enhance human resource development for both teachers and learners in the use of ICT;
- To facilitate the use of ICT to improve management, administration and access to teaching and learning resources; and
- To mobilise the buy-in of all the stakeholders; i.e. the public communities as well as the school community.

In order to achieve these goals and objectives the provincial strategy discusses a strategic framework within which it will operate. The strategy covers four broad areas, namely the establishment of an ICT forum; the establishment of an Information Management Unit; the establishment of an educational network and the continuation of current initiatives. The purpose of the ICT forum will be to discuss information issues that are of common interest to schools as well as to design strategies to address information sharing and shared systems. The purpose of the Information Management Unit will be to guide schools in determining their information needs through identification and dissemination of information. It is hoped that the Unit will assist with provision of IT infrastructure, with the aim of overseeing the integration and implementation of ICT as well as support and maintenance in schools. It is further hoped that through the activities and projects of this strategy an educational network linking all schools, will be established. As well as arsing in the provisioning of basic infrastructure such as computers and television sets, the Unit plans to oversee the developments of appropriate educational content and teacher-training in the use of the technology. The strategy further recognises the current and past initiatives of companies that were and are in partnership with the Department of Education in their endeavours to bridge the digital divide in the Eastern Cape [171].

The strategy recognises that a proper ICT audit needs to be conducted in the province in order to identify where aid is needed, as previous research has indicated that the status of ICT infrastructure, skill, access and usage are still very low within the province [171].

The strategy also looks at strategic initiatives that it feels should be addressed in order to realise the goals of the implementation of information and communications technology in education. Briefly, these include: creating an ICT network and infrastructure; facilitating the development of relevant electronic/on-line content for educational use; initiating Human Resource Development in the use of ICT in education; ensuring the integration of policies, projects and initiatives of ICT in schools; establishing partnerships to accelerate implementation of ICT in schools; developing mechanisms to ensure that support and maintenance is provided to the schools with ICT; and promoting the effective use of ICT in teaching and learning [171].

Unfortunately, nowhere in the strategic policy does it elaborate on concrete plans and methods to achieve these goals and objectives. There is no mention of how and when these ideas will come into effect. Furthermore, there is no mention of how a school within the Eastern Cape might go about applying to the Eastern Cape Department of Education for aid in realising its goals of ICT integration [171].

## 3.5 Conclusion

### 3.5.1 Gap in published documents of ICT in schools in South Africa

From the above discussion of the policies that govern ICT implementation in education, it is obvious that while national policy, namely the White Paper on e-Education, provides a broad framework of what the national Department of Education believes should be done in implementing ICTs in Education, the finer points of how this is to be implemented, i.e the translation from policy to practice, has been left to provincial government level.

The Eastern Cape Provincial policies on ICT in education tend to outline fairly high level intentions of implementing ICT integration into education. The policy mentions no specific practical steps that schools could take in deciding on appropriate infrastructure, how to obtain that infrastructure, make effective use of the infrastructure so that it would benefit the educational and administrative needs of the school, or maintain, sustain, or secure the infrastructure. There is no guide of how teachers are to be trained in computer literacy and computer integration, nor is there any guidance on how teachers will integrate computers into their specific learning areas. Both national and provincial policies leave schools, teachers and principals unsure of how to go about integrating ICT into the curriculum.

Realising the shortfall SAIDE was commissioned by the Department of Education to undertake research into the use of computers for teaching and learning in South African schools [169]. The research showed that one of the reasons why information and communication technology (ICT) projects in schools do not succeed is that principals are often not properly informed about what ICT can or cannot do [169], nor are they aware of how to go about obtaining and later integrating such infrastructure. For this reason the Principals' Guide to Managing ICTs in South African Schools was produced. The guide is generally practical in nature and provides schools with a fair degree of detail as to how to go about obtaining and maintaining ICT infrastructure as well as teacher training. However, the guide is not specific about the appropriateness of the infrastructure or the methods of integration, leaving the school to flesh out these areas on their own. There is also much that the guide does not cover, such as the benefits of certain types of infrastructure and how they measure against others, nor the appropriateness of open source software as compared with proprietary software in particular circumstances. Furthermore, there seem to be some misconceptions within the guide, as discussed earlier.

### 3.5.2 Need for procedures

While the Principals' Guide to Managing ICTs in South African Schools is an attempt to bridge the gaps between policy and practice, more is needed. The procurement, maintenance and sustainability of ICT infrastructure is a mammoth task alone, without considering the educational needs or integration into the curriculum. Schools will require specific sets of procedures so that they may move successfully through each stage of the process of integrating ICTs into education.

In terms of infrastructure alone, schools will need comprehensive guides in the following areas in order to contribute to the successful integration of ICTs into teaching and learning within their schools.

Firstly, schools will need to choose appropriate hardware, both computer and additional peripherals. Decisions about whether to have thin or think client machines need to be made, as well as the amount of computing power that will be necessary and further decisions about the types of motherboards, graphics and sound cards, RAM, hard-drive sizes and make, etc. All of these decisions should be based on what the school wants to do with the ICT technology and thus require a strategic ICT plan so that they purchase appropriate hardware across the board.

In addition to choosing appropriate hardware, schools need to choose appropriate software for their educational needs. A school will need to decide between proprietary and open source software. They will also have to choose between different packages that have similar functions. All these choices need to be based on what has the most educational benefit for the school, what is the most cost-effective, which is the easiest to maintain, etc. All the pros and cons need to weighed up so that well-informed decisions can be made. It is important to note that hardware decisions can affect the kind of software or operating systems that a school can run and vice versa.

Adding to the complications will be the local area network that a school may decide to run. The benefits of networked ICT infrastructure tend to outweigh stand-alone equipment as networking allows for sharing of resources. The school will have to make decisions as to whether it wishes to have a client-server network, peer-to-peer network or a hybrid network. All of these decisions can also affect the choice of hardware and software that a school purchases.

The White Paper on e-Education mentions a National Education Network which the Department of Education, together with the Department of Communications, will initiate for the benefit of all state schools. Should such a network come into being, schools will need to consider obtaining some form of connectivity. As highlighted in Chapter 2, there are many different types of wired and wireless methods of Internet connectivity. The choice of networking will depend on how many school hours will be spent on the network in a month, whether the school is in a rural, urban or peri-urban area, how much money the school can afford to spend on their network connectivity, etc. Furthermore, the school will need to choose an appropriate Internet Service Provider (ISP) and decide if they would like the ISP to perform duties for them such as email and web services as well as basic support. The school will need to decide what it needs and then approach ISPs and find out what each one is prepared to offer them. Should the school decide that they wish to run email and web services locally then they are going to need to obtain appropriate hardware and software for doing so, as well as a skilled individual in system administration of such services. They will also need appropriate bandwidth to support such services within the school.

An additional factor to take into consideration should the school choose to become connected to the Internet is the need for appropriate software to limit sites that the learners may view. Appropriate software will be necessary in order to make sure that the learners are prevented from gaining access to pornography or any other inappropriate materials. Furthermore, the school will need to employ appropriate firewall and anti-virus software for the protection of network from malicious attacks. Schools will need to make appropriate decisions about the physical security as well, such as decisions about employing armed security, burglar bars, locked-down workstations, etc. It would also be a good idea for a school to consider insuring their equipment against theft and destruction.

Further considerations need to be made regarding the use of cache servers to minimise Internet traffic, proxy servers to authenticate valid users of the school's Internet account and traffic shaping to ensure that the school does not use more than its allotted quote of bandwidth for the month.

A number of school policies will also need to put into place, for example Roll-down policies, Upgrade Policies and Maintenance policies. Such policies will govern whether and to where computers are rolled-down, when new computers should be purchased and how often, if the school does in-house maintenance or if it outsources its technical needs to a local business. Furthermore, the school should consider an Acceptable Use Policy (AUP) that all parents, learners and teachers sign. An AUP is a set of guidelines for the appropriate use of computer networks, outlining the terms and conditions of Internet use, rules of on-line behaviour and access privileges [173].

The integration of ICTs into teaching and learning requires careful planning and decision-making. The various infrastructure components have a direct bearing on other parts of the infrastructure, as well as teaching and learning. Schools need to be able to make informed decisions and thus comprehensive guides are required to help all schools understand the importance of making appropriate decisions from the outset.

### 3.5.3 Conclusion

Now that more is understand about the ICT needs of schools and the policies that govern ICT in schools in South Africa, as well as the network technologies available in South Africa and the legislation that governs them, the research design of this study can be considered. The research design draws from the background knowledge that was presented in this chapter and chapter 2 and guides the direction of the study in order to meet the research goals and provide answers to the research questions.

# Chapter 4

# Research design

## 4.1 Introduction

Having presented the background information, in chapters 2 and 3, pertaining to both computer networks that could be deployed in the Grahamstown Circuit as well as possible reasons for doing so, and a discussion of telecommunication policy and ICT in education policy, the research design of this project is now explained.

The chapter begins by presenting the research orientation in order to make clear the paradigm within which the research was conducted. From there the research goals, specifically looking at the research aims and questions, are discussed. The fourth section of this chapter covers the research environment, with an introduction to South African school classifications, the Grahamstown Circuit and the research participants. Section 4.5 covers the research design and framework, the research methods, tools and activities. The ethical issues that surrounded this particular study are discussed in section 6 and is followed by the final section on data analysis. In this section the two methods of data analysis, quantitative and qualitative data analysis as well as how they were employed in this study are covered.

Please note that the voice of this dissertation changes from the third person to first person for the remainder of the dissertation in order to clearly distinguish between work which was conducted by myself only, COE employees only, other researchers or a combination of these groups.

## 4.2 Research orientation

This study draws from the Sciences and Social Sciences in order to investigate the problem of how best to provide connectivity to schools, in order to contribute to the integration of ICT into schools. When considering research that involves only machines or calculations in a laboratory, the positivist approach [174] has merit; however, when research involves groups of people and their interactions with each other or inanimate objects, a positivist approach has limitations. Critics point out that people are not plants or chemicals and therefore variables can often not be identified nor isolated, controlled or measured (variables such as emotions and thoughts) [174]. Critics also question positivism's firm stance on being able to be completely objective. Positivist researchers believe that they have no influence on the research at all; they are nothing more than observers. This position is strongly criticised, because it is felt that it is impossible to be completely objective [174]. From the criticism of positivism, it was clear that it would not be a suitable paradigm for me to choose for this project.

A pure interpretivist approach, however, was not appropriate either, because of the experimental work that was done with networking and which fits comfortably within the positivist approach to research. For this reason a post-positivist approach was chosen.

Post-positivists accept that researchers cannot be completely objective at all times and that subjectivity will be found in their work, but that they will endeavour to limit it. Post-positivists also accept that people cannot be held to the strict measurements of the positivist approach and that the information provided by the individual is important and can not necessarily be generalised to others [175]. The post-positivist approach allows for the combination of the experimental research of the network deployment and testing of the project with the schools' survey and interviews of IT teachers.

A fairly recent form of post-positivism is critical realism. A critical realist believes that there is a reality independent of our thinking about it that science can study. Post-positivist critical realists thus recognise that all observation is fallible and that theories can be revised. This is largely different from the positivist approach, where definite facts are non-refutable. Thus, a critical realist is critical of our ability to know reality with certainty [175]. Trochim says it succinctly: "where the positivist believed that the goal of science was to uncover the truth, the post-positivist critical realist believes that the goal of science is to hold steadfastly to the goal of getting it right about reality, even though we can never achieve that goal" [175, para 6].

Within the study the key steps of action research were followed. Action research is a disciplined method for intentional learning from experience – a type of applied research, characterised by intervention in real world systems and followed by close scrutiny of the effects [176]. Thus this project is informed by a post-positivist critical realist paradigm and the main tenets of action research, attempting to bridge the sciences and the social sciences. I am aware that my results are fallible and not necessarily generalisable.

## 4.3 Research goals

### 4.3.1 Research aims

This research aims to establish the most cost-effective and organisationally sound means of networking computer facilities of schools in the Grahamstown Circuit in the Eastern Cape.

Thus this project will hopefully provide the schools in the Grahamstown Circuit with useful models of connectivity to help schools devise feasible plans for obtaining ICT infrastructure and Internet connectivity. The work will hopefully also contribute to the broader aim of integrating ICT into the curriculum, thus allowing administrative staff and teachers to do administrative work and plan lessons as well as provide ICT access to learners.

Furthermore, this project forms part of a bigger project that is being sponsored by the National Research Foundation (NRF). This project has as its aim the identification of the infrastructural, policy, pedagogical and learner-related issues that influence the integration of ICT into the curriculum. The main research question of this larger project is: "What strategic issues need to be addressed to ensure that secondary schools in the Grahamstown Circuit can successfully integrate ICT into the curriculum?" In order to answer this question a research team was put together, and I worked with two Master of Education (MEd) students, Nikiwe Maholwana-Sotashe and Nombeko Mbane, in contributing data to the project. Maholwana-Sotashe's focus in this overall project has been to identify how the use and integration of ICT affects the teachers in the schools, while Mbane was charged with identifying how the use and integration of ICT affects the learners in the school.

### 4.3.2 Research questions

In the light of the above research aims, the following research questions guided this study. The main research question is:

What networking technologies and models can support secondary schools in the Grahamstown Circuit in implementing their vision for integrating ICT into schools?

The subsidiary questions arising out of the main question are:

- What ICT infrastructure and computer networking technologies already exist in the schools?
- What are the infrastructural issues that the school principal, teachers, learners, parents and the state face in introducing ICT and Internet connectivity into schools?
- How can these infrastructural and connectivity challenges be overcome?
- What network technologies can be used in the Grahamstown Circuit in order to connect schools to the Internet?
- How exactly can those network technologies be used to gain maximum efficiency from them?

## 4.4 The research environment

### 4.4.1 South African school classifications

One of the features of apartheid was that South African schools were separated according to race. There were four basic departments which governed the different schools according to race as well as a number of Homeland departments. In each instance, there were separate education departments. In what is now the Grahamstown Circuit, there were schools falling under the House of Assembly (White schools), House of Representatives (Coloured schools) and the Department of Education and Training (Black schools) [124, 177]. Furthermore, there were independent or private schools who accepted learners from any race group provided they were able to afford the school fees.

When South African became a democratic nation these state school classifications fell away. The disparities of the past, however, still have a large affect on these schools today: former Department of Education and Training (FDET) schools tend to be more disadvantaged than former House of Assembly (FHOA) schools. For this reason we retain the former terms in order to differentiate between the historically most poorly resourced FDET schools and the mostly well-resourced FHOA schools [124] and independent schools.

In 1990 the House of Assembly announced a series of new governance models for the schools under its control. The proposal gave the schools four options: they could retain the status quo, or by a majority vote of the parents elect to adopt one of the three new governance models, A, B or C [177]. Model A provided for the conversion of the school into a independent school, and required the purchase by the community of the school buildings from the state [177]. Model B provided for the continuation of the school as a state school, but with the right given to a management committee, elected by the parents, to determine the admission policy, subject to certain limitations which would ensure that the majority of children were white [177]. Model C provided for the conversion of the school into a state-aided school under the control of a governing body elected by the parents. The major condition of this model was that the state would only cover the costs of salaries, and other recurrent costs such as textbooks and educational materials, maintenance and building insurance, rates and services [177]. All capital costs would have to be met by fundraising activities of the parent body [177]. However, in February 1992 there was a further development when an announcement was made that unless parents specifically voted against it, all status quo and Model B schools would be converted to Model C schools [177].

Within the former House of Assembly schools in the Grahamstown Circuit, there are former Model C schools. In order to preserve anonymity in this study the various schools are referred to as former Model C (FMC) schools, former House of Representative (FHOR) schools, former Department of Education and Training (FDET) schools and independent schools (IS), without identifying the individual schools.

### 4.4.2 Research site: the Grahamstown Circuit

Grahamstown is a small town situated in the Eastern Cape, with a population of approximately 120 000 and a diameter of 10 to 12 km. The town is situated in a valley with hills surrounding it. The greater part of the town lies within the bowl, but parts of the town extend into and over the hills. The section of the town within the city bowl is often referred to as Grahamstown West, while the section which extends over the hills is referred to as Grahamstown East. Historically, Grahamstown West was where mainly white people lived, while Grahamstown East was where black people lived. As a result of this, Grahamstown East is far less developed than Grahamstown West, with certain areas of Grahamstown East still without even basic sanitation facilities.

All of the FDET schools and the FHOR school are found in Grahamstown East, while the FMC and independent schools are found in Grahamstown West. Of the 13 secondary schools in the Grahamstown Circuit, 3 are independent schools, 3 are previously Model C schools, one is a former House of Representative school and the remaining 6 are former Department of Education and Training schools, providing a microcosm of the country's schooling systems. The term 'Grahamstown Circuit' is an Eastern Cape Department of Education (EC DoE) classification and it is used to represent the schools in the town of Grahamstown. There is a larger managerial area around Grahamstown, called the Makana District, in which the local DoE is responsible for the schools in the Grahamstown, Alice and Port Alfred Circuits.

The physical layout of Grahamstown also has a bearing on this study, as geography can either help or hinder networks. For example, the hilly nature of Grahamstown does not always allow for line of sight in wireless networks. This would affect the design of a network. Furthermore, the diameter of the town has some bearing on the network choices. For example residents or schools that are not close enough to the Telkom exchange, situated in Grahamstown West, would not be able to have a DSL connection, as DSL has a maximum limit of 5 km. See figures 4.1 and 4.2 for where the schools are found in Grahamstown and the contours of the town respectively.

### 4.4.3 Research participants

#### School infrastructure survey

As my part of the project involved the evaluation of the current ICT infrastructure, I approached the principals of the schools to request permission to survey (via a questionnaire) and then conduct follow-up interviews with the people in charge of ICT at their schools. These people were usually the IT teacher or a network manager at the schools. I was granted permission to survey and interview the person responsible for ICT at the 12 of the 13 schools. One school elected not to participate in the research project at all. Although I received 12 questionnaires from the ICT responsible person, I was able to conduct follow-up interviews with only 11 people as the IT teacher from one school was not prepared to be interviewed even though she had completed the questionnaire. Furthermore, as IS1 and IS3 share a common network, their IT managers chose to be interviewed together which resulted in one interview transcript for both schools.

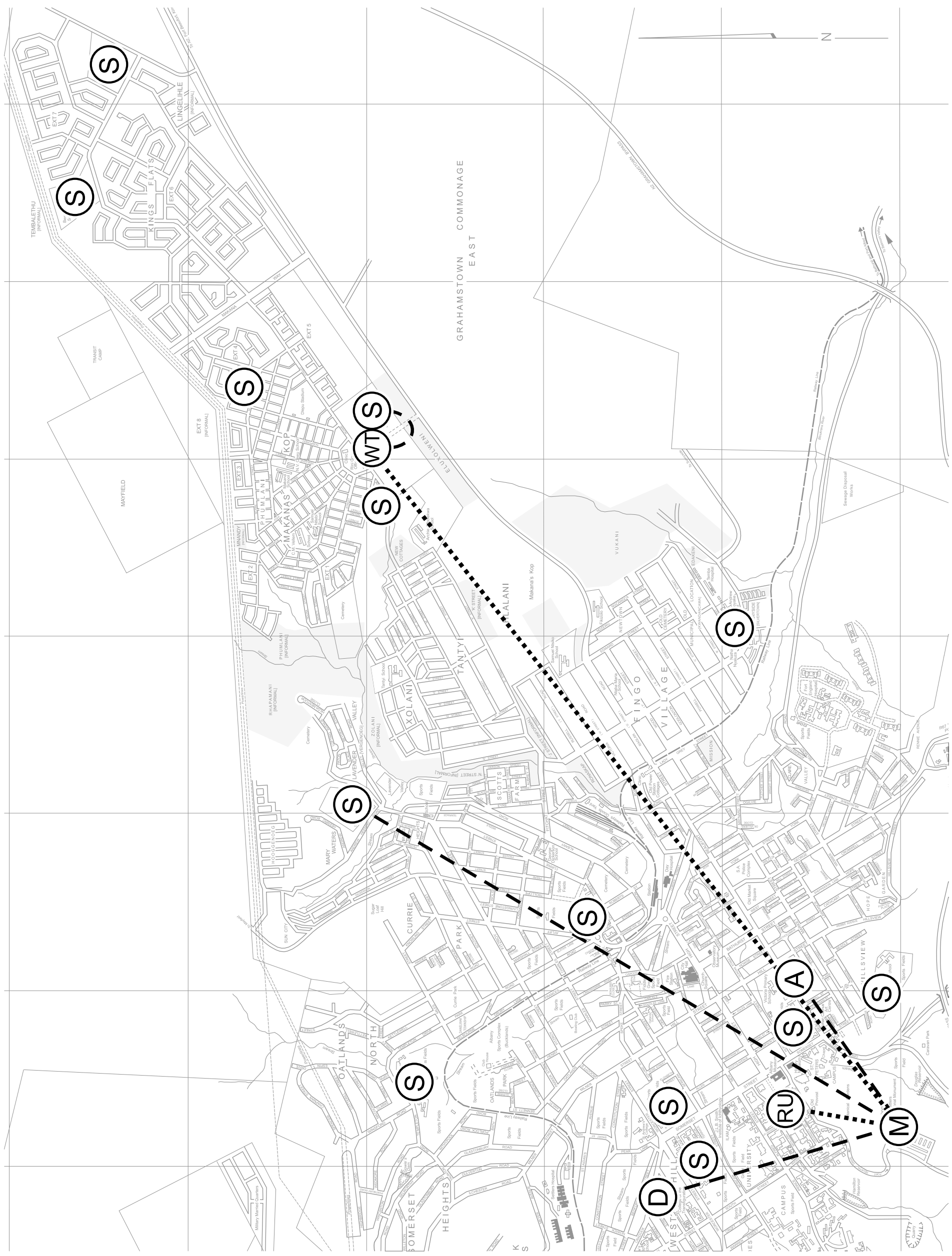


Figure 4.1: Map of Grahamstown

Depicting all 13 schools (S), the Monument (M), Rhodes University (RU), site A, site D and the water tower (WT). The dashed lines depict which sites were connected to the wireless network.

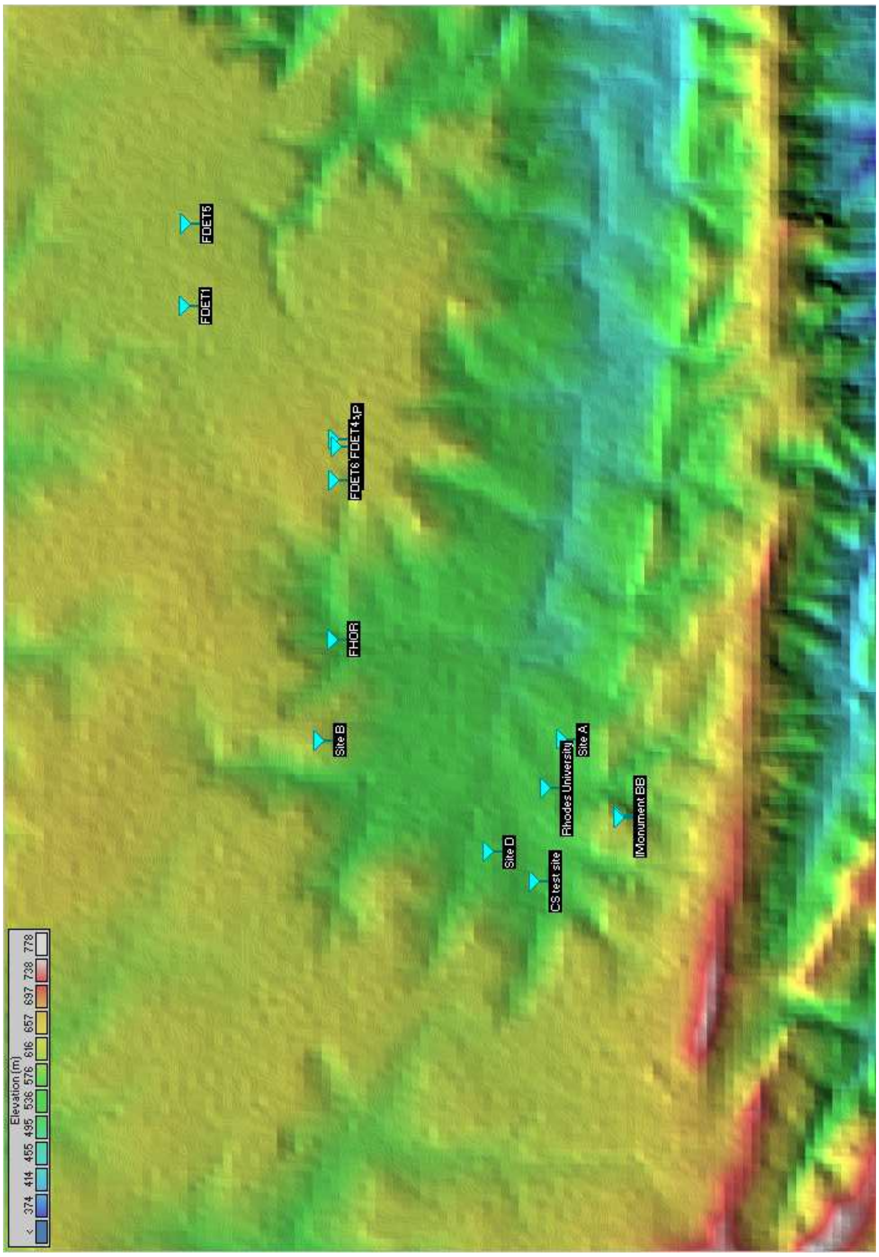


Figure 4.2: A contour map of Grahamstown.

Depicting the Monument APs, the water tower APs, Rhodes University, site A, site B, site D, a computer science test site, FDET1, FDET4, FDET5, FDET6, and FHOR.

| Type of Data | Data Collection Methods | Data Collection Tools |
|---|---|---|
| Quantitative Data | Survey | Questionnaire |
| Quantitative Data | Observation: On-site Audit | Blogging and Wiki |
| Qualitative Data | Semi-structured interviews | Transcripts of the interview recordings |
| Quantitative Data | 'Desktop survey' | Evaluation of Networks: Network 'desktop survey' |
| Qualitative Data | Action Research | Network deployment and testing |

Table 4.1: Research methods and tools employed in this study.

**Networking**

The DSL network deployed in the Grahamstown Circuit was extended to two primary (grades R - 7) schools and one secondary (grades 8 - 12) school in the Grahamstown Circuit. As this project is primarily concerned with secondary schools research data will only be included from the secondary school (FDET3). The DSL line at FDET3 terminated in a DSLAM in the network rack of the Centre of Excellence's (CoE) in the Computer Science department at Rhodes.

While the wireless network was subsequently earmarked for three of the secondary schools in the Grahamstown Circuit, FDET1, FDET4 and FHOR, it unfortunately could only be deployed in FDET4 and FHOR, during this project due to organisational issues at FDET1. In addition there was extra experimentation done at client sites in Grahamstown West at the homes of colleagues in the Computer Science department. Other parts of the wireless network included the backbone at the 1820 Settlers Monument and the water tower at FDET4. While a DSL line between Rhodes University and the 1820 Settler Monument was used to haul all Internet traffic generated on the wireless network back to Rhodes.

Deployments of these networks involves a fair amount of work and as such I needed some assistance in completing them. The CoE hires technical staff and as such these technicians aided me in the network deployments to the schools. Thus when I refer to "we" during the network deployments, I am referring to myself and the CoE technicians who aided me.

## 4.5 Research design and framework

### 4.5.1 Research methods and tools

For an overview of the research methods and tools employed in this study please see Table 4.1.

**School infrastructure survey**

All 13 secondary schools in the Grahamstown Circuit were invited to participate in a survey. Surveys are most effective when the aim is to reach a large proportion of a population. They tend to be used to extrapolate and generalise from a typically small sample of a population to the whole population [178]. I used a survey in order to gain a basic understanding of what ICT infrastructure was available, how ICT is being integrated and to what extent, so that by the time we arrived at the school we would already have an overview of the ICT infrastructure and ICT use at the school.

The survey was carried out through sending out a questionnaire with a covering letter explaining this project to the principal of the school. The questionnaire was a collaborative effort by Maholwana-Sotashe, Mbane and myself. My component of the questionnaire was targeted at the IT teacher or IT specialist within the school. It is important to note that an IT teacher is a teacher who teaches IT courses within the school, while an IT specialist is an administrative position and the person's sole responsibility is running and maintaining the school computers and networks (i.e. a system or network administrator). In cases where there was no IT teacher or specialist, one of the teachers answered the questionnaire as well as the deputy principal or a head of departments (HOD) of the school. The intent of the questionnaire was to gain an understanding of what exactly schools in the Circuit have in terms of infrastructure; how they have set up the networks at each school so that integration is possible; what limitations, geographical, cost and others, they need to overcome or work around in order to make networking to, and within, the school possible. The particular details of each school's ICT infrastructure, i.e. hardware, networking and Internet access, as well as the details pertaining to their organisational issues, such as location of computers and maintenance were gathered through questionnaires (See Appendix D).

Once confirmation was obtained from the schools and the completed questionnaires returned, arrangements were made to visit to the schools in person. Our visit allowed us to conduct the necessary interviews and to undertake an on-site audit. Maholwana-Sotashe interviewed the teachers at the schools; Mbane, the learners; and I interviewed the IT specialist. "Interviewing is a two-person conversation initiated by the interviewer for the specific purpose of obtaining research-relevant information, and focused by him on content specified by research objectives of systematic description, prediction or explanation." [179, p1]. For each interview there was an interview schedule (See Appendix E) of questions that I covered. These questions were based on the responses that the principal or IT teacher provided in the questionnaire. The interviews provided data that is richer than that of the questionnaire and it also allowed for more focused questioning and to clarify answers/responses from the questionnaire. These interviews created a deeper understanding for myself as to what the needs of each school were and what the problems are that they are facing. The interviews provided information about software, teacher training, cost issues, infrastructural issues and many other limitations that will be discussed further in chapter 5.

Through data collected from the questionnaires and semi-structured interviews I was able to compare schools with each other by calculating some statistics about school infrastructure from the data provided. This data provided me with some insight into the school's ICT needs and use. Furthermore, it served to highlight common trends that were found in the schools.

Another method of data collection that was used is that of observation. Observation is about describing or representing a setting [180]. Our observations were in the form of an on-site audit, to accompany and hopefully support (or possibly refute) data from the questionnaires and interviews. The trends that were found through the questionnaires and interviews were confirmed or denied by the observation undertaken at each of the schools. In observing each school, I noted what was found in the school (infrastructure and equipment) as well as the limitations faced by each school for possible recommendation later. The information from the on-site audit was captured in my research blog (http://ings.rucus.net/blog/) as well as the schools wiki (http://school-wiki.ru.ac.za/ currently only available from within the Rhodes University network), that a colleague and I created to document the infrastructure of each of the secondary schools that we visited. A blog, also known as a weblog, is a personal website consisting of regularly updated entries displayed in reverse chronological order. It reads like a diary or journal, but with the most recent entry at the top. A wiki is a web application that allows users to add content, as on an Internet forum, but also allows anyone to edit the content. Wiki also refers to the collaborative software used to create such a website.

#### Networking

In order to be able to suggest different models of connectivity to schools, it was imperative to establish as much about networks as possible. This meant having to do a 'desktop survey' of all possible networks, both wired and wireless, that are currently available in South Africa, or that have the highest chance of being available in South Africa in the future. Through the network 'desktop survey' I was able to gain a broad overview of various types of networks, their advantages and disadvantages and how they could be of benefit or use to secondary schools in the Grahamstown Circuit (overviewed in chapter 2). In addition the 'desktop survey' allowed me to consider and compare, where information was available, the costs, benefits and limitations of the various network types included in the 'desktop survey'. As a proof of concept [181, 182] of the surveyed networks, two types were chosen, one wired and one wireless, for experimentation purposes. These two types are DSL and IEEE 802.11.

The various networks surveyed provide a wide range of different choices for schools, some of the options being slightly older networking options while others were relatively new. Since South Africa is in large part a third world country, it makes sense to consider all the options, from the older to the newer technology, because the infrastructure for the older technology is more likely to be available than that of the newer technology, and the newer technology could tend to be more expensive than the older technology. The older technology, such as dial-up, provides a basis to compare all the other options against. On the other hand, as a result of having a low teledensity in the country, South African could be considered as a "green field" [183] and therefore has the possibility to leapfrog older technology to that which is new. For example, as the price of copper cable and optical fibre converge, it becomes more realistic to place optical fibre in the ground and thus leapfrog copper cable connectivity methods such as DSL, ISDN and dial-up. In Britain, British Telecoms (BT) is not in a situation where it actually has a "green field" but realises that the potential for change now is great and so is wiping its telecommunication infrastructure slate clean and beginning again so it they may leapfrog to a better network with the roll out of its 21st Century Network (21CN) project [184, 185].

The second phase of the network deployment involved identifying network technologies that would be deployed and then deploying the network. This process consists of constant refinement of the network. As we discovered new information about the network through deployment, I was able to refine the network and improve on it. The quality of the network and data transfer is based on the assessment of the speed (or throughput), reliability and latency. In providing guidelines for assessing a network, Cleveland lists these three factors (speed, reliability, latency) as parameters to be tested [186, p197]. Investigating the reliability of a network involves regularly checking the network and recording statistics of the network. One method of testing the network reliability is to send large volumes of data and note how many of the packets were dropped by the network. Measuring speed of data transfer involves measuring the time that it takes to transfer data on the network, while something as simple as ping would measure the round trip latency.

In order to test the networks, I ran two Perl scripts. Perl, the Practical Extraction and Report Language, is an interpreted procedural programming language [187], combining syntax from several UNIX utilities and languages, and is optimized for scanning arbitrary text files, extracting information from those text files, and printing reports based on that information [188]. Tests were run for anywhere between one to three weeks.

The first program, called *ping.pl* (Appendix A), used the ping utility to ping another machine, then recorded the minimum, maximum, average and standard deviation of the round trip time. The ping program was written in 1983 and is used to test reachability of destinations by sending them one, or repeated, Internet Control Message Protocol (ICMP) [189] echo requests and waiting for replies [190, 191]. *ping.pl* records the results mentioned above into a comma-separated value (CSV) file that can be imported into graphing software.

This ping test allowed me to test the reliability of the networks as well as the latency of the networks. From the values returned by the script I could determine the average time it takes for a response to be received from another machine on the network, (in other words the latency experienced on the network), while the number of packets that are returned indicates the reliability of the networks.

The second Perl script, called *transfer.pl* (Appendix A), copied a data file of a reasonably large size (768KB) from one machine to another and recorded the rate at which the file was copied. Graphs have been generated from the resulting CSV files. This transfer test allowed me to test the available bandwidth and reliability of the networks.

The ping test was run every 5 minutes while the transfer test every ten minutes, testing connectivity across the DSL network to FDET3, and connectivity to each of the schools on the wireless network. A detailed explanation of the action research and its results and findings will be discussed in Chapter 6.

This process of surveying and then network deployment was a contribution to an ongoing action research that is being conducted by the CoE in the Computer Science Department. Action research can be described as a family of research methodologies which pursue action (or change) and research (or understanding) at the same time [192]. In most of its forms it does this by

- using a cyclic or spiral process which alternates between action and critical reflection; and
- in the later cycles, continuously refining methods, data and interpretation in the light of the understanding developed in the earlier cycles [192].

It is thus an emergent process which takes shape as understanding increases; it is an iterative process which converges towards a better understanding of what happens [192]. In most of its forms it is also participative and qualitative [192]. The action research process is conceived as a spiralling relationship between the analysis of practice and the implementation of changed practices [193]. Action research has as its central feature the use of changes in practice as a way to improve the practice itself, as well as improve upon and better understand the situation in which the practice occurs and the rationale for the work [193]. Thus action research uses strategic action as a probe for improvement and understanding [193]. A diagrammatic representation of action research can be seen in figure 4.3, while table 4.1 depicts the research methods and tools that I employed during the course of this study.

### 4.5.2 Research activities

#### School infrastructure survey

Letters were sent out to each school, accompanied by a questionnaire, to request permission to include the school in the project and conduct interviews with the school principal, relevant teachers and learners. We needed permission to visit the school so that we could examine their current infrastructure and assess what was already present.

Once we obtained permission from the school, we then set up times to visit the school, conduct the interviews and view their facilities. I visited eleven secondary schools in the Grahamstown Circuit in order to assess what their current situations were and what they require in order to successfully integrate ICT into the curriculum as well as use it as an administrative tool for the staff.

In order to record the interviews that we conducted, we initially made use of a normal tape recorder. However, the quality of the recording was poor and difficult to transcribe. We then made use of a mixer with 130 degree surround-sound microphones together with a mp3 player/recorder. This too proved to produce poor quality recordings as the mp3 player/recorder was unable to provide feedback about the quality or success of the recording during recording time. Both these recording technology errors resulted in having to repeat interviews. Finally we made use of the mixer together with a notebook running *Audacity* [194]. *Audacity* is free, open source software for recording and editing sounds. With *Audacity* I was able to see the audio input on the monitor and thus able to finely control the quality of the recording. All the recordings

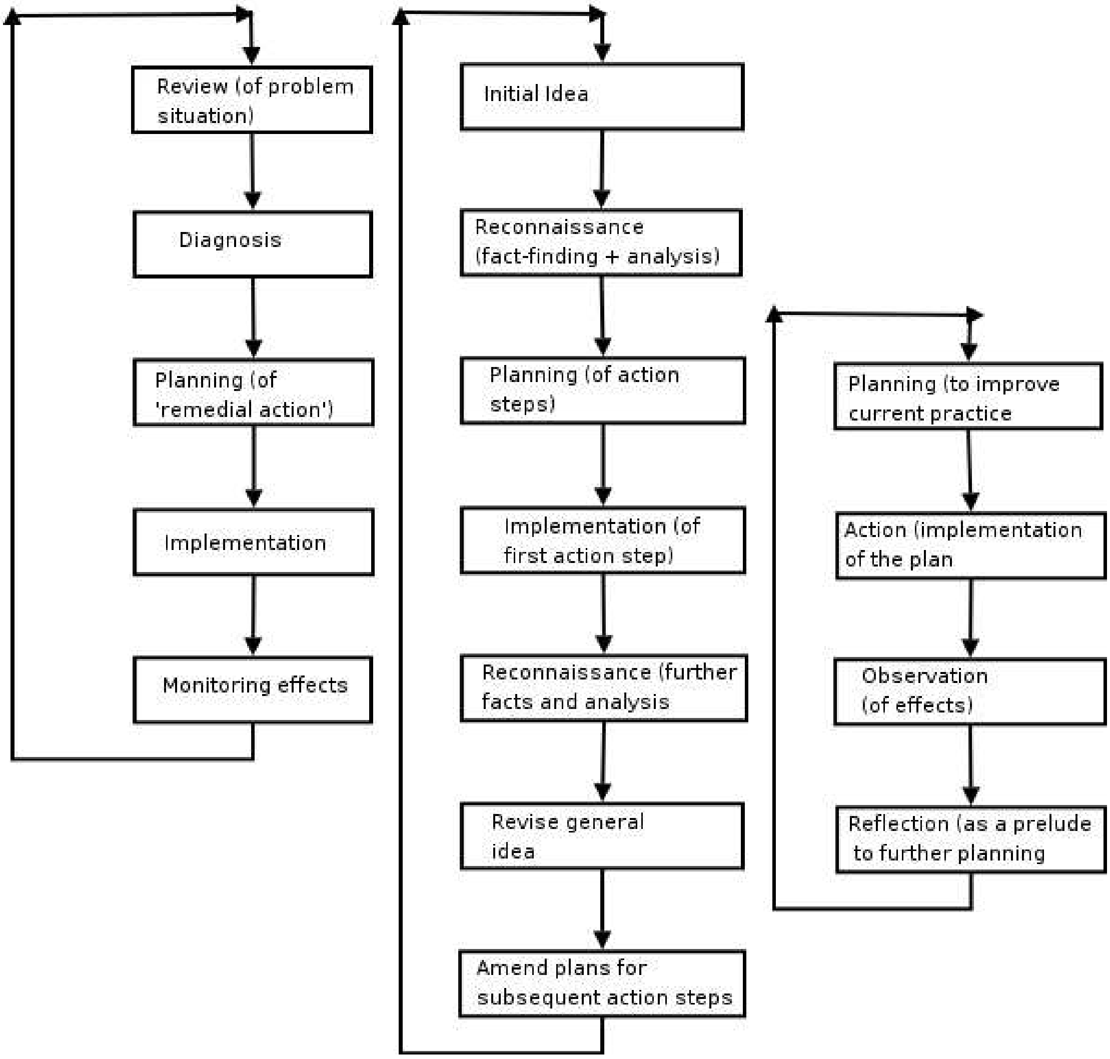


Figure 4.3: The action research cycle.

As interpreted by Elliot and Kemmis, as found in [193, p12].

were then converted from *Audacity's* native file type to mp3 format for storing on either CD or computer. This gave us the fine control over the audio that we needed in order to achieve good quality recordings. All interview transcripts (for an example see Appendix F) were sent back to the relevant person in order to confirm that the information that we obtained from the interviewee was an accurate record of the interview. From these questionnaires and transcripts I was able to identify problem areas that need addressing and common trends which provided insight to what ICT infrastructure schools would be requiring.

**Networking**

In addition to the survey of needs and facilities of the secondary schools in the Grahamstown Circuit, I also undertook an evaluation or 'desktop survey' of potential wired and wireless networks available to schools in South Africa (currently and in the foreseeable future). This allowed for an assessment of the advantages and disadvantages of each network technology, evaluating costs, productivity and reliability, amongst others, where possible. The feasibility of a connection depends on the following factors: whether the network performs satisfactorily for the required need, whether it is a reasonably cost-effective option and lastly whether it is a practical solution in terms of the requirements and limitations of the school and the technology.

In addition to this I also added to the connectivity work done previously by the Centre of Excellence (CoE) at the Computer Science Department, at Rhodes University. Three of the Grahamstown Circuit schools, one secondary, FDET3, and two primary were provided with DSL lines to their schools in order that they might have a broadband connection to the Internet. However, more than one third of the secondary schools in the Grahamstown Circuit are out of the range of DSL – further away from the Telkom exchange than 5 km. Other broadband, wired connectivity methods such as fibre optic were currently too expensive and so wireless methods of connectivity were considered for these schools. At the time the cheapest technology available, while complying with open standards and interoperability, was IEEE 802.11. Thus, a wireless IEEE 802.11 network was built in order to connect schools to the Internet.

In order to build the networks certain permission had to be obtained. Permission had to be obtained from each of the schools that were asked to participate in both the DSL network as well as the wireless network. Schools were naturally allowed to refuse us permission, although the promise of free Internet connectivity generally went well in our favour. In addition, we sought permission from the 1820 Settlers Foundation in order to use the 1820 Settlers Monument as the high point in town for our Access points and backbone network. Then Telkom was commissioned to install outdoor extensions to the schools which would be receiving DSL. The CoE then needed to purchase a DSLAM, DSL RTUs, Access points (APs), antennas, switches, routers, certain computers and any other necessary equipment in order to build the two networks.

Once all the components of the network had been purchased, it was possible to build the networks and use them to connect the schools to the university. For the DSL network, outdoor extensions were used to connect the schools to the Rhodes campus. These extensions then terminated in a DSLAM in the CoE's technical area. From the DSLAM it was possible to route the traffic to the Internet via the Rhodes network. For the wireless network, two APs were placed at the 1820 Settlers Monument. One was used to connect clients in Grahamstown West, while the other was used to connect clients in Grahamstown East. The Monument was connected to the Rhodes campus via a DSL line, which is also an outdoor extension from the Monument to Rhodes, which terminated in the DSLAM in the CoE technical area. This traffic was also then routed to the Internet via the Rhodes network. Client sites in Grahamstown West connect to one of the two APs and then are routed to campus via the DSL line. Client sites in Grahamstown East connect to the other AP, however, there is no direct line of site from the Grahamstown East clients to the Monument. Thus a repeater station had to be deployed in Grahamstown East in order to relay signal to the Monument. The repeater station was built on top of a water tower in the school yard of FDET4. The repeater station

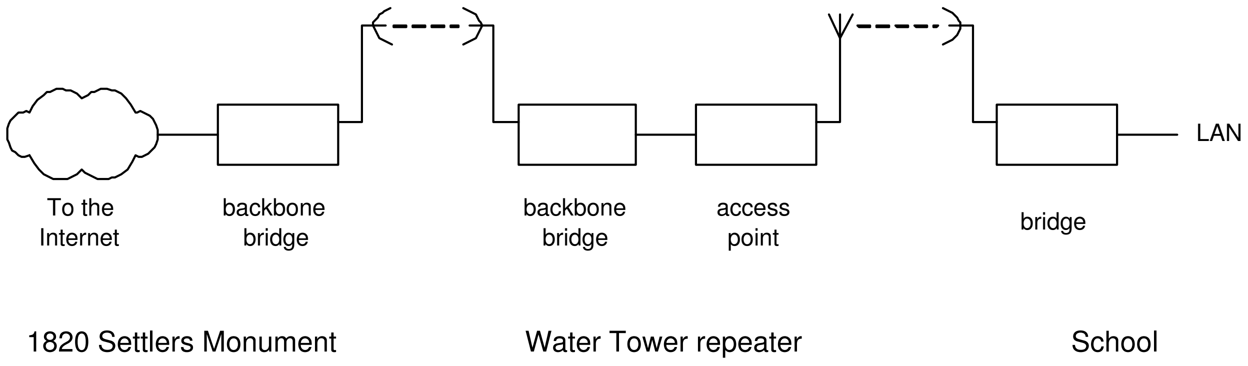


Figure 4.4: Wireless network topology from the 1820 Settlers Monument to the repeater station at FDET4.

consists of two APs, one acting as a bridge and associated with the second AP at the Monument, while the other AP at the repeater acts as an AP to the Grahamstown East clients. Grahamstown East clients associate with the AP on top of the water tower (repeater station) and their traffic is relayed then to the bridge, which is associated with the second AP at the Monument and traffic is relayed back to the second Monument AP. From there traffic is sent over the DSL line back to Rhodes campus. A diagrammatic representation of the wireless link from the Monument to the repeater station can be seen in figure 4.4.

For obvious funding constraints, we were not able to deploy computers and networking in all the schools. The school that was chosen for inclusion in the DSL network, was FDET3. The reasoning behind this was that FDET3 had recently won 16 new computers in a SchoolNet sponsored competition and were in need of an Internet connection [195]. Furthermore, they are within the 5 km distance for DSL. Other previously disadvantaged secondary schools in Grahamstown are not in the range of DSL. The schools that were included in the wireless network are FHOR, FDET4 and FDET1. Our reasons for these choices were two-fold: firstly all three schools have computer labs for teaching and learning, but no Internet connection and secondly, because of the network test data that they would bring to the study. FHOR has line of sight to the 1820 Settler Monument, while FDET1 and FDET4 make use of the repeater station on the property of FDET4. This allowed us to test the reliability of the repeater, while FDET1, who is very far from the repeater, allowed us to test long distances to the repeater and long distances to the Monument.

## 4.6 Ethical issues

During the study we wished to maintain a standard of ethics throughout the entire process, and therefore attempted to conform to accepted standards of social or professional behavior. Thus this project avoids scientific misconduct and research fraud. Scientific misconduct occurs when a researcher falsifies or distorts the data or the methods of data collection, while research fraud occurs when a researcher fakes or invents data that were not really collected or falsely reports how research was conducted [196].

Semi-structured interviews and participant observations require a great deal of trust between the researcher and the participants, and a good understanding of what it is that the researcher wishes to do with the research. For these reasons, participants were clearly briefed on what the research was about and what it would hopefully amount to. By this means we were very careful not to create false expectations. Particular attention was paid to the fact that we were not promising to bring free technology to the schools with a working solution. Although we hoped that this would be the case, there were no guarantees that our research would succeed. Thus we were able to avoid deception by making our intended goal known to all [196]. Deception can increase distrust by people who are frequently studied [196].

Ethical research requires balancing the value of advancing knowledge against the value of non-interference in the lives of others. Thus we sought voluntary inclusion by all participants [196]. It was made clear to all participants that they could withdraw from the research at any time or stage should they no longer wish to be a part of the research. They were under no obligation to take part in the research from the beginning. Only one school decided not to participate, while one IT teacher did not wish to be interviewed. A fundamental ethical principle that we followed in the study was: never coerce anyone into participating; participation must be voluntary [196]. It is not enough to get their permission to have them participate, they must also be informed of what the research will entail so that they can make informed decisions [196].

After each of the interviews and on-site audits had taken place all transcripts from interviews were sent to the interviewees so that they could verify our findings and that we could ensure that we were not misrepresenting them in any way. This is known as member checking. In addition we have protected the identity of each of the schools that participated in the study. In order to protect the privacy of the individuals participants remain anonymous or nameless [196]. In our research we provided each school with a code name based on their apartheid school classification and a number done in alphabetical order.

When we offered a free Internet connection to schools for the purposes of experimentation it was made clear to those schools that the offer was not necessarily a permanent one and it was also not guaranteed to work reliably all the time, as the network was not being run as a business, but rather as an experiment and thus those maintaining it would not always able to do so at all times. It was important for schools to understand that the research team was not able to venture out to the schools at any time of day or night in order to fix any ICT infrastructural problems. We explained that the research team were not able to provide money for computers or software. We emphasised that the role of the research team was to collect data in order to make known the facts to those who can help schools. This clarity allowed us to avoid further misconception or even deception and thus maintain good working relationships with all the schools involved in the research project [196].

## 4.7 Data analysis

Data analysis [197] permeates all stages of a study. Concern with analysis should begin during the design of a study, continue as detailed plans are made to collect data in different forms, become the focus of attention after data are collected, and be completed only during the report writing and reviewing stages [197].

There are commonly two types of data analysis, qualitative data analysis and quantitative data analysis. In the Social Sciences, qualitative research is a broad term that describes research that focuses on how individuals and groups view and understand the world and construct meaning out of their experiences; it is essentially narrative-oriented. Qualitative data can be described numerically using frequencies, or counts, cumulative frequencies and contingency tables or graphically using bar graphs, pie charts and categorised bar graphs [198]. Contingency and multi-way tables are used to describe relationships between qualitative variables. Qualitative is often referred to as categorical variables [198].

In Social Science, quantitative analysis refers to the use of numerical and statistical techniques rather than the analysis of verbal material [199]. In Computer Science, quantitative analysis involves the measurements of quantities [199]; more specifically to this study, the measure of variables within a network. Quantitative analysis involves the use of statistical techniques to understand quantitative data and to identify relationships between and among variables, often referred to as measurable variables [198].

From the questionnaire data and the network experiments data we were able to perform quantitative data analysis, which involves statistics of some kind from closed-ended questions or results from network experimentation. However, from the open-ended questions asked during the interviews, we were able to do qualitative analysis.

