Reflection on three years of rural wireless Internet Protocol communication research and fieldwork

W. D. Tucker, E. H. Blake, G. Marsden, M. Pearson and R. Westerveld

Abstract—This paper reports on three years of research and fieldwork with a rural wireless Internet Protocol communication project. We built a long-range WiFi network and custom communication software to support a rural telehealth project in the remote Eastern Cape. We report on our work using cellular networks, devices and applications as reference technologies because our users and beneficiaries are very comfortable with them. Of most concern are the technological and contextual issues affecting take up of the systems we designed. The paper intends to provide a summary analysis of our experience so that others in the field can learn from our successes and mistakes with respect to rural Information and Communication Technology for Development (ICT4D) in a South African context.

SATNAC Classification: Innovation and Regulatory – Telecommunications Developments and Inventions

Keywords: communication, ICT4D, Internet Protocol, rural wireless networks, SMS, telehealth, text, video, voice

I. Introduction

This paper reports on an Information and Communication Technology for Development (ICT4D) [1] project that has been running for over three years in a remote rural part of South Africa [2-4]. This project is concerned with the power, networks, devices and their application interfaces to support ICT4D, as in [5]. We orient the discussion around multi-modal (i.e. text, voice and video) messaging, using cellular technology as a reference point, because our beneficiaries are very comfortable with their cell phones.

The paper is organised as follows. First, we provide background on the project and its beneficiaries. Next we briefly cover some of the technical details. Then we place more emphasis on the contextual issues surrounding the project, especially with respect to infrastructure, regulatory issues and socio-economic and political realities. We explain our approach and methods for evaluation and impact assessment. Finally, we draw a brief conclusion with respect to cellular and wireless technology in an ICT4D context and plot future work.

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II. Background

Canzibe hospital and Lwandile clinic are located in the Libode district of the Eastern Cape, South Africa. The beneficiaries are a) the patients who receive more informed and productive healthcare closer to their homes, b) the rural health practitioner with improved ICT skills, c) district and provincial Department of Health (DoH) management interested in the effectiveness of telehealth communication and d) postgraduate students at the University of the Western Cape (UWC) and University of Cape Town (UCT) doing research theses on various aspects of the project.

Canzibe is typical of a rural Eastern Cape hospital that serves about a dozen rural satellite clinics. Cellular coverage in the area tends to be very good though some patches are still not served. For example, during the course of our research, coverage was added to Lwandile clinic. There is no culture or practise of hospital and clinic staff communicating with each other regarding rural patients. These patients prefer treatment at the clinic because treatment is free at the clinic (a small fee is required at the hospital) and closer to their home than the hospital.

South Africa has some of the most expensive telecommunications and Internet in the world [1]. So we built a pilot rural long-range WiFi network along with custom communication applications running on laptops. We now use WiFi-enabled cell phones because laptops (and our application prototypes) were proving too cumbersome. Many rural habitants are well versed with cellular handsets. We use smart phones that enable text, voice and video over WiFi much more cheaply than data over General Packet Radio Service (GPRS) available throughout many of the rural areas. We encourage users and our local support team to use applications like MXit and Fring to text. These Instant Messaging (IM) applications transfer text messages orders of magnitude more cheaply than Short Message Service (SMS).

A. Beneficiary selection

Transcape, a non-government organization (NGO), introduced us to the medical staff at Canzibe hospital. We had prior experience with another telehealth project [6]. We chose to link up the Lwandile clinic in 2005 because it was

the most remote clinic in the area with virtually no GSM (Global System for Mobile communication) coverage (at the time). On the positive side, though, it had solar power and four nurses to work with. The main beneficiaries are the residents of the Lwandile village, situated very close to Tshani village, where Transcape is based. Other beneficiaries include the DoH clinic managers and district level management who can have finer grained information (and response) to/about referrals, test results (from hospital to clinic) and material requests.

We hope that this research pilot that can one day hopefully be developed into a product that a locally staffed organisation can install and support. It is possible that the DoH could provide that organisation with the hardware, device, network and maintenance costs. Our users need ICT skills. We initiated a "train the trainers" programme. We use local Transcape members to train the users of the system.

