Softbridge: a socially aware framework for communication bridges over digital divides

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ABSTRACT

Computer scientists must align social and technical factors for communication technologies in developing regions yet lack a framework to do so. The novel Softbridge framework comprises several components to address this gap. The Softbridge stack abstraction supplements the established Open Systems Interconnect model with a collection of technical layers clustered around 'people' issues. The Softbridge stack aligns the technological design of communication systems with awareness of social factors characteristic of developing regions. In a similar fashion, a new evaluation abstraction called Quality of Communication augments traditional Quality of Service by considering socio-cultural factors of a user's perception of system performance. The conceptualisation of these new abstractions was driven by long-term experimental interventions within two South African digital divides. One field study concerned communication bridges for socio-economically disadvantaged Deaf users. The second field study concerned a wireless telehealth system between rural nurses and doctors. The application domains were quite different yet yielded similarities that informed the Softbridge and Quality of Communication abstractions. The third Softbridge component is an iterative socially aware software engineering method that includes action research. This method was used to guide cyclical interventions with target communities to solve community problems with communication technologies. The Softbridge framework components are recursive products of this iterative approach, emerging via critical reflection on the design, evaluation and methodological processes of the respective field studies. Quantitative and qualitative data were triangulated on a series of communication prototypes for each field study with usage metrics, semi-structured interviews, focus groups and observation in the field. Action research journals documented the overall process to achieve post-positivist recoverability rather than positivistic replicability. Analysis of the results from both field studies was iteratively synthesised to develop the Softbridge framework and consider its implications. The most significant finding is that awareness of social issues helps explain why users might not accept a technically sound communication system. It was found that when facilitated effectively by intermediaries, the Softbridge framework enables unintended uses of experimental artefacts that empower users to appropriate communication technologies on their own. Thus, the Softbridge framework helps to align technical and socio-cultural factors.

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DEDICATION

This research effort is dedicated to the memory of Zunade Dharsey. He helped run the Telkom Centre of Excellence (CoE) programme in the early days with South African universities. He prioritised the social benefits that information and communication technologies could bring to the disenfranchised across the country. I heard stories of him stopping in to help rural schools across the country as he travelled from university to university. He was a giant gentle bear of a man with an infectious passion for caring and doing something about it. After leaving Telkom, he led the world-renowned Amy Biehl Foundation. He drowned having saved the lives of two other drowning people near Arniston. My wife and I had the privilege to join him and some of his friends for dinner at his home a couple of weeks before he died. He was one of the most amazing humans I have ever met, and helped put me on the socio-technical path that I now explore.

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GLOSSARY

3G	Third generation cellular technology for broadband data
ACE	Australian Communication Exchange
ACM	Association of Computing Machinery, a professional organisation
ADSL	Asynchronous Digital Subscriber Line for broadband over the PSTN
AP	wireless Access Point
API	Application Programming Interface
ASR	Automatic Speech Recognition
ATM	Asynchronous Transfer Mode, a data and telecommunication protocol
Bakkie	South African term for pickup truck
Bastion	of the Deaf, the building in Newlands, Cape Town where the participating NGO, DCCT, is located
Breakout	To relay a VoIP call to the PSTN
Camfrog	An Internet-based video communication tool popular with Deaf users
Canzibe	Name of the hospital in the second rural telehealth site. The Canzibe project included Canzibe hospital and Lwandile clinic.
CB	Citizens Band (radio)
CC	Closed Corporation
CCD4D	Community-centred Design for Development (or Developing countries/economies/regions)
CHI	Computer Human Interaction, an ACM special interest group
CIF	Common Intermediate Format for cellular video conferencing
CoE	Centre of Excellence, a South African research programme led by Telkom
CORBA	Common Object Request Broker Architecture for remote procedure calls
CSIR	Council for Scientific and Industrial Research, South Africa
Data mule	Physically transports data, e.g. on a hard drive or CD, instead of a network
DC	Developing Country
DCCT	Deaf Community of Cape Town, a Deaf NGO
Deaf	The ‘D’ is capitalised to denote membership of a linguistic and cultural community that uses sign language as a first language.
DeafChat	Real-time text chat tool built for Deaf people
DeafVideoChat	Asynchronous video tool built for Deaf people
DEAFSA	Deaf Federation of South Africa, a national NGO
DECT	Digital Enhanced Cordless Telecommunications
DiffServ	Differentiated Services, a network QoS protocol
DIS	Designing Interactive Systems, an ACM conference

DoH	Department of Health, South Africa
DTN	Delay Tolerant Networking
FMFI	First Mile/First Inch, an IDRC-sponsored research collaboration
FOSS	Free and Open Source Software
FreeTTS	an open source implementation of Festival
FTP	File Transfer Protocol
GA	Go ahead marker used in text telephony
GPRS	General Packet Radio Service, a slow 2G cellular data protocol
GSM	Global System for Mobile communication
GUI	Graphical User Interface
H.323	a family of telephony protocols specified by the ITU
HCI	Human Computer Interface
HCI4D	HCI for Development (or Developing countries/economies/regions)
ICASA	Independent Communications Authority of South Africa
ICT	Information and Communication Technology
ICTD	ICT for Development (or Developing countries/economies/regions), also an annual IEEE/ACM conference
ICT4D	same as ICTD, used by IDRC
IDRC	International Development Research Centre (Canada)
IEEE	Institute of Electrical and Electronics Engineers, a professional organisation
IETF	Internet Engineering Task Force
IIT	India Institute of Technology
IM	Instant Messaging
IP	Internet Protocol, a connectionless protocol that runs the Internet
IS	Information Systems
ISDN	Integrated Services Digital Network, narrowband data over the PSTN
ISO	International Organization for Standardization
isTyping	an IM awareness mechanism that indicates when another person is typing
ITID	Information Technologies and International Development
ITU	International Telecommunication Union
ITU-T	Telecommunication standardization sector of the ITU
Joey	An open source Jabber server
Lwandile	The name of a village and clinic in the Libode district of the Eastern Cape. Part of the Canzibe project.
M&E	Monitoring and Evaluation
MAC	Media Access Control, typically used as MAC address, a globally unique address assigned to a network interface

MAP	Mobile Access Point
MBone	Multicast backBone
MDG	Millennium Development Goals
MIT	Massachusetts Institute of Technology
MMS	Multimedia Messaging Service on a cell phone
MOS	Mean Opinion Score, used to measure QoS
MPCC	Multi Purpose Community Centre
MPLS	Multiprotocol Label Switching protocol
MUTI	MUlti-modal Telemedicine Intercommunicator, telehealth prototypes
Nessie Knight	Name of the hospital in Sulenkama village, part of the Tsilitwa project
NIMBA	Narada-based version of SIMBA with guaranteed delivery
NIST	National Institute of Standards and Technology
NGO	Non-governmental organisation, also not-for-profit
NRS	National Relay Service
OLPC	One Laptop Per Child
OPD	Out Patient Department at Canzibe hospital
OSI	Open Systems Interconnect
OSPF	Open Shortest Path First
P2P	peer-to-peer
PBX	Private Branch eXchange
PDA	Personal Digital Assistant
PoE	Power over Ethernet
PSQM	Perceptual Speech Quality Measurement
PSTN	Public Switched Telephone Network
QoC	Quality of Communication
QoS	Quality of Service
QUASS	QUality ASsessment Scale
QuickNet	a company that manufactured PC cards and software for PSTN breakout
RA/RI	Real Access/Real Impact criteria from bridges.org
Recoverable	such that the epistemology of post-positivist research is recognisable to other scientists, e.g. well-documented and well-structured
RFC	Request for Comments, a standards process managed by the IETF
RSVP	Resource ReSerVation Protocol
RTCP	RTP Control Protocol
RTP	Real-time Transport Protocol
RTT	Round Trip Time

SANPAD	South Africa-Netherlands research Programme on Alternatives for Development
SASE	Socially Aware Software Engineering method
SASL	South African Sign Language
SIM	Subscriber Identity Module, a cell phone card
SIMBA	Softbridge Instant Messaging Bridging Architecture, a Deaf telephony prototype bridging Deaf and hearing users with IM
SIMPLE	SIP for Instant Messaging and Presence Leveraging Extensions
SIP	Session Initiation Protocol
SLA	Service Level Agreement
SLED	Sign Language Education & Development, an NGO
SMS	Short Message Service, a text message service for mobile phones
Softbridge	ICT4D design abstraction, also the name of a Deaf telephony prototype
SSM	Soft Systems Methodology
Sulenkama	Name of the village with Nessie Knight hospital, part of the Tsilitwa project
TCP	Transmission Control Protocol, a connection-oriented protocol
Telco	A large telecommunications provider, often an incumbent or a monopoly
Telgo323	Deaf telephony prototype bridging a Teldem to the PSTN with H.323
TelgoSIP	Deaf telephony prototype bridging a Teldem to the PSTN with SIP
TEM	Technology for Emerging Markets group in India
Temporal	an adjective relating to time, e.g. synchronous or asynchronous
Temporality	a noun, the state of existing within or having some relation to time, and one of the Softbridge stack layers
Text relay	a system to convert text to voice and back again for communication, e.g. between a Deaf user with a text telephone and a hearing user on a telephone
TIER	Technology and Infrastructure for Emerging Regions group at Berkeley
TISSA	Telephone Interpreting Services for South Africa
TOS	Type of Service
Tsilitwa	The name of a village and clinic in the Qumbu district of the Eastern Cape. The Tsilitwa project also included Nessie Knight hospital in Sulenkama.
TTS	Text-To-Speech
TTY	teletypewriter (text telephone for Deaf people)
UA	User Agent, a SIP client
UCD4D	User Centred Design for Development (same as HCI4D and CCD4D)
UCT	University of Cape Town
UDP	User Datagram Protocol, a connectionless protocol
UK	United Kingdom, or England

UPS	Uninterruptible Power Supply
USA	Universal Services Agency, South Africa
UTP	Unshielded Twisted Pair, common type of network cable
UWC	University of the Western Cape
VoIP	Voice over Internet Protocol
VRS	Video Relay Service
VSAT	Very Small Aperture Terminal for satellite access
WiFi	Wireless Fidelity (802.11abg), common wireless network protocols
WiLD	WiFi-based Long Distance network
WiMAX	Worldwide Interoperability for Microwave Access
XML	eXtensible Mark-up Language
XMPP	eXtensible Messaging and Presence Protocol

Chapter 1: Introduction

On a planet with 1.2 billion Internet users, a far less fortunate 1.2 billion people survive on less than a dollar a day.

Toyama & Dias (2008)

We argue that Western market forces will continue to meet the needs of developing regions accidentally at best.

Brewer et al. (2005)

However, initiatives to address the digital divide will have to also address those issues that are central concerns of HCI: How to improve the fit between technology, specific human needs, and human contexts; how to design technology to facilitate human interaction with it; and how best to manage the process of technology introduction.

Dray et al. (2003)

Design-actuality gaps are therefore more extreme and more explicit and, as a result, are easier to identify and to understand.

Heeks (2002)

In the end, the argument is that universal access can pay for itself.

Best (2003)

I walk down the street.

There is a deep hole in the sidewalk.

I fall in.

I am lost…I am helpless.

It isn't my fault.

It takes forever to find a way out.

Portia Nelson, Autobiography in Five Short Chapters

1.1 Digital divide landscape in South Africa

South Africa is home to some intriguing digital divides of information and communication technology (ICT). There are external divides in terms of South Africa as a developing economy compared with a fully industrialised knowledge economy like the United Kingdom (UK). For example, statistical data from the Millennium Development Goals (MDG) project (MDG, 2001) reported that in 2006 South Africa had 7.77 Internet users per 100 compared with 63.16 in the UK (UN, 2006). The International Telecommunication Union (ITU) pegged the South African statistic at 7.89 in 2004 (ITU, 2006). The numbers are similar for PC ownership: 8.36 per 100 for South Africans in 2005 compared with 76.52 in the UK (UN, 2006). These stark contrasts mask an even more extreme internal divide between the haves and have-nots in developing regions like South Africa (Dray et al., 2003). According to the ITU, only 60,000 out of a population of about 45 million South Africans had broadband ADSL (Asynchronous Digital Subscriber Line) in 2004 (ITU, 2006). According to Telkom, the incumbent 'telco' in the South African telecommunications market, that number had increased to half a million by March 2008 (MyBroadband, 2008), but the percentage is still only 1% of the total population.

The external and internal digital divides have become socio-economically entrenched. In 2001, the time of the most recent census data, roughly half of the South African population lived in informal rural and urban dwellings and 28.1% of the black population was unemployed (STATSSA, 2004). According to the Economist (2006), the plight of the poor in South Africa is getting worse despite improvements in the overall economy and infrastructure. The Economist (2007) recently reported that on the African continent, "South Africa is the

only country for which there are comparable data that has seen an increase in poverty this decade".

These socio-economic divides can have direct consequences for internal ICT divides. The Universal Services Agency (USA) failed to provide functional telecentres across South Africa at the turn of the millennium (Benjamin, 2001, 2002) and Telkom struggled to rollout and maintain landlines in rural areas. Oyedemi (2004) stated, "The assumption that simply making available telecommunications devices in semi-urban and rural areas contributes to increased universal access is erroneous". The South African government also hindered ICT uptake in other ways, in terms of expensive tariffs compared with the rest of the world (ITU, 2003b, 2006) and via restrictive regulatory legislation (DoC, 1996, 2001, 2005). For example, cheap Voice over Internet Protocol (VoIP) was illegal until 2005 and long-range wireless networks in public spectrum ideally suited for both rural and urban deployment remain strictly regulated.

Yet there is hope. Mobile communications in South Africa offer a bright alternative to the government and incumbent telco's failures to improve ICT access and usage for disadvantaged South Africans. Unfortunately, even that success is marred. The ITU (2003b) asked "Why, for example, do only one third of South Africans have a mobile phone when almost 100 per cent of the population is within coverage of cellular service?" Furthermore, 85.6% of mobile subscribers were prepaid (ITU, 2006) indicating the difficulties of most South Africans to pay for ICT. However, in light of the divides highlighted above, cellular communication in South Africa is an encouraging success story.

1.2 Social factors of ICT

From the perspective of computer science, the successes of mobile services like voice and SMS (Short Message Service) are perplexing for a number of reasons. Cellular connectivity is patchy compared with the 99.999% (or five 9's) uptime targeted by Telkom on the PSTN (Public Switched Telephone Network). Sound quality can be poor and connections dropped. From a human computer interaction (HCI) point of view, SMS is a clumsy and limited form of communication. Yet it is much cheaper to send an SMS than to call. Thus, SMS has become vastly popular. Cellular communication also provides relatively low data bandwidth, e.g. 3MB/sec with 3.5G, compared with landline 4GB/sec ADSL. Most

importantly, the cost of cellular communications is much higher than the PSTN. The cost of South African cellular services is also expensive relative to the rest of the world (ITU, 2006). Why do South Africans pay more to communicate with one another?

The answers lie in both social and technical explanations. Technically, mobile communication offers poor quality and clumsy interfaces. Yet it is more readily available than the PSTN, especially in rural areas. Socially, cell phones offer much more than just communication. Cell phones can be shared. Cell phones are a fashion statement, and an object of conspicuous consumption. SMS text and MMS (Multimedia Messaging Service) pictures are persistent and can be shown to others. Many view cell phones and related small mobile devices as the key to providing ICT for developing regions (bridges.org, 2001, 2003a, 2005c). ICT for development is known by many different acronyms. In this thesis, we follow the International Development Research Centre (IDRC, www.idrc.org.ca) and Heeks (2008) and use ICT4D.

1.3 Misaligned assumptions

The traditional telco view of telecommunications, e.g. the high expectations of the five 9s, is reflected in the way computer scientists are trained, including in developing regions like South Africa. Network performance is the assumed paramount objective. Users are not included in network design abstractions like the Open Systems Interconnect (OSI) model. Even when a network model does include the user, notably in Quality of Service (QoS) (discussed in detail in Chapter 2), the user's social environment is not explicitly considered. These models, then, carry with them socio-cultural assumptions about deployment scenarios. The ICT4D context is fundamentally different from that in developed regions because of social, cultural and environmental factors (Brewer et al., 2005). Thus, a technocratic approach to ICT4D does not work. The traditional network models do not accommodate social factors and are therefore inadequate for addressing ICT4D situations.

1.4 Research questions

In an ICT4D context, then, misaligned assumptions and understandings come from both system designers and end-users, and clearly involve both technical and social factors. Our goal is to address mistaken assumptions on either side, and advance toward alignment between the two. For the computer scientist building ICT4D communication networks and

applications, the process starts with the abstractions and models used to implement those communication systems. Therefore, this thesis aims to answer the following primary research question:

How can we align social factors with technical factors in the design and evaluation of communication networks and their applications in an ICT4D context?

Secondary research questions are: How can we conceptualise a network design stack that holistically includes technical, environment, and cultural factors inherent to ICT4D communication? Furthermore, how do we explicitly include the users and their social context into such a design stack? Regarding evaluation of the resulting design, what would a corresponding evaluation abstraction look like, and how can it be framed to include both social issues and modalities beyond the scope of the standard definition of QoS?

1.5 Methods

Computer science can be considered the study of abstraction, often accompanied by a reference implementation of software and/or hardware artefacts. Empirical and exploratory methods are characteristic of experimental computer science (NAS, 1994). As is customary with any scientific enquiry, it is necessary to question and challenge established tenets of a discipline in order to generate innovation and move the discipline forward. As computer scientists, we must therefore question and challenge established abstractions, especially those that are widely held, and have become taken for granted in our field.

Due to the interplay between social and technical factors, we chose action research (described in Section 5.2) as the guiding method for investigation of this research theme. Action research encourages us to consider situated perspectives (Harrison et al., 2007). Taken in an ICT4D context, situated perspectives allow the computer scientist to recognise a wider array of social and technical factors. In this post-positivist mindset, the views and assumptions that designers and end-users have of a given system are situated differently. Technical models can be viewed from a social perspective, and vice-versa. The end goal is to achieve an alignment of multiple perspectives in order to produce knowledge that is valuable to all stakeholders.

This thesis operates within the area of telecommunications, and critically challenges the applicability of two fundamental abstractions to the ICT4D context: the OSI network model

and related QoS evaluation. This thesis suggests that these abstractions suffer from multiple shortcomings that cause them to neglect the social environment of the user, particularly when building communication bridges over a given digital divide in a developing region. We propose a novel design and evaluation framework called Softbridge that aligns social and technical factors for the ICT4D context. The Softbridge framework provides a useful checklist and guide to ICT4D for both newcomers and experienced hands.

1.6 Outline of the thesis

Related work is divided into two chapters. Chapter 2 describes the two most well known abstractions that permeate the design and evaluation of modern communication systems, the OSI network model and QoS, respectively. Networked communication systems are designed according to layered abstractions. Network evaluation is performed at various layers in those abstractions. Therefore, both design and evaluation processes are based around self-similar abstractions.

Chapter 3 situates the design and evaluation processes within the context of ICT4D. The related work in ICT4D is predominantly characterised by technical approaches that emphasize social issues dominated by networking and HCI communities in the field of computer science. The fields of information systems and development studies offer complementary perspectives. Several monitoring and evaluation (M&E) tools prioritise social aspects of ICT4D in different ways. The end goal of all approaches, however, is to weave together technical and social aspects of ICT4D. Several prominent ICT4D groups and projects are used to illustrate ICT4D themes throughout the chapter. The emphasis is on networked communication systems built by computer scientists and therefore covers technical design and QoS aspects of ICT4D projects. Social issues are always prevalent in such technical-driven work, but factoring in social issues is not formalised. Instead, the inter-relationships of technical and social factors are offered as recommendations and lessons learnt.

Chapter 4 identifies and discusses significant gaps in the design and evaluation of communication technologies for development that emerge from the related work. This chapter describes these gaps in order to frame the research question for the thesis enquiry. We will argue that traditional design and evaluation abstractions are often inappropriate in an ICT4D context because of the associated technical, environmental and cultural challenges.

Furthermore, even when social factors are acknowledged and addressed, computer science-oriented responses to those challenges are often couched in a mindset still attached to those traditional abstractions. Therefore, efforts to align social and technical factors are reported as lessons learnt rather than as new abstractions on which to design and evaluate ICT4D communications. Perspectives from information systems and development studies offer complementary approaches to the alignment of technical and social factors in ICT4D design and evaluation. The chapter then restates the research questions from Section 1.4.

Chapter 5 argues for a methodology based on socially aware extensions to accepted experimental methods in computer science. ICT4D research involves complex and challenging inter-relationships of technical, social, cultural and environmental factors. Chapter 5 takes a top-down approach to methodological issues, starting with the tenets of experimental computer science. Then we argue for a post-positivist approach that leads us to pursue the 'dual imperatives' of action research: to craft successful ICT4D bridges over a given digital divide for a target community while simultaneously generating novel and useful knowledge for the field of computer science. After discussing the mechanics of action research and arguing for its scientific merit, we describe the experimental design for the study in terms of two field studies. We relate how these particular field studies were identified and initiated, and discuss data collection and analysis. Note that the action research cycles for the field studies are fully documented in Appendices A and D, respectively, and should be read in conjunction with the field study chapters. Finally, we discuss ethical considerations related to carrying out the field studies with an emphasis on disclosing the roles and contributions of collaborators and co-authors.

Chapter 6 analyses a field study on Deaf[1] telephony with a disadvantaged Deaf community in Cape Town, South Africa. An extensive series of action research cycles produced a number of communication prototypes. Appendix A chronicles the action research cycles for the field study and forms an essential background for this chapter. Chapter 6 introduces Deaf telephony by summarising related technology and its position in developed regions. The situation for Deaf people in South Africa is quite different, particularly for the

[1] Deaf with a capital ‘D’ denotes a person for whom sign language is the primary language and serves as a basis for a cultural identity.

Deaf community we engaged. The remainder of the chapter analyses and reflects on the design and evaluation of Deaf telephony prototypes, as well as the methods employed.

We also conducted a rural telehealth field study to explore the research questions in an entirely different scenario. Chapter 7 analyses a rural telehealth field study in much the same way as the previous chapter. A long-term series of action research cycles were conducted with healthcare professionals in the remote Eastern Cape. Chapter 7 begins with a brief introduction to telehealth in developed and developing regions, as well as in South Africa. Then the chapter provides project-specific background information. At this point, the reader is urged to review the action research cycles and their associated prototypes that are documented in detail in Appendix D. The remainder of the chapter reflects on the design, evaluation and methods involved with the rural telehealth field study.

At first glance, the Deaf telephony and rural telehealth field studies appear unrelated and dissimilar. However, Chapter 8 compares and contrasts the two field studies and synthesises the reflection from the previous two chapters. Beneath the community-specific objectives, both field studies are closely aligned with respect to design, evaluation and methodological aspects. Design similarities are used to derive the Softbridge stack, and then consequently to a related evaluation abstraction called Quality of Communication (QoC). The Softbridge stack is complementary to the OSI stack, as QoC is complementary to QoS. Both Softbridge stack and QoC appropriate an M&E tool from bridges.org to help align technical and social factors. The action research methods applied and lessons learnt about managing the projects are also quite similar.

Chapter 9 concludes with a statement of the contribution of the work, namely the novel Softbridge framework that aligns social and technical factors for the design and evaluation of ICT4D. We recommend guidelines for the use of the Softbridge framework, and discuss its limitations and advantages. Finally, we suggest avenues for future work.

Chapter 2: Communication system design and evaluation

I walk down the same street.

There is a deep hole in the sidewalk.

I pretend I don't see it.

I fall in again.

I can't believe I'm in the same place.

But, it isn't my fault.

I still take a long time to get out.

Portia Nelson

Several well-known abstractions permeate the design and evaluation of modern communication systems. Networked communication systems are designed according to layered abstractions. Network evaluation is performed at various layers in an abstraction. Therefore, both design and evaluation processes are based around the same layered abstractions. Section 2.1 discusses the most established network design abstractions. Section 2.2 discusses the traditional evaluation abstractions for those models. The conventional network design and evaluation abstractions described in this chapter are evident in much of the work related to ICT4D in Chapter 3 and represent the starting points for the novel socially aware design and evaluation abstractions presented in Chapter 4.

2.1 Design abstractions for communication systems

Layering makes networking software easier to understand and construct (Comer, 2000). A layer hides internal implementation details from layers above and below, and allows a developer to concentrate on one layer at a time. By specifying the responsibilities of a given layer, a stack of layers leaves the implementation details to the designer, thus allowing for multiple implementations of a given protocol at a given layer. As long as adjacent layers adhere to a common Application Programming Interface (API), the layers can communicate. Layering, then, provides sufficient abstraction to enable flexibility and complexity when building modern communication systems (Stevens, 1994).

The abstraction inherent in a layered model has a downside. Layering introduces inefficiency (Comer, 2000) and it takes computational effort and time to traverse from one layer to another. Furthermore, each layer does not know exactly what adjacent layers might

do. Adjacent layers are usually designed and implemented by autonomous (and not necessarily related) programmers or entities. Thus, a given layer is not necessarily optimised to pass data and/or formats from one layer to the next. Overall, however, this disadvantage does not take away from the conceptual and practical advantages that layering provides.

2.1.1 The OSI stack

The fundamental theoretical design abstraction for networked communication systems is the OSI model. The OSI stack, as it is commonly referred to, provides a sequentially layered abstraction structure from physical media (Layer 1) to programmatic application (Layer 7). Each OSI layer is responsible for a portion of the overall communication process as shown and described in Figure 2-1.

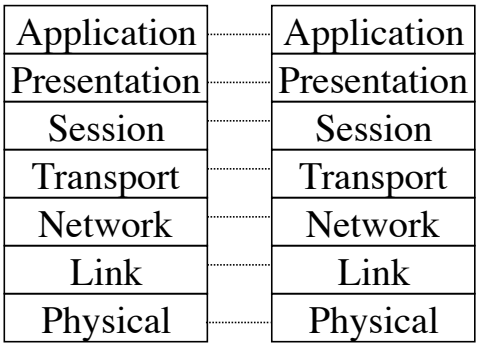

Figure 2-1 OSI stack

The OSI stack consists of seven conceptual layers. The Physical layer deals with physical transmission such as fibre or wireless radio. The Link layer holds protocols that define data transfer across a physical link such as Ethernet for wire line or 802.11b for wireless. The Network layer is responsible for routing services such as Internet Protocol (IP). The Transport layer provides either reliable or unreliable delivery with protocols like Transmission Control Protocol (TCP) or User Datagram Protocol (UDP), respectively. The Session layer specifies an application-dependent dialogue between applications. The Presentation layer handles conversion between platforms, e.g. Windows and Mac OS X. Finally, the Application layer refers to user application protocols, but not necessarily the application itself (Douba, 1995).

To illustrate how the OSI stack works and to demonstrate the inefficiency mentioned above, consider VoIP communication between two clients that begins its journey at the Application layer, moves down the stack, across a physical medium to move up the stack at the destination (refer to Figure 2-1). Each layer traversal adds or removes an envelope of layer-specific control information. A VoIP client application records a user's voice stream and chops the stream into packets. Each packet passes down the stack, is sent across the network, and passes up the stack on the other end. Each subsequent layer, all the way down to the

Physical layer, adds an envelope of control information. Layer 4 adds Real-time Transport Protocol (RTP) and UDP datagram envelopes. Then Layer 3 adds an IP packet envelope. Then Layer 2 adds an Ethernet frame envelope. At each progressive layer, the VoIP payload becomes a smaller percentage of the overall package.

Ethernet frames are then transferred across a physical connection to the subsequent routing hops across the Internet to the final destination. Each routing hop strips off and adds layers as required to pass the frame to the next hop. Once at the final destination, control layers are eventually stripped so that the payload can ultimately be passed to the other VoIP client. Each routing hop introduces delay due to transmission characteristics, routing decisions and the overhead of packing and unpacking of layer envelopes. As will be discussed in Section 2.2, all of those delays inherent to layered communication systems accumulate to interfere with real-time communication.

The OSI stack is an ideal model, and all of the layers are rarely fully implemented. The OSI model emerged from the ITU and was initially positioned as a competitor to the TCP/IP stack, discussed in Section 2.1.2 below. The OSI model is associated with the International Standards Organization (ISO). The ISO is "an international body that drafts, discusses, proposes, and specifies standards for network protocols. ISO is best known for its 7-layer reference model that describes the conceptual organization of protocols. Although it has proposed a suite of protocols for Open System Interconnection, the OSI protocols have not been widely accepted in the commercial market" (Comer, 2000). There are, however, several examples of protocols based on this model, e.g. X.25, a data network system that behaves much like a telephone system. Asynchronous Transfer Mode (ATM) is another ITU protocol family based on the ISO model (McDysan, 2000). ISO protocol families like X.25 and ATM have, for the most part, lost out to IP in the market place. Therefore, TCP/IP's simplification of the OSI stack has become more prevalent. However, the OSI model continues to serve as a conceptual reference for building network applications and protocols because of its layered abstraction.

2.1.2 TCP/IP stack

TCP/IP is a 4-layer simplification of the OSI stack (see Figure 2-2). The TCP/IP stack emerged from the Request for Comments (RFC) standards process managed by the Internet

Engineering Task Force (IETF). TCP/IP is the most widely implemented networking abstraction simply because IP has dominated over all other networking protocols. As mentioned above, full implementations of the OSI stack are rare. TCP/IP reference implementations abound. Both OSI and TCP/IP stacks place the application layer at the top of the stack. This means that the abstraction extends to the level of the application that an end-user interacts with, but not the user him/herself (Douba, 1995). This point is important because people use communication systems and decide whether they are acceptable or not.

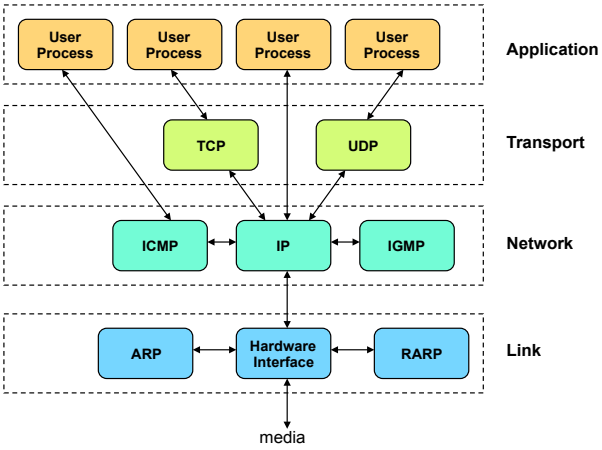

Figure 2-2 TCP/IP stack

The TCP/IP stack has four layers (Comer, 2000; Stevens, 1994). The bottom-most Link layer runs a protocol such as Ethernet over physical media. Internet Protocol operates at the Network layer along with some coordination protocols. The Transport layer acts as a buffer between IP and applications (and application programmers). The two main transport layer protocols are TCP that provides connection-oriented reliability and UDP that, like IP, provides neither. The topmost layer is the Application layer where applications communicate with one another on behalf of a user.

2.2 Evaluation of communication systems

It follows, then, that one needs to evaluate a communication system in both technical and user terms. This issue is central to the thesis: to combine both technical and user issues in order to design and evaluate communication systems. The OSI and TCP/IP abstractions stop at the application level, and do not include the user at all, either implicitly or explicitly. However, communication networks and their applications designed with the OSI and TCP/IP stacks are most often measured with an abstraction called QoS that addresses both technical performance and user perception. The ITU provides the dominant QoS definitions for real-time voice and video communication networks and their applications. This section begins

with traditional views on QoS, its definitions and technical aspects. Then the section presents work that criticizes traditional QoS and offers alternative views. The theme throughout the section is the attempt to wed user perception to technical performance in order to evaluate the underlying network and its communication applications.

2.2.1 Quality of Service

The term Quality of Service appeared as early as 1984 in RFC 905 (McKenzie, 1984). In early RFCs, QoS is seen as a measure, or cost, by which to route packets. The idea is to route a packet along the best possible path, as computed by some metric calculation. QoS has roots in the Type of Service (TOS) bits in the IP packet header. There are three precedence bits, and four TOS bits that can be used to make routing decisions. Some routing protocols, e.g. Open Shortest Path First (OSPF) (Coltun & Fuller, 1994), make use of these bits to compute paths, but in practice the TOS bits has been largely ignored.

Over the years, the ITU and other standards organizations issued a variety of recommendations and documents regarding communication quality. Examples include ISO 8402, ITU-T E.800, ITU-T I.350, ITU-T Y.1540 and ETSI ETR 003. Note ITU-T is the telecommunications standardization sector within the ITU. In an attempt to unify and standardize the conception of QoS, the ITU-T drafted recommendation G.1000 to provide "a framework and definitions for communications quality of service so as to establish a uniform approach to quality of service across the ITU-T and eliminate the confusion resulting from different frameworks and inconsistent definitions" (ITU, 2001). G.1000 was meant to upgrade the definition of QoS for IP telephony due to the rise of VoIP, a disruptive technology that has upset the dominant circuit-switched paradigm in telecommunication (Economist, 2005a, 2005b). G.1000 is therefore generalized to include just about any form of communication, from wire line, to mobile and multimedia. The recommendation defines quality as "the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs", taken from ISO 8402. G.1000 then defines QoS as "the collective effect of service performances, which determine the degree of satisfaction of a user of the service", taken from ITU-T E.800 (ITU, 1994). Finally, G.1000 situates QoS within a business environment that takes into consideration both network performance and the user's perception with implied financial ramifications. Figure 2-3 depicts these relationships.

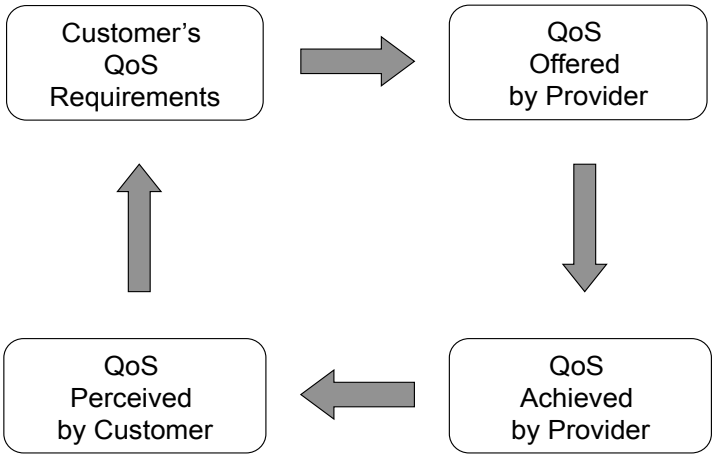

Figure 2-3 ITU G.1000 QoS relationships

For the G.1000 recommendation (ITU, 2001), QoS starts with user requirements, usually specified in non-technical terms. The Service Provider interprets those requirements into network provision parameters that are codified into a Service Level Agreement (SLA). The SLA tends to characterize services in terms of technical performance. Metrics associated with the actual service provision are measured, and then the user's perception of these services is measured with subjective tests and questionnaires. The results of the user's perception in turn drives the user's requirements, and the cycle continues. This cycle demonstrates the overall picture of how QoS is employed in the business world to manifest an implied financial relationship between technical network performance and user perception.

2.2.2 Service Level Agreement

Even though recommendation G.1000 desires to unify and focus its definition, QoS remains a vague combination of user perception, network performance, and business model. G.1000 particularly promotes the business angle, as the SLA is the main focal point for G.1000's discussion of QoS. The business case for QoS is concerned with a service provider meeting specifications of a given end-user contract and the perceptions evoked from that provision. With respect to QoS, an SLA typically guarantees access and performance, with a premium on reliable and predictable performance. An SLA specifies constraints and/or provisioning of the following: minimum amount of bandwidth to be provided by a service provider; maximum delays for specific types of services expressed in terms of end-to-end response time, or round trip time; maximum error toleration such as packet loss; and accessibility constraints, e.g. 99.999% uptime (Ferguson & Huston, 1998).

2.2.3 Performance metrics

Technical QoS is primarily concerned with bandwidth factors affecting transmission delay. Delays derived from the physical and logical traversal of the network stacks were

described in Section 2.1. There are three aspects to delay: latency, jitter and packet loss. Latency is the time elapsed during a packet's end-to-end traversal. The path back and forth to a destination is referred to as Round Trip Time (RTT). There are two forms of latency: real and induced (Ferguson & Huston, 1998). Real latency consists of "physical, binding characteristics of the transport media (electronic signalling and clocked speed) and the RTT of data" (Ferguson & Huston, 1998). Induced latency includes network overhead such as queuing delay, process delay, congestion, and other overheads that operate within communication protocols. It should also be noted that QoS mechanisms themselves contribute to 'induced' latency. Induced latency is the major contributing factor to uncertainty. RTT is important because it governs "TCP's timeout and retransmission algorithms and the dynamic data rate management algorithms" (Ferguson & Huston, 1998). Jitter is the variation in packet latency. Large buffers can smooth out jitter, but introduce even more delay. Packet loss results in the retransmission of packets, which incurs even more delay, or without retransmission a loss of data that results in patchy service delivery.

QoS can be measured purely in terms of latency, jitter and packet loss metrics and ratios. In this view, there are two fundamental approaches to providing QoS: over-provision of network bandwidth to prevent congestion, or reservation of enough bandwidth for a specific application. Either way, the goal is to minimize delay by creating and/or allocating a pipe large enough to handle packet transmission efficiently to minimize propagation delay.

It is commonly accepted that the delay tolerance for speech is 400-600ms, or roughly half a second (Hardman et al., 1995). Most VoIP packets contain roughly 20-80ms, or an average of about 40ms of voice content. Early Internet audio experiments with the MBone (multicast backbone) showed that there are three main problems with audio tools, and proposed algorithmic solutions for each one: 1) packet loss: introduce redundancy into the audio stream, 2) non real-time operating systems: introduce adaptive control mechanisms, and 3) acoustic problems: deploy better silence detection (Hardman et al., 1995, 1998). Other approaches include codec and compression schemes. Ultimately, however, the task is to develop network transmission and management protocols that are meant to reduce end-to-end delay in order to keep within the tolerances required by users. These protocols are normally associated with controlling packet latency at various layers in the OSI and TCP/IP stacks.

2.2.4 QoS protocols

The technical provision and measurement of QoS metrics can be directly addressed in specific layers in either stack. For example, a VoIP application developer might choose to run RTP over UDP to minimise induced latency. Application performance involves measuring UDP latency, jitter and packet loss at OSI Layer 4. These measures can also be computed with IP packets at Layer 3 or Ethernet frames at Layer 2. Thus, the OSI stack can also be used as an abstraction for measurement. Furthermore, protocols are designed at various levels in the OSI stack to deal with QoS metrics in different ways.

There are two main approaches to achieving precedence in IP packet forwarding: giving precedence to *flows* exemplified by Resource ReSerVation Protocol (RSVP) (Braden et al., 1997) and giving precedence to *types*, or classes, of flows exemplified by Differentiated Services (DiffServ) (Blake et al., 1998). The problem with communication over the global Internet is that all routing nodes would have to adhere to a particular strategy for prioritizing packets in order to minimize delays. This turns out to be practically impossible on the Internet, with its vast collection of internetworks, but can be achieved on dedicated IP networks. Multiprotocol Label Switching (MPLS) (Rosen et al., 2001) tackles the heterogeneity of routing protocols, such as mixed IP and ATM networks. In many ways, what is needed to provide QoS is not fairness, but *unfairness* with traffic shaping, admission control, IP precedence (of classes) and differential congestion management (Ferguson & Huston, 1998). This means that some classes of traffic are prioritised over others. Furthermore, "although resource allocation schemes differ in details, the premise from which they are constructed is fundamentally the same. The premise is to allocate service resources according to the assumed objective QoS requirements of applications" (Bouch et al., 2000). Objective metric measurement is rather straightforward. Subjective QoS for an end-user is entirely different.

2.2.5 The network and the user

In order to measure how a user perceives temporality and quality problems with communications, the ITU defined a family of tests to measure communication quality. ITU-T recommendation P.800 defines how to conduct experiments to measure the subjective response of a human to variable telephone communication quality (ITU, 1996). This test can

also be performed with VoIP, using the telephone system as the reference model for voice communication. Recommendation P.920 goes further to include both audio and visual communication (ITU, 2000). These recommendations are representative of an entire family of tests. The recommendations specify the laboratory conditions required to conduct a given test. A quality test such as P.800 or P.920 consists of the manipulation of specific quality conditions under uni-directional or conversational exchanges. There are two types of measurements: duration and activity factors are measured on-line and stored for subsequent analysis, and questionnaires are given to users. The questionnaires consist of 5 point Likert scale questions about communication quality and a yes/no final question, the "Difficulty" scale which directly asks the user "did you or your partner have any difficulty in talking or hearing over the connection?" The mean of the questionnaire answers is used to compile Mean Opinion Scores (MOS) (ITU, 2003a) and is subjected to an analysis of variance (ANOVA) to correlate the technical metrics to user perceptions.

The ITU came to advocate another technique, P.861 (ITU, 1998) based on Perceptual Speech Quality Measurement (PSQM), developed by KPN Research in Holland. While PSQM delivers similar results to MOS, it is restricted by several technical factors. PSQM does not adequately address packet loss, "clipping" effect or bit errors (Willis, 1999). Willis (1999) went further to say that the usefulness of those tests is really to tune a particular system to optimal quality (from a technical perspective), not to indicate whether a user finds the service acceptable or not.

Human perception is open to many forms of distortion. Partridge (1994) noted the overall "human-in-the-loop" issue. For example, "remembered latency" illustrates how a user's perception of network performance can be very different from its actual performance. A user remembers infrequent failures and associates those failures with the overall performance of the system, even if the system performs well for the most part. On the other hand, the "forgiveness effect" illustrates how good quality at the end of an experiment can cause a user to forgive poor quality experienced earlier (Seferidis et al., 1992). This distortion is closely tied to the "recency effect" by which a user tends to rate the overall system based on the most recent experience with the system, be it positive or negative (Aldridge et al., 1995).

The ITU evaluation methods attempt to control all aspects of the experiment, for example, piping words to users for intelligibility tests instead of using actual conversations. It

is debatable how applicable the results were to the 'real' world. Researchers cannot always control all environmental factors within an experiment. Furthermore, a user's claims of experience can differ from actual system usage (Watson & Sasse, 1996). Watson and Sasse compared a controlled experiment with a field trial in order to examine user-centred methods for evaluating quality. They found that different tasks require different levels of quality, and further, that because different users have different operating environments, e.g. network speed and hardware processing power, they also experience a similar exchange differently. Watson and Sasse (1996) suggested that informal and more HCI-oriented methods reveal much more about user experience, and noted how difficult it is to measure quality when the researcher cannot control environmental factors. They used observation, questionnaires, informal interviews and group discussions. Correlating all of these sources is difficult, and the correlation of user perception to underlying network performance is even more problematic (Watson & Sasse, 1996).

Even with a user-orientation to QoS, it is difficult to separate user perception from the underlying network transport characteristics. Tests like P.800 and P.920 collect subjective measures of human perception. However, the subjective measurement also implies a measure of quantitative objective behaviour of the underlying network and communication systems. There is a distinction between measuring the quality of communication and measuring the performance behaviour of the components that provide the communication. Therefore, the ITU tests actually measure the network, and not the inter-human communication itself. It is not unreasonable, then, to try to understand how a user perceives the communication process, as opposed to the network performance. Such an approach comes from a more HCI-oriented, or user-centric, understanding where the user is the focus of the measurement, not the network.