### 4.7.1 Qualitative data analysis

#### Theory

Qualitative data analysis includes of the following steps [200, 201]:

- Capture data
- Code data
- Categorise data
- Conceptualise data
- Create theory

Data capturing was done through the interview process. The interviews were recorded and then transcribed which allowed the researcher to then work with the data and begin the coding process. The coding of data can be done in two ways, through top-down analysis or through bottom up/in vivo coding [200]. Top-down coding is when data is approached with preconceived codes, in other words, preemptively expecting to find certain kinds of information in the data and so the coding process involves looking specifically for those kinds of data. This is also referred to as analytic induction or analytic research [200]. The codes that are used are either determined by theory or through a hypothesis that has been proposed. This kind of coding is often criticised as certain scholars believe that instead of the data speaking with its own voice, the ideas of the researcher are expressed instead, which creates interpretations that uphold the researcher's pre-conceived ideas [200].

In open coding or otherwise known as in vivo coding one works from the bottom up. Upon reading through the text (interview) the issues or areas that need to be coded will become obvious, so the data will speak to the reader [200]. However, in this kind of coding, where it is said that there is less of a bias when compared with top-down coding, it is not completely open. No matter how hard one tries, one can still bring one's own ideas into the data analysis process and thus there would still be a certain amount of bias in the coding.

Codes are usually attached to "chunks" of varying size - words, phrases, sentences or whole paragraphs, connected or unconnected to a specific setting. They can take the form of a straightforward category label or a more complex one, for example, a metaphor [201]. Various codes that are slightly similar can then be grouped together into categories [201]. These codes and categories can then be compared to what is known from literature and theory and concepts can be based on them [200].

In the process of performing data analysis, I used both top-down and in vivo coding in my analysis of the interview data from the secondary schools in the Grahamstown district. Once data had been coded it was then categorised according to common themes and the data could be conceptualised [200, 201]. From there it was possible to create theory based on the findings from the data [200].

#### In practice

After each interview was completed I used *Audacity* to play back the recording while I transcribed the interview. The reason for my choice of Audacity to play the audio back is that I was able to follow the recording visually as well as audibly, which made it easier to stop and start the audio in the correct places. During the transcription process I followed a sequence of listening to a couple of seconds of the recording, then pausing it to type that portion and then re-listening to the portion in order to make sure that I had typed it correctly. When I was satisfied that I had transcribed those few seconds correctly I moved on to listening to the next portion of the recording. I went along like this until I had completed the entire interview. Once the interview was fully transcribed I ran each one through a spell checker and sent off a copy to my supervisors for their perusal. Then a copy was printed along with a covering letter to explain that this was the transcript of the interview and requesting that the interviewee read through it and make sure that it was as accurate as possible, adding or deleting content as they saw fit. This process is known as member-checking [200]. When they were finished with the transcript they either returned it to me, or I would be asked to collect it from their school. Four of the transcripts were never returned, so I assumed that the interviewees were satisfied with their accuracy.

Once the transcripts had been completed and had undergone the member checking process, I was able to begin the next phase of the qualitative data analysis, namely to begin the coding process [200, 201]. This involves identifying the issues that were raised in the interviews by each of the interviewees. I began this process by looking for answers to my original research questions within the data. I colour coded each of my research questions and then looked for data within the interviews where those questions were discussed, top-down coding. At the same time I was identifying, with a pencil, topics that were repeatedly raised in numerous interviews; in vivo coding. Through the coding procedure, patterns started to become apparent. I began to see similarities, differences, patterns and structures within the 10 interview transcripts. After completing four of the interviews in this way, my supervisors and I were able to identify four broad categories [201] into which the original research questions fell. In addition, there was extra information, within each of the categories that were not queried specifically but rather provided by the interviewees. The categories were:

- Infrastructure
- Infrastructural issues
- How schools are overcoming infrastructural challenges
- Limitations and constraints of ICT infrastructure in the schools

Within the "Infrastructure" category all data about the schools' infrastructure was collected, from computer hardware, to communication facilities to basic building infrastructure. Within the "Infrastructural issues" category, I looked at the issues that they experience that are specific to infrastructure or lack of infrastructure at each school. Within the "How schools are overcoming infrastructural challenges" category, I looked at what proactive steps and measures the different schools are taking in order to overcome their specific infrastructural issues. Finally, within the last category, "Limitations and constraints of ICT infrastructure in the schools" I looked at other limitations and constraints. These included things such as costs, policies or lack thereof and teacher integration. For each of these categories I drew a tree diagram of the subcategories found within each of the overall categories and have included them in chapter 5. With each category identified, I went through the transcripts and highlighted in one of four colours where I felt a particular issue belonged. Once all the transcripts had been coded in the four overall category colours I could begin phase three of the qualitative data analysis.

Phase three consisted of a process of closer scrutiny of the interview data. The process involved identifying subcategories within the broader four categories identified earlier. I went through each of the transcripts four times, each time only looking for the parts of the data marked in one of the four colours. I would then identify what kind of information the data was providing. For example, within the Infrastructure category, the interviewee would provide information about the number and type of computers, or where those computers were kept or used. They would provide information about the types of software used and whether or not they had a local area network (LAN) or an Internet connection. All of this information was further grouped into subcategories within the bigger categories. This process allowed me to make a detailed tree diagram [201] of the information being provided to me and highlighted issues that had not been anticipated in the original questions asked. Once all the transcripts had been carefully processed in this manner, I was able to begin the fourth phase of my qualitative data analysis.

This phase entailed noting the frequency with which each of the categories was mentioned [201]. This provided me with an idea of the most pertinent issues at the schools currently and which thus needed to be addressed first. It also gave me a good indication of what needed to be reported on and what could be excluded from the report. Large quantities of data were provided by each of the interviewees and for that reason it was impossible to include everything within the report.

### 4.7.2 Quantitative data analysis

#### Theory

Quantitative data analysis was performed in both the social science aspect of the project and the Computer Science aspect. Generally, quantitative data analysis begins with some sort of theory. Theories can vary between abstract general approaches to fairly low-level theories to explain specific phenomena [202]. In the case of this project, there is no real theory behind the Social Science aspect of the project, but rather an hypothesis that ICT in education can be beneficial and thus the project looks to support the Grahamstown schools in their use of ICT. In terms of the Computer Science portion of the project, there is the basic network theory upon which the work is based as well as the hypothesis that such networks will work adequately and be beneficial to the schools. In quantitative data analysis, hypotheses relate to a limited facet of the theory and are used to test the theory [202].

In order to test a hypothesis it is necessary to decide what variables are needed to be known in order to answer the hypothesis. This process is known as operationalisation. There are several methods of performing operationalisation, and two of the methods that were used in this study are questionnaires and experimentation [202]. During the school survey a questionnaire was sent out to each of the secondary schools regarding their current ICT infrastructure. Their responses to the questions provide the necessary variables in order for me to ascertain whether or not they have appropriate ICT infrastructure, and what the most appropriate infrastructure might be for the school in question.

In terms of quantitative analysis with regard to computer systems, analytical models describe system behaviour and performance characteristics of the system [203]. During the network testing, experiments were conducted and results thereof recorded in order that the reliability, latency and throughput of the network and whether or not that network was of benefit to the school could be ascertained. Quantitative computer performance analysis consists of discovering and ascertaining the efficiency of a computer system [203] – where a computer system could also be a computer network. The findings of a quantitative performance study may be used to guide decisions relating to system design, the allocation of resources, acquisition of additional facilities or the fine tuning of existing configurations [203].

Once all data had been collected, in both the social science and computer science portions of the project, it was then analysed and from it findings began to emerge. These findings provided insight into both aspects of the project and are elaborated upon in chapters 5 and 6 of this dissertation.

**In practice**

Returned questionnaires were then labeled alphabetically. As my questionnaire was about "Infrastructure" it was given the number one. The other two questionnaires, used by the other two members of the research team (as described in section 4.3.1) were labeled "Learner's perspective" and "Teacher's perspective" and were thus questionnaires two and three respectively. The returned questionnaires were sorted into the four school categories of FDET, FMC, FHOR and IS. Once that had been completed each of the categories was sorted alphabetically by school name. The coding scheme worked as follows within each of the school type categories, the school was given the type, for example, FDET and then a number for the order, so the first would have been 1. Then it received the questionnaire number, Q1 and then the appropriate letter for which one it was in the pile, like A, B, C, D, etc. So the first questionnaire in the category of FDET schools would have been coded as follows: FDET1Q1A. The idea was that each respondent would get a unique identity as did each question that they answered within each of the schools. It also allowed us to provide anonymity while still being able to compare the different schools and school types as a collective.

Once the questionnaires were all coded it was then possible to table or graph the results using *MS Excel* [204]. Results from the questionnaires were used to support ideas/data that emerged from the interviews. This was then also comparable with the data collected from the on-site audit and I was able to see where IT teachers were unsure of their current infrastructure. It also allowed me to use numerical data to support or highlight various issues that the IT teachers had mentioned in their interviews.

In the computer science portion of the project I used quantitative data analysis as a means of determining the quality of the networks that I was experimenting with. In order to test the quality of the networks, I ran two small tests, a round-trip time test and a data through-put test. Both tests were run by bash scripts that were run every 5 or 10 minutes as a cron job.

The round-trip time test involved pinging the remote site every 5 minutes for 10 seconds and then recording the final values of shortest time, longest time and average time returned by ping to a file. This test allowed me to learn more about the delay on the network as well as the network reliability.

The through-put test involved copying a data file of 768 kilobytes to the remote site. The file was copied every 10 minutes and the time in which it took to copy that data was recorded. This test told me more about the through-put on the network and what data rates we were achieving as well as the reliability of the network to copy data successfully from one machine to another. Both of these test also provided an indication of the interference on the networks, particularly on the wireless networks.

The bash scripts as well as the questionnaires can be found in Appendix A and D respectively, while the results of the quantitative data analysis from each can be seen in Chapter 5 and Chapter 6 respectively.

## 4.8 Conclusion

The post-positivist critical realist research orientation enables this study to bridge the Science and Social Science disciplines in which the study was conducted. The next chapters discusses the results of the school survey and then the results from the network deployments in the Grahamstown Circuit.

# Chapter 5

# Findings from the Grahamstown schools survey

## 5.1 Introduction

In this chapter the findings of the ICT infrastructure audit in the secondary schools in the Grahamstown Circuit are presented. Four broad categories were identified during the qualitative analysis of the interview data, namely infrastructure; infrastructural issues; overcoming infrastructural challenges; and limitations and constraints. The following chapter discusses the findings under each of the four categories, with data from the questionnaire, interview transcripts and the on-site audit. I will highlight some of the important findings and what can be drawn from these findings.

## 5.2 Infrastructure

When I discuss infrastructure in this study I refer to the physical equipment and programs that comprises Information and Communication Technology (ICT). Examples of infrastructure include computers, software, local area networks (LANs), Internet connection, the building in which the ICT equipment is housed, security and electricity. When asked about the infrastructure at the twelve schools during the interviews with the school IT teachers or IT (Information Technology) specialists, 279 comments were made. In order to obtain a sense of the scope and depth of the comments, I have designed a mind-map of the different types of infrastructure that were mentioned during the interviews (Figure 5.1).

From this diagram I was able to identify some of the more pertinent comments surrounding the infrastructure of secondary schools in the Grahamstown Circuit. Within the infrastructure category, three subcategories emerged: information technology, basic infrastructure and communication technology. These are discussed in more detail in the subsequent sections.

### 5.2.1 Information technology

The information technology subcategory was the most commented upon category out of all three of the subcategories, with 190 statements (68 %) made by the 11 IT teachers/IT specialists. The information technology category was further broken down into hardware and software. Interestingly, software was discussed more often than hardware as can be see in Figure 5.1. I believe that this is because there are often more issues surrounding software than there are with hardware because of the high costs associated with software, as well as the flawed nature of software – no one piece of software is perfect. Also, the hardware

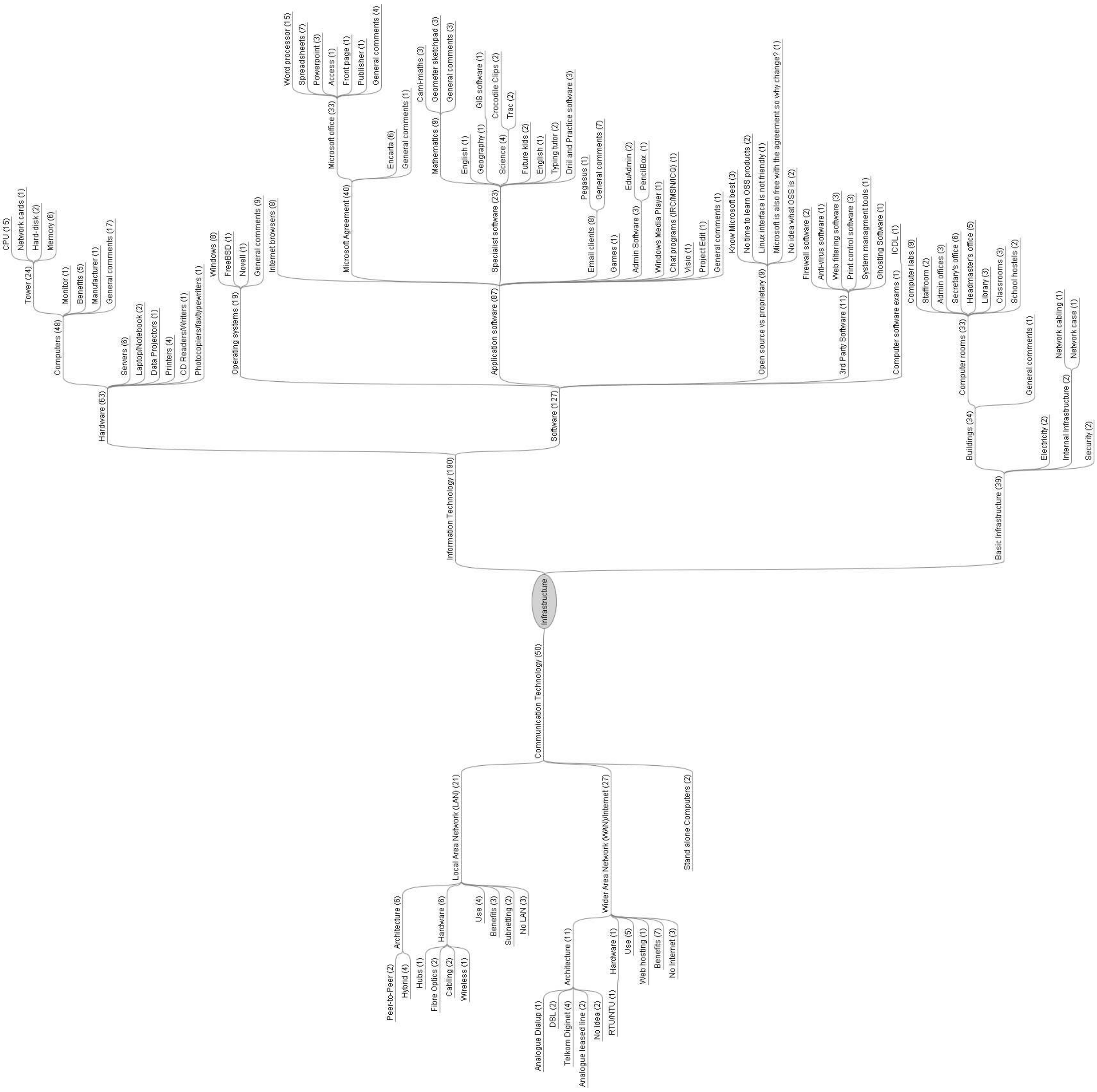


Figure 5.1: Infrastructure tree diagram.

As per data from the interviews held with the IT teachers at the Grahamstown Circuit schools.

| Type of Hardware | FDET1 | FDET3 | FDET4 | FDET5 | FDET6 | FHOR | FMC1 | FMC2 | FMC3 | IS1&3 | IS2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Computers (Total) | 5 | 36 | 14 | 4 | 1 | 18 | 55 | 33 | 62 | 235 | 170 |
| Computers (Working) | 5 | 16 | 9 | 1 | 1 | 8 | 55 | 33 | 62 | 235 | 170 |
| Servers | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12 | 3 |
| Printers | 1 | 5 | 2 | 1 | 2 | 3 | 12 | 10 | 12 | 60 | 12 |
| Scanners | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 12 | 2 |
| CD Writers | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 2 | 2 | 20 | 5 |
| Data Projectors | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 2 |
| Digital Cameras | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| Routers | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Switches | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |
| Modems | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 |
| Other | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

Table 5.1: Total amount of IT equipment found in the secondary schools.

that schools know about is fairly limited when compared to the range of available software in the world today.

**Hardware**

Within the hardware category more comments were made about computers than about any other hardware. I believe that the reason for this is that where schools do have some degree of ICT infrastructure, this infrastructure is largely limited to computer hardware. If we consider the data collected from the questionnaires on the hardware infrastructure of the school (Table 5.1), it can clearly be seen that there are substantially more computers than any other type of ICT equipment. It should be noted, however, that the figures quoted in the computers row of Table 5.1 were calculated based on the on-site audit, not the questionnaires as is the case with the remainder of the data in the table. This was done because the questionnaires requested the number of computers in broad categories, such as "10 to 20 computers", which did not provide sufficiently detailed data.

In Table 5.1 the independent schools, IS1 and IS3, are grouped together because in terms of IT infrastructure they share all their resources. They will therefore be referred to from here onwards as a single entity, namely IS1&3. An important aspect to note from the data, in Table 5.1, is that which is missing. Often this does not mean that the school did not possess that equipment, but rather that they did not feel the need to mention it in the questionnaire or perhaps that they did not realise that they possessed such equipment. For example in the questionnaire very few schools mentioned having equipment for networking, such as the routers, switches and modems. The independent schools did in fact possess a number of routers and switches on their very impressive network, which I was able to view during the on-site audit. In the case of the FMC schools they too did not seem to realise that they should mention what routing and switching capabilities they had. This might be due to the IT teacher being responsible for the computer components of their infrastructure, while their networking was mostly outsourced. So in a sense they didn't appear to pay much attention to the networking aspects of their infrastructure. However, in the case of the FDET schools and the FHOR school, they tended to not know what equipment they had at all. So while the school may in fact have had an Internet connection and a LAN they were not aware of what that really meant and what it entailed in terms of infrastructure. To quote the CAT teacher from FDET4 during the interview, "*I am not very sure about this Internet business, I only know how to use it.*" There are other instances where the

IT teacher reported one kind of equipment in the questionnaire or interview, but during the on-site audit I noticed that in fact the situation was completely different. For example, the FDET4 school reported in their questionnaire that they had a school server, when in fact they did not, rather they had a router for their Internet connection. Similarly, the FHOR school reported having only one CD Writer, when in fact they had three. From the discrepancies between the questionnaires, the interviews and the on-site audit it would appear that some the IT teachers didn't always know exactly what IT infrastructure the school had and that there are cases when they were confused or unsure of what they knew.

From the interview data it is interesting to note that the computer subcategory mentioned contains numerous references to the computer tower. This is because six of the IT teachers were aware of the processor model and memory capabilities of the school's computers, accounting for 44 % of the overall statements made about computers. However, they failed to mention any other components of the computer. I suspect that they either did not realise that giving that kind of information would be important to the study or that they did not know what the components were. In the questionnaires the schools were asked to provide information about how many computers they had by ticking the appropriate category (e.g. □ 10 - 20 computers). This was done because I was unsure of whether each IT teacher or the school would know the exact number of computers that they had at the school. An example of this confusion was found at FDET4, where they reported having 0-10 computers, but in fact they had 12 computers in their school lab and one in the school office and another one in the deputy principal's office. Results from the questionnaire about the number of computers the schools had can be seen in Table 5.2. The exact numbers for the number of computers owned by each school were calculated during the on-site audit and are reported in Table 5.3.

It should be noted at this point that the infrastructure found in the schools, particularly the FDET and FHOR schools, were often donations from outside organisations. This usually involved outside organisations coming to the schools and performing the necessary ICT installations in order to make the newly donated facilities work properly. Thus schools were often unaware of what ICT infrastructure they had and how it worked because they were not directly involved in the installation or in the day-to-day running thereof. This is seen in schools where ICT maintenance was outsourced to IT companies or local individuals from the university and/or the CoE. It is important to note that self-reporting of ICT infrastructure present in schools cannot always be relied upon to be accurate.

Table 5.2 depicts the total number of computers at the schools, both working and not working. By contrast, the total number of working computers can be seen in Table 5.3 as per information from the questionnaires answered by each school. The column "Actual number" was calculated during the on-site audit and provides the total number of working computers found in each of the schools. Comparatively, Table 5.1 provides the total number of computers, working and non-working, as found during the on-site audit. Comparing Table 5.3 with the on-site audit data (i.e. the computers row) in Table 5.1, it can be clearly seen that only the previously disadvantaged schools had broken computers which they could not make use of, while the FMC and independent schools had working computers which are all being used.

Since the survey the FHOR applied for and received 20 computers from the Shuttleworth Foundation, through the tuXlab project, as well as a generous donation from Dell Computers of 20 new computers. This brings their total number of computers to 58. Shortly after the survey, FDET1 was burgled and four of their five computers were stolen, leaving them with one computer. On a more positive note, FDET3 were fortunate enough to have new hard drives donated to them by the Rhodes University Computer Science Centre of Excellence and thus now have 36 working computers. Unfortunately the very old computers at FDET4 have become less reliable and they now only have seven working computers in the school.

When discussing the number of computers per school, researchers [124] often refer to the ratio of computers to learners in the school. Table 5.4 depicts the number of working computers in each of the schools

| School | 0-10 | 11-20 | 21-30 | 31-100 | >100 | No response |
|---|---|---|---|---|---|---|
| FDET1 | x | | | | | |
| FDET3 | | | x | | | |
| FDET4 | x | | | | | |
| FDET5 | x | | | | | |
| FDET6 | x | | | | | |
| FHOR | | x | | | | |
| FMC1 | | | | x | | |
| FMC2 | | | | x | | |
| FMC3 | | | | x | | |
| IS1&3 | | | | | x | |
| IS2 | | | | | x | |

Table 5.2: Number of computers, working and non-working, per school.

As per data from the questionnaire.

| School | 0-10 | 11-20 | 21-30 | 31-100 | >100 | Actual number |
|---|---|---|---|---|---|---|
| FDET1 | x | | | | | 5 |
| FDET3 | x | | | | | 16 |
| FDET4 | x | | | | | 9 |
| FDET5 | x | | | | | 1 |
| FDET6 | x | | | | | 1 |
| FHOR | x | | | | | 8 |
| FMC1 | | | | x | | 55 |
| FMC2 | | | | x | | 33 |
| FMC3 | | | | x | | 62 |
| IS1&3 | | | | | x | 235 |
| IS2 | | | | | x | 170 |

Table 5.3: Total number of working computers in the secondary schools.

As per questionnaire, while the column “Actual number” was calculated based on the on-site audit.

| School | Working computers (WC) | Learners | Computers:Learners | Current WC | Computers:Learners |
|---|---|---|---|---|---|
| FDET1 | 5 | 600 | 1:120 | 1 | 1:600 |
| FDET3 | 16 | 600 | 1:38 | 36 | 1:17 |
| FDET4 | 9 | 1100 | 1:123 | 7 | 1:158 |
| FDET5 | 1 | 778 | 1:778 | 1 | 1:778 |
| FDET6 | 1 | no answer | ? | 1 | ? |
| FHOR | 8 | 1180 | 1:148 | 48 | 1:25 |
| FMC1 | 55 | 610 | 1:12 | 55 | 1:12 |
| FMC2 | 33 | 400 | 1:13 | 33 | 1:13 |
| FMC3 | 62 | 400 | 1:7 | 62 | 1:7 |
| IS1&3 | 235 | 754 | 1:3 | 235 | 1:3 |
| IS2 | 170 | 385 | 1:3 | 170 | 1:3 |

Table 5.4: Ratio of computers to learners in each of the schools.

The number of computers was provided by the schools during the questionnaires and on-site audits, while the number of students per school was provided at a later date over the telephone.

as well as the total number of learners at each of the schools. In the table one can see the total number of working computers that were found during the survey, as well as the total number of working computers post the survey. From Table 5.4 one can clearly see that the independent schools enjoyed the best computer to learner ratios, namely 1:3, while the highest ratios were seen at some of the so-called previously disadvantaged schools of FDET1, FDET4, FDET5 and FHOR. (Please note that FDET6 refused to provide us with information about the number of learners at their school.) However, FHOR and FDET3 have improved their ratios from those that were seen during the survey, due to 40 new computers being donated to FHOR and 20 new hard drives to FDET3. Thus their ratios moved from 1:148 and 1:38 to 1:25 and 1:17 respectively. Unfortunately FDET1 and FDET4 are worse off than they were during the survey, due to theft at FDET1 and breakages at FDET4. Their ratios have moved from 1:120 and 1:123 to 1:600 and 1:158 respectively. Clearly FDET1, FDET4 and FDET5 do not have enough computers for teaching and learning with such high computer to learner ratios.

In terms of computer servers, the low occurrence with which they were mentioned in the interviews is due to the fact that only 5 out of the 12 schools interviewed had servers. It is unlikely that the other IT teachers would have mentioned servers if they did not have any at their schools. Those who did report that they did not have any servers, such as FMC2, cited financial constraints as the reason for not having a server at the school.

The fact that more hardware details were provided in the questionnaires than during the interviews is probably due to the IT teachers assuming that mentioning it in the questionnaire would be enough and thus they did not need to mention hardware again. The questionnaire data was also used to guide my questions during the interviews, so only in cases where their data had been vague or misleading did I raise the questions of specific hardware components again.

### Software

Within the software category four subcategories emerged from the interview data, namely the operating systems, application software, open source vs proprietary software and 3rd party software (see Figure 5.1). In the questionnaire there were no software specific-questions so there is no data on software from the questionnaires. However, during the interviews the topic of software was often discussed by the IT teachers at the various schools. This may be due to the high costs of proprietary software, as can be noted in Figure 5.5, where 44 % of the infrastructure costs mentioned concerned computer software. Interestingly, none of the on-site audit data contradicted what IT teachers said during their interviews (in terms of computer software). The following information on computer software at the various schools is based on the interview data from the various IT teachers/specialists.

From the operating system subcategory we can see that the majority of the schools used and knew about *Microsoft Windows*. The independent school, IS1&3, used *FreeBSD* on their firewall server, while the FMC3 school used an old version of *Novell* on their file server. However FMC3 has recently bought a new server for the school which runs *Windows Server 2003* [205]. IS1&3 and FMC3 also used *Microsoft Windows* on the schools desktops and the IS1&3 schools ran *Microsoft Windows* on some of their other servers.

When considering the subcategory of open source software verses proprietary software, it becomes apparent why schools are using proprietary software instead of open source software. IT teachers spoke of how teachers were used to using Microsoft products and were not interested in trying something new, while they themselves felt that even though they would like to try something new, they just didn't have the time for it – IT teachers felt that the learning curve was too steep and would take too much time. The IT teacher at the FMC1 school also mentioned that as far as he was aware, open source software and *Linux* in particular were more problematic than *Microsoft Windows*, "*I mean there is always gremlins with Windows but they are less than there are with Linux from what I hear [...] As in system crashes and that kind of thing, problems with the user interface and that kind of thing.*" Furthermore, IT teachers felt that as Microsoft products are already available at no cost through the Schools Agreement [170], there was no need to try open source software. In the independent schools where this was not the case, IT teachers cited a lack of time preventing them from learning how to use open source software and that the other teachers were not interested in learning anything new and being moved from their comfort zones. In the FDET schools none of the IT teachers knew about open source software. When looking at the Microsoft Agreement subcategory it can again be noted that schools knew more about Microsoft than other software – it was mentioned twice as often as the next most spoken about, specialist software. All the schools in fact, even those with very few computers, had heard of Microsoft and of the Schools Agreement. Many of them mentioned that they were using *Microsoft Office* and its applications specifically. They also spoke of *Encarta*, and its use by learners in doing research and projects.

Of the specialist software discussed, mathematics software was mentioned the most. Schools mentioned using *Cami-maths* and *Geometer Sketchpad*, while others mentioned that "math software" was used. In the cases where identification of the software used was vague, it seemed to be that teachers, other than the IT teacher, used the software to teach their classes and so the IT teacher was not sure what they are using. The other examples of educational software were mentioned less frequently and were predominantly discussed by the independent schools and less so by the FMC schools. Independent schools tended to have the most money and resources and thus were able to afford specialist software, which tends to be expensive. The FDET and FHOR schools only mentioned specialist software which had been donated to them, such as *Crocodile Clips*. They were unable to fund purchasing of specialist education software.

The remainder of the software, depicted in Figure 5.1, was mentioned predominantly by the independent schools, where they had the facilities, finance and expertise in order to be able to afford the software and use it properly. They clearly realised that such software would be beneficial to the school and its network; in particular the 3rd party software. It is important to note that the FDET, FHOR and to a certain extent FMC IT teachers were not as aware of the various software products, and in particular educational computer software available on the market. None of the IT teachers at the FDET and FHOR schools were aware of open source software or proprietary education specific software. However, IT teachers at the FMC schools

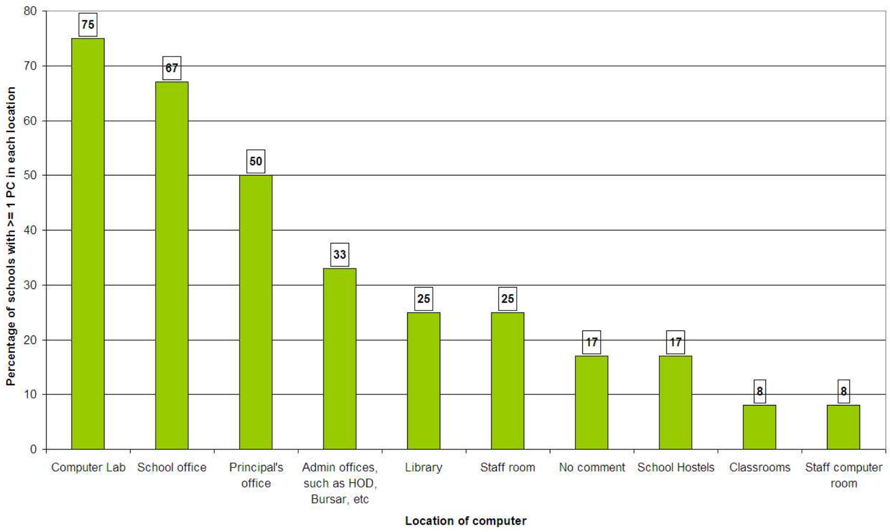


Figure 5.2: Location of computers in schools.

As per data from the questionnaires.

(and to a much lesser extent at the independent schools) had misconceptions about open source software. As a result many of the schools were not able to make well informed choices about the types of software that they chose to use for educational purposes and integration into other subject areas.

### 5.2.2 Basic infrastructure

Within the basic infrastructure category there were four subcategories that the IT teachers at the schools mentioned. These subcategories are buildings, electricity, internal infrastructure and security. Within the questionnaire there were only two basic infrastructure related questions, namely questions 6 and 8, which covered electricity and telephone lines.

From the interview data (seen in Figure 5.1) the buildings subcategory was the most frequently mentioned subcategory. Within this subcategory IT teachers mainly referred to where computers were found in their schools. Generally most schools had their computers in computer labs (75 %), followed by computers in the secretary's office (67 %), principal's office (50 %), administration offices (33 %), library (25 %) and the staff rooms (25 %) (see the graph in Figure 5.2). IT teachers cited the reason for computers being housed predominantly in either a computer lab or the secretary's office being that when the school had sufficient computers for a lab they preferred to have a lab rather than fan out computers to classrooms. The IT teachers said that this was done in order that more learners at a time per class could have access to the computers as well as making it easier to secure the computers. Furthermore, most schools seemed to have realised the importance of having computers to perform administrative work and therefore a large number of them tended to have computers in the secretary's (or school's) office. They claimed to use these computers for reports and letters and sometimes even for teachers to produce worksheets for their classes.

Most of the schools appeared to have adequate basic infrastructure: a room could be made available to house a computer lab. Only one school, FDET6, spoke of needing more space before they would be able to have a computer lab. Very few schools spoke of the internal infrastructure of the labs. This is again possibly due to some IT teachers not feeling that it was important to discuss, while others probably did not really know or understand much of the infrastructure within the computer labs or schools, such as local area networking, which I will discuss shortly.

In the questionnaires IT teachers were asked whether their schools had access to grid electricity or not. Every one of the schools that responded to the questionnaire said that it did have access to electricity. Electricity was mentioned as a potential problem by only one of the schools, FDET3, as in the past they had had problems with the the Department of Education not paying their school electricity bill timeously. Electricity was also mentioned as a problem by the FMC schools, as they had to pay the bill themselves since they had been classed as Section 21 companies (there will be further discussion on this in Section 5.5).

In terms of telephone connections, schools were only questioned as to whether or not they had a telephone line in the questionnaire. Each of the twelve schools that responded to the questionnaire said that it did have a telephone on the school premises. None of the teachers raised the topic of telephone lines in any of the interviews, which is probably because having a telephone line is essential in the day-to-day running of a school. The school telephone lines were not used in any of the schools as a means of connecting to the Internet. All schools that had an Internet connection had either purchased or had donated to them an additional copper cable pair for fixed line methods of connectivity (as will be seen in section 5.2.3).

Alarmingly, many schools did not mention security measures that were needed in order to secure computers within a school. However, 10 out of the 11 schools interviewed did in fact have Hi-Tec (a local security company) alarms in the rooms where they kept their computers.

### 5.2.3 Communication technology

Communication Technology was the second most discussed (18 %) category within Infrastructure (see Figure 5.1). The bulk of information was discussed around the topic of Internet connections, with 54 % of the total comments related to the schools' Internet connections. This is to be expected, as this is the main focus of my study. The subcategory of local area networks (LANs) was also thoroughly discussed with 42 % of the total comments being related to LANs. The least discussed subcategory was that of stand-alone computers, which only constituted 4 % of the total comments within the communication technology category.

#### Internet

Within the subcategory of the Internet it can be seen that the majority of the schools had an Internet connection of some sort, with only three of the schools that participated in the interviews indicating that they did not have an Internet connection. In fact there are four schools that did not have an Internet connection, but FDET1 elected not to participate in the interview process, although they completed the questionnaires. The data from the questionnaires pertaining to an Internet connection can be seen in Table 5.5 and Table 5.6.

The data provided in the questionnaires is in some cases inaccurate. These inaccuracies were noticed during the on-site audit of infrastructure that was undertaken during the school visits. For example, FDET4 marked that it had a satellite connection for its Internet connection. This is in fact incorrect as the school had a dial-dedicated connection to Rhodes University. Dial-dedicated is a method of dial-up that allows for a dedicated connection when the school chooses to dial up to the university. Both IS1&3 and IS2 had a DSL line to a central server belonging to the Albany SchoolNet project and from there they shared a Diginet line from the central server to Port Elizabeth to their Internet Service Provider (ISP). From Table 5.6 it can be seen that they each reported one of two parts of which their Internet connection consisted. I have filled in the portion which they left out in the appropriate "A"udit column (I have done likewise for the two FMC schools also sharing the Diginet line). FMC1 and FMC3 are similar in that they had leased line connections, on which they both ran dial-up modems to the same Albany SchoolNet server. From there they too shared a portion of the Diginet line to Port Elizabeth. Diginet is a dedicated and synchronous data transfer service, provided by Telkom, offering 64 Kbps up to 2048 Kbps [206]. FMC2 had a Telkom dial-up account, while

| School | Internet Connection | No Internet Connection |
|---|---|---|
| FDET1 | | x |
| FDET3 | x | |
| FDET4 | x | |
| FDET5 | | x |
| FDET6 | | x |
| FHOR | | x |
| FMC1 | x | |
| FMC2 | x | |
| FMC3 | x | |
| IS1&3 | x | |
| IS2 | x | |

Table 5.5: Schools with an Internet connection.

As per data received in the questionnaires.

| School | Analogue leased line | | Dial-dedicated | | Dial-up | | DSL | | Wireless | | Satellite | | Other | | Not sure | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q | A | Q | A | Q | A | Q | A | Q | A | Q | A | Q | A | Q | A |
| FDET1 | | | | | | | | | | | | | | | | |
| FDET3 | | | | | | | | x | | | | | | | x | |
| FDET4 | | | | x | | | | | | | x | | | | | |
| FDET5 | | | | | | | | | | | | | | | | |
| FDET6 | | | | | | | | | | | | | | | | |
| FHOR | | | | | | | | | | | | | | | | |
| FMC1 | x | x | | | | | | | | | | | | x | | |
| FMC2 | | | | | x | x | | | | | | | | | | |
| FMC3 | x | x | | | | | | | | | | | | x | | |
| IS1&3 | | | | | | | | x | | | | | x | x | | |
| IS2 | | | | | | | x | x | | | | | | x | | |

Table 5.6: Internet connection types for schools from the questionnaire data and audit data.

Columns marked with a "Q" are results from the questionnaires, while columns marked with an "A" are results from the on-site audit.

FDET3, that was unsure of its Internet connection, actually had a DSL line from their school to the Telkom Centre of Excellence (CoE) in the Rhodes University Computer Science Department. The line was paid for and sponsored by the CoE and the traffic generated by the school was part of the CoE generated network traffic.

Considering the interview data again, it is interesting to note that only one school, IS2, discussed the hardware that was necessary for an Internet connection. Furthermore, when considering the data from the questionnaires in Table 5.1 only IS2 and FMC2 mentioned necessary Internet equipment. The reason behind this is probably that many of the schools did not know or understand the hardware involved in having an Internet connection. The previously disadvantaged schools seemed to be the least well informed, while the FMC and independent schools tended to have more technically minded staff who were better informed about the technical aspects regarding an Internet connection. Further data highlighting how little IT teachers from the FDET schools understood about the technical workings of an Internet connection can be seen in Table 5.6 where one can see incorrect data about the connection or that they were unsure of information pertaining to their Internet connection.

During the interviews, I was particularly interested to hear what IT teachers were using the Internet for and what they perceived as benefits of Internet connectivity. The majority of the IT teachers mentioned that they used the Internet largely for research. Learners were encouraged to use the Internet to research school projects, as it was felt that the Internet was another useful repository of information much like libraries and encyclopedias. IT teachers also cited the currency and immediacy of information as a big incentive for schools wanting the Internet and using the Internet. For example, the IT teacher from FMC3 said, "*I think it's an amazing tool because the amount of information that you can find on there about anything is amazing, no library can rival that. It's up-to-date, whereas the books in the library get old and outdated. I know a lot of the girls come and research things like debates, you are not going to find those kinds of topical information anywhere else. Yes, so I think that it's an amazing tool to have, and it exposes the girls to so much more.*" IS2 also mentioned that it was used largely by the learners to correspond with experts in fields that they were currently learning about, while teachers used it for *user groups* and collaboration with other teachers all over the world. As the IT teacher from IS2 said, "*Um, having the Internet expands the power of your computer immeasurably. Absolutely immeasurably. It saves you having to have all sorts of software that one would need otherwise. It expands the classroom gigantically, allowing the teacher to take the kids out of the classroom through being able to ask an expert type thing, being able to watch rocket launches and others. Those sorts of things are fantastic. Being able to go onto user groups and as if you have got a problem, how do I solve X. You know for me I often have the learners asking 'how do I do such and such?' and I ask, 'how do you think you are going to do it? Is there anyone here that you can ask?', if not then, 'how can we go about finding such a person for you to ask, who may not necessarily be physically here, to answer your question?' And it expands them and it expands their minds and I think that that is the most important part of it.*"

The IT teacher at FDET3 also elaborated on the benefits of Internet access: "*Here at [FDET3], teachers have harnessed Internet resources more than expecting learners to produce word processed projects. Having Internet [access] has not been a waste of money and resources at our school. Why?*

- *Because one teacher of English, together with three learners attended a Civics literature conference in the USA.*
- *A head of department of Human and Social studies has attended a Met-Link conference in the USA. Since Met-Link project which involves weather forecasting and reporting around the world. I think that the Internet opened many doors for [FDET3].*

| School | LAN | No LAN | No Response |
|---|---|---|---|
| FDET1 | | x | |
| FDET3 | x | | |
| FDET4 | | | x |
| FDET5 | x | x | |
| FDET6 | | x | |
| FHOR | x | | |
| FMC1 | x | | |
| FMC2 | x | | |
| FMC3 | x | | |
| IS1&3 | x | | |
| IS2 | x | | |

Table 5.7: Schools with local area networks.

Data according to the questionnaires.

- *Our former students in tertiary institutions come back during the holidays and check their email and contribute tremendously towards our learners' advanced skills in web-page design.*"

**Local area networks**

Along with a discussion of the Internet, I questioned the IT teachers, on whether or not they had a local area network and what kind of networks they were operating. From the interview data tree (Figure 5.1) one can see that only two of the interviewed schools reported that they did not have a LAN. In fact there are three schools that do not have a LAN, but FDET1 was not included in the interview data, although the question of LANs was posed in the questionnaires as well as the interviews. In Table 5.7 one can see that FDET1, FDET5 and FDET6 noted in their questionnaires that they did not have a LAN, while FDET4 did not respond. The lack of response from FDET4 is probably because the IT teacher at the school was not sure as to whether they had a LAN or not, probably because she was unsure of what a local area network is and was further unsure if the computers in the school computer lab were connected to one another or a central server or router. FDET4 did have a LAN in their school computer lab and all the computers were networked to their router in order to access their Internet connection.

Table 5.8 provides an overview of the architecture of the LANs at the schools. This information was gathered during the interviews and on-site audit. This table shows that six of the schools' LANs were hybrid LANs, which means that their LAN had both Client/Server and Peer-to-peer aspects to it. Only two schools used a peer-to-peer model, as many schools had realised the benefits of having a server for the purposes of allowing teachers and learners to store files and using it to handle requests from the computers on the network to shared printers. Both FHOR and FMC2 cited that they did not have a server due to a lack of funding. At the time of the survey no school had a pure client/server model, however since that time FHOR has been the recipient of a Shuttleworth Foundation tuXlab, which is purely a client/server model – a lab of 20 thin clients connecting to a server off which they run all their applications and to which they can save their work. From the interview data we can see that not all of the IT teachers spoke about their LAN. This is because in the case of certain schools, such as FDET6, I never asked as it was obvious that there wasn't a LAN as they only had one computer.

From the interview data we can see that very few schools mentioned the hardware involved in having a LAN. The schools which did discuss their LAN infrastructure were the three independent schools, IS1&3

| School | Peer-to-Peer | Client-Server | Hybrid | No LAN |
|---|---|---|---|---|
| FDET1 | | | | x |
| FDET3 | | | x | |
| FDET4 | | | x | |
| FDET5 | | | | x |
| FDET6 | | | | x |
| FHOR | x | | | |
| FMC1 | | | x | |
| FMC2 | x | | | |
| FMC3 | | | x | |
| IS1&3 | | | x | |
| IS2 | | | x | |

Table 5.8: Architecture of local area networks found in schools.

Data according to the interviews and on-site audits.

and IS2. The IT specialists from both schools discussed at length their schools' current infrastructure, and in fact they were the schools with the most extensive and expensive infrastructures using fibre optic backbones on their respective campuses. The lack of discussion from other IT teachers in the schools leads me to believe that they were not as well informed as the IT specialists at the independent schools. We notice this again when we consider how few of the schools mentioned owning switches or routers in Table 5.1.

IT teachers from various schools were however quick to mention the uses and benefits that they had experienced from having a local area network. Many cited the ability to store to a central server as the most beneficial and useful fact about having a LAN. At FDET3, they had two computer labs and the newer of the two was networked to a central server, while the older was not initially, but they soon discovered the necessity of having all the computers networked, "*[Yes they are now] on the network. That was beautiful because it was out of need. The network was at first for this new lab. We would train the learners and then when we had a new group we said 'ag, go to the old lab', so they would not find their home directory. So I explained that to [Rhodes CoE technician], I said, 'the learners who are not part of the training want to continue with their work, which they have stored on their home directory but can't find their work in the old lab.' So he came and connected the other lab to be on the network and to the server.*" The IT teacher of FMC1 cited the benefits of resource-sharing and central file storing as the benefits and uses in his school, "*But definitely having computers networked is essential. I think stand-alones [computers] are useful, they have their uses but networking takes the burden off resources so you can utilise your resources and it makes backing up and saving things much easier. It also means that the kids can save work to the server and you can mark those paperlessly and that also makes things a lot easier for teachers as well.*"

The IS2 IT teacher commented that LAN allow for ease of ICT management as the IT specialist was able to connect to machines remotely in order to fix them as well as be able to roll out standard images to each machine on the network from one central point. Furthermore she commented that the learners benefited from the networks as they learnt how to become network literate, "*Well I don't think that there is any question stand-alone machines have such limited use. I think that if you are trying to prepare kids for using computers in the real world then they have got to be networked. They need to learn to become comfortable with using a networked computer and all the things that go with using a network. For example, security issues and understanding why they should save to their home space and not the local machine, etc. In my book as well, networks are better simply because of the support side of things.*"

Most IT teachers and specialists agreed that a local area network was far better to have than not. In addition, there were a few who felt that even without the Internet they could teach the learners a lot with just computers. FMC2 had this to say. "*You can go far without Internet access. I only use the Internet for the ICDL module and then for the kids, because it is here. I also give them the opportunity to come for information but if it wasn't there then I could teach them just as much as I do now. So ja, without Internet access you can do plenty.*"

### 5.2.4 Recommendations

Based on the findings from the questionnaires, interviews and on-site audits, the following points are worth highlighting. Firstly, it is important to note the number of times that there were discrepancies between what the IT teachers answered in the questionnaires or interviews and what was actually found during the on-site audit, across all the subcategories of Figure 5.1. Thus it would appear that, generally speaking, IT teachers in schools cannot be relied upon to know and understand the ICT infrastructure found in their schools, thus self-reporting evaluations of school ICT infrastructure might not be the best way to survey ICT infrastructure in schools. In this study it was found that it would be preferable to send an ICT specialist to the school in order to perform an on-site audit, as the information collected in this way would have a higher chance of being a true reflection of the school's ICT infrastructure. In addition teachers and in particular IT teachers, possibly with either the principal or a head of department (HOD), need to undergo intensive ICT technical training, so that they would be better able to make well-informed decisions about their infrastructure in their schools and be less reliant on help from outsiders.

Secondly, IT teachers and schools in general tend not to be well informed about appropriate hardware and software. It was evident that approximately 6 out of 7 of the FDET schools and the FHOR school were unaware of any software other than that of *Microsoft Windows* and *Microsoft Office*. Specialist education software was predominantly mentioned by the independent schools and the FMC schools and constituted 26 % of the total application software discussed, while the Microsoft products were mentioned 46 % of the time. Teachers and schools need to be made more aware of the various software options available to them, in both the open source and proprietary environments, so that they make well-informed decisions for their schools and learners.

Lastly, while IT teachers agreed on the benefits of having an Internet connection and in some cases a LAN, often teachers from the so-called previously disadvantaged schools did not understand how these networks work and thus seemed unable to make decisions about them. They were also not able to fix any networking issues that they experienced. It would appear that often schools and teachers did not realise the importance of the networking within and to their premises and thus did not place the appropriate emphasis on these systems. Either school IT teachers need to undergo training to make them more networking literate and understand how to maintain and possibly fix any networking problems that they encounter, or schools need to hire network technicians.

## 5.3 Infrastructural issues

Infrastructural issues was the second major category that emerged from the interview data from the IT teachers and specialists at the secondary schools in Grahamstown. From the interview data I was able to compile another tree diagram that can be seen in Figure 5.3. When looking at the tree diagram one can clearly see the four subcategories of Infrastructural issues. These are, Infrastructure, Manage ICT, Maintenance, and Acquisition. I will discuss each of these subcategories in the next section in this order as this is the order of most to least comments made within the category. Infrastructure was mentioned 34 %

of the total comments, while Manage ICT was 26 %, Maintenance was 24 % and Acquisition accounted for 17 % of the total comments made in this category. The total number of comments made in this category was 211.

### 5.3.1 Infrastructure

#### Information technology: hardware

The infrastructure subcategory of Infrastructural issues was the most discussed (59 %) of all the subcategories by the IT teachers and specialists. Within the infrastructure subcategory the most discussed (62 %) topic was that of hardware. It would appear that hardware issues plagued schools more than any other issue, including that of software (31 %). In fact, hardware issues were spoken of twice as often as software issues. This is probably because without appropriate hardware software will not work anyway, so schools have to prioritise hardware over software as a basic ICT necessity. When considering Figure 5.3 one can easily note that four schools, FHOR, FDET3, FDET4 and FDET5, complained of broken hardware – it was the most frequently mentioned (23 %) of all the hardware issues, followed by old/dated equipment (15 %) and poor quality hardware (15 %). Four schools also complained of non-homogeneous labs, which tended to be very hard to maintain and manage as will be discussed in section 5.3.2. Three schools, FHOR, FDET5 and FDET6, called for more computers, saying that what they had was too little to use effectively, while two of the schools (both the FDET schools) complained of having no computers for the purposes of teaching and learning. Other hardware issues that plagued schools were a lack of or no school servers, missing or broken components within computers and having to fix and deal with learners' computers. The latter problem was confined to the independent schools where learners were well-off enough to bring their own computers from home to their school dormitories. Furthermore, three schools, the two independent schools – IS1&3 and IS2 – and FMC1, mentioned the problems of how hardware and software had an impact on each other and with dated versions of either, management became difficult and the networks were susceptible to intrusion.

#### Information technology: software

There were 13 software comments while there were 26 hardware comments made by IT teachers/specialists from the various schools during the interviews (Figure 5.3). The most frequently mentioned software issues were do to with software being outdated (23 %) and the problems faced with having non-homogeneous images on machines on the network (23 %). This was a problem where schools had various different kinds of computers of varying ages, i.e. a mixture of P1 - P4s. For example, a P4 will happily run Windows XP where a P1 can at best run Windows '98. Often there are security flaws on older versions of software and after a number of years support on that software will cease – Windows '95 and '98 are no longer supported by Microsoft and therefore the flaws in those software products will persist. The IT teacher at FMC1 had this to say about problems with non-homogeneous systems, "*The hassle of course is the administration of that, setting up a network with 3 or 4 different operating systems on one network, it makes it logistically more difficult to administrate it. Because you have different security levels for the different machines and its just logistically difficult.*"

Other software issues mentioned included inappropriate software (15 %) – either poor educational software or software which places learners at risk, such as chat programs where learners could be susceptible to child molesters. Viruses (15 %), security flaws (8 %) and the interoperability (15 %) between proprietary software and open source software were some of the other issues mentioned by IT teachers and specialists.