B. Example use case scenario

Consider a blood test for a patient. A nurse draws a blood sample at the clinic. Every three weeks or so, a clinic manager visits the clinic. That manager takes the blood sample to the hospital where the blood sample is analysed. The results of the test are then returned to the clinic when the manager returns to the clinic. The worst-case scenario would be about six weeks round trip. This does not include the time the patient takes to get to the clinic, or the time that it takes to get the results back to the patient. Results are typically delivered from the clinic to the original patient by another patient that happens to live close by.

With our system, there is still a delay for the blood to reach the hospital, and for the results to reach the patient. However, the clinic nurse can use our system to inform the clinic manager (or appropriate staff at the hospital) that blood sample(s) is/are ready to expedite collection. As soon as the test is performed, especially if HIV/AIDs is involved, someone at the hospital can snap a digital picture with a smart phone and instantly send a picture of the test results to the clinic for free over the WiFi network. If the patient has a cell phone, the information or a message from the nurse can be texted via MXit or Fring at a fraction of the cost of an SMS, unless there is, of course, a budget for SMS expenditure, similar to [7].

III. TECHNICAL CONSIDERATIONS

We bridged several gaps with this project. The main gap is communication between the remote rural clinics and their hospital hub. Another gap is the digital divide faced by the nurses – they have very poor ICT skills. We therefore provided training to accompany the introduction of ICT4D technologies.

A. WiFi and SMS technologies

Our software prototypes, called MUTI, have been developed over several iterations (see Fig. 2) and provide real-time and store-and-forward communication of text, voice, pictures and video over WiFi [2-4]. MXit provides text-based Instant Messaging and pictures over GPRS. Fring provides Instant Messaging with Skype, Google Talk and MSN Messenger over both GPRS and WiFi. Fring also provides real-time voice over IP, although the quality is much better over WiFi than with GPRS. We chose not use SMS or GSM because Internet-based communication offers much more flexibility at a much lower cost. IP-based communication allows the user to package the information (text, voice, picture and video) in any desired combination.

Our software and the Internet tools have been deployed on mobile WiFi-enabled smart phones. Users make use of WiFi at the hospital and clinic hotspots. They can use GPRS almost anywhere in the area. Users can also use SMS or make normal GSM calls because the SIM card in the phone belongs to the DoH. Thus far, we have encouraged users to use our WiFi-based communications system because it costs them absolutely nothing aside from the installation of the WiFi network at roughly R4000/node and a R4000 handset.

We now encourage users and our technical staff to use MXit or Fring to text (Instant Messaging) over GPRS instead of sending an SMS. A single SMS costs about R.70, while 1MB of data (maybe a couple thousand messages) can be sent/received for R2 (at current cellular data prices). After we connect a (mostly hospital doctor-funded) VSAT Internet connection to the WiFi network, everyone can use WiFi to Fring both voice and text for "free".

B. Application content

The hospital doctors and clinic nurses create all communication content themselves. The next stage is to involve the nurses at the hospital and/or the clinic managers to a) send back test results and b) field resource requests. This project was undertaken with the explicit realisation that our methodology had to incorporate cyclical learning on our part as well as our targeted beneficiaries [8]. We began the project with the sole intention to provide nurse-to-doctor communication. We triangulated user needs and system usage via instrumented prototype usage metrics, semi-structured interviews, focus groups and ethnographic observation (see Fig. 3). We came to understand that nurse-to-doctor communication was just not happening as much as we had hoped. Much of the understanding came from Transcape NGO participants, as well as our long-term exposure to the users and beneficiaries. This interaction produced ideas for the transmission of test results and nurse-to-nurse communication (for resource requests). The demonstration of Internet-based communication prototypes enabled the realisation that these types of needs can be solved by technology.

We also attempted to involve the district level DoH in the project. However, their participation waned after the initial consent and enthusiasm. We also came to understand that the hospital did not manage the clinics. Rather, the district level DoH manages the satellite clinics. Over time, we have found the hospital doctors and the NGO to be the most helpful simply because they are the most ICT-literate. We suspect lack of ICT skills may also preclude the district level DoH management from getting involved because they may not understand (or even fear) the ICT systems.

