Research Testbed Networks: Practical Tools for Service Delivery?

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Abstract. The Telkom Centre of Excellence (CoE) at Rhodes University, housed in the Computer Science department was opened in 1997. The CoE's focus on Distributed multimedia service platforms soon showed that the technology being researched could be applied in the disadvantaged peri-urban communities. The CoE has thus concentrated its research on building a testbed network that delivers real services to real users. In 2007, the testbed was extended to include a marginalised rural area in the Siyakhula Living Lab.

The greatest factor in the sustainability of the CoE testbed network has been maintaining usefulness to all the stakeholders over the last 12 years. Industrial funding, University outreach goals and research goals could all be harmonised, while sustaining the delivery of high quality informatics services in the community.

This paper presents a brief case study of the communications network testbed and how it was applied to the Development Informatics space. It analyses the roles played by stakeholders in either assisting and sustaining or obstructing the service delivery. It makes key recommendations on best practices for research networks that can also bring informatics to disadvantaged communities. It shows how testbeds for the research of new technologies can be designed so as to allow Development Informatics work to take place on such networks.

Keywords: Testbed networks, sustainability, DSL, WiFi, WiMAX

1 Introduction

The Rhodes University Telkom Centre of Excellence (CoE) at Rhodes University, located in the Computer Science department, was opened in 1997. Its research focus is on distributed multimedia services platforms. The core missions of the CoE are to produce excellent post-graduates with practical industry-related experience and to produce excellent Information Communication Technology (ICT) innovation research.

This paper attempts to provide objective criteria to determine whether research testbed networks can provide meaningful and sustainable input into Development Informatics projects, if they include academia, industry, government and community actors. It does this by examining the history of the CoE and its core telecommunications project – a testbed network providing ICTs to marginalised rural and peri-urban communities. By testbed network, we mean a distributed platform on which one can try out new ICT technologies, be they hardware or software. The novel aspect of this testbed network is that it incorporates the community. It is thus a testbed which allows DI work to be performed through the deployment of useful prototypes, blurring the distinction between controlled lab experiment and deployment platform.

This paper also provides an in-depth description of the testbed, for two reasons: firstly to provide opportunities to replicate the construct and secondly, to allow deeper more meaningful insights into how such a sustainable testbed network can be established, in order to provide a reliable service to the community.

The paper is divided into four sections; the first briefly explains the Telkom Centres of Excellence programme specifically focusing on the CoE at Rhodes University and the collaborative activity which is encouraged by the THRIP programme. The second section details the various technologies that make up the access network within the testbed, while section three discusses the services that have been developed which are provided via the access networks. Finally, we discuss the lessons learned through deployments of the access network and the services that run on top of that network. Is this a practical undertaking and one that should be replicated at other learning institutions?

2 The CoE Testbed Construct, Actors & Stakeholders

The concept of the triple helix of actors in innovation and development projects refers to the co-operation between academia, industry and government to make optimal use of resources and different strengths that each of the actors has. The concept was popularised through the rise of the Living Lab methodology, which brings together the triple-helix and citizens (communities) to meet real needs, through the development (Mulder et al., 2008). The CoE brings together academia, government, and industry in a single project oriented organisation. Through its core testbed project, it additionally involves the community in decision-making and implementation of the project – thus adding a fourth strand. The CoE helps the Department of Trade and Industry meet its goals concerning human resources development through the THRIP programme, it performs industrial research valuable to its industry sponsors, and finally it supports the Computer Science Department and other departments at Rhodes University, improving research output.

The Centre of Excellence programme was conceptualised by Telkom South Africa in 1996 and was launched at the University of Cape Town in 1997 and hosted in the Electrical engineering and Computer Science departments. Sixteen Information Communication and Technology (ICT) Centres of Excellence have subsequently been established and an accumulative amount of more than 250 million South African Rand in financial support from Telkom South Africa, ICT companies in South Africa and the South African government has been raised. Approximately 1,800 postgraduate degrees have been awarded at the participant tertiary institutions (Browne & Leitch, 2009).