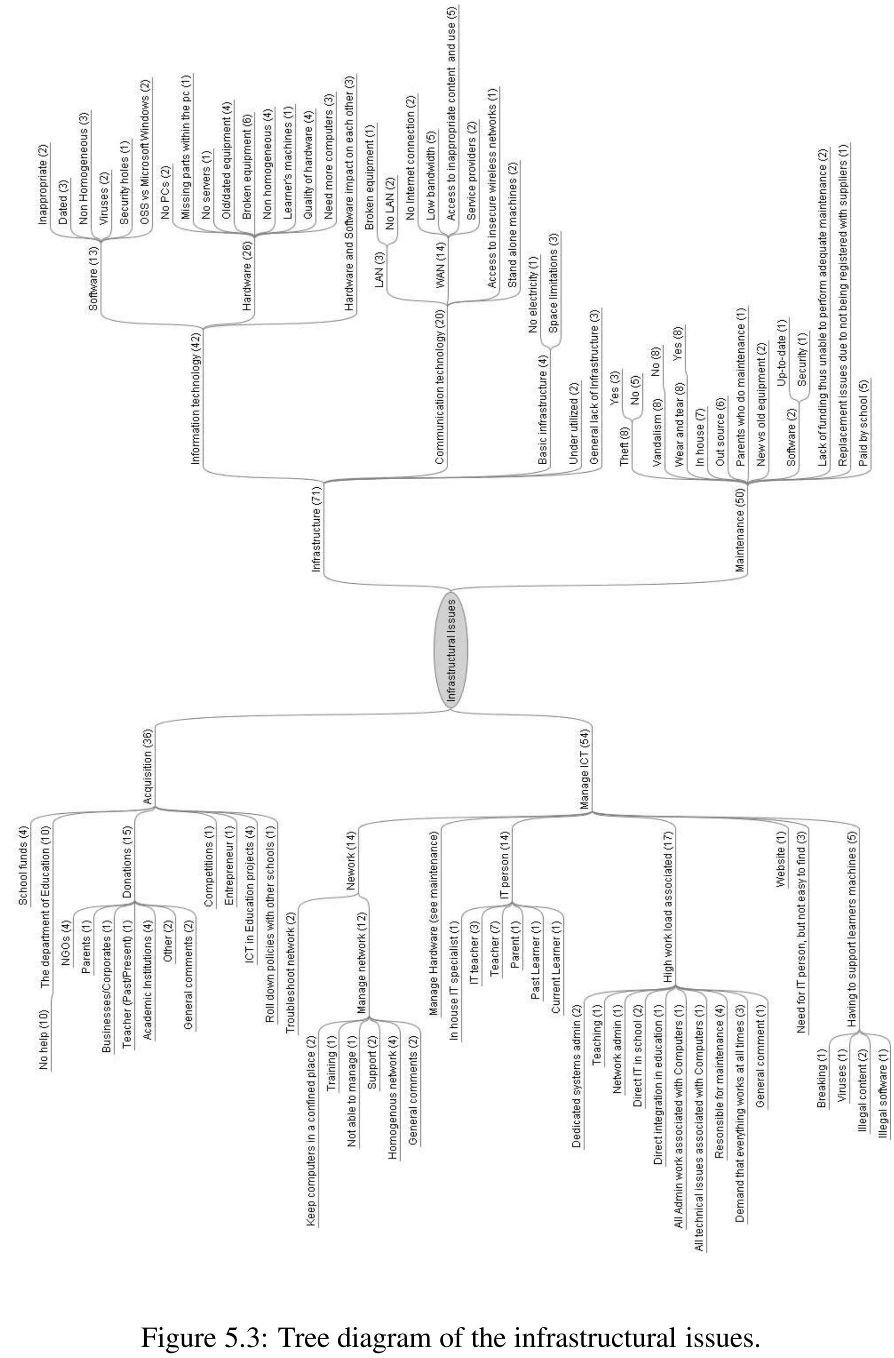


Figure 5.3: Tree diagram of the infrastructural issues.

As per data from the interviews held with the IT teachers at the Grahamstown Circuit schools.

**Communication technology: the Internet**

Communication technology was the next most frequently mentioned topic (28 %) within the Infrastructure subcategory. Within communication technology IT teachers and specialists spoke predominately (70 % of the total comments) about issues that they had with the Internet. The two greatest issues that secondary schools in the Grahamstown Circuit faced when it came to the Internet, were the access to inappropriate content and a lack of bandwidth, each of which made up 36 % of the total comments. As discussed in Chapter 2, Internet bandwidth in South Africa is very expensive and therefore most schools can't afford very much of it. As anticipated, all the schools complained of not being able to afford more bandwidth. The Internet is also not governed by a code of conduct and freedom of speech is the mechanism upon which everything works, thus there is a great deal of inappropriate content out there that schools have to try to protect learners from reaching. There is software for achieving this, which will be discussed in Section 5.4. Three of the IT teachers interviewed spoke of not having an Internet connection at all. From the questionnaire data we know that in fact four schools didn't have an Internet connection. In addition, one of the schools mentioned difficulties that they had with their service providers. For more data on which schools had an Internet connection and what type of connection they had, see Tables 5.5 and 5.6.

IS1&3 mentioned an interesting problem that they had found, which one might see more of as ICTs become more ubiquitous which is that their learners were gaining access to other off-campus wireless networks that were not properly secured. Issues here included learners picking up computer viruses, downloading illegal software or illegal content and then propagating them on the school's network. Thus while the IT staff might have taken proper precautions to secure their network from intruders, the lack of security on other networks could result in the learners bringing the viruses onto the school network.

**Communication technology: LAN**

Very few issues were mentioned about local area networks at the secondary schools in the Grahamstown Circuit. Two of the schools mentioned that they did not have a local area network (schools with LANs can be viewed in Table 5.7), while one school mentioned having broken network hardware. It would appear that as with software, schools did not notice networking issues when they had more rudimentary problems of insufficient or broken computers. Two schools, IS2 and FMC1, mentioned that stand-alone computers were not as useful as networked computers. One of the primary reasons cited for this was that technicians were unable to fix computers remotely or roll out a computer image to a stand-alone computer. The IS2 IT teacher's comments on this limitation of stand-alone computers was, "... *but a stand-alone machine is infinitely more work than one that is networked. For example you can't roll out an image to that machine: you actually have to be physically there and the same if there is a problem.*"

**Basic infrastructure**

Only 6 % of the secondary schools complained during the interviews about issues with their basic infrastructure. One school, FDET3 had complained of problems in the past where they had had no electricity as discussed previously in section 5.2.2. The majority of the basic infrastructure comments concerned the problem of lack of space with 75 % of the total comments made about this problem. One school, FDET6, commented that it would need an extra building in order to house a computer centre, while two other schools, FDET3 and FHOR, commented on large class sizes in comparison to the number of computers they had and the lack of space within the labs to conduct these classes.

| School | IT Specialist | IT teacher | Teacher | Parent | Past learner | Current learner |
|---|---|---|---|---|---|---|
| FDET1 | | | x | | | |
| FDET3 | | | x | | | |
| FDET4 | | | x | | | |
| FDET5 | | | x | | | |
| FDET6 | | | x | | | |
| FHOR | | | x | | | |
| FMC1 | | x | | | x | x |
| FMC2 | | x | | x | | |
| FMC3 | | | x | | | |
| IS1&3 | x | x | | | | |
| IS2 | x | x | | | | |

Table 5.9: IT person at the secondary schools.

As per information provided in the questionnaires as well as during the interviews.

Three of the schools, FDET4, FDET5 and FDET6 commented during the interviews on a general lack of ICT infrastructure, while FMC2 and FMC3 commented, also during the interviews, that their facilities were generally under-utilised by the other teachers at the school.

### 5.3.2 Manage ICT

Managing ICT was the second most discussed subcategory within the Infrastructural issues category. There are some very interesting things to note in this subcategory, specifically who performed the role of school IT person at the schools. In seven of the schools a regular class teacher performed the role of IT teacher, while four of the schools had IT teachers and two had IT specialists. Table 5.9 contains information about which of the schools have what kind of IT person. This information was obtained from data in both the questionnaires and the interviews.

From Table 5.9 one can see that the majority of the schools (64 %) that participated in the study rely on regular class teachers with a passion for computers to run the ICT in the school. In the cases of the independent schools, they not only had IT teachers, but also IT specialists. Often this arrangement left the teachers free to teach IT-related content to the students while the IT specialists took care of and managed the ICT infrastructure. In addition, parents might also aid the school in terms of its ICT infrastructure, as at FMC2, while other schools relied on the goodwill of their past and current learners, as at FMC1. Schools relied on these youngsters as they often knew a lot more about computers than the teaching staff, but also because the teaching staff were very over-worked when they not only had to run the computers and the network of their school with all the related administration, but they also had a full teaching load.

The topic of high workload was mentioned on 17 separate occasions (31 %) by the teachers in the various schools. Teachers mentioned that they were responsible for maintenance, directing IT in the school, systems administration and in some cases were even expected to perform all associated school administration that involved the use of computers, such as compiling the reports for every single child in the school. IT teachers and specialists also complained that it was expected of them to have the network and computers running properly at all times and often when things weren't working they were blamed and expected to drop everything to fix it. Teachers called for dedicated IT specialists in schools, but were aware that the chances of finding people who would want to do that would be slim or that schools would not be able to afford a dedicated IT specialist.

The next most discussed topic within Manage ICT was that of network management in which there were 14 (26 %) comments made. Four of the teachers mentioned the difficulties associated with managing non-homogeneous networks, i.e. networks which are made up of computers of varying ages and thus operating systems and application software of varying ages. Issues that they mentioned were security problems with older software as well as no support for older software. Furthermore, it was impossible to duplicate the same software image to every machine when some would be incapable of running new operating systems and application software. Two IT teachers mentioned that supporting computers and teachers at the school was a large part of their job, while only one commented on the importance of training for themselves, in terms of support, IT management and maintenance. Furthermore, two teachers commented that confining the computers to one place such as a computer lab made it easier to maintain and secure them. Only one school commented that they were unable to manage their network at all, while only two discussed troubleshooting on the network in order to discover errors and then fix them.

An interesting ICT management problem that was mentioned by the independent schools, and I suggest will probably become more evident in state schools as their infrastructure increases and South Africa's economy strengthens, is having to support and repair the computers brought to school by the learners. This included issues of the learners bringing viruses onto the campus network through their personal computers as well as illegal software or illegal content such as pornography. The question of who bears the responsibility of the illegal content and software is another important issue – will it be the school, the learner, the IT specialist, the parents or the house warden? These are important issues that all schools who allow their learners to bring their own computers to campus should be considering. It also helps to highlight the need to have Acceptable Use Policies at schools in order to help schools make appropriate decisions on difficult topics.

### 5.3.3 Maintenance

ICT maintenance was the next most discussed subcategory by the IT teachers and specialists during the interviews, with 50 (24 %) comments made by IT teachers/specialists during the interview process. It is very interesting to note that secondary schools in the Grahamstown Circuit tried to do in-house maintenance rather than outsourcing. There were four schools that did all their own maintenance: the independent schools (IS1&3 and IS2) and two of the former model C schools (FMC1 and FMC2). The FMC3, FHOR and FDET schools tried to do some maintenance on their own, but if they could not perform the repair they would then outsource it to a local computer company in Grahamstown. There were some schools, such as FDET4 and FDET5 who purely outsourced their maintenance. As the majority of the schools had to pay for their maintenance, many tried to outsource the work to people who would help them free of charge, such as Rhodes students through the CoE or through the help of NGOs such as SchoolNet or the Shuttleworth Foundation. According to the questionnaires three schools, FDET1, FDET5 and FHOR, mentioned that due to a lack of funding they were unable to perform any maintenance at all. Another issue mentioned during the interviews by the IT teachers was that it was easier to maintain newer equipment than older equipment as parts were easy to come by and newer technology had made improvements. One school, FDET3, commented that it was difficult to perform maintenance as they were not registered with any suppliers. For more data on computer maintenance obtained from the questionnaires, see Tables 5.10 and 5.11. Note that schools were able to give more than one option as to how they went about fixing broken ICT infrastructure or replacing ICT infrastructure.

In Table 5.10 one can clearly see that not one of the secondary schools received any funding from the Department of Education. The majority of the schools had to rely on their own funding in order to fix broken equipment, while some were completely reliant on donations, such as FDET6, who said as much

| School | Outside Donation | Government Funding | School Funds | Fundraising | Not able to |
|---|---|---|---|---|---|
| FDET1 | | | | | x |
| FDET3 | | | x | | |
| FDET4 | | | x | | |
| FDET5 | | | x | | x |
| FDET6 | x | | x | x | |
| FHOR | | | | | x |
| FMC1 | | | x | | |
| FMC2 | | | x | | |
| FMC3 | | | x | | |
| IS1&3 | | | x | | |
| IS2 | | | x | | |

Table 5.10: How do schools fix broken computer equipment?

Data according to that supplied by the IT teachers/specialist in the questionnaires.

| School | Outside Donations | Government Funding | School Funds | Fundraising | Not able to |
|---|---|---|---|---|---|
| FDET1 | | | | | x |
| FDET3 | | | | | x |
| FDET4 | | | x | | |
| FDET5 | | | x | | x |
| FDET6 | x | | x | x | |
| FHOR | | | | | x |
| FMC1 | | | x | x | |
| FMC2 | x | | x | | |
| FMC3 | | | x | | |
| IS1&3 | | | x | x | |
| IS2 | | | x | | |

Table 5.11: How does the school replace computer equipment?

Data according to that supplied by the IT teachers/specialist in the questionnaires.

in the interview. Schools without sufficient funds were not able to afford the fixing of computers, such as FDET1, FDET5 and FHOR. These schools didn't appear to be very proactive in attempting any fundraising initiatives of their own. Where schools were not being proactive, ICT may possibly not be considered important enough to the school to warrant such fundraising, including applying for donations.

In Table 5.11 one can again see that the majority of schools, eight out of 11 (73 %), used their own funds to replace computer equipment. Once again none of the secondary schools in the Grahamstown district received any funding from the Department of Education. Again in the four schools where there wasn't much in the way of school funds, they were just unable to afford to replace the equipment, while three schools made use of fundraising initiatives to raise the necessary funds for upgrades.

Looking again at the data from the interviews (Figure 5.3) it is very important to note that the majority of the breakages at schools took place due to normal wear and tear on the equipment while being used. This is important because no schools reported learners or members of the community vandalising the computer equipment, and only three schools had ever reported computer theft. Schools affected were FMC1 and

FDET3, where the theft had only taken place once and IS1&3, where laptops that had not been properly tied down had on occasion been stolen.

### 5.3.4 Acquisition

ICT acquisition is the last of the four subcategories and was the one mentioned the least during the interviews. It was mentioned 36 (17 %) times out of the 211 comments made about infrastructural issues. However, it is clearly one of the most interesting of the subcategories. When consulting the tree diagram (Figure 5.3) one will notice that donations were by far the most common way of schools obtaining ICT equipment, as 15 (42 %) of the 36 comments made pertained to computer donations. These donations were made mostly by NGOs, with four of the schools receiving donations from NGOs, such as the Shuttleworth Foundation or SchoolNet, while academic institutions, such as Rhodes University, were also responsible for a number of donations within the Grahamstown Circuit. Donations had also come from past teachers, parents and local business or international corporations, while local rugby clubs as well as other local organisations, such as local newspapers and the more affluent local schools, had also donated to needy schools. The donation to FDET6 was by a former teacher who had moved to London, while the donation to FMC2 was from a parent who had won R50000 in a competition.

In addition to pure donations where schools were merely given computers to do with as they pleased, there were also donations in the form of ICT in Education projects. One such project was the Khula project. The Khula project worked with science and mathematics teachers from the historically disadvantaged populations and provided the schools with computers and science and mathematics programs. Four of the schools were involved in the Khula project, FDET1, FDET3, FDET5 and FHOR.

Some of the schools had very interesting approaches to acquiring new ICT infrastructure, such as FDET3, who had entered into the Global Teenager project with SchoolNet and won 16 new computers [138]. The learners at the school competed in the Global Teenager project by using computers to make presentations about their school and life in Grahamstown, South Africa. Many schools all over the world entered the competition, but the submission from the learners at FDET3 resulted in them being chosen as the winners for which they were awarded a new computer lab for their school.

Meanwhile, FMC2, started a computer literacy business in the school. The money that the learners paid for literacy lessons went towards paying the IT teacher as well as purchasing necessary supplies such as paper and printer ink, as well as purchasing new ICT equipment and paying their Internet bill. Some schools, such as IS1&3 and IS2, had roll-down policies that allow them to donate their older equipment to needy schools who couldn't afford to purchase their own. Once again it is very important to note that none of these schools had benefited from any help from the Department of Education.

Data from the questionnaire pertaining to computer acquisition can be seen in Table 5.12. Note that schools could give more than one option as to how they went about acquiring ICT infrastructure. More interesting is the difference in what IT teachers said in their interviews (Figure 5.3) compared with what they wrote/filled in in the questionnaires (Table 5.12). Namely, in the questionnaires teachers said that new computer equipment was purchased mainly (at 7 out of 11 schools) from school funds and only three schools mentioned obtaining computers via donations. However, in the interviews only four schools mentioned purchasing computers with school funds, while eight cited donations. This discrepancy may be explained by the fact that often schools, especially the previously disadvantaged schools (FDET and FHOR schools) had obtained their first set of computers through donations and were subsequently expected to maintain and buy new equipment from their own funds.

| School | Outside Donations | Government funding | School Funds | Fundraising | Not able to | Other |
|---|---|---|---|---|---|---|
| FDET1 | | | | | x | |
| FDET3 | x | | | | | x |
| FDET4 | | | x | | | |
| FDET5 | | | x | | x | |
| FDET6 | x | | | | | |
| FHOR | | | | | x | |
| FMC1 | | | x | x | | |
| FMC2 | x | | x | | | |
| FMC3 | | | x | | | |
| IS1&3 | | | x | x | | |
| IS2 | | | x | | | |

Table 5.12: How does the school obtain new equipment?

Data according to that supplied by the IT teachers/specialist in the questionnaires.

### 5.3.5 Recommendations

Factors which contribute to concerns about infrastructural issues include a lack of funding, a lack of technical training and a lack of technical support. In addition, when a school had had computers donated, there seemed to be a lack of understanding about how much money would need to be budgeted for maintaining, fixing and replacing equipment. Furthermore there seems to be a lack of understanding regarding budgeting for these activities as well as a lack in technical knowledge required in running a computer lab. FMC2, FHOR, FDET1, FDET3, FDET4, FDET5 and FDET6 all had their first computers at the schools donated to them, either by having been given money for computers or by having the computers installed by the donor. These schools also tended to be the schools which commented most often about infrastructural issues.

Thus it may be worthwhile considering another model of donation to the standard one of just donating computers to any school deemed worthy and then leaving them to their own devices. The model that I suggest is that of the tuXlab model. The tuXlab model is more than a donation, but rather a partnership that is entered into by the Shuttleworth Foundation and the school [150]. In applying for a tuXlab schools are forced to work through an eight-step process, which involves learning first about the tuXlab project and open source software, then completing a questionnaire and putting together a business plan of how they are going to sustain their computer lab as well as how they are going to find the necessary initial funds in order to help get the computer lab ready. They are also expected to attend other tuXlab installations in order that they understand the process as well as to contribute to the organisation from which they are hoping to receive. Furthermore, through the business proposal process schools are forced to find local ICT technical support.

In addition, once the lab has been installed they are required to attend monthly meetings in which they will be able to collaborate with other schools and learn from their experiences as well as continually remain in touch with the Shuttleworth Foundation. Schools are further encouraged to send their staff members on training courses for both computer literacy and computer technical skills.

This process helps to alleviate many of the initial hindering factors, by firstly helping schools learn how to go about finding donations and generating funds of their own. Furthermore, it encourages schools to think about how they will support their computer labs in the long term, both financially and in terms of actual maintenance. Schools are able to further identify appropriate technical support avenues as well as obtain literacy and technical training for their staff members. Teachers and schools are also made aware of the imperatives of training as well as the complexities of having their own computer facilities. These benefits were evident at the FHOR school, which had installed a tuXlab in May 2005.

## 5.4 Overcoming infrastructural challenges

Having covered what infrastructure the schools in the Grahamstown Circuit had and what issues and problems they faced in terms of that infrastructure or the lack thereof, it is now necessary to discuss how schools were attempting to overcome these infrastructural challenges. A number of the schools were finding ways to work around their infrastructural challenges and were making efficient use of what they had.

The structure of the discussion is based on the findings from the interviews, which are represented as a tree diagram (Figure 5.4). There were no findings from the questionnaire in this category as schools were not asked to provide information of this nature in the questionnaires. The first subcategory discussed is that of the proactive attitudes and steps that the various schools were taking as they were most often discussed (27 %) during the interviews. The next most mentioned subcategory (22 %) was that of training as a means to addressing infrastructural challenges, then increasing infrastructure (10 %), efficient use of the infrastructure (8 %) and many others.

### 5.4.1 Proactive steps

Many of the schools suggested proactive steps that they had taken to overcome their infrastructural challenges. The most frequently reported of these was the provision of funding for ICT needs for the school. This was equally split between producing a formal budget and using school funds in an informal, needs-based fashion. The formal budget is more of a proactive step to the monetary needs of ICT, while the needs-based budget is more reactionary to challenges which need a financial response. Either way, schools found that making available funds for ICT was a huge help in overcoming infrastructural challenges.

Another proactive method employed was that numerous schools shared the costs of their infrastructure. A good example of this is the Internet connection for FMC1, FMC3, IS1&3 and IS2. The four schools shared the cost of a Telkom Diginet line from their central server to their ISP in Port Elizabeth. The schools shared the bandwidth and the cost of the line, making connecting more affordable for all concerned.

Some schools, FMC1 and IS1&3, had taken the initiative and arranged fundraising events in order to raise money for their ICT infrastructure, while FHOR, FDET3 and FDET4 had actively marketed themselves to NGOs and corporations in order to receive some degree of sponsorship or donation of ICT infrastructure. Entrepreneurial FDET4 provided ICT services to the community for training or provided the facilities for the use of the community after hours; FDET5, FDET6 and FHOR reported they would like to do this when they had better established computer labs. These projects generated funds that went back into maintaining the ICT infrastructure.

As mentioned in section 5.3.4, some schools had very interesting methods for acquiring computers. FMC1 leased its computers on a five year maintenance contract, after which time the computers would belong to the school. This method allowed the school to purchase the computers over a five year period and during that time they also received maintenance on the computers from the company with which they had the contract. FMC2 ran its computer centre as a business. The learners paid for IT literacy lessons and that money was used to pay the IT teacher – for whom there was not a state-paid post at the school – as well as to purchase new equipment and pay for the maintenance of the school's existing ICT infrastructure. FDET3 had entered the Global Teenager Project and won 16 new computers and the FHOR had applied to the Shuttleworth foundation for a tuXlab, which they had been granted. In addition, FHOR had applied to Dell for additional assistance and had been generously provided with 20 new Dell computers.

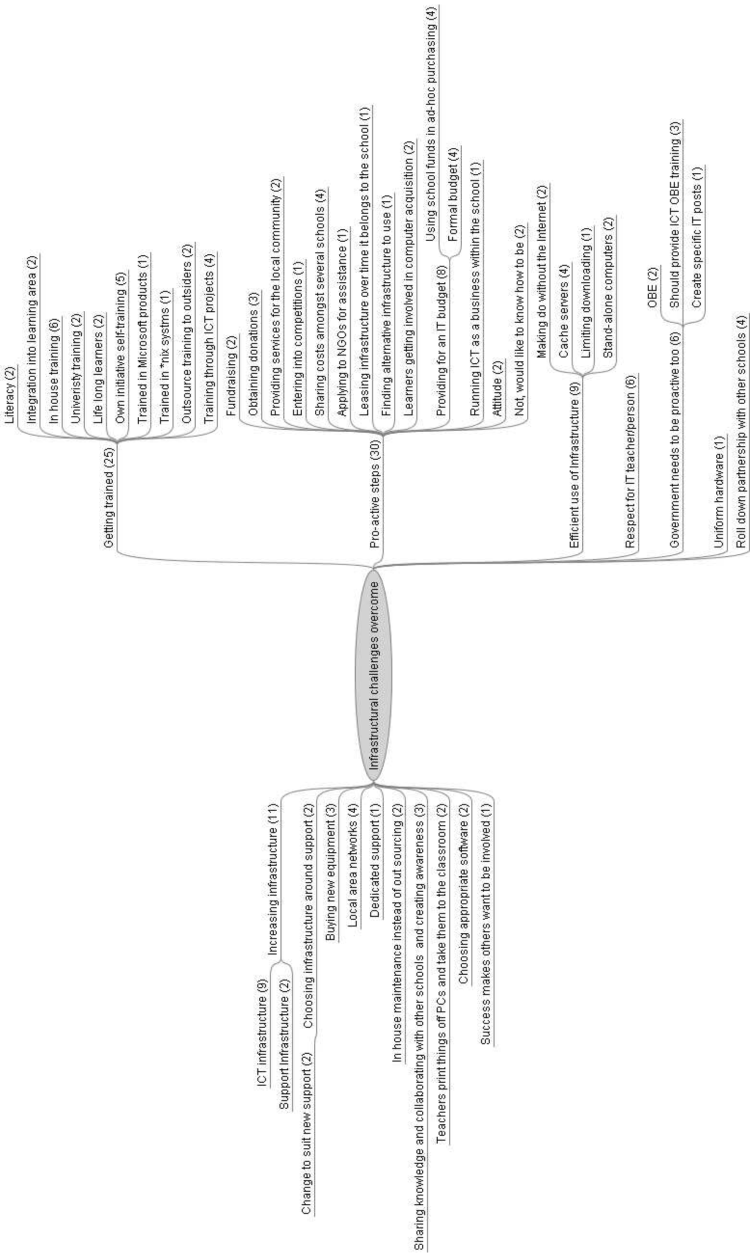


Figure 5.4: Tree diagram of how schools are overcoming infrastructural challenges.

As per data from the interviews held with the IT teachers at the Grahamstown Circuit schools.

Two of the schools interviewed, FDET5 and FDET6, commented that they were not proactive, but rather reactive. They did however mention that they would like to know more about how they could become more proactive. Three of the more proactive schools, IS1&3, IS2 and FMC2, also reported that they did and would like to continue sharing their experiences and what they had learnt with other schools.

### 5.4.2 Training

All of the schools were very quick to mention how important teacher training was to a school that would like to integrate the use of ICT into teaching, learning and administration. During the interviews teacher training was mentioned on 25 (22 %) occasions by the IT teachers/specialists that were interviewed. In response to the question of what they felt needed to be done in order for ICT integration in schools to be successful, FMC1 commented, "*Teacher training, teacher training and ja, teacher training...*". The IT teacher at IS2 had this to say in response to the same question, "*I think basically the key factor is staff training... Unless staff are properly trained they will never integrate computers into their teaching properly.*"

Most of the teacher training that was currently taking place seemed to be driven by the teachers themselves. Many of the teachers (five of those interviewed) were participating in training courses through initiatives of their own, either through university qualifications or enrolling in courses through NGOs such as SchoolNet SA or the Shuttleworth Foundation. Another major training route has been through ICT in education projects. An example of this was the Khula project which was aimed at Mathematics and Science teachers. The schools that participated in the project received computers with Mathematics and Science software and the Mathematics and Science teachers were trained in their use in order to be able to integrate them into their teaching.

A further source of training was that given in-house at several schools. The IT teachers of FDET3, FMC1, FMC2, FMC3, IS1&3 and IS2 all offered in-house ICT training courses to the other teachers and school administration staff in their schools. Other schools outsourced the training to outsiders. In FMC3, their ISP had done basic training with their IT teacher so that she was able to do more on her own before calling them out, while FDET3 and FDET4 had received some training from the students at Rhodes, either through organised courses with the university's student computer society or through informal technical training from the students who had done maintenance for the school. Two of the IT teachers, at IS2 and FMC3, had received training while studying for their degrees at university.

The IT teachers at IS2, FDET3 and FMC2 further mentioned that they had received training in computer literacy and integration into teaching and learning as well as product training in either Microsoft Windows or Unix/Linux.

The teachers from FMC1, FMC2, FMC3 and FDET3 stressed the necessity of being a life-long learner when it comes to ICT. The IT teacher from FMC2 had this to say about life-long learning and its importance, "*So for me it's a priority to study further and further so that I am always in advance of the kids... You can't stop learning with computers. You can't think at any point that you now know enough. You have to carry on learning because the software is always changing.*"

### 5.4.3 Increasing infrastructure

Increasing infrastructure, both physical infrastructure and support infrastructure, was mentioned 11 times (10 %) during the course of the interviews (Figure 5.4) by IT teachers as an aid to overcoming their ICT challenges. IT teachers from IS1&3, IS2, FDET3, FMC2 and FMC3 spoke of how an increase in infrastructure, such as increasing from one computer lab to two, had had a tremendous impact on the ICT running of the school. It had allowed for more integration and for fewer timetable clashes.

Also discussed was the purchase of new equipment. New equipment tends to be easier to manage and has fewer maintenance needs as well and when they do need maintenance it is easy to provide as spare parts are easy to come by.

Increases in the support infrastructure, such as appointing a specialist IT teacher or IT technician, also allows schools to overcome more of the challenges. Firstly there will be less of a workload for one teacher or specialist to bear, while allowing the ICT facilities to run more smoothly. The FMC3 school also suggested purchasing their infrastructure based on the available support companies. In other words, if the local support group or company were proficient in Linux then run Linux systems in the school, etc. FMC3 and IS1&3 had changed their infrastructure to match their support structures. Both schools highlighted the importance of having dedicated support.

### 5.4.4 Efficient use of infrastructure

Another means of overcoming infrastructural challenges was to make maximum use of their current infrastructure. Schools did this via a number of methods (Figure 5.4). One such method was to make use of cache servers in order to increase the efficiency of their Internet connections. A cache server is a server that saves (or caches) Web pages and possibly other files that users have requested from the Internet. This allows for successive requests for these pages or files to be satisfied by the cache server rather than requiring the use of the Internet. A cache server not only serves its users by getting information more quickly, but also reduces Internet traffic. A number of the schools, FDET3, FMC1, FMC3, IS1&3 and IS2 employed the use of cache servers in order to reduce the amount that they used their Internet connections. This helped to speed up the access to websites and also alleviated costs as the page would only need to be fetched once and then from there could be served from the cache. The IT teacher at IS2 said the following about their cache server, "*... so I would say that we have hits on our cache about 60% of the time, so it does help a lot...*"

IS1&3 also spoke of limiting the amount of downloading in order to save costs on Internet. Furthermore, in schools where there was not always access to the computer labs, such as FDET3 and FDET4, teachers used their spare time and did the research themselves and used the information with their classes in the form of either worksheets or information sheets. A few teachers, from IS1&3, FMC1 and FMC2, also spoke of how it was possible to teach the learners a great deal without the Internet. They realised that the computer on its own without the Internet was a powerful tool with benefit to learners.

A further method of efficient employment of infrastructure is that schools made use of the older computers to do less intensive tasks, such as computyping programs or other drill and practice software. This meant that schools could get use out of all of their infrastructure that was in working order, even those computers which were old. In addition schools could make use of those computers which weren't networked. While state schools tended to hold onto their working infrastructure, the independent schools rolled out their older hardware every four to five years. In these cases, these schools donated that hardware to less privileged schools.

Another useful method for overcoming challenges is to employ the use of a local area network. As mentioned previously in section 5.2.3, LANs allow one to take the burden off resources. A good example of this is if a school only had one printer, such as FDET1 or FDET5, having it networked to all the computers meant that any one of those computers could print to it. In a non-networked environment, in order for every computer to be able to print, a school would need a printer connected to every single stand-alone computer. A network also allows for all the computers in the school to be connected to other expensive resources such as a central file server and thus be able to save work to that server. The IT teacher at the FMC1 school spoke of these benefits when he said, "*... networking takes the burden off resources so you can utilise your* *resources and it makes backing up and saving things that much easier. Also it means that kids can save work to a server...*"

### 5.4.5 Additional steps

Additional proactive measures that schools had found to be beneficial in responding to the challenges were to perform in-house maintenance and to choose appropriate software. The resulting respect gained for the IT teacher or specialist from colleagues and learners made their work much easier to perform.

In addition there was a strong call from IT teachers and specialists in the Grahamstown Circuit secondary schools for more of a proactive stance from the Department of Education and the state. There was a call for more OBE training with specific reference to how ICT should be integrated as well as the state to create IT teacher posts so that the gaps in school ICT needs could be better supported and filled.

### 5.4.6 Recommendations

It is important to note that central to schools overcoming their infrastructural challenges is a proactive attitude. Unless schools are committed to having and using ICT facilities in their school they will struggle with the challenges in having such facilities. If schools actively decide that they want to have ICT infrastructure in their schools and that they are prepared to proactively obtain the necessary facilities and maintain them, then they will find it much easier to achieve great things and overcome the inherent challenges. However, if ICT infrastructure is "forced" upon a school through donations that they have not applied for, then they are likely to find having such infrastructure in their school far more challenging than those schools who have actively decided that this is the route that they would like to take.

Schools which had a more proactive attitude in all sectors, from the Governing Body to the teachers teaching the subjects, to the school administration staff, seemed to encourage teachers to be trained in the use of ICTs and the integration of the ICT tools into their individual learning areas. Furthermore, schools are likely to find that there will be a few teachers who are interested in being the technical support for the school and thus can undergo technical training. Should there be no suitable candidates among teaching staff to be the technical support, schools might find it within the administrative staff, or perhaps might find a local person in their communities who would be willing and eager to be technical support for the school's ICT infrastructure. Furthermore, schools might find that some of their learners are willing and able to supply ICT support for them, such as was found at FMC1.

With properly trained staff, schools will be able to make appropriate decisions about their infrastructure – hardware, software and networking. Schools will find it easier to make appropriate decisions about ICT policy to help govern the use and maintenance of their infrastructure. They will also find it easier to make efficient use of the infrastructure that they have and can afford. For example schools might see the benefits, as discussed in section 5.2.3, of having LANs within their schools. In addition to being able to make decisions about what is appropriate hardware and software, schools will also be able to decide what is inappropriate for their school's needs. They will be able to turn down any inappropriate donations that are offered to them should these hardware and software not be in line with their school's needs and ICT vision.

With proper training and understanding resulting from to proactive attitudes, schools will hopefully begin to undertake proper IT budgeting in a planned and organised fashion and in less of an ad-hoc manner. Furthermore, schools that are doing well and have the right proactive attitudes to ICT can show the way to those more reactive schools who would like to learn how to achieve the same things.

## 5.5 Limitations and constraints

In addition to the challenges of infrastructure there are additional limitations and constraints that have a bearing on the facilities and the ICT infrastructure found within all the schools. In this next section some of the limitations and constraints that were mentioned by the IT teachers and specialists during their interviews are presented. A total of 214 comments were made about additional limitations and constraints. A diagram of their responses can be seen in Figure 5.5. From Figure 5.5 the following subcategories are used to group the issues that were discussed by the IT teachers and specialists: policy, costs, lack of ICT support from the Department of Education, time constraints, ICT integration and training. This section contains data from the interviews only, as no questions of this nature were posed in the questionnaires, nor are they based on information seen in the on-site audit.

### 5.5.1 Costs

ICT infrastructure costs were the most mentioned limitation for schools, with a total of 59 comments made about cost limitations by IT teachers/specialist. ICT infrastructure is by no means cheap and since it needs constant maintenance the total cost of ownership is not limited to the once-off purchase cost of the equipment. Schools discussed the cost of the infrastructure as the primary cost issue that they faced: 39 % of the total cost comments were made about infrastructural costs. Interestingly, if one looks at Figure 5.5, it can be seen that the IT teachers tended to focus more on the cost of software and Internet bandwidth than that of the actual computer hardware. This might be because that while hardware does have an associated cost, that cost is not as high as the costs of software and Internet bandwidth. IS2, which as an independent school had to pay for all its software, quoted prices of R50000 for just one software licence. Certain proprietary software is very expensive and schools will pay high prices for the licence to run the software at their schools. As discussed in Chapter 2, Internet bandwidth in South Africa is almost prohibitively high relative to other countries and schools will have to pay dearly for even limited bandwidth.

In addition to the high costs associated with software licences and bandwidth, many state schools in the Grahamstown Circuit have been or are being converted to section 21 companies – 11 comments were made (Figure 5.5) about becoming section 21 companies by the eight state schools that were interviewed. This means that the state will make a contribution towards the running of the school and pay some of the teachers' salaries. However, the school is expected to run itself and to pay any extra teachers that it hires. Schools are run as a non-profit organisation, and make use of the funding from the state and then have to raise the rest from school fees and fundraising efforts. However, in South Africa today schools may not refuse learners the right to learn, even if they have not paid their school fees, so often schools struggle to get parents to pay fees and thus have very little money at all. The FDET5 school also complained that they had not received their funding from the state and were struggling financially. Considering Figure 5.5, it can be seen that a number of comments (11) were made regarding schools having to pay for all their infrastructure that was not donated to them. One school, FDET6, commented that they were completely dependent on donations due to a lack of funding from the state.

### 5.5.2 Policy

The subcategory of policy was commented on on 45 separate occasions by IT teachers and IT specialists at the secondary schools in the Grahamstown Circuit. Generally it can be seen (Figure 5.5) that there was a lack of ICT policy at these schools and that that was a major stumbling block for schools in attempting to adopt the use of ICTs into their schools.

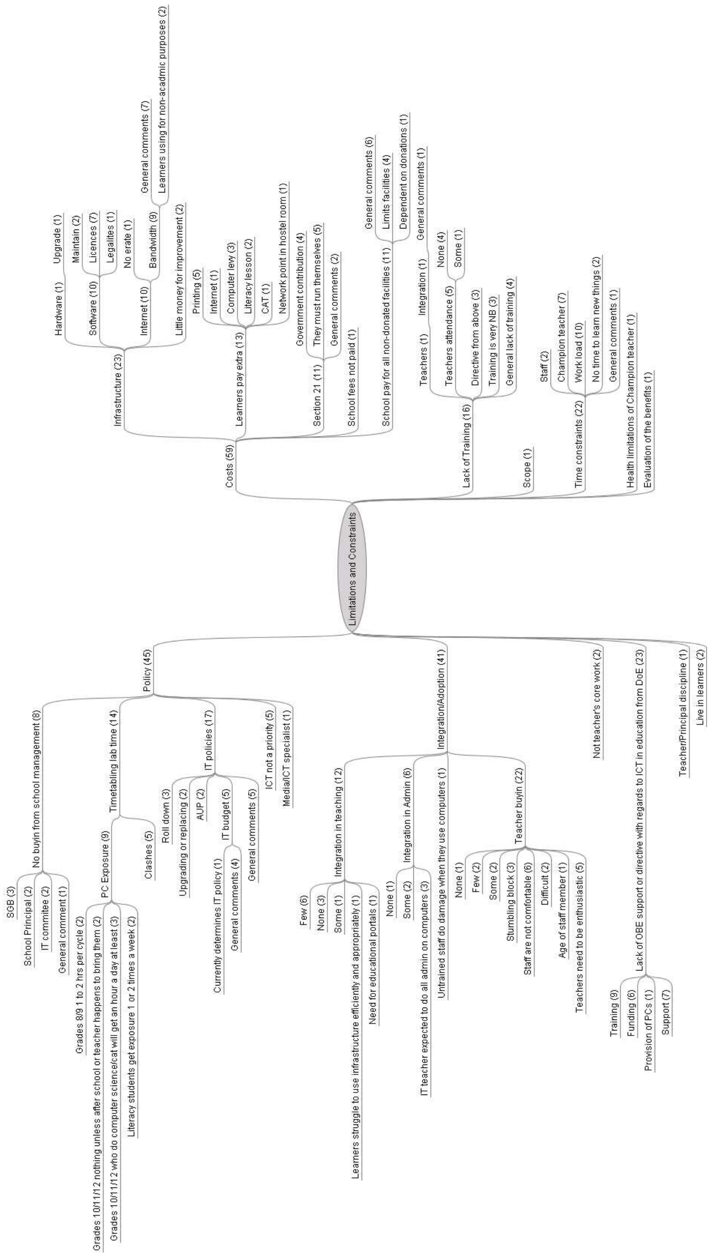


Figure 5.5: Tree diagram of the limitations and constraints.

As per data from the interviews held with the IT teachers at the Grahamstown Circuit schools.

Within the policy subcategory, the most discussed topic was that of IT policies, with 17 comments made by the teachers from the 12 schools interviewed. Slightly less than half of the secondary schools had an IT budget, namely IS1&3, IS2, FMC3, FMC2 and FMC1. Some of the previously disadvantaged schools, FDET3, FDET4 and FDET5, did not have a specific IT budget but rather tried to allocate school funds to ICT needs as they arose. Very few of the schools, only IS1&3 and IS2, had an Acceptable Use Policy (AUP), Roll down policy and Upgrade policy. ICT policies are very important in that they provide guidance to the school, from management to teachers, on how to make appropriate use of the ICT facilities.

A further factor that contributed to a lack of teacher buy-in is if there was no buy-in or support from school management. A number of schools, IS1&3, IS2 and FHOR, commented that there was little support from School Governing Bodies, principals and IT committees. The IT teacher from IS2 commented, "*I think the biggest problem with IT in schools is that there is very little understanding of what it exactly involves. Basically what it boils down to is that there is very little understanding from the upper echelons of what it actually takes to run an IT centre. Their understanding of it is that you just put the computers in and then they just work. They don't seem to realise that computers do not just work all of the time and they do actually require quite a bit of working on because that is the nature of computers and in fact they need a bit of fiddling with as well in order to tweak them to work as we would like them to, which also takes a fair amount of time. And then there is also the huge amount of support that has to be done. Not only does one have to support a lot of people, particularly the staff, funnily enough, who are not particularly well-informed users at all but they are not keen on learning either. So five years later you are still answering the same questions from the same people because they would rather just ask you and have you just immediately do it for them or spoon feed them.*" Often the leading cause in all of the above is that ICT was just not a priority at the school, as five of the schools indicated.

Related to a lack of ICT policy in schools is the amount of exposure the learners had with the facilities. The general trend (Figure 5.5) seemed to be that students in grades 8 and 9 in schools where they offer Technology were allocated two hours exposure per cycle (most cycles are generally nine days long), while learners in grades 10 - 12 who do CAT or Computyping were allocated an hour exposure almost every day. Those learners studying Computer Science had access generally for one or two hours a week, as most students taking Computer Science took it as a 7th subject and classes were in the afternoon. Learners who did not take either of these subjects in grades 10 - 12 generally got very little computer exposure and the majority of the exposure they got was by spending time in the afternoons in the computer labs, as many teachers did not seem to be integrating the use of ICT into their teaching.

A general lack of ICT policy can really hamper the integration and adoption of ICTs into schools and hamper schools in managing and directing their ICT facilities. Furthermore, principals and HODs will struggle to direct integration in a school where there is no policy to guide their decision-making.

### 5.5.3 ICT integration

The extent of integration of ICT into teaching at the secondary schools in Grahamstown appeared to be low when one considers what the IT teachers said in their interviews – 41 comments in total. Looking at Figure 5.5 one can see that IT teachers commented that "few" (55 %), "some" (9 %) or "none" (27 %) of their teachers were integrating the use of computers, while one of IT teachers did not comment on integration during the interviews. IT teachers and specialists mentioned how learners struggle to use ICT infrastructure effectively and efficiently. This is probably due to the lack of integration in the classroom.

One of the biggest integration issues is lack of teacher buy-in, with 54 % of the total integration comments concerning teacher buy-in. A number of schools, IS1&3, IS2, FMC1, FMC2, FMC3 and FDET3, commented that teachers tended to not be comfortable using computers or found it too difficult. Furthermore, schools commented that the generally low teacher buy-in was a large stumbling block for the integration process. However, IT teachers and specialists were quick to point out the necessity of teacher enthusiasm in successful ICT integration in schools. It is imperative to integration that teachers become comfortable and enthusiastic about ICT use in schools.

One of the IT teachers, from IS1&3, spoke of the need for an educational portal and I would agree. This would allow teachers from all over the country to collaborate with each other. Thus teachers who know how to use ICT in their teaching well would be able to teach those teachers who are unsure. The DoE has realised the need for an educational portal as well and has created Thutong (http://www.thutong.org.za), however it is currently underutilised by teachers, possibly because of a lack of knowledge about its existence or lack of training in how to use the portal.

From Figure 5.5 it would appear that teachers used computers and ICT facilities more in their administrative work than in their teaching work. Unfortunately, however, there were some schools, FMC2, FHOR and IS2, who expected the IT teacher to perform all ICT-related administrative work and thus the IT teacher had to collate all the marks for every child in the school and produce all the reports as they were the most IT-literate member of staff.

FMC2's IT teacher commented that while teachers on the whole did not integrate computers and ICT facilities into their teaching, she preferred this as most of the teachers there had not had much IT literacy training and she feared that they would break the computers and then she would have to spend hours fixing them! So she was not comfortable with the staff using the facilities without proper training.

### 5.5.4 Lack of ICT support from the Department of Education

The fourth most-mentioned comment (11 %) was the lack of support from the DoE. However, the lack of DoE support is also evident in the ICT policy limitations, as there appeared to be insufficient policy directives from the local education department in Grahamstown or from the Eastern Cape DoE. Furthermore, schools had not received any funding from the DoE for ICT infrastructure.

However, the biggest complaint from the IT teachers in the Grahamstown secondary schools, noted during the interviews (Figure 5.5), was that there was no ICT training for OBE (9 out of 23 comments (39 %)) and teachers did not know how to integrate ICT into their teaching. The IT teacher at FMC3 commented, "*No, [help] at all in terms of computers. Even when we go for our OBE training for grades 8s and 9s, computers don't feature anywhere in that, they don't even consider it to be part of any of the topics or learning areas. So absolutely no support from them or training. ... It would definitely help if it was included somewhere [ in OBE ] and given its own amount of time, they need to recognise how important it is. None of these learners will find a job that doesn't involve a computer and that's the whole point of OBE, to make learners by the end of grade 9 ready to go out and get a job. I think we are failing them a bit if we are not teaching them about and exposing them more to computers. So it does definitely need to become more recognised, more supports by the DoE.*"

Primarily, schools need the DoE to provide ICT training for use in OBE as well as proper support in terms of direction and policy. After that has been met it would be welcomed if the DoE should help with funding. Ideally, schools and the Department of Education should enter into a partnership, much like the partnership that the Shuttleworth Foundation and schools enter into when they deploy tuXlabs. Through such partnerships the Department should supply some of the ICT equipment that schools might require, in particular the more expensive equipment, while schools should be encouraged to arrange other facilities, such as cabling of the school or purchasing the less expensive hardware, such as monitors. As with the tuXlab partnership the Department should encourage the schools to adopt adequate ICT policies as well as support them with training, funding and direction. Schools should be encouraged to meet certain criteria in terms of their ICT facilities and should they then fail to do so, would then have to forfeit some of the benefits of their partnership until such time as they met those criteria. Through such a partnership, the DoE should also help to negotiate more competitive prices for schools, much like it did with the Microsoft school agreement. Thus there would be preferred hardware and software suppliers from which schools could purchase necessary equipment at discounted rates.

In addition, the independent schools, who arranged for their own training and policy development, might also benefit from guidance from the DoE, or alternatively they could provide help to the DoE in determining appropriate guidance as they have already made attempts and will be able to use the lessons that they learnt to help the DoE.

### 5.5.5 Time constraints

The issues of time constraints, especially for the IT teacher was mentioned in 22 comments by the interviewees (Figure 5.5), in particular the workload (45 % of the total time constraint comments), which relates back to the comments made by the IT teachers in section 5.3.2. The limitations due to work load on the IT teachers (also referred to as Champion teachers) is an important constraint that schools will face. In cases where the workload is just too much schools will need to consider seriously hiring additional staff. An example of an IT teacher who was experiencing a high workload was at IS2, where the work that she was expected to do included, Director of IT at the school, systems administrator, network administrator and a full teaching load. Often due to this work load the IT teachers were unable to learn new things and improve their skills as there was just no time for self-development. The school council at IS2 had thankfully realised this and one month after the interview with the IT teacher at IS2 the school hired a network and system administrator to help her with the work load, thus leaving her free to teach and direct ICT integration into teaching and learning at the school.

In addition other staff members experienced time constraints in terms of having to learn how to use computers, either literacy or computer integration, while still carrying their regular teaching load. Often it was this burden of having to learn something new while still maintaining their regular work load that prevented teachers from learning to become ICT literate and thus they were unable to integrate the use thereof into their teaching.

### 5.5.6 Training

In a number of the secondary schools, FMC1, FMC2, FMC3, FHOR, FDET4, FDET5 and FDET6, in the Grahamstown Circuit there seemed to be a general lack of training amongst teachers (Figure 5.5). Nine IT teachers complained that when they had run courses at the school for in-house training, few, if any, of the teachers had attended them. The IT teacher from FMC3 commented, "*Ja, well, we have actually offered courses ourselves, here at the school. [TeacherA] is in charge of staff training and so he has offered courses to the staff, but they weren't that well attended. And I think attended by some of the wrong people. One or two who should have been there came along but the rest couldn't be bothered and haven't tried. So some of it is technophobic and so they don't want to get involved, they would rather see it on a piece of paper.*" Three of the IT teachers interviewed stressed that if there was no directive from above, either the DoE, school principal or School Governing Body, that teachers were less likely to attend and take the need for courses seriously. The IT teacher at IS2 commented, "*... And for staff training to happen you have got to have support from your headmaster and the upper echelons of your school.*"

Three of the IT teachers stressed the importance of teacher training and how ICT integration in schools would never take place without it.

### 5.5.7 Recommendations

A large number of the limitations and constraints seemed to be as a result of a general lack of ICT policy within the secondary schools in the Grahamstown Circuit. With proper ICT policies in place at a national, provincial and local government level it may be possible to curb some of the associated high costs of ICT infrastructure that schools experience. For example, if the e-rate were to be implemented by policy from a national level, schools would be able to enjoy cheaper Internet connectivity. Alternatively, if the national Department of Education implemented policy for a national school education network, schools would also enjoy cheaper Internet connectivity through the buying power of forming purchasing consortia, as the universities do with TENET. In addition, with proper ICT policies in place on a national, provincial and local government level schools would be able to enjoy better support from the DoE.

ICT policies within each of the schools would help to direct and govern the use of and integration of ICT in the specific schools. School leaders and teachers would know what is expected of them and would attend training, both in-house and those organised by the Department of Education, in order to become firstly ICT-literate and secondly, learn how to use ICT tools to support and scaffold their individual teaching methods. In addition, with more teachers and administrative staff trained there would be less of a burden on the IT teacher as they would firstly not be the only member of staff who is ICT literate, nor would they have to worry about teachers breaking ICT infrastructure due to a lack of literacy. Thus more courses were needed for teachers to learn both literacy and how to integrate the use of ICTs into their teaching. Furthermore, school management would understand the pressures of running ICT infrastructure and would best be able to support their IT teachers (and or directors) and hopefully make provision for either additional staff or outsourcing avenues to help them with the workload.

## 5.6 Conclusion

There are a number of challenges, limitations and constraints in providing ICT facilities in schools, from the limited knowledge of IT teachers about their infrastructure and how it works, to the lack of policy in schools and lack of support from the Department of Education. Of those challenges it is interesting to note that some of them are in line with what was found in other research projects, such as the findings of Pelgrum [131] which were discussed in Chapter 3.

While an attempt has been made to highlight all these issues in each of the sections discussed, only that information which is pertinent to ICT networking will be expanded upon in the following chapters as this is the main focus of this study. However, it is important to know that while it is possible to build the perfect network for the Grahamstown schools and provide them with the best quality ICT equipment, neither would be of any consequence until these additional organisational issues are resolved.