IV. CONTEXTUAL CONSIDERATIONS

The patients speak Xhosa and very seldom English. The nurses (at both the clinics and hospital) speak Xhosa and English. The doctors tend to be foreign nationals (Dutch and Cuban) but all speak English. Therefore, most

communication is in Xhosa (nurse-to-patient and nurse-to-nurse) and English (doctor-nurse). The system easily supports any language in real-time or store-and-forward modes. The most challenging context issues are as follows:

- Both nurses and doctors are either too busy or too uninterested to sustain the additional burden of communication.
- The nurses and the DoH did not commission the system. Both technical and social aims originated from NGO, the doctors and us.
- The nurses do not appear to understand what "research" means and continue to be suspicious of our motives (supposedly financial). They also suspect the system monitors their performance.

A. *Technical infrastructure*

The rural environment is one of unreliable power (if available), no running water, and available but often poor GSM/GPRS coverage. Maintenance-free 12v vehicle batteries using very inexpensive networking hardware, e.g. WRAP PC and 16-24db antennae running 802.11b at 2.4GHz, power our WiFi network.

We only recently began to use real-time Voice over IP (VoIP) applications on WiFi-enabled cellular handsets. Some VoIP and Instant Messaging development libraries are available but often appear crippled by network service providers (and handset makers) because VoIP and Instant Messaging cannibalise GSM voice and SMS text revenues, respectively [9]. Hence, a combination of WiFi and GSM/GPRS allows for more possibilities and some control over communication expenses. The GSM/GPRS coverage in the rural areas is surprisingly wide, although the quality is often less than adequate. For example, a proper GPRS Internet link requires an external antenna connected to the phone or a 3G/GPRS PCMCIA card in a laptop or PC. On the other hand, building and extending WiFi networks is a cheap and easy way to provide much more bandwidth [10].

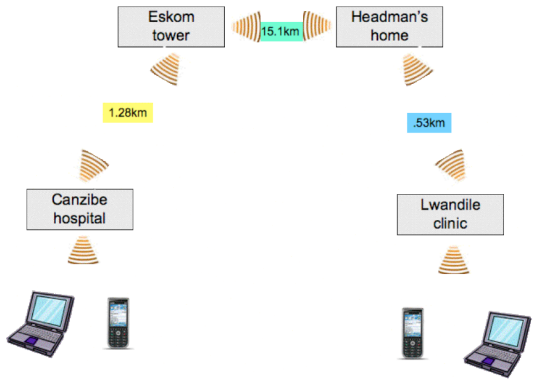

Fig. 1. The rural WiFi network consists of four nodes. The end nodes at the hospital and clinic have WiFi hotspots. Each node consists of outdoor waterproof customer premises equipment (CPE) case enclosing a low cost biscuit PC with 2.4GHz radio card(s). Users access the network via local hotspots.

WiFi hotspots provide ready and reliable access for the doctors and nurses to the communication tools at no additional cost (as shown in Fig. 1). There are only installation and maintenance costs. Only a lack of ICT literacy is holding the nurses back from exploring the array of ICT possibilities on their smart phones.

B. *Regulatory issues*

When we began the project in 2003, VoIP was illegal, and was only legalised in early 2005 [11]. Our long-range WiFi network's legal status might still be questioned according to the telecommunications legislation as enforced by the Independent Communication Authority of South Africa (ICASA). In 2004, we applied for a test license to build the network. That license lasted three months but took more than a year to procure. We were given another six months in 2005 by ICASA (after which we decided it was not worth the effort to renew). We obviously do not want to compete with Telkom as a telecommunications service provider (nor pay for that license!). We are currently endeavouring to use Telkom infrastructure in the area to expand the network in order to fall within their regulatory umbrella. However, the long-range WiFi links use too much power to fall within ICASA tolerances. South African telecommunications are some of the most heavily regulated in the world, hence a tariff regime that is often double the cost of similar services in the developed world [1].