2.2.6 User-centric QoS

User-centric QoS has the problem of finding ways to relate human perception to actual technical performance of the system. It is not clear how to go about doing this. "Traditional QoS metrics such as response time and delay no longer suffice to fully describe quality of service as perceived by users" (Bouch et al., 2000). Instead, Bouch et al. (2000) used focus groups to try to determine service quality. They felt that the output from focus groups could

be applied to improve system design. Even though their research was meant for web services, their approach can also be applied to IP communication. Most significantly, they found that users' *expectations* of the environment determine how they rate quality. To qualify this, they looked at QoS relative to a user's 'conceptual model' or assumptions and understanding of the system. The user either perceives the system service as a database lookup or a computation. Bouch et al. (2000) showed that the conceptual model of how the system operated influences expectations, and therefore the evaluation of quality. These conceptual models influence expectations and consequently how people tolerate delay.

Other research makes the case that user perception decides everything, and therefore recommends subjective assessment of quality (Watson & Sasse, 1998). Watson and Sasse (1998) criticised the ITU's measurement of real-time audio and video-conferencing quality, e.g. P.800 and P.921. Watson and Sasse (1998) found problems with vocabulary of scale labels, length of the test material, and the binary conversation difficulty scale. Watson and Sasse (1998) also believed that the typical 5-point Likert scale presents additional problems. Users tend to gravitate toward the low end of the 5-point scale. Instead of a labelled Likert scale, Watson and Sasse (1998) recommended a 200mm line with + and – at either end. They claimed that users are less likely to score at the extremes with a continuous scale. They also conducted focus groups with users to discover the terms that users use to describe quality aspects, as opposed to the technical terms used by researchers. Overall, Watson and Sasse (1998) felt that speech and video-conferencing quality was multi-dimensional. Most accepted measures are uni-dimensional (e.g. latency), as are the solutions (e.g. increase bandwidth). To deal with the aforementioned 'memory' effects, Watson and Sasse (1998) recommended continuous measurement, and offered a software version of a continuous scale called QUASS (QUality ASssment Scale) that users could easily use throughout the measurement session.

Watson and Sasse (1998) are not the only researchers to criticise the ITU's QoS methods. Willis (1999) pointed out that the ITU P.800 specification calls for a large sample size to counteract different people perceiving the same thing differently. In fact, the same person can perceive the same voice sample differently. Willis (1999) agreed with Watson and Sasse (1998) that the labels on the scales are often ambiguous, and also that the scales do not perform well across different languages. Furthermore, the ITU prescribes a very sterile environment, and does not necessarily reflect a 'real' environment. As will become clear in the

next chapter, the user's environment is a fundamental factor in ICT4D. The initiatives of ICT4D force us to consider users and their social environment.

2.3 Summary

This chapter presented traditional OSI, TCP/IP and QoS networking abstractions. QoS include a user's perception, but is still oriented toward underlying performance metrics. The abstractions described in this chapter emerged from and were geared toward developed regions. Chapter 4 will argue that the traditional design and evaluation abstractions ignore the ICT4D users' socio-cultural environment as well as the ICT4D-specific application needs because those performing design and evaluation of communication systems tacitly assume developed region social factors. Chapter 3 considers design and evaluation issues from the perspective of ICT4D that explicitly exposes social factors.

Chapter 3: ICT4D design and evaluation

I walk down the same street.

There is a deep hole in the sidewalk.

I see it is there.

I still fall in – it's a habit.

My eyes are open.

I know where I am.

It is my fault.

I get out immediately.

Portia Nelson

This chapter examines work related to the design and evaluation of communication technologies in an ICT4D context. Technical design and evaluation, at least for the communication systems, are often based on the traditional abstractions described in Chapter 2. Yet technical, environmental and cultural factors in ICT4D call for very different technical approaches as well as more socially aware approaches (Brewer et al., 2005, 2006). Very little computer science research literature specifically addresses the 'C', or Communication, in ICT4D. Therefore, the chapter emphasizes the design and evaluation of communication technologies in an ICT4D context while drawing upon the 'I', or Information, in ICT4D to round out the overall approach of combining technical and social factors.

Heeks (2008) argued for multidisciplinary teams and/or hybrids from three perspectives on ICT4D: computer science, information systems (IS) and development studies. For the domain of small-scale ICT4D interventions, particularly for communication bridges, we opt for a computer science-weighted hybrid approach. Thus, each section below firstly stresses the computer science perspective on the 'C' in ICT4D followed by information systems and development studies perspectives, respectively. The computer science perspective is further characterised by networking and HCI perspectives in particular.

The chapter is organized as follows: Sections 3.1 and 3.2 address work related to the design and evaluation of ICT4D systems, respectively. Both sections emphasize communication technologies and also draw on other types of ICT4D systems. Section 3.3 assembles the lessons learnt from all of those perspectives. Section 3.4 summarises the

chapter by identifying gaps in the literature that lead toward the innovative Softbridge abstractions introduced in Chapter 4 to bridge those gaps. Note that work specifically related to the field studies described in Chapter 6 and Chapter 7 are presented in those chapters, respectively. Also note that work related to ICT4D methods will be addressed in Chapter 5.

3.1 Design of ICT4D

There are several well-documented approaches to ICT4D design, each usually abstracted from a particular research group's experience in the field. A good example comes from the Technology for Emerging Markets (TEM) group at Microsoft Research India in Bangalore. TEM specifies five high level stages of technology design for ICT4D: wonder, exuberance, realization, adaptation and identification (Donner et al., 2008). TEM abstracted these generalised design stages from six on-going ICT4D projects including Text-Free UI (Medhi, 2007; Medhi & Toyama 2007) and Warana Unwired (Veeraraghavan et al., 2007).

This section abstracts technical design aspects of ICT4D projects from a wider collection of related work to achieve a more 'nuts and bolts' view of the technical design aspects of ICT4D. The section organises related work according to a technical, yet abstract, classification scheme offered by the Technology and Infrastructure for Emerging Regions (TIER) group at the University of California at Berkeley (Brewer et al., 2005) consisting of the four categories shown in Figure 3-1[2].

We chose the 'Big 4' for several reasons. Firstly, TIER publishes extensively in the computing literature. Secondly, the four technical categories are evident in all ICT4D projects. The four categories, or layers, are more highly abstracted than the OSI and TCP/IP stacks. Consequently, the 'Big 4' provides an essential basis of the novel Softbridge stack abstraction presented in Chapter 4. This section expounds the design aspects of ICT4D-related work fitted into the four categories: Section 3.1.1 addresses power provision, Section 3.1.2 addresses the network, Section 3.1.3 addresses devices and Section 3.1.4 addresses the user interface.

[2] As we are based in Africa, the 'Big 4' is a pun on the 'Big 5' animals celebrated by large game parks in Africa: lion, elephant, cape buffalo, black rhinoceros and leopard.

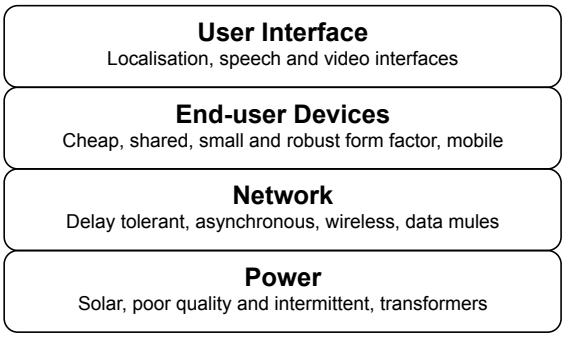

Figure 3-1 TIER's ICT4D stack, the 'Big 4'

TIER identifies the main problems faced by ICT4D projects as poor power and even poorer telecommunications (Brewer et al., 2005). TIER addresses unreliable power in developing regions with an intermittent, or delay-tolerant, approach to networking. Once intermittently connected, end-users use low-end cheap devices such as PDAs or cell phones to communicate. Finally, TIER, like other ICT4D groups, addresses user interfaces in native languages, especially speech and/or visual interfaces for users with limited literacy. We view these four components, or layers, collectively as a technology stack abstraction for the design of ICT4D systems.

3.1.1 Power design considerations

All modern computing technology requires some form of electrical power supply. Power in underdeveloped regions is frequently characterized by poor grid coverage and poor quality when available (Brewer et al., 2005, 2006; Johnson, 2007; Pentland et al., 2004). Brewer et al. (2005) found that voltage and current variation damages devices. Uninterruptible Power Supply (UPS) systems deal with outages, but are expensive and fall prey to brownouts. Solar systems struggle to convert up to 220v and then back down to 12v. Built-in smart chargers help charge battery-powered systems effectively. Solar systems can provide long-term maintenance free low voltage power (CRCNet, 2005; Pearson, 2006). In many cases, we can safely assume that problems with power systems are not even reported in the literature because the topic is so problematic.

Power for ICT4D therefore has to be locally applicable (Sewankambo & Riccio, 2003). For example, DakNet utilises an engine-driven Mobile Access Point (MAP) on a bus or motorcycle that simultaneously powers a wireless Access Point (AP) mounted on the vehicle (Chyau & Raymond, 2005; Pentland et al., 2004). Pentland et al. (2004) also mentioned that a human or animal-powered MAP could provide some form of generator. Frequently, however, the provision and duration of power supplies naturally leads to the use of handheld mobile devices (see Section 3.1.3 below). Power is often just one of many factors leading to a choice of handhelds. The SATELLIFE project specifically opted for long life battery powered

devices like PDAs as opposed to PCs (Sewankambo & Riccio, 2003), as did other projects like Zebranet (Juang et al., 2002). Power concerns are also a major consideration in the development of small computing devices like the One Laptop Per Child (OLPC) (Surowiecki, 2006). At one point, the OLPC project toyed with a built-in hand crank. These examples point toward the challenges of establishing infrastructure in developing countries.

3.1.2 Network design considerations

ICT4D networks tend to be wireless (Best, 2003; Galperin, 2005). Wireless networks in general, as opposed to wired networks, are low cost and provided instant widespread access. Wireless networks are easily expanded and introduced into situations where no infrastructure already exists (Galperin, 2005). Galperin (2005) mostly discussed 802.11b[3], or WiFi (Wireless Fidelity) networks in Latin America. However, WiFi ICT4D networks with broadband uplinks, e.g. with satellite-based Very Small Aperture Terminal (VSAT), are quite common around the world and continue to grow in number (Best, 2003). WiFi is currently the most ubiquitous broadband wireless networking technology because of its standardisation and low cost.

Cellular networks have also provided demonstrable success in digital divide communications (Best, 2003). Cellular GSM (Global System for Mobile communication) and GPRS (General Packet Radio Service) narrowband and 3G broadband connectivity along with up and coming 4G networks like WiMAX (Worldwide Interoperability for Microwave Access) are also becoming more and more prevalent. Many projects leverage standard narrowband GSM networks to provide innovative ICT4D services. Some examples include: SMS reminders for patients to take medication (Anand & Rivett, 2005; bridges.org, 2005c), SMS and GPRS-based agricultural data sharing (Veeraraghavan et al., 2007) and a SIM-based (Subscriber Identity Module) e-commerce system for a rural ICT project (Slay et al., 2007).

A significant difference between WiFi and cellular networks, besides the actual underlying technologies and protocols, lay in who has control of the network and how it is costed. GSM, GPRS and 3G cellular networks are controlled by large telcos, deployed in

[3] See Best (2003) for a consolidated primer on wireless networking technologies. 802.11b can achieve 11Mbps throughput at a distance of up to 100m, but is often deployed over much longer distances with consequently less throughput.

controlled spectra and consequently charged based on usage (Best, 2003). WiFi networks, on the other hand, operate in public 2.4GHz and 5.8GHz spectra and tend to be controlled by users (Best, 2003; Purbo 2003, 2004a). To repeat, WiFi networks are standardised, cheap and easy to install (Best, 2003; Galperin, 2005). Once installed, there are no running costs other than maintenance.

WiFi networks also consume very little power and can span large distances (Patra et al, 2007; Sheth et al., 2007; Subramanian et al., 2006; Surana et al., 2007, 2008). There are several WiFi deployment strategies to achieve widespread coverage with a technology designed only for 100m distances: embrace intermittent and fault tolerant networks (Brewer et al., 2005; Du et al., 2006), overcome challenges with low level, e.g. OSI Layer 2, tweaks (CRCNet, 2005; Patra et al., 2007; Sheth et al., 2007), use mesh networks (Bhagwat et al., 2004; Johnson, 2007; Surowiecki, 2006), use WiFi as-is (Galperin, 2005) or some combination of any of these (Best, 2003).

Intermittent connectivity is a common theme in the literature. Pentland et al. (2004) emphasised that users in remote developing regions do not have the luxury of always-on connectivity. Asynchronous services are sufficient to get an ICT4D foothold into a given area (Pentland et al., 2004). Therefore, DakNet is asynchronous and intermittent by design (Chyau & Raymond, 2005; Pentland et al., 2004). DakNet latency is measured in days and hours instead of microseconds and seconds because it uses a data mule[4], e.g. bus, motorcycle, bicycle or even an ox-cart fitted with a wireless AP and some data storage. The mobile AP, or MAP, travels along a route and automatically links up with remote wireless access points along the way. In remote areas, APs are situated at a village kiosk (India) or a school (Cambodia). The route of the MAP eventually links up with an existing Internet uplink with which incoming and outgoing transactions to the Internet are enacted. A MAP might drive past a given kiosk or school once a day, and can transfer about 20MB in each direction, with effective goodput[5] of 2.47Mbps (Pentland et al., 2004). DakNet relies on short communication distances so no modifications were required to 802.11 protocols or wireless equipment.

[4] A data mule physically carries a data storage device from one place to another.
[5] Goodput is similar to throughput but concerns only application data that gets through.

TIER designs long-range point-to-point WiFi networks for very challenging environments with standard WiFi equipment. However, these WiFi-based Long Distance (WiLD) networks implement low-level Media Access Control (MAC) layer enhancements (Patra et al., 2007; Sheth et al., 2007) and a Delay Tolerant Networking (DTN) approach that embraces asynchronous data transfer (Demmer et al., 2004; Fall, 2003, 2004; Jain et al., 2004). Asynchronous communication features heavily in the TIER projects, e.g. asynchronous medical tele-consultation (Luk et al., 2008). TIER also aims for more reliable WiLD networks (Subramanian et al., 2006; Surana et al., 2007, 2008). CRCNet also addresses long-range wireless connectivity by tackling low-level OSI Layer 2 protocol timing mechanisms on standard WiFi equipment and protocols (CRCNet, 2005). CRCNet's main objective, however, is to provide synchronous broadband access instead of asynchronous and intermittent access. Regardless of synchrony, the overriding goal for both WiLDNet and CRCNet projects is to design networks that can be managed by local inhabitants. This entails robust software that automatically configures itself and cheap reliable hardware that can be easily installed and maintained by end-users.

Another approach to widespread WiFi access is to use mesh networks (Bhagwat et al., 2004; Johnson, 2007). There are well-founded arguments against the use of long-range mesh networks (Subramanian et al., 2006). However, local short-range mesh networks address many ICT4D challenges. Mesh software can be put into both devices and APs meaning that mesh networks can be expanded easily just by adding more APs and user devices (Bhagwat et al., 2004; Johnson, 2007; Surowiecki, 2006).

While the projects discussed above tackle mostly rural areas in developing regions, MaverickNet is largely an urban phenomenon in Indonesia (Purbo, 2003, 2004a, 2004b, 2005). WiLDNet, DakNet, CRCNet and MaverickNet share a common aspiration in that the end-users should be empowered to set up a network themselves. The MaverickNet strategy is to build easy-to-use, low cost WiFi networks and educate people to deploy and use them (Purbo, 2004a). MaverickNet grew organically to provide Internet connectivity to millions of Indonesians via clandestine and illegal wire line and WiFi links in defiance of Indonesian regulatory legislation (Purbo, 2003, 2004a, 2004b).

In summary of the network design considerations, it should be noted that we infer that the network design for all projects reported herein, e.g. WiLDNet, DakNet, CRCNet and

MaverickNet, is accomplished with the traditional OSI and/or TCP/IP design abstractions. It is telling that stacks are usually not mentioned by name explicitly in publications other than an infrequent reference to an OSI layer, e.g. WiLDNet protocol substitution or CRCNet timing modification at Layer 2. In other words, the use of OSI and TCP/IP stacks is *implicit* in all projects' network design. Section 3.2.1 will show that the implicit use of traditional stacks also entails an implicit use of QoS to evaluate the efficacy of ICT4D networks.

3.1.3 Device design considerations

MaverickNet and CRCNet efforts are not explicitly concerned with the type of end-user devices deployed on the network. That is left to the user. Many other ICT4D projects, however, either design or choose devices specifically for various ICT4D challenges such as power consumption, mobility, ease-of-use, and cost. Pentland et al. (2004) noted that a low-cost network would only work with advances in "robust, low-cost terminals". The most well known contemporary example of device design for ICT4D is the OLPC project from the Massachusetts Institute of Technology (MIT). The OLPC goal is to build a robust mobile device with long battery life for US$100 (Surowiecki, 2006). The OLPC project has not yet realised that price goal and has not succeeded on the massive scale originally envisioned.

A more common approach is to appropriate existing small and cheap devices for use in ICT4D projects. TIER deploys cheap and shared devices ranging from PDAs and cell phones to laptops (Brewer et al., 2005; Kam et al., 2006, 2007b; Pal et al., 2006; Ramachandran et al., 2007). Key trade-offs include shared vs. personal devices, multi-purpose vs. tailored devices, and device form factor. The SATELLIFE project uses handheld PDAs chosen because of long battery life and ease of use (Sewankambo & Riccio, 2003). For Sewankambo and Riccio (2003), handhelds are not a replacement for PCs, but rather just another tool. Many ICT4D projects utilise standard SMS features, including: Cell-life (Anand & Rivett, 2005), Warana Unwired (Veeraraghavan et al., 2007) and mobile e-commerce (Slay et al., 2007). Mobile devices tend to feature in many ICT4D projects in part because end-users are already comfortable with a cell phone and its interface (bridges.org 2003a, 2005c, Marsden 2006, 2008; Maunder et al., 2006, 2007; Thinyane 2007a, 2007b).

3.1.4 User Interface design considerations

A recurring theme in ICT4D is to design audio and video interfaces for illiterate users. Mobile devices are very applicable in the ICT4D domain and are often the tool of choice (Marsden 2003, 2006, 2008; Veeraraghavan et al, 2007). TIER's illiterate users encounter problems with mouse clicks, pointers, languages and alphabets (Brewer et al., 2005). Localising text-based computing for illiterate users is very difficult, so researchers explore speech and video interfaces. DTN applications also have usability issues because of the asynchronous temporality. Learning to deal with issues such as these requires extensive visits in the field. TIER favours user-centred approaches like iterative design (Kam et al., 2007b), participatory design (Kam et al., 2006), multi-user design (Pal et al., 2006) and early stage co-design (Ramachandran et al., 2007). It appears that challenging socio-economic and cultural factors push HCI researchers to re-examine the concept and role of user-centred design itself, e.g. how to empower the user to design the interface (Marsden, 2008). Some ICT4D projects do not even include the use of computers in order to simplify and ease the interface, e.g. a paper and oral based system for community-based child health care in KwaZulu-Natal in South Africa (Byrne, 2003, 2004).

User-centred design is central to the HCI discipline. Consequently, Dray and Siegel (2003) and Dray et al. (2003) recommended the adaptation of HCI methods for the ICT4D context. Like the traditional network design and evaluation abstractions described in Chapter 2, standard HCI methods come with assumptions on the part of the HCI designer. Methods such as paper prototyping (Maunder et al., 2006, 2007) and participatory design (Kam et al., 2006) have to be modified to address poor literacy of digital divide inhabitants. Innovative video interfaces such as Bollywood-styled video user guides are helpful for users who can only really read numbers, not text (Medhi, 2007; Medhi & Toyama, 2007).

Marsden (2008) made a distinction between 'pragmatic design' and 'empowered design'. The former is meant to leverage existing technologies to create useful interfaces for ICT4D users, e.g. a photo navigation interface for 'normal' cell phones. 'Empowered' design, on the other hand, is meant to foster users taking control of the interface for their own purposes. This is much harder to do and requires the technology designer to 'step outside the box' to come up with innovative interfaces that can be appropriated more easily for ICT4D users (Marsden, 2008).

Evidence for a 'new' research community that advocates social considerations of user interface design and evaluation comes firstly from the introduction of several new acronyms: HCI4D (HCI for development), UCD4D (user-centred design for development) and CCD4D (community-centred design for development). Further evidence is that the 'new' ICT4D user interface focus has become the topic of several workshops at CHI and DIS[6] conferences (Deardon et al., 2007; Thomas et al., 2008a, 2008b). Research associated with these new acronyms also featured at recent joint IEEE/ACM[7] ICTD (same as ICT4D without the '4') conferences, most notably in 2007 (Kam et al., 2007a; Maunder et al., 2007; Medhi & Toyama, 2007; Veerarghavan et al, 2007).

3.2 Evaluation of ICT4D

The ICT4D research communities have devised a variety of evaluation approaches for the ICT4D context. This section presents work related to ICT4D evaluation from several perspectives. Section 3.2.1 discusses the evaluation of ICT4D systems from a QoS-centric viewpoint. Section 3.2.2 presents an information systems stance to evaluation. Finally, Section 3.2.3 portrays ICT4D evaluation from the perspective of development studies.

3.2.1 QoS-centric evaluation

Section 2.2 described how canonical QoS evaluation such as P.800 (ITU, 1996) and P.920 (ITU, 2000) correlate a user's perception of real-time voice and video communication to network performance. Traditional QoS measurement is therefore applicable to services like VoIP over CRCNet-type networks that intend to provide real-time services. The typical approach is to measure standard network performance and latency metrics (see Section 2.2.3). However, canonical QoS is not applicable to intermittent, asynchronous, fault tolerant or mesh ICT4D networks because they are fundamentally different types of networks (Subramanian et al., 2006). Subramanian et al. (2006) noted that it is possible to configure

[6] CHI (Computer Human Interaction) and DIS (Designing Interactive Systems) are two HCI-related ACM conferences (see next footnote).

[7] There are several dominant professional organisations for computer scientists: the Association of Computer Machinery (ACM), the Computer Society of the Institute of Electrical and Electronics Engineers (IEEE) and the International Federation for Information Processing (IFIP) that has working group 9.4 dedicated to ICT4D-related issues and a new specialist group TC13 on HCI and international development.

routers in a rural network, but "traditional QoS mechanisms do not blindly carry over due to peculiar constraints imposed by WiLD networks". This is due to the high amount of packet loss and the way bandwidth on one link affects bandwidth on adjacent links. All types of long-range WiFi networks experience bandwidth fluctuation (Pearson, 2006, Subramanian et al., 2006). QoS mechanisms (see Section 2.2.4) can assume some form of fixed bandwidth allocation to deal with application requirements. Also, low-level protocol design and loss recovery on WiLD networks can manifest variable delay, or jitter (Subramanian et al., 2006). Traditional QoS allocates resources for flow isolation, e.g. RSVP. Subramanian et al. (2006) chose to classify and prioritise traffic as with DiffServ. Traditional QoS also requires extra processing overhead. WiLD components are low power, low memory, low voltage and low wattage and can not handle too much extra processing (Subramanian et al., 2006).

MaverickNet WiFi networks, on the other hand, are urban and short range in nature, yet still not intended to achieve telco-style QoS. Purbo (2004b) claimed people would tolerate lack of QoS if costs are low enough and access is unrestricted. MaverickNet growth shows that guaranteed QoS is not required (see Table 3-1).

	Cost	Traffic	QoS
Telco PSTN	US$400-800/month/user	Limited quantity	High, guaranteed
MaverickNet	US$15-45/month/neighbor	Unlimited quantity	Low, variable

Table 3-1 Cost and QoS of Internet provision in Indonesia: MaverickNet vs. telco

The comparison between MaverickNet and the Indonesian PSTN highlights fundamental differences between top-down and bottom-up network design and evaluation. The wired PSTN provides limited high quality bandwidth for a high price. MaverickNet provides unlimited unguaranteed bandwidth at a low price. MaverickNet was so successful that it grew bottom-up to provide Internet and VoIP to millions of Indonesians.

QoS is firmly rooted in a telco-oriented PSTN mindset for telecommunication based on measuring delay metrics at various levels in the OSI stack. ICT4D communication design described in Section 3.1 is accomplished with OSI and TCP/IP abstractions, but the resultant networks and their applications are not necessarily synchronous or reliable. Social factors are also very different from the business-oriented locales associated with traditional QoS thinking. A crucial observation from Pentland et al. (2004) was that the telephone model is not appropriate for rural connectivity primarily because of the infrastructure outlay cost and the shared nature of devices. Access devices such as a telephone or a PC tend to be shared at a village kiosk. Without a personal device, it is difficult for a person to call another person

when it is unlikely that the other person is physically near a shared device. In such cases, store-and-forward is more appropriate than synchronous communication.

QoS-centric evaluation of ICT4D networks merely shows that a network operates with respect to some expectation of its performance. QoS might be applicable to some types of ICT4D environments (Pearson, 2006). For most, however, QoS is not applicable and social factors manifest more influence than technical factors. In the literature, however, social factors are often offered as lists of lessons learnt. Several such lists are provided in Section 3.3. There are no QoS-like frameworks or methods to evaluate social factors of communication networks and their applications in the ICT4D space. Therefore, the next two sections turn to sources other than computer science for socially aware evaluation frameworks.

3.2.2 Information systems-centric evaluation

The work of Heeks (2002, 2008) related to ICT4D represents an information systems (IS) perspective. Heeks (2002) surveyed IS literature and identified three general categories regarding success: success, total failure and partial failure. It was easier to define success and failure of IS in industrialized countries: 20-25% total failure, 33-60% partial failure and only a small percentage in the success category. Heeks (2002) surmised that the success rates are much worse for developing countries[8] (DCs). However, there is no real evidence due to a lack of literature on the topic in general and a lack of evaluation in particular. "The evidence base is not strong - and it urgently needs strengthening - but it all points in one direction: toward high rates of IS failure in developing countries" (Heeks, 2002). Heeks (2002) blamed the failures on the "design-reality gap", the lack of fit between the reality (actuality) and the intention (design) of ICT4D projects. He argued that at least the difficulties of ICT4D make the problems more easily recognised.

Heeks' (2002) model, then, was an assessment of the match or mismatch between "local actuality" and system design: the "design-actuality" gap. Of course, all stakeholders have their own subjective views of local actuality, so Heeks (2002) focussed on the designers and the

[8] Developing 'countries' is a commonly used term that refers to what we call developing 'regions', according to Brewer et al. (2005). We also prefer the term 'regions' because many countries, e.g. South Africa, have both developed and developing regions.

users. He suggested a combination of 1) theoretical IS literature, 2) descriptive process on the IS system components and 3) analytical case studies. Heeks (2002) added consideration of objectives and values (culture and politics), staffing and skills, management systems and structures, and other resources (time and money). This is very similar to bridges.org's (2004a) monitoring and evaluation framework discussed below. The overall idea is to assess and rate the mismatch for each of the dimensions in the model (Heeks, 2002)

Pulling on the theory of Suchman (1987), Heeks (2002) then discussed how the mindset/context of the designer could get in the way and influence the system. An action "taken in the context of particular, concrete circumstances" (Suchman, 1987) and the designer have preconceived notions and assumptions about the user's situation. "This includes assumptions about the users' activities, skills, culture and objectives" (Heeks, 2002). In other words, design decisions can be laden with incorrect values and/or perceptions and there is much opportunity for things to go wrong. This is mostly due to having IS and ICT systems developed in much different environments from those in which they are eventually deployed. In industrialized regions, the worlds of the designer and the user are very similar. This is not true for ICT4D in a developing country (DC)[9]. "The domain of developing country information systems is particularly dominated by the transfer of industrialized country designs to DC actualities" (Heeks, 2002). The development and research for ICT4D systems is often done elsewhere, emanating from the realities of business, politics of aid, perceived cultural superiority of developed region products, and globalization. The most extreme form is when a system is built purely with developed region needs in mind, and then transplanted to an ICT4D context.

Even when systems are intended for ICT4D scenarios, a design-reality gap can occur because the bulk of the design is done by non-DC participants/stakeholders. Heeks (2002) also argued that this could also happen when non-DC people are not even involved because there is often a mindset in DCs that Western ideas are superior. Therefore, non-Western locals often adopt Western approaches even when they do not really fit the local actuality. Heeks (2002) also noted "Hard-Soft Gaps" where 'hard' represents rational design associated with

[9] DC is Heeks' (2002) term. We prefer to use 'developing region'.

Western rationalism and 'soft' represents political reality often associated with third world cultural realities.

Heeks (2002) offered two suggestions to close the gaps: actuality and design improvisation. Actuality improvisation means "changing local actuality to make it closer to IS design" and design improvisation means "changing the (often 'imported') IS design to make it closer to DC user actuality". Heeks (2002) gave an example of a decision support system that had to be designed so particularly by a rational design process. "This deep design inscription will often create a large initial design-actuality gap" (Heeks, 2002). On the other hand, "actuality-supporting applications can be seen as more enabling" (Heeks, 2002). An example is a word processor because it is completely generic. "Shallow design inscriptions will be associated with a small initial design-actuality gap" (Heeks, 2002). Heeks (2002) meant that general purpose tools, design and components have more of a chance of lending themselves to both actuality and design improvisation, and that it is empowering local improvisation that provides an opportunity for success because that enables local take-up and ownership of ICT4D.

Lastly, when discussing the ability of locals to make the improvisations (namely, that they do not have the skills to do so), there is a need for intermediaries that he called a 'hybrid'. "Hybrids understand both context, organization, and work processes of their section and the role on information systems" (Heeks, 2002). Later, Heeks (2008) would define a hybrid as a person with intersecting skills of computer science, information systems and development studies when multi-disciplinary teams are not available or feasible. The next section addresses the third perspective of the 'hybrid', development studies.

3.2.3 Development studies-centric monitoring and evaluation

This section describes work related to ICT4D evaluation from the perspective of development studies. Development studies comprise a wide array of organisational entities ranging from NGOs to research institutes and global entities like the United Nations. M&E approaches are defined by abstracting common attributes from multiple ICT4D projects, just as for the computer science and information systems approaches described above. M&E approaches offer either explicit (bridges.org, 2004a; Oyedemi, 2004) or implicit (Bachelor & O'Farrell, 2003; Michiels & van Crowder, 2001) frameworks for combining technical and

social inter-relationships in order to measure impact. Unlike the approaches described in Section 3.2.1, these holistic approaches are higher level and consequently do not delve into performance and implementation details of underlying ICT4D systems. Instead, M&E approaches examine ICT4D interventions within broader contextual issues. M&E tools can be used either up front for requirements gathering and/or after-the-fact for post-mortem project examination. M&E tools can also be used continuously in a long-term iterative fashion throughout a project's life cycle.

Much work related to ICT4D evaluation fits within the Real Access/Real Impact (RA/RI) criteria offered by bridges.org listed in Table 3-2 (bridges.org, 2004a). RA/RI criteria did not emerge from formal academic research literature. Bridges.org is a non-governmental organisation (NGO) engaged in the ICT4D space. Thus, we use other related research literature to backup bridges.org's findings. RA/RI criteria will be appropriated into the innovative socially aware framework discussed in later chapters. Chapter 8 will argue, based on empirical evidence and reflection from Chapters 6 and 7, for the appropriation of RA/RI criteria by pulling on the related technical work from this chapter, especially the lessons learnt described below in Section 3.3. This section uses a series of tables and figures to introduce RA/RI criteria and other related frameworks. The text accompanying and between the tables and figures describe the frameworks in brief and demonstrate how other frameworks' components fit to the RA/RI criteria.

The bridges.org RA/RI criteria construe an explicit framework that emerged from a wide survey of ICT4D projects from around the world (bridges.org, 2004a). The bridges.org NGO originated in America led by Teresa Peters. They relocated to South Africa from 2000-2006 and then moved to Uganda. Their website has an extensive collection of reports on their methods and the projects to which they applied the methods. RA/RI criteria-oriented reports tend to be post-mortem examinations that employ RA/RI criteria as a lens to evaluate social impact and the extent to which target communities adopt ICT4D interventions. Reports on significant African ICT4D projects include analyses of SATELLIFE (bridges.org, 2003a), Tsilitwa telehealth (bridges.org, 2004c) and Cell-life (bridges.org, 2005c).

Physical access Is technology available and accessible to people and organizations?
Appropriateness Is the technology appropriate to the local needs and conditions of the community, and how people need and want to put technology to use?
Affordability Are the technologies and services affordable for local people to access and use?
Human capacity and training Do people have the training and skills necessary to use technology effectively? Do they understand how to use technology and its potential uses?
Locally relevant content Are there locally relevant content and services available to people through the technologies, especially in terms of language?
Integration to daily life Is technology use an additional burden to the lives of people already burdened by daily tasks, or is it integrated into their daily routines?
Socio-cultural factors Are people limited in their use of technology because of their gender, race, age, or other socio-cultural factors?
Trust in technology Do people have confidence in technology use, and do they understand the implications of the technology they use? Do people understand issues like privacy, security, or cyber crime?
Local economics Will the local economic environment sustain long-term technology use?
Macroeconomics Does the macroeconomic environment in the country or region, such as issues like deregulation, investment, or labour issues affect technology use?
Legal and regulatory Laws and regulations affect the use of technology?
Public support and political will Do people support the widespread use of technology in their communities? Do they understand the links between their local technology use and the government's overall political strategies to promote ICT for development? Does the government have the political will to drive needed change?

Table 3-2 RA/RI criteria from bridges.org

RA/RI criteria are social concerns related to ICT4D interventions. Bridges.org studied a worldwide array of technology projects to distil these characteristics to help determine the 'real' access and 'real' impact of ICT4D interventions. RA/RI criteria are intended to evaluate ICT4D projects.

Overall, RA/RI criteria provide a holistic lens to view a range of social issues involved with ICT4D interventions. This section does not go into a detailed discussion of RA/RI

criteria and how to use them. Rather, Table 3-2 briefly describes the twelve RA/RI criteria. The components of other M&E frameworks described below easily align with RA/RI criteria. The intention is to establish that RA/RI criteria sufficiently cover a representative set of relevant social ICT4D criteria from a development studies perspective.

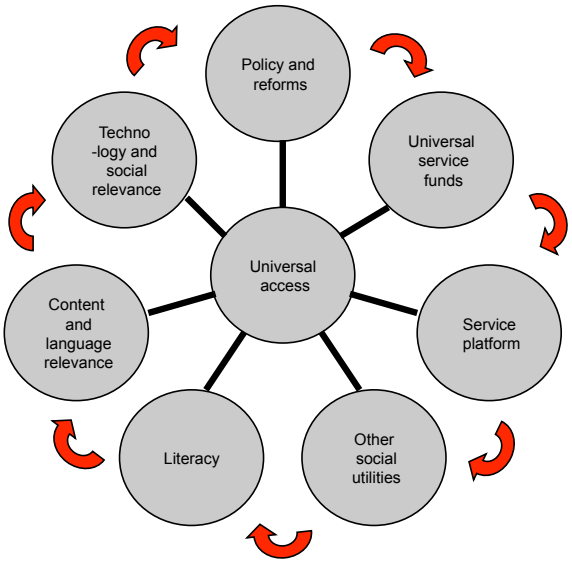

Figure 3-2 Universal access wheel

Universal Access Wheel offers a clear visual depiction of how various non-technical components work together to influence ICT4D scenarios (Oyedemi, 2004). If one of the components is faulty, the whole wheel does not turn so well. Oyedemi (2004) also stated that more spokes could be added to the wheel as required.

Like RA/RI criteria, the Universal access wheel (see Figure 3-2) provides another explicit framework that emphasises non-technical aspects of ICT4D. Oyedemi (2004) stated "the challenge for policy makers and national governments in Africa is to develop appropriate policy – policy that enhances the universal diffusion of and access to ICT services by adopting an holistic approach that takes cognisance of the social, cultural and political needs of the community". With respect to the wheel itself, "The universal access wheel does not project totality; rather it provides flexibility and dynamism typical of the information and communication technology sector. Consequently, as other elements and issues arise, they may be added to the wheel" (Oyedemi, 2004). Each Universal access wheel component aligns with one or more RA/RI criteria: policy and reforms fit 'legal and regulatory'; universal service funds fit in 'macroeconomics'; service platform is related to 'accessibility' and 'applicability'; other social utilities mean non-ICT utilities like water and electricity and are also tied to

'macroeconomics'; literacy fits 'human capacity and training'; content and language relevance are both clearly 'local content'; technology and social relevance involve 'applicability' and 'socio-cultural issues'. Oyedemi (2004) also noted that the Universal Access wheel could be extended to include more categories, including RA/RI criteria that are not there.

- Community driven - Innovative - User-friendly - Sustainable - Transferrable - Gender/youth-sensitive - Has a training component

Table 3-3 Lessons from the Magic Box

An early survey paper of ICT4D projects synthesised lessons and provided a categorisation scheme (Michiels & von Crowder, 2001). The 'Magic Box' identified issues closely aligned to RA/RI criteria. A follow up paper on the same projects two years later found the issues still relevant (Bachelor & O'Farrell, 2003).

The 'Magic Box' contains the examination of a collection of projects in order to distil general lessons about ICT4D. According to Michiels and von Crowder (2001), "Local appropriation of ICTs is about communities and groups selecting and adopting communication tools according to the different information and communication needs identified by them and then adapting the technologies so that they become rooted in their own social, economic and cultural processes". The 'Magic Box' themes are shown in Table 3-3, and align with RA/RI criteria as follows: community-driven involve 'local economics' and 'integration to daily life'; innovation reflects factors in multiple RA/RI criteria; user-friendliness fit well with 'appropriateness'; transferrable also implies 'appropriateness'; gender/youth-sensitive fits to 'socio-cultural factors' and finally, the training component is clearly 'human capacity and training'.

A follow up paper re-examined the original case studies to gauge how well they were doing (Bachelor & O'Farrell, 2003). Out of 24 case studies, six had no information available, four shared significant problems, and only one of the remaining 14 had evaluation data available, but those 14 still appeared to be ongoing. Bachelor and O'Farrell (2003) found the original 'Magic Box' principles still relevant. They also feel that the only way to share information about successes/failures is via case studies. They also noted that there still are no

proper methodologies for evaluating impact. Therefore, the 'Magic Box' is an example of an implied impact framework.

According to Bachelor and O'Farrell (2003), there are four guiding principles for ICT4D evaluation, all of which clearly dovetail with RA/RI criteria:

1. The need for empirical evidence or analysis of actual experiences of applying ICTs locally and their impact on the lives of the poor.
2. The process and approach for development interventions was key to appropriate development activity, and had in the recent past been overlooked in many ICT-related activities.
3. A focus on the *benefits* of the new technologies was needed rather than the *quantity* of technologies available.
4. Access to ICTs must be accompanied by the strategic creation of content for it to be locally appropriated and affect development.

3.3 Lessons learnt

This final section of related work highlights lessons with respect to the design and evaluation of ICT4D. Instead of listing lessons learnt from every significant ICT4D project, perspective and framework described above, this section focuses solely on two representative groups. Section 3.3.1 presents lessons learnt and recommendations gleaned by the TIER group's experience with ICT4D projects around the world. TIER's work is especially relevant to the Softbridge framework because of their emphasis on computer networks and their applications. Section 3.3.2 presents lessons learnt by bridges.org framed as 'best practice' that emanated from analysis of a very wide array of ICT4D projects rather than actual fieldwork. The work of bridges.org is representative of the development studies perspective. The information systems perspective has already been thoroughly dealt with in Section 3.2.2.

3.3.1 Lessons from TIER

The lessons learnt by the TIER group express a technical computer science-oriented fieldwork point of view on ICT4D design and evaluation. TIER categorizes lessons as technological, environmental and cultural (Brewer et al., 2006). From a technological perspective, TIER designs solutions for challenged environments where connectivity is intermittent, unreliable and very expensive. For communication applications, those conditions

dictate a store-and-forward and/or DTN approach that is fundamentally incompatible with traditional real-time QoS. From an environmental perspective, working in underdeveloped regions means dealing with exaggerated travel times, difficult road conditions, troublesome customs agents and threats of bodily harm. Finally, from a cultural perspective, TIER's work embodies a multi-disciplinary approach that actively involves local participants and beneficiaries to unearth underlying social issues that encourage or hinder use of ICT4D. Brewer et al. (2006) argued that local knowledge, social practices and content are the keys to successful ICT4D, and sought to integrate these considerations into the ICT4D process. Several important themes emerge from their projects.

The first theme is inclusion of the community in the project (Brewer et al., 2005). TIER recognizes that an ICT4D context requires technological researchers to address underlying social issues. Thus, TIER attempts to co-design and co-deploy a given ICT4D solution (Ramachandran et al., 2007). Due to poor literacy, and especially poor e-literacy, computer scientists and engineers partner with social scientists and NGOs. A co-located NGO is already tuned into the specific needs of a community and has experience integrating social processes into upliftment projects.

A second theme is transition planning and management such that any ICT intervention benefits locals. Of course, the whole intention of ICT4D is to benefit locals. However, there can be unintended negative ramifications from the introduction of ICT. For example, record keeping and activity monitoring can threaten informal arrangements, such as squatting (Brewer et al., 2005). ICT can also disrupt informal economies by introducing more effective information flow.

Another theme is free and open source software (FOSS). FOSS has the ability to localize and customize applications and interfaces. FOSS also avoids virus and spyware problems (Brewer et al., 2006). However, TIER also notes that the ubiquity of Windows makes it a valuable skill for locals to have. Therefore, end-user devices like PCs and laptops can run Windows while system and/or server devices run Linux.

TIER came up with a number of recommendations based on their experiences in the field working with real communities (Brewer et al., 2006). Those recommendations straddle technical and social issues, reflecting their influences on one another, and are summarised as follows:

Be flexible. Visiting a community in the field is a logistical burden including travel to the site, travel while at the site, ordering parts ahead of time and getting them in the field either in advance or with the team, and visiting with all the local partners. All of these issues leave very little time to actually perform the research. In underdeveloped regions, unexpected problems pop up all the time. Thus, flexibility is paramount.

Expect delays. All of the issues in the previous point are susceptible to 'time dilation'. TIER found that just about every activity in the field takes longer than expected. Such delays have to be taken into account and treated as an acceptable element of the research process.

Bulletproof everything. All software and hardware has to be made as reliable as possible simply because it is so hard to get out there and/or fix things at a distance. Remote maintenance, though problematic, is helpful.

Provide simple user interfaces. Interfaces have to be designed with the end-user in mind, e.g. web-based interfaces to Linux commands usually done at the command line by sophisticated users.

Leverage local partners. Local partners such as an NGO facilitate the introduction of an ICT4D project into the community and then help maintain a continued working relationship with a community. The trust earned by the local partner is transferred to the project. Most of all, local partners are present in the field to help when the research team is not there.