The Centres of Excellence programme promotes multi-stakeholder collaborative interactions in the telecommunications industry space. It also provides facilities to encourage young scientists and engineers to pursue their interests in South Africa. Research and development largely focuses on applied development with only a small amount of blue sky research taking place. The programme provides the tertiary institutions with funding to establish state-of-the-art facilities as well as to provide resources for student bursaries, running costs and opportunities to allow academic researchers to collaborate internationally. Each of the sixteen Centres has a particular research focus area in which it specialises, focusing the efforts of each centre and allowing as much of the ICT sector to be researched as possible (Browne & Leitch, 2009).

The Rhodes University CoE's focus on distributed multimedia service platforms has carved out a scope that focuses on both the physical networks which carry multimedia services to the customer/client as well as the development of the services and necessary software. The Rhodes University CoE has thus concentrated its research focus on building a testbed network that provides a service to its stakeholders. These stakeholders fall into three categories, namely, testbed owners, testbed researchers and testbed clients (end-users). The testbed owners consist of the CoE sponsor partners and Rhodes University, represented by the Head of the CoE. The testbed researchers are those students within the CoE programme at Rhodes University together with the CoE staff members who experiment with different facets of the testbed, either the network or the services. The testbed clients are those disadvantaged communities as well as Rhodes staff and students (generally also testbed researchers) who have connections to the network. In this paper we discount the latter and focus on the former. Where technology is described linking disadvantaged schools to the network, connections to other client stakeholders are also implied. The CoE has been actively encouraged to engage in social development and applied technology research. Combining research experimentation together with access provision to quality networks and digital services for previously disadvantaged schools and communities allows us to pursue both goals together in a productive and effective manner.

Since its inception in 1997 the CoE has been working with previously disadvantaged schools in the Grahamstown area. Over the years the number of schools involved in the CoE's research has increased to eight: one pre-school, three primary schools and four secondary schools. Each school is a client on the CoE's testbed network, with access to the various services offered on the testbed network. In 2007, the testbed was extended to a new rural site, which evolved into the Siyakhula Living Lab. The Siyakhula Living Lab testbed network is controlled monitored and maintained from the CoE and it is based on similar technologies as the original testbed network. By providing clear benefits to all stakeholders (clients, researchers and owners) the testbed has grown and evolved, eliminating and including technologies and services as their usefulness has evolved.

The subsequent sections detail the development and evolving natures of the network and its services. They try to distill technology decision criteria, that ultimately led to success or failure of each technology, as the basis of discussion on whether testbed networks are a sustainable tool for development.

3 The Network

This section details the progression and evolution of the network that staff and students working within the CoE deployed. The research and deployment of the network began in 1999 and is the accumulation of 10 years worth of technological evolution. Here we characterise different technologies along similar dimensions so that we are able to draw comparative conclusions in section 5.

3.1 ATM

The first element of the Rhodes CoE testbed network was Asynchronous Transfer Mode (ATM) technology which at that time was at the peak of its global success, and Telkom and the other industry partners had a strong interest in the technology. Given the budget constraints and the nature of the experiments envisaged on the ATM equipment, a simple network topology was deployed.

There was no practical user need for long distance connection between Ethernet segments, so the ATM switches were placed next to each other, able to support experiments on them but not providing any useful service to the rest of the network. In addition, by 1998, the Computer Science department (which hosted the CoE) already had substantial experience in IP. As a result, the installation received little use. A few experiments (such as a high speed link to a sister network in Johannesburg, over 1000 km away) were run and demonstrations during networking courses were held. The ATM network is currently unused.

3.2 DSL

The CoE began its research into the use of Digital Subscriber Line (DSL) technologies in 1999. Some of the research projects that have involved the use of DSL networks include Bandwidth Management and Monitoring for IP Network Traffic (Irwin, 2001), and Digital Video Broadcast via Asymmetric Digital Subscriber Lines (Sieborger, 2000). 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 as well as staff and students working within the CoE programme at Rhodes University.