C. *Socio-economic and political environment*

The cultural differences between the hospital staff (doctors and nurses) and the clinic staff (nurses only) is startling. The rampant poverty in the outlying areas has bred a culture of dependence on welfare cheques and despondency. That is reflected in the work ethic we experience with our rural nurses. For example, the clinic recently closed down in Dec and Jan because the nurses simply disappeared! The nurses, however, do appear interested in ICT training provided by Transcape and us. We think it may be because they view ICT literacy as a ticket out of the remote areas. For example, much of the hospital staff commutes about an hour from the main town in the area, Mthatha. We are therefore seriously considering a doctor's suggestion to include two other clinics where the nurses have a stronger work ethic and easier access to the main town in the area, thus lessening the remoteness factor.

We also suspect that the introduction of easily accessible communication between doctors and nurses has disrupted power relations from a clinic nurse's point of view. Without communication, they were able to operate with impunity. Perhaps now they believe they are seen as inferior when they consult the doctor with the technology in front of a patient. We feel this could be overcome by emphasising nurse-to-nurse communication. We have noticed that the nurses (almost 100% Xhosa female) do tend to feel more comfortable communicating with female doctors – but this may be due to the fact that one of those female doctors used to visit the clinics on a 3-weekly basis.

All of the participants are aware that the WiFi network is technically illegal. We recognise that the DoH will be reluctant to put financial support behind an illegal system, no matter how beneficial it may be. We can only endeavour to use our project to showcase the benefits that the current legislation is smothering, and hope that WiFi legislation, like VoIP, will soon be relaxed.

D. *Beneficiary skills*

ICT literacy is necessary for users to understand what the possibilities of our system are. For example, because of lack

of numeracy and literacy skills, we find it difficult to explain how much cheaper it is to MXit or email instead of SMS. People still use SMS even though their handsets are GPRS-enabled and they could MXit and email hundreds of messages for the price of a single SMS!

We have noticed that the nurses prefer to use voice and video communication rather than text. We suspect that this is a typing literacy issue but also potentially an English issue. English is a 2nd or 3rd language for patients, nurses and doctors. Yet all of them communicate in English quite well. If we are able to pursue the nurse-to-nurse communication, then the nurses might feel even more comfortable using the system with text, voice and video in their own choice of either Xhosa or English.

V. OUTCOMES

The intended outcomes for this project are as follows:

- To build a pilot WiFi communication infrastructure between a rural hospital and a clinic.
- To support users to use the system to help patients (and themselves).
- To develop a series of prototypes based on user feedback.
- To graduate post-graduate students and publish in academic fora.

Overall, take-up of our system and its prototypes has been disappointing. We have several theories as to why this is the case but believe it is mostly that the clinics and hospital staff have become accustomed to being isolated and are simply too busy to take the time to learn and use ICT systems effectively. The area used to have Citizens Band radio between the hospital and all 10 clinics in the 90's, but it was abandoned years ago. We also chose the most "difficult" remote clinic for the pilot that also turned out to be *socially* difficult as well: staff enthusiasm is weak, and staff numbers have halved. The doctors and our technical support believe we made a mistake choosing the most "difficult" clinic and wish to include two other clinics in the network for a "green fields" approach using the "new" communication tools on WiFi handsets.

On the technical side, we found that our rural WiFi network is quite stable with only one reboot in two years (see Fig. 1). We realised that our custom communication applications are as cumbersome to use as the laptops with peripheral headsets, USB webcam, digital camera, etc. So we recently (Sep 2006) moved some of the functionality to a WiFi-enabled iMate SP5 handset, and even put the DoH SIM card into the research handset (Mar 2007). We have also decided to "light up" the WiFi network with Internet (via VSAT) to train the users to use standard Internet communication tools such as Skype, Fring and MXit. The doctors have financed the VSAT by themselves (and built their own local WiFi distribution network) because they recognise the value of connectivity.

The Masters-driven approach to conducting projects of this type has several serious limitations. First of all, the students graduate and leave the project. We addressed this by overlapping (the typical 2-3 year duration of) several Masters students on the project. Another problem with Masters research projects, though, is that the priority is on the research thesis, and not a "product". We have begun to address this issue by hiring Masters graduates at less-than-industry salaries as full-time programmers/network specialists. These research assistants are able to respond to user needs much more quickly, thus improving the feedback loop between the users and our software prototypes.