# Chapter 6

# Grahamstown Circuit network deployments

## 6.1 Introduction

In parallel with the survey of ICT needs of Grahamstown schools that was discussed in Chapter 5, the study involved Internet network deployment to some of the schools in Grahamstown. While the survey tried to establish what the needs were of the schools, the network deployments tried to establish which network technologies could be employed to meet those needs.

This was achieved through several methods, namely, a 'desktop survey' of possible network technologies, network deployments, and laboratory testing. The details of the 'desktop survey' were presented in chapter 2 and helped ground the network deployment and laboratory testing decisions made. The network deployments were carried out using DSL and 802.11 technologies and have been part of a large action research project that has been undertaken by the Telkom Centre of Excellence (CoE) in the Computer Science department at Rhodes University. The DSL deployments, which were the initial phase of the action research, were undertaken before the commencement of this study, but are reported here due to the impact which they had on building the 802.11 wireless network. Furthermore, it was during my study that the latency, speed and reliability of those networks were formally tested. The 802.11 wireless network deployment, which forms the intermediate cycle of the action research project, was undertaken during the course of my study and is therefore thoroughly reported on. The laboratory tests were conducted in order to obtain a more thorough understanding of some of the networking technologies that might be considered for the peri-urban Grahamstown schools, as well as to possibly guide the future cycles of this action research project.

This chapter begins by discussing the network deployments to some of the secondary schools that were undertaken in the Grahamstown Circuit and the results that were seen from these deployments. The chapter also discuss our findings along the way and what we learnt from various stages of the network deployments. Alternative network solutions for the Grahamstown Circuit are then discussed. While these alternatives were not deployed to schools in the town, it was possible to do preliminary laboratory testing on the networks for purposes of comparison with that which was deployed, as well as in an attempt to look at alternatives for the future.

## 6.2 A DSL network

This section discusses one of the network deployments that was undertaken by the CoE. The work done by the CoE is part of a large action research project, of which my project formed a contributing cycle. The initial cycle was the deployment of a DSL network to three of the Grahamstown Circuit schools.

### 6.2.1 DSL deployment

In the Computer Science Department and the CoE the use of Digital Subscriber Line networks has been investigated since as early as 1998. Some of the projects that have involved the use of DSL networks include Bandwidth Management and Monitoring for IP Network Traffic [207], and Digital Video Broadcast via Asymmetric Digital Subscriber Lines [208]. As a result of this research the knowledge about DSL networks grew within the CoE. Together with the desire to use broadband technologies, the choice was made to extend the CoE DSL network to previously disadvantaged schools in the Grahamstown Circuit when approached for help.

Three of the Grahamstown Circuit schools, one high school (FDET3) and two primary schools have had ADSL Internet connections donated their schools. FDET3 and one of the primary schools were connected during the course of 2002 and the remaining primary school was connected in 2004. From the testimony of the IT teacher at FDET3 we know that after the school had won the sixteen new computers in the Global Teenager Project, the CoE was approached to help them with an Internet connection. Telkom was commissioned to install an outdoor extension from the university to the school. This line terminates in a DSLAM that is located in the CoE technical area. From the DSLAM traffic is routed to the Internet with all other Rhodes-generated traffic. The CoE makes use of a Paradyne Hotwire 8610 DSLAM chassis [209], with a Paradyne Hotwire 8000 management card [210] and Paradyne Hotwire 8373 RADSL [211] and 8312 ReachDSL port cards [212]. FDET3 is connected to a 8373 RADSL port card. At this school a Hotwire 6371 RADSL RTU [213] was installed at their end of the outdoor extension. This in turn is connected to a server. The server also acts as a router for the school, routing all Internet traffic back to the Rhodes network. Using NAT, or Network Address Translation (also known as IPMasq/ICS) the server is able to make all traffic originating from the computers on the school's LAN appear to originate from a single IP address allocated by Rhodes University to the server [195, 214]. The two primary schools are similarly configured to that of FDET3.

Each of the schools with DSL to the Rhodes campus is within 5 km of the university. However, not all of the Grahamstown Circuit schools are within 5 km of the university, especially the previously disadvantaged schools which are predominantly found in Grahamstown East. For those schools which are further than 5 km from the university, DSL cannot be used as it has a maximum distance limit of 5 km [17]. In the case of FDET4, the school currently has an Internet connection through what is termed a "dial-dedicated" line [195]. This is a leased line from Telkom that has been connected to the Rhodes PBX system. The result is effectively a 56 Kbps dial-up line with no call charges – only a fixed monthly rental for the line [195]. Several attempts have been made to establish a DSL link to FDET4, but it is simply too far away from Rhodes to allow this to work at all [195]. Even modern technologies such as ReachDSL equipment [215], which is designed specifically for long, poor quality lines, fail to negotiate a stable link over the line to FDET4 [195].

Other solutions (or network technologies) have to be used to connect the other previously disadvantaged schools which are beyond the reach (or range) of DSL. During 2003 it was decided to find a wireless alternative, as other wired alternatives, such as fibre optics, tended to be expensive options, while PLC technology was still immature, expensive technology [24] and difficult to deploy without the assistance of the municipality.

### 6.2.2 DSL network results

Both the ping and the transfer tests, as described in chapter 4, were run for the period of one week over the DSL line from Rhodes University campus to FDET3. The results of the ping tests, seen in Figure 6.1,

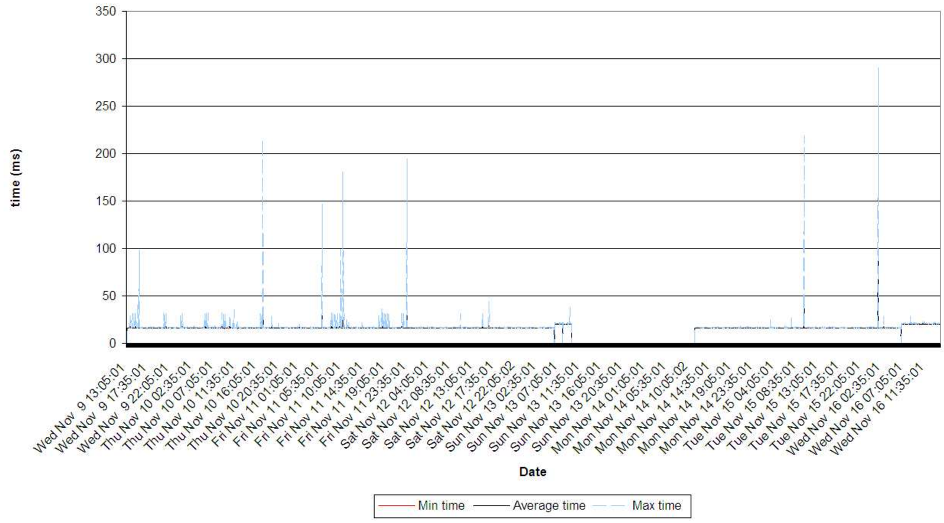


Figure 6.1: Ping test from Rhodes University campus to the router at FDET3 over the DSL line.

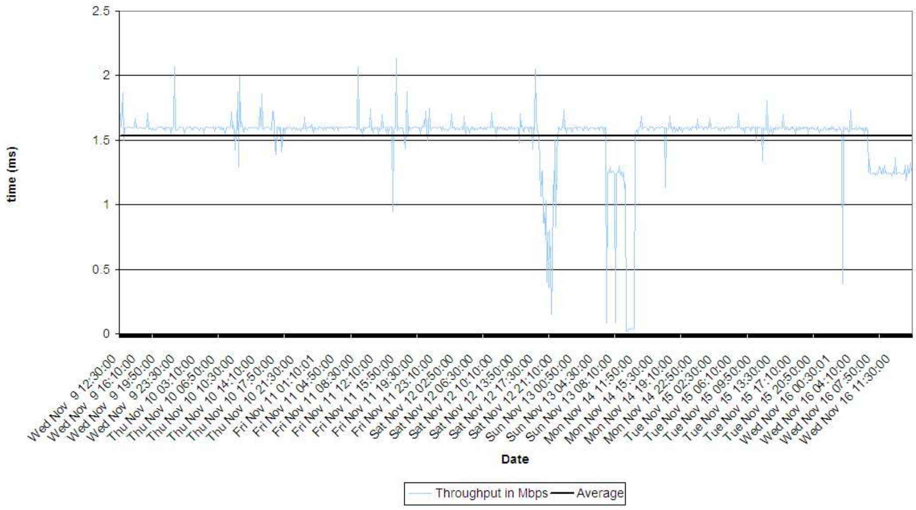


Figure 6.2: Throughput from Rhodes University campus to the router at FDET3 over DSL.

indicate that the average round trip time was never more than 100 ms, with the highest round trip time being slightly short of 300 ms. This indicates that the DSL line has a low latency and is generally reliable. A noticeable gap in the graph was caused by a power failure at the school, during which time no results were recorded.

The results of the throughput tests, seen in Figure 6.2, show that the school experienced a fairly consistent throughput rate of approximately 1.5 Mbps. The DSL RTU negotiated data rates of between 2.5 Mbps and 1.9 Mbps (see Figure 6.3), while the effective throughput achieved was approximately 1.5 Mbps. This discrepancy could be due to framing and packet overhead as well as occasional packet loss. Similar gaps in the graph were caused by the power failure.

The experiments at FDET3 indicate that DSL offers a good quality last mile connection to schools, with low latency and good reliability. Furthermore, the network connection provided broadband data rates (seen in Figure 6.4). The throughput tests that I ran over the last few weeks more than doubled the average amount of data transferred over the DSL line.

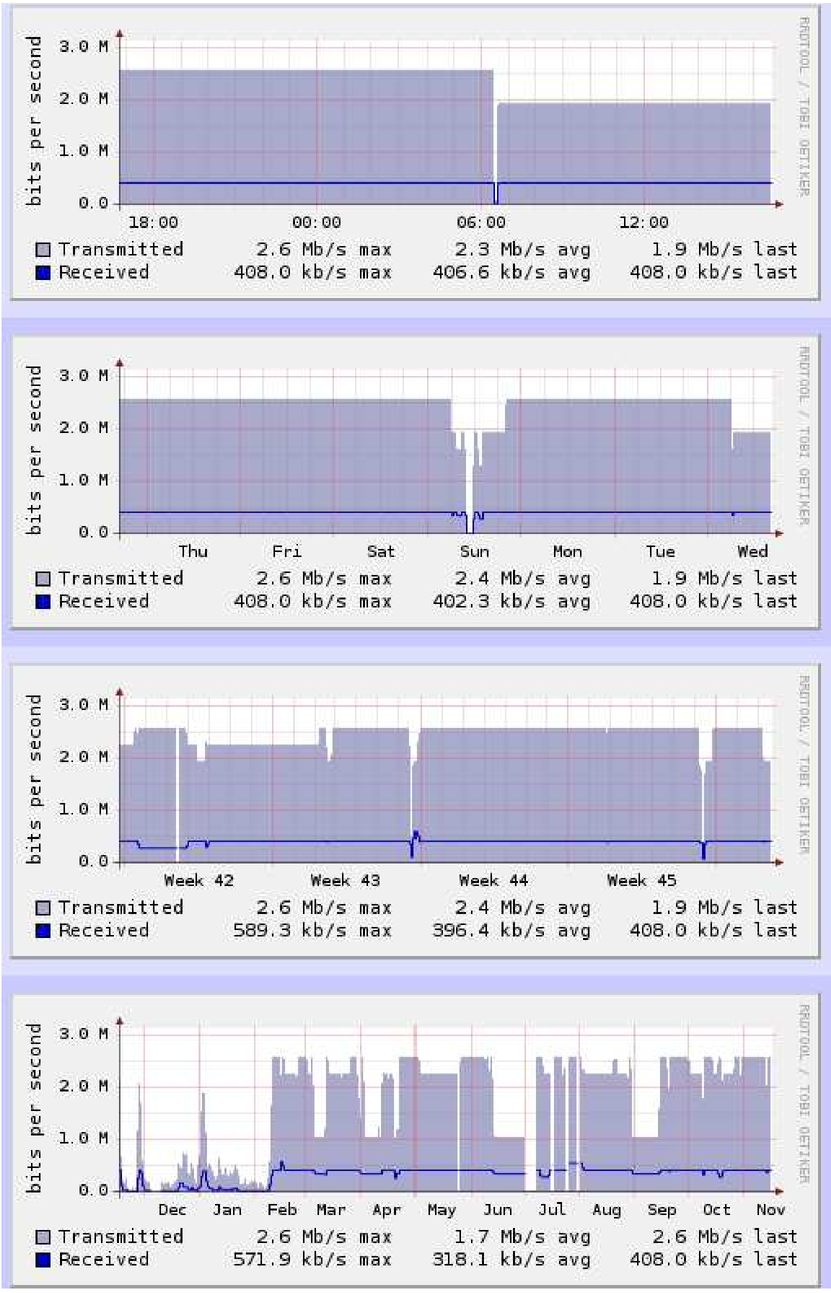


Figure 6.3: Line speed of the DSL line from Rhodes University to FDET3.

The first graph indicates the last 24 hours; the second, the last week; the third, the last 4 weeks; and the finally, the last year.

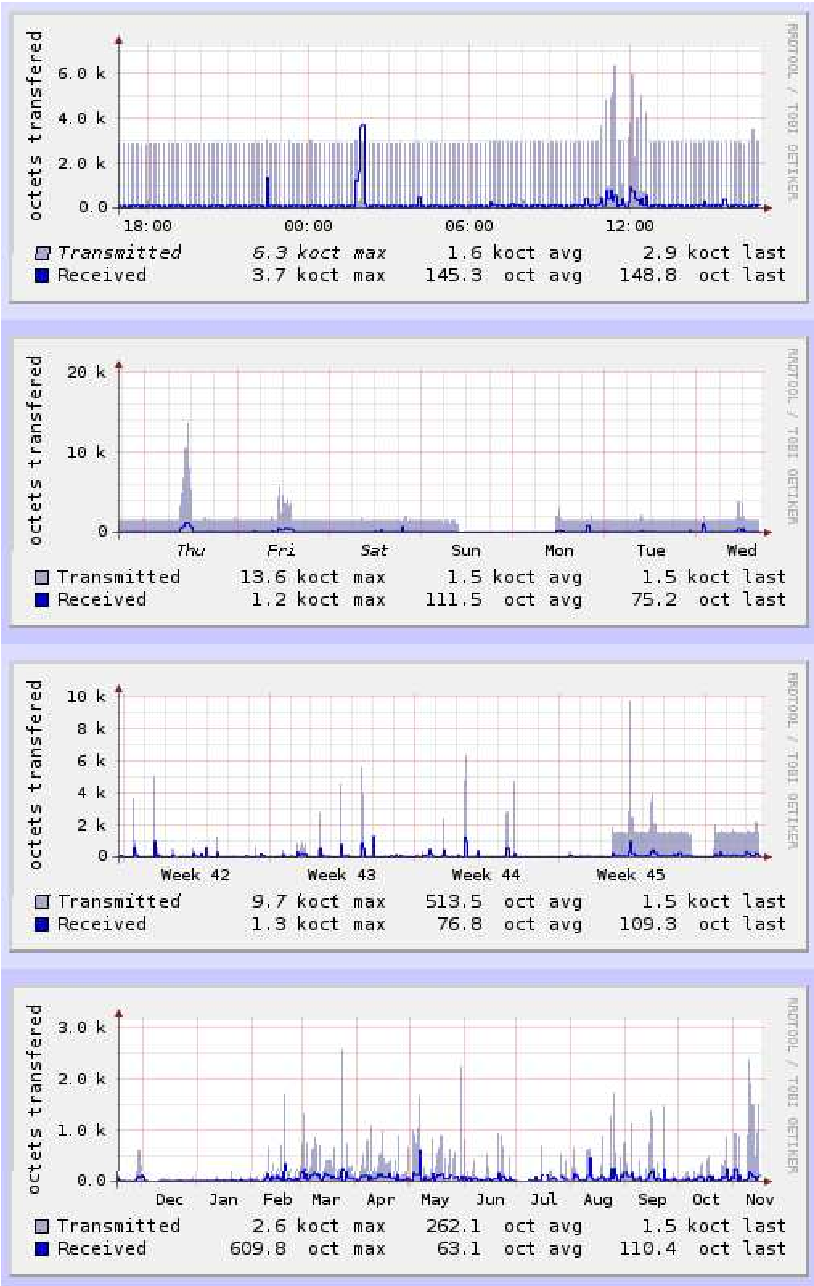


Figure 6.4: Total traffic over the FDET3 DSL line.

The first graph indicates the traffic in the last 24 hours; the second, the last week; the third, the last 4 weeks; and the finally, the last year.

| Service | Cost |
|---|---|
| Installation | R404 |
| Monthly Rental | R270 |
| DSL RTU | R800 |
| ISP Services | R199 |

Table 6.1: Telkom cost for a 192 Kbps DSL connection.

Using only the cheapest offerings and assuming that the customer only uses products sold by Telkom.

### 6.2.3 Maintenance and cost

The maintenance of a DSL Internet connection is relatively simple. Generally, off the shelf DSL RTUs (Network Terminating Unit (NTU)) can be plugged into the DSL line and will just work. In addition is it also possible to contact the service provider for help in configuring the DSL RTU to work properly for the connection. The only maintenance problem that should be borne in mind is that a DSL connection is an "always on" connection to the Internet when the computer is switched on. Thus is it important that the computers connected to this "always on" connection are protected by a firewall and anti-virus software. Schools should also note that while their service provider will be available for maintenance on their Internet connection, they will be charged unless a contract has been entered into, but at no point will those service providers necessarily be responsible for maintenance of the computers on the school network, unless specifically contracted to do so.

Currently, in South Africa, the only fixed line provider is Telkom. The cheapest Telkom DSL product on the market is the 192 Kbps, which this is specifically targeted at the home owner. However, for comparison's sake the cheapest services will be considered. Considering Table 6.1, it can be seen that if a school were to use Telkom as their service provider for all the necessary infrastructure on a DSL line, then the total installation cost for the school would be R1204, while the monthly rental rates will be around R469. The total cost per annum for the DSL 192 Kbps product for 2005 would be R5628. This is the cheapest Telkom DSL product for 2005. Schools wishing to have higher data rates with greater caps will pay more than this base rate. These figures are for 2005 and are subject to change in subsequent years [216].

## 6.3 An 802.11 network

This section discusses the second network deployment undertaken by the CoE and myself. This work formed the second major cycle in the action research project within the CoE and involved the deployment of a wireless network.

### 6.3.1 Preliminary network planning

In Grahamstown, approximately one third of the secondary schools, including many of the poorest schools, are beyond the range of DSL. They all have at least one phone line for conducting school administration, but usually cannot afford to have a second line installed for dial-up Internet access, let alone other more expensive options that Telkom can provide. For this reason, wireless connectivity is a very attractive solution.

The CoE has been investigating the use of IEEE 802.11b- and 802.11g-based wireless LAN technologies as a means of connecting these schools to the university and thus to the rest of the Internet, since 2003 [85]. This was the beginning of my cycle within the larger action research. A general evaluation into the viability

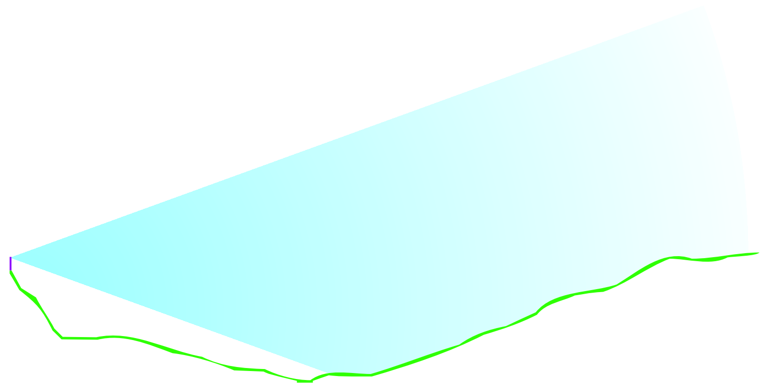

Figure 6.5: 8dB broadcast pattern superimposed on deployment area.

of a wireless network to connect the schools to the university was performed by Bradley Whittington as a Computer Science Honours project [85]. The initial findings were positive and thus a more extensive study into the implementation and improvement of the network was conducted in this study. During feasibility testing it was decided to use IEEE 802.11 wireless technology as it was an easily available technology, cheap, standardised, well documented and easy to deploy [85].

The initial wireless network design and deployments were undertaken by Whittington in his study during 2003 [85]. While building the network, the initial problem area was to provide access to the network from as much of Grahamstown as possible. For this, two methods were considered: firstly, to spread as many Access Points (APs) across the town so that a maximum number of clients could connect; or secondly, to carefully place one AP so as to offer the best possible coverage to as much of Grahamstown as possible. For a cross-section of Grahamstown see Figure 6.5. The latter option was chosen as the former is resource intensive. Furthermore, the university does not have access to the large number of high points around town that would be necessary to make the former viable. Thus the goal was to deploy a single access point, aiming to maximise coverage, and minimise resource use [85]. The equipment requirements of the network were then considered. During the preliminary testing, a Symbol Spectrum24 4121 was used. The Spectrum24 4121 predates .11g and thus supports .11b data rates up to 11 Mbps, and is capable of a maximum radio power output of 100 mW.

An appropriate antenna needed to be chosen for the single AP. Directional antennas would clearly be unsuitable for an AP which was to communicate with clients in many different directions. Consequently an 8 dB vertically-polarised omni-directional antenna which had previously been used for an in-building WLAN was selected as it provided 360° lateral coverage and 15° vertical coverage. This could radiate signal to most parts of Grahamstown West (see Figure 6.5) [85]. Thus the AP's standard 2 - 3 dB antennas were replaced with an 8 dB omni-directional antenna. After surveying the deployment area it was found the 1820 Settlers Monument suited the needs of the network almost ideally. The Monument stands approximately 620 m above sea-level (much higher than the buildings in the town) and is situated on the south western hills, relative to the centre of Grahamstown West. An existing ADSL line to the Monument made an ideal backhaul link. Unfortunately the point at which the RADSL router could be deployed, as well as the gateway server, was approximately 80 m away from the corner of the building that had been identified for the antenna and AP [85]. Mains power was not available on the corner of the building so power was supplied using Power over Ethernet (PoE) [217] on the Ethernet link to the server room where the RADSL RTU and access router were situated.

The high gain antenna and AP were chosen in order to try to boost the signal so that clients further than 100 m could associate. 100 m is generally the maximum distance that a wireless client can be away from the AP and still associate. Some schools which are the main target of the network, are as far as eight or nine kilometres away. Initial tests were conducted with a commercial flat panel antenna (19 dB gain, 18° beam width), connected to a notebook computer, from Sugar Loaf Hill (a distance of 3.2 km from the Monument). The results indicated that transfer rates in excess of 4 Mbps from Sugar Loaf Hill were sustained and more surprisingly from FDET4, on Makana's Kop (a distance of 4.8 km). This would mean that surrounding schools could share a connection of 4 Mbps [85].

As a result of positive initial tests, more permanent infrastructure was put in place. Thus instead of driving around with an antenna and computer, we installed 12 dB directional antennae connected to wireless Ethernet bridges at client sites, mostly within Grahamstown West. Using this configuration, we have been able to achieve data transfer rates in the region of 2 - 2.8 Mbps at distances of about 2 to 3 km with the original 802.11b equipment. Using a higher gain (22 dB) directional antenna, we have been able to associate with the AP at 5 km.

When deploying clients at various sites within the town, care was taken by Whittington, to make sure that those sites were not prone to signal degradation through obstacles in the line of sight to the AP, as well as attempting to reduce the amount of Fresnel diffraction [85]. In addition a small scale survey of the town was performed in order to choose the optimal channel to operate in, so as to avoid signal degradation through signal overlap with other APs that might be in the town [85].

During the course of this study, a repeater station was built on top of the water tower in the grounds of FDET4. The water tower stands approximately 700 m above sea level. This was done as schools in Grahamstown East do not have direct line of sight to the Monument. However, there is clear line of sight from the top of the water tower at FDET4, as well as a clear line of sight to the schools in Grahamstown East, thus schools can access the Monument AP via the repeater station. Initially this repeater station consisted of two D-Link APs namely, DWL-1000 and DWL-900. These were later replaced with DWL-2100AP+ APs, one of which was configured in bridging mode, while the other operated as a standard AP in order to cover Grahamstown East. Both APs are capable of both 802.11b and 802.11g modes, with a maximum transmission power of 63 mW. A 22 dB directional antenna was connected to the bridge and aimed at the onmi-directional antenna installed at the Monument on the south-western side of Grahamstown West. The water tower AP's factory fitted antenna was replaced with an 8 dB omni-directional antenna of the same type used at the Monument. Since mains electricity is not available at the top of the water tower, all the equipment is powered by solar panels, backed up by 12 v rechargeable batteries.

Clients at the schools in Grahamstown East were similar to those that were deployed in Grahamstown West and were able to associate with the AP on the water tower and have their traffic forwarded back to the Monument's AP and then onto Rhodes via the DSL line that connects the 1820 Settlers Monument to the university.

### Network security

Access controls exist to prevent unauthorised access to a network and its resources. Implementing access control in the wireless environment presents a challenge, due to its shared medium which has a non-discrete coverage area. The nature of wireless communications is that there are no observable boundaries of the LAN. For this reason, security of a wireless network is more complicated than that of a wired network. For our wireless network a number of access methods were considered in order to secure the network: the Wired Equivalency Protocol (WEP) which was standardised with IEEE 802.11, Point to Point Protocol over Ethernet (PPPoE), IEEE 802.1x, and IPSEC [85]. We needed an encryption layer that prevents eavesdropping and unauthorised access to the network. The standard Wired Equivalent Privacy (WEP) encryption algorithm was not used as it has been found to be substantially flawed [218]. The current standard, Wi-Fi Protected

Access (WPA) [219], had not been finalised at the time when the network was first set up and IEEE 802.1x was minimally supported at the time. Instead, Microsoft Point-To-Point Encryption (MPPE) Protocol was used to encrypt [220] Point to Point Protocol over Ethernet [221] (PPPoE) tunnels that were established between routers at the client sites and an access router situated at the Monument over the wireless Ethernet network. All traffic between clients and the Internet is routed through the tunnels.

### 6.3.2 Symbol 802.11b AP

Various factors were tested during the initial phase of testing by Whittington, and these included cable length, range tests, and data throughput [85] and this section discusses his findings as they were important to later work conducted in my study.

The effect of the length of the cable between the antenna and the 802.11 radio was tested. Initially, a six metre length of RG58 cable connected the radio and antenna, which was progressively shortened, while graphing signal strength after each metre was removed. It was found that each metre of RG58 cable between the antenna and radio decreases SNR (Signal to Noise Ratio) by about 1 dBm [85]. As a result, the cable length at all client sites is kept as short as possible, preferably two metres or less.

In order to test the effectiveness of different antennas, the effects that a ~12 dB gain homemade antenna, a commercial 13 dB gain Yagi antenna, a 18 dB gain flat panel antenna, and a 22 dB gain parabolic dish had on the reception range of wireless connectivity were tested [85]. The impact of antenna selection was tested by visiting two test sites, and recording the position and distance from the AP, as well as signal strength for each of the antennas [85]. Further testing was done to document the effect, if any, of sustained data transfer on the signal strength of the antenna [85]. These tests were conducted at three sites. Site A was 990 metres from the base site, while site B was 3.2 km away, and site C was 4.9 km away [85]. The results from all three sites confirmed that best results were achieved with the parabolic dish, while the worst were seen with the flat-panel antenna [85]. In addition, problems were encountered when using the homemade antenna due to faulty construction, which hindered the range testing of the antenna. This problem highlighted the drawbacks of using a home-constructed antenna. Without professional manufacturing tools there are limits to the quality control that can be imposed upon such a construction [85]. As a result, client sites either make use of a 12 dB Yagi or a 22 dB parabolic or grid dish.

Two aspects of data throughput were tested, short and long term sustained data transfer [85]. For the purpose of experimentation a ~12 dB homemade antenna was set-up at site A with with the intention of doing multiple sustained data transfers. Site A was chosen as it provided secure access, and allowed for a homemade antenna to be used for internal data transfers [85]. Site C was chosen for short term transfers as a long distance, proof of concept test bed. Unfortunately at the time it could not offer secure access. For data transfer testing, a commercial Yagi antenna and a commercial flat panel antenna were used. A file transfer over an encrypted PPPoE [221] tunnel was used to gauge data transfer speeds. At site A numerous transfers of 600 MB were done, while at site C a 100MB file was transferred using each of the antennas [85]. At site A tests were conducted at random intervals to reflect real world network usage and throughput rates were recorded. Sustained transfer rates varied from as low as 200 KBps to a maximum transfer rate of 619.8 KBps shown in Figure 6.6 (which corresponds to approximately 5 Mbps of bandwidth usage) attained once in the week-long period [85].

Tests at site C were conducted, initially, using the Yagi antenna. It was found that the wireless interface sporadically received at 11 Mbps, 5 Mbps, and a 2 Mbps data rates, but remained at 1 Mbps for the majority of the time. The graph (Figure 6.7) for the Yagi antenna shows a connection speed of 100 KBps (0.8 Mbps) which steadily decreased until the transfer ended [85]. The second set of tests was conducted using the flat panel antenna and showed a sustained, high-speed connection depicted in Figure 6.8. The transfer peaked

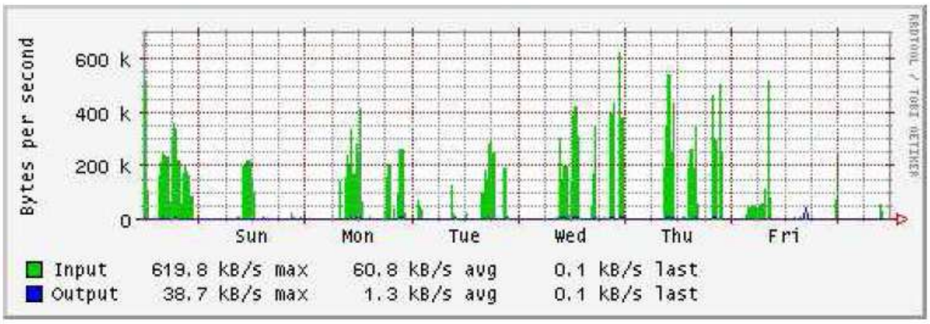


Figure 6.6: Data throughput using a homemade antenna.

Covering a distance of 990m using the Symbol AP with .11b data rates, from [85].


Figure 6.7: Data throughput using a yagi antenna.

Covering a distance of 4900m using the Symbol AP with .11b data rates, from [85].

initially at 365 Kbps (2.92 Mbps), with an average of 345 Kbps (2.76 Mbps). The promising data rates suggested that using a correctly aligned high gain antenna would show a higher transfer rate [85].

### 6.3.3 D-Link 802.11g only AP

Based on the positive results seen in the work done by Whittington, it was decided to increase the available bandwidth of the network and thus experiment with the 802.11g standard. I, together with a team of interested CoE colleagues, replaced the Symbol access point at the Monument with a D-Link AP (DWL-2100AP+). We also replaced all the client bridges with newer, 802.11g compatible models. While experimenting with the 802.11g standard, we began to notice decreased signal strength, slower transfer rates, increased delay and increased packet loss between the AP on the Monument and the clients in Grahamstown West.

The results of experiments using the 802.11g protocol were peculiar when compared to the previous results achieved when implementing 802.11b with the Symbol AP. During this testing phase we once again

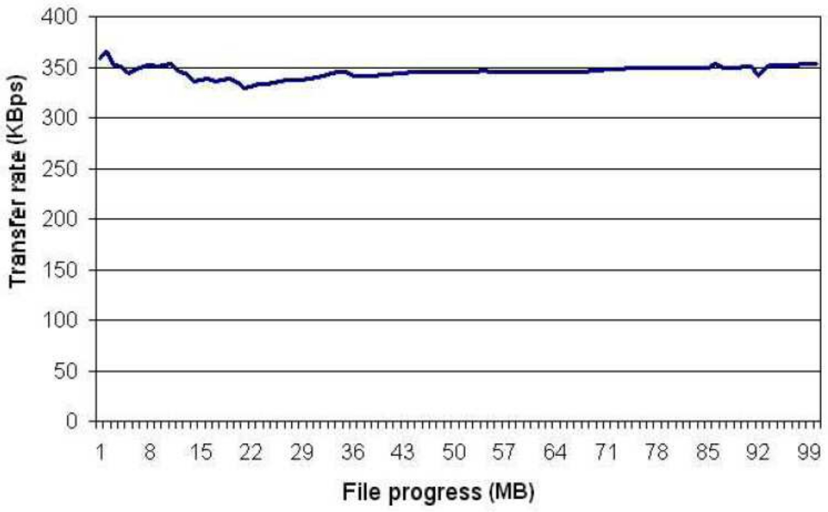


Figure 6.8: Data throughput using a flat panel antenna.

Covering a distance of 4900m using the Symbol AP with .11b data rates, from [85].

made use of site D, and the original site C – the water tower on the grounds of school FDET4. Site D is the home of a colleague in the Computer Science Department and is approximately 1.2 - 1.5 km away from the Monument. Initial tests performed by Whittington at site C had been promising, especially with the use of high gain directional antennas and it was hoped that these could be improved upon with the use of the newer 802.11g protocol. Considering Figure 6.9, we note an increase in the erratic nature of the throughput, as well as a marked decrease in the average throughput. This decrease in throughput took place on the Friday afternoon, which can probably be attributed to the fact that on weekends the network was frequently used compared to week days. This highlights the problem of the blind client or hidden node (HN). The "hidden node" effect is caused by clients being prevented from detecting carrier use, due to the use of directional antennas. Only the access point can receive traffic from all clients; clients of the access point are unaware of traffic destined for the access point originating from other clients [85].

This phenomenon, in which the mutual interference of nodes outside the carrier-sensing range of each other, may increase the packet-collision rate significantly is well-known in 802.11 networks [222]. A link with sender node A and receiver node B is said to suffer from HN if the data exchange in this link fails because A did not sense the ongoing data exchange of another interfering link before initiating its transmission, or A cannot be sensed by the sender of another interfering link after A has initiated its transmission [222]. A network is said to suffer from HN if any of its link suffers from HN [222]. HN arises fundamentally as a result of the 802.11 protocol constraints and gives rise to many performance problems, including throughput degradation, unfair throughput distribution, and throughput instability [222]. There are a number of proposed methods for removing hidden node problems from wireless networks. These methods include a new method of network design called "Hidden-node Free Design" (HFD) [222], use of collision avoidance schemes [223] and various software applications such as Frottle [224]. Due to time constraints I was not able to implement any of these methods, but provided they were implemented correctly it is possible that they would help to alleviate those problems caused by hidden nodes on the network. A diagram of the hidden node effect in the Grahamstown wireless network can be seen in Figure 6.10.

On one particular occasion (seen in Figure 6.9), one of the other clients (who was not being monitored for testing purposes) was uploading large video files to campus and all other clients on the network experienced

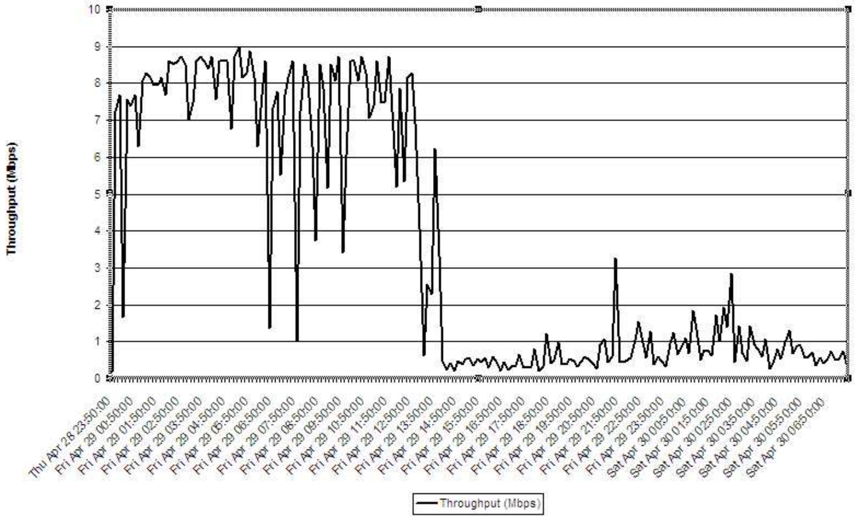


Figure 6.9: Throughput at site D using the D-Link equipment with 802.11g data rates.

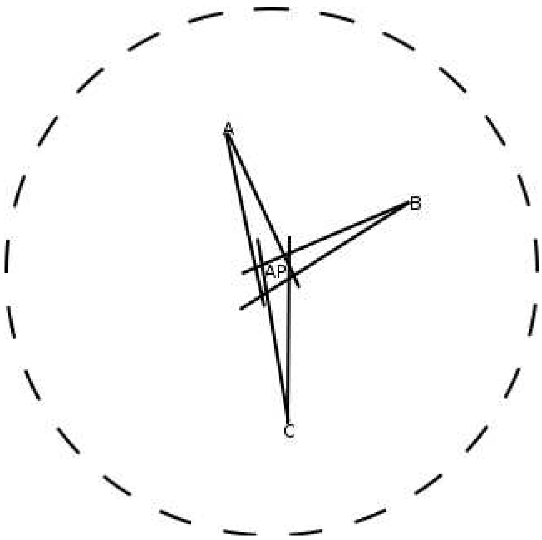


Figure 6.10: The hidden node effect in Grahamstown.

Each of the clients communicates with the parent AP using a directional antenna and cannot detect other traffic on the shared medium being generated by nearby clients also communicating with the parent AP.

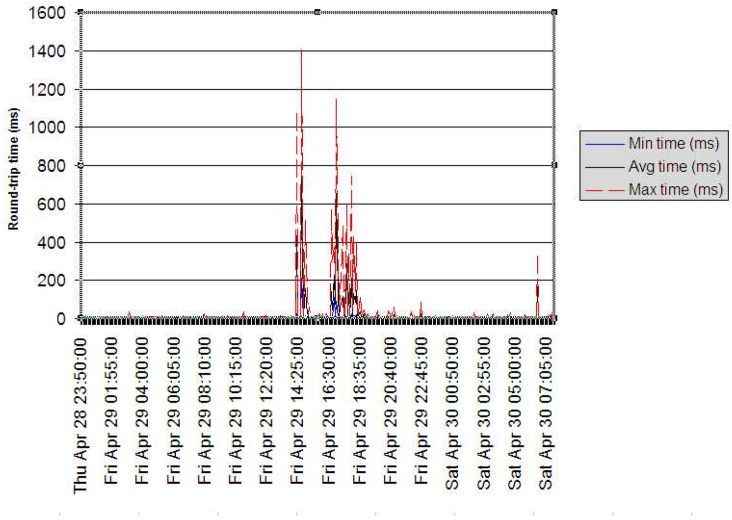


Figure 6.11: Ping test at site A using the D-Link equipment with 802.11g data rates.

a massive decrease in speed, latency and reliability on the network, as their 802.11 interfaces were unable to detect that the other client was using the shared medium extensively. At the same time, considering Figure 6.11, one can clearly see that the latency and reliability of the network were affected over the weekend period.

More interesting results were seen when testing the link between the water tower at FDET4 and the Monument AP. At the time of the testing none of the schools were connected to the repeater in Grahamstown East and therefore it was not possible to conduct throughput tests from the Rhodes network to machines connected to the wireless network on the far side of the repeater station. We could however conduct the ping tests against the AP itself. From Figure 6.12 one can clearly see that none of the ping packets were returned and there was a 100% loss of data. In addition to data loss on this link, a number of the clients in Grahamstown West complained of an increase in the latency of the network as well as a decrease in the reliability and speed. Many also experienced occasional disconnections from the network. As a result of both of these problems, we initially felt that the problems may have been caused by an incorrect implementation of the 802.11g protocol. In order to rule this out, we decided to run the network in 802.11g mode that would degrade to 802.11b should the network be unable to operate correctly in the 802.11g mode.

### 6.3.4 D-Link in 802.11g and 802.11b mode

In order to rule out bad implementation of the 802.11g protocol we ran additional experiments with the APs configured to the 802.11g standard that degrades to the 802.11g standard when conditions were inappropriate for 802.11g, but noticed the same degradation in the signal thus concluding that bad implementation of the protocol was not the cause of the network degradation.

The bridge at the water tower received a very weak signal from the Monument AP, whether the Monument AP was operating in 802.11b or 802.11g mode. The bridge was able to establish an 802.11 layer two association, but the signal was too weak for complete IP packets to be transferred from one to the other. It can be seen in Figure 6.12 that there was a 100% packet loss rate when pinging the water tower bridge in 802.11b mode. The same results were seen when trying to ping the water tower AP, on the far side of the bridge and also when using the 802.11g standard.

From the top of the water tower we received beacons from a number of different 802.11 networks within Grahamstown West. Five of these beacons belonged to non-Rhodes networks. From this we deduced that

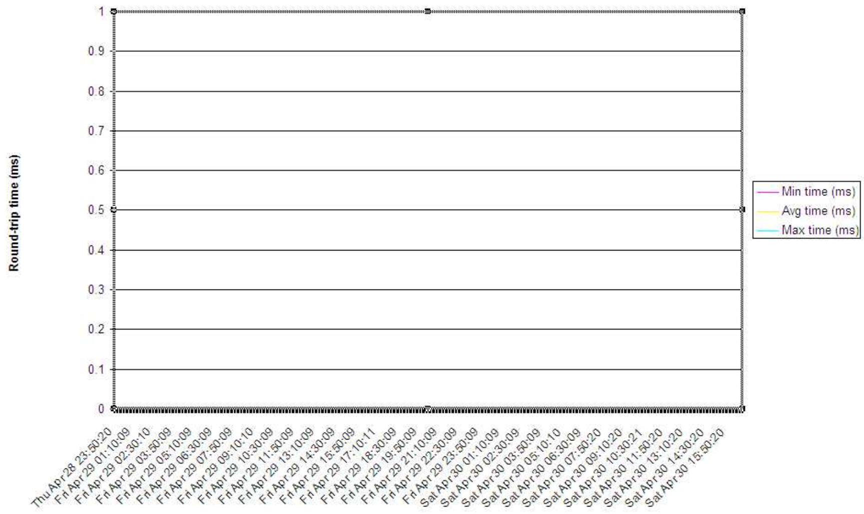


Figure 6.12: Ping test results from the Monument to the water tower AP.

Operating in a bridge configuration, using the D-Link equipment with 802.11g data rates – 100% data loss.

the amount of interference had increased substantially within the town, as these beacons were not detected during the initial tests of the network in late 2003. This interference coupled with the weaker signal output from the AP (100 mW vs 63 mW), as well as a omni-to-directional link (directional to directional would be less susceptible to interference) resulted in signal strength degradation beyond usability.

If one considers Figure 6.13, it can be seen that the network throughput seems to be more erratic than it was before. While the average throughput here is higher than it had been in previous tests, 2.7 Mbps, the network was extremely intermittent to the point that users felt it was extremely frustrating to use. In Figure 6.14 we can again see high values of latency, indicating an unreliable network with packet loss. This is especially clear in Figure 6.15 where there is still 100% packet loss.

In order to try to assess what was causing such degradation in the network, we attempted to eliminate possible causes. The first possibility was that the directional antenna at the water tower could have become misaligned – possibly due to high winds or human tampering. An inspection of the site showed that the problem was not the antenna alignment, as no slight adjustments could improve reception. We found that the bridge was able to make an association with the AP at the Monument on layers one and two of the IEEE 802.11 protocol, but at layer three, IP traffic was unable to get through. In addition, while trying to associate with the Monument AP from the water tower we discovered a number of wireless AP beacons, five of which did not originate from networks belonging to Rhodes University, but rather to networks run by local people in the town. These were either from ISPs operating as Wireless ISPs (WISPs) or from wireless networks in people's homes or offices. Figure 6.16 shows the results of a scan for beacons run from the water tower bridge. The increase in the number of wireless networks within the town was contributing to increased interference in our wireless network, which explained the degradation in the network performance that was experienced.

In addition to increased interference in the town it is also possible that the link between the Monument and the water tower was experiencing additional interference due to Fresnel Diffraction [225, 226]. In radio communications, a Fresnel Zone, named after the physicist Augustin-Jean Fresnel, is one of a (theoretically infinite) number of a concentric ellipsoids of revolution which define volumes in the radiation pattern of a generally circular aperture. Fresnel Zones result from diffraction by the circular aperture. The cross

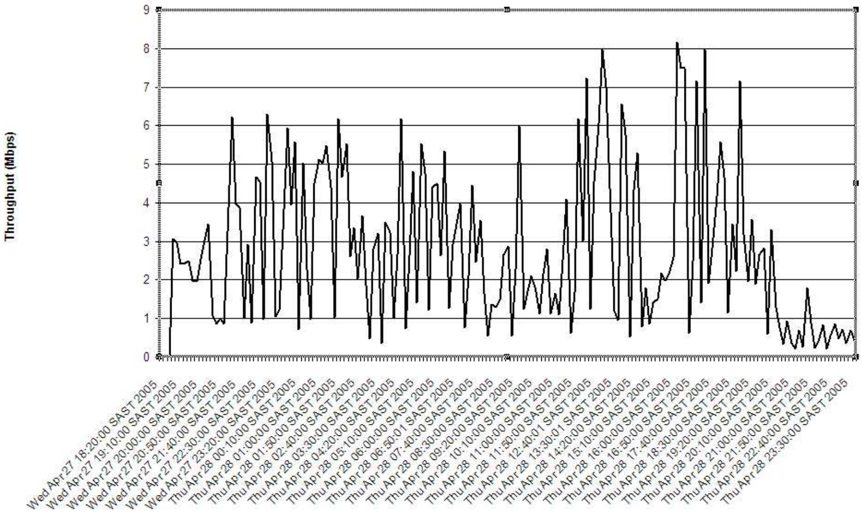


Figure 6.13: Throughput of site D using the D-Link equipment running in both 802.11g and 802.11b data rates.

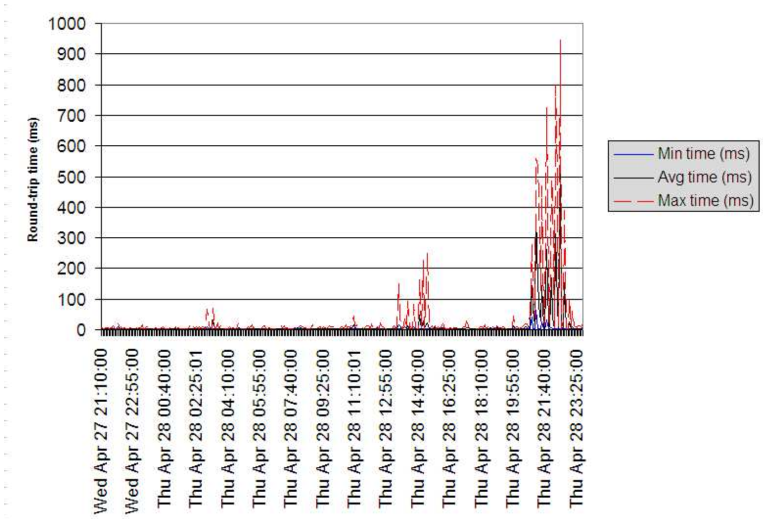


Figure 6.14: Ping tests of site D using the D-Link equipment running in both 802.11g and 802.11b data rates.

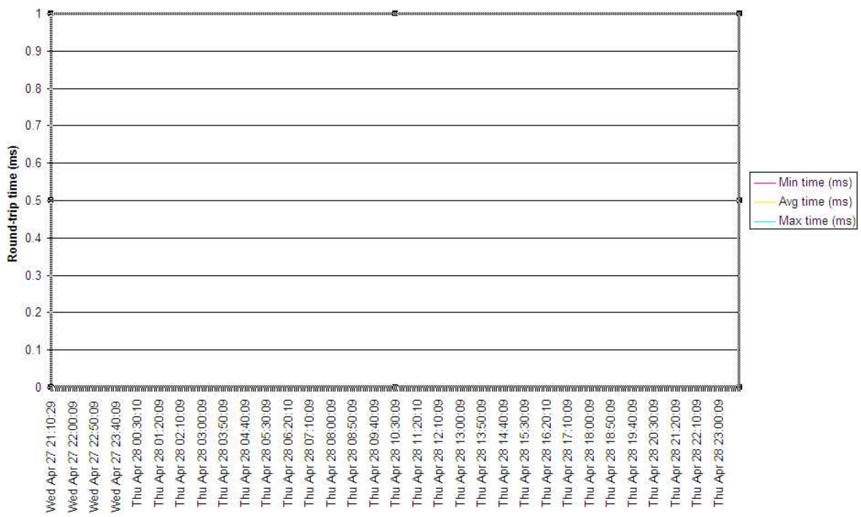


Figure 6.15: Ping Tests of site C (FDET4 water tower) using the D-Link equipment running in both 802.11g and 802.11b data rates.

```
Traffic will be disrupted during the channel scan => BSS'es from the selected
wireless mode
BSS Type     Channel      RSSI     BSSID                  WEP     SSID
Ad-hoc        2.412 ( 1)     19      02:02:36:b4:2c:0e     ON        *Mk7lnK#
AP BSS        2.412 ( 1)      5      00:0f:3d:df:c5:dc     OFF       Rhodes
AP BSS        2.422 ( 3)     39      00:0f:3d:9f:f6:e7     OFF       scw2
AP BSS        2.437 ( 6)     14      00:02:6f:35:62:db     ON        amcctai
Ad-Hoc        2.437 ( 6)      4      02:02:c7:56:58:a5     OFF       PJO
AP BSS        2.437 ( 6)     15      00:02:6f:37:0a:4b     ON
AP BSS        2.452 ( 9)     10      00:0f:3d:df:47:e8     OFF       scw
AP BSS        2.462 ( 11)    21      00:02:6f:32:26:77     ON        #Ap93kM*
AP: 6, Ad-Hoc:  2.  Total BSS: 8
```

Figure 6.16: Wireless beacons found from the water tower at FDET4.

The beacons marked “Rhodes”, “scw” and “scw2” are those which belong to the University’s network.

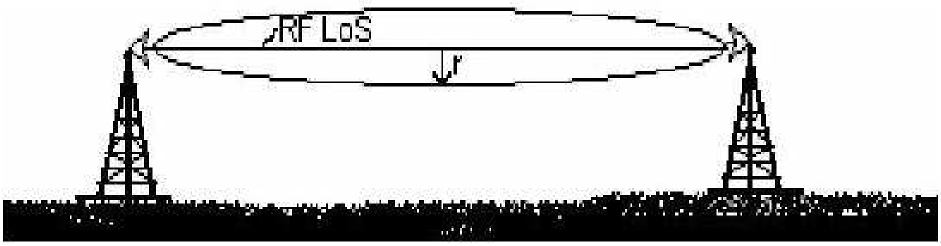


Figure 6.17: Fresnel zone.