Start by doing some homework.
Perform a needs assessment.
Identify and encourage local ownership and a local champion.
Engage a local problem solver.
Form sound partnerships.
Set concrete goals and take small steps.
Ensure technology-neutrality.
Involve excluded groups.
Identify and understand external challenges.
Monitor and evaluate with appropriate tools.
Make it sustainable.
Widely disseminate the results.

Table 3-4 The 12 habits of highly effective ICT-enabled development initiatives

Along with RA/RI criteria, bridges.org offers these 12 habits to assist with the project management aspects of ICT4D interventions. As for RA/RI criteria, the 12 habits were synthesised from studying a large number of ICT4D projects around the world. The simplicity and obvious nature of the 12 habits are testimony to their efficacy.

3.3.2 Lessons from bridges.org

In addition to the RA/RI criteria, bridges.org also suggest a list of "12 habits of highly effective ICT-enabled development initiatives" (bridges.org, 2005a). These 12 habits represent a project management-oriented collection of lessons learnt, and is listed in Table 3-4. The 12 habits are very simple and self-explanatory. However, like the RA/RI criteria, the 12 habits offer a well thought-out crosscutting collection of lessons learnt from studying a wide array of ICT4D projects in the field. Chapters 6, 7 and 8 show how bridges.org's RA/RI criteria and 12 habits are used in practice.

3.4 Chapter Summary

The design and evaluation communication technologies for development, and ICT4D in general, is fundamentally different from the design and evaluation of telco-oriented real-time communications based on the traditional abstractions described in Chapter 2. That is not to say that OSI and QoS are not applicable to ICT4D. Rather, OSI and QoS are applicable to low level networking aspects of ICT4D in a limited fashion. ICT4D systems have technical, environmental and cultural factors that are significantly different from the Western developed region scenarios where OSI and QoS are perfectly applicable. In the technical space, the design of ICT4D systems tend to be dominated by network and HCI perspectives within computer science to deal with noteworthy ICT4D challenges such as intermittent power and illiteracy, respectively. Evaluation of ICT4D communication systems from a computer science perspective is still influenced by QoS-oriented methods although recognition of social and environmental factors is widely acknowledged. Perspectives from information systems and development studies are much more open to the inclusion of social factors in the evaluation of ICT4D interventions. In fact, representative lessons learnt have much more to do with social considerations than technical ones. It follows that we need to learn how to formally integrate awareness of the social aspects of ICT4D into the design and evaluation of communication technologies for development.

Chapter 4: Research questions

I walk down the same street.

There is a deep hole in the sidewalk.

I walk around it.

Portia Nelson

Significant gaps in the design and evaluation of communication technologies for development emerge from the previous two chapters on related work. This chapter describes these gaps in order to frame the research question for our enquiry. Section 4.1 argues that traditional design and evaluation abstractions are often inappropriate in an ICT4D context because of the associated technical, environmental and cultural challenges. Furthermore, when social factors are acknowledged and addressed, computer science-oriented responses to those challenges are often couched in a mindset still attached to those traditional abstractions. Therefore, efforts to align social and technical factors are reported as lessons learnt rather than as new abstractions on which to design and evaluate ICT4D communications. Perspectives from information systems and development studies offer complementary holistic approaches to the alignment of technical and social factors in ICT4D design and evaluation. A combination of these perspectives helps to identify gaps in ICT4D design and evaluation for the computer scientist. Sections 4.1.1 and 4.1.2 describe gaps in traditional design and evaluation abstractions, respectively. These gaps help frame the research question in Section 4.2.

4.1 Gaps in the related work

There is more to the design of communication technologies for development than what is provided by the seven-layer OSI stack or the four-layer TCP/IP stack. The traditional design stacks subsume many technical issues, however, socio-cultural, HCI and application-oriented factors of ICT4D are outside the purview of those abstractions. The work of Brewer et al. (2005) identifies four key components of ICT4D systems: power, network, device and user interface. OSI and TCP/IP are only applicable to the network component. Section 4.1.1 argues the need for a more holistic design abstraction that includes technical, social and environmental factors. In a similar fashion, traditional QoS evaluation of the network component is tightly coupled to a user's expectation of technical network performance.

However, as for design, there is more to ICT4D communication system evaluation than latency, jitter and packet loss. Social rather than user or technical issues significantly affect the take-up of communication technologies in a given digital divides. Furthermore, real-time communication associated with QoS is neither always needed nor feasible. Section 4.1.2 argues the need for a new evaluation abstraction to include these ICT4D-specific factors.

4.1.1 Gaps in ICT4D design

Traditional design abstractions and approaches are often inappropriate for ICT4D because OSI and TCP/IP design stacks exclude the user and application spaces. The pervasive network abstractions described in Section 2.1 each contain a layer named 'application'. However, the application layer is a misnomer that more precisely depicts the network API of an application, not the application itself (Douba, 1995). Much more significantly, traditional design stacks do not include a layer for the user or the user's social environment at all. One could argue that the absence of these factors in the abstractions is implicit in the abstractions themselves. For example, the point of a network design model is to abstract the network away from the application and its users. The conceptions of applications, and indeed the conceptions of users and their social environments, are therefore tacit assumptions of the network designer. Heeks (2002) would argue that the communication network and/or application designer would tacitly assume that the technical needs and social environment of the end-user are the same as the designer's. The result almost certainly entails a misalignment between design considerations and ICT4D scenario realities. Heeks (2002) called this the 'design-reality gap'.

Brewer et al. (2005) argued that technologists working in an ICT4D landscape must consider technical, environmental and cultural factors that are foreign to a traditional technology mindset. Thus, network design has to address unreliable power and intermittent connectivity. Application design has to accommodate the illiteracy of users with special attention to devices and the user interface. Those four aspects comprise the 'Big 4': power, network, device and user interface. Brewer et al. (2005) did not proffer the 'Big 4' as an explicit design stack like OSI and TCP/IP. However, when viewed as a stack (as shown in Figure 3-1), the 'Big 4' also implies the inclusion of application and user factors.

For computer scientists like Best (2003), Brewer et al. (2005, 2006), Donner et al. (2008), Marsden (2008), Pentland et al. (2004) and Toyama and Dias (2008), however, technological assumptions are contextualised within the socio-economic realities of ICT4D. There are many notable efforts within the computer science literature to address these issues: ICTD conferences, workshops at ACM CHI and DIS conferences, journals like ITID (Information Technologies and International Development) from MIT, and a special issue of IEEE Computer (Toyama & Dias, 2008). In particular, much HCI-oriented ICT4D research explicitly states that traditional HCI approaches need to be modified in order to fit the ICT4D context (Dray & Siegel, 2003; Kam et al., 2006, 2007a; Maunder et al., 2007). Overall, ICT4D-specific design considerations are typically portrayed in the literature as lists of lessons learnt and/or recommendations that could easily be classified into bridges.org's RA/RI criteria categories. However, these lessons have thus far not been formally factored into a design abstraction for computer scientists working in the ICT4D domain. Because evaluation abstractions are implicitly tied to design abstractions, a similar situation holds for ICT4D evaluation from a computer science point of view.

4.1.2 Gaps in ICT4D evaluation

Whereas traditional design abstractions suffer from Heeks' (2002) 'design-reality' gaps in an ICT4D context, QoS suffers from corollary 'evaluation-reality' gaps. Section 2.2 showed how traditional QoS is used to objectively evaluate user perception of technical network performance so that communications could be costed accordingly. Designers and evaluators in a traditional networking or telco context tacitly assume performance expectations and social factors. QoS is therefore restricted to the evaluation of real-time voice and video. ICT4D considerations expressly include non-real-time communication networks and applications in all media modalities, including text (Brewer et al., 2005; Pentland et al., 2004). ICT4D applications also require voice and video, yet both are quite demanding of bandwidth. The validity of the traditional QoS mindset has been called into question in both ICT4D settings (Purbo, 2004a, 2004b) and non-ICT4D settings (Bouch et al., 2000) because allocating more bandwidth is avoiding the problem rather than solving it. In ICT4D settings particularly, more bandwidth is a scarce commodity and even less of a solution. Therefore, objective evaluation of ICT4D networks and their applications is torn between traditional QoS

evaluation where appropriate, like measuring packet loss (Sheth et al., 2007), and measuring what users actually do with a given system, e.g. how they use the Internet (Du et al., 2006). Thus, where QoS is fundamentally user-centric and technical, the ICT4D context requires more social evaluation.

The HCI-oriented ICT4D literature makes it clear that social factors are very difficult to manage (Brewer et al., 2005, 2006; Donner et al., 2008; Dray & Siegel, 2003; Dray et al. 2003; Kam et al., 2006, 2007a, 2007b; Marsden, 2003, 2008; Maunder et al., 2007; Medhi 2007; Medhi & Toyama, 2007). It appears that the social, environmental and technical challenges are more difficult with the interface and device components of the 'Big 4' than the network and power components. The nascent HCI-oriented workshops on ICT4D confirm that the social aspects of interface design and evaluation are very difficult and remain open problems for the research community (Deardon et al., 2007; Thomas et al., 2008a, 2008b). Again, the literature often reports results as lessons learnt rather than as a new framework or abstraction for dealing with these social challenges.

4.2 Research question

We have argued that the use of traditional abstractions and methods in an ICT4D context are tacitly value-laden and consequently perpetuate 'design-reality' and 'evaluation-reality' gaps. Such gaps hinder traditionally trained computer scientists no matter how well intentioned in an ICT4D context. The limitations of traditional abstractions and their methods are reflected in the disproportionate number of failed or partially failed ICT4D projects, especially in South Africa, as described in Chapter 1. Many ICT interventions may work technically yet not be appropriated, e.g. the PCs and Internet connectivity often functioned properly at failed telecentres. We would argue that the telecentre designer(s) did not align the technical deployment with the target social environment because of tacit assumptions about how a telecentre should function instead of how it would be appropriated by a given target community. In stark contrast to such scenarios, cell phone connectivity has been quite successful in both South Africa and other ICT4D environments. Thus, cellular communication technology appears to have achieved alignment between technical and social realities. Our goal is to learn how to achieve similar success in aligning technical and social realities in the communication technology for development context. Therefore, the gaps in the work related

to design and evaluation abstractions in an ICT4D context lead towards a single challenging and relevant research question in the field of computer science:

How can we align social factors with technical factors in the design and evaluation of communication networks and their applications in an ICT4D context?

Several secondary research questions are embedded in this central pursuit, and emerge directly from the gaps identified above:

- How can we conceptualise a network design stack that holistically includes technical, environment and socio-cultural factors inherent to ICT4D communication?
- How do we include the users and their social context into such a design stack?
- What would a corresponding evaluation abstraction look like?
- How can a socially aware evaluation abstraction include both social issues and non-QoS type media and temporal modalities?
- What methods would the use of such socially aware abstractions require?

4.3 Chapter Summary

This chapter identified significant gaps in the work related to communication system design and evaluation in an ICT4D context. Firstly, both people and communication applications are missing from traditional design stacks. Secondly, the socio-cultural factors in ICT4D environments are tacitly ignored by both traditional design and evaluation abstractions. Finally, traditional QoS ignore both non-real-time communication and text. These gaps are evidence that computer scientists, even those trained in developing countries, do not possess adequate design and evaluation abstractions for successful ICT4D interventions. Furthermore, communication systems designed and evaluated with traditional abstractions could fail even if they work perfectly well. Conversely, imperfect systems such as cellular communication technologies have been appropriated very effectively within ICT4D situations. These considerations frame the research questions. The next chapter conveys the methodology used to address that research question.

Chapter 5: Methodology

I walk down another street.

Portia Nelson

This chapter describes the methodological approach and experimental design employed to answer our research question. Section 5.1 motivates for a post-positivist and qualitative approach to experimental computer science. This somewhat controversial approach to computer science leads us to pursue the 'dual imperatives' of action research: to craft communication bridges over a given digital divide for a target community while simultaneously generating novel and useful knowledge for the field of computer science. Section 5.2 discusses the mechanics of action research and argues for its scientific merit and applicability to the ICT4D context. Later, in Section 8.3 we will make the case for a socially aware software engineering approach that utilises action research. We carried out two field studies guided by this socially aware method. Section 5.3 addresses the pragmatic matters of research design for those field studies, including how the field study communities were chosen and how data was collected. Section 5.4 then discusses ethical considerations related to carrying out the field studies. The longitudinal field studies enabled long-term reflection on the alignment of technical and social factors during the design and evaluation of iterative ICT4D interventions.

5.1 Experimental computer science and situated perspectives

A central tenet of experimental computer science is that hardware and especially software systems are inherently malleable (NAS, 1994). Malleability enables experimentation in controlled settings to ascertain and predict the impact of changes in complex systems. The usual course of events is a measurable and repeatable process of iterative changes and/or enhancements to such systems. Such computer science is therefore empirical in nature and tends to be explored and documented with a variety of objective and quantitative methods (Tichy, 1998). These methods are firmly rooted in the positivist tradition of the scientific method.

For the ICT4D context, social phenomena are just as important, if not more important, than computational phenomena and so the research task becomes more complex. ICT4D yields so much social and computational phenomena that empirical observation is a very

appropriate method to study it. People in a given ICT4D context use communication networks and applications, and people and their social context must be factored into the experimental process to design and evaluate such systems.

Contemporary computing literature on experimental computer science recognises the importance of including users and embraces both qualitative and quantitative methods (Basili & Zelkowitz, 2007; Feitelson, 2007). Basili and Zelkowitz (2007) reflected on the software development activity itself:

> *"because software development is a human-based activity, experimentation must deal with the study of human activities. Experimentation, in this context, involves evaluating quantitative and qualitative data to understand and improve what the development staff does (such as defining requirements, creating solutions to problems, and programming)".*

Following on the discussion of related ICT4D work in Chapter 3, qualitative methods are ideally suited to ICT4D situations. ICT4D research often includes both quantitative and qualitative methods. A natural extension of this combination of quantitative and qualitative methods is the third HCI paradigm, or situated perspectives, as described by Harrison et al. (2007). According to Harrison et al. (2007), the "informal histories of HCI commonly identify two major intellectual waves that have formed the field: the first orienting from engineering and human factors with its focus on optimizing man-machine fit, and the second stemming from cognitive science, with an increased emphasis on theory and on what is happening not only in the computer but, simultaneously, in the human mind". The third paradigm, or situated perspectives, espouses situated methods such as action research (see Section 5.2). Such situated methods are germane to the ICT4D context. Situated methods employed by related ICT4D projects are similar to action research methods from the field of information systems. In both cases, there is collaboration between researcher and community, and the activities are iterative in nature. The overall goal is to align social and technical considerations. A notable method unrelated to ICT4D to accomplish this is Checkland and Schole's (1990) Soft Systems Methodology (SSM) that models human organisations in much the same manner as software

systems in order to achieve a closer parallel between the two: replace business organizations with digital divided communities and, in essence, the goals are very similar.

Even though the iterative action research method lends itself very well to iterative prototyping (see Section 5.2), there are very few examples of action research discussed in the computer science literature other than Avison et al. (1999) and our own publications. This is most likely because action research is post-positivist. Even if action research methods were employed, for example, iterative prototyping informed by community participation and collaboration, the label 'action research' is shunned because results from one particular study cannot be generalised. This controversy is discussed in Section 5.2.3. For now, suffice to say that in ICT4D the researcher is inherently immersed in the field and cannot avoid including both users and their social issues in the design and evaluation processes.

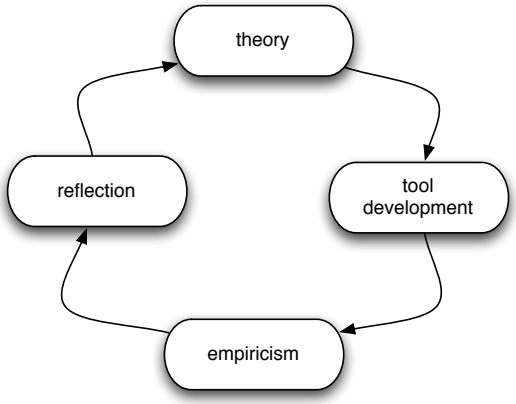

Figure 5-1 Experimental computer science with situated critical reflection

Basili and Zelkowitz (2007) argued that empiricism and experimentation complement theory formation and tool development within computer science. To this we add a step of critical reflection so that experimental and empirical results may inform subsequent iterations of theory evolution and tool development.

Action research, particularly in an ICT4D context, can make use of quantitative methods when appropriate, but the emphasis is on qualitative enquiry because the goal is to change actual communities and not conduct controlled laboratory experiments. Action research combines the efforts and reflection of both community participants and technical researchers within a context of iterative interventions with and for the community. It would appear that experimental computer science enhanced with situated perspectives leads to action research as an ideal approach from which to explore ICT4D concerns for both praxis and

theoretical gain. Within this context, "any future advances in the computing sciences require that empiricism takes its place alongside theory formation and tool development" (Basili & Zelkowitz, 2007). Figure 5-1 illustrates the compatibility between experimental computer science and situated critical reflection inherent to action research.

5.2 Action research

Action research is a qualitative method that affords a great deal of interaction between researcher and community. The method is primarily intended to inform and achieve organization and social change (Avison et al., 2001). The fundamental principles of action research are the 'dual imperatives' concerning the parallel pursuit of academic and community goals. The 'dual imperatives' are described in Section 5.2.1. Iterative cycles of carefully prescribed stages are used to carry out these imperatives. The stages are described in Section 5.2.2. The knowledge gained from performing action research is limited to the community where interventions are performed. Section 5.2.3 argues for the scientific validity of action research with respect to positivism.

5.2.1 The dual imperatives of action research

According to McKay and Marshall (2001), the 'dual imperatives' of action research are to address the actual problem at hand, owned by community participants, and the research enquiry, owned by the researcher. Action research prescribes iterative interventions such that there are two simultaneously interlinked cycles: one a solution to a community problem and the other to generate new knowledge for the research community. For McKay and Marshall (2001), the parallel efforts distinguish the research effort from consultancy to solve a community problem. This forces the action researcher to clearly define what the research enquiry is about, and not just report on how a particular problem is solved. The underlying goal of the dual imperatives, then, is to align the research effort with the underlying community need for change. Avison et al. (2001) called this the 'double challenge'. Baskerville (1999) commented that many action research projects are criticized for either being too much praxis and not enough research, or vice versa. A balance is difficult to achieve.

5.2.2 Stages and iterative cycles of action research

Susman and Evered (1978) defined the contemporary cyclical process of action research and its stages, as depicted in Figure 5-2. Action research cycles take place within the context of a mutually agreed client-system infrastructure, or research environment. The initial stage diagnoses the problem. Then an intervention is planned. The plan is implemented in the community, followed by evaluation of the intervention's effects. Finally, the researcher, preferably together with the participants, engages in critical reflection and iterates through the cycle of stages again.

Action research's iterative nature offers a good match to iterative software prototyping techniques (Avison et al., 1999; Baskerville, 1999; Baskerville and Wood-Harper, 1996; Checkland & Scholes, 1990). The stages are also functionally similar to orthodox stages in the software development life cycle (Sommerville 2000). The diagnosis stage is similar to the gathering of user requirements. Plan action is similar to requirements analysis followed by high level and low-level design. Implement action is functionally equivalent to coding and deploying a software artefact. Evaluate action is equivalent to testing a system. Action research adds a stage of reflection. Repeat the action research stages and the entire process resembles the activity of iterative software prototyping.

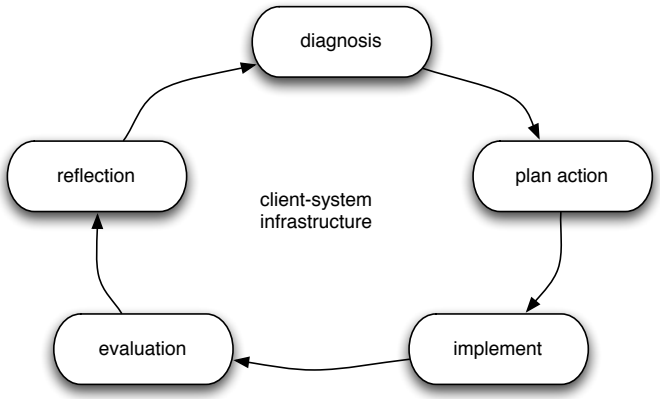

Figure 5-2 Action research cycles

Susman & Evered (1978) defined the fundamental cyclical process of action research. The stages are depicted independently in a directed graph, yet cycles of these stages often overlap. Reflection during the entire process is common, although it is often formalised at the end of a given cycle after evaluation and reflection has been performed.

5.2.3 Scientific validity of action research

> *"Action research is a method that could be described as the paragon of the post-positivist research methods. It is empirical, yet interpretive. It is experimental, yet multi-variate. It is observational, yet interventionist. Enticingly, the research subjects are often quite willing to pay the costs of being studied, especially since they may influence the outcomes of the project. To an arch positivist it should seem very unscientific. To the post-positivist, it seems ideal."*
>
> Baskerville and Wood-Harper (1996)

Social science and natural sciences are based on the empirical tradition and tend to dismiss approaches not based on "the statistical tradition of Pearson, the nomothetic logical positivism of Hempel or the falsifiability of Popper" (Baskerville and Wood-Harper, 1996). These concerns are fundamental and include both philosophical and pragmatic concerns. Action research is therefore controversial in computer science, and this issue cannot be resolved. As a compromise, Checkland and Holwell (1998) argued that action research is valid because it is *recoverable* such that the epistemology is recognisable to other scientists. Repeatability is the basis for the validity of positivist natural science methods. Action research results cannot be repeated, so action research proponents need to be careful about how they phrase validity. Even though action research cannot yield replicability like natural science experiments, action research can be defined such that it is recoverable. This gives action research a 'truth claim' lesser than natural sciences, but more than mere plausibility. However, Checkland and Holwell (1998) felt the bulk of action research literature did not lay out the epistemology methodically enough to make solid claims of validity. This was not a problem with the method but with how the research was documented.

Checkland and Holwell (1998) suggested that there were elements universally applicable to any type of research, be it positivist or post-positivist: a methodology is applied to an area of concern that yields knowledge that can be formulated in a framework. In action research, however, the scientist begins with a set of research themes, as opposed to hypotheses, and having declared a framework and methodology for examining these research themes, enters the 'real world problem situation'. By actively participating in the problem

domain, and allowing residents of that domain to collaborate in the process, interventions enable reflection on the framework and methodology. Reflection leads to scientific findings and feeds back into the research themes for the cycle to continue iteratively (Checkland and Holwell, 1998).

5.2.4 Applicability to ICT4D

Action research has been employed in several ICT4D situations. Tacchi et al. (2003a, 2003b) described a special case of action research called ethnographic action research specifically for ICT4D environments. Averill (2006) also employed ethnographic action research in a rural health study. In South Africa, Byrne (2003, 2004) used a culturally aware participatory approach to action research for a health study on rural children. Ethnographic methods are an alternative to action research, and can also be combined with action research. With respect to this thesis, we did not perform ethnography. However, we feel that action research, with or without ethnography, is particularly well suited to carrying out ICT4D work. Action research calls for interventions in the field to solve community problems and also to generate new knowledge for the ICT4D scientists engaged in such activity. In order to pursue the dual imperatives of action research, we engaged in iterative prototyping with two long-term field studies.

5.3 Experimental design

This section presents an overview of the pragmatic concerns of conducting two field studies that will be analysed in detail in Chapters 6 and 7, respectively. Section 5.3.1 describes why and how the field studies were identified. Section 5.3.2 provides an overview of data collection techniques used. Section 5.4 addresses ethical issues.

5.3.1 Purposive sampling

The field studies were selected because they were characteristic of digital divides found in South Africa. The selection method was purposive sampling because it fostered a "selection of cases with a specific purpose in mind" and was "normally used to select samples for exceptional or atypical populations" (Van Vuuren and Maree, 1999). We had a social agenda to apply technology to bridge various digital divides in South Africa. We also had a technical agenda to explore modern and primarily IP-based networks and their applications. Our

research agenda, as described by the research question in Section 4.2, was to align social and technical factors in the design and evaluation of digital divide communication bridges. Therefore, we identified these field studies because they were compatible with these agendas. A series of chance encounters established a network of research relationships that gave rise to both field studies.

We became aware of a local Deaf telephony project at a conference presentation on the Teldem trials by Glaser (2000). A subsequent work-oriented encounter with Glaser resulted in initial ideas about using IP networks to construct communication bridges for Deaf people with the Teldem (Glaser & Tucker, 2001). Later, Glaser assumed the role of intermediary to a specific local Deaf community and became a frequent co-author of research publications (described below in Sections 5.4.2 and 5.4.4, respectively). Chapter 6 analyses the Deaf telephony field study, and Appendix A chronicles its action research cycles.

The novel Softbridge framework (to be described in Chapter 8) initially grew out of the Deaf telephony field study. The emergent socially aware framework inspired us to explore its applicability in a completely different application arena. The intention was not to establish replicability. Rather, we wanted to make the framework recoverable and use the same epistemology as described in Section 5.2.3. Deployment and documentation of our proposed novel framework in two independent field studies, in light of related work, would strengthen the epistemological presentation for other computer scientists working in the ICT4D domain. A second field study would also allow us to abstract similarities between the two. Technically, the Deaf telephony bridges we built throughout the field study were based on VoIP and other IP technologies. Therefore, we actively searched for another digital divide that could also exploit VoIP for social benefit, particularly because VoIP was illegal at the time in South Africa.

We became aware of a rural tele-consultation project (CSIR, 2002) at another conference. One of our postgraduate students involved (see Section 5.4.3) presented a short talk on the desire to demonstrate to the South African government that VoIP should be legalised to overcome digital divide bridges (Chetty, 2003). Subsequent discussion led to collaboration with the Centre for Scientific and Industrial Research (CSIR) and the initiation of the rural telehealth field study. Chapter 7 analyses the rural telehealth field study, and Appendix D chronicles its action research cycles.

5.3.2 Data collection

User needs were initially guided by previous ICT4D efforts in both communities. However, the community's agenda for bridging various digital divides eventually became evident by performing iterative action research cycles. The research reported in this thesis employed both qualitative and quantitative data collection methods. For the most part, action research was conducted with actual communities and not in a computer science laboratory. Therefore, we engaged community participants in an iterative series of ICT4D interventions. Each action research cycle correlated to the design and evaluation of a specific prototype. Thus, the documentation of the action research cycles constitutes the primary source of data for the research and should be read in conjunction with the fieldwork chapters. Appendices A and D contain a complete breakdown of the action research cycles and stages for both field studies.

Action research data was collected with notes on observations in the field, interactions with stakeholders, semi-structured interviews and focus group sessions, as suggested by several sources, e.g. Babbie and Mouton (2001) and Hildrum and Strand (2007). Semi-structured interviews were based on a schedule of topics that were prepared in advance. Focus groups were conducted on particular topics, e.g. a specific prototype. These interactions were sometimes recorded and transcribed, but the bulk of the data consisted of notes handwritten into notebooks. Interviews and focus group sessions primarily recorded user feedback on experiences with the communication prototypes. The methods for conducting the interviews and focus group sessions differed slightly between the field studies.

For the Deaf telephony project, semi-structured interviews and focus group sessions took place with Deaf participants at the Deaf community centre. English was translated to South African Sign Language (SASL) and back with the use of an interpreter. We did not need to schedule interviews or focus group sessions with Deaf users because we visited them on a weekly basis. We did, however, schedule large meetings well in advance to secure attendance. We also conducted spontaneous debriefing sessions amongst researchers and intermediaries at the community centre.

For the rural telehealth field study, we conducted semi-structured interviews and focus group sessions at specifically scheduled times and venues because we visited the remote field sites infrequently. We scheduled such sessions a week or two in advance of our arrival. The

format of a semi-structured interview typically consisted of a set list of topics encouraging the participants to provide open-ended feedback. A focus group session followed a simple agenda to allow for as much discussion as possible. We also conducted spontaneous debriefing sessions amongst researchers and intermediaries in the field. As will be described in Chapter 7, we often spent between one and three weeks in the field when visiting rural communities.

Quantitative data was collected automatically by instrumenting communication prototypes to collect performance and usage statistics in the spirit of traditional QoS. We were initially interested in measuring latency metrics associated with various aspects of the communication bridges, but later resorted to collecting usage statistics of ICT in general. Qualitative and quantitative data was used to triangulate correlations in the data as shown in Figure 5-3.

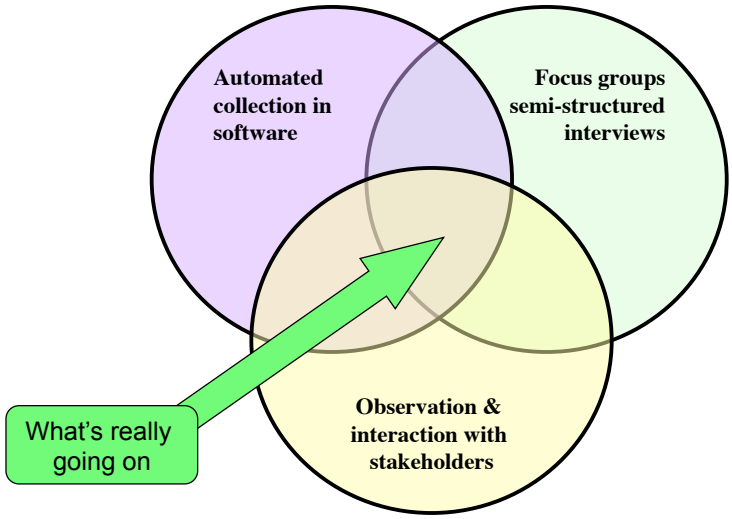

Figure 5-3 Data collection methods and triangulation

We collected data in three ways. Firstly, software prototypes automatically collected quantitative usage statistics. Logs recorded calls, messages, timestamps and delays. Secondly, we conducted focus group sessions and semi-structured interviews with participants. Some of these were digitally recorded, but most were documented by hand. The third data collection method was interaction with stakeholders. We purposefully dedicated much time befriending intermediaries and participants to collect qualitative data. These three data collection methods enabled effective data triangulation to determine what was really happening with the ICT4D interventions.

5.4 Ethical considerations

Several ethical considerations arose given that most of the data collection came from interacting with and observing human participants over the course of the field studies. We also collected quantitative data of participants' usage of the ICT4D prototypes and recorded

their conversations. Section 5.4.1 briefly summarises participant-oriented issues. The rest of this section discusses ethical issues related to the collaborative contributions of others. Section 5.4.2 describes the roles of NGOs and intermediaries. Section 5.4.3 discusses the supervision of postgraduate students and their programming efforts that constituted ICT4D interventions within the field studies. Finally, Section 5.4.4 addresses the issue of co-authored publications.

5.4.1 Ethics clearance considerations

This section summarises the ethnical considerations specified in an UCT-approved ethics clearance for the PhD research (Rybicki, 2005). The field studies comprised non-invasive observation research "involving no risk or interference with the mental or physical integrity of the human being" (MRC, 2006). The risk of harm to the participants was negligible. All research participants signed consent forms emphasising voluntary participation and identity protection (see Appendices C and F, respectively). The identities of interview participants are not included anywhere in this thesis, and the automated collection of prototype metrics did not record the names of end-users, although conversations and usage metrics were logged. A single page describing the project written in English accompanied the consents forms. The Deaf telephony information sheet and consent form are included as Appendices B and C, respectively. An interpreter was used to translate the text into SASL, but we still handed out the information sheet. As noted in Section A.6.4, we also made a graphical depiction of the information sheet (see Figure A-13) for the benefit of illiterate Deaf users. We initially handed out the forms in English as shown in the appendices. In the later cycles, we bulleted the information form (as it changed from prototype to prototype) and had it translated into SASL. The rural telehealth information sheet is included as Appendix E and the accompanying consent form is included as Appendix F. We always handed out these exact forms because the nurses and doctors were educated and spoke English competently. Note that all of the interaction with nurses and doctors was in English unless noted otherwise.

For the Deaf telephony field study, a hired SASL interpreter assisted during semi-structured interviews and focus group sessions. The interpreter had a professional responsibility to maintain confidentiality. During some of the prototype experiments, speech-to-text translation was performed by a member of the research team acting as a relay operator, who was also bound by the same ethical practice. For the rural telehealth field study, some

interviews were conducted in isiXhosa and transcribed into English because we were fortunate enough to have an isiXhosa-speaking student on the project for two years.

A peculiar ethical aspect of the post-positivist methodology employed was that we exercised the notion of 'informed participation' (Hersh & Tucker, 2005) in addition to informed consent. Informed participation recognised the view that the participants were just as much a part of the research process as the researchers and deserved to be informed about the goals and mechanisms of the research process. Informed participation entailed that we told participants exactly why we were conducting the field study, what we were interested in exploring and how we intended to go about the process.

5.4.2 Disclosure of the roles NGOs and intermediaries

We worked with several NGOs and intermediaries in both field studies. In some cases, the NGOs were the community intermediaries. This subsection briefly discusses the relationships and roles of all involved NGOs and intermediaries.

We contracted the services of an NGO called bridges.org to evaluate the field studies externally. Bridges.org authored summary documents (bridges.org, 2003b, 2004b, 2005b) based on a series of workshops conducted with our research group. Bridges.org also accompanied us to the initial rural telehealth site before the rural telehealth field study commenced and produced a critical evaluation of the CSIR efforts (bridges.org, 2004c).

Usually, however, we engaged an NGO as an intermediary to the field site community. For the Deaf telephony project, we worked with the Deaf Community of Cape Town (DCCT), an NGO described in Section 6.2.2. We employed DCCT staff members to manage the computer lab at the community centre and also for SASL interpretation. We also engaged full-time DCCT staff members as research participants because they regularly attended the English literacy courses scheduled to follow our research sessions. There was, however, an intermediary to DCCT. Meryl Glaser was a lecturer at UCT and had a long-standing relationship with DCCT. She was also part of the Telkom Centre of Excellence (CoE) research programme that made possible the conference attendance and subsequent informal meeting described in Section 5.3.1. Later, Glaser left UCT and joined another Deaf NGO called Sign Language Education & Development (SLED, www.sled.org.za). We hired Glaser as a consultant on the project and co-authored research papers together (see Section 5.4.4).

For the rural telehealth project, a CSIR telehealth research group invited us to the initial field site and thus became our intermediaries to the rural communities there. The CSIR also invited us into an IDRC funding umbrella for a larger wireless networks project that came to be known as First Mile/First Inch (FMFI) project (www.fmfi.org.za). After more than a year at the initial site, the CSIR team asked us to leave their site (see Section D.2.4) and we moved to a second site where we engaged members of an NGO called Transcape (www.transcape.org.za) as intermediaries to the communities at the new location. We contracted Transcape to perform on site network and PC maintenance and computer training. Recently, the primary technical support and trainer from Transcape formed a closed corporation (CC) and we migrated financing to the CC because Transcape had determined that the telehealth project was beyond the scope of their responsibility.

5.4.3 Disclosure of the role of postgraduate students

All of the communication prototypes discussed in the remainder of the thesis were coded by postgraduate students under direct supervision of the author at the University of the Western Cape (UWC) or co-supervised at other universities. Students and their prototypes also collected some of the data as described in Section 5.3.2. Each prototype was tied to a specific action research cycle. Therefore, a cycle's summary table in an appendix identifies who coded a given prototype. It must be stressed that the prototypes were neither the main subject matter nor the contributions of this thesis. The prototypes were designed, deployed and evaluated under the guidance of the novel framework contributed by this thesis. None of the postgraduate students contributed directly to the definition of the framework, but the framework did emerge from the action research cycles that included student participation. The same relationship applied to the graduates that were later hired as full-time programmers on the project. It should also be noted that much of the software referred to herein is freely available at http://softbridges.uwc.ac.za.

5.4.4 Co-authored publications

It follows that any publication concerning the technical details of a specific prototype was co-authored with the coder as first author. Such publications are noted in the overview table for each action research cycle in the appendices. These papers convey implementation details beyond the scope of this thesis. However, the evolving socially aware framework

fundamentally informed those implementations. This thesis also references papers co-authored with research collaborators. For example, several Deaf telephony papers were co-authored with Meryl Glaser where the thesis author's contribution primarily concerned the technical aspects of Deaf telephony and her contribution primarily concerned social aspects, e.g. literacy of the Deaf community. Some papers offer limited and incomplete snapshots of the novel framework described in this thesis, e.g. Tucker et al. (2004) and Blake and Tucker (2006a, 2006b). None of those papers present the component abstractions in their entirety as they are described herein. In all such co-authored papers, the thesis author primarily provided material concerning framework components and the field studies' context and prototypes. Lastly, all bridges.org reports were authored solely by bridges.org and are available online at www.bridges.org.

One further point of interest regarding co-authored publications is the use of the word 'Softbridge'. Because the Softbridge framework components evolved over a period of seven years, we used the word in different ways at different times. Originally, the word 'Softbridge' was used to name a reference implementation of a Deaf telephony prototype described in Section A.3. Reflection on that prototype gave rise to an abstraction stack at first called Open User Interconnect (Tucker et al., 2004). Later, the word 'Softbridge' started to refer to that abstraction stack and 'a' Softbridge was a reference implementation of that abstraction (Blake and Tucker, 2006b). However, the Softbridge stack was still evolving at that time. This was also the case for QoC, although the name 'QoC' stayed constant from its introduction by Tucker et al. (2004). This thesis represents the definition of the Softbridge framework components based on the reflection on the action research field studies.

5.5 Chapter Summary

This chapter argued that a post-positivist approach to experimental computer science rooted in the third HCI paradigm of situated perspectives (Harrison et al., 2007) is applicable to the challenge of aligning technical and social factors in ICT4D work. The cyclical nature of action research also lends itself well to iterative prototype design and evaluation. Furthermore, the action research method dovetails with the dual technical and social research agendas. Action research could therefore help align the technical, environmental and socio-cultural aspects of ICT4D design and evaluation. This chapter also discussed pragmatic and

ethical considerations of an experimental design based on long-term field studies. We chose and carefully documented two independent field studies in order to achieve recoverability for the resultant Softbridge framework. The chapter also discussed the triangulation of qualitative and quantitative data collection methods. The post-positivist action research approach caused us to adopt 'informed participation' where we hid nothing about the research project from the end-users. The most pressing ethical considerations for the sake of the originality of the thesis, however, lay in disclosing the roles of all collaborators and co-authors. The roles will become more apparent when reading the next two chapters on the two field studies and their respective appendices.

Chapter 6: Deaf telephony field study

I walk down the street.

There is a deep hole in the sidewalk.

I fall in.

I am lost…I am helpless.

It isn't my fault.

It takes forever to find a way out.

Portia Nelson

This chapter reflects on a field study conducted to explore dual action research aims: the ICT empowerment of a disadvantaged Deaf community, and the design and evaluation of ICT4D communication systems built for that community. A long-term series of action research cycles were conducted with members of DCCT, an NGO described in Section 6.2.2. The field study's action research cycles are fully documented in Appendix A. Section 6.1 provides an introduction to Deaf telephony by summarising related technology and its position in developed regions. Section 6.2 characterises a rather different situation for Deaf people in South Africa, particularly for DCCT. Section 6.3 provides an overview of the field study. Appendix A ought to be consulted before proceeding. The remainder of the chapter reflects on the results of the action research cycles. Section 6.4 reviews the technical and social design aspects of communication bridges built for DCCT. Section 6.5 considers the technical and social aspects of evaluating those bridges. Section 6.6 reflects on the methods employed during the field study.

6.1 Introduction to Deaf telephony

Deaf telephony encompasses remote telecommunication by Deaf people with either Deaf or hearing users. A Deaf user cannot use audio, and therefore must use either text or video (for sign language). Text telephony can employ a TTY, or text telephone, such as the Teldem (shown in Figure 6-1). A text telephone plugs directly into the telephone system and enables 2-way text communication in real-time. Some TTYs are mobile. Pagers and cell phones have become more widespread for Deaf users because of their small form factor (Nelson & Underschultz, 2003; Power & Power, 2004). Both paging and SMS are

asynchronous in nature. More recently, Deaf people in developed regions can use PCs for Instant Messaging (IM), email and video conferencing.

Figure 6-1 Teldem text telephone for Deaf people in South Africa

The Teldem is a TTY built and marketed by Telkom in South Africa since 1996. The Teldem has a miniature keyboard and a two-line display. It can run on mains power or batteries. The Teldem connects to the PSTN with an RJ-11 connector just like a telephone. Keystrokes are converted to tones, sent over the phone line, and then converted back into text (a Baudot variant) on a Teldem on the other end. Sender and receiver see the same text at the same time, but the communication is actually half-duplex. This means only one party can type at a time. Deaf users employ a GA (go ahead) protocol to signal when a message is finished so the other person can start typing. Typing time causes conversation delay, but for the most part, communication is synchronous.

Relay systems enable communication between Deaf and hearing people. A text relay converts a Deaf user's text to voice for a hearing user, and back again. A relay operator facilitates text relay with two telephones: a text phone and normal handset. Relays were not common toward the end of the previous century (Bergmeister et al., 1999) and are, at present, only modestly available in developed regions. Figure 6-2 portrays a hypothetical text relay system with the Teldem. Examples of text relay include Typetalk at British Telecom (www.typetalk.org), TalkingText (www.talkingtext.net), AT&T Relay Service (www.consumer.att.com/relay), Australian Communication Exchange's (ACE) National Relay Service (NRS), and Sprint Relay (www.sprintrelayonline.com). Text relay is available on mobile devices, e.g. Vodaphone's service for the Nokia 9210i (www.vodaphone.co.uk) and the Mobile TextPhone (Andersson, 2001). Over the Internet, examples of text relay include services from Sprint and AT&T.

However, Deaf users without text literacy prefer communication in sign language. It is a common misunderstanding that sign language is a finger spelled equivalent of a written language like English. While a given sign language may include some finger spelling, a particular sign language has a unique language-specific syntax and signed vocabulary that comprises manual signs and facial expressions. SASL is one of many sign languages

throughout the world. Of course Deaf people can also learn written languages as a second language but prefer to communicate in sign language.

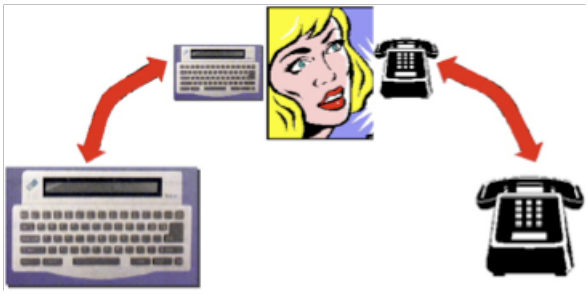

Figure 6-2 Hypothetical Deaf-to-hearing relay with the Teldem

A Deaf person can use a TTY like the Teldem to 'talk' with a hearing user via a relay operator. The Deaf user dials a relay service to request a call to a hearing party. The relay operator has both a Teldem and a telephone. The operator sets up a regular phone connection to the hearing party. Then the operator relays the Deaf user's text to voice for the hearing person on the telephone, and relays the hearing user's voice to text that is sent back to the Deaf user with a TTY.