For each of the clients on the DSL portion of the network, Telkom was commissioned to install an outdoor extension from the university to the school. A server located at the client site connects along the line to a DSLAM that is located in the CoE technical area. From the DSLAM, traffic is routed to the Internet with all other Rhodes Internet traffic. The server also provides other useful services to the school such as a Squid cache, which is configured to block access to undesired websites and data from the Internet.

The reach of DSL is however limited, despite its cost effectiveness (Halse and Terzoli, 2002). As a result other solutions (or network technologies) needed to be used to connect clients beyond 5 km of the University. During 2003 it was decided to find a wireless alternative, as other wired alternatives, such as fibre optics, tended to be expensive, while power line communications (PLC) technology was still immature, expensive (Mackie, 2003) and difficult to deploy without the assistance of the municipality.

Since 1999, DSL connectivity has moved from a cutting edge to a consumer technology. It has become affordable to most private persons and schools, if their local telephone exchange is enabled. Further, Telkom no longer installs new outdoor extensions (since 2010), so the CoE DSL experiment cannot be expanded or replicated elsewhere, thus diminishing its attractiveness. However, since the technology provides very fast access to the testbed and Internet at a fixed cost, it is still in use.

In 2010, DSL was discontinued at one school owing to copper theft. Cables were replaced twice by Telkom within a period of two months, after which data connectivity was provided by WiMAX. Cell phones provide voice connectivity to the school.

3.3 WiFi

In 2003 the CoE began investigating the use of IEEE 802.11-based wireless LAN technologies (WiFi) as a means of connecting clients which were further than 5 km away from the university to the university's network and thus to the rest of the Internet (Whittington, 2003) and the services being developed on the CoE's multimedia platform.

We connected wireless network clients, mostly within Grahamstown West, by using 12 dB directional antennae connected to wireless Ethernet bridges. Using this configuration, we were able to achieve data transfer rates in the region of 2 - 2.8 Mbps at distances of about 2 to 3 km. Initial tests had shown that the wireless network could potentially connect school clients as far as five kilometres away. Tests were conducted with mobile equipment, from several locations including at a distance of 4.8 km. The tests showed that surrounding schools would be able to share a connection of 4 Mbps via a repeater (Whittington, 2003). A network was installed and soon required an upgrade because of radio interference from other WiFi networks which had sprung up in town, despite an upgrade (Brandt et al., 2007). It was time to move to something new.

WiFi equipment is still in use in Grahamstown East, owing to the low cost of hardware and low interference levels there. WiFi technology allows the CoE to construct network extensions easily and cheaply, in order to be more inclusive. Other initiatives also make use of WiFi for development purposes (Patra, et al., 2007).

3.4 WiMAX

In 2006 a WiMAX (Worldwide Interoperability for Microwave Access) network was deployed as part of the CoE testbed in order to address the limitations experienced when using WiFi technologies to reach remote clients. WiMAX addressed the network instability experienced by WiFi due to interference from other network providers in the town because WiMAX operates in a different electromagnetic spectrum to WiFi. The base station was installed on a high point over Grahamstown West. The WiMAX base station broadcasts in a 360 degree sector covering most of Grahamstown West and the surrounds (Sieborger & Terzoli, 2007).

The WiFi network in Grahamstown East, connecting the Grahamstown East schools is transmitted to the Monument via WiMAX. This has increased the stability of the schools' connections, while keeping costs low, as WiFi equipment is at the time of writing still about 75% cheaper than WiMAX equipment – although the performance is not comparable under the same circumstances.

WiMAX is a technology that has still not made it into the mainstream, as broadcasting stations and client end-user devices cost much more than other consumer technologies. For this reason any research results based on investigations into this technology are interesting to stakeholders in the testbed network. At the same time, the technology does improve quality of service to client stakeholders (Sieborger & Terzoli, 2007).