The cross sectional radius of the first Fresnel zone is greatest in the center of the RF LoS, and can be calculated as: r = 43.3 *(sqrt(d/(4 f))) where r = radius in feet, d = distance in miles, f = frequency transmitted in gigahertz (from [227]).

section of the first Fresnel Zone is circular and subsequent Fresnel Zones are ring-shaped in cross section, and concentric with the first. The concept of Fresnel Zones (see Figure 6.17) may be used to analyse interference caused by obstacles near the path of a radio beam. The first zone must be kept largely free from obstructions to avoid interference with the radio reception. However, some obstruction of the outer Fresnel Zones can often be tolerated. As a rule of thumb the maximum obstruction allowable is 40%, but the recommended obstruction is 20% or less [227, 225, 226]. In order to establish the Fresnel Zones one must determine the line of sight of the radio signal. The zone surrounding it is said to be the Fresnel Zone [228, 227]. Thus, when building a wireless network one needs to maintain not only a clear line-of-sight, but a clear area surrounding the direct line-of-sight.

Any obstructions, including buildings, vegetation, and the ground that enter the Fresnel Zone will reduce the communication range. As the distance between antennas increases, so the diameter of the Fresnel Zone increases, and the ground can begin to obstruct the Fresnel Zone [229]. In Grahamstown (Figure 6.5), Makana's Kop rises up between the Monument and the water tower. The water tower stands further back from the hill, on the Eastern plateau and stands 12 m tall. There is a slight drop from Makana's Kop to where the tower stands and there are also trees approximately 7 m in height growing on top of the Kop. As a result of these obstructions we feared that there may be Fresnel Zone interference on the network between the Monument and the water tower.

In order to ascertain whether this was the case or not, software was downloaded off the Internet, called *Radio Mobile* [230]. This software is a tool used to predict the performance of a radio system [231]. It uses digital terrain elevation data for automatic extraction of path profile between an emitter and a receiver [231]. Data is added to the system, and environmental and statistical parameters are used to feed the Irregular Terrain Model radio propagation model [231]. Elevation data can also be used to produce virtual maps in background, elevation data for most of the world is available [231]. The software can also provide 3D views, stereoscopic views, and animation [231]. A map of the Makana District was downloaded from the U.S. Geological Survey website [232], and imported into the *Radio Mobile* program. From there, the co-ordinates were given for the water tower, on which the map was centred, providing a geographical map of the city of Grahamstown. From there it was possible to plot additional network sites onto the map, using their longitude and latitude. The Monument, site A, B, C, D and the schools were added to the map. Once this was done it was possible for the software to plot the radio link between two of the network sites. The link between

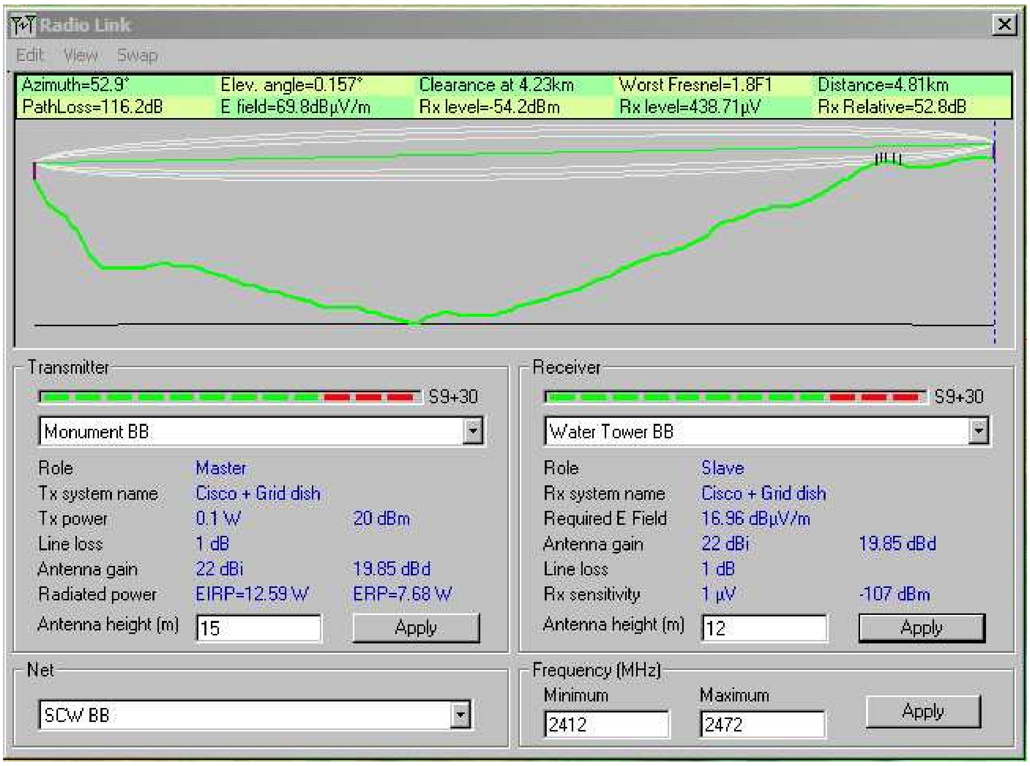


Figure 6.18: Fresnel zone diffraction on the link between the Monument backbone AP and the bridge at the water tower.

The small black lines on the hill on the right hand side are the trees on Makana's Kop. The green line is the point to point line of sight connection and the white ellipses surrounding that are the Fresnel zones. The outer ellipse is Fresnel zone 3, while the inner is Fresnel zone 1.

the Monument backbone and the water tower bridge can be seen in Figure 6.18. Unfortunately, additional obstacles such as the trees on top of Makana's Kop cannot be taken into account using the *Radio mobile* software, thus they were added using the *Paint* software package, so that the diffraction might become a little clearer. The software has drawn the tower to scale, and the trees are slightly more than half its height, which was easy enough to measure when using *Paint*. When adding in the trees (Figure 6.18) it is clear that they contribute to a greater Fresnel Zone diffraction, and in fact protrude into the first Fresnel Zone. Thus Fresnel Zone diffraction will be a problem on the Monument to water tower link. Although removal of the intrusive trees would help to alleviate this problem, Makana's Kop is sacred Xhosa ground and removal of the trees would be impossible. For additional Fresnel Zone diffraction information on other radio links within the network, see Appendix C.

### 6.3.5 D-Link 802.11b AP

In order for complete protocol testing it was decided to also run the network in 802.11b mode only, in order to be able to compare the results that were seen with those seen using 802.11g only, and in combination with 802.11b. For the purpose of testing the new D-Link 802.11b equipment one test site was chosen, site D. When considering the graph in Figure 6.19 we can see a slight decrease in the performance of the wireless network when we compare this with the results achieved in the initial test phases done by Whittington [21]. The average throughput rate of Figure 6.19 is 1.9 Mbps, while the average throughput rate of Figure 6.6 was approximately 2.5 Mbps. This decrease in throughput rate could be due to the fact that the distance from

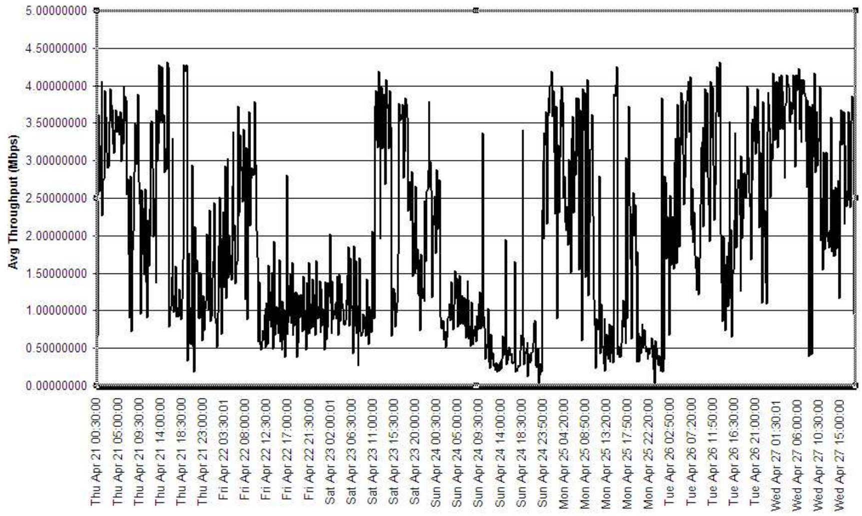


Figure 6.19: Data throughput at site D using the D-Link 802.11 equipment in .11b mode.

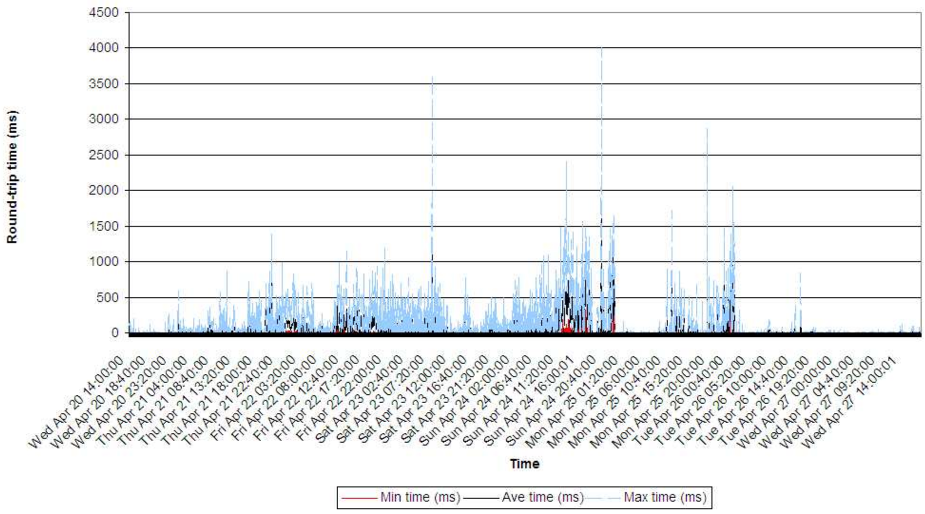


Figure 6.20: Ping test results at site D using the D-Link 802.11 equipment in .11b mode.

site A in the original tests was 300 - 800 metres shorter than the distance to site D in these subsequent tests. The erratic nature of the results in the graph of Figure could be due to the “hidden node” effect.

When considering the reliability and latency of the network, depicted in the graph in Figure 6.20 we determined an average latency of 800 ms or less with some very high maximum time spikes. The data provided when running the tests in 802.11b did not aid much in clarifying the issues surrounding the network and thus provided no more insight as to what was causing the problems with the network.

### 6.3.6 Cisco 1310 in 802.11b and 802.11g mode

As a result of all the problems experienced when using the D-Link equipment, it was decided to replace the D-Link APs at the Monument and water tower with Enterprise grade Cisco APs. The Cisco Aironet 1310 wireless bridges are capable of signal output of 100 mW and both 802.11b and 802.11g protocols. All the APs at the Monument and the water tower were replaced with Cisco 1310s. In addition, we installed a second AP at the Monument, connected to a high gain 22 dB directional antenna. This antenna is directed at the water tower in order to create a dedicated point-to-point connection from the Monument to the water

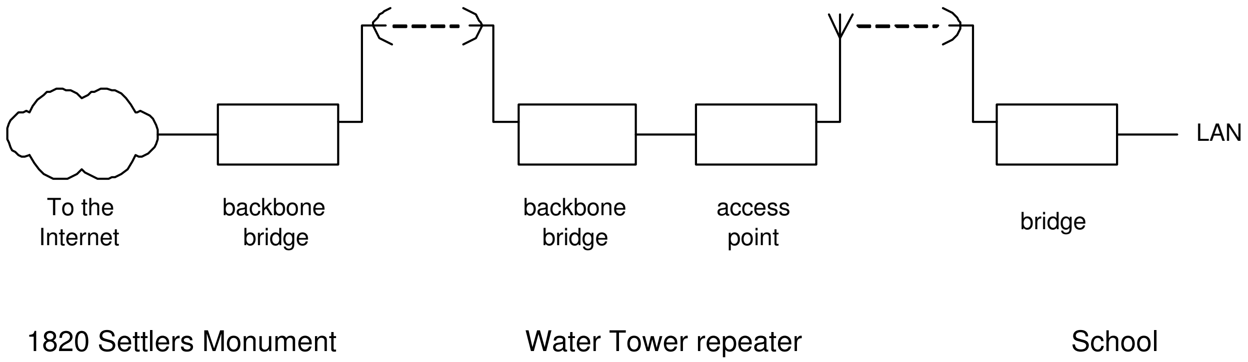


Figure 6.21: Wireless network topology from the Monument to the water tower at FDET4.

Using the Cisco 1310 series equipment.

tower. Using two directional antennas minimises the potential for interference from other networks by narrowing the field into which the radio signal was radiated. It was hoped that these changes would result in a strong enough signal for a successful Monument-to-water tower connection. This connection would act as the backbone to link clients of the water tower AP to the Monument. A diagram of the network topology can be seen in Figure 6.21.

Testing from the top of the water tower showed that the two Ciscos were able to transfer data from one to the other at a rate of approximately 6 Mbps, even before proper antenna alignment was performed. Testing from within the city bowl showed transfer rates averaging 3 Mbps.

The aim of the network modifications was to overcome the interference created by other networks, through using enterprise equipment with a better maximum power transmission (63 mW vs 100 mW) for the clients in Grahamstown West and the water tower-Monument link. In addition, using a directional point-to-point connection, together with the increased transmission power, we hoped to boost the signal from the Monument to the water tower and overcome any signal loss due to interference from other APs or Fresnel diffraction. Directional antennas are used to form highly focused beams of radio radiation, suitable for purposes of long distance wireless links [85].

In order to gain the most from the equipment and have the best of both of the 802.11g and 802.11b worlds meant running the APs in such a way that they would use the 802.11g protocol in preference, but if it became impossible to do so it would then degrade to 802.11b in order to continue to function at an optimum level. This was also the Cisco recommended method of running the APs. The Cisco APs provide detailed statistics about the network, which are accessible from the AP through its web and console interfaces. Data from the AP (seen in Figures 6.22 and 6.23) shows that when running in the recommended state of all 802.11g and 802.11b data rates enabled, the Monument AP prefers to transmit data using the 802.11b rate of 11 Mbps when the network is not able to operate at 802.11g, while it tends to receive data mostly at 802.11g rate of 18 Mbps. On average the Monument AP receives data at 802.11b rates 55% of the time, while it transmits data at 802.11g rates 57% of the time. It is possible that this is because the majority of the client sites in Grahamstown West use the D-Link equipment (DWL-2100AP+). Thus the majority of the traffic received is using 802.11b protocols and this would also explain that even though the Monument AP tends to use 802.11g data rates more often to transmit, the single most used data rate for transmission is the 802.11b rate of 11 Mbps.

With a working network, schools could finally be added to the clients. The first school to be added was FHOR. The school had recently received a Shuttleworth Foundation-sponsored tuXlab and was unable to

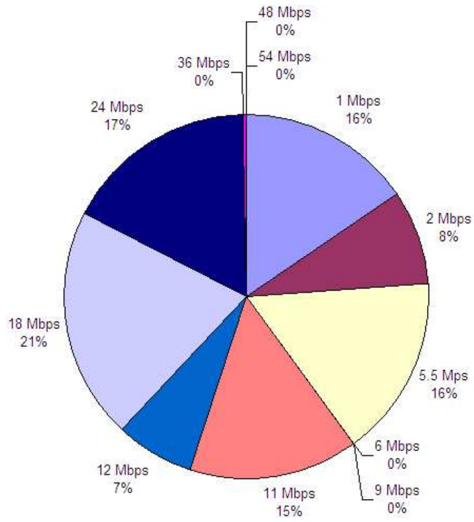


Figure 6.22: Receive data rates on the Cisco 1310 Monument AP.

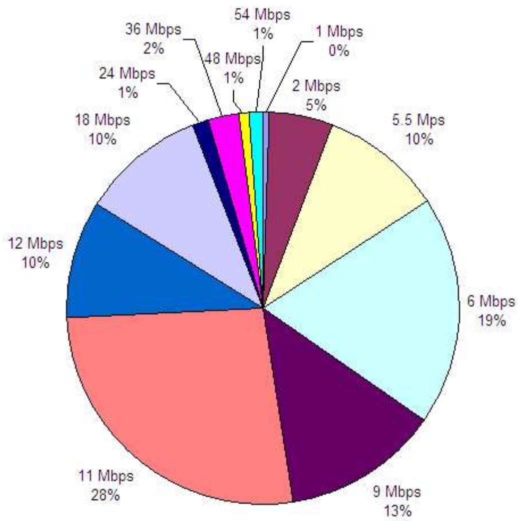


Figure 6.23: Transmit data rates on the Cisco 1310 Monument AP.

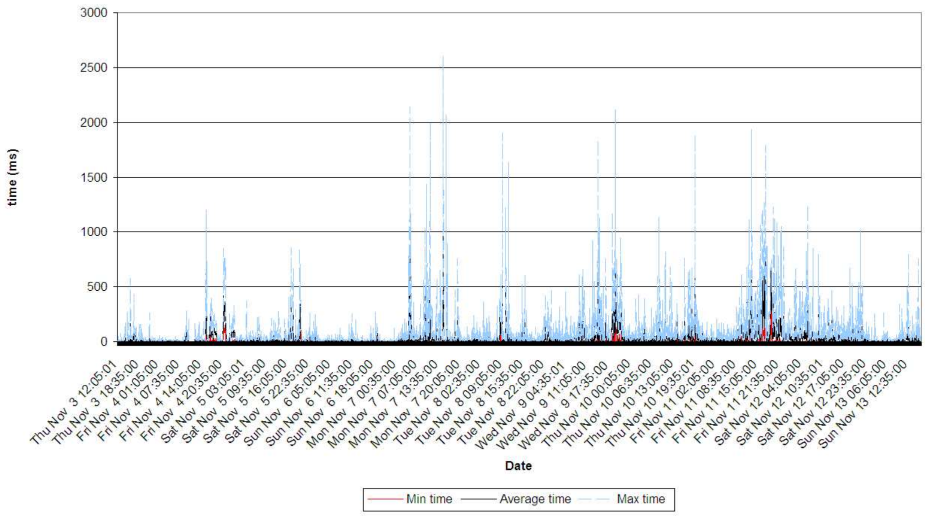


Figure 6.24: Ping test from Monument router to site D.

Using the Cisco equipment operating at .11g and .11b data rates.

afford an Internet connection through Telkom or another ISP. FHOR is a fair distance from the Monument, approximately 3.5 km. For this reason it was decided that it would be best to also provide the school with a Cisco 1310 outdoor AP and a 22 dB gain grid directional antenna. The school building is three storeys tall and it was possible to bolt the grid directional antenna high on a wall with a clear line of sight to the Monument AP and omni-directional antenna. The AP was configured as a bridge and placed in a weatherproof box in the roof. The school arranged a mains outlet in the roof to power the AP. Ethernet cabling connects the AP to the router in the computer lab, which performs NAT routing and DNS proxying functions.

If we first consider the round trip tests to site D, FDET4's bridge and AP and the client at FHOR, it can be seen that the average round trip time is 500 ms or less. This is an improvement on the average that was seen during the D-Link tests, which averaged around 800 ms. Considering each graph individually, we notice that the worst round trip time client is that at site D (Figure 6.24). The reasons for this could be that firstly site D experiences a fair degree of interference from other wireless networks in town as it is the closest to the sources of these networks. It is also the site which generates the most traffic out of those tested, thus there is more congestion on the network. Similarly, the client at FHOR (Figure 6.25) has higher round trip times as there is more contention on the network there than currently at the water tower, where at the time of the ping tests there there were no client sites. The spike at the end of the graph in Figure 6.25 is due to a power failure experienced over the weekend. The round trip times at the water tower to both the bridge and the AP (Figures 6.26 and 6.27) are very low and a substantial improvement from when using the D-Link equipment (when there was no throughput at all). The reasons for the low times was probably due to uncontested network access, as at the time FDET1 and FDET4 had not been added to the network, as well as an improvement in interference handling on the backbone link from the water tower to the Monument.

If one now considers the throughput seen at site D and FHOR (Figures 6.28 and 6.29), it can be seen that the throughput at site D is better than that at FHOR – the average at site D is 2.4 Mbps, while the average at FHOR is 1.8 Mbps. The reason for the better throughput rates at site D than at FHOR is probably due to site D being closer to the Monument AP (~1.2 km away) while the client at FHOR is much further away from the AP (~3.5 km). The anomalies in Figure 6.28, either impossibly high throughput or zero throughput, are

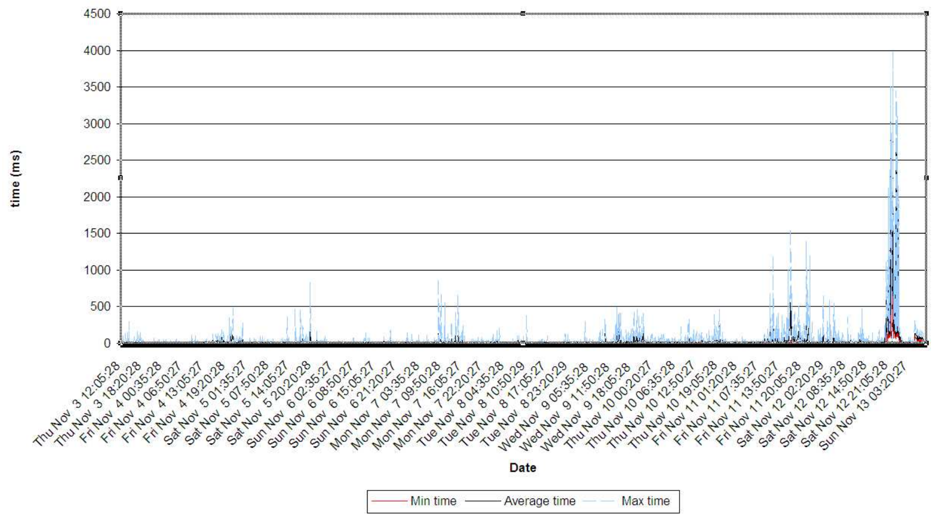


Figure 6.25: Ping test from Monument router to FHOR.

Using the Cisco equipment operating at .11g and .11b data rates.

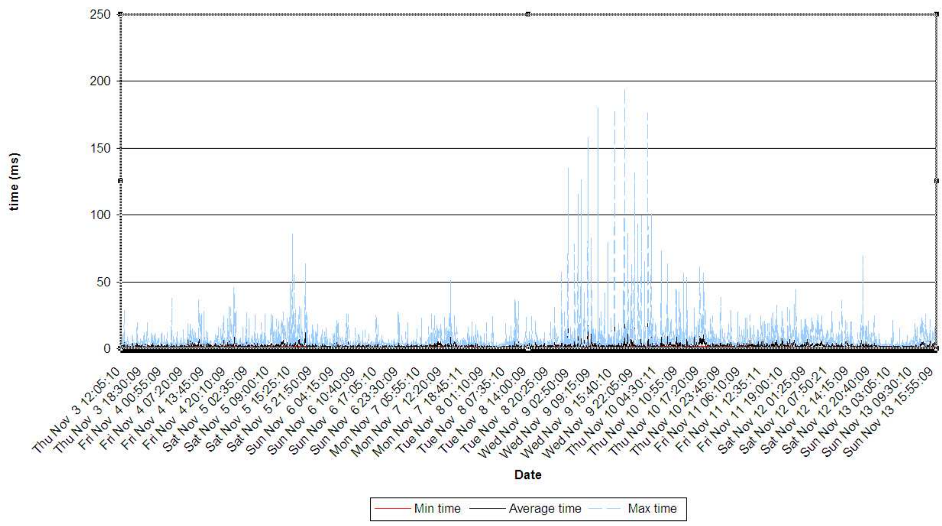


Figure 6.26: Ping test from Monument router to water tower bridge at FDET4.

Using the Cisco equipment operating at .11g and .11b data rates.

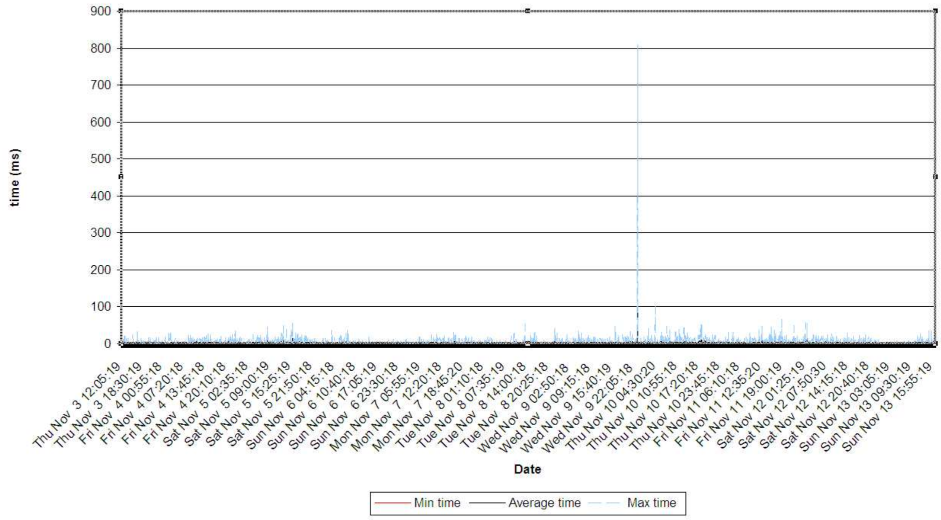


Figure 6.27: Ping test from Monument router to water tower AP at FDET4.

Using the Cisco equipment operating at .11g and .11b data rates.

due to power failures. In the cases of the high recordings the *fetch* command runs, in order to copy the file from one machine to another, but immediately fails and the time returned is close to zero. When dividing the length of the file (in bytes) by the small time value, we get an apparently enormous throughput.

Following FHOR, FDET4 was connected to the wireless network and was the first school to be connected to the network via the water tower repeater. The water tower is on the school's property and the school lab is no more than 100 m from the water tower. Thus it was possible to make use of the D-Link equipment at the school as the signal did not have far to travel in order to reach the school lab. A 22 dB parabolic dish was used and bolted into the outside wall of the school lab, just below the roof. The building is only a single storey, but as it is so close to the parent AP this was not a problem. A weatherproof box containing the D-Link AP running as a bridge was placed in the roof of the lab, as well as D-Link PoE equipment used to power the bridge as there was no electricity in the roof of the school. After the installation was completed it was discovered that the association between the router's (which is an old computer housed in the school's lab) MAC address and the water tower AP was unstable: the association was very intermittent. Due to a lack of access to the school as the school holidays had already begun by the time this problem was discovered I was unable to determine exactly where the fault lay. Possible explanations for the intermittent association could be due to the old hardware of the school's router, a faulty NIC on the school router, faulty cabling or a faulty bridge. It is important to note that the association between the D-Link bridge, that was installed at the school, and the water tower AP was not affected by the problems occurring between the router and the water tower AP.

As a result of this intermittent association the testing method for throughput had to be modified slightly. A script was written that attempts to ping the water tower AP. As soon as the router at FDET4 is able to ping the water tower AP (i.e. the router and AP are associated) the PPPoE session is started and the router will copy the testdata file from the central router at the Monument and record the time taken. The testdata file is copied every 3 minutes until such time that the router can no longer ping the water tower AP and hence is no longer associated with the water tower AP. When the association is terminated the script will terminate the PPPoE session until such time as it can ping the water tower AP again. When the school opens in 2006, and there is once again access to the computer facilities, the exact problem can be determined and hopefully

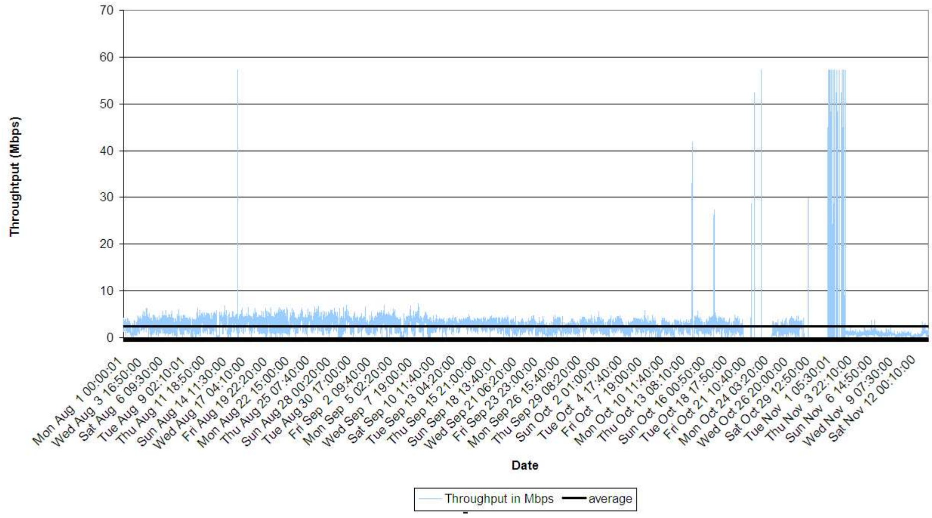


Figure 6.28: Throughput from Monument router to site D in Mbps.

Using the Cisco equipment operating at .11g and .11b data rates.

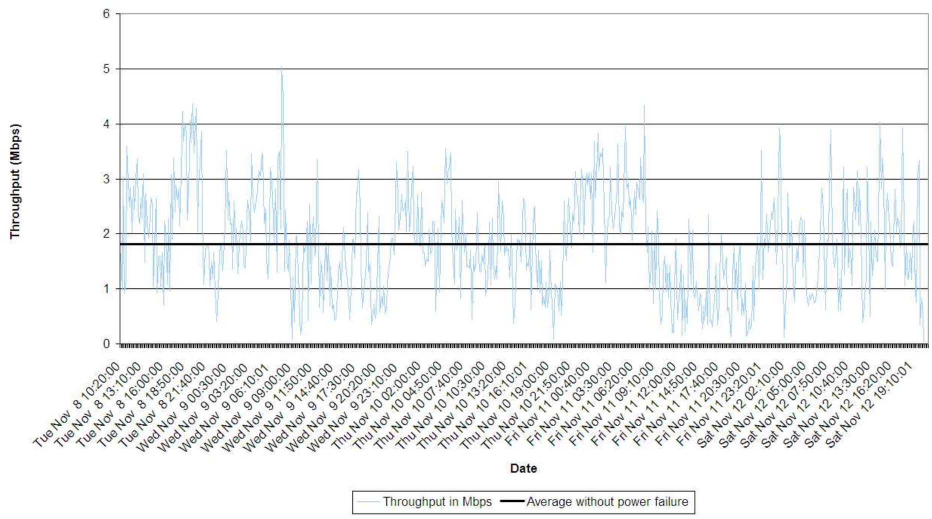


Figure 6.29: Throughput from Monument router to FHOR in Mbps.

Cisco equipment was used operating at .11g and .11b data rates.

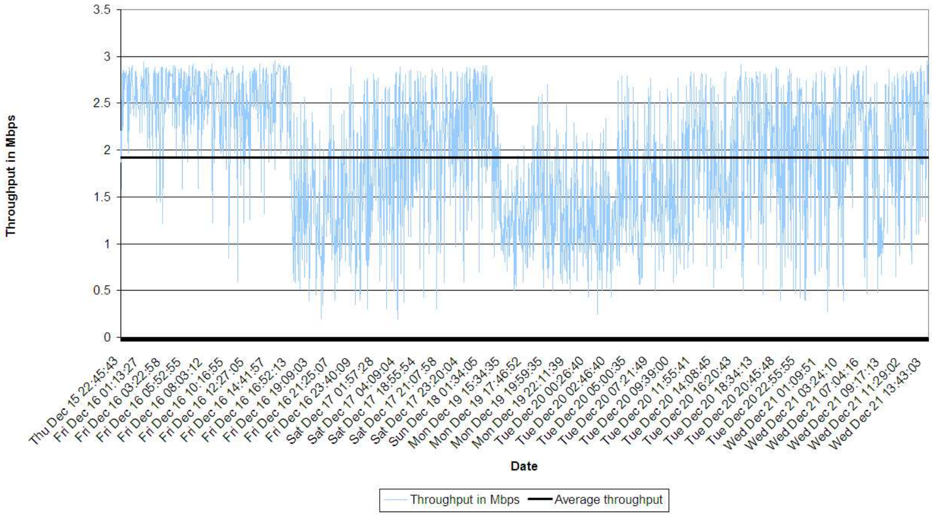


Figure 6.30: Throughput test to FDET4.

Using a slightly modified throughput test script in order to work around the intermittent association between the router and the water tower AP.

corrected. The throughput results for the modified script can be seen in Figure 6.30. From Figure 6.30 one can note that the average throughput for the tests was approximately 1.9 Mbps.

The ping test conducted from the central router at the Monument to the bridge at FDET4, which can be seen in Figure 6.31, revealed that the latency between the Monument router and the bridge at the school was very good. This latency on average was less than 100 ms. The spikes towards the end of the graph are probably due to the power problems that the schools in Grahamstown East experience, namely that at times the schools do not have electricity due to some fault that affects the entire area.

The last school that was to be connected to the wireless 802.11 network during the course of this study, was FDET1. Initial tests were conducted at the school to verify whether a wireless connection from the water tower to the school would be feasible. The two are approximately 2 km apart. The initial tests were promising, with data transfer rates of between 1 and 2 Mbps. However, the school was unable to provide the necessary electricity to the roof of the administration building, where the network equipment was to be mounted on time. Consequently FDET1 will be added to the wireless network during 2006.

### 6.3.7 Cisco 1310 in b-only mode

Having achieved a working network using the method described above, of having the AP run in 802.11g that degrades to 802.11b date rates where necessary, I decided to run the network in 802.11b mode only in order to compare the quality. For the purposes of this comparison only the results from site D and FHOR were included as they painted a sufficient picture of how the network operated. Predictably, test results indicated that the reliability and latency of the network were hardly affected, but the throughput was substantially decreased due to reduced available bandwidth on the network. If we consider the results from the ping tests (Figures 6.32, 6.33, 6.34 and 6.35) we can see very similar results to those found in the previous section, namely that the round trip time is generally less than 600 ms. The increase is ever so slight, from 500 ms to 600 ms and can probably be attributed to less available bandwidth when using 802.11b.

The decrease in available bandwidth was very noticeable when I ran the throughput tests over the network. The average throughput to site D decreased from 2.4 Mbps to 0.7 Mbps, while the average throughput

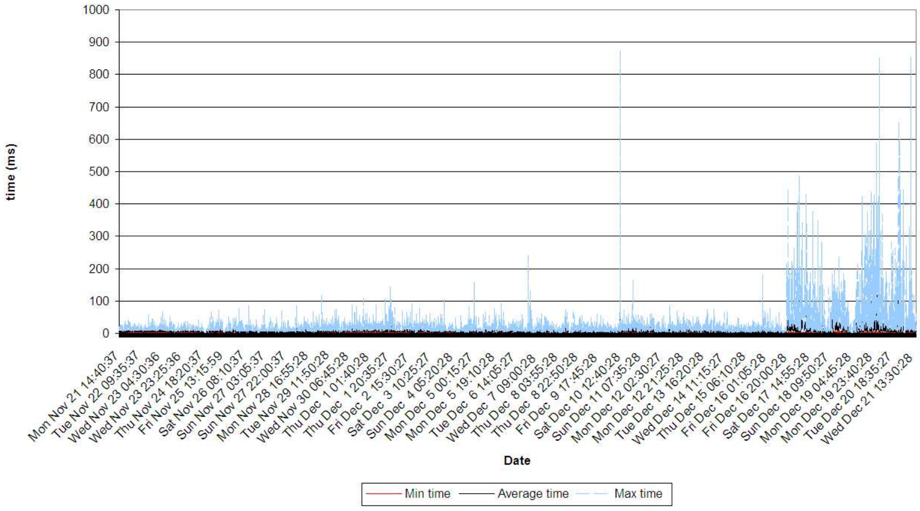


Figure 6.31: Ping tests results from the central router at the Monument to the bridge at FDET4.

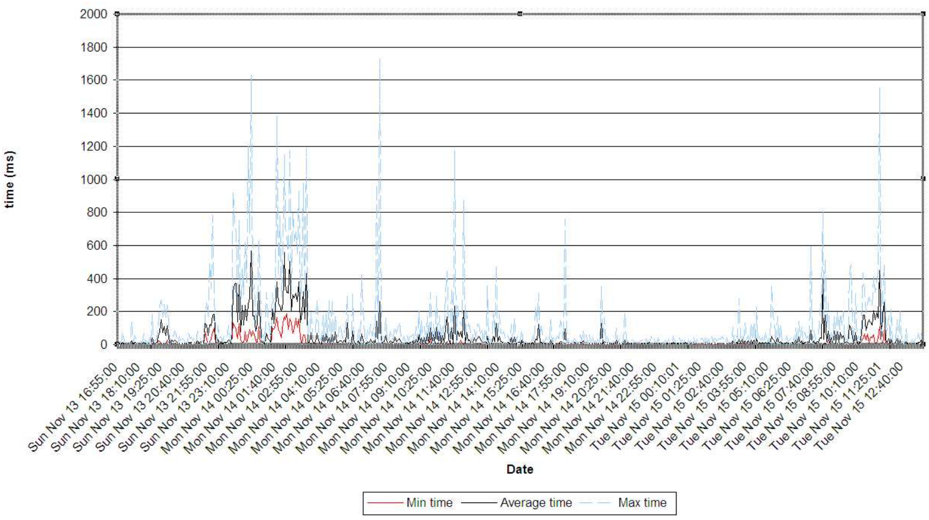


Figure 6.32: Ping test from Monument router to site D.

Using the Cisco equipment operating at .11b data rates.

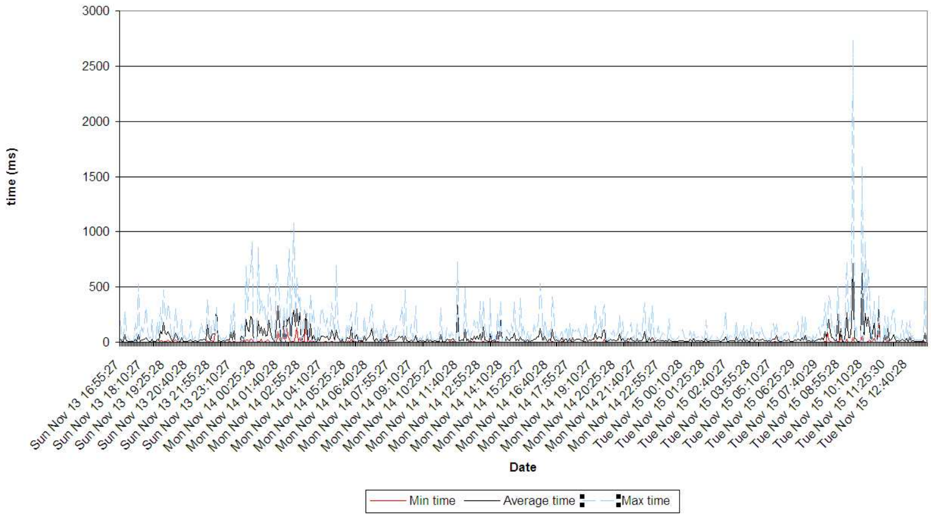


Figure 6.33: Ping test from Monument router to FHOR.

Using the Cisco equipment operating at .11b data rates.

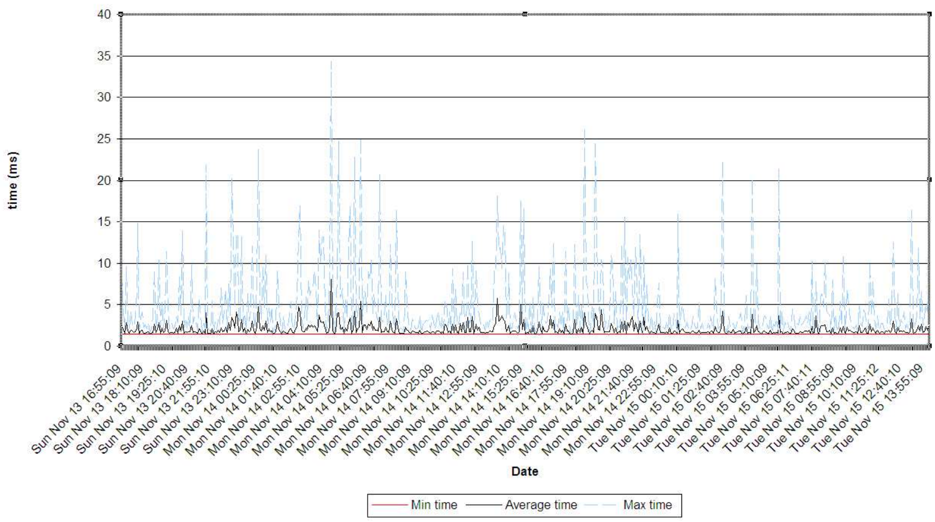


Figure 6.34: Ping test from Monument router to water tower bridge.

Using the Cisco equipment operating at .11b data rates.

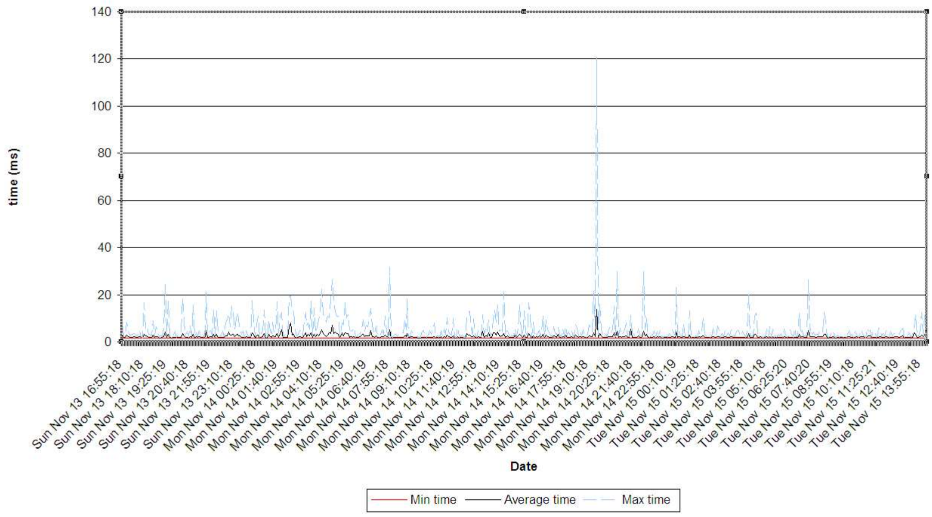


Figure 6.35: Ping test from Monument router to water tower AP.

Using the Cisco equipment operating at .11b data rates.

at FHOR decreased from 1.8 Mbps to a little less than 0.3 Mbps. When considering the two graphs in Figures 6.36 and 6.37, it can be seen that neither of the two clients were able to even peak at the average seen in the previous section.

### 6.3.8 Cisco 1310 in g-only mode

Having tested the network running the APs as 802.11g and 802.11b compatible and 802.11b compatible only, it was decided that for comparative purposes, the network would be run in an 802.11g enabled mode only. However, when the APs at the Monument were configured to support only 802.11g data rates, only the other Cisco APs were able to associate. The D-Link clients tried to associate, but were consistently unable to do so. It is possible that this is due to the age of the D-Link clients – they were produced shortly after the .11g standard was finalised – and many not be as adept at handling the .11g data rates as well as the age of the firmware that they run. Upgrading the firmware to newer versions caused other troubles: the bridge, when forwarding traffic to the root AP, rewrites the MAC address from which the traffic originates with its own address, and so when the return packets arrive they are addressed to the bridge. The bridge is able to forward IP packets to the original sender, but cannot forward non-IP traffic, including PPPoE frames which are used in our wireless network as discussed in section 6.3.1. This made it impossible to establish PPPoE tunnels using D-Link bridges with newer firmware.

The best network results were seen when running the network in an 802.11g that degrades to an 802.11b (when needed) configuration and so the default settings for running the network have been maintained.

### 6.3.9 Maintenance and cost

The maintenance of a wireless broadband connection is as similar to that of a DSL connection. While during the building of the wireless network in Grahamstown (my colleagues and I experienced problems) the user or school of a wireless network would not experience such problems as the service provider would resolve these issues prior to installation. A customer could either purchase the wireless bridge from the service provider or off the shelf from a local computer store. The service provider would then come in and

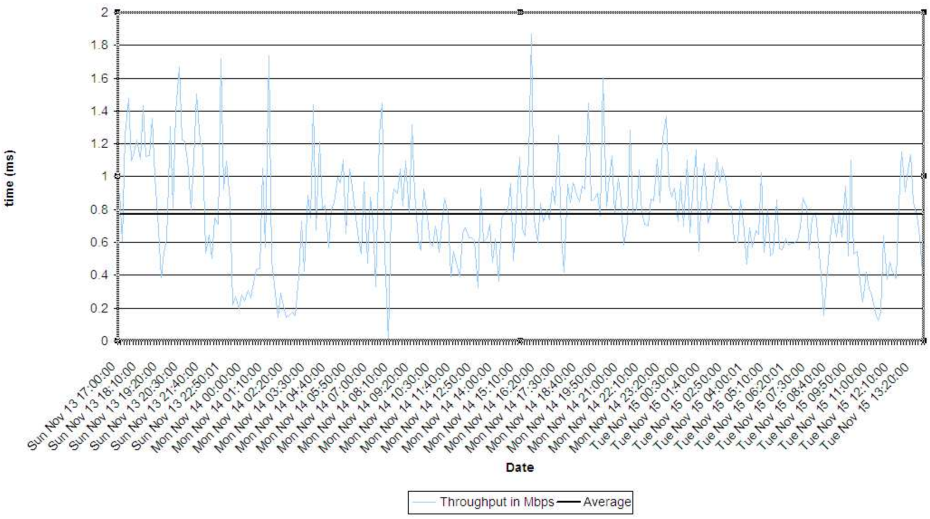


Figure 6.36: Throughput from Monument router to site D's router.

Using the Cisco equipment operating at .11b data rates.

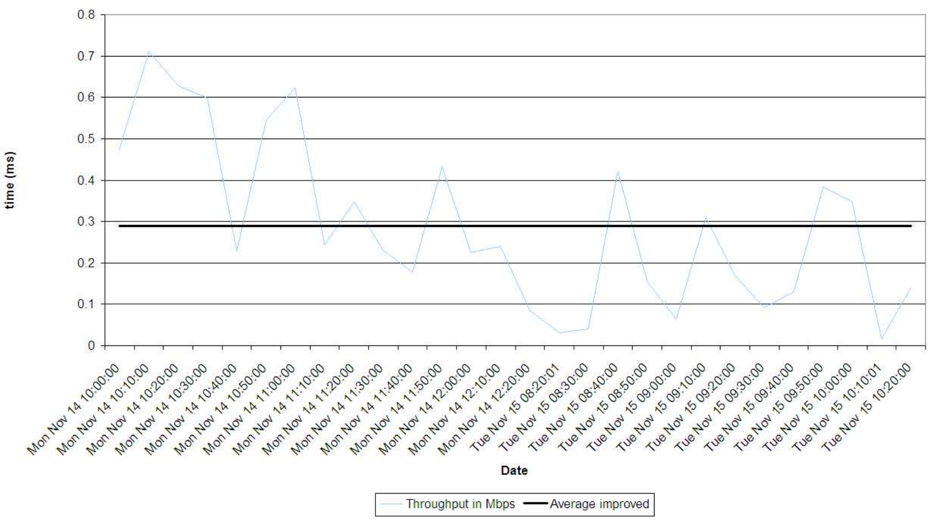


Figure 6.37: Throughput from Monument router to FHOR's router.

Using the Cisco equipment operating at .11b data rates.

perform the installation and configuration of that network connection. Again, as with the DSL connection, the service provider is usually only responsible for the network connection, unless specifically contracted by the school otherwise. In addition, this type of connection is also an 'always-on' broadband connection and therefore the school's network will need to be protected by a firewall and anti-virus software.

Currently, in South Africa, there are very few 802.11 wireless product offerings, so it is more complicated to determine the prices of these services. The cost of installation and monthly rental may or may not be of a similar price to that of DSL. However, there is less infrastructure in place for wireless networks, so it might be fair to assume that the prices might be cheaper. A D-Link AP is in the region of R700, an aerial would cost up to R650 and installation consumables (cabling, aerial mount, rawl bolts, etc) a further R1000 which adds up to a total of less than R3000 per school for the once-off installation price.

## 6.4 Summary

Both of the networks that were deployed provide sufficient bandwidth (throughput), latency and reliability for school use. While DSL tends to be more reliable, with a lower latency and a consistent data throughput rate, it cannot be used to connect schools further away than 5 km or 6 km from the DSLAM or where there are filters or poor copper cabling within the access loop. DSL is a more reliable connectivity method as it does not use a shared medium as in the case of the wireless network. DSL is also easier to work with and deploy and therefore was less complicated to deploy. Generally one can just deploy and walk away. There is little need for constant maintenance.

The wireless network had a longer teething phase as it was deployed using a saturated spectrum, while attempting to stretch a LAN technology over a WAN. However, when using equipment that had a higher power transmission of 100 mW vs 63 mW (a 66 % increase in transmission power), as well as the use of directional antennas over long distance hops, I was able to overcome these problems and build a reliable network with broadband data rates to which two schools and two additional town clients were connected. The wireless network was able to provide sufficient data rates to the schools while still maintaining a low enough latency and good enough reliability to make the network usable.

## 6.5 Alternative network solutions

While the bulk of the investigative work in the study was the exploration of the DSL and 802.11 (Wi-Fi) networks, there are other alternatives that could be deployed in the Grahamstown Circuit. None of these alternative network solutions were deployed to schools, but basic laboratory tests were performed on the technologies.

The next two subsections of this section discuss 3G technologies and satellite technologies. I have conducted the same network tests performed on the DSL and Wi-Fi networks in order to be able to compare them fairly to the DSL and Wi-Fi networks. The subsection on fibre optics as an alternative solution is based on the findings of using a fibre optic network on Rhodes campus as well as results from use in other metropoles in South Africa. I use these initial findings to extrapolate the possibility of a metropole-wide fibre optic network. Following this is a subsection on powerline communications. Work in this area was undertaken by a Computer Science Honours student in 2003 [24]. Using some of his results and recent publications from other researchers, I discuss the possibilities of using powerline communications for Internet connectivity in the Grahamstown Circuit. I then move on to a brief discussion on the possibilities of WiMAX technologies.

| Telkom ADSL | |
|---|---|
| Line installation | R316,10 |
| Monthly line rental | R92,28 |
| Once off installation fee | R 404 |
| Monthly fee | R477 (512Kbps) R680 (1024Kbps) |
| Modem cost | R299 - R1999 |
| ISP * | R 269 |
| Total cost - installation | R1019,10 – R2719,10 |
| Total cost - monthly usage | R838,28 – R1041,28 |

** Consumers can choose their ISP, but for simplicity's sake, TelkomInternet had been used in this example; the 3gigabyte shaped option*

Figure 6.38: Telkom ADSL price as depicted in [238].