Many of the companies mentioned above also offer a video relay service (VRS). VRS interprets sign language to voice to enable a Deaf user to communicate in sign language with a hearing user. Internet-based VRS can also make use of IM systems like Skype. Deaf-targeted VRS projects include UmptiDumpti (Verlinden, 2000), Wisdom (Bauer & Kraiss, 2001) and ACE's NRS video trials (Spencer, 2000). The Total Conversation service from Omnitor (www.omnitor.se) combines all of these types of services and is active in promoting ITU standards to this effect. Several other research projects are working sign language into automated parts of the relay, including Visicast (www.visicast.co.uk) with Tessa (Cox et al., 2002), an airport security system (Lancaster et al., 2003), and the commercial service from SignTel (http://signtelinc.com).

In developed regions, landline, cellular and Internet connectivity supporting Deaf telephony technologies are quite common. Both text and video relay services are available and staffed by highly skilled operators. Very few of these components and assumptions hold for Deaf communities in developing regions, particularly in South Africa.

6.2 Field study background

Section 6.2.1 begins the field study background with a characterisation of Deaf people in South Africa in general. Section 6.2.2 addresses DCCT, the community we engaged and its NGO support structures. Section 6.2.3 relates their prior experience with ICT.

6.2.1 Deaf people in South Africa

> *"In the developing world, the vast majority of deaf populations are neither participants in, nor beneficiaries of, the information revolution currently sweeping the world. By contrast, the impact is evidently more positive among deaf populations in developed countries, where computers and the technology necessary to use the Internet are much more affordable and accessible."*
>
> Agboola and Lee (2000)

There are disparate estimates of the size of the Deaf population in South Africa. In 1994, the Central Statistics Service's mid-year estimate suggested that there were 4 million people with hearing impairment in a country of approximately 44 million people: 402,847 'profoundly Deaf', 1,208,539 'extremely hard of hearing' and 2,417,078 'hard of hearing' (SANCD, 1995). Of these, 1,611,386 were thought to use SASL as a first language. However, the 1996 and 2001 national census statistics showed 383,408 and 453,104 'Deaf' people, respectively (STATTSA, 2004). These statistics suggest that the 'profoundly Deaf' group from the 1994 estimates is likely the Deaf community that uses SASL as their preferred language. This is a far higher proportion of the population than found in America or the European Union, possibly because of differences in healthcare and immunization.

The South African Constitution (RSA, 1996) and related legislation such as the Integrated National Disability Strategy (ODP, 1997) sets forth some of the most proactive approaches to access for disabled people in the world. However, much of this sentiment remains at the policy level and implementation lags behind. 30% of all South African Deaf adults are believed to be functionally illiterate as a result of inadequate educational practices (Asmal, 2001; Glaser & Aarons, 2002). The vast majority of Deaf children in South Africa never attend school or attend school at a very late age (Asmal, 2001; Kiyaga & Moores, 2003). Education for Deaf children only became compulsory in 1996 (Aarons & Akach, 2002). About 65% of all Deaf adults are unemployed, and many of those with jobs are under-employed. This impacts negatively on the socio-economic status of the Deaf community. Regrettably, there is a paucity of teachers who are equipped to teach Deaf learners through the medium of SASL. There are also very few sign language interpreters at tertiary level educational institutions (Asmal, 2001). Unfortunately, when limited and expensive telephone

and Internet access conditions in South Africa are combined with poor literacy, ICT skills are difficult to cultivate. Such is the context for the field study described herein.

6.2.2 Deaf Community of Cape Town

This field study engaged a doubly disadvantaged Deaf community in Cape Town. Firstly, the participants are profoundly Deaf and are therefore physiologically precluded from using auditory interfaces to telecommunication applications and devices. Secondly, the participants come from economically and racially disadvantaged backgrounds that render them under-educated and under-employed, caught in an ongoing cycle of poverty. This community is served by an NGO named DCCT, based at the Bastion of the Deaf in Newlands, Cape Town.

DCCT has supported a community of approximately one thousand Deaf people in the Cape Town area since 1987 (Axelrod, 2005). Two socio-cultural factors unite the DCCT community. The first uniting factor is that the Deaf people served by DCCT communicate primarily with SASL. Many also have poor levels of spoken, written and reading literacy in any of the eleven official South African languages that their families may use (Glaser, 2000; Glaser & Aarons, 2002). Table 6-1 illustrates the poor English literacy of a PC-literate Deaf user. The second uniting factor is that the DCCT community is comprised of people from previously disadvantaged ethnicities, mostly coloured[10] and/or black. These two uniting characteristics manifest as inter-related demographics of poverty, unemployment, poor education and illiteracy (Glaser, 2000; Glaser & Aarons, 2002). Therefore, DCCT's services to the Deaf community include a wide range of welfare programs such as group work and community development, a burial fund, job placement and training programs and an HIV/AIDS awareness program. DCCT also has a Deaf awareness program targeted toward the hearing public. Overall, DCCT supports Deaf culture and society within greater Cape Town, maintains relationships to other Deaf organizations in the area, the country and the rest of the world.

[10] The term 'coloured' was designated during South Africa's apartheid era. A common misunderstanding is that coloured people are solely the product of mixed race relations. While this is often the case, the term applies primarily to descendants of Malaysian and Indonesian slaves and indigenous South African peoples from the early days of South African colonisation. Their mother tongue is usually Afrikaans (Venter, 1974).

Ok, i want to knw. Where did bastion number? I still stress with work.
I still busy from overseas. I need email with files (docment). It is
very impartant. It's difficult for pc or laptop!

Table 6-1 Example of poor English literacy with a Deaf participant

This email excerpt characterises the type of English that a Deaf person might use. It is clear that the Deaf person possesses some knowledge of English, but may be struggling with an attempt to directly translate sign language into English and/or the use of second language English.

For the remainder of this chapter and Appendix A, we must distinguish between DCCT managers, staff and members. DCCT managers sanctioned the ICT interventions by the research team. They also helped coordinate the schedule and provided some financial support for the project. Note that DCCT managers are Deaf as their preferred language is SASL, but they can also speak and hear with hearing aids. Deaf DCCT staff members perform various jobs for the NGO, and were consequently on site to participate in the technology research trials. Our weekly visits were most often with these two groups: DCCT managers to discuss the overall management of the project, and DCCT staff for feedback on our technology initiatives. A third group, the DCCT community, were users of the PC lab and often participants in the technology trials. We hired the services of one of the DCCT managers as a sign language interpreter for communication with the other two groups. We also hired several DCCT staff to manage the PC lab during the day.

6.2.3 DCCT's initial encounters with Deaf telephony

DCCT was involved with two Deaf telephony studies prior to the one described in this chapter. The first was a trial of the Teldem TTY (Glaser, 2000) and the second was a trial of a video relay service (Ngubane, 2002). Both studies involved technology that was intended to serve the greater South African Deaf community. Unfortunately, both trials ended up with the technology unused. Use of the Teldem petered out when free services were no longer provided. Furthermore, no one had provided a relay service with the Teldem like the one depicted in Figure 6-2. The second study was a video relay service called TISSA (Telephone Interpreting Services for South Africa). TISSA provided remote telephonic interpretation services for all eleven official South African languages as well as SASL (Ngubane, 2002). Sign language relay was accomplished with ISDN (Integrated Services Digital Network) videophones: one in the Bastion of the Deaf and the other with a remote interpreter. The Deaf and hearing communicants had to be co-located in front of the video terminal at the Bastion of

the Deaf to receive interpretation services from an interpreter over the ISDN video connection. Unfortunately, after the pilot, TISSA support for SASL was not continued while the official eleven languages were (van der Merwe, 2005). Both Teldem and TISSA pilot field studies revealed much about how both technical and social issues combined to contribute to failure of these services within DCCT, even though similar services had been very successful elsewhere in developed regions as described in Section 6.1.

Alternatively, text-based SMS with cellular handsets has been fairly successful with Deaf South Africans who use a second or third language, such as English and Afrikaans, for mobile texting. Rapid SMS exchanges approximate semi-synchronous communication, but in reality, SMS is functionally asynchronous and unreliable. One cannot really know if the other party has actually read a message or not, only that the message had been 'delivered'. SMS is very useful, but it is not applicable to all situations, particularly where synchronous, acknowledged communication is required. In addition, SMS is not appropriate for more formal communication requirements (Tucker et al., 2003a). An explanation for the popularity of SMS, despite its clumsy nature, is the socio-cultural context in which texting becomes relevant to people's lives (Sun, 2003; Power & Power, 2004). This is particularly evident in the South African Deaf community, where these days almost every Deaf person has access to a cell phone and uses SMS on a regular basis.

6.3 Field study overview

The field study had four distinct phases shown in Figure 6-3. Each phase produced multiple prototypes where each prototype was associated to an action research cycle. The action research cycles are documented in Appendix A, and sections/cycles in the appendix are frequently cross-referenced herein. A timeline of the field study is shown in Table 6-2. The Telgo phase involved semi-automated text relay from a Deaf user on a Teldem to a hearing user on a phone with text-to-speech (TTS) (see Cycles A.1-A.2). The Softbridge[11] phase provided fully automated text relay between a Deaf user with an IM client on a PC and a hearing user with a similar PC-based client using freely available TTS and automatic speech recognition (ASR) (see Cycles A.3-A.4). One such Softbridge prototype was tested with a

[11] Note that in this instance, the word 'Softbridge' refers to the nascent design stack abstraction and also to its reference implementation.

single Deaf user (Tucker et al., 2003b). The SIMBA (Softbridge Instant Messaging Bridging Architecture) phase was to a semi-automated relay with a human relay operator to convert speech to text (see Cycles A.5-A.7). The final phase targeted Deaf-to-Deaf communication with synchronous text prototypes followed by a semi-synchronous approach to video sign language communication (see Cycles A.8-A.9). We also explored a gesture recognition interface for the semi-synchronous video tool in order to provide hands-free operation. All four phases were conducted with DCCT participants. However, the final phase also included another Deaf NGO called SLED. Most of the SLED staff is also Deaf. However, SLED's Deaf staff had the benefit of work experience and in-service training. Consequently, their English and ICT literacy are more advanced than DCCT members.

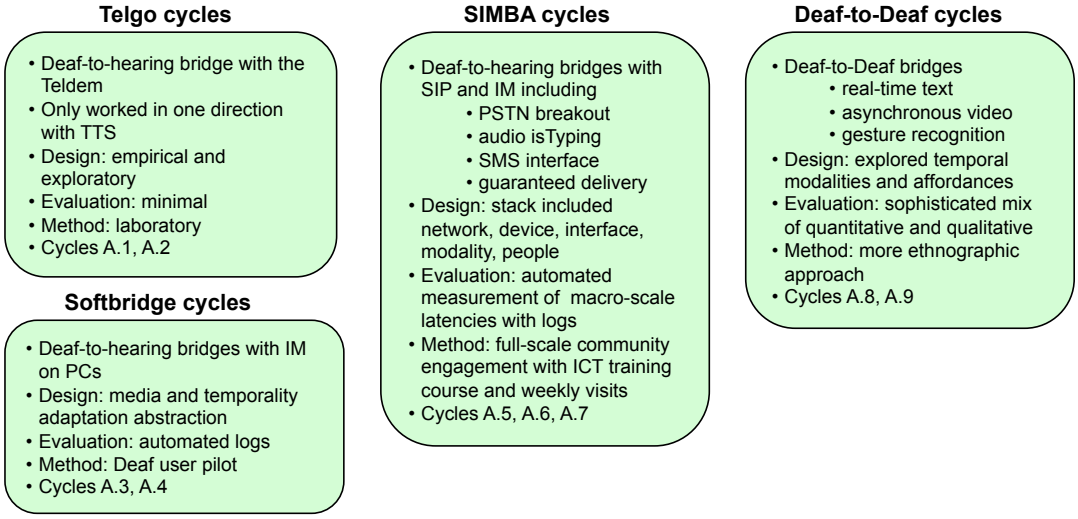

Figure 6-3 Deaf telephony field study phases

The Deaf telephony action research cycles described in detail in Appendix A can be grouped into several phases: the Telgo phase explored relay with a Teldem device; the Softbridge phase initiated IM-based relay; the SIMBA phase provided IM-based relay with a human relay operator and PSTN breakout; and the Deaf-to-Deaf phase concentrated on text and sign language communication between Deaf participants. Each phase is characterised by its central aims and salient design, evaluation and method issues. The constituent cycles are also identified for each phase.

The communication scenario for DCCT members characterised a digital divide that provided impetus for an innovative abstraction to design ICT4D bridges. Components of the innovative socially aware Softbridge framework initially emerged from early Deaf telephony prototypes. The rural telehealth field study prototypes described in Chapter 7 also influenced development of the Softbridge framework, as the action research cycles in both field studies were concurrent and influenced each other in profound ways. The rest of this chapter

addresses the three components of the Softbridge framework with respect to the Deaf telephony field study. Section 6.4 reflects on technical design issues, Section 6.5 reflects on the evaluation of the Deaf telephony prototypes, and Section 6.6 reflects on overall methodological issues. Appendix A is considered required reading before proceeding.

2002	Semi-automated text relay systems in the laboratory (Cycles A.1, A.2 and A.3)
2003	Testing a fully automated text relay system with a Deaf user (Cycle A.4)
2004	Introduction of PCs to DCCT, and ICT literacy course for Deaf people (Cycle A.5)
2005	SIMBA semi-automated relay experiments (Cycles A.5, A.6 and A.7)
2006	Shift from Deaf-to-hearing to Deaf-to-Deaf communication systems (Cycle A.8)
2007-8	Synchronous and asynchronous video to support sign language (Cycle A.9)

Table 6-2 Deaf telephony field study timeline

The Deaf telephony field study unfolded over seven years. Details are provided in the identified appendix sections/cycles. All activities took place with DCCT participants, mostly at the Bastion. We proceeded through a series of Deaf telephony prototypes, moving from fully and semi-automated text relay systems to real-time and asynchronous text and video communications dedicated to Deaf-to-Deaf communication.

6.4 Design of Deaf communication bridges

This section reflects on technology design issues that emerged from the Deaf telephony field study. The text relay prototypes from the Telgo, Softbridge and SIMBA phases shown in Figure 6-3 had compelling modality considerations. Text relay required adaptation between media modalities, e.g. text to voice and vice versa, and injected macro, or large-scale, latencies into an otherwise synchronous exchange. That entailed a combination of both synchronous and asynchronous temporalities. Relay prototypes also had to provide user interface mechanisms individually tailored for both Deaf and hearing users. Figure 6-4 depicts the media and temporality adaptation for a text relay scenario. The Deaf-to-Deaf prototypes also yielded intriguing temporality considerations, albeit without media adaptation. Thus, all Deaf telephony prototypes aimed to provide semi-synchronous communication. The media and temporality considerations also had significant implications for evaluation and will be discussed in Section 6.5.

These media and temporality adaptation considerations caused us to expand on the 'Big 4' discussed in Section 3.1. Recall that the 'Big 4' shown in Figure 3-1 included power, network, device and user interface. The adaptation needs of the Deaf telephony prototypes

compelled us to add a modality layer to this 'stack'. Media and temporality modalities were so central to the Deaf telephony prototypes that we eventually separated that single modality layer into two: one for media modalities and one for temporal modalities. After including a layer for people, the resultant stack for text relay between Deaf and hearing users is shown in Figure 6-5. We now call this the Softbridge stack. The rest of this section analyses these layers with respect to the field study action research cycles and accompanying prototypes.

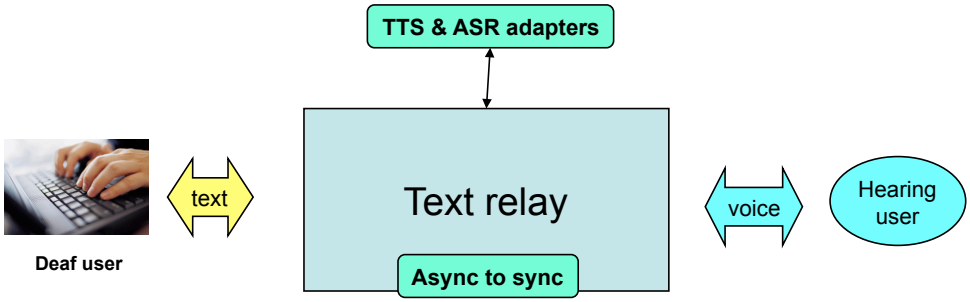

Figure 6-4 Media and temporality adaptation for text relay

A text relay service provides media adaptation between a Deaf user's text and voice for the hearing user with TTS and ASR adapters. When the Deaf user presses the Return key to send a text message, the transfer is asynchronous. Voice is relayed to and from the hearing user in real-time. Thus, temporality adaptation is also provided by the text relay service.

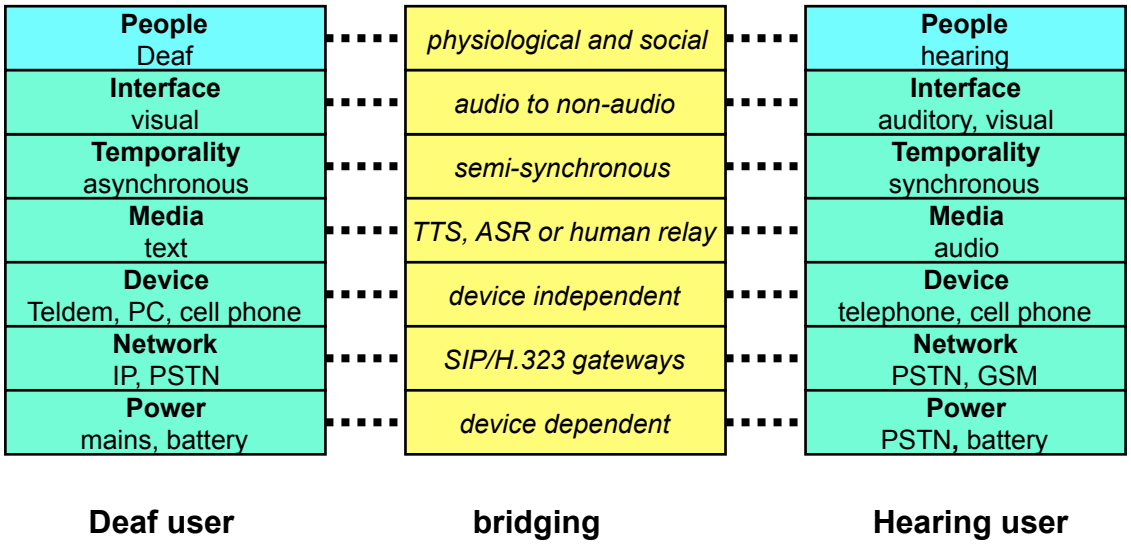

Figure 6-5 Deaf relay design layers

Text relay prototypes demonstrate bridging in multiple ways. This diagram shows bridging at the seven layers that comprise the Softbridge design stack described in Section 8.1. Text relay connects a Deaf user to a hearing user with a variety of devices powered in different ways. Those devices are connected to a variety of networks, and various gateways bridge exchanges between them. The devices also support different types of interfaces, and interfaces are very different between Deaf and hearing users. Text relay introduces significant latency as text is converted into voice and vice versa. Further delay arises from type time. Thus, the overall exchange is semi-synchronous and therefore requires temporality adaptation.

6.4.1 Power

Power considerations for all Deaf telephony prototypes were entirely device-dependent. Initial Telgo cycles (Cycles A.1-A.2) used a Teldem that usually ran on mains power, although it could also run on batteries. The PCs for those cycles were deployed as PSTN gateways that also ran on mains power. Later, the Softbridge (Cycles A.3-A.4) and SIMBA (Cycles A.5-A.7) prototypes ran entirely on PCs. Public utilities in Cape Town rival that of most developed regions. Although South Africa had seen some outages over the past several years (see www.eskom.co.za), grid power is usually reliable so we did not explicitly design prototypes to handle those infrequent outages[12]. The PSTN side of the Deaf telephony bridges provided its own power to telephone handsets. A hearing user's cellular phone, on the other hand, had its own battery.

Most Deaf participants used SMS on a regular basis. To take advantage of that, we provided an SMS interface (Cycle A.7). During Cycle A.8, we encouraged Deaf participants to use MXit, Fring and Gmail over GPRS/3G on their cell phones. The power consumption for GPRS was significant, e.g. causing a four-day charge cycle to be reduced to one day or even a few hours. We had expected excessive power consumption of 2.5G and 3G to inhibit to the take up of data services, but the Deaf participants did not mention it at all during focus group data collection. WiFi drained cell phone batteries much less, so we provided WiFi connectivity in the Bastion. However, most Deaf users' cell phones had no WiFi capability and they just used the PCs for IM, email and Internet instead of their phones[13].

6.4.2 Network

Network protocol standards like 802.11bg (WiFi) and SIP (Session Initiation Protocol) (Handley et al., 1999) were central to the design of all Deaf telephony prototypes. All relay prototypes (Cycles A.1-A.7) required bridging between a variety of networks, including ADSL, Ethernet, WiFi, GSM, GPRS, 3G and PSTN. The most prevalent gateway was between IP and PSTN/GSM networks. We experimented with both the H.323 (Cycles A.1 and

[12] We did not install UPS systems because of poor price-performance determined by our experience in the Eastern Cape (see Cycle D.1) as well as with related work (see Section 3.1).

[13] We provided a WiFi-enabled phone to the Deaf technical support team to try out advanced technology that they could not afford.

A.3-A.4), and SIP (Cycles A.2 and A.5-A.7) gateways. We eventually settled on Asterisk (www.asterisk.org), an open source PBX (Private Branch eXchange). We designed all Deaf telephony prototypes with network protocol standards like SIP and FTP (File Transfer Protocol). IP-based entities, as opposed to PSTN-based, allowed us to easily add functionality such as media and temporality adaptation. We could also customise SIP clients on any device that supported a standard SIP stack and conversely customise SIP servers to use standard SIP clients. SIMBA prototypes (Cycles A.5-A.6) used open source SIP IM from NIST (National Institute of Standards and Technology). We also commandeered SIP for unorthodox real-time delivery of text (see Cycle A.8). Overall, the empirical evidence from using network standards and open source software demonstrated that many forms of network bridging at OSI layers 1 through 4 were easily attained with some software tweaking. Furthermore, we could make such modifications on a variety of devices.

6.4.3 Device

The action research cycles described in Appendix A produced Deaf telephony bridges between a variety of end-user devices: Teldem, PC, telephone, and cell phone. Bridges between devices were accomplished by modifying IP-based components. Sometimes, those modified components were resident on a given device, but they could also run off-device. Standard off-the-shelf clients could connect to modified servers with standard network protocols. Thus, devices could also be 'fooled' into interacting with non-native media and temporal modalities. Media adaptation services were typically not resident on a given end-user device. Temporality bridges were also coded off-device. Telgo prototypes (Cycles A.1 and A.2) bridged a Teldem and a telephone using H.323 and SIP gateways, respectively. Both prototypes used off-device IP-based modifications to provide relay functionality, e.g. Telgo323 put the TTS engine in the H.323 ISDN gateway because we could not modify a Teldem or a telephone (see Cycle A.1). Rather, we connected the PSTN device to an IP network via gateways and accomplished the bridging within the IP space. On the other hand, prototype clients were easily modified on a PC. The Softbridge and SIMBA prototypes used PC-based clients (see Cycles A.3-A.7). The hearing client was a soft phone, or VoIP client, running on a PC while the Deaf client was an IM client. In either case, we could code a client

ourselves or use a standard client unmodified because the adaptation services, both media and temporality, were performed elsewhere.

Based on the Deaf participants' use of and feedback on video conferencing during Cycle A.9, both external and built-in web cams were rarely conducive to sign language communication in real-time. We experimented with a range of web cams and video applications on the PC, starting with low-end web cams to determine the most affordable options. However, we were forced to upgrade to achieve sufficient resolution and frame rate. With synchronous video applications, Deaf participants were frustrated that smaller video windows gave better image quality because they wanted full screen video. Asynchronous video allowed larger video images with acceptable visual quality (see Cycle A.9). Lastly, the physical mounts of the web cams were designed to place the subject's face in field of view, not the upper body that was necessary for sign language communication. Over the course of the action research cycles, it became clear that commonly available devices were simply not designed for universal usage (see www.universaldesign.com). We did not attempt to build video prototypes on a cell phone because even when a cell phone had a video conferencing camera on the front, it was only Common Intermediate Format (CIF) and was too low resolution. Cameras on the backside of a cell phone were much higher quality, but a signing user required the video camera on the same side as the display so as to sign and see the other person at the same time. Software development kits for cell phones were also particularly limited for the SIP libraries that we wanted to use in order to protect cellular provider revenues[14]. Overall, the cell phone was an ideal device for Deaf users, but the physical and software characteristics made it very difficult to manipulate.

6.4.4 Media

Relay prototypes performed two forms of media bridging: text-to-speech and speech-to-text. We did not attempt any form of video-based SASL conversion. Fully automated prototypes (see Cycles A.3 and A.4) used Festival and Sphinx open source engines for TTS and ASR, respectively. One motivation for full automation was to provide confidentiality to the Deaf user so that a third party was not privy to the conversation. Another motivation was

[14] VoIP calls 'stole' revenue from cellular providers, as did video over Internet. Thus, real-time libraries on cell phones were often 'closed' and/or notoriously difficult to program.

to reduce the cost of the service by not employing a human interpreter. However, ASR performed so poorly during Cycles A.3 and A.4 that we were compelled to use a human relay operator to convert speech to text (see Cycle A.5). The use of the human relay operator obviated both motivations for a fully automated relay, yet it pointed toward a semi-automated solution involving SASL. An overriding design goal was to encapsulate the TTS and ASR functionality so that either could easily be replaced with alternative solutions. We wrapped TTS and ASR engines as web services. SIMBA (see Cycle A.5) also wrapped the human relay operator interface as a web service. Thus, the same web service API could accommodate any ASR tool should we decide to use a different one.

Deaf-to-Deaf prototypes were homogenous, either text-to-text (see Cycle A.8) or video-to-video (see Cycle A.9), and therefore did not require media bridging. However, all of the Deaf telephony prototypes experimented with delivery temporalities for text, voice and video. The resultant design experience pointed firstly toward treating all three media in an abstract fashion in synchronous, asynchronous and semi-synchronous modes. Consequently, we had to rethink how to evaluate both media and temporal modalities in terms of QoS. The next section addresses design for temporality and Section 6.5 will reflect on its evaluation.

6.4.5 Temporality

All Deaf telephony prototypes were designed with some form of mixed or adapted synchronous and asynchronous temporalities in all three media modalities. Temporality design was mostly accommodated at the network layer with synchronous H.323, synchronous SIP, asynchronous SIMPLE (SIP for Instant Messaging and Presence Leveraging Extensions), asynchronous XMPP (eXtensible Messaging and Presence Protocol) and/or asynchronous FTP protocols. The Telgo prototypes (Cycles A.1-A.2) took real-time text from the Teldem and serially transmitted chunks of converted speech with RTP and RTCP (RTP Control Protocol) using either H.323 or SIP respectively, to coordinate the VoIP session. The Softbridge prototype (Cycles A.4) provided asynchronous XMPP-based text to a Deaf user with an IM client and discreet asynchronous voice chunks also with XMPP. The SIMBA prototypes (Cycles A.5-A.7) handled text asynchronously for the Deaf user while voice was synchronous with RTP, RTCP and SIP. SIMBA had three distinct temporality combinations:

asynchronous text for the Deaf user, both asynchronous text and synchronous voice for the human relay operator, and synchronous voice for the hearing user.

Taken together, the text relay prototypes demonstrated semi-synchronous communication: either synchronous communication was interrupted to appear asynchronous or asynchronous transport was so rapid as to appear virtually synchronous. The term semi-synchronous is not commonly used, and related work has used other terms that have also not become commonplace, e.g. 'peri-synchronous' in the context of email (Tyler & Tang, 2003) and 'blended synchrony' in the context of IM (Erickson, 1999).

Deaf-to-Deaf communication prototypes also proved to be semi-synchronous. In Cycle A.8, Deaf participants were exposed to several popular IM tools that employed page mode, or Return key-driven, transfer of text. No matter how fast one typed, asynchronous IM text was at best semi-synchronous. Cycle A.8 produced DeafChat to give Deaf participants an IM interface similar to what they had experienced with the Teldem. DeafChat sent characters in real-time as on the Teldem. However, slow user type-time still made the tool appear semi-synchronous. We also used the Internet-based IM tools to expose Deaf participants to real-time video, but they found those tools unsuitable for SASL communication (see Section 6.5). So we designed an asynchronous video tool called DeafVideoChat (see Cycle A.9). Asynchronous delivery of video provided better quality video resolution at the expense of additional delay. The results of codec and transport protocol experiments indicated that the synchronous x264 codec could be co-opted with standard asynchronous FTP transmission to provide semi-synchronous SASL communication (Ma & Tucker, 2008).

6.4.6 Interface

The Deaf telephony prototypes posed significant user interface challenges: how to design interfaces specifically for Deaf and hearing users, and how to deal with the macro delays inherent to relay systems. The focus was primarily on the Deaf user interface for both Deaf-to-hearing and Deaf-to-Deaf communication bridges. Interface bridging consisted of hiding the bridging done at other layers described above. The PC afforded on-device interface modification not available on 'closed' devices like the Teldem and telephone. The latter devices required off-device modification of media and temporal modalities.

The relay prototypes did not address sign language, so their interfaces focussed on enabling users to deal with macro delay. For example, each SIMBA prototype had three distinct user interface combinations: asynchronous text for the Deaf user, a combination of text and voice for the human relay operator, and synchronous voice for the hearing user. In Cycle A.6, SIMBA v2 provided different awareness mechanisms for Deaf and hearing users, respectively. isTyping is an IM awareness feature that indicates that another person is typing a message. For a Deaf user, we implemented isTyping as a text message in the IM client interface that appeared when the hearing user was speaking and the voice was converted to text. For a hearing user, SIMBA v2 provided an audio isTyping facility that played music when the Deaf user was typing and that text was converted to speech. The music let the hearing user know that TTS-generated speech was on its way. Another innovative isTyping interface materialised implicitly in the real-time DeafChat interface in Cycle A.8. Most IM tools use a page mode approach for text messaging. DeafChat, however, sent each character to its destination(s) as it was typed, manifesting an implicit isTyping mechanism. Each user's text was colour-coded such that the isTyping awareness mechanism also made it easy to see who was typing what.

DeafVideoChat (Cycle A.9) provided an asynchronous interface to video conferencing. Most video conferencing interfaces were fully synchronous. DeafVideoChat looked very similar with two adjacent video screens, one incoming and one outgoing (see Figure A-17). However, the user interface was more complex because the users had to record and send each sign language message separately. That led us to explore making the interface easier for the Deaf user with gesture-based interaction. That would allow hands-free operation of DeafVideoChat. We designed the gesture recognition interface prototype to be application-independent so it could become a generic gesture-driven menu interface for any application. The gesture recognition prototype has not yet been completed.

6.4.7 People

Design for the Deaf participants' physiological limitations and socio-economic environment compelled us to integrate RA/RI criteria into the process. Over the course of the action research cycles, an understanding of the RA/RI criteria emerged in a mutual fashion. Exposure to ICT over the course of the field study empowered the Deaf participants to

progressively provide valuable feedback and suggestions from their perspective. The alignment between our technical goals and their social needs produced a shift from Deaf-to-hearing to Deaf-to-Deaf bridges over the course of the field study.

We initially designed text relay with the Teldem because many of the participants had been exposed to it. However, the Telgo phase prototypes were discontinued because most of the Deaf participants did not have a Teldem, and if they did, they did not trust it nor could they afford to use it (Glaser, 2000). Furthermore, as technology designers, we could not change the Teldem. So we moved design efforts to PCs and cell phones that offered Deaf participants a higher degree of access to technology and the programmers a higher degree of manipulation of that technology. However, the Deaf participants did not adopt text relay, and the reasons for this are discussed in Section 6.5. The lack of adoption of text relay led to a shift toward Deaf-to-Deaf communication. We designed DeafChat (Cycle A.8) specifically for the Deaf research participants. They had become comfortable with PCs and English due to weekly research visits being co-scheduled with an English literacy course. The PCs were also often used as a vehicle for the literacy course. Thus, the PCs became integrated into that aspect of their lives, and they provided their own content, even if it was in English. To address local content and appropriateness of remote SASL communication, we began with the DeafVideoChat prototypes (Cycle A.9). The design focus was to improve video quality in order to support SASL communication.

6.5 Evaluation of communication quality

We initially evaluated communication prototypes for Deaf users with a modified approach to QoS, but then came to incorporate RA/RI criteria into the evaluation process. Section 6.5.1 discusses the problems we had with traditional QoS trying to correlate macro latency within text relay systems to user perception of communication quality. Section 6.5.2 then reflects on the inclusion of RA/RI criteria into the evaluation process.

6.5.1 QoS orientated evaluation

Text relay had macro latencies that were fundamentally different from the latency in microseconds associated with traditional QoS. Delay associated with media adaptation caused otherwise synchronous communication to become semi-synchronous (see Sections 6.3.4 and 6.3.5). We instrumented Softbridge and SIMBA prototypes to collect latency metrics, e.g.

type-time, TTS overhead, and PSTN breakout processing time. We conducted semi-structured interviews and focus groups to determine end-user perception of the conversation in order to learn if users felt the conversation was useful despite the attendant macro latencies. However, actual usage of the relay prototypes was so minimal that objective data acquisition and subsequent correlation to qualitative data were rendered insignificant.

QoS did not accommodate text or the relayed voice. Human relay condensed or re-interpreted voice for the Deaf user. Automated TTS did no such interpretation; whatever the Deaf user typed went through the TTS engine no matter how poor the spelling or syntax of the text. Tests determined that Deaf text was actually comprehensible to hearing subjects: "It was observed that despite instances of inaccurate output speech, context was a larger determiner of comprehension" (Zulu and Le Roux, 2005). However, Deaf users were very conscious of their poor spelling and English literacy. Thus, socio-cultural aspects overshadowed the technical performance of a given Deaf telephony bridge.

Similar considerations manifested during the Deaf-to-Deaf phase, especially regarding video communication (Cycle A.9). We used traditional automated QoS mechanisms to measure the physical characteristics of asynchronous video transmission and also conducted semi-structured interviews with participants (Ma & Tucker, 2008). Analysis revealed that social issues were more significant than technical ones.

6.5.2 Socially aware evaluation

RA/RI criteria influenced the adoption of video communication tools like Camfrog at both DCCT and SLED[15]. Table 6-3 shows a comparison of RA/RI criteria issues relating to overall adoption of research prototypes and Internet tools at DCCT and Internet tools only at SLED. Adoption of research prototypes and common IM video tools was particularly poor at DCCT, although PC usage (see Table 6-4) and ADSL activity (see Table 6-5) were robust and encouraging. Usage records indicated that most Deaf users used the PCs to search for jobs and download sports videos. Deaf participants only used the research prototypes during weekly research visits and rarely asked to use SIMBA, for example, of their own accord.

SLED users, on the other hand, rapidly appropriated tools like Camfrog (for SASL) and Skype (for text) into their daily activities. The two SLED offices are geographically separated

[15] We only engaged SLED during Cycle A.9 and only used off-the-shelf tools.

with one office in Cape Town and another in Johannesburg, a 12-hour drive or a 2-hour flight. SLED leveraged ICT to conduct their daily business affairs. Furthermore, SLED end-users at both offices had very similar attributes, e.g. English and PC literacy, and ready access to PCs with web cams on their desks with ADSL broadband connectivity. Relatively high access to ICT at both sites encouraged the appropriation of a tool like Camfrog for SASL communication. SLED users used the text facility to clear up misunderstandings in video communication, and vice versa.

RA/RI criteria	*Research prototypes DCCT*	*Internet tools at SLED*
Physical access	Difficulty with transport to shared PCs	PCs at work place
Appropriateness	No one to 'talk' to	SASL communication for work
Affordability	Became part of DCCT's budget after 2 years	Part of operating budget
Human capacity	Poor text and PC literacy	Sufficient text and PC literacy
Local content	Job and sports information	Work-related communication
Integration	Primarily during research sessions	Used everyday for work
Socio-cultural	Awkward communication outside community	ICT necessary to get job done
Trust	Little trust in technology	Trusted Internet communication
Local economics	Mostly donations with some services income	Contract work to offer SASL courses
Macroeconomics	Deaf under-employed and under-educated	Empower Deaf people with ICT
Legal/regulatory	VoIP was illegal until 2005	N/A
Public support	Deaf member in parliament, DEAFSA	Deaf member in parliament, DEAFSA

Table 6-3 Comparison of RA/RI criteria between DCCT and SLED

We built a number of research prototypes for Deaf users at DCCT. We also observed their use of off-the-shelf Internet tools like Skype and Camfrog at SLED. The RA/RI criteria differed because SLED end-users used the tools for work while the DCCT end-users used the research prototypes only during the research sessions.

	PC lab open #days/week	# Individual people	Daily visits average	Weekly visits average	Monthly visits average	Max monthly visits
2004	2	25	5	9	42	53
2005	4	30	3	11	43	54
2006	6	105	5	26	120	170
2007	5	96	5	20	86	123

Table 6-4 PC lab attendance at the Bastion of the Deaf

There are approximately one thousand DCCT members in the Cape Town area. The small fraction of attendees reflects financial and other difficulties with transport. The average columns depict visits to the PC lab, not the number of individuals. By 2006, many Deaf users had integrated the PCs into their lives.

At the Bastion, most DCCT staff members had a PC on their desks. They worked in the same building, so face-to-face contact was preferable to, and more convenient than, remote contact. Unlike with SLED, DCCT staff members were not compelled to use ICT in order to get their work done. That is not to say that DCCT staff, and indeed the wider group of DCCT-related research participants, did not require communication with people off-site. However, users at the Bastion had much more ICT4D access than off-site Deaf and hearing users in

their potential connectivity circle. RA/RI criteria such as accessibility, appropriateness, affordability, training, local content and integration into daily life had a major influence on the potential of the size of the DCCT participants' connectivity circle. These were largely due to socio-economic circumstances. The access provided by with the research effort was therefore quite limited. Even when Deaf telephony prototypes functioned adequately, there was not a wider connectivity circle in which to use them. The lack of take up of research prototypes at DCCT and the simultaneous take-up of Skype and Camfrog at SLED demonstrated that the social RA/RI criteria-related considerations were fundamentally more important than the technical attributes of any ICT4D system we could devise.

Month	Bytes
Sep-06	1 172 153 885
Oct-06	4 145 496 890
Nov-06	3 915 693 074
Dec-06	870 957 051
Jan-07	1 197 870 680
Feb-07	1 904 797 258
Mar-07	2 482 917 181
Apr-07	3 095 107 978
May-07	4 285 823 367
Jun-07	4 087 940 678
Jul-07	5 638 914 969
Aug-07	5 804 970 862
Sep-07	4 102 868 855
Oct-07	5 184 549 196
Nov-07	7 784 645 167
Dec-07	2 934 484 389
Jan-08	4 919 850 509
Feb-08	6 354 555 188
Mar-08	5 344 599 097
Apr-08	5 866 233 028

Table 6-5 ADSL usage statistics

Monthly ADSL usage at the Bastion grew steadily over the last two years. The low numbers during the months of December reflect that the Bastion was closed during the holiday season.

6.6 Method and project management

We had intended to follow a participatory action research approach. However, our methods were not all that participatory during the Telgo and Softbridge phases. Even during the SIMBA phase when we fully engaged the Deaf community, we still retained a technical bias. We prioritised computer science research goals because we did not fully understand the

Deaf community's needs. Thus, we focussed on IP communication software construction, HCI techniques and measuring latency and communication quality. Over time, we learned to focus more on empowering Deaf users with text and ICT literacy so that they could better appropriate ICT4D from the project. We had an ICT-literate intermediary deeply connected to the target community. However, it still took several years for us to be accepted as a part of the extended community. The acceptance of the research project, despite its shortcomings, by the community positioned us to learn more about RA/RI criteria in order to align technical and community objectives. We also learned about bridges.org's 12 habits of highly effective ICT initiatives from seeing them in action (see Table 6-6).

6.6.1 Data collection

We originally intended to automatically collect latency data and correlate it to users' perceptions of the communication. However, the relatively low usage of the prototypes did not yield enough automated data to make those sorts of correlations viable. We turned instead to qualitative forms of data collection as described in Section 5.3.2: focus groups and semi-structured interviews. Introduction of each new prototype followed the same pattern: technology installation, training, hand-holding during use, then several weeks of use followed by focus group discussions with users (using a SASL interpreter). We documented our observations of the users using the technology and their feedback with journals. Later, when we used off-the-shelf communication tools like email, Skype and Camfrog, we used the tool itself to gather user feedback. In most cases, we were the primary communicants with the Deaf participants. In retrospect, we should have emphasised this form of data collection even more with our own prototypes. Using the tool itself to collect data was the best way to learn about the tool.

6.6.2 Mindset and ethical considerations

Another way to express the alignment of technical and social objectives was in terms of the three HCI paradigms (set Section 5.1). We began with the so-called first HCI paradigm and viewed the problem as a mechanical challenge to build Deaf-to-hearing bridges in the lab without the involvement of Deaf users (Cycles A.1-A.3). With SIMBA (see Cycles A.5-A.7), methods were more aligned with the second HCI paradigm, the 'cognitive revolution'. We collected quantitative data to learn how macro latencies correlated to software usage and

Start by doing some homework

We started with the results of the Teldem (Glaser, 2000) and TISSA trials (Ngubane, 2002) but found no related work in developing regions other than Agboola and Lee (2000).

Needs assessment

Needs assessment was conducted during the diagnosis stage of every action research cycle. Initial needs assessment followed on the outcomes of the Teldem trial (Glaser, 2000).

Local ownership and champion

The intermediary, then DCCT management and finally one of the Deaf technical support staff successively assumed the role of local champion. However, the Deaf community only took local ownership of the devices and the network, not the applications.

Engage local problem solver

We were the primary problem solvers since DCCT staff did not possess enough technical capability. We did, however, train a Deaf support member to solve many problems.

Form sound partnerships

We formed a fruitful partnership with the intermediary and from there we built a sound partnership with DCCT. We also had three major South African universities involved.

Set concrete goals and take small steps

We conceived a series of relay bridges, but jumped to the last and most complicated one. Later, DeafChat and DeafVideoChat took smaller steps because both were based on ICTs that participants had become familiar with during earlier cycles.

Technology-neutral

We aimed for platform-neutrality and device independence. A central design goal was to have modules that could be swapped out easily, e.g. TTS engines.

Involve excluded groups

The entire project was with an excluded group. We were especially supportive of older females. We targeted them for extra attention during training, and hired one to co-manage the PC room.

Identify and understand external challenges

A recurrent unsolved challenge was that the potential communication circle outside the Bastion did not have the requisite devices and connectivity.

Monitor and evaluate with appropriate tools

We automated data collection of the system to learn what people were doing with it, and conducted regular focus group sessions to triangulate the data.

Make it sustainable

Emphasis shifted from revenue generation to securing a place in the budget. The NGO came to recognise the importance of ICT in the community and found ways to fund it internally.

Widely disseminate

We disseminated in academic forums, on public radio and in a weekly news magazine. The latter venue attracted the most inquiries from Deaf people.