VI. EVALUATION METHODS

We used several methods to evaluate this long-term project. First, we employed critical reflection during Action Research cycles [12-14]. The cycles for this project are shown in Fig. 2. We collected data about our users' and stakeholders' behaviours with the Outcome Mapping methodology [15]. Finally, we employed an external consultant (bridges.org) to evaluate the project and advise our Computer Science postgraduate students about how to perform ICT4D in the field. We used the bridges.org Real Access/Real Impact criteria [16] (see below) as a lens to view the project design and evaluate its implementation at each iterative stage in prototype development.

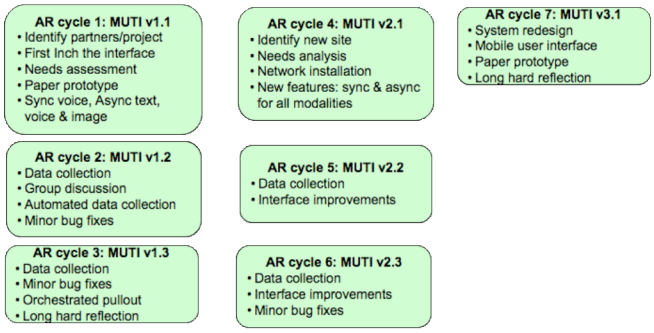

Fig. 2. Action research cycles for the project spanned the last three years. Each cycle is associated with a particular prototype version of the telehealth software called MUTI [2-4].

Action Research is a critical process based on participant and community engagement. Outcomes and impact are gauged via reflection. Outcome Mapping is not intended to measure impact. Again, the bridges.org Real Access/Real Impact criteria provides a comprehensive framework from which to evaluate project outcomes and impact [16]

A. Data collection

The primary means to collect information about system usage is by counting the number of times the system was used for each media and temporal modality. We collect this data in two ways. First, we instrument the software to collect this data for us. This is one of the main reasons why we built our own software in the first place. Second, we talk with the users, both formally and informally. Unfortunately, the system has been used so little (as are many ICT4D systems [17]), we can only say that the potential of the system has not been reached. We use various forms of data collection to triangulate the data (as shown in Fig. 3).

Everyone involved in the project exchanges regular emails and uses Skype and Fring to communicate on a regular basis. We have regular face-to-face meetings locally (UWC and UCT). We visit the rural site and meet with our users and NGO partner 3-5 times per year, usually for 1-2 weeks at a time. The international collaborators have both visited the site once each, and we have visited them in their

home countries (New Zealand and Netherlands) once each. A member of our NGO partner has even visited with our Dutch collaborator in Delft (because he, too, is Dutch).

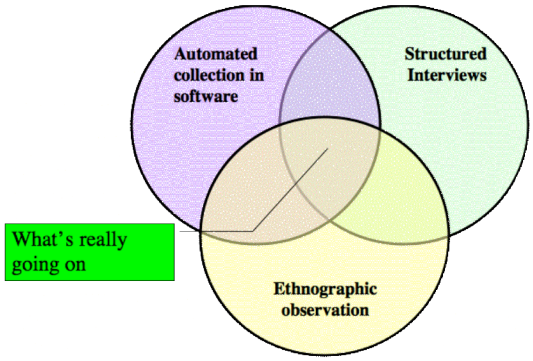

Fig. 3. Data triangulation shows us what is really going on in the field. First, we instrument our software to collect usage metrics. We also conduct structured interviews. Most of the data, however, is gathered qualitatively via ethnographic observation.

We do not directly communicate with the indirect beneficiaries, the patients. However, we do spend as much time as possible with the doctors and nurses when in the field with both formal and informal interviews and focus groups. We find that the most informative feedback comes when the voice recorder is turned off and we are enjoying a meal or drink together after work.

A nurse told us that it took her 20 minutes to create a store-and-forward message to send to the doctor. This is why she preferred to make a VoIP call instead, even though the doctor almost never answered it. When we watched how she worked, we realised one of the problems emanated from the complications of using peripherals on a laptop: headphones, camera, webcam, mouse, etc. So, we ported the application to a mobile handset and changed the interface to resemble Multimedia Messaging Service (MMS). A related problem hindering the take-up of mixed media messages was the lack of thumbnails for voice and video clips. The pictures had small thumbnails, so one of the nurses asked for voice and video thumbs. We provided this on the laptop version, as well as the mobile version. Creating a mixed text/voice/picture message now takes her less than a minute.