3.5 Wireless 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. When the wireless network was first designed a number of access methods were considered in order to secure the network. The simplest method was to use Microsoft Point-To-Point Encryption (MPPE) Protocol. All traffic between clients and the Internet is routed through this secure medium (Sieborger & Terzoli, 2007).

3.6 Summary of Network Technologies

In table 1. we characterise the network technologies along simple dimensions. The dimensions we considered answer the following questions: 1. which partner in the enterprise was the motivating factor for the adoption of the network technology, 2. what were the costs involved in purchasing and maintaining the technology, 3. was the technology stable and in common use, or was it a “cutting edge” technology with a high degree of innovation, 4. which stakeholders benefited from the application of the particular technology.

The way in which each stakeholder benefits was defined according to the following criteria: A researcher benefits, if she is able to gain novel insights from her work on the testbed, which can be disseminated in a publication or similar; a community member benefits if their life quality is improved in one of the following ways – they gain information which they are able to use to make better informed decisions (knowledge) in a manner that improves health, income or social status, they gain employment or income, they obtain directly through the technology the means to save costs or to improve some aspect such as health; an industrial partner benefits if they are able to “productise” technology outputs, to sell, use or licence, or if they are able to gain marketing value through participation (advertising, branding, etc.).

We chose these dimensions for our analysis, because they are commonly used to analyse projects (for instance, they are often focus questions in project proposals).

	Who decided	**Cost**	**Cutting Edge**	**Research Benefit**	**Com-munity Benefit**	**Industry Benefit**
ATM	Industry	huge	no	no	no	yes
ADSL	Academic	high	yes	no	yes	yes
WIFI	Community /Government	low	no	no	yes	no
WIMAX	Industry	high	yes	yes	yes	yes
SECURITY	Academic	low	no	no	yes	no

Table 1. network technology comparison along 4 dimensions

4 The Services

The second important component in the investigation of technologies for a distributed multimedia services platform are the services themselves. These are of paramount importance to the community as they represent the value of the testbed network to the community. The services have evolved over time from basic Internet access and email provision to VoIP and video IP services and social media.

4.1 Internet Access

One of the most fundamental services that networks provide is access to information and communication. The Internet provides a plethora of information via the World Wide Web (WWW) and access to organisations and individuals via email. The schools wish to have access to information and resources available on the Internet to promote teaching as well as school management. Such a service is thus valuable to them. The marginalised communities in the SLL value Internet access for similar reasons to the above.

4.2 iLanga

Tertiary institutions are well positioned to work with and develop innovative solutions based on open source software. In particular, given current high costs of telecommunications in developing countries, the development of open source software for this domain is highly desirable. Shortly after it was released in 2004, students at Rhodes University began experimenting with the Asterisk IP PBX. These efforts culminated in the creation of an open source telecommunications platform with Asterisk at its core, which was given the name local word meaning “the sun” – iLanga (Penton and Terzoli, 2006). iLanga was able to provide free voice and video IP communication for both students and staff of the Computer Science department, over a relatively under-utilised Ethernet network.

iLanga as a multi-protocol agent. The use of Asterisk allowed us to link separate testbed networks together, for the purposes of VOIP communications, through the IAX (Inter-Asterisk eXchange) protocol. IAX provides both signalling and media control to better support communication across network address translators and firewalls (Spencer et al., n.d.). IAX connections were established in places such as the University of Fort Hare and the SLL.

Aside from linking separate IP networks, iLanga was also able to connect to non-IP networks such as GSM (cell phone) and PSTN (Telkom network). The services are currently still in use by students and staff, but a large scale offering to the community was not possible. Since the CoE does not run as a business, managing the access to paid services by the community was not a feasible activity for the CoE.