Table 6-6 Reflection on 12 habits for Deaf telephony field study

The project evolved from a simple software development effort into a full-fledged research programme involving a growing number of researchers and participants. Lessons from the management are summarised here with the 12 habits of highly effective ICT-enabled development initiatives (bridges.org, 2005a).

satisfaction. That activity led to several interface innovations discussed in Section 6.3.6. Prototype usage was so infrequent that we abandoned the quantitative approach and moved into the third paradigm, 'situated perspectives'. The action research goal was to generate knowledge by aligning the perspectives of users and researchers. To this end, we followed informed participation in addition to informed consent (Hersh and Tucker, 2005). Therefore, users were completely informed of the objectives concerning the experimentation they would take part in. We intentionally discussed the research goals and ideas with the Deaf participants throughout the cycles.

6.7 Chapter summary

This chapter reflected on the design and evaluation of communication bridges built for a disadvantaged Deaf community in Cape Town, South Africa. The main divide between DCCT members and hearing people is that Deaf people prefer to communicate in SASL, not in text. DCCT's digital divide is made more extreme by poverty, underemployment and text illiteracy. We built a series of Deaf telephony prototypes from 2002, but only really engaged DCCT participants from 2004 when we provided a PC lab at the Bastion of the Deaf, gave an ICT literacy course and commenced weekly research sessions. The prototypes did not become popular, yet about ten percent of the community came to use the PCs at the Bastion on a regular basis. Furthermore, the DCCT NGO assumed payment for the ADSL Internet access.

The chapter discussed design considerations in terms of a seven-layer stack that includes power, network, device, temporality, media, interface and people. The social challenges compelled us to include a people layer in the design stack. It follows that the people layer also informed the evaluation process. RA/RI criteria explained the observed take-up of the PCs, Internet communication tools and our research prototypes. DCCT participants acquired a temporary increase in ICT4D access when they visited the Bastion while their potential connectivity or calling circle did not. The results of the field studies shifted us from a QoS orientation toward social evaluation in order to explain why users were not adopting perfectly adequate communication bridges. Thus, the integration of the people layer into the design and evaluation processes helped us to achieve an alignment between technical and social imperatives. The rural telehealth field study presented in the next chapter displays similar processes at work.

Chapter 7: Rural telehealth field study

I walk down the same street.
There is a deep hole in the sidewalk.
I pretend I don't see it.
I fall in again.
I can't believe I'm in the same place.
But, it isn't my fault.
I still take a long time to get out.
Portia Nelson

We conducted a rural telehealth field study to explore the research questions in an entirely different scenario. The Deaf and rural communities and their ICT needs were very different. However, as Chapter 8 will show, we were able to synthesise many similarities. The action research aims were essentially the same: to empower an underserviced community with ICT, and to explore the design and evaluation of ICT4D communication systems. This chapter presents the rural telehealth field study in much the same way as the previous chapter on Deaf telephony. A long-term series of action research cycles were conducted with healthcare professionals in the remote Eastern Cape described in Section 7.2.1. The field study's action research cycles and their associated prototypes are fully documented in Appendix D. Section 7.1 provides an introduction to telehealth in both developed and developing regions. Section 7.2 characterises the rural telehealth situation in South Africa, particularly in the Eastern Cape. Section 7.3 provides an overview of the field study. Appendix D ought to be consulted before proceeding. The remainder of the chapter reflects on the results of the action research cycles. Section 7.4 reviews the technical and social design aspects of telehealth communication bridges built for the Eastern Cape. Section 7.5 considers the technical and social aspects of evaluating those bridges. Section 7.6 reflects on the methods employed during the field study.

7.1 Introduction to telehealth

> *"Telemedicine can broadly be defined as the use of telecommunications technologies to provide medical information and services. Although this definition includes medical uses of the telephone, facsimile, and distance education, telemedicine is increasingly being used as shorthand for remote electronic clinical consultation."*
>
> Perednia and Allen (1995)

Much of the telehealth literature tends to focus on technology implementation because most telehealth, or telemedicine, makes use of advanced telecommunication technologies (Perednia & Allen, 1995). Examples from the computing literature include a report on telemedicine in Hong Kong that stressed technology implementation and management as key determinants of a successful system (Chau & Hu, 2004) and context-aware extensions to Instant Messaging to support in-hospital information management (Muñoz et al., 2003). Telehealth in both developed and developing regions share many technological features, but differ in the social arena. Section 7.1.1 portrays related work in developed regions and Section 7.1.2 introduces related work in developing regions.

7.1.1 Telehealth in developed regions

Telehealth systems bridge geographical access to medical experts, either between patients and experts, or between experts themselves. Developed regions' rural and under-populated areas are therefore prime targets for telehealth deployment. According to Perednia and Allen (1995), many telemedicine projects were successfully initiated in the 1970s and 1980s, but most of them were terminated prematurely. Technology costs and the cost of connectivity are only partially responsible. More often, socio-political and economic issues affect telemedicine take-up in developed regions, especially with regard to how telemedicine systems and their users are billed and regulated (Grigsby & Sanders, 1998; Huston & Huston, 2000; Perednia & Allen, 1995). On the other hand, socio-economic factors since the 1990s, such as the rise of health management organizations (HMO'ss) in America, have combined with technology advances to dramatically increase the use of telemedicine (Huston & Huston, 2000; Perednia & Allen, 1995).

Our interest is mostly in the media and temporal modalities of telehealth systems. Some claim that voice and pictures were enough (Watts & Monk, 1997). Many feel using the telephone to discuss an electronically transmitted textual description or image is adequate (Perednia & Allen, 1995). Thus, many telehealth systems have been low fidelity, and do not necessarily resemble sophisticated virtual reality remote surgery systems. Furthermore, many telehealth systems are asynchronous because the busy schedules of health practitioners allow very few opportunities for real-time communication. Perednia and Allen (1995) listed the following modes of interaction: real-time (one-way and two-way) interactive motion video; store-and-forward images; video clips and text together with real-time voice on the telephone; and one-way or two-way real-time or delayed video. These modes of interaction cover the whole range of media modalities, and also the whole range of temporality in communication. The mix of media and temporal modalities is particularly applicable to telehealth in developing regions.

7.1.2 Telehealth in developing regions

Scarce resources and a paucity of personnel mean that telehealth receives a great deal of attention in developing regions. A telehealth study in India identified three key areas where ICT for telehealth brings benefits to the developing region context: 1) continuing education for health practitioners, 2) ability to deliver healthcare to remote and poor locations and 3) transparent access to information to "improve the availability and delivery of publicly provided health services" (Chandrasekhar & Ghosh, 2001). Their study also recognized the difficulties and challenges: a prevalence of inadequate infrastructure, lack of access to a given telehealth system by most people and the sad case that most of the system users lack the skills to use them appropriately. Studies in India (Surana et al., 2007, 2008) and Ghana (Luk et al., 2008) confirmed that poor infrastructure and poor user skills also make for challenging deployment scenarios. Thus, telehealth issues are clearly both technical and social, although the social considerations are more basic in developing regions than in developed regions.

The SATELLIFE project in Uganda is an example of a successful telehealth system in Africa (bridges.org, 2003a; Sewankambo & Riccio, 2003). That project deployed PDAs (personal digital assistants, e.g. a Palm pilot) for doctors to collect and collate statistics, and access reference material while working in the field. SATELLIFE illustrates how relatively

leading-edge technology can be applied in a digital divide environment. The project also illustrates how a non-real-time approach is useful. Such approaches are usually less expensive and have also been deployed in Cambodia (Chyau & Raymond, 2005) and advocated for use in Africa (Fraser & McGrath, 2000). Thus, low fidelity and asynchronous systems are equally applicable in both developed and developing regions.

7.2 Field study background

Section 7.2.1 begins the field study background by introducing a telehealth project in South Africa that we were asked to join. Section 7.2.2 describes the rural environment where the field study was based. Section 7.2.3 relates the participants' prior experience with ICT.

7.2.1 Telehealth in South Africa

One telehealth project in South Africa was of particular interest for our field study. The CSIR had built a rural WiFi network in the Eastern Cape (CSIR, 2002; Morris & Makan, 2007). They installed PCs and VoIP handsets in a hospital, clinic, school and police station in two rural villages, Tsilitwa and Sulenkama. The communication modalities offered were good examples of the mix and match alternatives described above. A doctor at the hospital could surf to a web camera at the clinic to view one-way video of a patient in real-time. A nurse at the clinic conversed with the doctor using a handset. Lastly, an email system was used to send high-resolution images taken with a digital camera. Overall, the approach was to use 'off the shelf' solutions. When the network was up, the system worked very well. However, in practice, the system was under-utilised (bridges.org, 2004c). The CSIR invited us to participate in their project because we were interested in difficult communication scenarios, particularly those involving VoIP.

The CSIR also made us aware of a telemedicine project run at the provincial level of the Department of Health (DoH). That project had two arms: ISDN video conferencing between far-flung rural hospitals, and a custom web-based tele-pathology application. We were shown both systems and told that both were under-utilised. Under-utilisation of ICT was a recurrent theme in the Eastern Cape.

7.2.2 Eastern Cape

During the apartheid era, the South African government set aside Transkei as the homeland of the Xhosa people (KMLA, 2006). When apartheid was abolished in 1994, Transkei was combined with other homelands and today forms part of the Eastern Cape Province. A vast majority of the Eastern Cape population speak isiXhosa. The unemployment rate in the area is very high at 77%, and 99% of the houses are informal traditional sites without running water or electricity (ECDC, 2006). Only 9% of households have potable water and only 49% have access to a flush toilet (ECDC, 2006). There are few densely populated centres, so a village is spread over a wide area (see Figure 7-1). The dirt roads often become temporarily impassable during the rainy season (Oct-Feb).

Figure 7-1 Rural area around Lwandile clinic

The mud wall and thatch roof rondavels of Lwandile village are scattered across a hilly landscape in the rural Eastern Cape. Lwandile clinic is in the middle of this picture that was taken from the village headman's house.

Landline telephone deployment is very expensive, and therefore quite sparse. There are Digital Enhanced Cordless Telecommunications (DECT) phones, but cell phones are vastly more popular. Three major South African networks (MTN, Vodacom and Cell C) provide coverage to the area. Cell phones are shared in two ways: family and friends share a handset and pay a fee to charge the phone at a nearby shop or a mobile phone shop provides community phone services. The phone shop often consists of a truck container with a power source and several fixed-mobile handsets. In both situations, users pay up front (pay-as-you-

go). In South Africa, only the caller/sender pays a fee, so it is possible for poor cell phone users to receive calls (and SMSes) without paying.

7.2.3 Initial encounters with ICT

We worked with two communities, and both of them had different prior experiences with ICT. The Sulenkama/Tsilitwa site (herein referred to collectively as Tsilitwa) was involved with the CSIR telehealth project described above. Cycles D.1-D.3 cover our involvement with the Tsilitwa project. The hospital doctor and the clinic nurses were already familiar with PCs, real-time VoIP (with traditional handsets) and one-way video. Their primary difficulty with the system appeared to be network unreliability caused by frequent power outages and vandalism.

Healthcare workers at the Canzibe/Lwandile site (herein collectively referred to as Canzibe) were not as accustomed to modern ICT. In the 1990s, the hospital and ten surrounding clinics were outfitted with a CB (Citizen's Band) radio system built by Dutch donors. The clinic nurses used the system to contact the hospital about emergencies, to hold conference meetings between all of the clinics, and to schedule and coordinate in-service training. According to some of the older nurses and a former missionary (Ijzerman, 2005), nurses regularly used the system until it fell into disrepair due to lack of maintenance. The CB radios and antennae were still mounted at the clinics, but did not work anymore. Thus, there was no telecommunication between the clinic and the hospital when we started working there.

Canzibe hospital had some networking hardware installed, including a 128k Diginet link to the DoH network and fibre between several main buildings on the hospital campus, each with its own network cabinet, switch and UTP (unshielded twisted pair) patch panel. There were several PCs in the administration building, but none of them were in use when we initially visited in 2004. We learned from visiting a number of other sites in the area that lack of use was a common scenario for ICT equipment 'dropped' in the rural Eastern Cape.

When we joined the CSIR at Tsilitwa, the hospital had a generator and a DECT line, but the clinic did not. However, the doctor and all of the nurses each had a cell phone that they used to make calls for emergencies. The DoH did not pay for work-related cellular calls so doctors and nurses were paying for calls out of their own pockets. The situation was the same at Canzibe except that Lwandile clinic did not even have cell coverage. However, toward the

end of the project, the DoH convinced one of the network providers (MTN) to provide coverage to the clinic and gave nurses a pre-paid cell phone.

7.3 Field study overview

The field study had three distinct phases shown in Figure 7-2. Each phase had several prototypes, each associated to a single action research cycle. The action research cycles are documented in Appendix D. A timeline of the field study is shown in Table 7-1. The VoIP phase was meant to make recommendations regarding VoIP policy in South Africa (Chetty et al., 2006). Technically, the VoIP phase dealt with some of the difficulties of the CSIR telehealth system by introducing a store-and-forward message orientation that combined voice, text and images (Chetty et al., 2003, 2004a, 2004b). We called the prototypes MUTI[16]. MUTI stood for Multi-modal Telemedicine Intercommunicator, and technically referred to the communication software, but also came to refer to the wireless network we built at the second site. The second phase at Canzibe added video in both synchronous and asynchronous temporalities (Vuza & Tucker, 2004; Vuza 2006). The final mobile phase ported some of the MUTI prototype functionality to WiFi-enabled cellular handsets (Maunder et al., 2006, 2007).

The MUTI prototypes in all three phases were designed, evaluated and deployed with the evolving framework that initially grew out of the Deaf telephony field study. There was minimal interplay between the Deaf telephony and rural telehealth field studies in terms of community domains and application prototypes. However, the two field studies occurred side-by-side and common themes emerged, especially with respect to the integration of RA/RI criteria into the design and evaluation processes. As we learned key underlying lessons in one field study, we were able to apply them to the other field study.

Appendix D is considered required reading before proceeding. The rest of this chapter reflects on the design, evaluation and methodological considerations for the rural telehealth study in the same fashion as the previous chapter on Deaf telephony. Chapter 8 compares and contrasts the results of the two field studies to synthesise commonalities.

[16] Muti is a colloquial term for medicine in South Africa, originally from isiZulu for 'tree'.

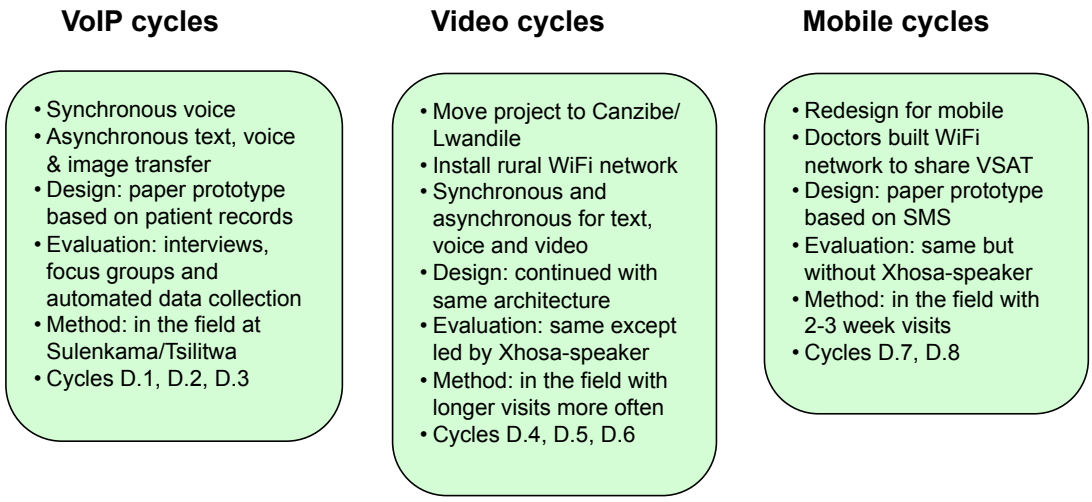

Figure 7-2 Rural telehealth field study phases

The rural telehealth action research cycles described in detail in Appendix D can be grouped into several phases. Each phase emphasises VoIP, video and mobile respectively. Each phase is characterised by distinct central aims with respect to design, evaluation and methodological issues. The constituent cycles are identified for each phase.

2003	Devised store-and-forward solution for Tsilitwa telehealth project (Cycle D.1)
2004	Deployed a series of MUTI prototypes with laptops (Cycles D.1-D.3).
2005	Moved project to Canzibe hospital and Lwandile clinic (Cycles D.4-D.6).
2006	Ported MUTI to a cell phone to simplify the user interface (Cycles D.7-D.8).
2007-8	Connected the MUTI network to the doctor's VSAT network (Cycle D.8).

Table 7-1 Rural telehealth field study timeline

This table shows the overall unfolding of the rural telehealth field study. Details are provided in the identified appendix sections. The MUTI project was initiated as a collaborative effort with an existing CSIR telehealth project at Tsilitwa in the Eastern Cape. We subsequently relocated the field study to Canzibe.

7.4 Design of rural telehealth bridges

This section reflects on technology design issues that emerged from the rural telehealth field study. The sections are organised along the design layers presented in the previous chapter. The MUTI prototypes emphasised store-and-forward, or asynchronous, delivery of mixed media messages to address two significant problems we observed with the CSIR telehealth system: poor power supply and the busy schedules of rural healthcare practitioners. Asynchronous communication in the rural healthcare environment exhibited macro latencies, e.g. it might take a doctor several days to respond to a nurse's message due to power outages

and/or busy schedules. MUTI was designed to cope with such delays. MUTI was also designed to provide real-time communication when possible. By the second phase, MUTI provided both synchronous and asynchronous delivery of text, voice and video. The third phase moved MUTI to a mobile handset. A Softbridge stack representation is shown in Figure 7-3. The Softbridge stack abstraction will be described in Section 8.1.

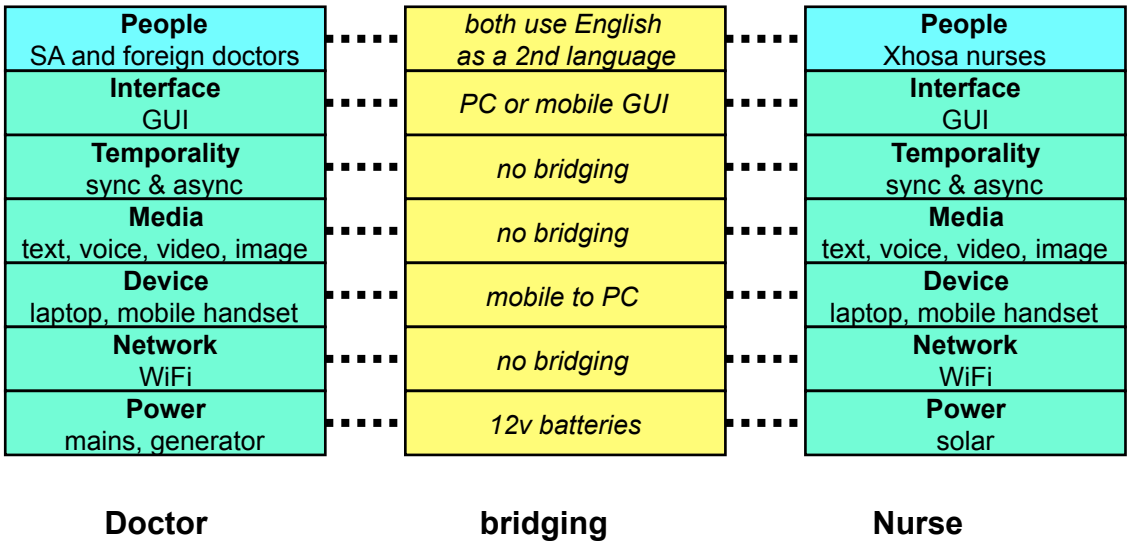

Figure 7-3 Rural telehealth prototype Softbridge layers

MUTI prototypes connected rural doctors and nurses. Both parties used the same physical devices and interfaces. Users could choose from several media modalities, and could also choose the delivery temporality. Physical network provision were WiFi hotspots, but various power supplies were bridged with 12v batteries to provide continuous uptime. Overall, most layers had homogenous bridges.

7.4.1 Power

The power outages at Tsilitwa led us to devise unconventional power bridges. Both Nessie Knight hospital and Tsilitwa clinic were connected to a rural mains electricity grid that could drop offline for several days at a time. The wireless network relay between the two villages was also connected to the mains grid. UPS units protected all computing equipment, but frequent brownouts caused the UPS equipment to malfunction and require a manual reset. To cope with this situation, we designed the initial MUTI prototypes to provide asynchronous messaging (Cycles D.1-D3). We ran MUTI on a laptop chosen for its long battery life so that a user could read and write messages offline. At the second site, Canzibe, we built the network from scratch so we could also design the power supply ourselves. Each node on the

Canzibe wireless network (see Section 7.4.2 and Cycle D.4) ran on a bakkie[17] battery. The 12v 96aH battery was deep-cycle and maintenance-free. We chose low wattage routers to run on such a battery. Where mains power was available, we trickle charged the battery as shown in Figure 7-4. Otherwise, a solar panel or array[18] charged a similar type of battery. Figure 7-5 includes power provision information for the Canzibe wireless network. The mains power at Canzibe hospital was more reliable than at Nessie Knight, but when the power went out, it also went out for several days. Lwandile clinic had a solar power array built by Dutch missionaries. Each Tsilitwa visit had required some form of network or power reset. Power was not an issue on the Canzibe network because the bakkie batteries bridged disparate power sources very effectively. That said, the solar panels were stolen from Lwandile clinic in 2007 and put an end to the telehealth connectivity between the hospital and clinic (see Cycle D.8).

Figure 7-4 Battery enclosure at the Eskom tower relay

This waterproof enclosure was placed at the base of the Eskom tower relay (see Figure 7-5). Eskom provided mains power (for free) that charged the same type of battery used at a solar site. A Power over Ethernet (PoE) injector fed power (and network) via a UTP cable to a router mounted near the top of the 22m tower.

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[17] Bakkie is a South African term for pickup truck.

[18] Note that Lwandile clinic's solar array charged older batteries that required maintenance, e.g. periodic topping up with distilled water that was difficult to acquire in the area.

7.4.2 Network

The Tsilitwa wireless network was designed and built by the CSIR (2002). An external antenna was mounted at each client site and all networking hardware was housed indoors. Inside, all network points were wired to a switch. The network used an H.323 server to run VoIP services. The power was most frequently out where that server was housed, so the client-server VoIP system was often dysfunctional even when other nodes were online. Therefore, we approached network design differently at Canzibe with respect to both structure and protocols. The Canzibe wireless network (see Figure 7-5) was designed on the CRCNet architecture (www.crc.net.nz). We mounted a router board in an external waterproof enclosure with an integrated antenna (see Figure 7-6) at all four nodes. As mentioned in Section 7.4.1, bakkie batteries powered all network equipment. We deployed WiFi hotspots at the hospital and clinic rather than wired connections to encourage mobility (see Section 7.4.3). We also turned the headman's home into an Internet hotspot (see Cycle D.8).

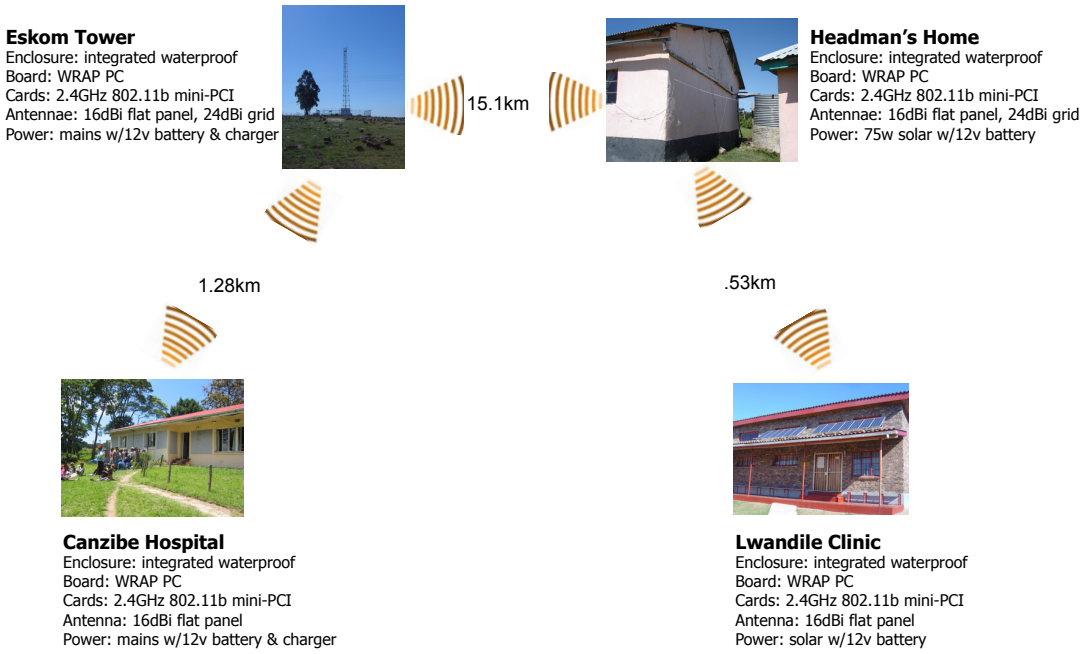

Figure 7-5 Canzibe-Lwandile wireless network

The Canzibe-Lwandile network had two relay nodes between Canzibe hospital (lower left) and Lwandile clinic (lower right). All four nodes used the same integrated waterproof enclosure to hold a router board powered by a 12v battery charged by either mains or solar power. Distances are given 'as the crow flies'. Actually travel distances were much longer along dirt roads that meander across hills and rivers.

MUTI prototypes were designed with peer-to-peer (P2P) VoIP services instead of client-server, removing dependence upon a server. All MUTI prototypes also used SIP instead of H.323 for real-time services for similar reasons mentioned in Section 6.4.2. Store-and-forward messages were delivered with FTP. As will be described below, the combination of SIP and FTP allowed for the design of flexible media and temporal modalities.

Figure 7-6 Waterproof enclosure mounted at Canzibe hospital

This unit provided the link between Canzibe hospital and the Eskom tower. The waterproof enclosure integrated an 18db antenna into a housing for a small router board. The cable coming out from the bottom had PoE, so a single UTP cable could provide both power and network connectivity. A battery enclosure similar to that shown in Figure 7-4 was in a doctor's office and powered the unit. That battery also powered an AP that made the doctor's office a wireless hotspot.

Both Tsilitwa and Canzibe networks were connected to the Internet with VSAT in 2007. The CSIR also installed VSAT for Tsilitwa. At Canzibe, the doctors banded together to install and pay for the VSAT themselves. They also built their own WiFi network to share the uplink to their homes. Their WiFi network was based on our research network's architecture. We interconnected the MUTI network to the doctors' VSAT network, thus providing Internet connectivity to the Out Patient Department (OPD), the village headman's home and the clinic. We also contributed to the monthly cost of the VSAT Internet connectivity.

7.4.3 Device

We introduced laptops at Tsilitwa to enable offline computing to support the store-and-forward messaging of the MUTI software (see Cycle D.1). We chose the Dell 5150 Inspiron laptop because of its battery life, about 4 hours. The Dell was a rather large laptop, more a desktop replacement than a portable device. The Tsilitwa users were already familiar with Windows, so we retained that operating system and developed MUTI prototypes with .Net and SIP. Thus, all MUTI prototypes would run on any device with .Net and SIP support. When the project moved to Canzibe (see Cycle D.4), we transplanted the laptops and peripherals such as the microphone headsets. A web cam was added in Cycle D.4 to enable two-way video communication.

At Nessie Knight hospital, the laptop was locked in a room reserved for the doctor. However, that room was not his office and he rarely used the laptop during office hours. At Canzibe hospital, we put the laptop into a doctor's office. Because there were several doctors, that meant only one could use it at a time. At both clinics, the laptop remained in one of the patient examination rooms. At both sites we fully intended users to take the laptops home after work to encourage them to integrate technology into their lives. The doctors at both hospitals appreciated such use of the laptops, but the nurses left the laptop in the workplace.

After prolonged lack of use of the telehealth system for various reasons discussed in Section 7.5, we ported MUTI to a cell phone. We chose an iMate SP5 because it looked like a normal cell phone, albeit with a larger screen (see Figure 7-8). The SP5 was also chosen because it supported .Net. Thus, the software development effort could follow on previous versions. The SP5 also supported 802.11b that made it usable in and around the WiFi hotspots we had installed at the hospital and clinic. The cell phone port harked back to the original CSIR goal of making the device less intimidating to the end-user. A cell phone integrated all of the PC peripherals into a single package: headphones, microphone and camera. Moreover, each nurses had her own cell phone and was much more comfortable with a cell phone than the laptop. The laptops and handsets were the most expensive equipment in the field study. We had chosen the Dells for their extra long battery life and they cost about R18,000 each. Cellular handsets equipped with WiFi like the SP5 were relatively expensive, but we could buy several of them for the cost of one laptop.

7.4.4 Media

MUTI prototypes provided a variety of homogenous media bridges rather than converting one medium to another. The CSIR telehealth system focussed on real-time voice together with one-way real-time video. This enabled the doctor to talk to the nurse about a patient when the patient was in front of the web cam. Even when scheduled, sporadic network connectivity usually prevented this scenario from being actualised (see Section 7.4.5). MUTI v1 prototypes addressed that type of situation with store-and-forward messaging (see Cycles D.1-D.3). MUTI v1 provided a combination of text, images and a voice clip to support telehealth in store-and-forward mode (shown in Figure 7-7). MUTI v1 also provided real-time VoIP. Note that early MUTI prototypes operated in parallel with the CSIR system. The next series of prototypes, MUTI v2, were deployed at the second site (see Cycles D.4-D.6). MUTI v2 rounded out the media spread with video, and provided asynchronous and synchronous modalities for all media types (see Table 7-2). MUTI v2 used the same P2P SIP architecture as MUTI v1, but modified the transport of asynchronous messages. MUTI v3 provided all of the aforementioned media except video, but only in store-and-forward mode (see Cycles D.7-D.8). At the time, the VoIP libraries were problematic on the mobile .Net platform. Table 7-2 compares the media and temporality capabilities of all four different telehealth prototypes.

	Synchronous			*Asynchronous*			
	Text	Voice	Video	Text	Image	Voice	Video
CSIR telehealth		X	X				
MUTI v1		X		X	X	X	
MUTI v2	X	X	X	X	X	X	X
MUTI v3				X	X	X	

Table 7-2 Media and temporality summary of telehealth prototypes

The CSIR system provided real-time VoIP and one-way video. MUTI v1 prototypes addressed the unreliable network with store-and-forward messaging. MUTI v2 expanded media selection by including video and an IM facility. MUTI v3 provided asynchronous messaging on a mobile handset, but without video.

MUTI prototypes aimed to provide the full range of media modalities so that users could decide what was most appropriate for a given situation. In retrospect, the array of choices may have overwhelmed the nurses, especially at Canzibe where their initial MUTI prototype combined text, voice and video in both store-and-forward and real-time. We thought that the choices would be more palatable to nurses on cellular handsets, but then again, the nurses were only really familiar with real-time voice, voicemail and SMS on the mobile. The IM features of MUTI may have been too complicated for them.

7.4.5 Temporality

MUTI allowed the user to choose between real-time and asynchronous modalities. The temporalities of all MUTI prototypes are summarised in Table 7-2. We emphasised asynchronous communication throughout the field study. At Tsilitwa, MUTI's store-and-forward mode was designed to handle network outages due to poor power provision. Later, with a more stable network at Canzibe, we learned that store-and-forward was also advantageous to bridge the busy schedules of the healthcare workers. However, Lwandile nurses preferred real-time video (even more than voice), but were rarely able to connect with a hospital doctor in real-time. Difficulty with the message interface caused them to avoid the store-and-forward facility (see Section 7.4.6).

Clinic nurses at both sites had both social and technical difficulties with MUTI. Socially, they were not inclined to communicate with doctors at all because they had rarely done so due to their geographical and status separation. Technically, the nurses struggled with the interface and presence (see Section 7.4.6). The doctors at both sites appeared open to using MUTI providing they had the time. The doctors at Canzibe were also very comfortable with IM tools. Perhaps with continued exposure to VSAT Internet connectivity, the nurses would have come to use IM and learn how to integrate it into their daily work schedules, especially if they were able to communicate with their superiors and peers over the network. Unfortunately, Lwandile clinic was burgled and so we were not able to continue MUTI development or familiarise them with the Internet.

7.4.6 Interface

The MUTI interface bridged the variety of media and temporal modalities described above. MUTI's IM-like mixture of modalities was originally posited as an alternative interface for the users of the CSIR telehealth system. We designed the store-and-forward facility of MUTI to address the rural realities of poor power provision and the difficulty of coordinating meetings between doctors and nurses. In doing so, however, asynchronous communication complicated the user interface (see Figure 7-7). In addition, real-time calls with a laptop were much more complicated on the GUI than using a keypad on a handset. The MUTI interface provided a contact list from which real-time calls were initiated. However, the menu-driven, rather than icon-driven, interface required a series of mouse clicks to drill down into the

required function. MUTI's faulty presence facility made matters worse as nurses would not call when presence incorrectly showed the doctor offline.

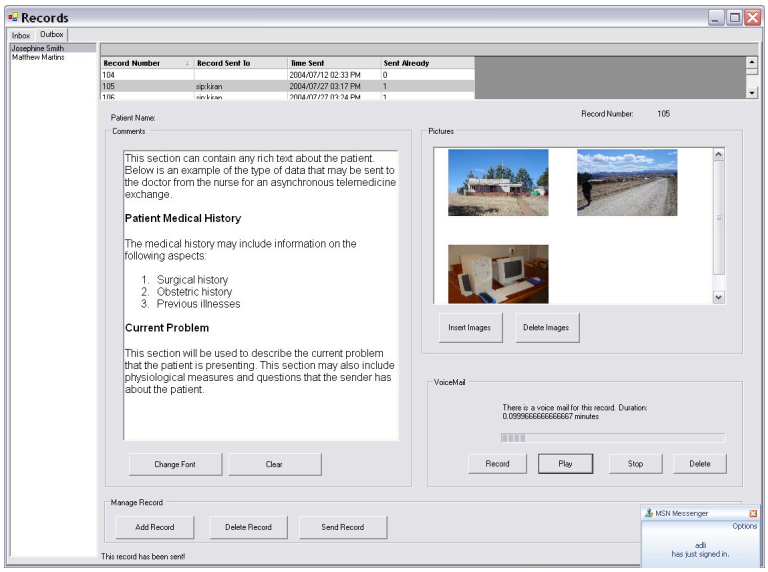

Figure 7-7 MUTI v1 store-and-forward message

MUTI store-and-forward messages were organised by patient. To access or create messages for a particular patient, the user clicked on a patient name in the leftmost column. This screenshot came from an early MUTI v1 prototype that allowed a mixture of text, images and a single voice clip (see Cycle D.1).

There were also problems viewing and creating patient records (messages). The layout of MUTI v1 was table-driven, not conversation-driven like most contemporary IM systems. MUTI v2 provided video (see Figure D-5) and also more feedback to let the user know when a new message had arrived, but still required a hunt through the list of patients to find a new message. This was especially bothersome for the doctor, and would only get worse as the system collected more records on more patients. The Lwandile nurses claimed it took up to 20 minutes to create a new patient message. They had no experience with email so the concept of attachments was foreign to them. We provided automatic attachment of photos and video with MUTI v3. The mobile interface of MUTI v3 clarified much that was confusing for the nurses on the PC version of MUTI. We intentionally designed the interface to be very similar to SMS and MMS (see Figure 7-8). The nurses had not used MMS before, but the jump from SMS to MUTI v3 was much smaller than their jump to using PC-based MUTI from their own cell phones. To address these user interface issues, we provided training as described in Sections D.4.3 and D.6.4.

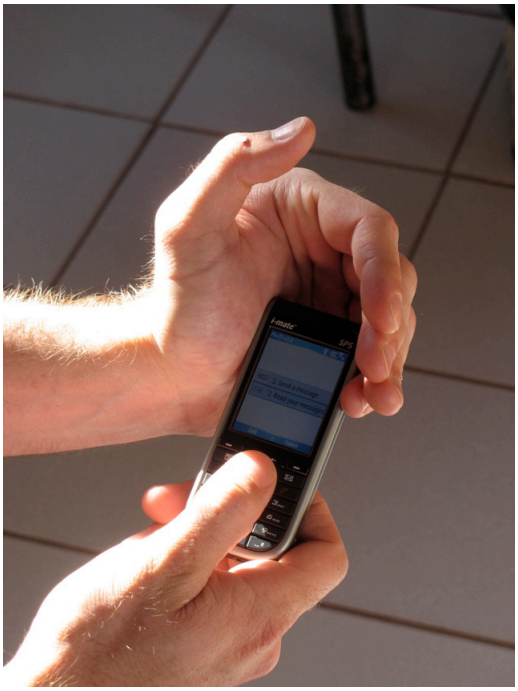

Figure 7-8 MUTI v3 interface on a mobile device

The MUTI v3 interface closely resembled that of SMS or MMS. Text was added in the same fashion. MUTI v3 streamlined the attachment of images, voice and video by making them automatic upon creation. There was no need to record first and then attach.

During Cycle D.8, we considered providing different interfaces for doctors and nurses. The doctor interface would remain complicated with a full listing of patient records (or conversations). The nurse interface would be simplified to make calls and create messages and not necessarily view them all. That would have provided some heterogeneous interface bridging. We built a simplified web interface to MUTI v3, but after the Lwandile burglary, all MUTI development ceased.

7.4.7 People

MUTI prototypes were designed to provide cheap and effective rural communication bridges between foreign doctors at a hospital and Xhosa nurses at a remote clinic. The main focus was to use asynchronous messages to overcome two obstacles to real-time communication: poor power supply and busy schedules. Following on the CSIR telehealth system, we approached the problem predominantly from a telehealth perspective. We continued with that perspective when we moved to the second site at Canzibe, where the social and physical distances between doctors and nurses were just as great. Thus, we

continued to design successive versions of MUTI around telehealth. We designed the system components according to perceived RA/RI criteria needs, e.g. a cell phone interface. However, we might have had better luck starting out with mobile MUTI rather than the PC interface, at least for the nurses at Lwandile. We also would have more success at Canzibe if we had connected clinic nurses with hospital nurses, or with nurses at other clinics. RA/RI criteria characteristics amongst the nurses were more similar than between nurses and doctors. Unfortunately, the hospital laptop was in a doctor's office and not made available to the hospital nurses. MUTI could have been designed more for nurse-to-nurse communication, after which nurse-to-doctor communication would come more easily.

Thus, the goal should not have been to design telehealth systems, but to design generic communication systems that extended or enhanced existent communication links. That would have provided a better base on which to explore enhancements and changes to a given communication system. The emphasis on tele-consultation prioritised a standalone network between doctors and nurses. On the contrary, Internet connectivity should have been the first and foremost priority. The VSAT link during Cycle A.8 provided bridges between doctors and their families, friends and colleagues. The nurses may have been unlikely to have people to chat with over the Internet, but Internet connectivity could have provided bridges between nurses and their managers, and nurses at other clinics. That would have been more similar to the CB radio system that was in place before.

7.5 Evaluation of communication quality

As for the Deaf telephony field study, we initially evaluated rural telehealth communication prototypes with a modified approach to QoS, but then also came to incorporate RA/RI criteria into the evaluation process. Section 7.5.1 discusses the issues we had with traditional QoS trying to correlate macro latency to user perception of communication quality. Section 7.5.2 then reflects on the inclusion of RA/RI criteria into the evaluation process.

7.5.1 QoS orientated evaluation

We measured network performance with standard procedures (see Table 7-4 and Table 7-5). We also collected data on the use of research prototypes (see Table 7-3). The intention was to correlate performance and latency-related data to user perception of the system

recorded by semi-structured interviews and focus group discussions. As with the Deaf telephony field study, actual usage of MUTI prototypes was quite low (see the evaluation stages of the action research cycles in Appendix D, e.g. Cycle D.1.4), so we abandoned such correlation efforts. However, since we built the Canzibe network ourselves, we were always interested in making sure it worked properly.

```
User Name: Hospital
Message Contents: Are You There?
Message Length: 14
Time Received: 8/4/2005 12:19:13 PM
Time Sent: 8/4/2005 12:19:14 PM
Delay Time: -00:00:01.0225000

User Name: Hospital
Message Contents: ok then
Message Length: 9
Time Received: 8/4/2005 12:58:23 PM
Time Sent: 8/4/2005 12:58:23 PM
Delay Time: -00:00:00.5693750
```

Table 7-3 Automated data collection with MUTI v2

We instrumented MUTI to collect usage statistics so we could measure the delays between message volleys. We could calculate inter-message delays by subtracting timestamps. This data shown in this table is not so interesting because it was recorded during a practice session.

A key difference between the Tsilitwa and Canzibe networks was uptime. The Canzibe network achieved continuous uptime because of the power arrangements described in Section 7.4.1. The continuous uptime meant that store-and-forward functionality moved away from dealing with faulty connectivity to bridging the busy schedules of the doctors and nurses. When visiting a site, we collected two forms of wireless network performance metrics. Firstly, we examined ping statistics upon every visit, and before and after each network modification (see Table 7-4). Secondly, we also examined signal strength to look for problems (see Table 7-5). The Canzibe wireless network had only 11Mbps capacity with 802.11b. The long links frequently halved that throughput. However, since the bandwidth was entirely dedicated to the MUTI project, the voice and video were both deemed by users to be of acceptable quality. The nurses preferred video instead of voice. On several occasions they used MUTI video to meet new doctors (at the hospital) for the first time, but alas not for subsequent patient consultation. While some reasons were technical in nature, it appeared that social factors were more significant in inhibiting the use of the MUTI prototypes. We therefore turned to a more socially aware approach to evaluate the system.

```
From clinic:
[headman]
--- 10.2.252.1 ping statistics ---
103 packets transmitted, 103 packets received, 0% packet loss
round-trip min/avg/max = 0.8/0.8/1.2 ms

[eskom]
--- 10.2.253.1 ping statistics ---
116 packets transmitted, 116 packets received, 0% packet loss
round-trip min/avg/max = 3.7/10.6/20.5 ms

[hospital]
--- 10.2.254.1 ping statistics ---
104 packets transmitted, 104 packets received, 0% packet loss
round-trip min/avg/max = 5.4/11.0/30.4 ms
```

Table 7-4 Network ping statistics

We routinely performed ping tests each field visit. The statistics shown here reflect a normal state of affairs. Aberrations in RTT lengths or any packet loss immediately alerted us to any problems in the network.

```
root@esk:~# iwconfig
ath0      IEEE 802.11b  ESSID:"ECN-hsp-esk-11"
          Mode:Managed  Frequency:2.462 GHz  Access Point: 00:02:6F:38:B1:9B
          Bit Rate:11 Mb/s   Tx-Power:50 dBm   Sensitivity=0/3
          Retry:off   RTS thr:off   Fragment thr:off
          Encryption key:off
          Power Management:off
          Link Quality=30/94  Signal level=-65 dBm  Noise level=-95 dBm
          Rx invalid nwid:24727  Rx invalid crypt:0  Rx invalid frag:0
          Tx excessive retries:102  Invalid misc:102   Missed beacon:12

ath1      IEEE 802.11b  ESSID:"ECN-esk-lwn-1"
          Mode:Master  Frequency:2.412 GHz  Access Point: 00:02:6F:38:B1:91
          Bit Rate:0 kb/s   Tx-Power:50 dBm   Sensitivity=0/3
          Retry:off   RTS thr:off   Fragment thr:off
          Encryption key:off
          Power Management:off
          Link Quality=12/94  Signal level=-83 dBm  Noise level=-95 dBm
          Rx invalid nwid:55719  Rx invalid crypt:0  Rx invalid frag:0
          Tx excessive retries:17143  Invalid misc:17163   Missed beacon:0
```

Table 7-5 Wireless network metrics

We also routinely examined signal characteristics of the wireless network. The data shown here lists metrics for the two links on the Eskom relay tower. The link between the hospital and tower is strong, but the long distance link was problematic. This particular reading caused us to realign the antennae.