### 6.5.1 GPRS and 3G technologies

In South Africa the two biggest cellular phone service providers are Vodacom and MTN [233]. Vodacom has the largest subscriber base of approximately 11 million South Africans [234], while MTN has a little more than 6 million subscribers [235]. Of the two, MTN has the largest coverage area [235], but together the two companies cover about 90% of the country in their combined footprints [235, 236]. With a total of approximately 20 million South Africans subscribed to one of the three cellular phone companies, approximately 47% of the population has access to telecommunications via cellular telephones. The number of fixed line subscribers has fallen to 5.3 subscribers per 100 South Africans, totalling approximately 5 million [99].

Historically, wireless 2.5G and 3G data services have been provided by our cellular phone service providers. However, a further two companies, neither of which are cellular phone providers, have been licenced to sell wireless data services to the public, namely Sentech and WBS. In a recent survey conducted by the MyADSL Wireless Broadband forum [237], it was found that of the wireless data services offered by Sentech, Vodacom, MTN and WBS, Sentech was the top performer. The results are derived from live performance tests conducted by actual users as well as tests administered under laboratory conditions. A sample of South African wireless broadband users performed thousands of upload, download and latency performance tests using their broadband connections. Numerous diagnostic tests were also conducted in the newly formed Broadband Laboratory at the University of Johannesburg [237]. An algorithm was then used to rate each broadband service according to various criteria, including cost, reliability, upload speed, download speed, latency, service restrictions, and technical support.

The benefits of the 3G products over Telkom DSL was compared in a recent article in MoneyWeb [238] following the publication of the wireless report from MyADSL. From the article, one begins to see cost benefits of using 3G products, where they are available, instead of Telkom products. Figures 6.38 and 6.39 depict some of these findings. As a result of the popularity of cellular phone technologies and their extensive coverage of South Africa, as well as the cost benefits that are beginning to be seen over wired alternatives (while still obtaining similar connection speeds), they should be regarded as an important technology for connectivity.

Unfortunately, the Sentech network doesn't cover Grahamstown, so for this project we made use of the second best performer, Vodacom 3G, which is available in Grahamstown. In order to test and compare the 3G network provided by Vodacom I attempted to run the same tests used in the DSL and 802.11 network deployments.

| | Wireless offerings | | | |
|---|---|---|---|---|
| | Sentech MyWireless | Vodacom 3G | WBS iBurst | MTN 3G |
| Price per month (1Gig service) | R 449 | R 499 | R 469 | R 499 |
| MyADSL rating | 87% | 81% | 80% | 78% |

Figure 6.39: Wireless prices as depicted in [238].

However, using Vodacom's 3G service in Grahamstown was more difficult that I had hoped. Once I had the SIM card initialised in order to be able to do data transfers and had configured PPP on Linux to use the 3G card, connecting to the network was still challenging. Negotiating PPP connections from the notebook with the Vodacom 3G card to the Vodacom network was very erratic, in both Windows and Linux. Once the connection had been established it did not remain up for very long, with the longest ever connection to the network being about 30 minutes. Generally the connections lasted between 5 and 10 minutes with some being as short as 2 minutes in length. It would appear that when attempting to download "large" data files, such as the *testdata* file that I used in my experiments, the chances of being disconnected from the network were higher. When using the network for less bandwidth intensive activities such as *ssh* or browsing web pages that are not too big, the connection stayed up for longer. Furthermore, the erratic connectivity was puzzling, as Vodacom cellphone users did not appear to be complaining of poor connectivity. I therefore initially hypothesised that cellular telephones possibly have better radio receivers than the radio receiver in the 3G card, as cellular phones are made to work, as far as possible, all over the country no matter how far the nearest tower is, while the 3G cards were marketed at business people operating in large urban areas such as Johannesburg or Cape Town where coverage is extensive. However, when using a cellular phone together with the SIM card and *Bluetooth*, the same erratic nature was seen when trying to download "large" data files. The erratic nature of the network can be seen in Figure 6.40. In the Figure 6.40, where the round trip time dropped to zero the connection was lost and to be re-established. In some cases this was every 2 or 3 minutes. In Figure 6.41, the ping test was conducted by pinging the Rhodes University web server, which provides an idea of the latency to Internet sites, while Figure 6.40 provides latency figures within the network itself. From these two figures we can see that the latency on the network averages around 3 seconds, while latency to the rest of the Internet reaches up to 3.5 or 4 seconds. (Round trip figures for DSL, section 6.2, were substantially less than these latency figures, while the latency figures of the wireless 802.11 network, section 6.3, were 1 to 3 seconds less.)

Download speeds also varied greatly. On occasion I was able to connect to the Vodacom 3G tower in Grahamstown, but unfortunately this was not very often, as there is only one tower and thus coverage is not as good as in bigger urban areas where there are more 3G-capable towers. When connected to the 3G network, speeds as fast as 220 Kbps were achieved. Figure 6.42 depicts the speeds that could be achieved when connected to the 3G network. When connected to the GPRS network, speeds of 32 Kbps to 50 Kbps were achieved. Figure 6.43 depicts the speeds of transfer when connected to the GPRS network. When the speeds drop to zero the network connection had dropped. It is possible that network connectivity would be greatly improved in bigger urban areas such as Johannesburg or Cape Town.

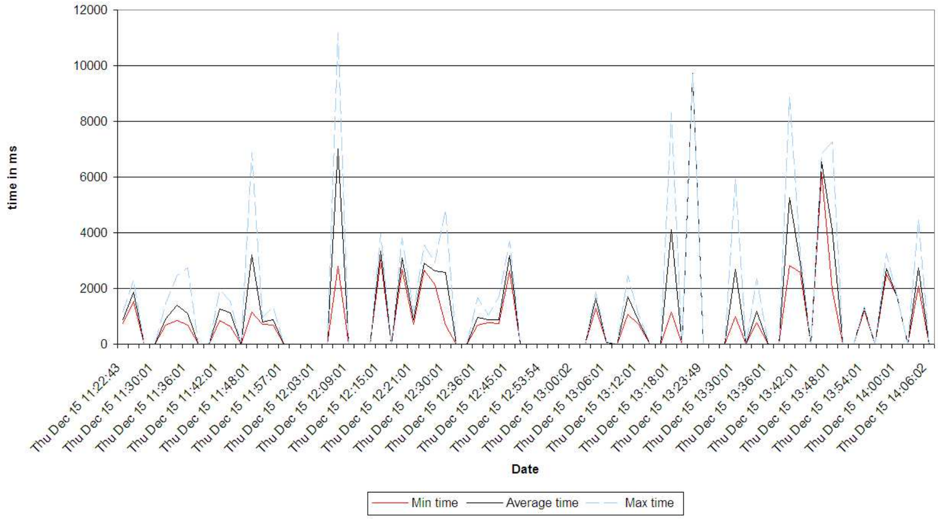


Figure 6.40: The ping test run over the cellular network.

This was done by pinging one of the DNS servers on Vodacom's network.

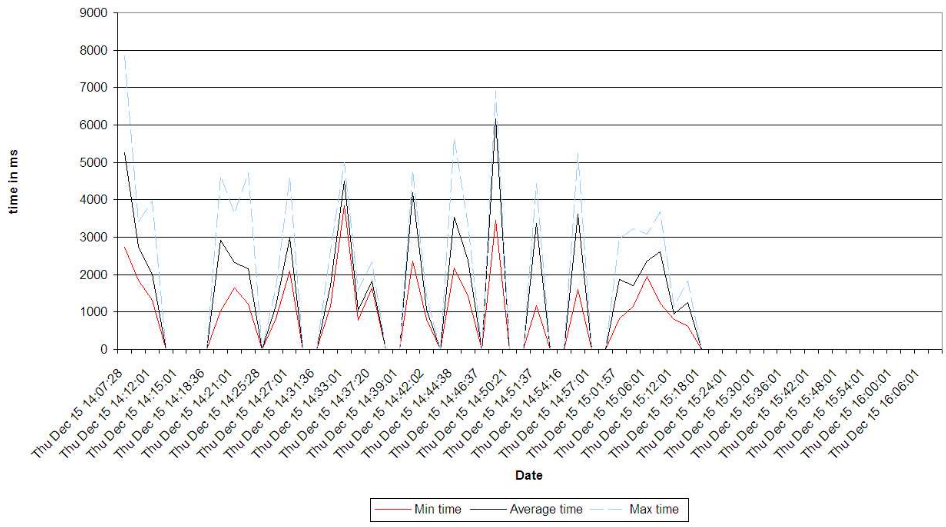


Figure 6.41: The ping test over the cellular network and beyond.

This was done by pinging the Rhodes University web server on Rhodes' campus.

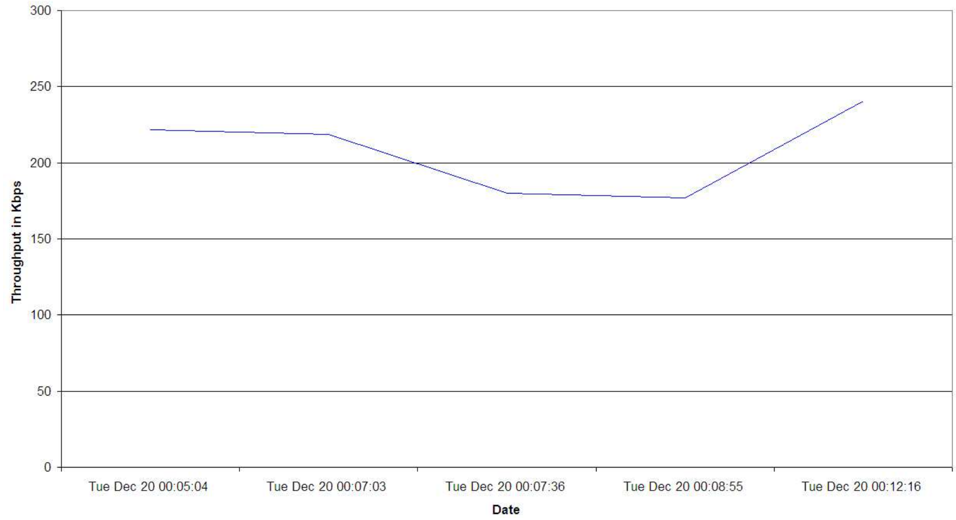


Figure 6.42: Throughput results when connected to Vodacom's 3G network.

The throughput test was used in order to calculate these figures.

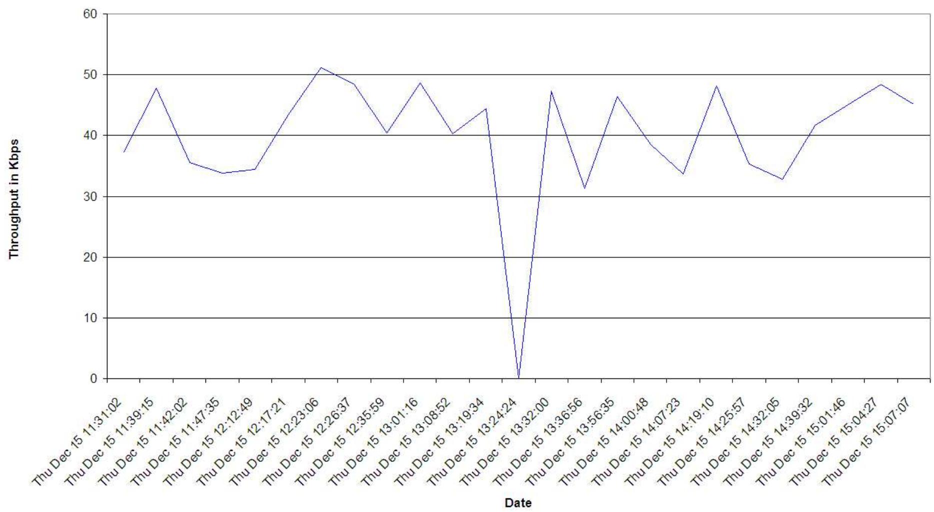


Figure 6.43: Throughput results when connected to Vodacom's GPRS network.

The throughput test was used in order to calculate these figures.

For the sake of interest I experimented briefly using an MTN SIM card. In Grahamstown there are no 3G services from MTN, but I did find that the network speeds for GPRS were slightly better on the MTN network and ranged from 55 Kbps to 66 Kbps and were sometimes even as high as 70 Kbps. In addition, the MTN network did not suffer from the erratic connection problem that Vodacom seemed to. MTN did not once drop my connections no matter how large the data file being downloaded was, and all network terminations were initiated by me.

In terms of cost, we know that Sentech is the cheapest of the 3G solutions available in South Africa. One should keep in mind that once a 3G card has been purchased it is up to the user to configure his computer to connect to the network. This involves installing the necessary drivers and configuring the computer appropriately. The Vodacom 3G card comes with a driver CD for Windows. The Windows driver on the CD is fairly easy to install and the Vodacom software for connecting to the Internet is fairly easy and intuitive to use. In Linux getting the appropriate drivers was simple, however configuring PPP was very challenging and took quite some time. While I was able to make use of on-line forums (Ubuntu and MyBroadband) neither were enough to get it to work properly. In order to get the PPP connections to work I had to approach colleagues with more extensive knowledge about the workings of PPP than I have in order to successfully connect to the network. Currently, in order to connect to a 3G network with a computer that runs Linux or FreeBSD one would need extensive knowledge about these operating system as well as PPP.

Due to the erratic connectivity and the generally low transfer rates experienced in Grahamstown I would not recommend 3G/GPRS technologies in current use to the Grahamstown Circuit schools as a method for connecting their schools to the Internet.

### 6.5.2 VSAT

A VSAT, or Very Small Aperture Terminal is a two-way satellite ground station with a dish antenna that is smaller than 3 metres [239]. These terminals are used across the world as a means of delivering Internet access to sites in remote or rural locations [239].

As part of our study we bought a VSAT connection from Telkom. The VSAT SSE256, which provides 256 Kbps downstream and 64 Kbps upstream and a 2G cap with an additional 1G cap on the upstream, was purchased. In order to test and compare the VSAT network to those deployed in Grahamstown I ran the same tests as those that were used on the DSL and 802.11 deployments. In order to ping a machine, I had to ping lizard.ru.ac.za, the university's web server, as it was the only machine on campus that I am able to reach via ping. In order to copy the test data, I had to copy it from a web server that could be seen from outside the university. For this I chose the RUCUS (Rhodes University Computer Users Society) website, and placed a copy of the file on my web page (http://ings.rucus.net/testdata) for the test. These tests, when run on the DSL and 802.11 networks, tested only the network medium. However, running these tests over the VSAT network not only tested the link from the VSAT on our department, but also the availability of the bandwidth from SAIX (South African Internet eXchange) to the university. Thus we need to consider the university's local Internet link, depicted in Figure 6.44. It can be seen that the university's 1,448 Kbps local Internet connection uses on average only 353 Kbps, and thus there is a large amount of free capacity on the link. I was therefore sure that this link would not be a bottleneck in my VSAT tests, and can accept the results as a fairly accurate reflection of the VSAT network capabilities.

If we consider the results of the ping test, in Figure 6.45, we notice that on average the round trip time is approximately 2 seconds, with peaks as high as 6 seconds. This is higher latency than experienced in either of the DSL or 802.11 wireless networks. Thus, when using real time applications this latency can be problematic, but if there are no alternatives to satellite then it does have the advantage of being able to connect one to the Internet from anywhere. While the user's computer is on and the Telkom account

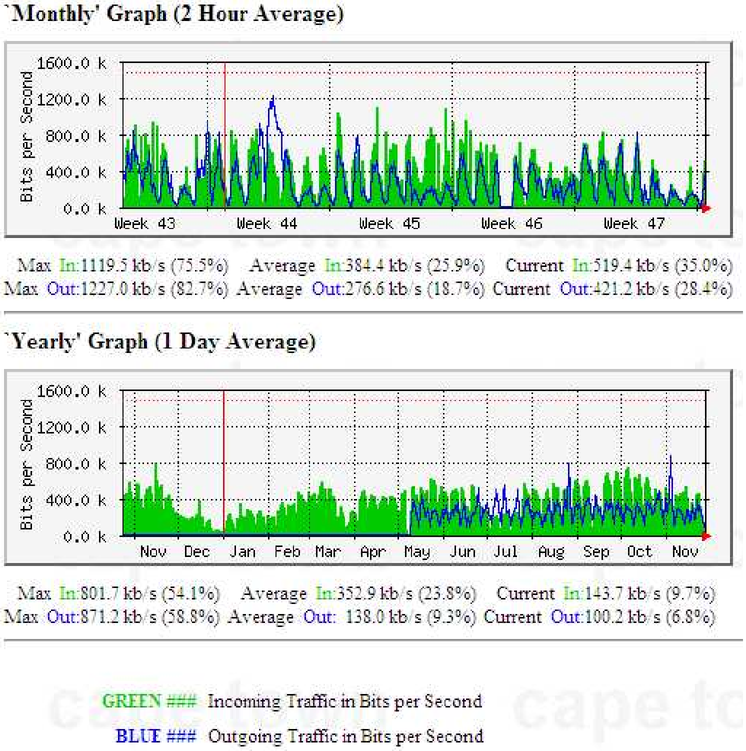


Figure 6.44: Rhodes University national traffic graphs, taken from [240].

information has been entered, the user is connected to the Internet. As such, this product is not really 'always on' broadband, as the user has to connect via username and password on a web page either every 24 hours or every time the computer is switched on. In effect it is more like dial-up, however you are not charged like dial-up and the transfer rates are faster. We can see this in Figure 6.45. When the round trip time drops to zero it is because the network log on has timed out after 24 hours and one needs to reconnect in order to remain on-line.

The available bandwidth on the VSAT connection can be seen in Figure 6.46. The anomalies on the graph are caused by the connection being terminated after 24 hours, which then returns to normal as soon as the connection is restored. The black solid line in Figure 6.46 depicts the average throughput, however it is the average which includes the anomalies. The red line in the graph is the average minus those anomalies, and is a truer reflection of the throughput on the network. The red line represents an average of 230 Kbps, which is in line with the product that we bought, namely the 256 Kbps VSAT connection. The 26 Kbit difference could be do due to packet overhead and the occasional dropped packets.

In terms of maintenance of the system, the service provider, in this case Telkom, did the installation of the VSAT and alignment for us as well as configured the VSAT Network terminating unit (NTU) or modem on our behalf. Should we experience any problems with the network connection, Telkom will repair it for us. However, Telkom is not responsible for the computer(s) networked to the VSAT Internet connection and any faults that occur on the local network are our responsibility. The configuration of the computer on the network was relatively easy. The computer was set to DHCP in order to obtain an IP address and from there we are required to 'log on' to the Internet once every 24 hours – this is apparently done in order that Telkom can bill its customers. Even though this technology is not 'always on' by definition, it would still be a good idea for the consumer to have a firewall and anti-virus software protecting their computers on their local network.

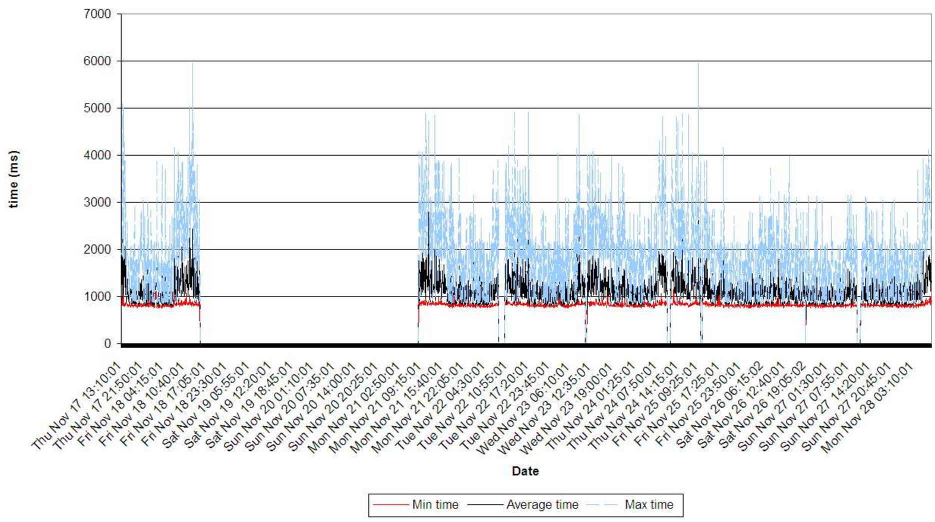


Figure 6.45: Ping test on the Telkom VSAT connection.

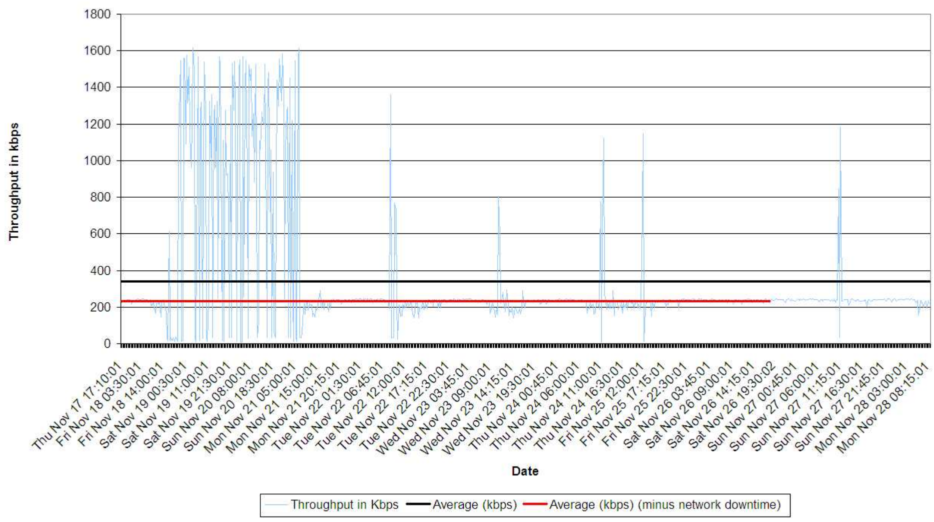


Figure 6.46: Throughput test on the Telkom VSAT connection.

In South Africa, there are two VSAT providers, Telkom [75] and Sentech [67]. As an example, Telkom SpaceStreamExpress128 (SSE128), with 128 Kbps downstream and 32 Kbps upstream with a 1GB cap, has an installation fee of R3100.00, monthly rental of R1243.97 (on a 3 year contract) and a monthly ISP fee of R349.00 [241, 36]. A similar service, the Sentech VStar 128 Internet product, with 128 Kbps downstream and 128 Kbps upstream uncapped, has an installation fee of R3990.00 and a monthly rental of R5186.00 [242]. The Sentech prices are higher as Internet access is not limited and upstream and downstream bandwidth is symmetrical. These prices tend to be high for a school. For example, FDET4 has 1100 learners who paid R120 per annum in 2005. Assuming all the learners pay their school fees (they are not obliged to, and if they can't afford to pay, the school cannot force them to pay) the school has a total budget of R132000. This must cover all running costs, as well as any additional Governing Body-paid teacher posts. If FDET4 were to purchase the cheaper of the two products, (from Telkom) they would pay R14927.64 for the year, which is at least 11% of their total income. Thus in areas where DSL or other high speed Internet is available, satellite is not competitive and therefore only under-serviced markets are natural markets for two-way VSAT Internet access [71, 243].

VSAT communications are expensive not only in South Africa. According to [71], approximately 150 such VSATs are used by high schools in Alaska for two-way Internet access, although the cost per user of this configuration is extremely high. That said, if we consider the trend of ICT prices to decrease with time, it is a realistic possibility that VSAT offerings will become cheaper, especially as more competition is introduced in the telecommunication industry through the new Electronic Communications Act.

In addition, in order to make the cost of VSAT offerings more reasonable we would suggest to schools that they could share one VSAT connection amongst some of the schools. One of the primary findings of [71] is that it is possible to find technologies and system architectures which can provide high-speed low-latency shared access to the Internet for large numbers of users at a low cost.

The Telkom VSAT product delivers what it claims to, namely the 256 Kbps we paid for. The network is fairly consistent. The latency can be frustrating, however it is in line with what we know about communication via a GEO satellite. While the price of the product is relatively high compared to other services, if there are no fixed line alternatives then VSAT technology could be very useful to schools in more rural areas.

### 6.5.3 Fibre optics

Recent advances in optical fibre technology have reduced loss to the extent that no amplification of the optical signal is needed over distances of hundreds of kilometres. This has greatly reduced the cost of optical networking [244]. The choice between optical fibre and copper cable transmission for a particular system is made based on a number of trade-offs. Optical fibre is generally chosen for systems with higher bandwidths than electrical cabling can provide, spanning longer distances [244]. The main benefits of optical fibre are its exceptionally low loss, allowing long distances between amplifiers or repeaters, and its inherently high data-carrying capacity, such that thousands of electrical links would be required to replace a single high bandwidth fibre [244]. One further benefit of optical fibre is that even when run alongside each other for long distances, optical fibre cables experience no crosstalk, in contrast to some types of electrical transmission lines [244]. The demand for high-speed Internet connectivity, coupled with advances in optical technology such as dense wavelength-division multiplexing (DWDM), has dramatically increased transmission capacity and reduced costs, making it economically attractive for carriers to offer dark-fibre and high-bandwidth services in the metro market [245].

While 'fibre to the kerb' is being deployed in the USA and Europe [246] and being used in education networks [247, 248], in South Africa it is still very rare, due to high costs of optical fibre networks. However, that is not to say that there is no potential gain from implementing optical fibre networks instead of copper cable networks. For example, the Tshwane Municipality has built a city-wide optical fibre network in Tshwane [98]. This network allows the municipality to run a PTN across the entire city to all their offices, with plenty of spare capacity which can be sold to local business [98]. Provision is made in the Electronic Communications Act (formerly the Convergence Bill) for municipalities to build their own networks without having to engage Telkom [98] and to openly resell capacity to commercial operators (as a licence-exempt private telecoms network owner) [98]. While the Tshwane network is currently one of few of its kind, with legislation liberalising to allow local governments to enter into such ventures, it is possible that more networks of this nature will be deployed.

The deployment of such a network in Grahamstown would take some time as there are many other problems that the local government has to overcome. Even though Grahamstown East could be considered a "green field" in which any network infrastructure can be deployed, optical fibre is probably not currently a viable option, even though the prices of optical fibre and copper cabling are converging. Grahamstown lacks expertise in building and maintaining a optical fibre network. While Rhodes University runs a campus-wide optical fibre network, it has to outsource maintenance and additional network deployment of single-mode optical fibre connections – the university only has experience in multimode fibre, but single-mode is required in order to travel long distances. While a optical fibre metropolitan area network (MAN) for Grahamstown seems unlikely at present, in the future as prices continue to drop and optical fibre becomes easier to work with, as well as the possibility of an increase in local expertise, a city-wide optical fibre deployment could be possible.

### 6.5.4 Powerline communications

The use of powerline communications (PLC), as discussed in Chapter 2, is attractive as it makes use of the existing electrical grid. In Grahamstown, where most areas have electricity and the local government prioritises the installation of electricity where there is none, this could be a very attractive solution for the population of the town.

The nature of PLC technology (see Figure 6.47) is that bandwidth is shared between users of the same substation [20]. In South Africa substations tend to service 100 to 200 customers [20]. If we imagine 100 customers sharing 45 Mbps, each customer would have a connection of 450 Kbps, which is about eight times the speed of a dial-up connection. Thus it would be possible to provide large portions of Grahamstown East with PLC connectivity, and that connectivity would be relatively fast. As the technology continues to improve and data rates are increased it might be possible to service the same number of customers with higher data rates of up to 2 Mbps [20]. However, good quality of service is dependent on good quality of copper cabling.

The feasibility and quality of powerline communications networks has been researched within the Rhodes University Computer Science Department and CoE during 2003 [24]. At the time, the research found that the PLC system was not cost effective for use in rural development especially when comparing PLC to other broadband solutions such as wireless networks. Rather, it was found that PLC systems could be better utilised as the network technology within a building rather than a last mile solution. Furthermore it was found that while the technology has potential, high bandwidth PLC was at the time very immature. In addition, regulations would need to be drafted and standardised as well as issues such as interference with other high-frequency spectrum users would need to be examined [24].

However, this technology continues to mature. In 2003 data rates of up to 45 Mbps were the highest rates advertised and rare to find, while today 45 Mbps equipment is common, and 100 and 200 Mbps data rates are being cited [20]. The Open PLC European Research Alliance (OPERA), a European project launched with the aim of promoting broadband over power lines (BPL) is set to release its specifications, thus standardising

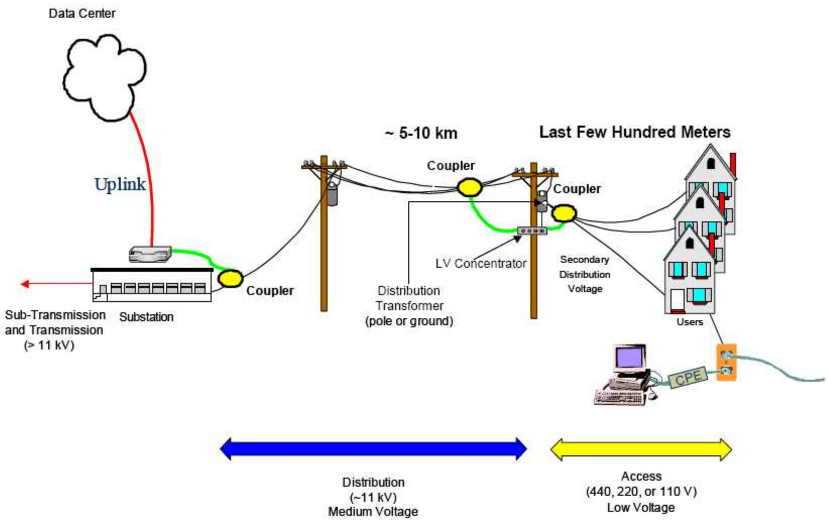


Figure 6.47: Generic PLC system network.

This is based on PLC being used across both the medium- and low-voltage portions of the network, all the way up to the end-user, as depicted in [20].

the use of PLC, by the end of 2005 [249]. Claims of its potential in rural development are still prevalent and, in South Africa, where rural development is important, the employment of PLC technologies could be beneficial. In the Tshwane municipal area, PLC test networks have been deployed through a partnership between the local government and a national ISP, Storm [250, 251, 252]. Through projects like this, local governments can make available access methods that telecommunications companies cannot. South Africa is not the only African country to see the potential that PLC technology offers: in Ghana there are also plans to deploy PLC networks in order to make broadband connectivity available to the country [253]. Further afield, PLC technology is being considered as a viable last mile technology by vendors, such as IBM and Sony [254], and countries, such as the USA [255], alike.

PLC technology is fairly new in South Africa and as such there are currently very few services of this nature available in South Africa and most of them are still experimental. In addition it is not easy to find PLC equipment freely available on the South African consumer market. Thus it is difficult to associate a price to the technology. In terms of maintenance, it is conceivable that, should ISPs offer such services to the consumer market, consumers will be able to purchase all necessary equipment from the ISP, pre-configured. The ISP or service provider would maintain the Internet connection for the customer, but would not be responsible for maintaining the network on the customer's premises unless specifically contracted to do so. As with other 'always-on' broadband connectivity, the customer will require a firewall and anti-virus software in order to protect the network.

As PLC technology improves and data rates increase, together with the already-planned expansion of the electricity supply grid to most areas of Grahamstown, PLC last mile access could become an attractive solution for providing Internet connectivity.

### 6.5.5 WiMAX

The advantages of WiMAX, as discussed in chapter 2, have led to plans to deploy a test network in Grahamstown in order to test the network performance and compare it to that of 802.11. The WiMAX network will be tested both as an alternative to the 802.11 network, as well as a backhaul method for numerous 802.11 hotspots. However, this work is scheduled for 2006 and no results can be considered in this dissertation.

WiMAX, like most other wireless technologies, is considered to be a valuable technology to rural areas where it is expensive to place cable in the ground. Thus, in South Africa, where large portions of the country are rural and without network connectivity, WiMAX could be a potential solution to bridging the digital divide. For this reason, Telkom is testing WiMAX equipment with the hope of being able to deploy the technology in the country. It has been said that users in recent Telkom WiMAX trials were impressed with the technology. Telkom is confident that WiMAX will be able to deliver speeds and reliability equivalent to that of ADSL [256], also indicating that usability of the technology might be fairly high. In Grahamstown East, where little wired infrastructure exists and customers are too far from the exchange for broadband wired services, WiMAX could present a very viable connectivity solution to the residents, schools and businesses.

In our 802.11 network deployment the main problems experienced were hidden nodes and interference while attempting to stretch the technology over distances that it was not designed for. With the advent of WiMAX these issues can be resolved. Firstly, WiMAX covers much greater distances than 802.11; secondly, the hidden node problems are alleviated as clients are allocated time slots in which they may transmit to the parent/root access point, and lastly, interference is minimised by employing OFDM and the use of licenced frequencies [49, 53, 51]. An analysis and performance evaluation of a metropolitan area network using 802.16 found that the achievable capacity of 802.16 is sufficient to provide a powerful wireless last mile technology to potential customers even in a challenging non line of sight (NLOS) environment [55].

The costing and maintenance of WiMAX technology are currently difficult to establish. This is because WiMAX technology is relatively new and at this time has not been experimented with at Rhodes University. As mentioned, the Rhodes University Computer Science Department and the CoE are to begin WiMAX trials in 2006. The equipment to be used in these trials cost the department approximately R4000 per client (school) to purchase. This price is fairly close to the price of 802.11 equipment per school discussed in section 6.3.9. These figures are very promising, especially when considering that the current cost of WiMAX equipment is bound to be high due to being relatively new, and over time these prices should continue to become even cheaper.

## 6.6 Conclusion

In the context of Grahamstown there are numerous network technology options available to schools, some more expensive than others, some more legal than others. From the network deployments of DSL and 802.11, we know that both are viable solutions to connecting schools to the Internet, although 802.11 appears to overcome some of the distance issues and poor quality copper cable problems that DSL suffers from. 802.11, however, is not without its own shortcomings, most notably that of interference. With improved network technologies such as WiMAX and optical fibre, it is hoped that in the future these networks will replace 802.11 and DSL (and other copper cable-based solutions) to further improve network connectivity to the schools of Grahamstown as they would improve on the shortcomings of the current infrastructure.

Furthermore, the current network structure and deployment to the schools has been fairly ad-hoc and each school deployment was approached as a entity in itself, rather than considering a bigger picture of how best to service all the schools in the Grahamstown Circuit. There will therefore be a need for a much more consolidated and organised approach to providing schools with the necessary networking and ICT services that they might require. This consolidated approach is discussed further in chapter 7.

# Chapter 7

# The Grahamstown Circuit Metropolitan Education Network

## 7.1 Introduction

Having reviewed the results from the schools' survey and the network deployments, this chapter presents a possible networking solution, for the Grahamstown Circuit secondary schools, namely the Grahamstown Education Network. The chapter draws from the networks that are already in place, what has been learnt from the schools' survey and network performance tests.

In the Telecommunications Act of 1996 [39], provision was made for a possible national education network that would connect all state schools to the Internet. In addition the White Paper on e-Education stated that the "Departments of Education and Communications will initiate the development of a national education network in collaboration with other relevant government departments" [5]. This national education network would be designed in such a manner so as to serve the goal of universal access for every school and provide high-speed access for learning, teaching and administration [5].

However, the Telecommunications Act of 1996 will soon be replaced by the Electronic Communications Act. The new act makes no mention of any plans to establish a National Education Network for schools in South Africa, thus such a network might have to be established by schools and local communities themselves. However, there have been hints that the Department of Education is negotiating with Telkom to retain the e-rate [97], which subsidises connectivity costs.

This chapter begins by reviewing the current school Internet connections as well as other Internet provision projects for schools and other Grahamstown Internet players such as ISPs. From there possible local loop network models for the Grahamstown Circuit schools, as well as possible Internet connections models for the schools are described. Finally the benefits of having a Grahamstown Circuit Metropolitan Education Network are discussed.

## 7.2 Current Grahamstown networks

From the schools' survey and the network deployment thus far, we have gained insights into and understanding of the current school Internet connections in Grahamstown. The next section discusses firstly the current Internet connections, providing a summary of what was found during the school survey as discussed in chapter 5 as well as including the new network connections that were introduced in chapter 6. This will be followed by an introduction to the Albany SchoolNet project (ASYNC) and the GINX project, as both of these would play a vital role in a Grahamstown education network of the future.

| School | Internet Connection | No Internet Connection |
|---|---|---|
| FDET1 | | x |
| FDET2 | | x |
| FDET3 | x | |
| FDET4 | x | |
| FDET5 | | x |
| FDET6 | | x |
| FHOR | x | |
| FMC1 | x | |
| FMC2 | x | |
| FMC3 | x | |
| IS1&3 | x | |
| IS2 | x | |

Table 7.1: Schools with and without Internet connections.

As per the schools' survey results and the network deployments.

### 7.2.1 Schools' ICT infrastructure

From the data collected in the schools' survey and the networks deployed in the Grahamstown area we ascertained that, of the twelve secondary schools, four were not connected to the Internet in any way (see Table 7.1). Furthermore, of the nine schools which were connected to the Internet, four of the schools were connected through DSL or legacy modem over analogue leased lines to the Rhodes University campus and from there they shared a Telkom Diginet line to their ISP in Port Elizabeth (PE), Internet Solutions (IS) (Table 7.2). This changed during the second half of 2005 and FMC1 and FMC3 now use SDSL modems connecting them at the university to the shared Telkom Diginet Internet connection to PE. The schools involved in sharing the Diginet line are the three independent schools (IS1&3 and IS2) and two (FMC1 and FMC3) of the former Model C schools.

Three of the remaining four schools not yet discussed, were connected to the Internet via the CoE projects, namely the wireless network or the DSL network. FDET4 and FHOR were connected via the wireless network, while FDET3 was connected via the DSL network. These schools were connected to Rhodes University as part of the university network and gain access to the Internet via the university's Internet connection. As 'previously disadvantaged' schools their Internet connection and all associated costs are sponsored by the CoE, as part of ongoing research into various network technologies, such as WiFi and DSL, as well as for community outreach purposes. Table 7.2 depicts the Internet connections of those schools who are connected to the Internet as found in the schools' survey as well as their current Internet connections.

Finally, the remaining school, FMC2, had a standard Telkom dial-up account. However, as mentioned in Chapter 5, it is likely that FMC2 will join the other former Model C and independent schools in the Albany SchoolNet (ASYNC) project and have expressed an interest in doing so [205]. The ASYNC project will be discussed in more detail in section 7.2.2.

All of the IT teachers interviewed expressed problems of high Internet costs (100 % of the IT teachers interviewed); a lack of bandwidth or inability to afford more bandwidth due to high costs (80 % of the IT teachers interviewed); maintenance difficulties (70 % of the IT teachers interviewed); learners gaining access to inappropriate content (50 % of the IT teachers interviewed); and a lack of IT support (30 % of the IT teachers interviewed) as major issues surrounding their schools' Internet access. There are additional

| School | DSL | 802.11 Wireless | legacy modem over Analogue leased line | Dial-up | Internet connection via: |
|---|---|---|---|---|---|
| FDET3 | x | | | | Rhodes University |
| FDET4 | | x | | | Rhodes University |
| FHOR | | x | | | Rhodes University |
| FMC1 | o | | x | | Diginet to IS in PE |
| FMC2 | | | | x | Telkom |
| FMC3 | o | | x | | Diginet to IS in PE |
| IS1&2 | x | | | | Diginet to IS in PE |
| IS3 | x | | | | Diginet to IS in PE |

Table 7.2: Types of Internet connections.

The “x”’ symbol marks the schools’ connectivity methods as per the schools’ survey, while the “o” symbols marks where schools have later changed their method of connectivity.

issues which could affect a school’s Internet connectivity, which include a lack of appropriate ICT policies within the school or a lack of appropriate teacher training; these organisational issues that cannot be solved by any network improvements. However, it is important to be aware of them because it is possible that even the best solution will still not be properly adopted because of organisational issues.

When designing a Grahamstown Circuit Metropolitan Education Network all the needs of the schools and technical issues that they face will need to be taken into consideration in order to make sure that the network will address all these issues. In other words, in order for the network to have the highest chance of being adopted by the schools the network will need to be:

- relatively cheap so that schools can afford to be a part of it, or so that sponsors can be enticed to pay for it on the schools’ behalf
- provide sufficient bandwidth to meet the teaching and learning as well as administrative needs of the individual schools
- relatively easy to maintain
- prevent the learners from gaining access to inappropriate content on the Internet, such as pornography
- designed in such a way that it is easy to support and maintain by people and organisations who are willing to be involved, such as the CoE or the Albany SchoolNet project (ASYNC).

### 7.2.2 Albany SchoolNet (ASYNC)

The Albany SchoolNet project (ASYNC) is a collaborative effort in the geographical area of the former Albany District (now known as the Makana District) in the Eastern Cape, South Africa, to enable primary and secondary schools or educational institutions to gain access to the Internet [257]. The Albany SchoolNet project is a subset project of the Eastern Cape SchoolNet project, which was started to enable Internet connections for formerly disadvantaged schools [257]. Thus the original idea behind the projects was that better resourced schools participating in the regional SchoolNet would be able to share skills and experience with schools less fortunate than themselves [257]. The schools currently involved in Albany SchoolNet are

FMC1, FMC3, IS1&3 and IS2. Thus Albany SchoolNet is a not-for-profit organisation that consists of IT members from each of the four schools, some volunteers and paid associates [205].

Rhodes University was the first institution in South Africa to gain access to the Internet and in 1989 they extended this access to IS1, which is believed to be the first school in South Africa to have gained access to the Internet [257]. As IS1&3 merged and grew, the school began to use too many of the university's network resources. Rhodes would have preferred to charge for the school's Internet usage (and increased their own capacity), but this idea clashed with the upstream provider agreement that they have with TENET and so ASYNC was born [205]. Thus Albany SchoolNet (ASYNC) started out as a method for the schools to afford to be connected to the Internet. Initially ASYNC connected to Albany Net (then known as EastCape Net), a local Grahamstown ISP, but Albany Net could not provide ASYNC with sufficient bandwidth and so ASYNC changed their ISP to Internet Solutions (IS) [205], a larger national ISP. As more labs were built at the various schools, the bandwidth bought from Internet Solutions was increased. Over time a bandwidth sharing system was developed [205]. The remainder of the information in this section about Albany SchoolNet was provided by [205] during a personal conversation.

ASYNC schools share a single connection to IS, a 448 Kbps Diginet line. The bandwidth sharing system allows each school to get at most four times the bandwidth, or at least the bandwidth for which they have paid. In addition, the ASYNC schools are able to share access to each school's caching proxy servers. Furthermore, intelligent spam tools are able to learn from four times the volume of mail (i.e. for the mail being sent to each of the four schools, IS1&3, IS2, FMC1 and FMC3), reducing spam for all the schools. Providing services at a shared, central point is more cost-effective than duplicating those services at each school, while minimising the necessary maintenance.

Currently, ASYNC offers four primary 'value added' services: mail exchange, web services, DNS and the bandwidth sharing system. However, due to high bandwidth prices coupled with the growing demand for bandwidth, ASYNC is re-evaluating its current infrastructure. ASYNC plans to increase its infrastructure by installing new servers and providing new services as well as increasing the shared bandwidth. To the existing 448 Kbps line they will add a 1 Mbps ADSL connection. Eventually they plan to reduce the Diginet line to the minimum that they require and increase the number of 1 Mbps lines to three. Retaining the Diginet line allows them to retain their static IPs in order provide services such as web hosting and mail transport. The faster ADSL connections will provide them with the downstream bandwidth that the four schools require for web browsing and other applications.

ASYNC is increasing the number of servers it has in order to provide new services to the current schools as well as to provide services for some of the other schools in Grahamstown East. The four ASYNC servers, comprising new and old, have varying specifications, namely, a proxy server with a fast disk and a substantial amount of RAM (2GB), which is tailor-made to cache small and large objects and manage bandwidth usage; a services server, which performs all other required services: web, mail exchange, DNS, databases, mailing lists, statistics, voice and video, backups and documentation sharing; Windows update server, which is used to update Windows computers at the schools; and a firewall, which protects the ASYNC network and routes between the VLANs, manages non-web bandwidth usage, collects statistics for the services server, provides tunneling services and VPNs (Virtual Private Networks). ASYNC hopes for the following benefits from these upgrades: voice and video services between schools and possibly Rhodes University; a computer society for the schools, similar to the Rhodes computer society, RUCUS, which would hopefully be able to liaise with RUCUS; an on-line Wiki where schools can share ideas and collaborate; off-site backup services; and VPN access for staff who work at home or travel.

Once these infrastructural improvements have been completed, ASYNC plans to take on more outreach projects in line with the original vision of the Eastern Cape SchoolNet [257]. These projects could include

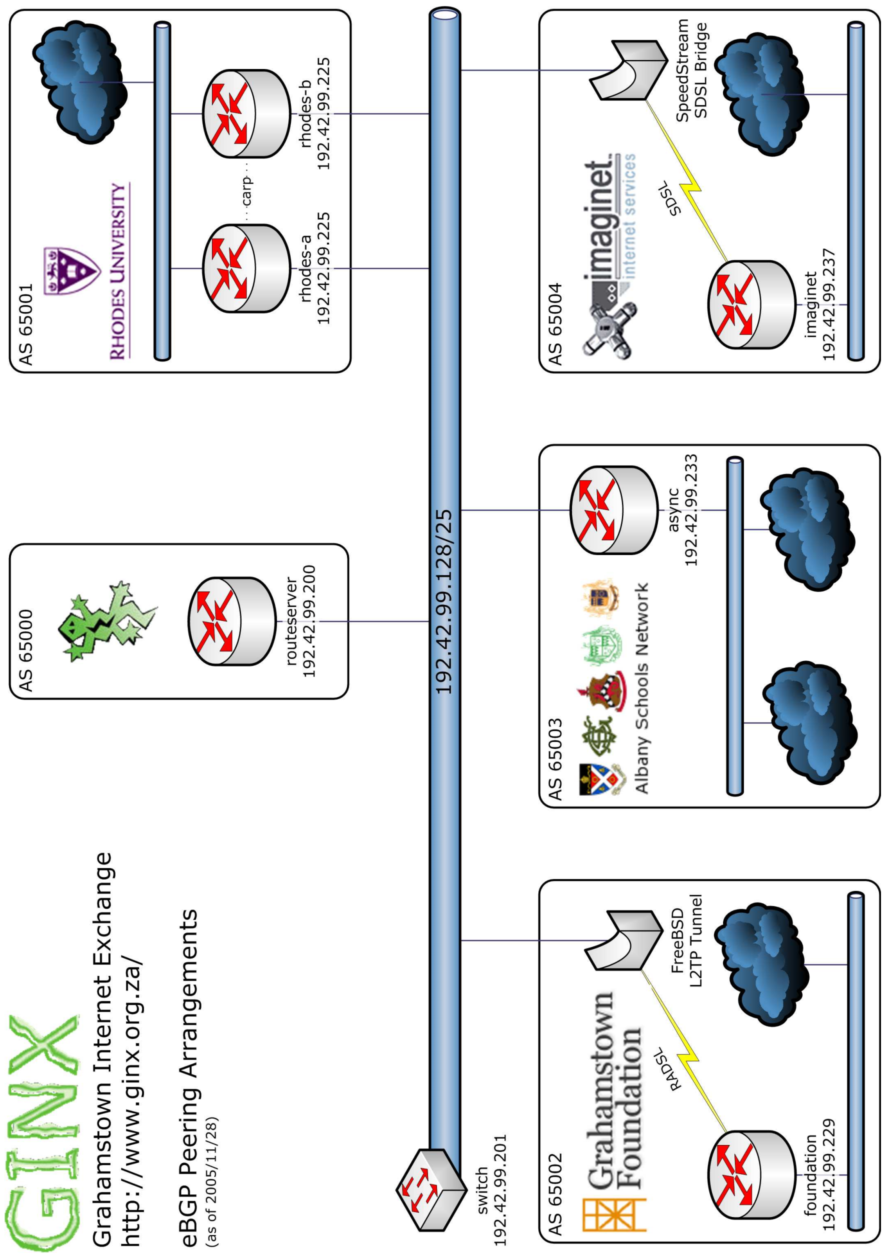


Figure 7.1: The GINX network and participants.

videoconferencing lessons from more affluent schools to disadvantaged schools, much like the work being done by St Alban's College discussed in Chapter 3. In addition, schools would be able to collaborate on teaching content and share knowledge and thus lift the various skill sets found in all the schools.

### 7.2.3 GINX

The Grahamstown Internet Exchange (GINX) [258] is a non-profit, community-based project co-ordinated by Rhodes University. The aim of the project is to provide better network connectivity between autonomous networks located in and around the Grahamstown Circuit [258]. Networks connected to GINX include the Rhodes University network, the Albany SchoolNet network, the Grahamstown Foundation network and Imaginet (a local ISP) [258]. Figure 7.1 depicts how the various parties are connected to GINX.

An Internet exchange involves the peering of independent networks in order to exchange Internet traffic and work together for the benefit of each of the independent networks. "Peering involves three elements:

physical interconnection of the networks; technical liaison between the networks in order to allow exchange of routes; and commercial and contractual peering agreements [259]."

Peering is considered as an agreement, usually between ISPs or other network providers, as to how traffic will be exchanged between networks. Peering points are mostly located in a single place, referred to as co-location centres [259]. GINX allows for a local Internet loop within the town of Grahamstown and allows Grahamstown Internet players to peer and thus conserve some bandwidth in their interactions with each other.

In terms of the schools, GINX allows ease of access to resources that are within Grahamstown, such as ISPs and the university. In effect GINX is what connects the school networks to other local networks and resources and as such would be an integral part of ensuring that the schools connected on the ASYNC local loop and the schools connected on the CoE local loop are able to communicate and share resources.

## 7.3 The Grahamstown Circuit Metropolitan Education Network: local loop

This section presents local loop options that schools or organisations, working on behalf of or with schools, could employ in building the Grahamstown Circuit Metropolitan Education Network. The local loop, also referred to as the last mile connection [17], is the connection from the premises of a customer to the central exchange of the service or network provider. Originally the local loop was a copper cable pair(s) to the customer's premises and carried voice calls, but as technologies have improved and data networks have become more important, the local loop is used to describe any method of connecting the users to the network [260]. This can be done wirelessly or via other wired media such as optical fibre. A slightly alternative method and way of thinking is to build a metropolitan wide "LAN", called a Metropolitan area network or MAN. A MAN is a large computer network that spans a metropolitan area, such as a city or a town. MANs typically deploy high bandwidth wireless technologies or optical fibre to connect all the sites within the MAN to the network [261].

From Table 7.2, we know that currently the local loop connection for the majority of the Grahamstown Circuit secondary schools is either via xDSL or an 802.11 wireless network. In the next section the various local loop options that may become available to the secondary schools in the Grahamstown Circuit are considered. The discussion progresses from what we currently have and are most likely to see in the immediate future, to a more long term and ideal plan of building our own MANs. This local loop will hopefully connect each school in the Grahamstown Circuit to the other schools in the Grahamstown Circuit and any central services that might be offered.