Service integration in iLanga. In addition to providing a multi-protocol ecosystem, a significant amount of attention went into integrating innovate application services into iLanga. Students were able to use Asterisk's native service interfaces such as the dial-plan, AGI (Asterisk Gateway Interface) and a TCP interface known as the Asterisk Manager Interface, to regularly extend the testbed by deploying new real-time communication services into iLanga. Service creation in iLanga is the topic of (Hitchcock, 2006), which details the use of various open source tools to add value to the testbed.

iLanga evaluation. Recent trends in telecommunication research have elevated the study of Next Generation Networks (NGNs) and the IP Multimedia Subsystem (IMS) in particular above open Internet-style platforms such as Asterisk. Fortunately, the Fokus Fraunhofer Open IMS Core, an implementation of the IMS core entities, is available and provides an ideal environment for the creation of an IMS testbed (Fraunhofer Fokus, 2009). As a service platform for IMS, we have chosen an implementation of the JAIN (Java APIs for Integrated Networks) SLEE (Service Logic and Execution Environment) standard called Mobicents, which allows for the deployment of several types of services such as media, presence, web and billing (Red Hat Middleware, 2009). The benefit in this move is that our research, and ultimately the extension of the testbed, will be more in line with that of our counterparts in this growing area. Also, the utilisation of Mobicents will allow for the creation of more sophisticated and integrated services, allowing service building blocks to be re-utilised across different composite services.

4.3 awareNet

awareNet is social networking software, offering similar core functionality to Facebook, with a few significant differences. awareNet was conceived of and implemented by the Village Scribe Association vzw., a non-profit organisation with the aim of promoting innovative information and communication technologies in marginalised rural areas (MRAs) and impoverished peri-urban areas (VSA, 2009). The aim of awareNet is to promote cross-cultural contact among students in African MRAs and European students at high school level (Grade 9 Grade 12). It also promotes innovation research and long-distance collaboration as demonstrated in a joint project with 20 German Informatics students in 2009 (Freie Universität, 2009).

awareNet is free/libre open source software designed for high-speed wide area networks (WANs) which have limited Internet connectivity, which is the case with schools attached to the testbed, as they have a limited Internet quota. An awareNet server situated within the WAN gives local nodes high speed access to the social media and allows users to upload rich multimedia content, without impacting on the quota. Within social media, as in most P2P applications, a critical mass of users is required to create a sustainable service and first users need incentives to come on board (Wilcox O'Hearn, 2002).

4.4 Further Education Services

Collaboration and communication tools have evolved from pure email to also include tools like wikis. An example of this is the e-Yethu project. e-Yethu is the Grahamstown Schools' Project and is a joint venture between the CoE and the Education Department at Rhodes University. The project aims to support schools in Grahamstown in the realm of ICT, both technically and in terms of ICT integration for teaching and learning. The project makes use of a wiki which all participants have access to and supports planning and collaboration amongst team members within the project.

4.5 Summary of Services to the Community

In table 2. we characterise the services introduced above along the same dimensions as in section 3.6. For an explanation of the columns, please refer to that section.

	Who decided	Cost	Cutting Edge	Research Benefit	Com-munity Benefit	Industry Benefit
Internet	Academic	Low	No	Yes	Yes	Yes
iLanga	Academic	High	Yes	Yes	No*	Yes
awareNet	Industry	Low	Yes	Yes	Yes	Yes
Further Education	Community	High	Yes	Yes	Yes	Yes

Table 2. services comparison along 4 dimensions

Notes to table 2:

* The iLanga VoIP services were under-utilised by the community, since they could only communicate with other testbed network nodes using this technology. CoE staff and students use the service more, because paid services are made accessible to them. Thus the community benefits little from this service.

5 Testbeds for Development Informatics

This section looks at success or failure of each aspect of the project from the point of view of each stakeholder. The stakeholders of our testbed fall into three groups (as previously mentioned), the testbed clients, the testbed researchers and the testbed owners.

We also attempt to evaluate the construct of a testbed network, as a means to bring infrastructure into communities, so that ICT research can also make a developmental (DI) impact.