7.5.2 Socially aware evaluation

At both sites, we became aware of the cumbersome nature of the external connections and wires surrounding the laptop. The headset caused difficulties because when it was plugged in, one could not hear incoming calls. Users got in the habit of only plugging in the headset's microphone and using the laptop's built-in speakers to hear an incoming call, but did

not always do so. Issues like that, in addition to difficulties with the interface (see Section 7.4.6) led us to port the MUTI prototype to a cellular handset (see Cycle D.7).

We had expected the nurses to embrace asynchronous messaging since they were already accustomed to the very long communication delays endemic to their geographical isolation. For example, it could take weeks to return test results from the hospital to a patient. We expected a one or two day turnaround on messages with a doctor would be acceptable to nurses. We thought that delay would be a relative and elastic concept. For the field study, however, it seemed that because real-time was available, the nurses wanted to use that and nothing else. They told us that the asynchronous part of MUTI took time away from patients because of the cumbersome MUTI interface.

The levels of ICT comfort between the doctors and nurses differed greatly. The doctors were much more comfortable with PCs and were keen to participate in the research project mostly because they wanted access to ICT. The nurses also appeared keen, but actually did not appropriate the ICT as much as their initial enthusiasm had indicated. At Lwandile, in particular, the ICT was seen as threatening. One of the nurses told us she thought the laptop was used to spy on them. Thus, the nurses appeared to seldom use the laptop even for personal reasons (see Cycle D.6). On the other hand, Canzibe doctors banded together to install a VSAT with WiFi distribution of the bandwidth to their homes.

We should have leveraged ICT to reinforce communication bridges that already existed. MUTI's focus on telehealth stressed a doctor-nurse connection that did not exist before the project, at either site. If we had rather started by enhancing communication that already existed, the doctor-nurse connections may have evolved on their own, rather than at our urging. For example, in Lwandile, we should have rather emphasised clinic-to-clinic and nurse-to-nurse communication as the previous CB radio system had done.

7.6 Methods and management

We began this field study with a belief that our social agenda to improve healthcare in a rural community would result in successful ICT4D prototypes via participatory design. That confidence emanated from our understanding of technology and the ease of its manipulation. We knew we needed more than a cursory understanding of underlying social mechanics to achieve community goals. However, a detailed understanding of the target communities was

difficult to cultivate. On the one hand, we were fortunate to have an isiXhosa-speaking student on the project for two years to communicate better with the nurses. However, the key to understanding RA/RI criteria was to engage a local intermediary that had a deep understanding of the local social agenda. Essentially, we had to learn how to integrate the intermediary into our overall method. That meant aligning the perspectives of three main parties: participants, intermediaries and ourselves. Section 7.6.1 reflects on issues concerning data collection. Section 7.6.2 discusses more general methodological issues. Table 7-6 summarises what we learned about the management of the rural telehealth field study according to bridges.org's 12 habits of highly effective ICT initiatives.

7.6.1 Data collection

Data triangulation as described in Section 5.3.2 helped us learn how MUTI was really being used (see Figure 5-3). Nurses were eager to please us and tended to overstate their use of the prototypes. In reality, according to automated data collection, the MUTI system was rarely used. An early objective was to collect data on delays involved with sending and receiving of messages in order to correlate those delays to users' perception of the system; an objective communication quality measure to show that large delays could be tolerated. Unfortunately, we could not collect enough data to make this worthwhile. We came to rely almost exclusively on qualitative data collection methods, but still collected usage statistics. We tried to convene a large group meeting at least once during each field visit. We invited nurses, doctors, their managers and the district DoH administrators. We only managed one such meeting at Tsilitwa, but had several at Canzibe. However, over time, the DoH administrators declined to attend.

At Canzibe, the most informative meetings tended to be informal, in the evening, over a glass of wine and standing around the braai[19], mostly with intermediaries and doctors. At the informal gatherings, doctors were very forthcoming with their views on the MUTI prototypes and the nurses' involvement with the project. We were not able to have similar casual encounters with the nurses or their managers. Those meetings were always formal and took place at the clinic. It appeared the more relaxed atmosphere of the informal gatherings was more conducive to genuine project discussion.

[19] A South African barbeque.

Start by doing some homework

We started by examining the Tsilitwa project. We also visited several other rural telehealth and telecentre sites in the Eastern Cape. Then we examined global literature.

Needs assessment

Needs assessment was an ongoing process, and was a fundamental part of the diagnosis stage of each action research cycle. The CSIR project at Tsilitwa started this process.

Local ownership and champion

Tsilitwa clinic had a local champion, the head nurse. There was no local champion at Canzibe or Lwandile. We relied on an intermediary to act as surrogate champion. Toward the end of the project, the Lwandile village headman's son emerged as a potential ICT champion.

Engage local problem solver

This task fell to the Transcape NGO chairman, as the NGO decided that the telehealth project was beyond their mandate. He later founded a small CC to provide these services.

Form sound partnerships

We were very successful with a close partnership with Transcape. The partnerships with CSIR and provincial level DoH were less productive.

Set concrete goals and take small steps

A series of MUTI prototypes slowly grew in functionality and interface. However, we suspect we went too slowly by only addressing a single clinic.

Technology-neutral

We chose to install 802.11b, but in reality, the MUTI application would run over any IP network, including GPRS (although real-time VoIP and video would suffer).

Involve excluded groups

The whole project was with previously excluded groups, especially black Xhosa female health practitioners in deep rural areas.

Identify and understand external challenges

The biggest external challenges were local politics, cultural and social dynamics. We were not able to effectively deal with these issues. We were fortunate that VoIP became legal during the course of the project, but rural WiFi did not.

Monitor and evaluate with appropriate tools

We instrumented software prototypes with data collection facilities in order to triangulate with qualitative data.

Make it sustainable

The unrealised goal was for the district level DoH to assume financial responsibility for expanding the project, to train the nurses and maintain the networks. The doctors, however, installed and paid for their own Internet connectivity with VSAT and a wireless network.

Widely disseminate

We published extensively in the academic literature, and also on the web at www.fmfi.org.za.

Table 7-6 12 habits analysis of rural telehealth research management

7.6.2 Mindset and ethical considerations

At Canzibe, the Transcape NGO was crucial in facilitating the alignment of our technological goals and the social goals of the community because that was the midway space they occupied. The local technical support team at Tsilitwa fulfilled a similar role. They and the Transcape chairman were knowledgeable about networking basics, but not as technically adept as we were with networking software and programming. Transcape is a mixed group of foreign nationals and locals who live in the community. The Transcape chairman often acted as a proxy for us in the field. He either conducted or enabled much of the training and measurement activities when we were not there. He also made many suggestions regarding the prototypes. Regrettably, we were slow to implement some of his suggestions, particularly for nurse-nurse communication during the initial stage of that project. At Tsilitwa, local support had encouraged us to engage clinic and hospital managers. By the time we started to do this at Tsilitwa, the CSIR had asked us to leave. However, we made more of an effort with management at Canzibe. Unfortunately, we were not able to actively involve managers enough in the project, especially the clinic managers. It took a while to learn that the clinic nurses did not report to the hospital, but to clinic managers stationed at Buntingville clinic. The clinic managers reported directly to the district level DoH. We had established a good relationship with the hospital because the Transcape chairman was based there, as his wife was a hospital doctor.

The nurses at both clinics questioned our motives for the intervention. They suspected that we were 'in it for the money'. The head nurse at Tsilitwa repeatedly questioned our connection to the CSIR because she was frustrated with them. One of the nurses at Lwandile clinic actually told us she thought we were using MUTI to spy on her. Perhaps it was because we knew the nurses were frequently not on duty when we visited[20]. In both cases, we tried to explain what postgraduate research meant and that we were not interested in financial gain. We also were very explicit about the research goals, especially concerning macro delays and asynchronous communication in text, voice and video. Unfortunately, our explanations did not relieve their suspicions, and their participation in the project remained minimal.

[20] We often had to get the clinic key from neighbours to work on the network hardware.

Perhaps the biggest lesson we learned from this field study was the need to better utilise the authority structures, firstly with the DoH and secondly with the headman. Toward the end of Cycle A.8, both seemed to be happening. Transcape had put the clinic managers at Buntingville clinic on the Internet with GPRS and the Lwandile headman's son started using GPRS and then the WiFi network to access the Internet. He used the Internet to seek funding for community projects and to organise community workshops and activities. Even though the original technological and social aims of the telehealth project were not entirely successful, they did lay the groundwork for such community-driven initiatives. We hope that the DoH and village leadership structures will encourage the future uptake of ICT within the communities. Thus, reflection on the research method was that our priorities, even if somewhat tunnel-visioned, were still responsible for laying the foundation for those local initiatives. Perhaps we could have prioritised them earlier, but we needed the time to learn about them and time to expose the locals to the opportunities of ICT.

7.7 Chapter Summary

This chapter reflected on the design and evaluation of communication bridges built to support telehealth in the rural Eastern Cape province of South Africa. Worldwide, telehealth consists of a blend of media and temporal modalities. Asynchronous communication tends to predominate because of challenging and expensive network access. The rural Eastern Cape is characterised by pervasive poverty, low employment, scattered settlements and GSM/GPRS coverage. The goal for the project was to leverage low cost but illegal WiFi communication between a rural clinic and its rural hospital so that patients would not have to travel to the hospital. Technical research goals included dealing with macro delays caused by poor power provision and the busy schedules of the rural doctors and nurses. We built a series of rural telehealth prototypes, and engaged two different communities in the process. At first, we joined a telehealth project initiated by the CSIR. Then, we built our own rural wireless network at a second site and moved the MUTI telehealth prototypes there. The last phase ported MUTI to a mobile phone. The MUTI prototypes did not achieve the desired take-up, and the burglary of Lwandile clinic's solar panels put an end to the telehealth effort. However, the process of exposing ICT to the rural inhabitants enabled them to appropriate ICT into their lives. The rural inhabitants, especially the doctors and village headman's son, have become

much more aware of a wide range of ICTs and will be more likely to appropriate sophisticated communication tools in the future. We hope that local inhabitants will benefit from this indirectly.

The chapter, like the previous chapter, argued that people issues explained the observed take-up of the PCs, Internet communication tools and our research prototypes. The doctors increased their ICT access by participating in the project, especially when they connected to others on the Internet. Socio-cultural and trust RA/RI criteria helped explain why the nurses were not able to appropriate ICT into their lives. To this end, we ported the MUTI prototypes to a mobile device and connected the MUTI network to the doctors' VSAT connection. However, over time we came to understand the intermediary's suggestion that we should have rather fostered nurse-to-nurse communication, especially with the clinic managers.

As with the previous chapter, this chapter discussed design considerations in terms of a socially aware seven-layer design stack that we now call the Softbridge stack. Social factors also informed the evaluation process. The results of the field studies shifted us from a QoS orientation toward RA/RI criteria evaluation in order to explain why perfectly adequate communication bridges were not being appropriated. Thus, the social aspects of the design and evaluation processes helped us to achieve an alignment between technical and social imperatives. The Deaf telephony field study presented in the previous chapter displayed similar processes at work. The next chapter synthesises the reflection from the two field studies. The similarities, with respect to design, evaluation and methodological issues, helped define the novel Softbridge framework.

Chapter 8: Synthesis of the Softbridge framework

I walk down the same street.

There is a deep hole in the sidewalk.

I see it is there.

I still fall in – it's a habit.

My eyes are open.

I know where I am.

It is my fault.

I get out immediately.

Portia Nelson

On the surface, the Deaf telephony and rural telehealth field studies appear unrelated. However, comparison and contrast between the field studies reveals that they are similar with respect to social, technical and methodological aspects of ICT4D. This chapter describes a novel framework called Softbridge that coalesced during the course of the two field studies. The Softbridge framework aligns technical and social aspects of ICT4D design and evaluation in order to answer the research questions posed in Chapter 4.

The framework comprises three components: Softbridge design stack, QoC evaluation and a socially aware software engineering (SASE) method. The novel design and evaluation abstractions are predicated on OSI and QoS, and their gaps, as discussed in Chapters 2 and 4 respectively. The Softbridge stack extends the 'Big 4' reported in Chapter 3, and appropriates bridges.org's RA/RI criteria in order to include social factors into the design process. QoC is the associated socially aware evaluation process. The SASE method combines user-centred HCI methods, participatory design, exploratory prototyping and action research. SASE was responsible for the iterative evolution of the Softbridge framework via the production of ICT4D prototypes for the two field studies described in Chapters 6 and 7 (and Appendices A and D). Section 8.1 describes the Softbridge stack and how it informed, and evolved from, the design of the field study prototypes. Section 8.2 defines QoC and its application to, and emergence from, the evaluation of those prototypes. Finally, Section 8.3 portrays the SASE method and describes how it was used to recursively produce the Softbridge framework.

8.1 Softbridge design stack

The Softbridge stack is a socially aware, or people-oriented, abstraction for the design of ICT4D communication systems (see Figure 8-1). The Softbridge stack extends the 'Big 4' described in Section 3.1 with three additional layers: media, temporality and people. The media and temporality layers are added to include communication application properties into the design stack. The people layer represents connectivity between end-users within the context of their socio-economic and socio-cultural environment. We use RA/RI criteria to explore the people layer to enable the model to reach beyond technology to bridge Heeks' (2002) 'design-reality gap', and achieve an alignment of technical and social considerations. The inclusion of the community is also aligned with the arguments of Best (2003) and Purbo (2005) that the community is the primary source of successful ICT4D projects.

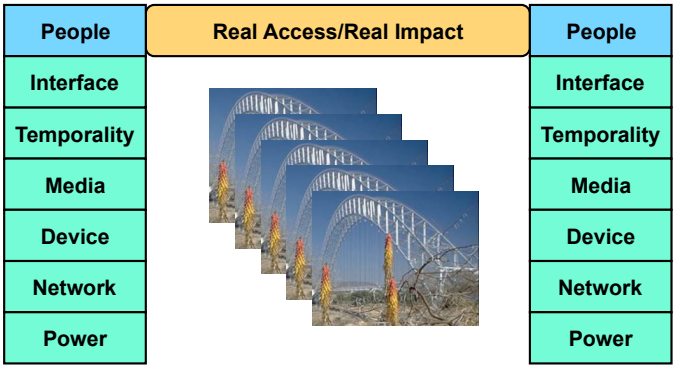

Figure 8-1 Softbridge design stack

The Softbridge stack specifies seven key ICT4D bridges. Power bridges deal with the poor power provision that is common in developing regions. Network bridges involve networking equipment and protocols, usually wireless. A variety of end-user devices can be deployed; mobile devices are particularly useful. Media includes text, voice and video communication, and can be adapted, e.g. text-to-speech. The temporality bridges can be any combination of synchronous, asynchronous and semi-synchronous. User interface bridges are usually linked to media and device characteristics. The ultimate communicating entities are people, not applications. Social influences on the entire process are examined with RA/RI criteria.

The Softbridge stack is not meant to be a replacement for the OSI and TCP/IP models. Rather, the Softbridge and OSI stacks should be viewed as complementary. The OSI stack can be considered a 'drill down' into the Softbridge network layer, as shown in part (a) of Figure 8-2. It is also possible to think of the Softbridge stack as an expansion and extrapolation of the OSI application layer. In this view, the Softbridge stack represents application layer considerations not limited to the network API.

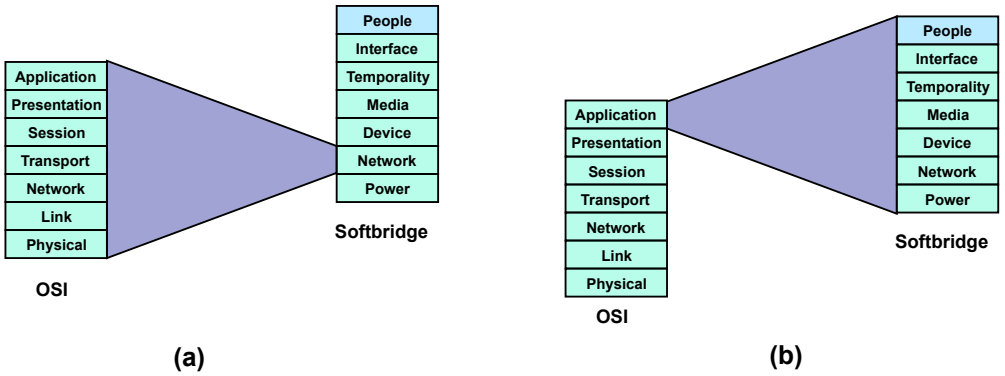

Figure 8-2 Softbridge stack's relationship to OSI

The Softbridge stack is not meant to be a replacement for the OSI stack for the network programmer. The two stacks should be considered as complimentary. As shown in (a), the OSI stack can be considered a 'drill down' into more detailed internals of the Softbridge network layer. On the other hand, (b) shows how the Softbridge stack can also be construed to include application-oriented considerations for the OSI stack.

The combination of the words 'soft' and 'bridge' are derived as follows. There are bridges between components at respective layers. These bridges may be homogenous or heterogeneous. In a digital divide context, bridges are often between disparate components, e.g. SIMBA v3's bridging between SMS on a cell phone to IM on a PC server to voice on a PSTN handset or VoIP soft phone. SIMBA v3 had heterogeneous bridging at all seven Softbridge layers (see Figure A-14). On the other hand, MUTI prototypes are examples of homogenous bridges with respect to a variety of choices, e.g. provision of text, voice and video media in either real-time or store-and-forward modes. Bridges are considered 'soft' because they are malleable, usually in software.

Softbridge and OSI stacks are very similar structurally and conceptually. Each layer can be considered a 'black box' where components can be swapped in and out based on encapsulation and data hiding. Both Softbridge and OSI stacks hide implementation details for the benefit of designers, as discussed in Section 2.1.1. The virtual bridges between Softbridge layers are conceptually similar to the virtual connectivity between OSI layers (see Figure 2-1). Packet traversal through the OSI stack follows an ordered trajectory. Softbridge layers are also layered according to dependencies. People require a user interface to use an application and the application requires temporalities and media, all of which are implemented on a device that is, in turn, connected to a network, all of which have to be powered.

There are, however, fundamental differences between Softbridge and OSI (or TCP/IP) stacks. Firstly, the communication application is explicitly included in the Softbridge stack in the media and temporality layers. Secondly, people are explicitly included in the Softbridge stack to emphasise socio-cultural relationships to the technical layers. RA/RI criteria considerations affect design choices made at all Softbridge layers and carry design ramifications between and amongst layers. Softbridge characterises how social factors can impact on all of the technical layers. A different view of the stack is shown in Figure 8-3.

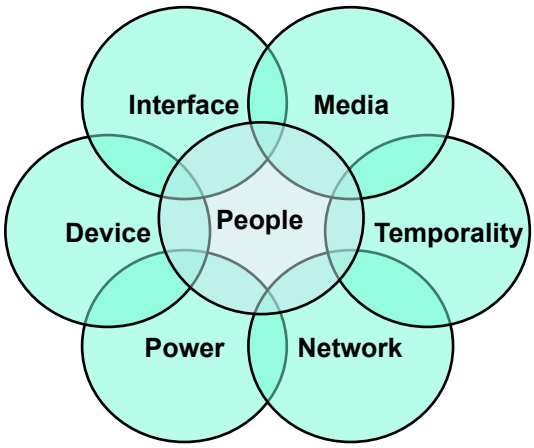

Figure 8-3 Intermeshed Softbridge stack layers

Unlike the traditional models, Softbridge layers are very much intermeshed and all layers have some inter-relationship to all other layers via both technical and social considerations. The flower petal arrangement does not restrict interaction with adjacent layers. For example, the poor power in rural environs called for a store and forward approach to temporality. Rather, the arrangement of technical layers around the people layer emphasises the intermeshed nature of Softbridge layers with an emphasis on the people aspects.

For OSI, the parameters and return values of the APIs are the 'leaks' between layers. The leakiness and encapsulation in the Softbridge stack operate differently. The two views of the Softbridge stack convey two complementary approaches to use of the stack for design. Firstly, the layers can be considered stacked as in Figure 8-1 in order to encapsulate and isolate design decisions and implementation within each layer. Secondly, the layers as shown in Figure 8-3 help tease out inter-relationships to better inform the design of each layer in terms of social factors. Thus the Softbridge layers can work differently from the OSI stack layers.

Placing people at the centre of the abstraction explicitly includes the challenging social aspects of ICT4D. The research communities involved with ICT4D advocate such a people-centred approach (Brewer et al., 2005; Deardon et al., 2007; Dray et al., 2003; Thomas et al., 2008a, 2008b; Toyama & Dias, 2008). In order to do this, we use RA/RI criteria to address

the people issues in the Softbridge stack as reported in Sections 6.4.7 and 7.4.7. We often used RA/RI criteria as a checklist and lens to include social issues in ICT4D design. We could manipulate software prototypes in an effort to increase access to ICT, or at least target a prototype at some level of access. For example, SIMBA v3 included SMS as an interface to text relay because many of the participants had already integrated cell phones and SMS into their daily lives. The mobile MUTI v3 prototype was based on very similar reflection concerning handhelds. The nurses already had their own cell phones. The cell phone device for MUTI v3 was much more accessible and appropriate for them than the cumbersome laptop and peripherals of the first two MUTI phases. Thus, the RA/RI criteria of accessibility and appropriateness were designed into communication software prototypes. Successive prototypes became more aligned with social realities via iterative action research, as people layer issues became better understood and designed into prototypes. It follows, then, that RA/RI criteria also feature strongly in evaluation of communication.

8.2 Quality of Communication evaluation

> *". . . human conversation does not follow the kind of message-passing or exchange model that formal, mathematical theories of communication posit. Rather humans coconstruct the mutual intelligibility of a conversation through an extraordinarily rich array of embodied interactional competencies, strongly situated in the circumstances at hand (the bounds and relevance of which are, in turn, being constituted through the same interaction)."*
>
> Suchman (2007)

Quality of Communication, or QoC, is a socially aware evaluation abstraction, as described in Sections 6.5.2 and 7.5.2, that follows on the Softbridge stack (see Figure 8-4). QoC is to the Softbridge stack as QoS is to the OSI stack. QoS, as described in Section 2.2, addresses user perception and network performance with respect to temporality variation and latency across various layers in the OSI stack. QoC reaches beyond the user to include the user's social environment in the appraisal of communication quality, as Suchman's (2007) quote above evokes. QoC is more concerned with an assessment of how ICT enables "mutual intelligibility", whereas QoS is more concerned with system performance (Bouch et al., 2000). Thus, QoC takes the view that while QoS is a 'nice to have'; it is not necessary, as

argued by Purbo (2004a, 2004b). QoC is a holistic appraisal of intermeshed Softbridge layers. QoC employs RA/RI criteria to examine how computer mediated communication functions with respect to social mechanisms and challenges. QoC is therefore more challenging to measure than QoS. We used qualitative approaches for QoC measurement precisely because it is so people-oriented. Thus, QoC and QoS can also be viewed as complementary in the same way that Softbridge and OSI stacks are complementary.

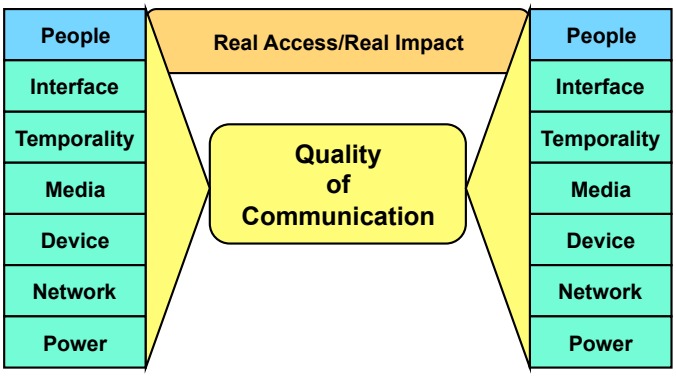

Figure 8-4 Quality of Communication

Just as QoS examines characteristics of each layer in the OSI stack, QoC examines characteristics at Softbridge layers. However, in the case of Softbridge, there is intermeshed interaction between technical and social issues. QoC characterises communication quality within that interaction. While QoC may make use of QoS performance metrics, most QoC is mostly expressed qualitatively in terms of RA/RI criteria.

During the opening phases of both field studies, we thought QoC could be expressed like QoS in terms of MOS (ITU, 2003a), or correlating macro latencies to user acceptance and perception of communication prototypes. We instrumented prototypes to collect latency data and usage statistics, and also conducted semi-structured interviews to learn what participants thought of the system. Over time, however, two matters caused us to abandon that approach. Firstly, the participants in both field studies did not use the prototypes enough to enable statistical significance. Neither were there a large number of participants. Secondly, the macro latencies yielded larger implications for communication software design and evaluation. Where QoS is relevant to real-time voice and video communication, QoC is not limited only to 'perfectly' operational systems with minimal micro-scale latency. QoC applies to both asynchronous and synchronous systems.

The related work covered in Chapter 3, and both field studies, attest that asynchronous communication is quite applicable to 'imperfect' and challenging ICT4D situations. It is

arguable that asynchronous communication, e.g. email and Instant Messaging (IM), has become just as necessary and ubiquitous as synchronous communication in developed regions. Email and IM approximates synchronous communication when exchanges happen quickly enough (Tyler & Tang, 2003) and IM could demonstrate 'blended synchrony' (Erickson, 1999). For difficult scenarios, fault tolerance and large delays are part and parcel of ICT4D deployment (Brewer et al., 2005; Pentland et al., 2004). Pentland et al. (2004) considered asynchronous connectivity to be a stepping-stone toward full synchronous connectivity. In our view, temporality in human communication is actually a continuum between asynchronous and synchronous exchanges, and therefore primarily semi-synchronous. The SIMBA and MUTI prototypes demonstrated various forms of semi-synchronous communication with multiple media modalities.

Accordingly, QoC includes several very non-traditional notions of service quality. Firstly, QoC is more concerned with the use of an ICT4D system within a user's social environment than with an individual user's perception. Secondly, Softbridge, hence QoC, layers are not insulated from one another. Rather, they are intermeshed and often influence one another. As with Softbridge, QoC intermeshing between and across layers is made complicated by the social entanglements in the environments in which ICT4D prototypes are deployed. Informed by RA/RI criteria, QoC offers a way to bridge 'evaluation-reality gaps' just as the Softbridge offers a way to help avoid Heeks' (2002) 'design-reality gaps'. The design and evaluation processes are complementary. Together, the Softbridge stack and QoC can address the alignment of technical and social factors during design and evaluation of ICTD, respectively. Table 8-1 compiles crosscutting people issues in terms of RA/RI criteria abstracted from the two field studies.

Physical access: Provide mobile and shared devices with wireless connectivity. Appropriateness: Technological appropriate solutions may not be socially appropriate. Affordability: Design for top end IP-based services. What is expensive today will be cheaper later. Human capacity and training: Train up NGO members so they can pass on skills to the community. Locally relevant content: Application-independent infrastructure lets users choose their own content. Integration to daily life: Focus on lower Softbridge layers first and get authority figures to use ICT. Socio-cultural factors: Start from an existing communication task/norm before extending circles. Trust in technology: The trust of the NGO in the researcher and the research extends to the community. Local economics: Sustainability is ultimately the responsibility of the community, not the researcher. Macroeconomics: South African macroeconomics does not benefit the disadvantaged as intended. Legal and regulatory: Using restricted technologies can help lead to their legalisation. Public support and political will: Projects like these improve awareness of ICT4D realities.

Table 8-1 Crosscutting Real Access/Real Impact criteria

This table lists RA/RI criteria that were clearly evident in both field studies. The similarity of issues underscores the use of the RA/RI criteria to inform consideration of the people issues in the Softbridge stack.

The alignment of social and technical imperatives is a tricky balance. For example, at one point we thought that Deaf participants were not so interested in text or communicating with hearing people (Cycle A.7). Then they briefly showed some enthusiasm for the DeafChat prototype (Cycle A.8). However, Deaf participants actually wanted to communicate in SASL with both Deaf and hearing people. We now feel that a sign language interface to video relay would appeal to DCCT participants. Despite the relative failure of the text relay prototypes, their introduction enabled ICT infrastructure to take root in the Deaf community. We had not expected so many Deaf people to use the PCs so often, and certainly had not expected the DCCT NGO to assume payment for the broadband connectivity.

Similarly, our understanding of the appropriateness of the MUTI system evolved over the course of the rural telehealth field study. We came to understand that telehealth needed to include more people than just the nurses and doctors. Improving QoC meant enabling nurses to communicate with other nurses and their superiors, and actually for doctors and nurses to communicate with whomever they wanted. We had not provided Internet access at Tsilitwa because we had concentrated solely on telehealth. By 2007 both Nessie Knight and Canzibe hospitals had their own VSAT for Internet access.

It appears that QoC is easier to attain at lower levels in the Softbridge stack, closer to where QoS operates. However, one could also argue that QoC needs to be built at lower levels first, including some modicum of QoS, so that QoC can be attained at higher levels later. This process takes time, and requires a number of cyclical interventions.

8.3 Socially aware software engineering method

The Softbridge stack and QoC abstractions evolved through the course of the action research cycles of both field studies. The process situated iterative system prototyping within action research stages. Cyclical reflection, as conveyed in Chapters 6 and 7, and Appendices A and D, provides the means to align social and technical imperatives. This caused us to include social factors in the design and evaluation abstractions, and consequently into the research prototypes deployed and evaluated in the field. Reflections on the research method itself helped to recursively evolve the SASE method. Blake and Tucker (2006a) described initial thoughts on SASE. That description combined user-centred HCI methods, participatory design, software prototyping and action research. As mentioned in Section 3.1.4, methods like participatory design can be problematic until participants acquire sufficient ICT literacy. Users cannot help design, but they can actively participate. SASE therefore requires a great degree of help from intermediaries. However, the Softbridge abstractions and the method are not meant for the intermediaries or the participants. The Softbridge framework comprises a tool for the computer scientist to align social and technical imperatives in an ICT4D intervention. The overall Softbridge framework is shown in Figure 8-5.

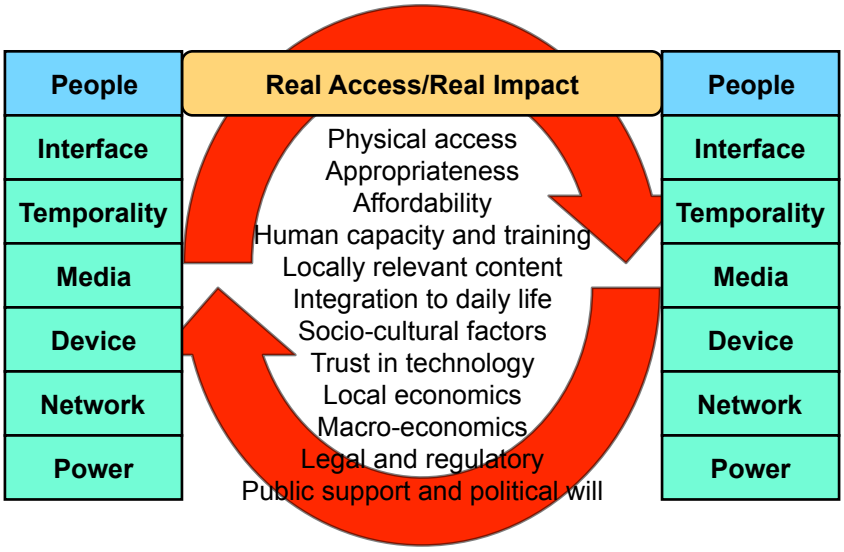

Figure 8-5 The Softbridge framework

The Softbridge framework abstractions and method arose from the iterative process of action research because we were able to abstract common characteristics from reflection on the Deaf telephony and rural telehealth field studies and their prototypes. We used RA/RI criteria during the design, evaluation and reflection stages of each action research cycle. We revised prototypes based on that reflection that in turn led to a better understanding of the Softbridge framework components.

The methods for the two field studies were very similar because they indirectly influenced one another. The initial Deaf telephony bridges instigated ideas about semi-synchronous delivery and media bridging that gave rise to both Softbridge and QoC abstractions. Lessons learnt at one field study informed the umbrella framework that could then be applied to the other field study. Table 8-2 summarises an abstracted trajectory of the SASE method over the course of both field trials. The most significant progression was from an emphasis on the production of prototypes to the encouragement of participants to pursue their own technological agenda.

2003	We acknowledged the need for external evaluation because we were trained software engineers with a social agenda. We contracted bridges.org to assist in that regard.
2004	We began interacting with communities via intermediaries. In both cases we emphasised technological solutions for community needs that we thought were most important.
2005	The software prototypes were not used as much as we had hoped for. We tried to increase usage by redesigning technical features, but prototype use still did not increase.
2006	The communities began to use research infrastructure in other ways. They adopted ICT into their lives, but not the prototypes that we originally envisaged to be most beneficial to them.
2007	We supported the burgeoning alternative uses of the infrastructure we had provided.

Table 8-2 Evolution of the research method

The improvement in participants' training and human capacity enabled this progression to happen in conjunction with our growing understanding of RA/RI criteria. Participants in both field studies came to embrace fundamental Internet access and generic Web 2.0 tools much more than the research prototypes. However, it was the process of experimentation with the prototypes that enabled the underlying infrastructure to be laid, and the consequent increase in ICT skills. As evidence for the integration of ICT into their lives, DCCT took over payments for the monthly ADSL and Internet costs and Canzibe doctors installed their own VSAT. The doctors, together with Transcape, applied the MUTI wireless network approach to share that bandwidth.

Both field studies required substantial effort in coordinating stakeholders, including participants and their coordinating bodies, e.g. the district DoH for rural telehealth; NGOs and intermediaries; and software developers, e.g. post-graduate students and full-time programmers (who were mostly former students). ICT4D research projects also require a great deal of funding for human resources, hardware and travel. In some ways, an ICT4D project leader is most often a project manager. Someone with both technical and social skills needs to manage such ICT4D projects, e.g. one of Heeks' (2008) hybrids. Project management was primarily driven as a software development exercise informed by bridges.org's RA/RI criteria and their '12 habits'. Table 8-3 summarises a synthesis of the latter.

Start by doing some homework*
: Start with the target community. Try to find information about similar communities in other parts of the country. Then look to global literature.

Needs assessment
: Perform this in iterations. The evaluation and reflection phases of each action research cycle become the needs assessment for the next cycle.

Local ownership and champion
: There can be multiple types of champions and not all champions are effective. A champion based in a local NGO is helpful because they take ownership, and tend to stay in the area.

Engage local problem solver*
: NGOs are also a good source of local problem solvers. They need not also be champions.

Form sound partnerships*
: Partner with an intermediary to gain entry to and trust from a community.

Set concrete goals and take small steps
: Take small steps, but take them quickly so participants see and participate in their progression.

Technology-neutral*
: Design for interchangeability at all Softbridge layers.

Involve excluded groups
: Train such groups to empower them to participate. Give them project responsibilities. Use a 'teach the teacher' approach.

Identify and understand external challenges
: Recognise that understanding of underlying social dynamics will unfold over time and that technology can be designed to accommodate such dynamics.

Monitor and evaluate with appropriate tools
: System instrumentation helps triangulate qualitative data.

Make it sustainable
: Sustainability is not the researcher's responsibility. That lies in the hands of the community power structures and government, and can be fostered by local NGOs. Empower the community to help itself.

Widely disseminate
: Popular media such as radio and weeklies is much more effective than academic literature.

Table 8-3 Synthesis of bridges.org's 12 habits from the field studies

This table identifies the key similarities between the two field studies with respect to bridges.org's 12 habits of highly effective ICT-enabled development initiatives. Because of their interaction with us, bridges.org's added four habits to the original eight. These are marked with an asterisk. Again, the similarities between the two field studies argue for the usefulness of bridges.org's work in the field of ICT4D.

The importance of being in the community on a regular basis cannot be stressed enough. The two field studies had drastically different visit schedules. We visited the Eastern Cape infrequently, but often stayed at least a week (see Table D-1). We visited the Bastion on a

weekly basis for several years, but only for a few hours at a time. In both cases, the repeated and regular presence built relationships, and established trust and acceptance within the respective communities. Virtual presence was just as important as physical presence. ICT-based communication between participants and researchers established familiarity with ICT and acted as an example for usage with others. We used SMS, email, IM and the cell phone to keep in constant contact with participants and technical support in the field. Constant contact with intermediaries provided surrogate contact with community participants since they interacted with the community on a daily basis.

8.4 Chapter Summary

This chapter synthesised the reflection on the three components of the Softbridge framework: Softbridge stack, QoC and SASE. The RA/RI criteria were utilised at all Softbridge layers in both design and evaluation of prototypes in the field. The Softbridge stack and QoC were likened to OSI and QoS. Softbridge and OSI stacks are complementary, as are QoC and QoS. The social aspects of the Softbridge framework, by including RA/RI criteria, had several interesting consequences.

Firstly, software developers are compelled to consider the social ramifications of design decisions made at various Softbridge layers. Those social considerations cause the technical aspects to be intermeshed with each other and the people layer as understood using the RA/RI criteria. Secondly, the macro delays inherent to ICT4D communication, combined with a mix of media modalities, entails that 'perfectly' working ICT4D systems are not necessary. On the other hand, 'perfectly' working ICT4D systems are often not adopted because of social reasons. Thus the next social consequence is that the main determinant of the success of ICT4D system is how well it is appropriated by a community, not necessarily the system's technical performance. Both field studies had limited success in terms of prototypes. Some of the challenges were once-off, such as getting the rural wireless network up and running while others were routinely faced, such as training and dealing with theft of components. Lastly, computer scientists need to be open to a given community's imperatives in terms of ICT provision. That does not mean that computer scientists should not pursue their own technological agenda because that agenda is what gets ICT into the field in the first place.

Regardless of whether our prototypes were successful or not at higher Softbridge layers, the result of trying the prototypes out did result in substantial infrastructure in lower Softbridge layers, e.g. the network and devices. From there, increased ICT awareness and dexterity on the part of the participants enables the alignment of social and technical imperatives as the researcher becomes more aware of the social considerations and the participants become more adept with ICT.

Chapter 9: Conclusions

I walk down the same street.

There is a deep hole in the sidewalk.

I walk around it.

Portia Nelson

The design and evaluation of communication systems in developing regions must cope with a variety of technological, social and environmental factors that are quite different from those that can be assumed in developed regions. This ICT4D research effort commenced with two fundamental limitations observed with traditional computer science abstractions for the design and evaluation of communication systems. Firstly, people and their socio-cultural context are not included in conventional design abstractions like OSI. Secondly, technical QoS could not be the sole determinant for successful communication systems because socio-cultural factors are just as, if not more, important. This thesis contributes the socially aware Softbridge stack to bridge the first gap, and QoC for the second. The Softbridge framework combines these two novel abstractions with a socially aware software engineering method. Section 9.1 provides a summary of the contribution. Section 9.2 recommends guidelines for the use of the Softbridge framework. Section 9.3 discusses the limitations and strengths of the thesis. Finally, Section 9.4 suggests avenues for future work.

9.1 Contribution

The contribution of this thesis is the Softbridge framework. The framework provides a useful checklist and guide to ICT4D fieldwork for both newcomers and experienced hands. The framework consists of three components: Softbridge stack, QoC and the SASE method. We chose to address two difficult communication scenarios characteristic of digital divides in South Africa. South Africa is peculiar in that developing regions frequently co-exist with developed regions because of the relics of apartheid. Crafting communication prototypes for the two field studies revealed recurring themes that informed the development of the Softbridge stack, a socially aware design abstraction for the construction of ICT4D communication systems. The Softbridge abstraction incorporates a people layer and the Real Access/Real Impact, or RA/RI, criteria to enable the alignment of technological and social issues. A consequence of the Softbridge design stack was the need for a correspondingly

socially aware approach to the evaluation of ICT4D systems. QoC plays the same role for the Softbridge stack as QoS plays for the OSI stack. QoC posits that social factors help explain why end-users might tolerate macro delays and poor quality in communication systems and conversely, why perfectly functioning communication systems might be shunned and unused. We iteratively developed a series of prototypes based on the Softbridge stack and evaluated them with QoC guided by a socially aware software engineering method, or SASE.

A result of the SASE method was that we also iteratively refined the two novel abstractions based on cyclical reflection. The SASE method had the additional benefit of recursively refining itself via reflection. Together, Softbridge stack, QoC and SASE form the Softbridge framework. Section 9.1.1 recaps the Softbridge stack. Section 9.1.2 explains QoC, and Section 9.1.3 comments on the SASE method.

9.1.1 Softbridge stack

The Softbridge abstraction combines technical and social issues in a reference model for the design of ICT4D communication bridges (see Section 8.1 and Figure 8-1 in particular). Softbridge stack layers include power, network, device, media, temporality, interface and people. Four of the layers are the same as Brewer et al.'s (2005) 'Big 4' (see Figure 3-1). People issues affect all layers and are factored into the model with RA/RI criteria. The Softbridge stack is meant to be complementary to the OSI and TCP/IP stacks (see Figure 8-2). The technical Softbridge layers are conceptually organised similarly to OSI layers except that Softbridge layers are fundamentally interrelated and centred on people factors (see Figure 8-3). The people layer requires software engineers to consider social factors during the design process.

RA/RI criteria were utilised at all layers in the Softbridge stack in order to comprehensively include social issues that arose during both field studies. RA/RI criteria were simple and easy to apply. The NGO was co-located with us in Cape Town. We were able to establish a good rapport with them, and contracted their services to help the research team apply RA/RI criteria to our endeavours. However, any reasonable ICT4D M&E tool, e.g. Universal Access Wheel (see Figure 3-2) could be utilised to inform consideration of the people layer in the Softbridge stack to complement the technical design issues. It follows, then, that socially aware evaluation is required to evaluate ICT4D systems built on the Softbridge stack.

9.1.2 Quality of Communication

The Quality of Communication abstraction, or QoC, focuses on RA/RI criteria to assess how well bridges operate at various layers in the Softbridge stack (see Section 8.2 and Figure 8-4 in particular). The original idea for QoC was that social factors rather than bandwidth could help overcome disadvantages of QoS-challenged networks, e.g. large latency and poor quality. That view implies that QoS is often not applicable to ICT4D scenarios because those environments oblige participants to accept low QoS, thereby negating the need to design specifically for QoS. For example, QoC helps to explain why store and forward systems like SIMBA (Section 6.5.2) and MUTI (Section 7.5.2) could be beneficial. A traditional QoS view infers that users would reject asynchronous communication based on technical performance delay. However, the quality of QoS-poor store and forward communication is as much social as technological. The poor adoption of SIMBA and MUTI prototypes had more to do with social than technical factors. Comparing QoC with QoS in this manner is still in terms of network performance and an individual's perception of the communication service. Over the course of the field studies, QoC became more aligned with the idea that quality is situational. This view is compatible with "quality is in the eye of the beholder" (Bouch et al., 2000), albeit on a social rather than an individual sense. We use RA/RI criteria within the Softbridge stack to reflect on the social aspects of QoC. This is very different from traditional QoS measurement techniques. An implication of QoC is that imperfect systems can be tolerated as long as they address social factors effectively. A further implication is that one could explicitly design imperfect systems. Designing to achieve QoC does not mean minimising delays, as QoS mandates, but rather to maximise social cohesion with ICT. Achieving QoC, or the lack thereof, is a factor of how well ICT4D system addresses RA/RI issues, and was a significant determinant of communication system take-up in both field studies.