B. *Impact analysis*

We use the bridges.org Real Impact/Real Access to assess the impact of our project [16]. The Real Impact/Real Access criteria applied to our rural telehealth project are listed in Table 1. We contracted bridges.org to evaluate our project on a bi-annual basis for two years. Full reports on this project using these criteria was documented by bridges.org, and are available through their website (or by request from the first author).

C. *Data integration*

We record the experiences, viewpoints and behaviours of participants and partners with the Outcome Mapping [15] method. A mistake we may have made was stopping short of involving the beneficiaries in the formulation of the Outcome Mapping progress markers. We did, however, make extensive use of formal and informal interviews in a longitudinal ethno-methodological context to integrate their experiences and viewpoints into the impact assessment.

1.	*Physical access to technology:* WiFi hotspots in the hospital and clinic.; shared handsets and laptops.
2.	*Appropriate technology.* PCs vs. laptops vs. cell phones. The latter seems most appropriate.
3.	*Affordability of technology and technology use.* IP communications are definitely cheaper than GPRS.
4.	*Human capacity and training.* Transcape trains the nurses on ICT literacy skills weekly.
5.	*Locally relevant content and services.* IP communications are mostly language-independent. The users create their own content.
6.	*Integration into people's daily routines.* ICT for rural telehealth *is* a burden, and is difficult for health practitioners to integrate into daily life.
7.	*Socio-cultural factors.* The system may upset community power relations. The most problematic issues are in this category!
8.	*Trust in technology.* Our network is trusted, but our MUTI software is not. We hope to establish trust in Internet communication tools and improve our software, too.
9.	*Legal and regulatory framework.* Long-range WiFi is still illegal, although VoIP is now legalised.
10.	*Sustainability and the local economic environment.* The area is extremely poor. We hope the Department of Health will support the project when we can demonstrate the benefits. The doctors have already installed VSAT and a local WLAN on their own.
11.	*Macro-economic environment.* GPRS is available (rurally) nationwide, but the pricing regime prohibits more widespread take-up of wireless data.
12.	*Public support and political will.* Many rural people have cell phones but lack the awareness to use them effectively, e.g. MXit. It is doubtful that they understand the links between their local technology use and the government's overall political strategies. Our government enthuses about ICT4D but the political will to *change* restrictive policy and over-pricing appears lacking.

Table 1. Real Impact/Real Access criteria applied to the rural telehealth project.

VII. CONCLUSION AND FUTURE WORK

We do not use SMS for this project because a) GPRS and WiFi-based text is orders of magnitude cheaper and b) SMS is text only and we desire a combination of real-time and store-and-forward text, voice, picture and video that MMS can provide, but at a similar cost. We are using our projects to alert the government to legalise long-range WiFi in the same way that VoIP regulation was relaxed, and we shall continue publishing policy papers to reflect this, as in [18].

We hope that the system could be used to facilitate training, e.g. HIV/AIDS education, as well as for day-to-day communication needs. By combining both GPRS and WiFi, it may even be possible to reach the patients directly with the system and alert them about test results, return visits, medication timetable, etc. similar to [7].

We now encourage project participants to use applications like MXit and Fring. If and when limitations crop up with these Internet-based applications, we can develop our own prototypes to address our users' specific needs. Note that we have not yet provided any security mechanisms on the communication systems other than username/password control, and will need to address this.

ACKNOWLEDGMENTS

The authors are most grateful for the participation of the staff and members of Canzibe hospital, Lwandile clinic, Transcape and bridges.org. The South African Council for Scientific and Industrial Research (CSIR) invited us to participate in their rural telehealth project to begin with, and Eskom lets us use their tower for the our current WiFi network. We also thank the following for their financial support: International Development Research Centre (IDRC), the South Africa-Netherlands research Programme on Alternatives for Development (SANPAD) and Telkom, Cisco, Siemens and THRIP Centres of Excellence (CoE). Lastly, the layout and content of this paper is largely due to answering a superbly crafted research questionnaire administered by Sally-Jean Shackleton of Women'sNet (www.womensnet.org.za), on behalf of UNICEF.

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