5.1 Testbed Clients

The testbed clients are those users who make use of the network in order to access the various services, such as the Internet, email, VoIP and awareNet. As mentioned above, for the purposes of this paper, we do not consider the privileged staff and students who are end-users, we consider only the disadvantaged community within the Grahamstown district and at the SLL. The services that the testbed offers are *real* to the clients – the clients depend on the services, and the services are made accessible under real-life conditions. The networks span many kilometres, and are faced with environmental challenges. Through their usage of the facilities, the clients generate usage data and fault reports. The testbed clients, thus help to generate information regarding the performance and user experience of the network and services. This feedback from the testbed clients is often essential within the research being conducted by the testbed researchers.

The consumption of technologies or services by the testbed clients has an effect on which technologies and services remain. For example, when the WiMAX technologies were incorporated into the testbed a number of the WiFi testbed clients opted to move from the WiFi access network infrastructure to the WiMAX access network. The testbed clients experienced the interference problems with the WiFi network firsthand and were instrumental in the encouragement to find a solution to the problem or investigate alternatives. In addition, requirements engineering of applied DI research experimentation is improved, through feedback from real users about specific requirements. Thus commercial services developed by industry partners can be adjusted and improved in order to better meet the needs of the consumers of actual products that arise out of the research.

Thus a testbed initiative works together with the community, as the implementers and the users depend on each other. It is this dependency, which is beneficial to the construct and makes it viable in a DI context. On the other hand there are not many other pilots, which have been delivering services to communities for 12 years. If one considers sources such as Batchelor (2003) or Grace et al. (2004, p. 39), sustainability is the exception rather than the rule.

An example of the interaction around the testbed is as follows: the adoption of awareNet was problematic for technological and social reasons. awareNet did not initially meet requirements of the clients (educators and learners alike) and had to be adapted. The following steps were taken to address this issue: A local community co-ordinator was trained to help the community understand the value of the service and to bring back ideas to improve the service. Further, awareNet was embedded in teacher ICT training courses, as an example of collaborative work. The problem of teachers not having any time for awareNet also originated an idea of automatic lexical and AI based systems to monitor system usage by the learners in order to secure their experience using it. Thus researchers engaged through the testbed services were successfully able to improve the experience of the community.

5.2 Testbed Researchers

The testbed researchers are the students within the CoE programme at Rhodes University together with the CoE staff members and supervisors who work on the different facets of the testbed, either the network or the services. For the large part, these are affiliated to the Computer Science Department. These researchers use the testbed network to conduct tests and research, and to develop and experiment with new services or networking technologies. Their constant interaction and development of the testbed network helps to make the testbed sustainable. They develop and adapt the network to suit the changing circumstances, including new or different users, changing trends in research and industry and new technologies.

Examples of the development and adaptation of the testbed are, firstly, the case of the ATM component of the network. With the introduction of Ethernet, which was cheaper and easier to use than ATM technologies and provided the same benefits and services to users, ATM became obsolete and eventually only Ethernet was used on the testbed network. Secondly, the WiFi component of the network is undergoing a similar process. There has been a marked increase in the amount of interference within the WiFi spectrum in Grahamstown, which resulted in degraded network quality. As a result the CoE decided to expand the testbed and its research by including WiMAX technologies, which provide users with improved services. Finally, the existence of the testbed allows a service such as awareNet to ride on the testbed using “unused cycles/space” to provide added value to the clients. This is because the regulations governing the testbed tend towards supporting new experiments.

In order to maintain this form of sustainability there needs to be a constant stream of students taking up projects within the CoE programme to replace those that are completing their studies and moving out of the university. New students are attracted through bursaries and the state-of-the-art equipment mentioned in the following section. In addition, the testbed allows students to work in a real world environment network where they can implement real testing and development and achieve real results.