Section 7.5.2 described how various QoC aspects inhibited take-up of research prototypes at DCCT. Participants did not use SIMBA no matter how much they needed to communicate with hearing people because SIMBA was text-based. Deaf users eventually told us they wanted to communicate in SASL, a language that defined their culture. Deaf participants did briefly use the real-time text chat despite their awareness of poor grammar and slow typing, but that was because they were communicating with fellow Deaf participants in the Bastion. DCCT participants could not embrace Internet tools like Skype or AIM

because they had temporary privileged access to ICT while at the Bastion that most of their friends and family did not have. Deaf users were also slow to adopt Internet-based video conferencing despite the possibility of SASL communication for that same reason. Camfrog appeared to satisfy technical requirements for real-time SASL language communication, but a lack of a calling circle inhibited usage. However, despite the lack of adoption of research prototypes, many DCCT members continue to take advantage of the Internet connectivity associated with the research infrastructure. The DCCT NGO saw how ICT access was increased by the connectivity and budgeted to sustain its use.

Social factors regarding prototype adoption were also prevalent in the rural telehealth field study, e.g. as described in Section 6.5.2. Clinic nurses would have much preferred to communicate with other nurses at the hospital and their managers, like the discontinued CB radio system had done. Unfortunately, the hospital laptop was put in a doctor's office and it was not readily available to hospital nurses. The doctors took to the technology because it bridged them to colleagues and information, and to friends and family on the Internet. The nurses, like the Deaf users, did not have such a connectivity circle. Regarding MUTI specifically, poor QoC rather than poor QoS was the main inhibiting factor to take-up. Despite the entire range of media and temporal modalities at Lwandile clinic offered by MUTI on both PC and cell phone, the nurses simply chose not to establish social connectivity with the doctors. Of course, the stolen solar panels eventually prevented them from using MUTI, but they had ample time in which to use the tool and they chose not to do so.

Social issues that arose during the Deaf telephony project described in Chapter 6 and the rural telehealth field study described in Chapter 7 motivate placing people at the top and centre of the Softbridge stack (see Section 8.1) and consequently being central to QoC (see Section 8.2). If people do not use ICT to bridge their own social gaps, then no technological bridge can ever span such gaps. Therefore, research methods were necessarily qualitative in nature. One could design for social factors and could become aware of them through a socially aware iterative process of software design.

9.1.3 Socially aware software engineering

Section 5.2 describes how action research espouses the dual imperatives of community and academic goals. In our case, the community goals are empowerment of respective communities via Deaf telephony and rural telehealth. The academic goals are to learn how to

design and evaluate ICT4D systems, as articulated by the research question in Section 4.2. To address both imperatives, we constructed a series of communication prototypes for both field studies as reference implementations for the evolving Softbridge stack and QoC abstractions. By infusing people factors into the design and evaluation processes, the socially aware software engineering, or SASE, method (see Section 8.3) helped us align community and academic goals. Based on our experience in the field, NGOs as intermediaries can form an essential part of that process.

9.2 Recommendations and guidelines

This section recommends guidelines for using the Softbridge framework in the field. These lessons are very similar to the lessons learned by others in the field (see Section 3.3). The main difference is that the Softbridge offers a new theoretical underpinning to the design and evaluation of ICT4D communication systems. We have tried to incorporate many of the lessons learnt into the Softbridge framework. We divide these lessons into simple and sophisticated categories. The guidelines are organised accordingly, and listed below to help one to use the Softbridge framework to align technical and social factors during an ICT4D intervention.

9.2.1 Simple suggestions

- Find an NGO, or a similar body, to act as an intermediary to the community. NGO members will already have some ICT experience although they will likely not be as technical as software engineers. An NGO can act as the primary bridge between the community and the researchers, and can also provide technical support. An NGO is also a good vehicle to train the trainers, and tend to stay resident and keep their expertise in the community.
- Try to communicate about ICT without using acronyms and technical terms when conversing with NGOs and participants. They are not interested in APIs, software development kits and platforms. Use language as one would with one's mother (assuming the mother is not a software engineer!).
- Ask open-ended questions of participants rather than yes/no questions. Many participants will answer 'yes' to any question just to be polite.

- Use the prototypes to communicate between participants and the research team over the Internet. This is useful for debugging and active feedback, and also provides usage data.
- If at a tertiary institutions, hire dedicated programmers instead of using only postgraduate students to build prototypes. Students have too many other responsibilities. Dedicated programmers can respond more effectively to users' needs and deadlines.
- Document your ICT4D project and make it widely available. There are literally thousands of small-scale and large-scale ICT4D activities taking place worldwide. We can all learn from each other's successes and failures, partial or not.

9.2.2 Sophisticated suggestions

- As early as possible, try to figure out exactly what the users really want.
- Address all levels in the Softbridge stack. Recognise that lower levels of the Softbridge stack, e.g. power, network and device, are easier to provide and more likely to succeed at first. Treat problems in the application space of media, temporality, interface and people as opportunities and challenges. The users will not be ready for innovative applications at the start. We must prepare them with basic infrastructure and skills, and also get authority structures to buy into that basic infrastructure and accompanying skills.
- Design so that Softbridge layer components can be swapped out as modules. For example, better ASR could replace human relay operators when the ASR or even sign language recognition becomes more effective.
- The previous point brings about a very subtle aspect of any design stack like Softbridge, OSI or TCP/IP. The whole is always greater than the sum of the parts, and one must be mindful of both the whole and each individual part and how they fit together.
- Last, but not least, practice becoming socially and self-aware.

9.3 Limitations and strengths of the study

The main limitation of this post-positivist action research-driven research is that neither field study is replicable. However, the discussion in Section 5.2.3 established that the epistemology of action research could be made recoverable through stringent application and documentation. We have performed and documented both field studies thoroughly. The knowledge, experience and prototypes are clearly field study-dependent. The comparison and contrast of the design, evaluation and overall methods of these two in-depth field studies

yielded the Softbridge framework. The framework may not work in every ICT4D situation, but it is nonetheless useful. The layers that comprise the Softbridge stack and QoC can act as a checklist for other ICT4D scenarios in conjunction with the iterative SASE method. As the cycles progress, the researchers, community members and intermediaries become more adept at aligning the technical and the social. This process is quintessential experimental computer science, to try something out, and iterate until a desirable empirical outcome is achieved. The SASE method may or may not include quantitative methods. Some may view this as a limitation. However, qualitative methods are not less objective. Our experience and the experience of the UCD4D and IS communities has shown that situated methods are both applicable and beneficial. The networking community within computer science can benefit from these lessons. The Softbridge framework provides mechanisms for network-oriented technologists to design and evaluate ICT4D communications effectively in a socially aware fashion.

9.4 Future work

A tutorial document on the Softbridge framework should be forthcoming. Such a document will enable the framework's adoption and use by other practitioners and researchers. External usage of the framework will also encourage its refinement.

This thesis reports on the results of fieldwork conducted until 2008. Both field studies are still evolving. Section 9.4.1 presents some ideas for future work with the Deaf telephony project and Section 9.4.2 considers future directions for the rural telehealth project.

9.4.1 Deaf telephony

The next generation of SIMBA prototypes must provide a video sign language interface for Deaf users. Video relay can utilise a SASL relay operator in both directions until automated tools become feasible. All Deaf telephony prototypes should also be ported to mobile handsets. The handset should have a high resolution and high frame rate camera on the same side as the display or use an external display. We should also continue to explore the gesture-based interaction. More English and ICT literacy is recommended for DCCT members. Deaf users with poor text literacy skills should get the opportunity to improve text literacy with ICT that will in turn open them up to more ICT literacy.

9.4.2 Rural telehealth

The name of the project should be changed from rural telehealth to rural telephony to emphasize wider use of the network beyond healthcare. Recent developments with the Lwandile village headman's son and a new NGO in the area indicate that locals will leverage the rural WiFi network to pursue community goals. We should expand the network to get the key players in that NGO online. Hopefully, they will take matters into their own hands and expand the WiFi network on their own. The most efficient way to expand the network would be to deploy long point-to-point links with 5GHz WiFi or WiMAX and then distribute locally with 2.4GHz wireless mesh technologies. With WiFi mesh, Push-to-talk (like old CB radio systems) VoIP systems could provide a cheaper alternative to cellular voice services.

EPILOGUE

I walk down another street.

Portia Nelson

The quotes from Portia Nelson represent what I have learnt as a human being by iterating my understanding of ICT4D 'holes'. I have learnt to recognise a few holes and chose to view them not as obstacles, but rather as challenges in a positive way. Aspects of this research endeavour fell into the same holes again and again until we began to recognise them as such – as holes. Then in refining the Softbridge framework, its abstractions and its method, we became *aware*. Over time, that awareness enabled our colleagues, our research beneficiaries and us to learn various mechanisms to avoid some holes and seek alternate streets to stroll.

I now call this 'slaggate' theory. 'Slaggate' is the Afrikaans plural for 'potholes', pronounced 'slag-it' in South Afrikaans (sic) English. ☺ Slaggate theory is my personalised view of what I think Portia Nelson was trying to say. If you go back and look at the beginning of each chapter again, you may now notice that each verse from Portia Nelson matches the theme of the chapter.

Slaggate theory applies well to the ongoing development of the Softbridge framework. Slaggate theory now also guides the way I view almost everything in life: challenges disguised as obstacles that can be dealt with over time in an iterative fashion informed by awareness. When slaggates are viewed as challenges, we can open our minds to alternative ways of solving problems. To me, this is also the essence of computer science and can serve as a metaphor for life in general. Computer scientists often start with an abstraction and iterate through a series of small innovative changes to reach a goal. So do human beings. We just use ourselves as the computer and our thoughts as software. We choose to fall into slaggates, we choose to avoid them, and we choose to walk down another street if need be. We base our own abstractions and methods on the abstractions and methods of others and walk on down the road.

I'm not saying Softbridge is *the* only way to do ICT4D. I'm also not saying slaggate theory is *the* model for everyone. However, Portia Nelson nailed it all on the head with these five short verses. At least she nailed it on the head for me!

Autobiography in Five Short Chapters
By Portia Nelson

I
I walk down the street.
There is a deep hole in the sidewalk.
I fall in.
I am lost…I am helpless.
It isn't my fault.
It takes forever to find a way out.

II
I walk down the same street.
There is a deep hole in the sidewalk.
I pretend I don't see it.
I fall in again.
I can't believe I'm in the same place.
But, it isn't my fault.
I still takes a long time to get out.

III
I walk down the same street.
There is a deep hole in the sidewalk.
I see it is there.
I still fall in – it's a habit.
My eyes are open.
I know where I am.
It is my fault.
I get out immediately.

IV
I walk down the same street.
There is a deep hole in the sidewalk.
I walk around it.

V
I walk down another street.

Black, Claudia, *Repeat after me*,
Denver, M.A.C. Printing and Publications, 1985.

Appendix A Deaf telephony action research cycles

This appendix chronicles the action research cycles of the Deaf telephony field study analysed in Chapter 6. The action research cycles were linked to a series of prototypes developed for DCCT from 2002 to 2008 and can be grouped as shown in Figure A-1. This appendix has a section for each cycle. Each cycle is reported in standard action research stages: diagnosis, plan action, implement action, evaluate action and reflection. Within the prototype groups, the reflection and diagnosis stages of successive cycles are combined. An overview table precedes each cycle, showing the timeframe, location, local champion, intermediary, prototype name, coder(s), supervisor(s), and references to technical details.

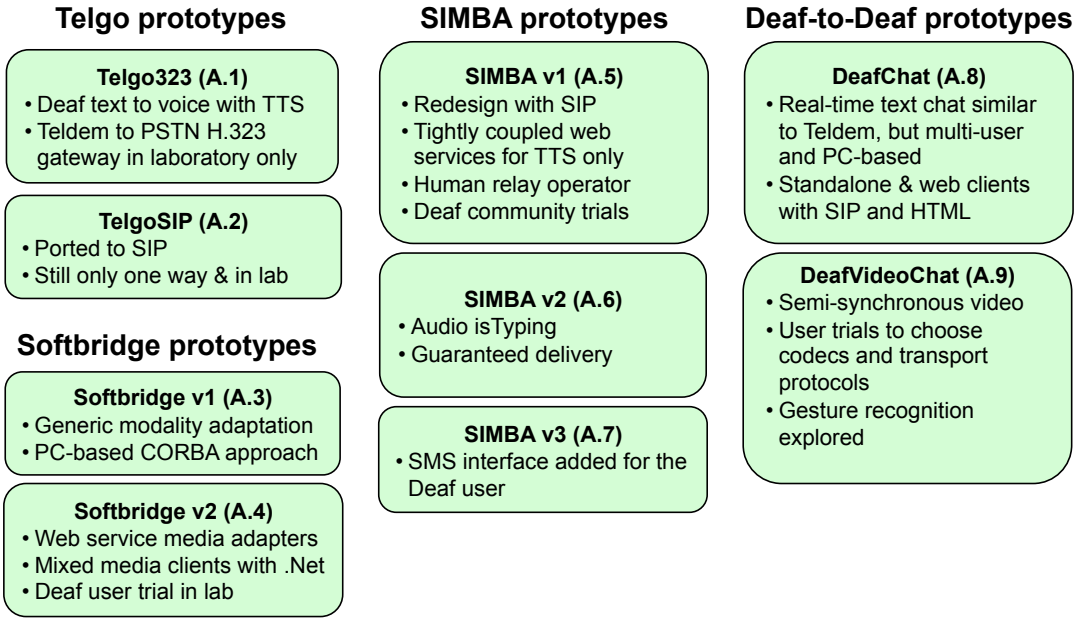

Figure A-1 Deaf telephony prototypes

The Deaf telephony prototypes are grouped along several architectural themes. The Telgo prototypes were uni-directional bridges from a Deaf user with a Teldem text terminal to a hearing user on the PSTN with TTS. The Softbridge prototypes provided fully automated Deaf-to-hearing bridges between text and speech using Instant Messaging, TTS and ASR. The SIMBA prototypes used SIP-based Instant Messaging and a human relay operator instead of ASR. The Deaf-to-Deaf prototypes provided synchronous text messaging on PCs similar to the Teldem and semi-synchronous video messaging to support sign language communication.

A.1 Telgo323

Telgo323 was our first attempt at a Deaf telephony solution. During this cycle, we engaged an intermediary to the Deaf community rather than the community itself. Together we devised an overview of telephony options for members of DCCT (Glaser & Tucker, 2001). An MSc student at Rhodes University designed and built an initial prototype (Penton et

al., 2002). Telgo323 converted a Deaf user's text on the Teldem to speech on the telephone. We felt that a two-way conversation was necessary to demonstrate the prototype to Deaf users, and therefore did not show it to them. Table A-1 provides an overview of the cycle.

Cycle overview	*Description*
Timeframe	Early 2002
Community	N/A
Local champion	N/A
Intermediary	Meryl Glaser (UCT)
Prototype	Telgo323
Coded by	Jason Penton (Rhodes)
Supervised by	William Tucker (UCT/UWC), Alfredo Terzoli (Rhodes)
Technical details	(Glaser & Tucker, 2001; Penton et al., 2002; Penton, 2003; Tucker et al., 2002)

Table A-1 Telgo323 cycle overview

A.1.1 Diagnosis

A prior Teldem field study showed that ICT could be designed with adequate functionality and the best of intentions yet still not be adopted by the target community (Glaser, 2000). Deaf users approved of the Teldem concept, but could not, or would not integrate the Teldem into their lives. The Teldem exhibited frequent technical faults that required a tedious reset process. It was difficult to discern if the displayed text came from a person or the Teldem itself. If the former were true, there was no way for a Teldem user to identify the other caller. When the latter occurred, the text was often incomprehensible. There were also financial issues with the Teldem. A Deaf user needed access to a Teldem, and had to pay for calls. The duration of text-based calls was longer than voice calls due to type-time and was therefore expensive. In addition, some Deaf users felt that hearing users would use their phone plugs when the Teldem was absent and they would have to pay for it. Such problems resulted in Deaf users not trusting the Teldem.

At the time, we considered the Teldem to be the only real-time communication option to give DCCT members an independent means to communicate with anyone, both hearing and Deaf users. One could argue that voice-based synchronous communication could be substituted by asynchronous text-based mechanisms. However, we felt synchronous communication was the only way to reliably ensure that a communicative exchange was actually happening. It was therefore imperative to use synchronous mechanisms. The main problem, as we saw it, was to bridge synchronous communication from Deaf to hearing users.

The technical challenge was to convert text on the Teldem to voice on the PSTN, and back again.

A.1.2 Plan Action

At the time, the Internet offered many text and video-based opportunities for Deaf-friendly communication. The Teldem had no connection to Internet. If the Teldem could interface to the Internet via the PSTN, the Deaf participants' connectivity circle could grow and the prospects of communication independence could increase as well. To work toward this aim, we planned a series of bridges utilising the Teldem (Glaser & Tucker, 2001). The first Deaf telephony bridge would be a system where a human operator relayed communication from a Teldem user to a hearing party on a telephone. We also conceived of various software solutions that offered connectivity between the Teldem and the Internet. A final bridge enabled text and speech to be automatically converted and relayed between text and voice users in real-time.

A.1.3 Implement Action

Directly after presenting the ideas for these bridges at a local telecommunications conference (Glaser & Tucker, 2001), Jason Penton, a Masters student at Rhodes University, offered to code the last bridge because it fitted within his Masters project to create VoIP services with H.323 (Penton, 2003). We called his prototype Telgo323 because it enabled a Teldem to connect to a telephone on the PSTN with ISDN via H.323 (Penton et al., 2002; Tucker et al., 2002). The bridge was implemented in one direction (see Figure A-2). The Deaf user typed text on a Teldem that was converted to speech and delivered as voice to a hearing user. The reverse direction, from speech to text, was beyond the scope of Jason's thesis, and was left as future work. At the time, the Softbridge concept was gestating. Figure A-3 shows the Softbridge stack design of Telgo323 in hindsight.

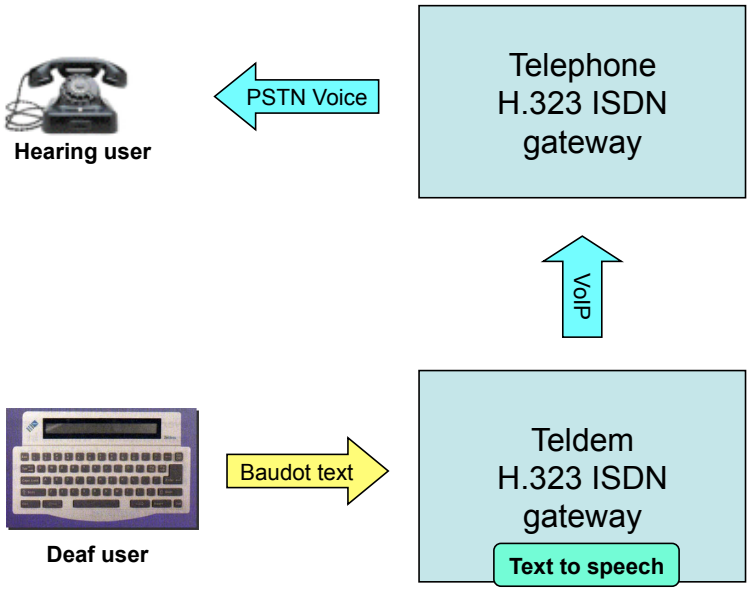

Figure A-2 Telgo323 architecture

The Telgo323 prototype relayed text from a Deaf user to voice for a hearing user. The Teldem issued a real-time stream of Baudot-encoded text characters to an H.323 ISDN gateway enhanced with an open source text-to-speech (TTS) engine from Festival. The converted voice was relayed to a telephone with an H.323 gateway. The gateways resided in the IP space where we were able to make software modifications.

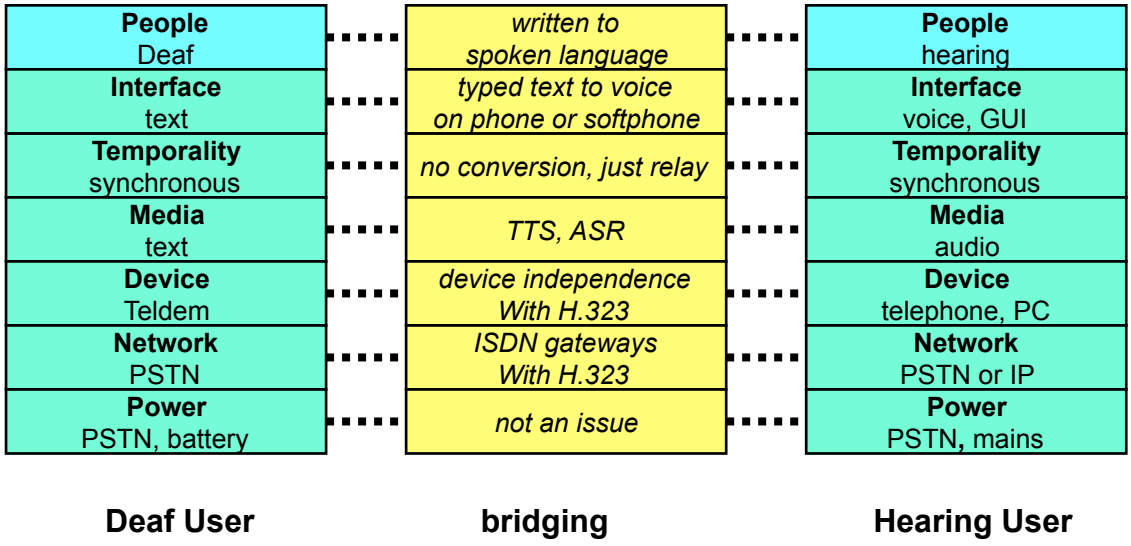

Figure A-3 Telgo323 Softbridge stack

Telgo323's aim was to provide a two-way automated translation bridge between a Deaf user using a Teldem and a hearing person with a telephone or soft phone. Telgo323 only implemented the communication in one direction, using an open source text-to-speech engine called Festival to relay text typed on the Teldem to a handset connected to a PSTN-based PBX or an H.323 endpoint, a soft phone running on a PC.

A.1.4 Evaluate Action

The Telgo323 prototype only worked in one direction from a Deaf user to a hearing user. Because the Teldem's Baudot encoding was non-standard, the struggle of returning text to the Teldem caused us to abandon that task. Another reason to postpone the speech-to-text delivery was that TTS technology worked fairly well at the time, but ASR was difficult to train over the phone. Furthermore, open source ASR tools did not easily recognize South African accented English. Telgo323 was designed to 'plug and play' the ASR and TTS tools so that as technology improved, a new tool could slot into the architecture.

A.1.5 Reflection/Diagnosis

Telgo323 work ceased because Jason completed his Masters (Penton, 2003). In order to test the tool with a Deaf user we needed to convert speech to text, but first we wanted to move the implementation of VoIP to SIP (Handley et al., 1999). SIP was an IETF competitor to the ITU's H.323 protocol family and has since replaced H.323 as the VoIP protocol of choice. We decided the next step would be to port Telgo323 to SIP.

One concern for using VoIP, with the intention of eventually deploying this solution over the Internet instead of just inside our laboratory, was that VoIP in South Africa was illegal (DoC, 1996; DoC, 2001). We felt that the legislation hindered the take up of tools like Telgo323 and kept South African Deaf people even more disadvantaged. We hoped the situation would change and indeed VoIP eventually became legal in 2005 (DoC, 2005).

A.2 TelgoSIP

Later in 2002, two interns from the Indian Institute of Technology (IIT), Harsh Vardhan and Nitin Das, came to UWC to port Telgo323 to SIP for their final year project. We still did not engage the Deaf community. However, this prototype is included as an action research cycle for completeness. Table A-2 provides a brief overview.

A.2.1 Plan action

The intention for the interns was only to port Telgo323 to SIP, and not be concerned with implementing the reverse direction (with ASR and text-to-Baudot conversion). We knew this prototype would not be sufficient to trial with a Deaf user, so we did not even plan to do so. We would, however, test the technical performance in the laboratory.

Cycle overview	*Description*
Timeframe	Mid 2002
Community	N/A
Local champion	N/A
Intermediary	Meryl Glaser (UCT)
Prototype	TelgoSIP
Coded by	Nitin Das and Harsh Vardhan (IIT/UWC)
Supervised by	William Tucker (UCT/UWC)
Technical details	Not published

Table A-2 TelgoSIP cycle overview

A.2.2 Implement action

We completed the port from H.323 to SIP and called the new prototype TelgoSIP. TelgoSIP used the VOCAL open source SIP platform from Vovida (http://www.voip-info.org/wiki/view/VOVIDA+SIP). The PSTN gateway was implemented with the VOCAL stack on a QuickNet card. TelgoSIP offered a cleaner solution with modification of a user agent (UA) client instead of modifying gateways as with Telgo323. We still used open source Festival to convert text to speech. The speech was then sent via the QuickNet card using an unmodified VOCAL gateway. The TelgoSIP architecture is shown in Figure A-4. The Softbridge architecture was virtually identical to that of Telgo323 as shown in Figure A-3.

A.2.3 Evaluation action

Because neither Telgo323 nor TelgoSIP was able to successfully work out the reverse direction, we did not test either prototype with a Deaf person. We brought out another pair of Indian interns to work on that problem in 2003, but they were not able to solve the problem. We therefore aborted what would have been a second TelgoSIP cycle. We had learned that the Teldem was a failure in terms of social take up in South Africa, and was also so difficult to work with on a technical level that further development was unjustified.

A.2.4 Reflection

We decided to abandon the Teldem, but did not abandon the goal for a Deaf-to-hearing relay bridge. The Telgo323 and TelgoSIP prototypes demonstrated a software bridge concept that, when completed in the opposite direction, could enable Deaf people to communicate synchronously with hearing people on the PSTN and Internet. The most obvious bridge was between Deaf and hearing people accomplished by bridging between voice and text modalities. Another bridge was at the network level between the PSTN and the Internet, and

consequently between physical devices, e.g. handset, Teldem and soft phone. Another network bridge was between high and low bandwidth, because most of the data transport between gateways and/or user agents was text that required much less bandwidth than voice. All of this bridging meant that anybody, hearing or Deaf, with access only to a PSTN line via a handset or Teldem could communicate via IP on the Internet.

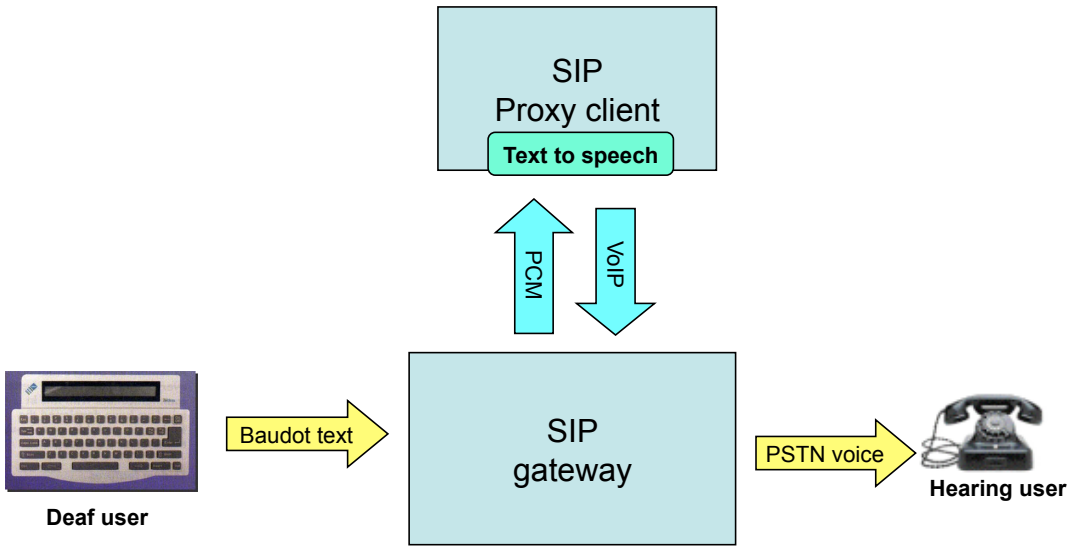

Figure A-4 TelgoSIP architecture

TelgoSIP ported Telgo323 to SIP. TelgoSIP modified a SIP client that acted as a proxy for the PSTN-connected Teldem. Modification at the client level significantly decreased the complexity of the overall design. TelgoSIP did not provide hearing-to-Deaf communication, and therefore was not tested with end-users.

A.3 Softbridge v1

While the Telgo prototypes were in development, another MSc student at UCT started working on an approach based on generic adaptors between various disparities. The most obvious adaptation was between text and voice. The preliminary Softbridge abstraction emerged from this effort. This cycle still did not engage the Deaf community, but abandoning the Teldem encouraged IP-based opportunities to build Softbridge reference implementations. Table A-3 provides an overview.

A.3.1 Diagnosis

To perform action research, we needed to test a fully functional bridge with actual end-users. We considered establishing a manual bridge with a human relay operator. Human relay call centres were already in place throughout developed regions, mostly subsidised by

government and a respective telco. However, in South Africa, as in many developing regions, the incumbent telco did not provide this service simply because it was perceived not to be able to generate revenue. Our research group did not have the funding or the clout to establish a relay service. The Teldem, produced by Telkom, was difficult for us to integrate into a solution. We had to consider other devices besides the Teldem, and revisited our conceptual bridges (Glaser & Tucker, 2001). The chat interface on the PC appealed because it resembled an Instant Messaging approach.

Cycle overview	*Description*
Timeframe	Mid 2002
Community	N/A
Local champion	N/A
Intermediary	Meryl Glaser (UCT)
Prototype	Softbridge
Coded by	John Lewis (UCT)
Supervised by	William Tucker (UCT/UWC), Edwin Blake (UCT)
Technical details	(Lewis et al., 2002)

Table A-3 Softbridge v1 cycle overview

A.3.2 Plan action

A preliminary Softbridge abstraction shown in Figure A-5 emerged from the design specifications of the Telgo and Softbridge prototypes (Lewis et al., 2002). The model concentrated on media and temporality bridging. However, Deaf telephony also required adaptation at other layers in the Softbridge stack (see Figure A-6).

A.3.3 Implement action

A reference implementation was initiated with CORBA (Common Object Request Broker Architecture) as the platform for inter-process communication, but was not completed. Therefore, this cycle emphasised preliminary conception of the Softbridge abstraction. Unlike in the OSI model, the user application itself, not the application network API, was included in the design. The text relay bridge application required media and temporality bridging. Another significant difference from the OSI model was that communication modalities could be converted, or adapted, from one to another based on user capabilities. Thus, it was clear that the user must be included in the Softbridge stack.

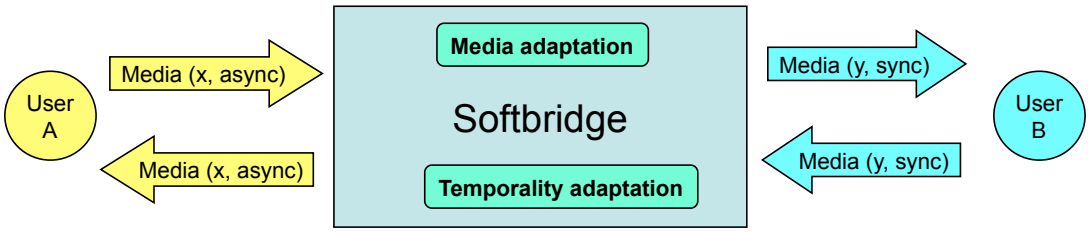

Figure A-5 Generic Softbridge approach to Deaf telephony

The early Softbridge approach adapted various forms of media in and out, e.g. text, voice or video. Softbridge also adapted delivery of media between synchronous and asynchronous temporalities, creating a semi-synchronous form of delivery. The adaptations did have negative quality consequences, however. Text-to-speech and vice versa incurred quality degradation of the message content, and semi-synchronous communication incurred latency in message delivery.

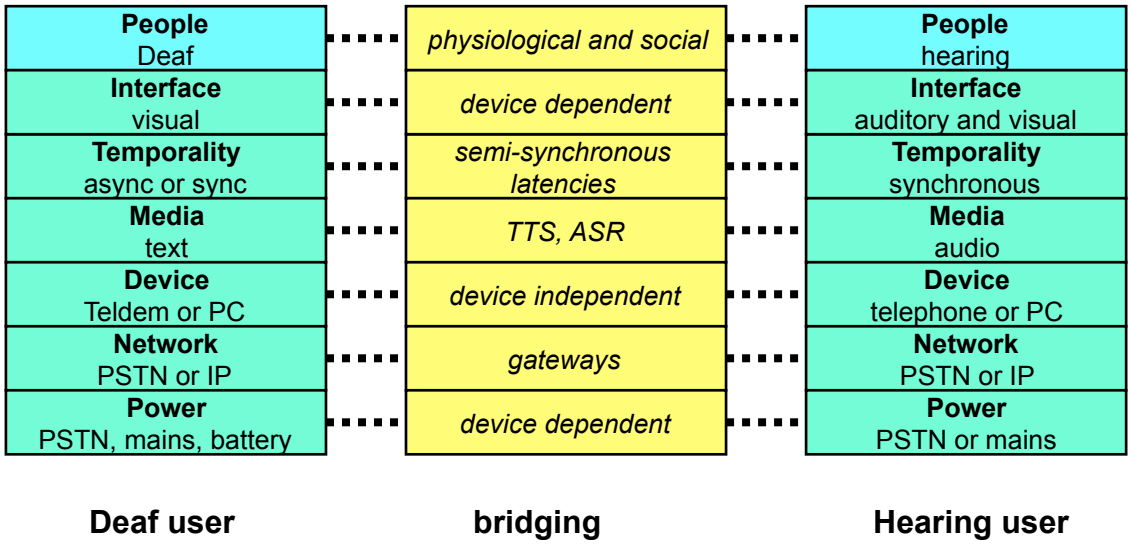

Figure A-6 Fully automated text relay Softbridge stack

Whereas the Telgo prototypes implemented bridging as part of the Deaf telephony application itself, the initial Softbridge prototype moved the media and temporality adaptation out of the application into middleware. This distinction was significant to the design process in order to hide bridging from the users. Media adaptation could not be hidden so easily. The Deaf user knew the text was being converted to speech, and the hearing user was also painfully aware that a TTS engine was being used. The temporality bridging was more interesting. Both Deaf and hearing users would be aware of the delays incurred due to the TTS and ASR adaptation even though they most probably would not realise the extent to which asynchronous Instant Messaging was being converted to synchronous VoIP.

A.3.4 Evaluate action

Softbridge design implied that bridging synchronous and asynchronous temporalities could produce semi-synchronous exchange. Communication quality in the conventional QoS sense was obviously degraded by the large latencies incurred by media adaptation with TTS and ASR. One research aim was to determine if and how those quality problems could be

overcome. While TTS functioned reasonably well, we knew ASR would be problematic. Furthermore, temporality adaptation between asynchronous text and synchronous voice introduced delays into the system, especially for the hearing user. Later, we would instrument the code to record these delays, and also explore ways to measure the quality of the TTS and ASR output.

A.3.5 Diagnosis/Reflection

This cycle produced an initial Softbridge abstraction that was mostly concerned with media and temporality bridging. However, other bridges were also relevant to bridge between Deaf and hearing users with different types of interfaces, devices, networks and their power systems. These considerations would coalesce in the Softbridge models to come. However, the task remained to build a Softbridge prototype that could be tested with the Deaf community.

A.4 Softbridge v2

The preliminary Softbridge abstraction began to take shape in a second Softbridge reference implementation that successfully provided a bi-directional Deaf telephony system. The action research method also improved during this cycle because of the first engagement of the Deaf community with a Softbridge prototype. We tested the prototype with a single literate Deaf person who provided valuable input about the prototype and more importantly about the social processes surrounding the introduction of such technology. Table A-4 provides an overview.

Cycle overview	*Description*
Timeframe	Late 2002 – mid 2003
Community	DCCT
Local champion	N/A
Intermediary	Meryl Glaser (UCT)
Prototype	Softbridge v2
Coded by	John Lewis (UCT)
Supervised by	William Tucker (UCT/UWC), Edwin Blake (UCT)
Technical details	(Lewis et al., 2003; Tucker, 2003; Tucker et al., 2003a, 2003b)

Table A-4 Softbridge v2 cycle overview

A.4.1 Plan Action

The plan was to provide Deaf-to-hearing communication in both directions. Leveraging the ease of IP-based tools, we planned to employ an IM interface on a PC for the Deaf user.

The system would convert IM text to voice for the hearing user on some form of audio device, and convert the hearing user's spoken voice back to text for delivery to the Deaf user. We designed a bi-directional prototype based on the early stages of the evolving Softbridge concept (see Figure A-7). We named the prototype Softbridge, but this should not be confused with the Softbridge abstraction. Here, the Softbridge prototype was an instance of the Softbridge abstraction (as were all subsequent Deaf telephony prototypes in one form or another).

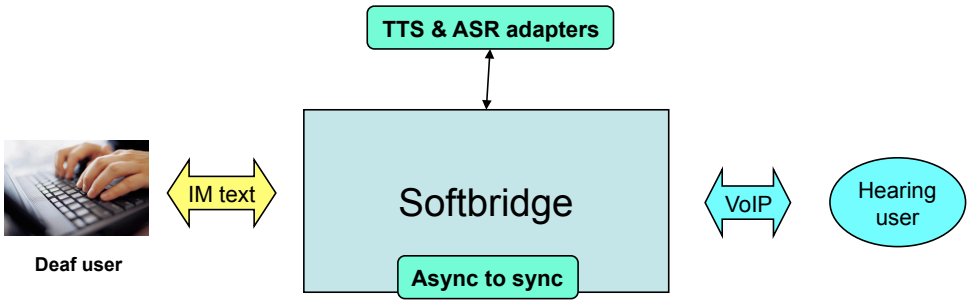

Figure A-7 Instant Messaging-based Softbridge architecture

The Softbridge prototype would replace the Teldem device with an Instant Messaging client running on a PC. The Softbridge would automatically adapt between voice and text, and also between asynchronous Instant Messaging for the Deaf user and synchronous VoIP for the hearing user. The adaptation between text and voice would be implemented with web services. Note the only difference between this architecture and the one shown in Figure 6-4 is the name of the prototype, Softbridge.

A.4.2 Implement Action

The actual architecture for the implemented prototype is shown in Figure A-8, and was described by Lewis et al., (2003). The system architecture was based on a generic Softbridge core with clients specifically built for Deaf telephony. A Jabber-based IM client coded with .Net provided text in and out for the Deaf user. The hearing user also used a Jabber client, but for speech. We also built a hearing client that had both voice and text so the hearing user could see what the Deaf user typed in addition to hearing the TTS-generated speech. We also wanted the hearing user to be able to type messages to the Deaf user when the ASR failed to deliver intelligible text. The TTS and ASR engines were wrapped as loosely coupled web services, thus making them very easy to plug and play.

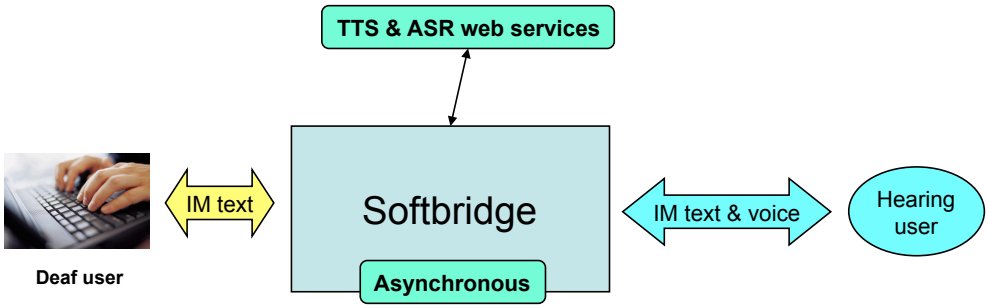

Figure A-8 Softbridge v2 architecture

The actual architecture differed slightly from the planned approach shown in Figure A-7. Both text and voice transport were implemented with an asynchronous protocol. That meant no adaptation to synchronous VoIP. We reasoned this was acceptable because there were already large delays introduced by TTS and ASR adaptation. Those adapters were loosely coupled web services. We built a variety of clients for the hearing user. For example, one had voice only and another had both voice and text so the hearing user could see exactly what the Deaf user typed.

Instead of using real-time VoIP, a speech clip of maximum 2MB was packaged into XML (eXtensible Mark-up Language) messages to and from a modified Joey server (an open source Jabber server). The modified Joey server effectively became a Softbridge server. The speech XML packets were delivered with XMPP, Jabber's asynchronous protocol. Therefore, no temporality adaptation was required or performed. The intention was to deliver the voice messages as quickly as possible to appear semi-synchronous. However, the TTS and ASR media adaptation in both directions introduced additional delay and also often distorted the message content.

We tested the prototype with a Deaf user who was somewhat unique in that he was PC literate and also had some experience with research studies (Tucker et al., 2003b). We built several clients to experiment with different types of bridging, mostly at the media layer (see Figure A-9). The Deaf user client was text in/text out. The hearing client allowed us to pick and choose media capabilities. We experimented with the following combinations: text & TTS in/text out, TTS in/text out or TTS in/ASR & text out. The reason for the combinations was to use text to clarify the output of the TTS and ASR. We began the experiment with instructions interpreted to SASL, then used the tool itself to convey instructions to the Deaf user.