### 7.3.1 Regulated exchanges

Currently Telkom is the only supplier of telecommunications infrastructure in South Africa [39]. However, the Second Network Operator (SNO) has recently been licenced [262], in November 2005, and should commence business during the course of 2006 [87]. With the increase in competition, due to deregulation through the Ministerial Determinations and the Electronic Communications Act, as well as the pending licencing of the SNO, is it possible that either Telkom or the SNO will place an exchange in Grahamstown East. With an exchange in Grahamstown East it would be possible for schools (as well as surrounding business and homes) to initially purchase DSL connectivity as it would place the schools within the 5 km radius of DSL. Furthermore, other network technologies could be employed with a local exchange including 802.11 wireless solutions, WiMAX wireless solution and optical fibre.

Alternatively, Telkom/SNO/any other licenced party could build their own optical fibre network (MAN) within the city of Grahamstown, so that there would be optical fibre to every street. The telecommunication company could then decide to terminate the optical fibre for a street in a box on the side of the road which could then contain a DSLAM. From the DSLAM DSL could be run to each of the houses on that particular street, thus effectively building a optical fibre to the kerb network within the town.

Thus the schools in Grahamstown East could be connected to a local exchange or a MAN, which in turn would be connected to the telecommunications company's backbone – to which all the telecommunication company's exchanges or MAN networks would be connected and therefore the Grahamstown East schools' traffic could be routed to anywhere, including to the Albany SchoolNet servers on Rhodes campus.

### 7.3.2 Local loop unbundled

It is hoped that with local loop unbundling (LLU) the price of telecommunications in South Africa will drop further as it has around the world where other local loops have been unbundled [263, 264]. LLU is when any telecommunications company may gain access to the last mile connection from the central exchange to a customer's premises. Previously the local loop will have belonged to the incumbent telecommunications operator – in South Africa, Telkom. Currently in South Africa Telkom has sole rights to the local loop, but there has been much discussion about unbundling the local loop in order to increase competition in the market [265]. Should the local loop be unbundled then any telecommunication company would be able to place their own equipment in the exchanges – leasing space from the exchange owner, such as Telkom – and connection directly to the customer's premises and then make use of their own backbone networks to transport data traffic from the exchange, without having to rely on the incumbent.

LLU could result in lower telecommunication prices for schools as well as potentially allowing school network organisations such as Albany SchoolNet to gain access to the local loop and thus provide additional services to the schools. It could be possible for Rhodes or the CoE or even Albany SchoolNet to have a point of presence within local exchanges in Grahamstown. Thus the schools in Grahamstown West and East (assuming an exchange has been built in Grahamstown East) could be directly connected to either the Rhodes/CoE network or the ASYNC network.

### 7.3.3 Local government PTN

According to the Electronic Communications Act local governments (municipalities) will be allowed to apply for a Private Telecoms Network (PTN) licence [98]. This licence will allow them to legally build their own municipal networks and then sell off spare capacity to other business and consumers [98]. Thus it is possible that the local municipality, Makana Municipality, could apply for its own licence and begin to build a Grahamstown city wide network (or MAN). The network could be built using any number of technologies including, WiFi, WiMAX and optical fibre.

Furthermore, the Makana Municipality could involve other interested parties, including the CoE. The effect would be that the local government could outsource the building of the network to the CoE (or any other interested parties such as ISPs). Similar network deployments are currently taking place in both Knysna [266, 267, 268] and Tshwane [98, 269]. Outsourcing the network deployment to the CoE would ensure that the current wireless local loop that was built during the course of this study, for experimental purposes, is legal. In addition, the WiFi equipment that is currently being used in the experimental network, could be upgraded to use WiMAX technologies in order to produce a better network (i.e. increased speed and reliability with decreased latency and Fresnel Zone diffraction), with improved quality of service.

Currently the 802.11 wireless network that was deployed in Grahamstown as discussed in chapter 6, suffers from interference from other networks within the city, as well as Fresnel Zone diffraction on a number of the wireless links. Furthermore, the 802.11 wireless network is being stretched far beyond its

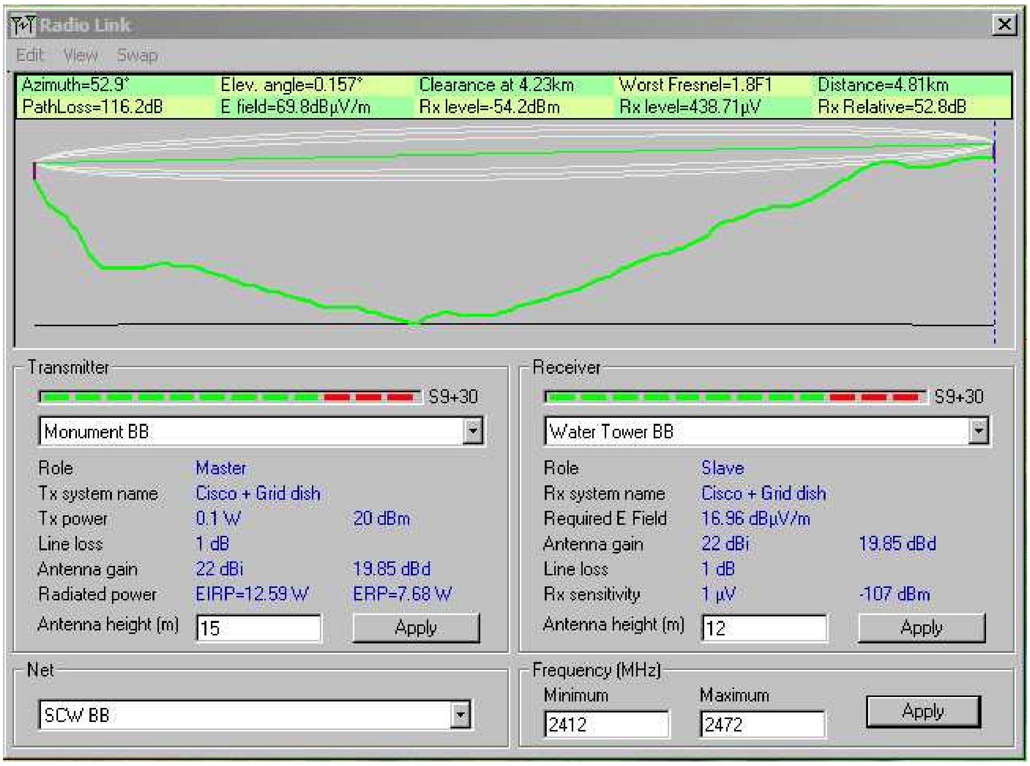


Figure 7.2: The Fresnel zones from the Monument backbone AP to the water tower bridge backbone, using 2.4 GHz spectrum.

The image is a simulation of the connection in Grahamstown. From a map the profile of the route from the Monument to the water tower is drawn. The two purple lines indicate the Monument and the water tower, while the green line indicates the connection between the two. The white ellipses surrounding the green connection line are the Fresnel zones. The innermost ellipse is the first zone while the outermost is the third zone.

recommended range. The simplest means for improving this network would be to build the network using the WiMAX technologies. In using the WiMAX technologies we can use licence spectrum or the higher licence exempt spectrum around 5 GHz. However, licenced bands would be best as they would provide a guarantee that no other wireless ISP would be operating in that spectrum. This would substantially minimise the interference experienced on the current wireless network deployed in Grahamstown.

In addition, using higher (than 2.4 GHz spectrum used in Wi-Fi) spectrum would reduce the effects of the Fresnel Zone diffraction. The radius of the Fresnel Zones is dependent on the inverse of the frequency used in the wireless network, thus as the frequency is increased the radius of the Fresnel Zone is decreased. This will result in a “tighter” or narrower signal that will be less prone to projections from the ground causing Fresnel Zone diffraction, as can be seen in Figures 7.2 and 7.3.

In addition, WiMAX technologies have also been designed to be used over distances of up to 50 km [50, 51]. Thus we would not be stretching the network technology beyond its recommended limitations, but rather employing it well within its limitations. For these reasons WiMAX technologies are the logical next step in improving the quality of service and performance of the wireless network to the schools in the Grahamstown Circuit.

As the network matures and there are more people making use of it, it would be possible to improve upon it further by building the network using better technologies that will improve the quality of service that the network provides, as well as increase speed and reliability, while decreasing latency. An example of

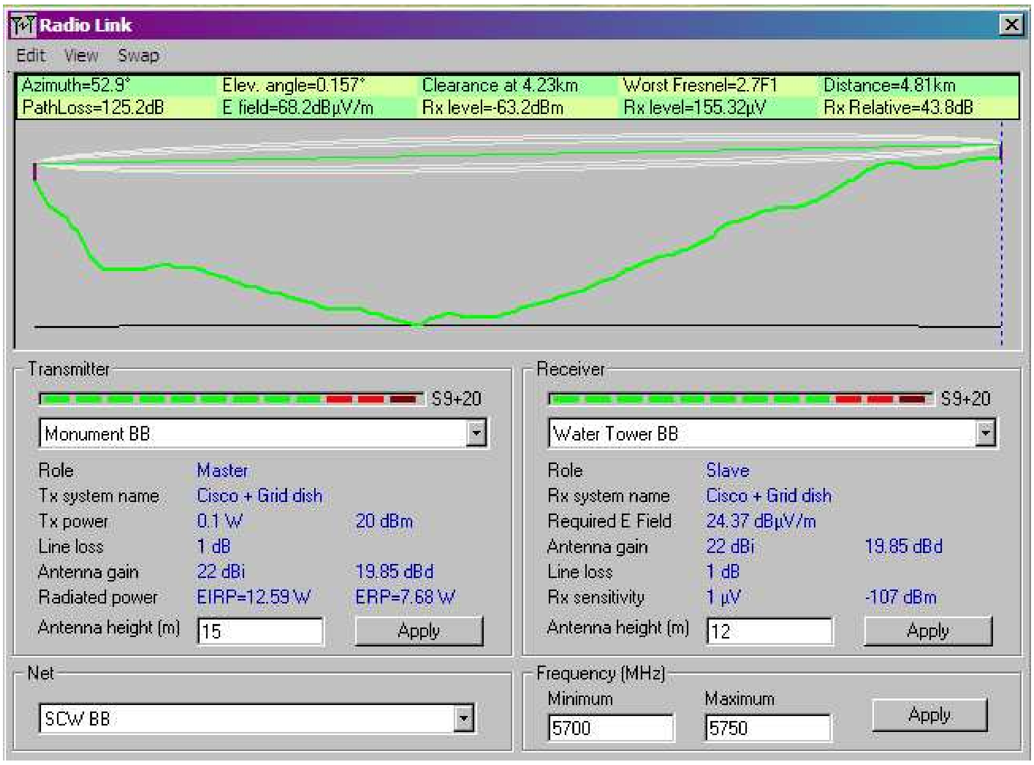


Figure 7.3: The Fresnel zones from the Monument backbone AP to the water tower backbone bridge, using 5.7 GHz spectrum.

The image is a simulation of the connection in Grahamstown. From a map the profile of the route from the Monument to the water tower is drawn. The two purple lines indicate the Monument and the water tower, while the green line indicates the connection between the two. The white ellipses surrounding the green connection line are the Fresnel zones. The innermost ellipse is the first zone while the outermost is the third zone.

technology that would improve these variables over those of WiMAX would be optical fibre, which is being deployed in the Tshwane municipality [98].

### 7.3.4 Summary

There are many local loop possibilities that could be available to schools in the future, via exchanges being built in Grahamstown East, local loop unbundling or through building PTN networks. Currently the simplest of all these methods and the one which could be implemented right now (i.e. 2006) would to build our own networks and thus our own local loop. For the schools that are not currently connected to the local loop, of which there are four (Table 7.2), the simplest method would be to add them to the 802.11 wireless local loop access network, with a view to upgrading that network to WiMAX in the future and possibly optical fibre in the very distant future.

## 7.4 The Grahamstown Circuit Metropolitan Education Network: Internet connections

An Internet connection would connect the schools of Grahamstown to the rest of the country and the rest of the world, i.e. connect the schools' local education network (the local loop connections) to that of a bigger world wide network. This section considers the various Internet connection options available to schools in the Grahamstown Circuit, beginning with the current solution and ending with what I consider to be the most appropriate solution – a national education network. It is hoped that over time schools will work their way through these solutions, eventually connecting to the Internet via a national educational network.

### 7.4.1 Centre of Excellence

The current method of gaining access to the Internet, for three schools (FDET3, FDET4 and FHOR) in Grahamstown East, is via the Rhodes University network. Both the CoE wireless and DSL networks terminate in the DSLAM in the CoE technical area and are routed as CoE generated traffic from there to the rest of the campus network and the Internet. In effect the Grahamstown East schools connected to the Internet via the CoE projects are part of the greater Rhodes University network and are connected to the Internet via the university's Internet connection.

Each school has the same amount of access as an individual Rhodes student, which is 13 MB per day that they may download over the Rhodes Internet connection. The 13 MB per day translates to approximately 390 MB per month, which is substantially less than the minimum amount allowed on Telkom networks, which is 1GB. Furthermore, Rhodes' total bandwidth going out from campus is 6328 Kbps (6.3 Mbps), which is shared by all 1300 staff, 6500 students and the schools (figures are per the year 2005).

Should schools in Grahamstown East decide that this is insufficient bandwidth for them, then they would need to find the necessary funds and join the ASYNC network. However, most of the schools tend to find 390 MB per month more than enough and from the usage graphs (Chapter 6 – especially the usage graphs for FDET3, running the network tests on their network doubled their traffic), it was clear that schools in Grahamstown East were not flat-lining any of their available bandwidth, nor the amount of data they were allowed to download.

### 7.4.2 Albany SchoolNet (ASYNC)

Short of a national education network, the onus will rest on each individual education institution to provide its own connection to the Internet. In the case of Albany SchoolNet this is done via the use of Telkom's

Diginet products and ADSL together with their ISP, Internet Solutions (as discussed in section 7.2.2). As ASYNC currently has only four schools on board, the single Diginet line and the three ADSL lines will probably provide sufficient bandwidth for the schools to serve web pages and receive mail as well as search and download from the Internet.

However, as more schools from Grahamstown East become more and more ICT literate and the economy of the hosting communities is lifted – moving away from the poverty line – it is possible that these schools might also wish to join the Albany SchoolNet project officially. This would involve them contributing funds to the project, allowing them to benefit by having access to the shared Internet connection as well as proxy server caches. As the ASYNC project grows with more schools joining in, they would need to once again increase their total bandwidth, which could be done by purchasing additional ADSL accounts. In fact this is the initial solution that ASYNC is most likely to adopt. However, as the prices of technologies decrease and competition increases, further lowering prices, it is conceivable that in some years' time ASYNC might be able to afford a direct connection to the Internet [270], via Telkom or the SNO or any other service provider who is allowed to offer those services. This could mean that ASYNC would have a optical fibre connection connecting them directly to the Internet, providing them with as much bandwidth as they need or can afford.

### 7.4.3 The national education network

In South Africa most of the tertiary institutions are members of TENET, the Tertiary Education Network. TENET is a non-profit organisation whose mandate is to manage the Internet needs of the various universities and tertiary institutions [271]. TENET liaises between the tertiary institutions and the service, technology and network providers [271]. Currently in South Africa such an organisation does not exist on behalf of the schools. However, this could change as there is provision for such a network for the schools within the Telecommunications Act of 1996.

The White Paper on e-Education [5], which is intended is to guide the use of ICTs in education in South Africa, refers indeed to the Telecommunications Act 103 of 1996. The White Paper states that the Communications "Minister shall, with the concurrence of the Minister of Education, establish an entity to construct and operate an educational network" [39]. The White Paper further states that the "Departments of Education and Communications will initiate the development of a national education network in collaboration with other relevant government departments" [5]. The White Paper claims that such a network will be designed to serve the goal of universal access for every school and shall provide high-speed Internet access for learning, teaching and administration.

However, the Telecommunications Act of 1996 will soon be replaced by the Electronic Communications Act. The new Act contains no provisions to secure a national education network for schools in South Africa, and schools might therefore have to ensure the development of such a network themselves. While there have been hints that the Department of Education are negotiating with Telkom to retain the e-rate [97], there appear to be no further plans to implement a national education network.

However, if schools across the country begin to implement their own small local loop networks with other schools and organisations in their local community, each building their own local education network, it may become possible to establish a network that links those smaller networks together in order to form a national education network. The Department of Education, for example, could contract Telkom, the SNO or any other licenced infrastructure provider to build such a backbone for all the local school networks on its behalf, similar to the tertiary education network. In all likelihood such a backbone network would be built out of optical fibre and thus all the other schools on the national education network in the country, as well as to any education portals and services run by the Department of Education would be networked together. With all South African schools connected to the same network, the Department of Education would be able to liaise with them on a regular basis, whether to provide the schools with managerial information or educational content.

## 7.5 Network services

Having discussed the potential network implementations in terms of both the local loop access and Internet access the benefits of having a Grahamstown Circuit Metropolitan Education Network are now considered. Firstly in terms of the benefits of centralised services and the collaboration that centralised services could encourage. Then the perceived benefits in terms of bridging the digital divide through the deployment, use and adoption of ICTs in schools are presented.

### 7.5.1 Centralised services and collaboration

As a result of the proposed network solution, FDET1, FDET2, FDET3, FDET4, FDET5, FDET6 and FHOR would, initially, all be connected to the Rhodes University network through the CoE, while FMC1, FMC2, FMC3, IS1&3 and IS2 would be connected to the Albany SchoolNet servers (which are housed in the Rhodes server room). Through GINX, schools on the CoE network would easily be able to communicate with the schools on the Albany SchoolNet network. All the secondary schools in the Grahamstown Circuit would thus have access to central servers and services. Centralising servers and services is desired as this solution is scalable. Historically, the support work that the CoE has done with the schools was in an ad-hoc manner and it approached each school as if it were an island unto itself and not a part of a bigger problem that many schools in the Circuit faced. Each school was presented with a model of having its own servers and services per school. However, as more schools required help it became obvious that certain services decentralised was not easily manageable and not scalable.

Thus if we stop to consider the alternative to centralisation, namely, decentralised services and each school with its own server performing such services as mail and web hosting, there will potentially be at least thirteen separate servers that will need to be managed and maintained. While the independent schools have the funds to hire an IT specialist for each school, state schools are not able to do likewise. Either the CoE-hired school technician (who is generally a Computer Science postgraduate student) or the Albany SchoolNet technician (historically also a Rhodes student) have to take care of those schools and the more servers there are at the various schools, the more work those two people would have to do. There is also the added cost of each school having their own entry-level servers, instead of sharing the costs and buying a few to share amongst themselves. A system of centralised services of mail and web hosting, etc is a much more scalable solution. More schools can be added to the network without making the workload for the technicians unmanageable, nor substantially adding to the schools' costs.

All services, mail and web hosting, DNS, possible voice and video servers, etc would then be centralised and all schools would be able to gain access to them and make use of the services that they supply. In addition, more schools could easily join the network and introduce the of ICTs in their schools. These central services could scaffold collaboration between the various schools. The advantaged schools would be able to share resources with schools that are less fortunate than themselves. This could be done in a number of ways. Some of the possible central services and their perceived benefits are discussed next in more detail. The proposed Grahamstown Circuit Metropolitan Education Network, with centralised services, can be seen in figure 7.4.

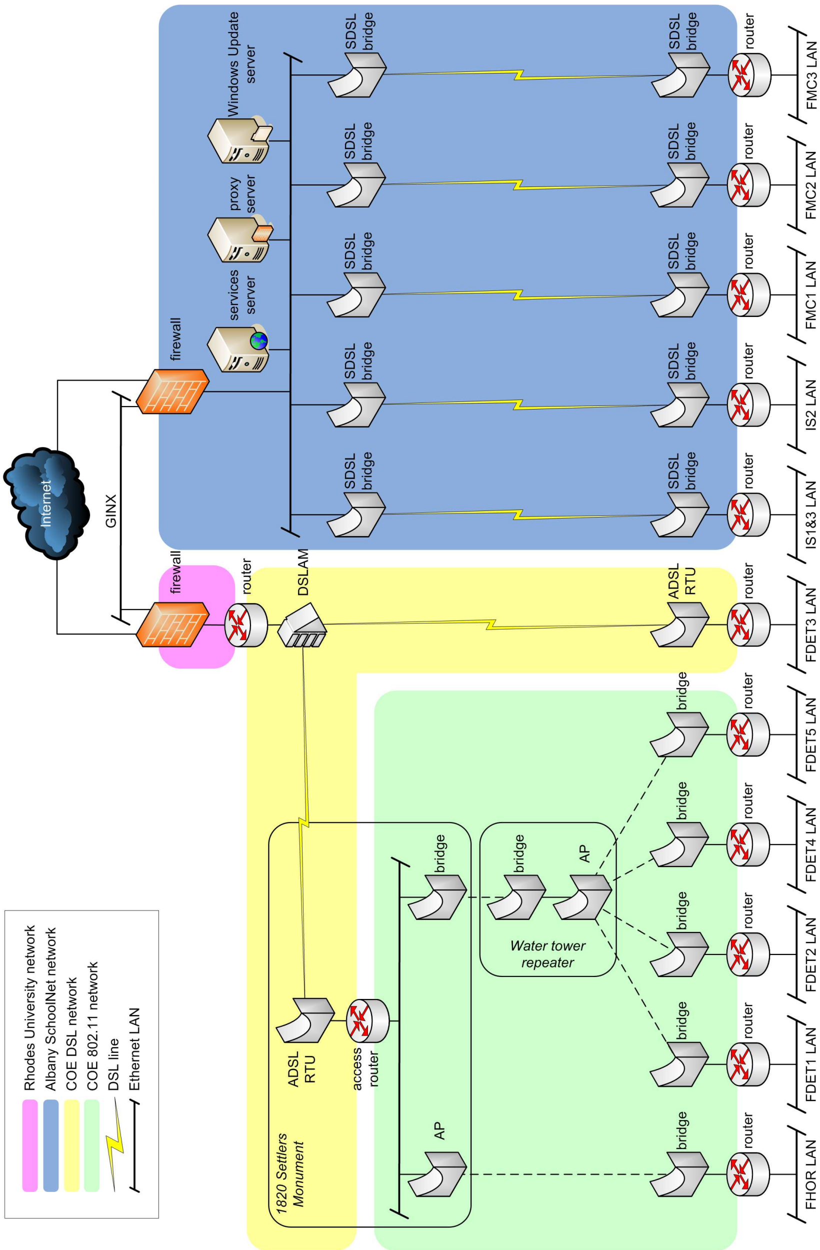


Figure 7.4: The Grahamstown Circuit Metropolitan Education Network and proposed central services

making use of the current infrastructure already available in Grahamstown. As time goes on this infrastructure can be upgraded and changed, however the basic principles will still apply.

**Mail**

The planned central servers could provide email for each of the schools should they decide that they want the service. Not only would the central email service allow schools to communicate with people all over the world, giving them access to experts all over the world [106], but it would also allow the local schools to be part of mailing lists of interest. For example, all the technical people in each of the schools could be part of a technical mailing list, which they could use to ask each other technical questions – there is bound to be one member of the list who would be able to help another member as they experience similar problems in their schools. Furthermore, email will allow schools to lodge help requests from technical people within the CoE or the technical team at Albany SchoolNet. In addition, there could be an ICT in Mathematics (or any number of learning areas or subjects) mailing list, in which the Mathematics teachers at each of the schools could share ideas about how to integrate the use of ICTs into teaching Mathematics. Teachers would be able to share teaching material such as lesson plans, worksheets, rubrics or even tests.

**Web services**

A central web server would allow the provision of services such as central education web portals, which each of the schools could use as a central storage media for educational content. Teachers from each of the schools would be able to contribute and view lessons for various subjects. This would allow teachers to collaborate on lessons that they teach, learning from each other.

Furthermore, a school Wiki could be created, which would be used to store information such as the ICT infrastructure of each school, its capabilities, who is responsible for the infrastructure and other details that schools might need to know about each other, as well as making that information easily accessible to the technicians that work with the schools.

Another useful tool that a web server could provide would be a helpdesk system, where schools can log onto a helpdesk web page and add a ticket requesting for technical help at their school. Technicians could reply to these, making times to come and view the problems, or possibly fix them remotely and then notify the school of what they have done. This would create a "paper trail" of what has happened in the schools and make sure that all issues are addressed and not forgotten about.

In order to help schools prevent learners from accessing inappropriate content a similar scheme to that of the proxy cache server system could be put in place. Namely, that software (such as *surfcontrol [272]* or the like) on local school servers could be used to prevent learners from accessing inappropriate content and the same or similar software could also be run on the central proxy server as an additional preventative measure.

All the schools in the Eastern Cape may apply to Albany SchoolNet (who have been authorised by the Eastern Cape SchoolNet) for a ecape.school.za domain name for their school and then create their own school web pages [257]. Few schools in Grahamstown have done this, but it is hoped that with central web services more schools will take up this opportunity and create their own school web sites.

**DNS**

"The Domain Name System (DNS) is a system that stores information associated with domain names in a distributed database on networks, such as the Internet [273]". The purpose of DNS is to provide the associated IP address with a domain name. In other words it consists of a database which knows about various domain names and their associated IP addresses, which are necessary in retrieving information from a computer registered with a particular domain or in order to send data to that computer [273]. DNS also contains information about which mail exchange servers will accept incoming emails for a particular domain name [273]. Domain names are used when we visit URLs on the web using our web browsers or when we send email to someone we know. Using the centralised DNS services would mean that the web and mail services that Grahamstown Circuit schools are offered will work correctly. In other words, mails addressed to headmaster@FDET1.ecape.school.za will find the correct recipient, while web searches for http://www.FDET1.ecape.school.za will find the correct web page.

#### Proxy services

A proxy server allows clients on its network (i.e. computers in the school labs or offices, etc) to make indirect connections to other computers on different networks on the Internet [274]. The computers on the network, i.e. those found in the schools, will connect to the proxy server and request either a connection to another computer, or a file, or any other available resource on the remote server [274]. The proxy server then provides the requested item or resource to the client by either fetching it from the specified server on the Internet, or fetching it from its own cache [274]. The cache is a collection of duplicates of the original item fetched off the Internet and is employed in order to save bandwidth [275]. The proxy server keeps copies of the content it fetches from the Internet, for a specified time, in order to provide that content to other clients when they request it, without having to use the Internet connection [275].

#### Voice over IP

Voice over Internet Protocol (also called VoIP) is the routing of voice conversations over an IP network [276]. VoIP research and development at Rhodes University, and certainly at many other institutions and business all over the world, is taking place on a large scale. Thus providing VoIP services to the local schools would a simple process. One of the central servers could be configured to run as an *Asterisk* [277] server, providing VoIP services to the local schools. Thus they would be able to call each other and anyone else with an extension on the server, allowing them to have easy access to CoE and ASYNC technicians as well as being able to easily collaborate with each other. In addition, being connected to the Internet will allow them to access WAN VoIP services. Using softphone software on their computers they would be able to phone other people all over the world running similar software, all of which would be connected to the same asterisk server. Services such as these would hopefully help to reduce the overall spending on telephone bills for schools in financial difficulty.

#### Videoconferencing

Through the use of videoconferencing technologies, learners are able to learn collaboratively with other children who could be anywhere in the world [107]. Should schools not be able to invest in specific videoconferencing equipment it might be possible to make use of webcams in order to achieve something similar, or alternatively teachers could record their lessons and place them on the central servers from which other teachers could easily download them and view them at their leisure. A similar project is being undertaken in Mamelodi, in the Ulwazi project [62], where videoconferencing lessons take place with the help of web cameras and high speed Internet connections connecting the various schools [161]. The lessons are then facilitated by one teacher at one of the schools while the learners are in multiple locations [160].

### 7.5.2 Benefits of having a local school server

Having discussed the benefits of centralised services through the use of central servers, it is also important to note that, assuming schools could afford it, having a local school server also has its benefits. Entry level servers, or cheaper desktop machines, could be employed at the various schools in order to provide them with File server services and possibly an additional firewall and routing from their school labs (or LANs) to the local education network. In addition, the local school server could also perform some web caching to help alleviate bandwidth demand and be a part of the proxy server network employed by ASYNC as mentioned in section 7.2.2.

The proxy system of checking all proxy cache servers connected to it before fetching the web page off the Internet is currently the best way for alleviating bandwidth demand and the IT specialists at IS1&3, IS2 and FMC1 endorsed this view. The IT specialist at IS2 spoke of how they used their cache server for 60% of the web pages that were requested which was helpful in alleviating their bandwidth problems. Thus those schools that can afford a server which can do caching would benefit from being able to use their cache as well as other caches first before resorting to fetching the page from the Internet. Schools which cannot afford a server would still be able to benefit from those schools who do have enough money for a server.

## 7.6 Conclusion

In section 7.2.1 some of the major issues that IT teachers/specialists commented on was recapped. These issues were that the cost of Internet access was high, that they had a lack of bandwidth (generally due to high costs), that learners had access to inappropriate content, that they had trouble performing necessary maintenance and that there was a lack of ICT support. This chapter outlined how the proposed Grahamstown Circuit Metropolitan Education Network could work to reduce or prevent the problems experienced by the schools.

The high costs of Internet connection experienced by schools could be reduced in this model through the collaboration and sharing of costs on the ICT infrastructure. Through pooling their funds and resources schools could afford to achieve more than they would on their own. This would also help to alleviate the lack of bandwidth, which is further aided by the proxy cache server system. While in order to help schools prevent learners from accessing inappropriate content, software such as *surfcontrol [272]* could be used.

The lack of support and inability to provide necessary maintenance would be curbed through a central ticket system which they could use to lodge tickets of infrastructural issues that they are experiencing. In addition, through mailing lists and VoIP services, IT teachers/specialists across all schools would be able to collaborate with each other and thus gain support from each other.

# Chapter 8

# Conclusion and recommendations

## 8.1 Summary

This dissertation described the work done during the course of this study in order to answer the research question of "What networking technologies and models can support secondary schools in the Grahamstown Circuit in implementing their vision for integrating ICT into schools?" The dissertation consisted of eight chapters, two of which were more Computer Science in orientation, namely chapter 2 and chapter 6, while chapter 3 and chapter 5 were more educational in their orientation, the remaining four chapters, 1, 4, 7 and 8, were a hybrid of both orientations and attempted to bridge the two disciplines.

Chapter 1 introduced the work done during this research study. The chapter introduced the problem area by presenting background to the study as well as the research design in terms of aims, research questions and methodology. This chapter was the first of the hybrid chapters and attempted to present the problem that this research wished to address, highlighting the need for the two disciplines of Computer Science and Education to work hand in hand. The chapter concluded with the structure of this dissertation.

Chapter 2 presented an overview of the various networking technology solutions and telecommunication legislation in South Africa. This chapter introduced the reader to specific networking technology and legislation in order to provide the background knowledge that would be necessary in building appropriate networks for schools in South Africa.

Chapter 3 discussed the possibilities afforded by networks to schools and introduced the reader to current ICT-in-education projects taking place in South Africa. Furthermore, the chapter discussed current ICT-in-education policies, perceived gaps within those policies and suggested ways to fill those gaps. This chapter presented the reader with background information regarding ICT-in-education in South Africa in order that appropriate technologies from chapter 2 might be recommended to schools.

Chapter 4 presented the research design underpinning this study, namely the research orientation, introduction to the research site and participants, tools and activities as well as the data analysis methods employed. Chapter 4 was the second of the hybrid chapters and attempted to bridge the technical and educational components in the design of this study.

Chapter 5 described the results of the Grahamstown Circuit schools survey. The survey employed the use of questionnaires, semi-structured interviews and an on-site audit. This chapter highlighted issues that were raised by the IT teachers/specialists at the 13 Grahamstown Circuit secondary schools in terms of the ICT infrastructure deployed and used at those schools. This chapter specifically drew attention to those issues and challenges that pertained to networking as any solution presented by this study would need to be based on the needs of the schools.

Chapter 6 examined the network deployments undertaken in the Grahamstown Circuit. The chapter described the deployments and presented the results of network tests performed on those networks. Furthermore, it described alternative network solutions, to those that were deployed, for the Grahamstown Circuit. The chapter highlighted network lessons learnt that could be used in creating a network solution for the secondary schools in the Grahamstown Circuit.

Chapter 7 presented the proposed model of Internet connectivity for secondary schools in the Grahamstown Circuit, namely the Grahamstown Circuit Metropolitan Education Network. This chapter drew from what was learnt in Chapter 5, the schools survey and Chapter 6, the Grahamstown Circuit network deployments. The chapter attempted to bridge both the technical and educational components of the study and provided recommendations of how schools in this circuit could be connected to the Internet.

Chapter 8 concludes this dissertation by presenting a summary of the chapters, re-examining the initial research questions and discussing how these questions were answered. In addition, it presents possible contributions of this study, recommendations from the study and suggests future work that could be done in this area.

## 8.2 Research questions revisited

This section revisits the research questions that were posed in chapters 1 and 4. The section begins with the subsidiary questions and works its way through to the main research question, which will be discussed in section 8.3.

### 8.2.1 What ICT infrastructure and computer networking technologies already exist in the schools?

From the data from the questionnaires, interviews and on-site audit we found that every school had at least one computer, but not all the schools had computer labs or computers for teaching and learning. The independent schools had the best computer-to-learner ratios of around 1:3, while the worst of the computer-to-learner ratios were seen at some of the former Department of Education and Training schools, with ratios as high as 1:778 at FDET5.

Four of the 13 secondary schools in the Grahamstown Circuit were not connected to the Internet and three had no local area networks (LANs). Likewise, in terms of Internet connection and local area networks, the independent schools were better resourced than the state schools, particularly the FDET schools.

With respect to buildings required for computers, most of the schools were satisfied with the number of buildings and condition of buildings they had; only one school, FDET6, commented that in order to have computers in the school it would require additional buildings to accommodate a computer lab.

Besides the disparities in terms of infrastructure, there was also a marked disparity in terms of having skilled and trained IT staff. The independent schools were fortunate enough to have not only IT teachers but also IT technicians. State schools, on the other hand, were fortunate if they had an IT teacher. Seven had regular teachers performing the tasks of the IT teacher – in addition to the learning area for which they were hired – often with very little training.

#### Recommendations

During the course of the study it was found that IT teachers and schools in general tended not to be well informed about appropriate hardware and software. It was evident that approximately 6 out of 7 of the FDET schools and the FHOR school were unaware of any software other than that of *Microsoft Windows* and

*Microsoft Office*. Specialist education software was predominantly mentioned by the independent schools and the FMC schools. Teachers and schools need to be made more aware of the various software options available to them, in both the open source and proprietary environments, so that they make well informed decisions for their schools and learners.

Often teachers from the so-called previously disadvantaged schools did not understand how the school's LAN or Internet connection worked and thus were incapable of making decisions about them. They were also unable to fix any networking issues that were experienced. It appeared that schools and teachers often did not realise the importance of the networking within and to their premises and thus did not place the appropriate emphasis on these systems.

Generally speaking, IT teachers in schools can not be relied upon to know and understand the ICT infrastructure found in their schools, thus self-reporting evaluations of school ICT infrastructure might not be the best way to survey ICT infrastructure in schools. It would therefore be preferable to send an ICT specialist to the school in order to perform an on-site audit, as the information collected in this way has a higher chance of being a true reflection of the school's ICT infrastructure. In addition, teachers and in particular IT teachers, need to undergo intensive ICT technical training – literacy, integration and system administration – so that they may be able to make well-informed decisions about their infrastructure in their schools and be less reliant on help from outsiders.

### 8.2.2 What are the infrastructural issues that the school principal, teachers, learners, parents and the state face in introducing ICT and Internet connectivity into schools?

The infrastructural issues constituted the bulk of the problems schools have to address and were mainly due to faulty hardware or problematic Internet connections. In addition, schools commented that their software was also dated, leading to problems with viruses, and software was often non-homogeneous across all the computers in the school, making it hard to administer their computer networks. The next issue was that of managing ICTs. Here, the disparities in number, technical ability and workload of IT staff at the various schools were highlighted once again. Better training, appropriately qualified staff and increased support would help in these areas.

Following the management was the issue of maintenance. It was encouraging to note that, on the whole, ICT equipment failure was due to normal wear and tear and not to theft or vandalism. This gave the impression that learners, teachers and the community were pleased about the ICT access at the schools and wished to retain it and hence took good care of the infrastructure. Schools also commented that they performed in-house maintenance as much as possible, but when they were unable to do so due to a lack of expertise, they would outsource their maintenance. Some schools, such as FHOR and FDET5, commented that they were unable to perform adequate maintenance due to a lack of funds.

In terms of ICT acquisition, from the data presented in section 5.3, we ascertained that the majority of the schools, especially the state schools, relied on donations in order to acquire ICT infrastructure. The independent and FMC schools, however, were able to make use of school funds in order to purchase the necessary equipment. There were, however, schools with more innovative approaches to ICT infrastructure acquisition, such as FDET3 which had won the Global Teenager Project and had been awarded a 16 station computer lab [138]. FMC2 started a computer training school, within the school, in order to fund their labs and their IT teacher's salary. A parent of one of the learners at FMC2 had won a competition run by a national clothing store chain and donated the winnings of R50000 to the school in order to purchase computers.

Therefore factors which contribute to concerns about infrastructural issues have been identified. They include a lack of funding, a lack of technical training and a lack of technical support. In addition there seems to be a lack of understanding about how much money is involved in maintaining, fixing and replacing equipment as well as a lack of understanding about how much technical knowledge is required in running a computer lab. FMC2, FHOR, FDET1, FDET3, FDET4, FDET5 and FDET6 had all had their first computers at the schools donated to them, either by being given money for computers or by having the computers installed by the donor. These schools also tended to be the schools which commented most often about infrastructural issues.

**Recommendations**

I suggested considering another model of donation to the standard one of just donating computers to any school deemed worthy and then leaving them to their own devices. The model that I suggested is that of the tuXlab model. The tuXlab model is not a donation, but rather a partnership that is entered into by the Shuttleworth Foundation and the school [150]. In applying for a tuXlab schools are encouraged to work through an eight-step process: learning about the tuXlab project and open source software; completing a questionnaire and business plan of sustainability; and donating time to other schools to help them with their tuXlabs. Through the business plan process schools are forced to find local ICT technical support. Through the partnership schools collaborate with other tuXlab schools and maintain close relationships with the Foundation at all times. This helps with sustainability and results in training and advancement of teaching staff.

This process helps to alleviate many of the initial hindering factors; firstly by helping schools learn how to go about finding donations and generating funds of their own. Secondly, it encourages schools to think about how they will support their computer labs in the long term, both financially and in terms of maintenance. Schools are able to further identify appropriate technical support avenues as well as obtain literacy and technical training for their staff members. These benefits were evident at the FHOR school, which had installed a tuXlab in May 2005.

### 8.2.3 How can these infrastructural and connectivity challenges be overcome?

The question of how can these infrastructural challenges be overcome was addressed in section 5.4 of this dissertation. There were numerous methods that schools employed in overcoming their infrastructural challenges, but I chose to focus on those that were discussed most often, namely the proactive attitude of the school, training, increasing infrastructure and efficient use of their infrastructure.

The proactive attitude of the school was the most frequently raised topic. This highlights that the more proactive the attitude of the school, the more likely it was that they would overcome all challenges. Schools employed a number of proactive steps, including ICT budgeting, sharing ICT costs amongst a number of schools, actively seeking ICT donors, fundraising and participating in competitions.

The next most discussed topic was training. Here the schools emphasised the strong need for ICT training amongst staff. Without good training teachers will struggle to integrate the use of ICTs into their teaching. Furthermore, they will fail to realise the benefits of the ICT tools available to them. Good training is also necessary for the IT teacher so that (s)he can perform adequate support for staff and maintain their facilities.

Following training, increasing infrastructure and following that, efficient use of infrastructure, were discussed as methods of overcoming ICT challenges. Increasing the school's infrastructure, by adding additional computer labs, helped to ease the demand on facilities and made it possible for increased exposure for learners. Efficient use of infrastructure, such as employing a cache server for more efficient use of bandwidth, or employing the use of a LAN in order to share scarce resources across the network, further helped schools achieve more from what limited infrastructure they had.

#### Recommendations

I think it is important to note that central to schools overcoming their infrastructural challenges is a proactive attitude. Unless schools are committed to having and using ICT facilities in their school they will struggle with the challenges in having such facilities. Proactive schools seemed to find it easier to encourage teachers to be trained in literacy as well as integration. Furthermore, schools may find it easier to find teachers interested in learning the skills of technical support, or perhaps administrative staff or learners. Should there be no suitable candidates among teaching staff to be the technical support, schools might find it within the administrative staff, or perhaps might find a local person in their communities who would be willing and eager to be technical support for the school's ICT infrastructure.

With properly trained staff, schools will be able to make appropriate decisions about their infrastructure – hardware, software and networking. Schools will find it easier to make appropriate decisions about ICT policy to help govern the use and maintenance of their infrastructure. They will also find it easier to make efficient use of the infrastructure that they have and can afford. In addition to being able to make decisions about what is appropriate hardware and software, schools will also be able to decide what is inappropriate for their school's needs. They will be able to turn down any inappropriate donations that are offered to them should these hardware and software not be in line with their school's needs and ICT vision.

### 8.2.4 What network technologies can be used in the Grahamstown Circuit in order to connect schools to the Internet?

The question of what network technologies could be used in the Grahamstown Circuit in order to connect schools to the Internet was answered in chapter 6 of this dissertation. From the successful deployments of the DSL and 802.11 networks I ascertained that both are good technologies for use in the proposed Grahamstown Circuit Metropolitan Education Network. Furthermore from the discussion in section 6.5 I determined that VSAT, optical fibre, PLC and WiMAX are also good network technologies for use in connecting schools to the Internet. The use of GPRS or 3G was found to be inappropriate for the use of Grahamstown Circuit schools in connecting to the Internet.

#### Recommendations

Wireless networks and more specifically 802.11 technologies provide a cost-effective and fairly acceptable network, in terms of reliability, throughput and latency, for the schools in the Grahamstown Circuit. Thus 802.11 technologies can be used to connect schools in urban, peri-urban and rural areas that are approximately 5 - 10 km apart. For greater distances than that, WiMAX technologies or VSAT could be employed. Furthermore, the use of wireless technologies to connect rural and peri-urban schools is cost effective to the infrastructure provider as there is no need to lay cable in the ground in order to reach the schools.

Where mains electricity is available PLC technologies can also be employed by infrastructure providers to connect schools. As technologies become cheaper over time and the South African economy possibly improves, we might see more optical fibre to schools being employed by infrastructure providers.

### 8.2.5 How exactly can those network technologies be used to gain maximum efficiency from them?

In terms of the DSL network it was found that the default configurations of the technology were sufficient for school use and no further tweaking was necessary in order to improve efficiency. In terms of the 802.11 network, however, numerous techniques were employed in order to improve upon the network. For example, we changed our AP and bridge equipment in order to increase the transmission power from 63 mW to 100 mW. The added power boosted the signal allowing more ground to be covered and to overcome interference. Furthermore, we employed the use of high gain directional antennas in order to cover longer distances and further improve interference issues.

In the future the use of newer technologies such as WiMAX will be able to further improve our current network by eliminating the problems of hidden nodes and Fresnel zones, as well as further improving upon interference issues.

These improvements and others discussed in chapter 6, allowed us to use inexpensive LAN technology to build an affordable metropolitan area network for the Grahamstown Circuit secondary schools.

#### Recommendations

As 802.11 technologies are designed for local area networks some tweaking is necessary in order to make sure they work effectively over distances that are greater than 100 m. We found that using equipment with the highest legally allowed power transmission of 100 mW is desirable, as is the use of high gain directional antennas over long distances. Clearly the use of technologies which are designed to cover larger areas, such as WiMAX, will produce a wireless network that has improved throughput, latency and reliability as well as improving upon interference and hidden nodes.

This study also found that solar panels are an effective method of powering wireless equipment in places where there is no mains electricity, such as the top of a water tower. In cases where there is no electricity in schools, schools might want to investigate the use of larger panels or diesel generators to power computer labs.

## 8.3 Conclusion and recommendations

The main research question that guided this study was:

What networking technologies and models can support secondary schools in the Grahamstown Circuit in implementing their vision for integrating ICT into schools?

This study presented the various network technologies available to the Grahamstown Circuit schools as well as a brief overview of their visions for and challenges of ICT in their schools. Furthermore, this study has considered models of Internet connectivity to secondary schools in the Grahamstown Circuit in the Eastern Cape. Thus, based on the information provided by the Grahamstown Circuit secondary schools and the findings of the network technology 'desktop survey' and results of the network deployments, I proposed the Grahamstown Circuit Metropolitan Education Network as the most appropriate model for connecting the schools in this Circuit. This network would allow all the schools in the Grahamstown Circuit to connect to one another, sharing resources and allowing for collaboration.

Originally this network would make use of the already available technologies that are deployed at those schools that already have an Internet connection, such as DSL and 802.11. However, as technologies become cheaper and the network expands, the technologies could change to use better technologies, with lower latency, higher throughput and greater reliability. An example of such a technology would be optical fibre.

Furthermore, through the central services provided by the proposed network, schools would have access to the facilities and infrastructure that they require. These central services make the solution scalable so that the number of schools could increase without increasing the workload, cost, infrastructure and maintenance exponentially. These services would not only allow schools to pool their money and other resources, but also encourage collaboration amongst schools and teachers. This collaboration would be facilitated through mailing lists, on-line education portals, videoconferencing and proposed VoIP services would facilitate collaboration and communication. Furthermore, the schools would have access to ICT support through a proposed on-line ticket system and because the services are centralised, fewer technicians will be able to maintain the network and thus reduce the costs of the support services to schools.

Thus my recommendation for the Grahamstown Circuit schools is to build a Grahamstown wide area network, connecting all schools to each other, the Internet and to central services, which would include mail, web, VoIP, DNS, proxy and videoconferencing.

## 8.4 Cost concerns

While the question of costing was not part of the focus of this study it became apparent from the schools (as seen in chapter 5) that costs were a major concern for schools. Therefore the concern is discussed briefly here (as well as made reference to in chapter 6 where costing is briefly considered within the two network deployments) in order to highlight this important issue. However, it must be noted that a more in depth study should be conducted into the issues schools face in terms of cost with respect to ICTs.

### 8.4.1 What are the costs of infrastructure and connectivity?

The issue of cost in terms of ICT infrastructure was discussed in section 5.5, along with other limitations and constraints that schools in the Grahamstown Circuit had experienced in acquiring and maintaining ICT infrastructure. The problem of cost was the most discussed limitation within section 5.5. High costs were associated mostly with software and Internet connections in South Africa. Schools commented that they all had to make use of school funds in order to purchase or maintain infrastructure, having not received any assistance from the DoE. In the case of state schools this often meant that they were unable to adequately fund or perform ICT maintenance.

Due to the limitations of cost, the network deployments in this study were designed and chosen to be as cost effective as possible. The costs associated with two of the technologies, Wi-Fi and WiMAX, were approximately R3000 and R4000 per school for a once-off installation. Following that, bandwidth costs were covered by the university. DSL, too, is a fairly cost effective solution and can supply necessary bandwidth for schools at cheaper rates than dial-up (when Internet use is more than 26 hours per month, see Appendix B) or Diginet.

#### Recommendations

The issue of high costs associated with ICT infrastructure is an important one and needs to be addressed as it frequently holds schools back from acquiring and maintaining such infrastructure. Schools need the help of the state in order to be able to afford such facilities. This could be through initiatives such as the e-rate, where the state negotiates cheaper prices for schools with various business and service providers. This could be done for purchasing computers, Internet connections and all necessary peripherals in building the desired ICT facilities of a school. Furthermore, the state could supply some of the more expensive infrastructure such as switches, routers and servers to schools, and then schools could purchase the rest through purchasing consortia that the state has negotiated on their behalf.

In addition, the use of cost effective technologies could also be employed. For example wireless technologies could be employed in areas where there is no fixed-line infrastructure in order to connect schools to the Internet.

Furthermore, through the proposed Grahamstown Circuit Metropolitan Education Network costs could be reduced through schools pooling their funds and sharing the costs of the resources amongst themselves.

## 8.5 Potential research contribution

There are a number of possible contributions that this research project makes.

Firstly, through the survey of the 13 secondary schools, data was collected that will help to inform these schools of their current infrastructure and what they can do to either improve their infrastructure or maintain it, etc. The same data could be of value to the Eastern Cape Department of Education in order to inform them of the current infrastructure of the Grahamstown Circuit schools.

Secondly, this study provides a detailed deskopt survey of the various networking technologies available in South Africa, as well as technologies that are likely to be available in the foreseeable future in South Africa. Through the network deployments and documentation thereof, this study provides information pertaining to the architecture throughput, reliability and latency of the network technologies deployed in schools in the Grahamstown Circuit.

Thirdly, it presents evidence for the use of local or metropolitan area networks in order to connect local schools to one another and to the Internet. It outlines the procedure for building local education networks, and outlines the advantages thereof, such as pooling resources and working collaboratively.

Fourthly, this study helps to bring together multiple ad-hoc efforts of ICT in education projects, from a number of interested parties within Rhodes University. It has helped to co-ordinate the efforts of the university in aiding schools in ICT procurement as well as ICT integration in schools.

Fifthly, in terms of research regarding ICT facilities in South African schools there are limited publications. There is some documentation on the work that has been done in first world countries, such as [278, 279] and limited research has been conducted in South Africa [124]. It is hoped that this study will contribute to the growing body of South African research as well as encouraging further research.

Sixthly, this project aims to inform legislation that affects the acquirement of ICT infrastructure and the use of ICT in education. It is hoped that this study will provide guidance to those who are involved in policy and decision making in these legislative areas. These policies include those which govern telecommunication and ICT in education.

Finally, this study has led to an increase in the number of schools that are connected to the Internet, and it has also aided in helping some schools acquire and install ICT infrastructure. Furthermore, the study has broadened knowledge about ICT in education in the Grahamstown Circuit, while scaffolding collaborative relationships between the various schools.

## 8.6 Future work

While this study attempted to be as exhaustive as possible, there are areas which could be improved upon or taken further. I have a number of suggestions of future work that could build on this study.

Firstly, the survey of the schools is unfortunately incomplete, due to one school not returning their questionnaire and one of the IT teachers from another of the schools choosing not to be interviewed. It might be valuable for someone to complete the survey. In addition, there are some gaps in the data from the schools thus a follow-up survey could be done in order to fill the gaps.

Secondly, one or two of the schools could be chosen for a more in depth case study of the school in order to learn better how the teachers are integrating ICTs or not and possibly gain a deeper understanding of the needs and vision of the school so that the ICT infrastructure could be carefully planned in such a way as to complement these teaching and learning strategies.

Thirdly, research could be conducted into the effects of the tuXlab model and whether or not thin client labs are better than thick client labs and when is that the case and when not. Furthermore, one could conduct research into the benefits of how the tuXlabs are supported and run. Thus one could consider the merits of getting the schools to be more involved and taking ownership, i.e. the partnership model as opposed to the donate-and-leave model that many other organisations adopt as they don't have the time to be more involved with the schools. In addition, one could compare the educational benefits of open source software vs proprietary software in education.

A fourth suggestion for future work would be to replace the 802.11 network with a WiMAX network and compare how the networks perform and note which is better where. Furthermore, such a study could consider any educational benefits that schools experience from the new network technology.