Sustainability is further achieved through the use of open source software and standardised hardware. The use of open source software and open standards makes it easier for work within the project to grow and continue as the students change over time. It makes existing systems accessible as new students can access past work as well as a wealth of support, not only within the CoE but also worldwide within the open source communities. Past systems and services can also be integrated into the new systems and services being developed should users still require or make use of them.

In addition, students are also attracted through the undergraduate and honours programmes where they receive a “taste” of the research and development that takes place at a post graduate level and decide to stay on to further their studies. Through supervision from the members of staff that conduct their research within the auspices of the CoE, students are kept motivated and guided through the often murky waters of research. Without supervision students can lose their drive and often find themselves in positions where they are unable to solve research related problems without assistance.

The constant research, development and testing that the testbed facilitates is another important characteristic in maintaining the testbed network's sustainability. Without the testbed researcher users the testbed would not grow, develop and adapt. Furthermore, sustainability of the testbed would be compromised without the use of open source software and open standards equipment.

5.3 Testbed Owners

The testbed owners are the CoE sponsors and Rhodes University, represented by the Head of the CoE. Together the owners provide governance and leadership within the testbed. The CoE sponsors provide the necessary funding for the CoE and its projects. In terms of the government sponsor, namely the Department of Trade and Industry (DTI), their ongoing support contributes to their project vision in the Technology and Human Resource for Industry Programme (THRIP). The ongoing support of the university is also a contributor to ongoing sustainability of the CoE testbed. The three pillars of the university are research, teaching and community engagement. The CoE testbed contributes to all three of these pillars.

The owners of the project are however more interested in the other pillars – human resource development and research, rather than outreach. This is a weakness of the approach as it is currently being implemented. The industrial interest in the so called “bottom of the pyramid” sector of the population, including often the rural poor, has recently become an interesting market, as demonstrated by successes achieved by for example the Grameen Corporation. Also as developed markets become saturated, telecommunications operators look to these new markets for growth. However, this shift in attitudes is only barely perceptible in the CoE project.

Sustainability of the testbed network would be jeopardised without the governance, funding and support of the testbed owners, which would not be ongoing if the testbed was not of use to the owners through providing quality graduates and in turn supporting the vision of sponsors like the university and the Department of Trade and Industry (DTI). The community may be served better however, if the value in the DI aspect of the testbed were presented more clearly.

5.4 Measuring Testbed Success

Specifically from a DI standpoint (i.e. considering the benefits to the community, refer to table 1. and table 2.), the testbed does seem to be a success. The project has provided Internet and ICT services to a number of schools in the impoverished parts of Grahamstown an in the rural testbed, for over 6 years, at an acceptable cost. Around 2000 learners have been introduced to ICTs and have gained initial ICT literacy in the rural testbed alone. This figure stems from a 2010 survey of the numbers of children in classes run by community co-ordinators. Educators have been able to familiarise themselves with the Internet and new technologies, and to improve their own skills.

True success of the testbed construct lies not only in the sustainability and endurance of the project, as it may be argued that the sustainability rests only on the continual support afforded to the project by the combination of actors involved, and to whom the DI aspect of the testbed is just a nice side-effect. An additional measure for success would be the replicability of the model. If more research institutions in the developing nations (BRIC countries), where the distance from impoverished communities to wealthy developed ones is small, were to adopt such small infrastructure testbed networks to serve the disadvantaged communities, that would point to real success. It would also assist in establishing more user-driven solutions as suggested by Dias and Brewer (2009). Aspects of this testbed that are replicable anywhere are the choice of a robust and inexpensive infrastructure, as used in Grahamstown East, which require little maintenance, cheap to roll out and enable a multitude of services, and a great scope for experimentation (Brandt, 2006).