Fifthly, this study resulted in some schools becoming connected to the Internet for the first time. Research could be done into the effects of having an Internet connection, comparing various aspects of the school and how the teachers teach and the learners learn subsequent to their new Internet connection (and in some cases, new computers as well).

Lastly, thorough research could be conducted as to whether the model for the Grahamstown Circuit Metropolitan Education Network is the best possible solution. This could be done by comparing this model to other models that may have been implemented in other parts of South Africa or similar environments around the world. Thus research could be conducted into the effects of the implementing the Grahamstown Circuit Metropolitan Education Network.

## 8.7 Parting thoughts

By providing Internet connections and ICT facilities at schools across the country, where not only learners at the school but also the local community can access the facilities, we can begin to bridge the digital divide in South Africa. This bridging of the digital divide would further help realise the networked society and collective intelligence that Cornu spoke of in [100]. In this networked society people and information are connected in a networked form, which results in a change in the relationships between people and between people and information [100]. This kind of society means that people are able to communicate with each other whether they know each other or not [100]. This is different from how society has worked previously – a hierarchical structure where people could not communicate with others that they did not know personally [100].

Furthermore, bridging the digital divide will also help in realising Cornu's definition of collective intelligence. This collective intelligence of which Cornu speaks would be made up of a network of individual intelligences, which would be juxtaposed as well as interrelated in ways to make them complementary [100]. This collective intelligence would allow people to work together and solve problems and address questions in new and innovative ways [100]. Through our collective intelligences South Africans can build a better country for us all.

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# Appendix A

# Program listings

## A.1 The ping test program

Used to ping another computer on a network in order to obtain data about the latency and reliability between the two computers on the network.

```
#!/usr/bin/perl -w
#The Ping program called ping.pl

use strict;

my $dst = $ARGV[0];

my $date = ‘/bin/date‘; # get the date
chomp($date);
my $output = ‘/sbin/ping -c 10 -q $dst‘;  #send the ping packets

#records the output of ping and saves to appropriate variable
my ($received, $min, $avg, $max, $stddev);
if ($output =~ m/, (\d+) packets received/) {
$received = $1;
if ($output =~ m# = ([\d\.]+)/([\d\.]+)/([\d\.]+)/([\d\.]+) ms#) {
$min = $1;
$avg = $2;
$max = $3;
$stddev = $4;
}
}
else {
$received = $min = $avg = $max = $stddev = 0;
}

printf("%s,%d,%f,%f,%f,%f\n", $date, $received, $min, $avg, $max, $stddev);
```

## A.2 The transfer test

Used to transfer a test data file (768KB) of random content from one machine to another over a network, in order to obtain data about the available throughput and the reliability of the network.

```
#!/usr/bin/perl -w
#The transfer program, called transfer.pl

use strict;

my $url = 'http://dukat.dsl.ru.ac.za/~ings/testdata';

my $date = `/bin/date`;
chomp($date);

#fetches the test file from the url and records the time it took to do so
#this file is run by cron and cron pipes the results of the script to a csv
#file which can be used to calculate throughput later on

my $output = `/usr/bin/time /usr/bin/fetch -qd $url 2>&1`;

my $real;
if ($output =~ m/\s([\d\.]+)\sreal/) {
$real = $1;
}
else {
$real = 0;
}

printf("%s,%f\n", $date, $real);
```

## A.3 The test program

Used to run multiple instances of the ping program to various computers on a network.

```
#!/bin/sh
# The Test program, called test.sh

#passes the IP of the machine to be pinged and provides the file to which
#the results should be stored
/home/ings/ping.pl 169.254.0.25 >> figlet.csv
/home/ings/ping.pl 169.254.0.4 >> wt-bridge.csv
/home/ings/ping.pl 169.254.0.3 >> wt-ap.csv
```

## A.4 The programs used in testing FDET4

The following two programs were used in testing the throughput to FDET4:

### A.4.1 The testing program

Used in order to ensure that the PPP daemon was running as regularly as possible. PPP was unstable due to the instability and intermittent association between the school's router and the water tower AP.

```
#!/usr/bin/perl -w
#This is the testing program to see if the school router and water tower are associated.
```

```
#If they are then then the transfer test can be run.
#called testing.pl
use strict;

my ($last, $now, $watertowerap, $uptime) = (0, 0, '169.254.0.3', 0);

while (1) {
`ping -i 0.2 -c 5 -q $watertowerap`;
$now = ($? == 0);
print("now=$now; uptime=$uptime\n");

#if we can ping the water tower start PPP and run the transfer script
if (! $last && $now) {
print("rising edge\n");
$uptime = 0;
`ppp -background scw`;
print("ppp started; result code=$?\n");
if ($? == 0) {
`/home/drs/transfer.pl >> results.csv &`;
} else {
$now = 0;
}
}

#if we can't ping the water tower kill all PPP, fetch and PPP tunnels
if (! $now && $last) {
print("falling edge\n");
`killall -TERM ppp`;
`killall -TERM fetch`;
`ifconfig tun0 delete`;
}

if ($now) { # is it time to run the test again?
$uptime += 10;
if ($uptime >= 180) {
$uptime = 0;
print("retesting\n");
`/home/drs/transfer.pl >> results.csv &`;
}
}

$last = $now;
print("sleeping\n");
sleep(9);
}
```

### A.4.2 The modified transfer program

This is the transfer program used in all other network tests, but slightly modified in order to work with the testing program to test the throughput at FDET4 despite the intermittent association between the school's router and the water tower AP.

```
#!/usr/bin/perl -w
```

```
#The slightly modified transfer test for FDET4
use strict;

my $url = 'http://dukat.dsl.ru.ac.za/~ings/testdata';

my $date = `/bin/date`;
chomp($date);
my $output = `/usr/bin/time /usr/bin/fetch -qd $url 2>&1`;

my $real;
if ($? != 0) {
exit(1);
}
elsif ($output =~ m/\s([\d\.]+)\sreal/) {
$real = $1;
}
else {
$real = 0;
}

printf("%s,%f\n", $date, $real);
```

# Appendix B

# Current costs of dial-up and ADSL Internet access

| Dial-up | | Broadband | |
|---|---|---|---|
| POTS line | 122.60 | 122.60 | POTS line |
| TelkomInternet account | 79.00 | 199.99 | TelkomInternet powered by ADSL account (2GB p.m.; shaped) |
| 26 hour local call at peak time | 593.42 | 477.00 | ADSL line (512 Kbps) |
| Total | 795.02 | 799.59 | Total |

School days in month: 20

Break-even point: 1.3 hours per day (average)[1]

[1]Based on prices found on the Telkom and TelkomInternet websites as at January 2006. Prices include VAT. The Internet account chosen for ADSL is the standard and cheapest, while the 512 Kbps account was chosen as the 192 Kbps and 384 Kbps are home owner products and not business products. Finally all the local calls are calculated at peak rates (for dial-up) as schools operate during peak hours.

# Appendix C

# Fresnel diagrams

This Appendix contains the diagrams of Fresnel zone diffraction on some of the other radio links in the 802.11 network. In all the diagrams please note that the central green line depicts the line of sight from one antenna to another, while the white concentric ellipses surrounding the green line are the three Fresnel zones. The inner most ellipse is zone one while the out is zone three. The direction of traffic in these diagrams is always from the AP (either the Monument APs or the Water Tower AP) to the client, but this flow of traffic does not affect the Fresnel diffraction, it is the same in both direction regardless of current traffic flow. In the top of each diagram on the right hand side there is a variable called "Worst Fresnel". It is this variable which indicates how much of the Fresnel zones are penetrated by the earth. It is this penetration that results in the diffraction.

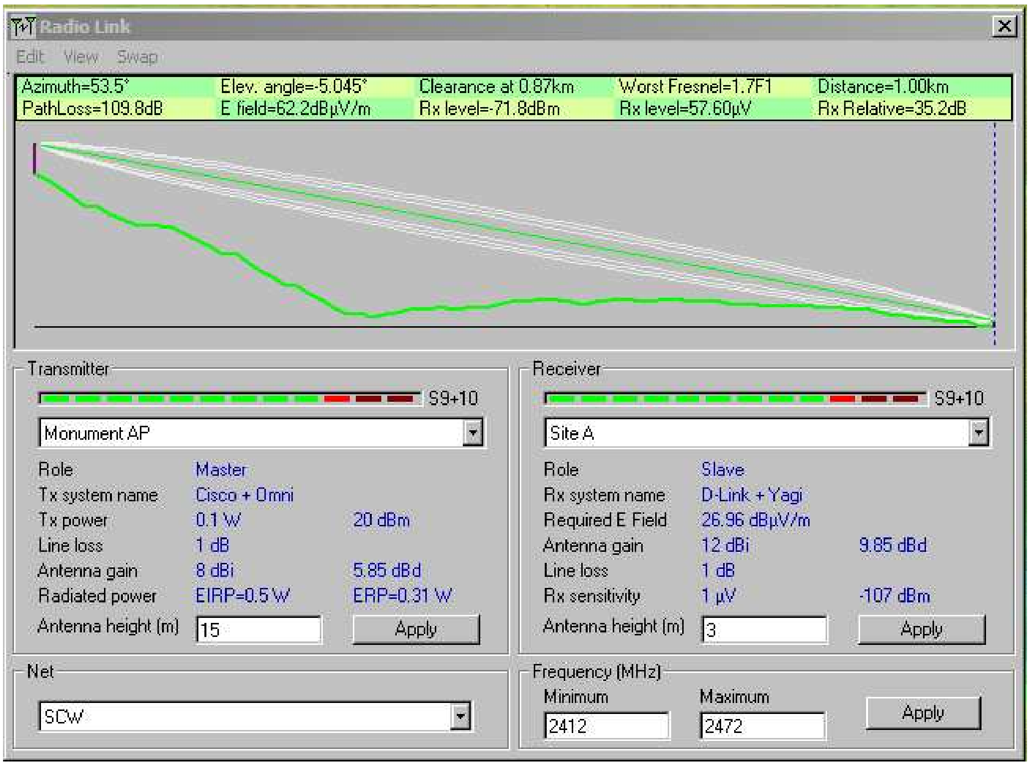


Figure C.1: The Fresnel zone at site A
A strong radio link with land penetrating the 3rd zone only

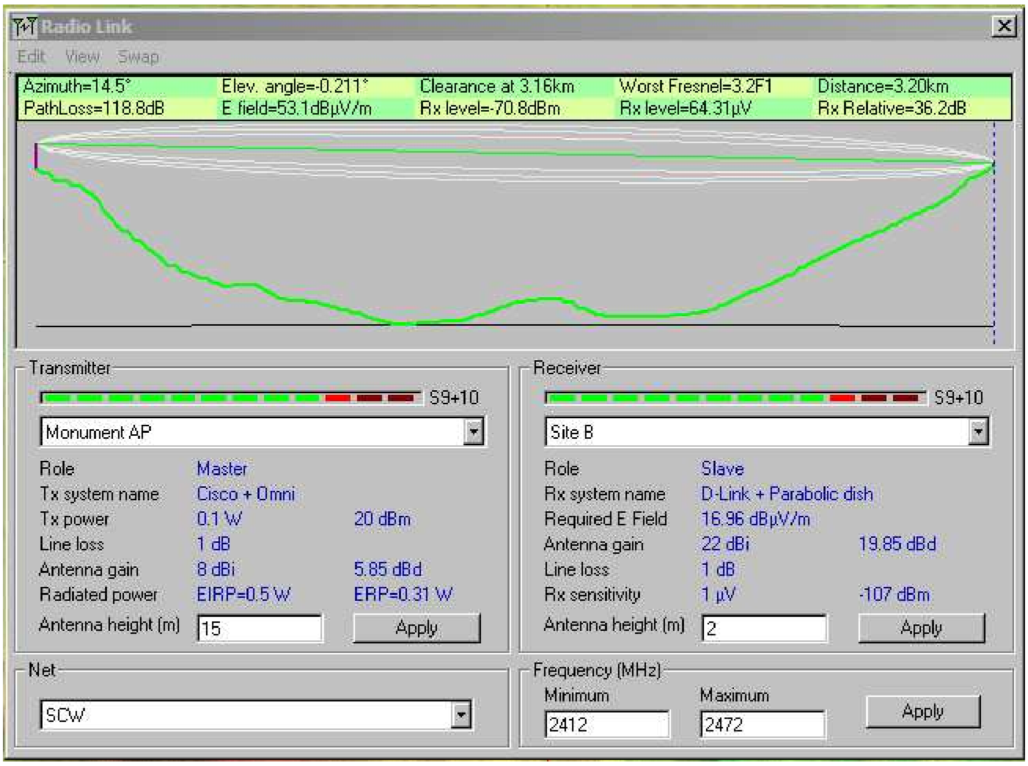


Figure C.2: The Fresnel zone at site B

No Fresnel zone diffraction in any of the three zones

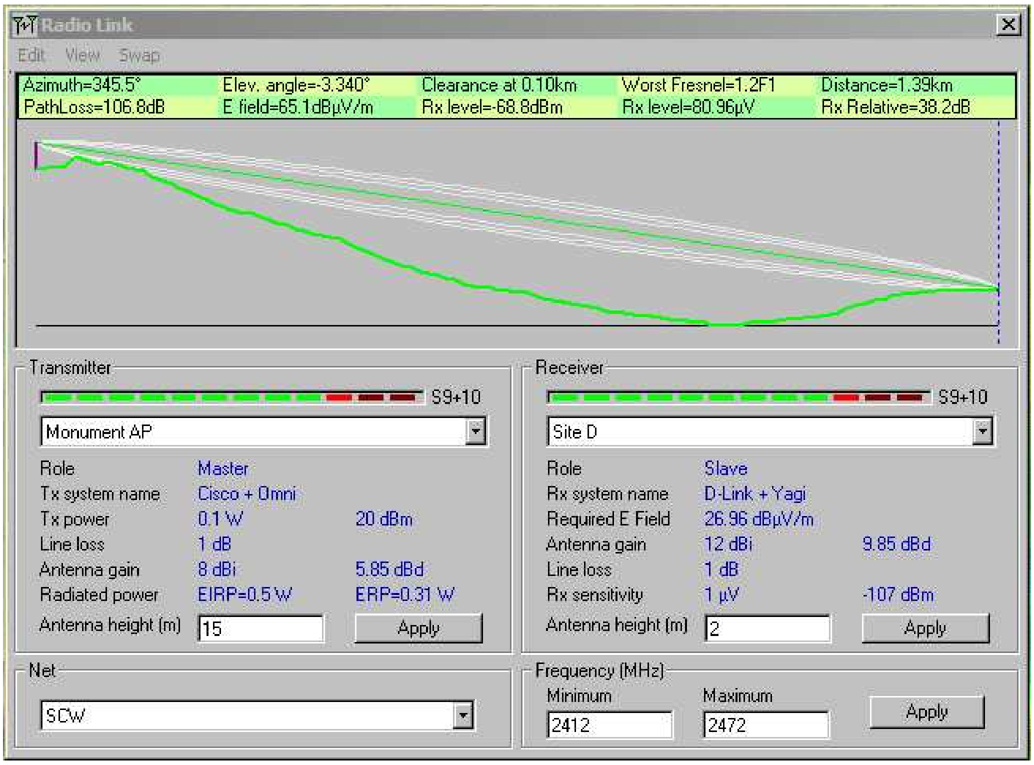


Figure C.3: The Fresnel zone at site D

This signal will not be as strong as that of site A as there is a greater penetration of the Fresnel zones, this time penetrating into both zones two and three

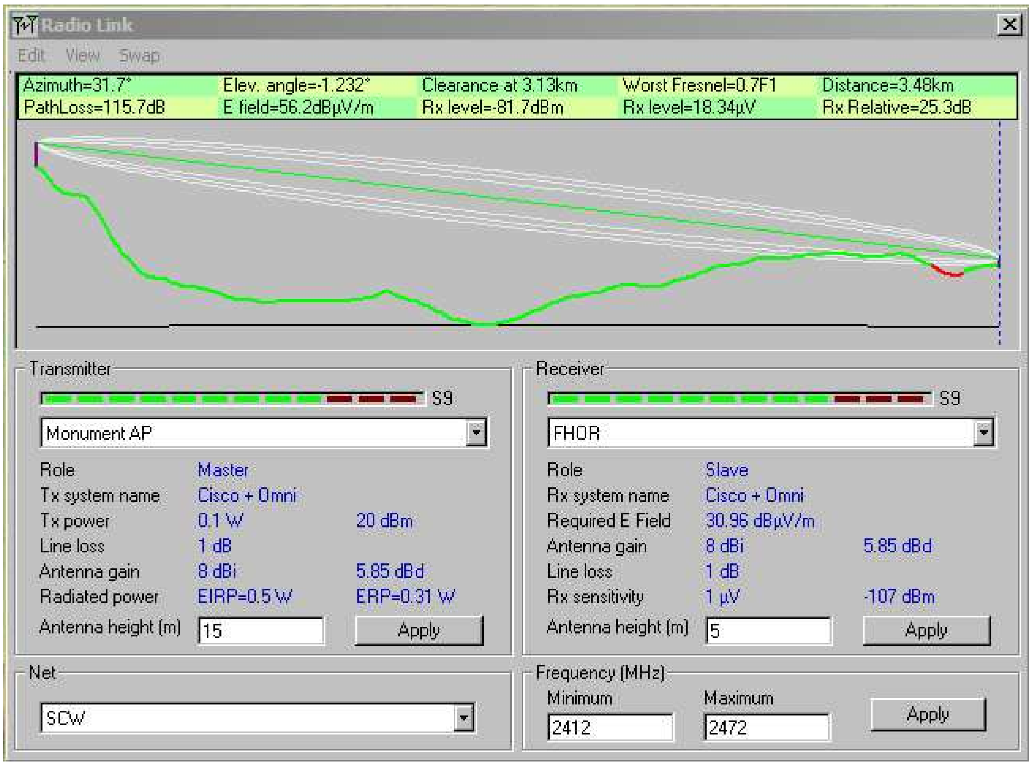


Figure C.4: The Fresnel zone at FHOR

This link is more susceptible to Fresnel zone diffraction and hence interference than any of the above. All three of the Fresnel zones are penetrated on this radio link

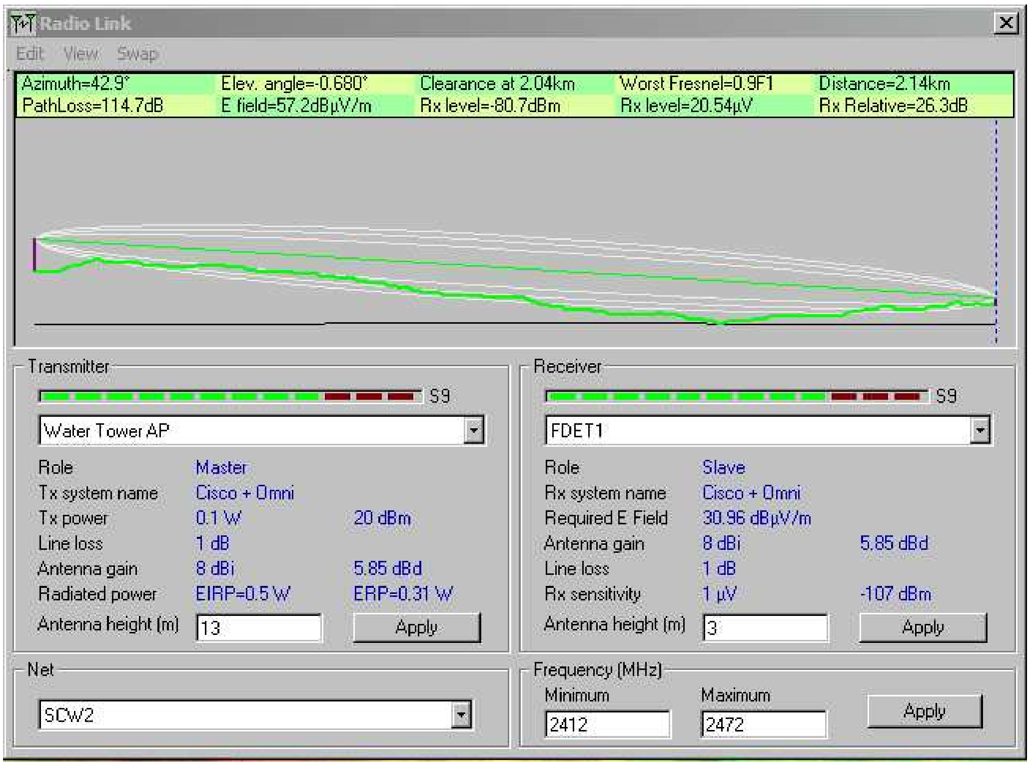


Figure C.5: The Fresnel zone at FDET1

This radio link is slightly better than the one between FHOR and the Monument AP, with 0.9F1 vs 0.7F1

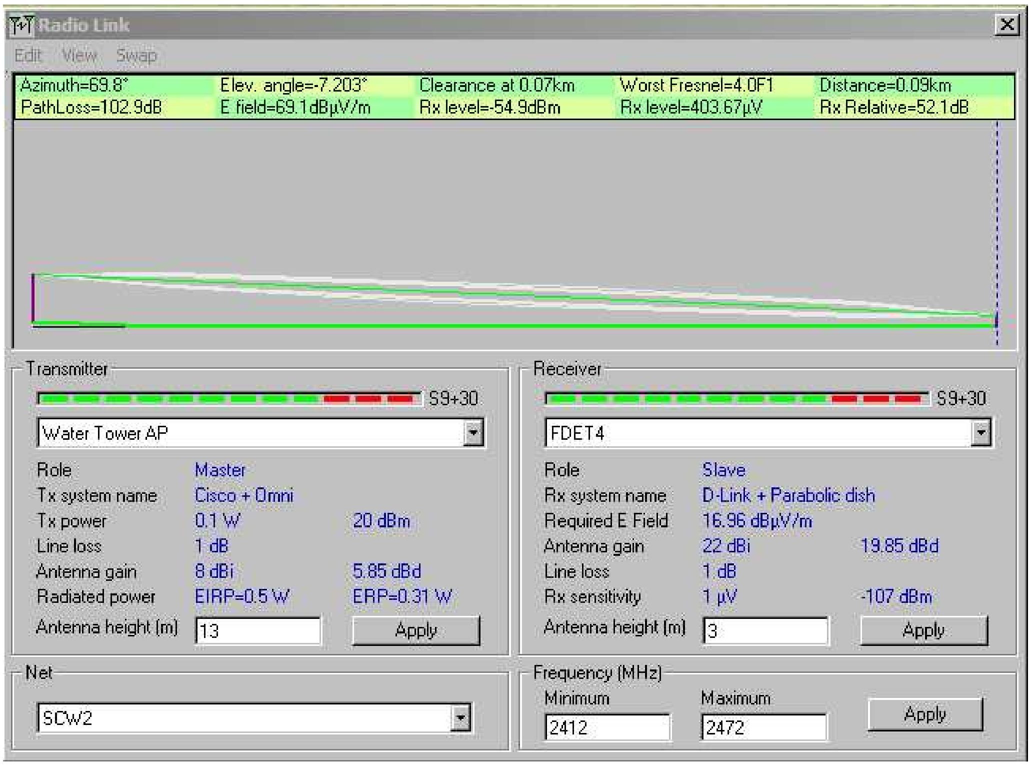


Figure C.6: The Fresnel zone at FDET4

No Fresnel zone diffraction on this link. This is to be expected as the AP and the client are on the same property and are 9 m apart

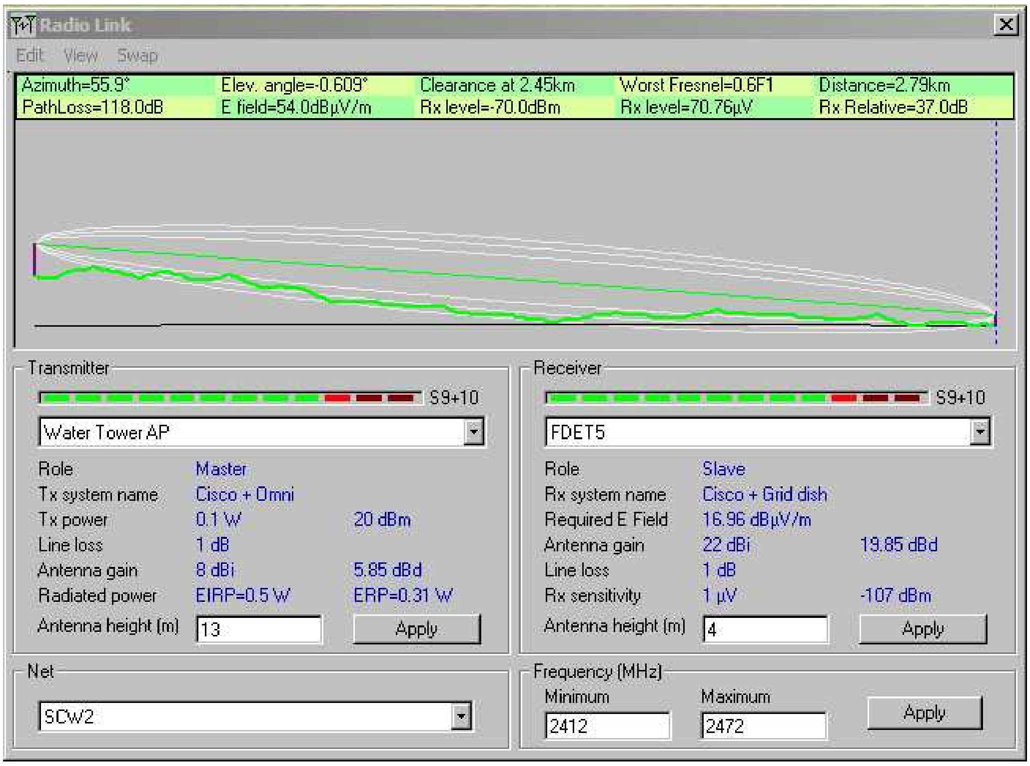


Figure C.7: The Fresnel zone at FDET5

There is a fair amount of Fresnel zone diffraction on this link, more so than the FHOR link, with a Worst Fresnel of 0.6F1

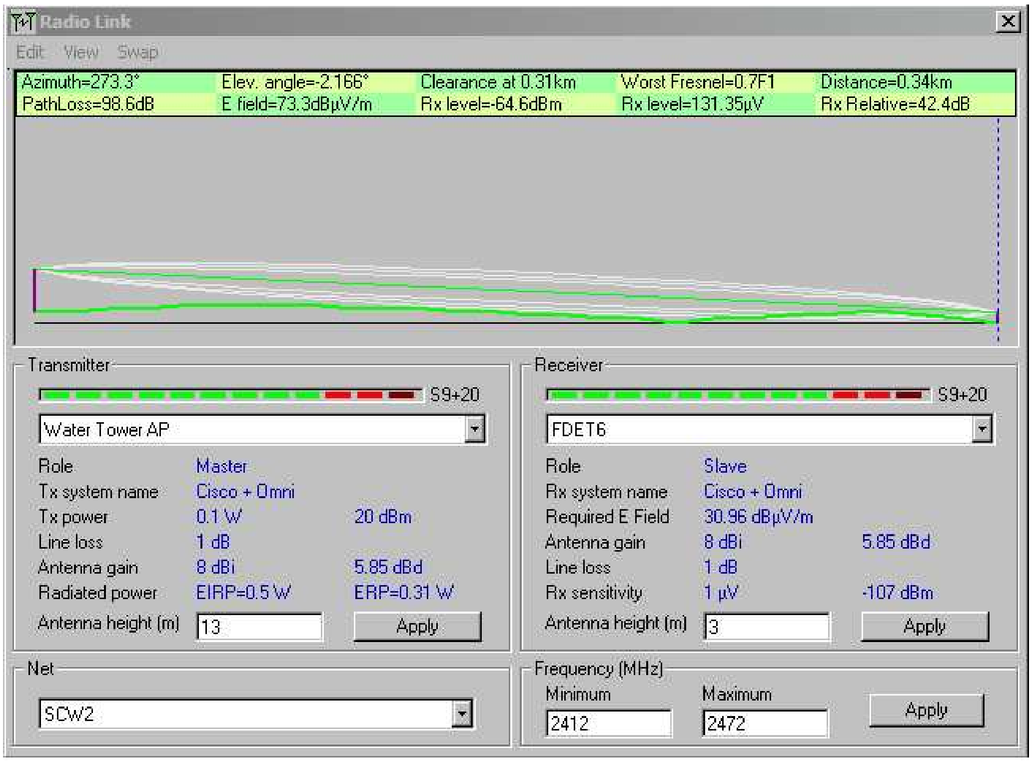


Figure C.8: The Fresnel zone at FDET6

The Fresnel diffraction on this radio link is surprisingly bad - the same as the link to FHOR - however this schools is 34 m away from the AP, while FHOR is 3.84 km away from its AP

Other diagrams of interest pertaining to the 802.11 wireless network are those which depict the coverage area of the APs. Below are two diagrams, one is the coverage area, over Grahamstown, for the Monument AP. The second is the coverage area, over Grahamstown, for the water tower AP.

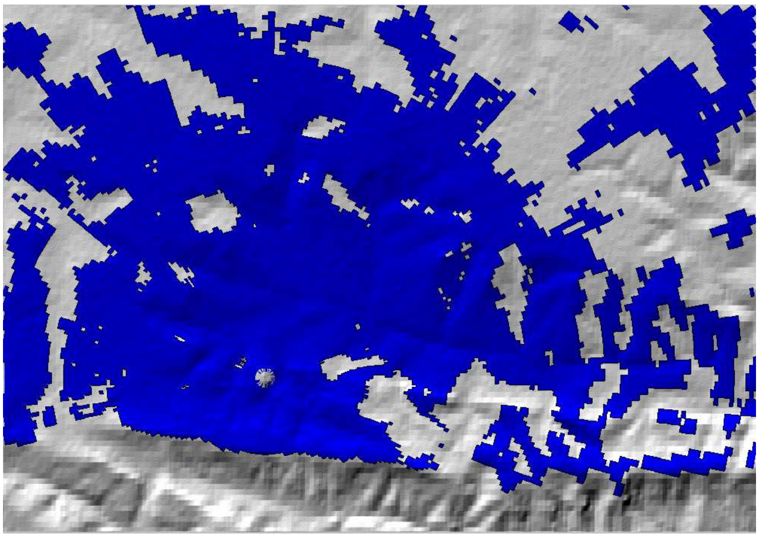

Figure C.9: The coverage area of the Monument AP

The small round, near perfect circle of grey in the lower left hand side of the image is where the Monument AP is found. The blue areas depict the coverage area over Grahamstown. Compare with figure 4.2 the contour map of Grahamstown

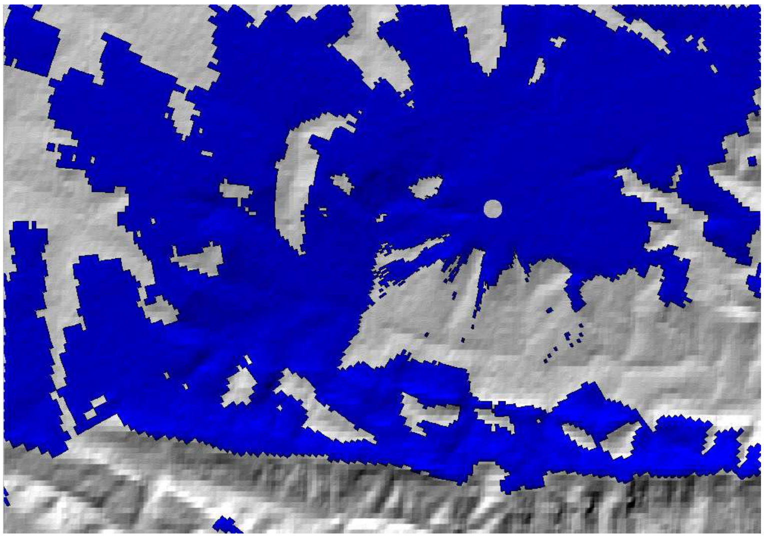

Figure C.10: The coverage area of the water tower AP
The small round, near perfect grey circle on the middle to upper right hand side of the diagram is where the water tower AP is found. Again the blue area depict the coverage area over Grahamstown. Compare with figure 4.2 the contour map of Grahamstown

# Appendix D

# The questionnaire

Below is a copy of the questionnaire that was sent out to the schools.

<u>Computer Infrastructure Questionnaire</u>

Please answer the questions below on the infrastructure of the computers in your school.

1. What is your name? ..............................................................................................
2. Which School do you teach at? ……………………………………………...
3. What is your post at the school? ..........................................................................
4. Do you have an IT teacher or a teacher who oversees IT in your school?
   Yes No
5. If you answered yes to the previous question could you please give that teacher's name?
   ...............................................................................................................................
6. Does your school have electricity?  Yes  No
7. If you answered yes to the last question, who is responsible for the payment of the school's electricity bill? ..................................................................................
   ……………………………………………………………………………..
8. Does your school have a telephone line?  Yes  No
9. If you answered yes to the last question, who is responsible for the payment of your phone bill? ..................................................................................................
10. How many computers do you have (working and not working)?
    - between 0 - 10
    - between 11 – 20
    - between 21 – 30
    - between 31 – 100
    - more than 100

    If more than 100, please specify exact number of computers that you have.…..
11. How many working computers do you have?
    - between 0 – 10
    - between 11 – 20
    - between 21 – 30
    - between 30 – 100
    - more than 100

    If more than 100, please specify exact number of computers that you have.…..
12. If you do have computers are you able to make use of all of them?
     Yes  No
13. If you answered No to the last question could you please give a reason why.…
    ...............................................................................................................................
    ...............................................................................................................................
    ...............................................................................................................................
    ...............................................................................................................................
14. If your school has computers, where are they found? i.e. In the school office, the headmasters office, the library, the computer labs, etc ……………………
    ...............................................................................................................................
    ...............................................................................................................................
    ...............................................................................................................................
    ...............................................................................................................................
    ...............................................................................................................................
15. Does your school have networking within the building, in other words, are the computers that you have connected to each other?  Yes  No
16. Does your school have Internet access?  Yes  No

17. If you answered Yes to the last question, i.e. you do have Internet access, then what kind of networking medium are you using?
    □ Analogue leased line (dialup)
    □ Digital Subscriber line (DSL)
    □ Wireless
    □ Satellite
    □ Not sure
    □ Other (Please Specify) ....................................................................................
18. How does the school go about obtaining new computer equipment?
    □ outside donations
    □ government funding or donations
    □ school funds
    □ fund raising
    □ we don't/aren't able to
    □ other (specify)…………………………………………………………………...
19. How does the school go about fixing broken computer equipment?
    □ outside donations
    □ government funding or donations
    □ school funds
    □ fund raising
    □ we don't/aren't able to
    □ other (specify)…………………………………………………………………...
20. How does your school go about replacing computer equipment?
    □ outside donations
    □ government funding or donations
    □ school funds
    □ fund raising
    □ we don't/aren't able to
    □ other (specify)…………………………………………………………………...
21. Does your school have a server(s)? □ Yes □ No
    If you said Yes then please specify how many servers your school has. ………
    ……………………………………………………………………………………..
22. Does your school have any extra peripherals, for example printers or scanners, etc. If you answer Yes to any of these please also specify how many the school has.
    □ Printers ...........................................................................................................
    □ Scanners ..........................................................................................................
    □ CD Writer ........................................................................................................
    □ Others (Please Specify types and how many here) ........................................
    .............................................................................................................................
    .............................................................................................................................
    .............................................................................................................................
    .............................................................................................................................
    .............................................................................................................................

Thank you so much for your help and co-operation.
Ingrid Brandt
MSc Research Student
Rhodes University

# Appendix E

# Interview schedule

Below is an example of one of the interview schedules for an interview at . Each schedule was slight different as each questionnaire from the various schools was responded to slightly differently.

## E.1 Interview schedule for FMC2

Hi, first off I would like to start by thanking you for agreeing to be interviewed and that the information that you provide me with today will greatly assist in my research.

For the purposes of the recording can I just ask you state your name and the school at which you are a teacher as well as the position that you hold at your school.

1. From the responses in your questionnaire I noted that the Department of Education was not paying your electricity bills. As I understand they are suppose to do that, do you know why they aren't paying your school's bill?
2. I also noted from your answers that all your computers are in working order. After some of the schools that I have seen where more computers tend to be broken than fixed you are doing very well. How does the school go about this kind of maintenance?
3. When you do have breakages are those generally due to normal wear and tear or do you find you have problems with vandalism in the school?
4. Have you ever had computers stolen? And how much security do you provide for your school and the computers?
5. You have a fairly strong number of computers at your school. How did you manage to secure them?
6. Your Internet connection is an analogue leased line, how much bandwidth are you getting off that and would you say that it is enough for your school?
7. Is every computer in this building networked and linked to your server?
8. Who set up this infrastructure for you?
9. What kinds of machines do you have in the school? Pentiums? 486s? And are they capable enough to do the things that you require of them or would it be better if you had newer and better machines?
10. Do you think that for teaching purposes its enough to just have a plain old Pentium, or do you think that schools really need monster computers? Maybe just a monster server rather?

11. Do learners and/or teachers have to pay any money to use the computer facilities at your school?
12. Do learners and/or teachers pay for printing or Internet usage?
13. Do you think that majority of the people concerned have difficulty in affording these charges that you require?
14. What kind of a cycle do you have hear at your school?
15. Do you find that there are timetabling issues with regards to the use of the computers in your school? And if so how do you work to rectify that?
16. On average how much computer exposure can you give to the learners?
17. How many teachers try and integrate computer use into their teaching methods? And which classes are they usually from?
18. If they aren't integrating them into the teaching process do the majority make use of the computers available for administrative work?
19. Would you say that your learners are enthusiastic about using computers?
20. Do you feel that computer integration into teaching methods is a good or a bad thing? And if you were to go with integrating them how would you structure the computers around your school? i.e. in a computer lab, in each classroom, in the library, all three, etc.
21. How comfortable would you say are the majority of the teachers in your school with using computers?
22. Have the teachers in your school had any sort of formal training in integrating ICT into their lessons?
23. Do they receive any support from the DoE for integrating ICT and the use thereof?
24. Do you think that majority of teachers here feel that computers are a valuable asset?
25. What programs would you say that teachers use the most?
26. Are teachers making use of the Internet in your school?
27. Do teachers use email extensively?
28. Would you say that teachers feel that having the Internet is a valuable resource?
29. Do you find that other teachers respect you as the IT teacher and feel free to approach you for help?
30. Have you had any sort of formal training in IT or are you self taught?
31. What kinds of computer issues are you able to help with or fix? Can you handle technical errors, etc?
32. What does the school do about computer problems that you are unable to fix?
33. What would you say the learners use computers for on the whole? What programs, etc do they use the most?
34. Would you say that children used the computers more often for the Internet? Do they make extensive use of the Internet?
35. Do they make extensive use of email?

36. What do you feel needs to be done in order to successfully integrate ICT into schools and the curriculum?

37. Would you say that having an Internet connection adds value to having a computer? If so then how much value and in what ways? In other words is a networked machine better than a stand-alone?

38. Do you think that ICT has a role to play in the future of Education? Or do you rather feel that it is all a waste of time and money? Explain fully.

# Appendix F

# Interview transcript

Below is an example of an interview transcript. This transcript is from the interview conducted at FMC2. All other interview transcripts can be found on the CD accompanying this dissertation.

## F.1 Interview at FMC2

Interviewer: Ingrid Brandt

Interviewee: TeacherX[1]

Ingrid: Thank you very much for agreeing to talk with us. Can I ask you to say your name and what your actual job description is here at P.J. You can speak in Afrikaans.

TeacherX: OK, well I will try. My name is TeacherX and I am the computer teacher here and I am responsible for teaching computer literacy, computer studies and then also the maintenance of the computers.

Ingrid: OK, from the questionnaire that filled in for the infrastructure for the school, how many computers do you have? Over 30 or so?

TeacherX: Yes.

Ingrid: Do you know how many exactly?

TeacherX: No.

Ingrid: OK. But you do have more than your average school, so what I was wondering was how did the school get those computers? Did the school buy them or were they donated to you?

TeacherX: Um, the one lab has 20 computers in it and that was from a donation. Somebody won an Edgars club competition and won 50 thousand rand and then donated that to the school and they used that to start a computer lab. but the lab was only used for computyping and at that stage future kids, I don't know if you know future kids?

Ingrid: Its a SchoolNet programme?

TeacherX: No, its not a programme, its an organisation that comes into schools and they supply you with the curriculum and then you just teach those lessons and stuff. They started here with 4 computers - donated those 4 computers - and placed those in a different room from the computyping computers and that was where I started teaching computer literacy. Then later the school decided that it was too expensive because they have to pay a monthly fee and so we decided that we would start a new lab. So the school bought the computers in the lab this where we are now.

Ingrid: OK. The maintenance of the machines, does the school also pay for that?

TeacherX: Yes, the school pays for everything.

Ingrid: How do you raise the money for the maintenance of the machines?

[1] Name removed for anonymity

TeacherX: We mainly take that money from the school fees.

Ingrid: When you do have computers breaking, is that due to general wear and tear or do you have problems with vandalism?

TeacherX: No, not at this stage. the older computers are having hard-disk and motherboard failures and its all due to wear and tear. We have had no vandalism yet.

Ingrid: And what about any problems with theft?

TeacherX: No, not at all.

Ingrid: You Internet connection is a leased line according to the questionnaire. Is that a dial-up line?

TeacherX: Yes, its dial-up.

Ingrid: Is it one 64K line?

TeacherX: Yes, the normal one.

Ingrid: OK. And is that to Rhodes?

TeacherX: No, not to Rhodes, to Telkom.

Ingrid: So you are not a part of the Diginet line to P.E. that Graeme, V.G and the independent schools share?

TeacherX: No, not at all. But we have been approached recently by Imaginet and they were talking about a satellite or an aerial or something...

Ingrid: Wireless?

TeacherX: I don't know if its wireless, but they said to us that they would be finished setting it up during this holiday and then we will have free access to the Internet. But I really am not sure what is going there, its something new and hopefully we will know more soon.

Ingrid: Is your building completely networked? Are the machines here connected to the machines in the other lab?

TeacherX: No.

Ingrid: So you only have networking within the room that the computers are?

TeacherX: Yes.

Ingrid: Are any of the machines connected to a server?

TeacherX: No, its all peer-to-peer.

Ingrid: Who set up the infrastructure in the labs for you?

TeacherX: Myself and one of the parents helped me. And that's all.

Ingrid: The machines that you have, what are they? Pentiums, 486s?

TeacherX: Its not Pentiums, its AMD CPUs. I think that they are 2.6 GHz.

Ingrid: Those are the new ones?

TeacherX: Yes.

Ingrid: And the old ones?

TeacherX: Oh no, they are Pentium 1s with 16MB RAM. I don't know the speed of the CPUs, but they are old.

Ingrid: Its probably around 166MHz

TeacherX: Maybe, but they might be even less.

Ingrid: As someone who does teach computer literacy to the children do you think that its necessary to have very strong desktop machines like in this lab, or do you think that using older machines like in the other lab is also effective for ICT integration?

TeacherX: From my experiences the old lab is just used for computyping and as I said they are very old and with low memory and that's sufficient for them because they just type there. But where I am teaching computer studies and ICDL you need a stronger computer.

Ingrid: So it depends on what you are using it for?

TeacherX: Yes.

Ingrid: You said earlier that children have to pay for computer lessons. Do they pay once every term? What do they pay?

TeacherX: No, they pay R50.00 per month and then they have one hour lesson per week. So that's 4 hours per month for 50 rand.

Ingrid: Do you think that that is well within the means for the parents who send their children here? So its not like half of the school fees or something?

TeacherX: Ja, no its not high. We are in fact thinking of increasing that now.

Ingrid: Do you find that you have timetabling problems with trying to find time to teach the children who have paid or for children who want to come and use them in the afternoons?

TeacherX: No, not timetabling because that is worked out by one of the other teachers. We use to have trouble when it was just the old lab because there was no free periods when that lab was open for a child to come and work there, because is it wasn't being used by the computyping class it was being used by myself.

Ingrid: Would you say that on the whole the children in your school are excited about using computers, do they get enthusiastic about the prospect of using a PC?

TeacherX: Yes, well I certainly hope so. *giggle* The thing is that you have to challenge them, you can't just teach them up to a standard and then just accept that. You should try improving on their skills. Like yesterday, I was so excited by the grade sixes, they came in here and as you know I am doing the ICDL with the high school children. And then the grade 6's came here - and there are some bright children there - and I challenged them and told them that next time I saw them we were writing a test on three of the programs, MS Word, Excel and PowerPoint and those students who pass the test (get 90% or more) will be allowed to start with the ICDL in grade 7. I also told them that there is a trophy at the primary school prize giving for the learner who gets the highest mark in the upcoming test. And they were just so excited, their eyes were sparkling. I could see that they were just so excited for that lesson. And that makes me happy because I can see that I am of some use and benefit to these children.

Ingrid: I know that you don't have many (or enough) computers at this stage but do you think it will be possible for teachers to bring classes here to teach them something using the computers?

TeacherX: Um, yes if we could add 10 more computers to this room and so have 20 then the possibility would be there to start using the lab for other subjects. But if it's going to be me doing that teaching in here, I don't know that I will be able to do all that teaching and I can't see the other teachers coming here to teach on their own. And if they aren't computer literate then I don't want them here on their own because then I will have to battle to fix anything that they break. So that's another problem.

Ingrid: OK. Do you think then that trying to integrate computer use into other areas and getting all teachers computer literate is a good idea or should we be doing something else?

TeacherX: Ja, that's what I meant. Because it's either going to be that way or it's going to be me that has to sit with them and find out what it is that they want to teach and then teach that for them.

Ingrid: That is not necessarily a good idea.

TeacherX: Ja, but I don't know which way would be the best.

Ingrid: Do you think that teachers in your school are comfortable using computers? Well, the majority, at least.

TeacherX: NO.

Ingrid: So majority not.

TeacherX: I can count the number on my hands, there are only five of us.

Ingrid: Have you had any training or offers of training from the DoE to get teachers more literate and willing to use computers?

TeacherX: No. But, you know the funny thing is that I offered to give them courses but they weren't interested, I offered courses for free but they were not interested. So I don't know, but our staff are middle-aged so maybe it's an age thing, but I don't know.

Ingrid: OK, so would you say that teachers think it's a valuable asset? I mean, if you removed all the computers today, would they notice - is it an asset to them?

TeacherX: For them, the majority of them are not using it but I think if they saw what the kids were doing and what they were learning based on what they do here then they'll think it's an asset. They will never say that there is no place for computers at this school. They do see the importance of them.

Ingrid: Do any of them use it for their own administration work, like spreadsheets for marking or report writing or tests, etc?

TeacherX: Ja, the one teacher uses Excel for his marks and Riaan is also very much computer literate and uses Excel and things for his work. Then there is also the computyping teacher and myself.

Ingrid: So the rest are just using pencil and paper?

TeacherX: Ja, you see I am also responsible for entering all the marks from the different subjects into the computer at the office for reports and things. So they bring all the marks to me and I must do all that work. So they are not forced to do it themselves so they don't bother.

Ingrid: Those five teachers that you mentioned, do they -

TeacherX: They don't use the machines here, they use what they have at home.

Ingrid: At home, OK. So it's only you who uses the Internet here?

TeacherX: Yes, for the children.

Ingrid: Do any of your teachers make use of email at all?

TeacherX: Ja, but again only at home. And the secretary in the office, but not even the principal - the secretary does it for him.

Ingrid: And the kids, do they use email?

TeacherX: Ja, they do. They go onto Hotmail and create their own email accounts.

Ingrid: So you don't have internal email here at the school.

TeacherX: No, we don't.

Ingrid: Do you think that the teachers respect you as the IT teacher so in that they don't feel intimidated by you because you know more about a computer than they do? If they were trying to teach themselves about computers that they would come and talk to you about it.

TeacherX: No, I don't think so. They do respect me, I think, but I don't think that they find me intimidating. I think that they feel free to come and ask me if they want to know something. I have never experienced that someone is scared to ask me.

Ingrid: Have you had any formal computer training? Did you study it somewhere like varsity?

TeacherX: No, not at varsity. But I did a Further Diploma in Education through Tukkies, which involved integrating computers into subjects and stuff like that. And then I was with Future Kids for three years and they provided us with certifying courses. And I am currently doing a programming course through UNISA. Java, that I am battling with.

Ingrid: It's not an easy language at all.

TeacherX: And that's - ja. But you see I am quite scared that I will get to the stage where I don't know enough. So it's for me a priority to study further and further so that I am always in advance of the kids.

Ingrid: Do you find that type of continuous learning fulfilling?

TeacherX: Yes, I do. You can't stop learning with computers. You can't think at any point that you now know enough. You have to carry on learning because the software is always changing.

Ingrid: If something breaks, how technical can you get before you have to call someone else?

TeacherX: I am fairly advanced there. I can open the machine up and start looking for the problems. But if I see that it's something beyond my skills then I will call someone else. But I must first try and sort it out myself because the school is not financially that strong and I have to save where I can before calling in someone else.

Ingrid: When the children come to the lab what is the most widely used program or software that they use? Like MS Word or the Internet?

TeacherX: Windows Media Player. I am telling you, that is the most widely used. *giggle* But otherwise, Word, yes, for their projects and then the Internet.

Ingrid: What do you feel needs to be done in order to successfully integrate ICT and computers into the curriculum in your school and others?

TeacherX: I would definitely have more computers. I would also love to have a data projector with a laptop to use for teaching. And also to promote the school.

Ingrid: Would you have PCs in every classroom?

TeacherX: No, another thing I would like to do is place some computers in the library with at least Encarta on them so that the kids can go there to look for information. I mean they can come here for the Internet but they can also know that they don't have to use the Internet but that there is also other software that they can use. And then I would put that in the library for them so that it's in a study atmosphere. Then also a little computer lab for the teachers so that they can do their work there too, and maybe that will encourage them to use the computers and get more computer literate.

Ingrid: Do you feel that there needs to be more support and involvement from the DoE in getting computers into schools and teachers training?

TeacherX: That's my aim. You know, I was in the service of the department. I resigned my post, it was a big mistake to do this on my own because there is no scope and the department didn't help us. And I am doing this like a business and the kids come voluntarily here and that must be my salary. But we are not a big school so the number that come is not that high, so I can't have the salary that the department paid me. So financially I took a step back. And so I would love to go back. But the only way is if they create posts for IT teachers at each and every single school. But where are they going to find those people? So there must be some sort of training, from their side as well, courses or whatever.

Ingrid: Would you say that having the Internet is an asset? Is it of any value, do you gain from it or is just having a PC enough?

TeacherX: You can go far without Internet access. I only use Internet for the ICDL module and then for the kids, because it is here, I also give them the opportunity to come for information but if it wasn't there then I could teach them just as much as I do now. So, ja, without Internet access you can do plenty.

Ingrid: Then lastly do you feel that computers and ICT have a role to play in the future of education in this country?

TeacherX: Oh, ja, for sure! Ja, definitely. Every career you see today you need to operate a computer, you need to know how to work a computer. So, ja, and there are lots of kids who don't have these facilities at school and so they are so behind when they leave school. So, ja, for sure.

Ingrid: OK. Thanks very much.

TeacherX: Pleasure.