A large measure of the success of the testbed network as a DI project is the view of the community users. Obtaining permission to roll out the testbed in the schools involved was very simple and little bureaucracy stood in the way. This may have been the case owing to the perception by the community of the University as a neutral or trustworthy agent and also because the schools keenly desired the service being offered. The community users, in this case schools in disadvantaged areas, felt and still feel that they have the right to ICTs since the regional Department of Education has been publicising ambitious aims to connect all Eastern Cape school by 2013 (in a white paper from 2008, unavailable). Looking forward, one may also ask how the schools will continue to obtain services if funding to the project is cancelled.

Certainly, the network would continue to operate for several months with volunteer efforts, since the amount of maintenance required is in general minimal and most maintenance can be provided by student interns, who would continue to gain valuable experience by providing the service. Equipment failure would certainly slowly erode the network, since most of the hardware is not under the manufacturer's guarantee any longer. However, some schools have recently (August 2010) indicated that they would be willing to pay for the services they receive, especially if their quotas could be raised. It seems that the project has created a market within the community for the services.

Thus, while this testbed seems to be a successful method of performing DI in certain limited contexts, the final verdict is still outstanding at present time.

5.5 Factors of Success

Turning losers into winners is possible if one focuses on strengths. While research institutes in developing nations do not have the same level funding nor the large pool of skilled students and staff as do institutes in the developed world, nevertheless they have two attributes that should be considered strengths: they have the opportunity to leap-frog development initiatives directly to the current state of the art, omitting costly technological evolutionary steps (Paz and Seo, 2009); they also have a large pool of research subjects on their doorsteps, who not only come from an impoverished community but also have strengths themselves that may be potentiated by ICTs (Sutinen, 2009).

Utility of the technologies employed is also a key factor to success. If the technologies deployed are not actually used, then they tend to become neglected, do not have a champion and fail to gain support. This was quite clear in the example of the ATM technologies as opposed to the WiMAX technology, which had very broad backing.

Other pragmatic choices may need to be made to keep such a testbed functioning. For example, one of the principles of the project is to use only free open source software. As discussed in section 3.5, Microsoft's MPPE security mechanism was employed, although it may seem to contradict project principles, because Microsoft corporation has a long tradition of costly closed source solutions. Nonetheless MPPE is an open standard, which is widely used and supported by all vendors of hardware and software unlike equivalent solutions from the open source community.

When running a DI project using the testbed construct, one must also be prepared to include services and hardware that do not directly address the needs of the community, in order to satisfy the needs of other stakeholders in the project. It is only through symbiosis, i.e. value delivery to all stakeholders that sustainability can be achieved. Through sustainability, one can attain the position that many generations of users can be trained and can gain access to the Internet and to the offered services.

Learning from other stakeholders is also important to the project success. For instance, Table 1. and Table 2. support a common trend in the telecommunications industry away from providing simply a conduit (or network infrastructure) to value-added services. Table 2. seems to specify more benefits than Table 1, which is to be expected, since the community is interested in services and not the network per se.

The testbed is thus able to support novel services, which can be prepared in collaboration with other research departments in the fields of health, education, government etc. It is an instrument that can bring novel DI ideas to life.

6 Conclusion

This paper explains the evolutionary process which the CoE testbed underwent, to reach a position in which it is a valuable service providing construct in impoverished and marginalised communities. It lists the network technologies and services that were offered to the communities participating.

We show here that the construct of testbed networks can bring together several stakeholders and enable multi-disciplinary research and development, which directly affects and benefits the community, and which is directly affected and benefited by the community's participation. We also list lessons that we learned in implementing the testbed network are listed.

We propose that testbed networks are a good way to create a sustainable platform for relevant and useful pilot projects, which might then spin-off other sustainable ventures as they are able to play to the strengths of the community and stakeholders.

The CoE testbed network demonstrates how a research vehicle can quite feasibly be extended or re-engineered to provide Development Informatics infrastructure. The testbed provides services to which the communities would not otherwise have had access, including: Internet and email, VoiP communications, social networking, ICT literacy training and security. It also provides a platform to researchers who are able to create novel customised technologies, such as awareNet, that can be developed according to the community's needs and wishes.

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