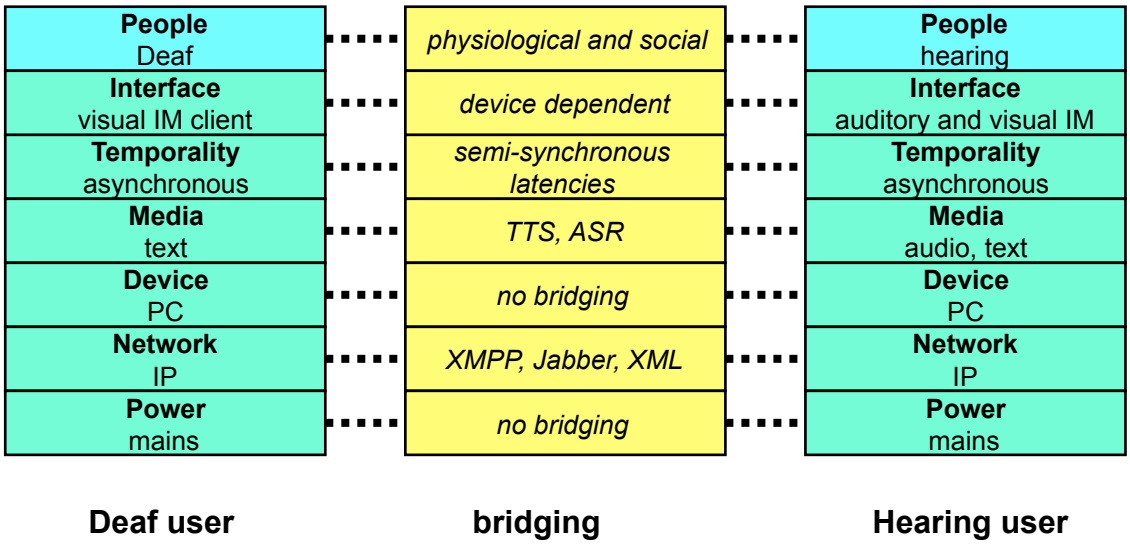

Figure A-9 Softbridge v2 Softbridge stack

For the Softbridge v2 prototype, bridging was not necessary at the lower three Softbridge stack layers. We used this prototype and several client interfaces to conduct an experiment with a Deaf user.

A.4.3 Evaluate Action

We found that the Deaf user treated the IM client like a Teldem. He was not aware that characters were not being sent one at a time, but rather in page mode, or one message at a time. He also used the GA terminator as if in half-duplex mode. He informed us that Deaf users would type English slowly, and likely with SASL grammar. He gave us some examples, and of course, the TTS engine could only pass on what it received. On the hearing side, TTS messages arrived unexpectedly. The natural rhythmic exchanges in voice conversation were disrupted by the delays caused by typing time and TTS conversion.

A.4.4 Reflection

Our intermediary had long urged us to test the prototype with real Deaf users; that building solutions in the laboratory was pointless. The compromise was to test a solution in the laboratory with a Deaf user. We had emphasised the Deaf user interface, but learned that we also had to address the needs of hearing users. A case in point was the way that the TTS speech appeared without warning. The Deaf user had a persistent textual representation of the conversation in the IM interface. However, a hearing user with an audio-only interface was at a disadvantage not being able to see the conversation in order to rescue the misunderstandings due to spelling/grammar mistakes and poor ASR conversion.

The MSc student had devoted a substantial amount of time to the technical implementation of the Softbridge prototype and its clients. He managed to bridge voice from the Jabber-based platform to an H.323 soft phone client. Unfortunately, the effort ceased prematurely before an intended H.323 gateway was provided to connect the system to the PSTN. Implementation interruptions of this sort had happened several times already because the lead programmer was an MSc student who either graduated or terminated their studies.

A.5 SIMBA v1

This cycle continued the firming up of the Softbridge abstraction, and instigated a completely different reference implementation. SIMBA v1 provided bi-directional Deaf-to-hearing communication to the PSTN with a human relay operator. This cycle produced the first full-scale engagement with the Deaf community at the Bastion of the Deaf in Newlands. The DCCT NGO abetted the intervention. We visited the Bastion twice weekly where SIMBA was tested with a number of Deaf people who participated in a PC literacy course. Table A-5 provides an overview.

Cycle overview	*Description*
Timeframe	Mid 2004 – mid 2005
Community	DCCT members
Local champion	Stephen Lombard (DCCT)
Intermediary	Meryl Glaser (UCT), DCCT staff
Prototype	SIMBA v1
Coded by	Sun Tao (UWC)
Supervised by	William Tucker (UCT/UWC)
Technical details	(Blake & Tucker, 2004; Glaser & Tucker, 2004; Glaser et al., 2004, 2005; Sun & Tucker, 2004; Tucker, 2004; Tucker et al., 2004)

Table A-5 SIMBA v1 cycle overview

A.5.1 Diagnosis

Several concerns emerged from the initial Softbridge trial. Firstly, we had to trial the technology with more users. However, Deaf users from the DCCT community would struggle with both PC and text literacy, causing problems for both Deaf and hearing users. Secondly, ASR was not adequate for generalised recognition. Lastly, we needed to put more students onto the project to avoid relying on only one programmer.

A.5.2 Plan Action

To begin to address these issues, we planned a small PC lab for the Bastion with Internet connectivity. We also needed a PC literacy course specifically dedicated to the target

Deaf community so they could learn to use those computers. We also assigned parts of the project to several more students, one of who came up with the next prototype architecture shown in Figure A-10.

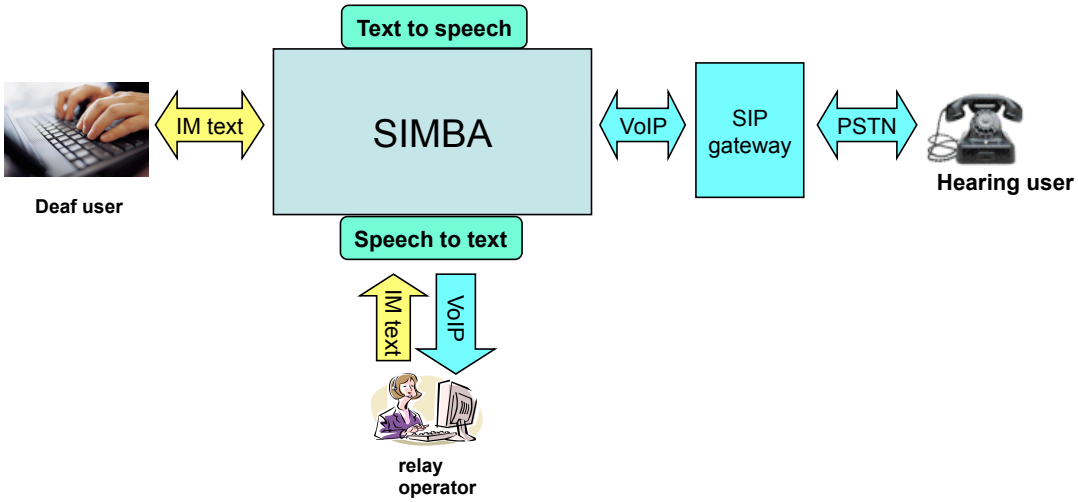

Figure A-10 SIMBA v1 architecture

SIMBA v1 was similar in design to the previous prototype, but had several key differences. SIMBA had tightly coupled web-services for TTS and ASR, replaced ASR with a human relay operator (though still wrapped as a web service), provided IM with SIP instead of Jabber and implemented VoIP with SIP instead of H.323. SIMBA was intended from the start to breakout to the PSTN.

A.5.3 Implement Action

In mid-2004, Glaser et al. (2005) trained 20 Deaf people on basic PC literacy skills at the Bastion using the newly installed computer lab equipped with ADSL broadband connectivity. The course prepared participants for the trial of the next text relay prototype (Glaser et al., 2004). We spent two afternoons a week helping them get accustomed to typing, email and Internet. We also hired a Deaf assistant (a part-time DCCT staff member) to work with Deaf users, and an interpreter to help us interview the Deaf participants.

The SIMBA prototype enabled communication between a Deaf person using an IM client on a PC situated at the Bastion and a hearing person using a phone or cell phone. SIMBA had several significant differences from the prior Softbridge prototype (see Figure A-10). SIMBA bridged asynchronous IM with real-time voice with both VoIP and the PSTN. The Softbridge layers are shown in Figure A-11.

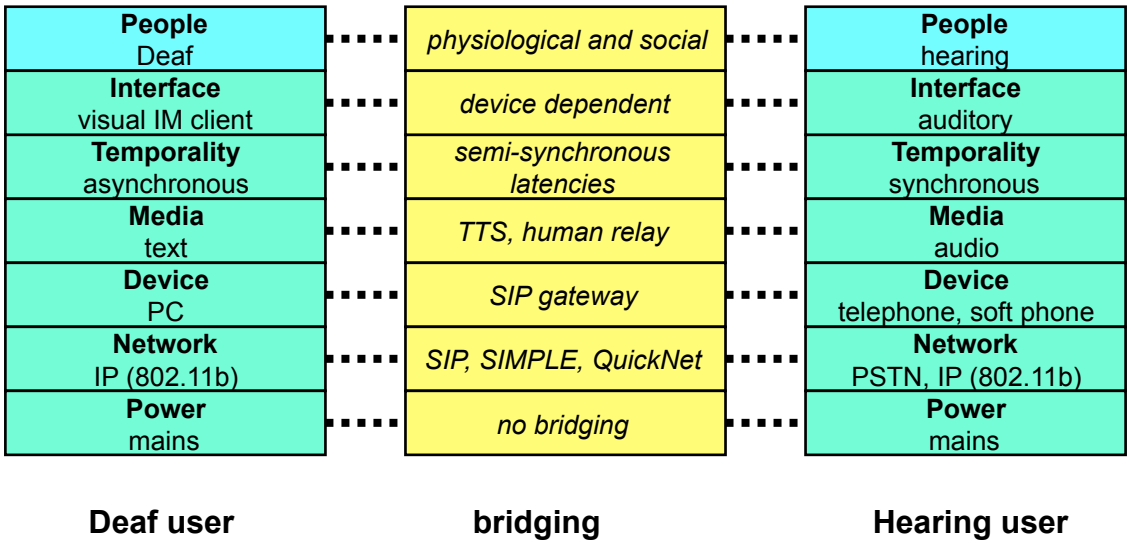

Figure A-11 SIMBA v1 Softbridge stack

SIMBA v1 provided the next reference implementation of the Softbridge abstraction. Several modifications were based on previous experience. A human relay operator replaced the ASR with an interface wrapped as a web service so it could be easily replaced at a later date. SIMBA also bridged asynchronous IM text to fully synchronous VoIP with SIP and a SIP gateway to the PSTN. Hearing users could use a variety of devices: telephone, cell phone and PC-based soft phone.

A.5.4 Evaluate Action

Between the PC literacy class in July 2004 and the introduction of SIMBA in December, an average of six Deaf people came every Wednesday, and five people every Thursday to the PC lab at the Bastion. We had installed five PCs with video cameras. When we were not there, the PCs were covered with a cloth. This indicated that DCCT staff wanted to take care of the machines. However, no one would use them while they were covered. Demonstrating more dedication to the project, DCCT built a dividing wall in the office to create a distinct PC lab within their office space.

In 2005, we hired one of the PC literacy class participants (a part-time DCCT staff member) to keep the lab open during the day four days per week. Attendance averaged three people per day. We still visited twice weekly for two-hour research sessions, but the attendance during this cycle dropped off to as low as two people per session. We began exposing Deaf participants to SIMBA during these sessions.

We asked all potential SIMBA users, Deaf and hearing, to sign research consent forms (see Appendix C). This was a long and drawn out process. Deaf people signed fifteen consent forms, and hearing people completed fourteen. Before initiating a SIMBA call, we would call

the hearing recipient to inform them what was happening. Many of the initial SIMBA calls were hindered by the fact that the hearing people called were working at the time or the system malfunctioned or crashed.

We instrumented SIMBA to collect usage statistics and record conversation transcripts. We also added instrumentation to measure the delays in the various stages of the Deaf-to-hearing communication process. However, so few calls were made, the usage statistics were not useful. The only successful SIMBA calls were made between one of the DCCT staff and a hearing social worker assigned to DCCT. One of those calls was 45 minutes long, but most of them were much shorter. SIMBA transcripts were used to determine that hearing people could indeed understand the voice synthesised from Deaf text despite poor spelling and grammar (Zulu and Le Roux, 2005).

A.5.5 Reflection/Diagnosis

Engagement with more Deaf participants during the cycle led to the recognition of several significant challenges. Most importantly, both textual and PC literacy was evidently lacking. We began to address these deficiencies with training and follow-up sessions (Glaser et al., 2004; Glaser et al., 2005), yet both text and the PCs continued to intimidate the Deaf users. Typing skills were so poor that the scheduled research sessions consisted mostly of practice with a typing tutor. During the weekly visits in 2004, we observed that another reason Deaf participants were not using Internet-based communication tools was that they had no one to email with, and certainly no one to IM with as their friends and relatives did not have access to ICT at home or at work.

A number of technical issues arose from the SIMBA prototype. This was to be expected because it was the first used outside of the laboratory. There were niggling user interface issues such as faulty scrolling and presence that were easily fixed. More serious problems involved continuous rebooting of the system components in order to get the system ready to make a call.

The research protocol also hindered usage of SIMBA because we insisted that all users, Deaf and hearing, sign consent forms. This proved difficult because we had to rely on the Deaf participants to deliver and return the signed consent forms from their hearing co-participants. They often did not understand that we wanted them to do this. In the end, we

dropped the requirement for hearing participants since we were most interested in building solutions for Deaf people. We were also not recording the hearing user's voice, although we did record the relayed text. It was telling that the most successful SIMBA experiences were performed at the DCCT premises between two staff members (one Deaf, one hearing).

A.6 SIMBA v2

We hired the lead student from the previous cycle, Sun Tao, to code for the project full-time after he finished his MSc. His first task was to fix bugs and to provide awareness features for both Deaf and hearing users. This resulted in an innovative audio isTyping awareness feature that let the hearing user 'hear' when the Deaf user was typing. Another MSc student wrapped SIMBA with a guaranteed delivery framework for both synchronous and asynchronous communication. SIMBA trials continued on a weekly basis, with very little change in attendance and usage. Table A-6 provides an overview.

Cycle overview	*Description*
Timeframe	Late 2005
Community	DCCT members
Local champion	Stephen Lombard (DCCT)
Intermediary	Meryl Glaser (UCT), DCCT staff
Prototype	SIMBA v2
Coded by	Sun Tao (UWC), Elroy Julius (UWC)
Supervised by	William Tucker (UCT/UWC)
Technical details	(Hersh & Tucker, 2005; Julius, 2006; Julius & Tucker, 2005; Sun, 2005)

Table A-6 SIMBA v2 cycle overview

A.6.1 Plan Action

This cycle's main focus was to fix the bugs in SIMBA v1 and make SIMBA v2 more usable and reliable. We had noted that the long latencies made communication difficult for hearing users by upsetting expected voice conversation rhythms. We planned to leverage IM awareness and presence mechanisms to deal with such macro latency. A simple message on the IM client GUI (graphical user interface) would let the Deaf person know that someone was speaking, and furthermore, that speech was being converted to text. We wanted to provide a similar awareness feature for the hearing user, such that the hearing person would know that text was being typed and/or converted to voice. We would play a tone to let the hearing user know that this was happening. We called this 'audio isTyping'.

Another MSc student joined the project. His research topic was to explore guaranteed delivery of semi-synchronous messaging (Julius & Tucker, 2005). The purpose of his study

was to demonstrate to the Deaf user that SIMBA could guarantee delivery of messages where SMS could not.

Since we had poor participation during the weekly sessions in the previous cycle, we decided to concentrate on the DCCT staff members who were working at the Bastion. In order to do that, we had to expand the wireless network and put PCs on their office desks.

A.6.2 Implement Action

We identified and fixed many SIMBA bugs, and added a number of features during this cycle: configuration parameters for gateways, dynamic instead of fixed IP addresses, handled a busy signal, enabled the relay operator to terminate a call, parameterised the TTS engine via the SIMBA interface and recovered when the telephone hung up. One particular problem with the relay operator's audio was difficult to fix: the operator heard the outgoing result of the Deaf user's TTS. The most significant feature addition was isTyping for the Deaf user, and audio isTyping for the hearing user (see Figure A-12). The overall SIMBA architecture remained as depicted above.

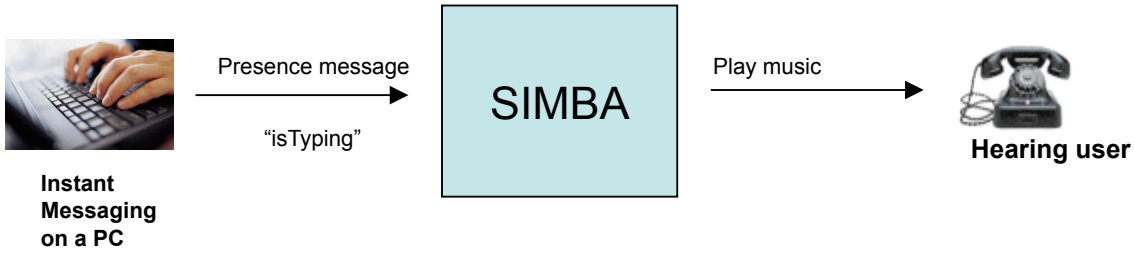

Figure A-12 SIMBA v2 audio isTyping awareness feature

The audio isTyping feature caused SIMBA to play music for the hearing user when the Deaf user was typing text. SIMBA also provided awareness for the Deaf user. A message was displayed on the Deaf user's IM client when the hearing user was speaking.

An offshoot of SIMBA, built with the Narada brokering facility from Indiana University (www.naradabrokering.org) was implemented as NIMBA (Julius, 2006). NIMBA provided guaranteed delivery of real-time components with forward error correction and of store-and-forward components with Narada.

Several old PCs had been donated to DCCT and we put these in the staff offices. We extended the WiFi network to include staff offices with a second AP with a strong directional antenna (borrowed from the rural telehealth project) to get through the thick brick walls.

A.6.3 Evaluate Action

NIMBA experiments were conducted with several regular attendees, but we had little success getting them to use either NIMBA or SIMBA. It continued to be very difficult to reach hearing co-participants. There was only one instance when a Deaf person asked us to set up a SIMBA call for them. Instead, we were continually asking them to make a SIMBA call. One person noted that if a Deaf person wanted to contact a hearing person, they would just use SMS.

One technical problem with SIMBA was that its FOSS TTS engine, FreeTTS, stopped processing text after the first full stop (period) in the Deaf user's message. Thus, when a Deaf user typed a long message with multiple sentences, only the first sentence would be sent to the hearing user. Therefore, we encouraged the Deaf participants to use short single sentences. FreeTTS also did not intonate punctuation like other TTS engines, so the result appeared quite mechanical and synthetic to hearing users.

A.6.4 Reflection/Diagnosis

During focus group sessions, DCCT staff members identified several inhibiting factors regarding the poor take-up of SIMBA. Deaf users could not use the system when we were not there. Firstly, this was due to the continued problems with operating SIMBA. Secondly, SIMBA was closely associated with our presence. Because of the poor take-up, we did not hire a relay operator so one was not always available. The end result was that Deaf users could not use the system any time they wanted.

Consent forms also inhibited take-up. Very few people brought in consent forms for hearing users. At first, the Deaf users completely misunderstood that the consent form (Appendix C) was supposed to be signed and brought back because they had had little experience with research and research protocol. They often brought back the written project information sheet instead (Appendix B). They also had difficulty understanding the text. We made graphical sketches of the system, and then put large posters in the Bastion (see Figure A-13). Those helped explain the project to the Deaf users better than the written text.

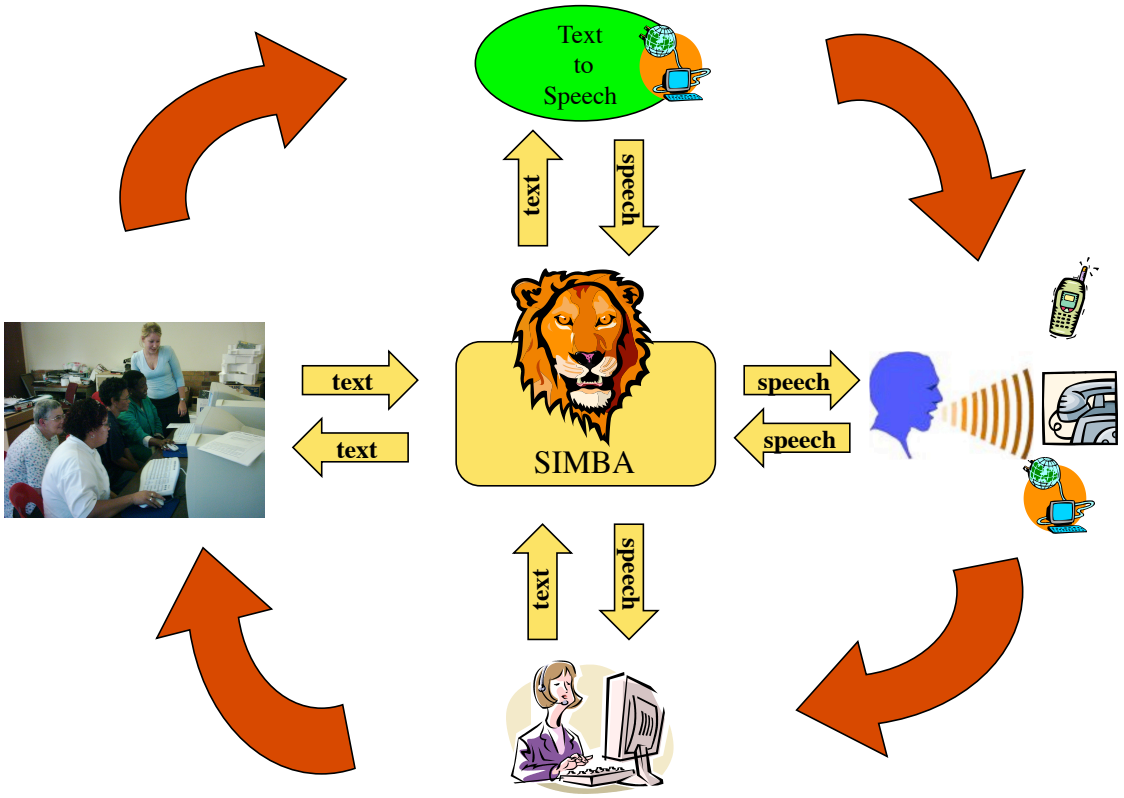

Figure A-13 Visual information sheet for the SIMBA system

The Deaf users had difficulty with the written information sheet for the project (see Appendix B). We drew this graphical depiction of the system for them, and also placed a large poster in the PC room at the Bastion. We would write subsequent information sheets (for other prototypes) in point form to make it easier for an interpreter to translate into SASL.

Our operation hours were also awkward. They may have been convenient for the Deaf users, but were not convenient for the hearing users. Thursday evening sessions were problematic because many hearing co-participants were Muslim, and did not want to be disturbed at dusk during prayer time. The other time slot was Friday morning when hearing participants were working.

Some significant non-research events also occurred during this cycle. The PC lab assistant left to have a child and was replaced by someone else who became difficult and ceased working for the project. Thus, we realised we should employ more than one assistant in case we had similar problems in the future. Our initial intermediary resigned her post at UCT and began working for another Deaf NGO called SLED (Sign Language Education and Development, www.sled.org.za). However, she remained active with DCCT, and with our project.

Most significantly during this cycle, DCCT said they would budget for ADSL the following year. This demonstrated buy-in to the project, and acknowledged the importance of having the computers at the Bastion. We thus came to view DCCT also as intermediaries.

We learned that the Deaf people in this community were not accustomed to calling or sending an SMS to 'any sector'. They were used to communicating within their tight knit Deaf circle, and felt cut off from other sectors. When asked what they wanted from a SIMBA-like system, some of the Deaf people replied that they wanted to use SASL instead of text and one recommended access to SIMBA with SMS in addition to IM. Since we were still trying to automate as much of the system as possible, we opted to follow up on the latter request.

A.7 SIMBA v3

A third version of SIMBA provided an SMS interface to the Deaf user. SIMBA v3 trials continued on a weekly basis, yet also failed to attract users. However, the project saw significantly increased use of the PCs in the Bastion. Table A-7 provides an overview.

Cycle overview	*Description*
Timeframe	Early 2006
Community	DCCT members
Local champion	Stephen Lombard (DCCT)
Intermediary	Meryl Glaser (SLED), DCCT staff
Prototype	SIMBA v3
Coded by	Sun Tao (UWC)
Supervised by	William Tucker (UCT/UWC)
Technical details	None published

Table A-7 SIMBA v3 cycle overview

A.7.1 Plan Action

A brief overview of the technical design of the SMS interface is presented in Figure A-15 and Table A-8. SIMBA v3 was particularly interesting in that it involved bridging at all seven Softbridge stack layers (see Figure A-14).

A.7.2 Implement Action

An SMS agent was integrated into a SIMBA client. The SIMBA server was not changed. The SMS agent used a GPRS card to send/receive an SMS. To initiate a SIMBA call, the Deaf user sent a specially formatted SMS to the SMS agent. From then on, the user sent and received SMS as normal, with SIMBA performing relay to a telephone. The system was implemented exactly as detailed in Section A.7.1.

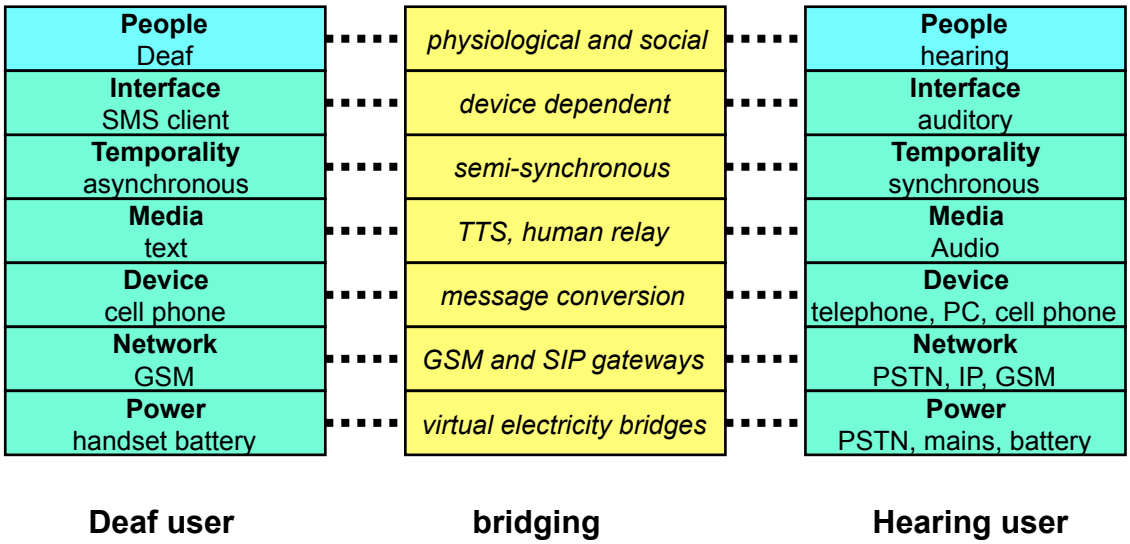

Figure A-14 SIMBA v3 Softbridge stack

SIMBA v3 was particularly interesting because it involved bridging at all seven Softbridge layers. The SMS interface for the Deaf user entailed differences in power provision, network access, end-user devices, text and voice media, synchronous and asynchronous temporalities, user interfaces and of course between Deaf and hearing people.

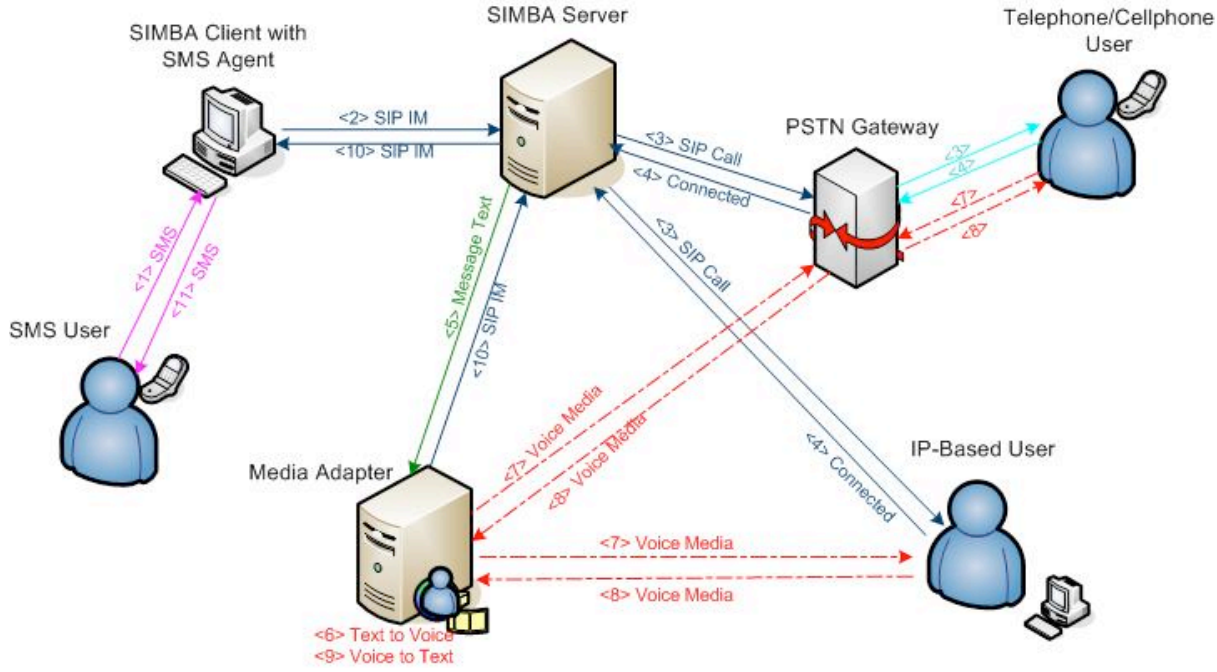

Figure A-15 SMS interface to SIMBA v3

This diagram shows the sequential flow required to add the SMS interface to SIMBA. The arcs are defined in Table A-8.

1	SMS user sends an SMS to SMS Agent. The message looks like "*0722032817* how are you?". The content between the asterisks is the called user's number or name.
2	SMS Agent extracts the message from SMS and formats a SIP IM for the SIMBA Server. The SIP IM looks like "sip: 0722032817@Softbridge.org".
3	SIMBA Server receives the message and sets up a SIP call to the called user, either via a PSTN Gateway for a telephone/cell phone or directly if it is an IP-based user.
4	Called user answers the call and a connection is set up.
5	SIMBA Server sends the IM message text to Media Adapter.
6	Media Adapter converts text to voice.
7	Media Adapter sends voice stream to called user.
8	Voice stream is sent from called user to Media Adapter.
9	Media Adapter converts voice to text via Relay Operator.
10	Media Adapter packs text to SIP IM and sends it to SMS Agent via SIMBA Server
11	SMS receives SIP IM, gets text message, packs to SMS and sends to a Deaf user.

Table A-8 Flow diagram for SMS interface to SIMBA v3

The sequential steps shown detail the flow arcs shown in Figure A-15.

A.7.3 Evaluate Action

Experimentation with SIMBA v3 occurred as in earlier cycles, in twice-weekly research sessions. Participation continued to be sparse, despite increased daily attendance for the open lab (see Table 6-4). As expected, the SMS interface exhibited long latencies due to 'tap' time. Unfortunately, take up did not improve and we conceded that SIMBA was not going to be taken up as a service by this community.

A.7.4 Reflection

The SMS interface and isTyping features were not enough to boost SIMBA usage. In hindsight, both were technically interesting ideas, but added little value for potential users. We came to realise that addressing perceived problems with yet more technical bells and whistles was not going to improve take-up. The problems were deeper, and more social in nature. We were told by DCCT leaders that perhaps the Deaf community was so close knit that the members really had no desire to 'talk' to people outside the community. They were more interested in ICT that enabled them to communicate with one another, like SMS, email, IM and especially video conferencing. This was clearly evident by attendance during the week at the PC lab. With two lab assistants, the open days for the lab were increased to six days/week, and overall attendance increased dramatically (see Table 6-4). While technical research with SIMBA was floundering, the lab was being used in record numbers two years after we had introduced the PCs.

Related to the sentiment above that our technical concerns were overshadowed by the social factors, we contemplated the efficacy of the informed participation approach as described by Hersh and Tucker (2005). At the time, our main concern was to explore QoC and learn how macro latencies could be overcome to provide a still useable communication platform. We quite openly discussed delay issues with participants. It might have been that they may were confused about the purpose of the project: was it PCs, Deaf telephony, or delay?

With a full-time programmer on the project, we were able to more quickly address bugs and enhancements. Unfortunately, the lead programmer immigrated to Canada and we replaced him with another MSc graduate. We also added another MSc student to the project whose activity is reported in cycle A.9.

A.8 DeafChat

We next built a real-time text chat system that sent characters to chat participants as they were typed instead of waiting for the terminating new-line. DeafChat proved to be very popular during the weekly research sessions. The Deaf users actively participated in the design of the tool by offering feedback. Since the programmer was not a student, we were able to react quickly to their suggestions. Table A-9 provides an overview.

Cycle overview	*Description*
Timeframe	Mid-late 2006
Community	DCCT members
Local champion	Stephen Lombard (DCCT)
Intermediary	Meryl Glaser (SLED), DCCT staff
Prototype	DeafChat
Coded by	Yanhao Wu (UWC)
Supervised by	William Tucker (UCT/UWC)
Technical details	None published

Table A-9 DeafChat cycle overview

A.8.1 Diagnosis

It appeared that the Deaf people were more interested in communicating with each other than with hearing people. We had introduced them to IM systems like MSN, Skype and AIM, but rarely saw them using those tools. Many of the Deaf participants had prior experience with the Teldem, even if they did not own one or use one. We reasoned that a real-time text chat tool, similar to the Teldem in synchrony, might appeal to Deaf people.

A.8.2 Plan Action

We designed a real-time text tool that transmitted characters in real-time, similar to the Teldem. Unlike the Teldem, however, this tool would support multiple participants, have a PC GUI interface and identify users. IM clients typically transmitted in 'page mode', meaning that text was transmitted in chunks defined by the user hitting the Enter key (new-line). The Teldem operated in 'session mode', sending one character at a time. Thus, the plan was to imbue an IM client with Teldem-like synchrony since we could not add IM functionality to the Teldem.

A.8.3 Implement Action

We built two versions of DeafChat, both of which were client-server in nature. The first version was built with SIP, using the MESSAGE mechanism to pass one character at a time to the server that would then broadcast the characters to all connected clients. The clients managed the screen, relegating the character to the appropriate position. A sample interface is shown in Figure A-16. Based on user feedback, we colour coded users' text and improved the interface. We subsequently moved the entire application to a Java-coded web-based client to remove the necessity of having to install and upgrade software.

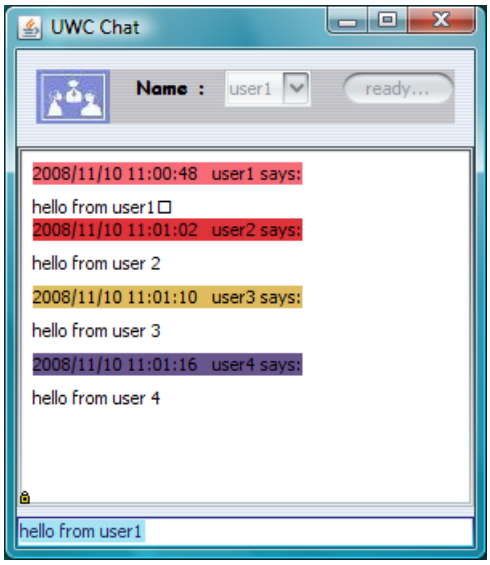

Figure A-16 DeafChat interface

The standalone SIP implementation of DeafChat had implicit isTyping. As a user typed, characters were sent to all other chat participants and positioned according to that user's current message. After pressing Enter, a 'GA' token appeared to indicate: "I am finished typing now". GA was a holdover from the Teldem. Multiple users could type simultaneously. Any characters typed in a local input box appeared both in the local output box and any connected client's output box in the correct position in real-time.

A.8.4 Evaluate Action

DeafChat was well received by the regular research session participants in a way we had not experienced before. During this cycle, the whole group frequently used DeafChat during the research sessions. When new people came in, they often asked to get on it, too. The tool was also used by the weekly literacy course. Sometimes, they would already be involved in a group chat before we arrived. They also did not mind us participating in their chats, which mostly consisted of poking fun at one another, and at us. DeafChat was rather basic. Login was not authenticated and the application was limited to the local area network, but these issues did not matter to the Deaf users.

A.8.5 Reflection

There were several innovative technical features of the tool. At the network layer, the tool appropriated SIP messages to deliver text characters in real-time. SIP was designed for real-time voice and video (Handley et al., 1999), and only provided for asynchronous text with SIMPLE (Campbell et al., 2002). At the interface layer, DeafChat provided isTyping awareness implicitly. A user could always tell what the other chat participants were doing (or typing) based on a quick visual scan of the screen. DeafChat was deployed on PCs at the Bastion, yet the web-based client interface made it possible to port the DeafChat to cell phones. However, that would still require a GPRS, 3G or WiFi data connection.

After struggling for so long with the SIMBA prototypes, we were pleasantly surprised by the instant popularity of DeafChat. However, that popularity was short-lived. After the novelty wore off and Yanhao Wu (the programmer) left the project, DeafChat retired into the same disuse that befell prior prototypes. In spite of that, there were several instructive explanations for its brief success. Unlike SIMBA, DeafChat was fundamentally a Deaf-to-Deaf tool. DeafChat was modelled on Teldem-like modalities familiar to the participants, and enabled them to feel comfortable with textual content amongst themselves, much as with SMS. It was notable that the participants were also comfortable with the researchers participating in the chats. The participants had acquired a solid base of computer literacy via the previous prototype trials. In addition, most of them were also participants in an on-going English literacy course that was co-scheduled with the research visits. Thus, the Deaf participants felt more confident using both ICT and English text. Most importantly,

participants used DeafChat with each other because they all had the same degree of technology access in the lab during the research sessions. This also explained why DeafChat could not achieve larger penetration into the Deaf community; a user had to be physically in the lab to use it. When the circle was closed and small, DeafChat usage was encouraging. Yet outside the circle, potential users were sidelined by lack of access to technology.

A.9 DeafVideoChat

We exposed Deaf users to several off-the-shelf video IM tools to respond to the need for SASL communication. None of the common IM video tools appeared to support sign language conversation with webcams, even relatively high-end webcams with large amounts of P2P bandwidth on a local network. Thus, we conducted a preliminary investigation into asynchronous video in 2006 with an Honours (4th year) project. We continued the project in 2007-8 as an MSc project. We also began to explore an innovative gesture recognition interface to the asynchronous video prototype. Table A-10 provides an overview of the cycle.

Cycle overview	*Description*
Timeframe	2006-2008
Community	DCCT, SLED
Local champion	Richard Pelton (DCCT)
Intermediary	Meryl Glaser (SLED), DCCT staff
Prototype	DeafVideoChat
Coded by	Zhenyu Ma (UWC), Russel Joffe (UCT), Tshifhiwa Ramuhaheli (UCT)
Supervised by	William Tucker (UCT/UWC), Edwin Blake (UCT)
Technical details	(Ma & Tucker, 2007, 2008)

Table A-10 DeafVideoChat cycle overview

A.9.1 Diagnosis

A primary need expressed by Deaf participants was to communicate in SASL. We had temporary success with DeafChat (see Section A.8), but it did not support video. We reasoned that we should abandon the 'do-it-yourself' approach characterised by the SIMBA cycles and expose the Deaf users to off-the-shelf video tools in order to learn about their advantages and disadvantages.

A.9.2 Plan Action

We would expose the Deaf participants to off-the-shelf free video tools available online. The aim was to familiarise them with what was available, encourage them to use the tools and

to learn how they performed with respect to Deaf needs. While participants were exploring synchronous video, we would also investigate asynchronous video to provide higher quality.

A.9.3 Implement Action

DCCT participants dismissed Skype and other common video chat tools because of poor video quality for sign language. The tools appeared to be designed for hearing users, prioritising voice over video quality. Thus, sign language communication was blurry and jerky. This prompted us to implement an asynchronous video tool, herein called DeafVideoChat. It was a simple tool with two video windows as shown in Figure A-17. The outgoing recorded video could be replayed to check for correctness, and the incoming video could also be replayed. Exploratory experiments were carried out with various compression techniques, and also with several transmission techniques in order to determine an optimal combination (Ma & Tucker, 2007). Further experimentation at an MSc level resulted in the integration and optimal configuration of the x264 codec into the system (Ma & Tucker, 2008). We also began work on a gesture recognition interface. This should not be confused with sign language recognition. The point of the gesture recognition interface was to provide gestured control of the asynchronous video tool, e.g. to start or stop recording.

We upgraded the webcams in DCCT twice over the course of this cycle. After frustration with tools like MSN and Skype, some DCCT users started using Camfrog (www.camfrog.com) as their preferred video tool for remote sign language communication[21]. We bought Camfrog Pro licenses to enable the use of full screen video and some other features. Some DCCT users took advantage of the social networking that Camfrog offered for Deaf communities around the world. Camfrog's lack of privacy controls made it cumbersome for users who did not enjoy open access from the global Internet community. DCCT users also used the tools to chat to the SLED NGO, and the researchers.

A.9.4 Evaluate Action

Iterative revisions of DeafVideoChat configured the x264 video codec to improve sign language compaction for store-and-forward transmission. One of the Deaf participants reported that it was the first time he had seen clear enough video to understand the sign

[21] Interestingly, both Deaf NGO's developed their own sign for Camfrog. This also taught us that there are sign language dialects just as with any spoken language.

language. However, Deaf participants did not take to DeafVideoChat as with DeafChat. Firstly, they were more interested in real-time communication. Secondly, the issues regarding the size of the connectivity circle were still relevant. No Deaf people in the potential connectivity circle physically outside the Bastion could communicate with the tool.

Figure A-17 DeafVideoChat interface

The Capture window on the left was for user1 to capture a SASL video message to send to user2. The Playing window on the right was for user1 to play and replay the last SASL message received from user2. Information messages were displayed in English in the bottom right-hand corner.

On the real-time front, even though Camfrog Pro enabled full screen video, the Deaf users chose a smaller screen size in order to increase video quality. We noted that several frequent Camfrog users with DCCT tended to use Camfrog for its community features. Meanwhile, we were aware that SLED (another Deaf NGO nearby) actively used Camfrog to conduct its daily business because they had two offices, one in Cape Town and one in Johannesburg. SLED users had deemed Camfrog to offer superior quality to Skype.

A prototype of the gesture recognition interface was shown to Deaf users with favourable responses. Unfortunately, the gesture recognition interface project was temporarily halted then restarted as the responsibility passed from one MSc to another.

A.9.5 Reflection

DeafVideoChat clearly offered superior video quality with respect to sign language comprehension. Still, Deaf users who actually used a remote video tool rather chose Camfrog. It should be noted that very few of the participants used a video communication tool outside the research sessions. There were only a couple of regular DCCT video users. SLED, on the other hand, adopted Camfrog as a part of their everyday business conduct. There were several explanations why regular users preferred the lower quality tool, and why so few DCCT participants used the tool.

Camfrog was synchronous and was therefore easier to use than the asynchronous interface that required numerous button presses to record, receive and send video.[22] Camfrog also had the advantage of being clearly associated with Deaf users on an international basis. Camfrog provided established chat rooms for users from all over the world. Deaf users related to Camfrog as a SASL tool whereas Skype was a text tool even though it also supported video. DeafVideoChat, on the other hand, was a research tool clearly associated with our weekly visits. Camfrog's perceived superior quality may have been linked to these social issues rather than purely technical ones. We cannot say for sure because we could not perform automated objective video quality tests on Camfrog or Skype as we could with DeafVideoChat because the internals of the web tools were not accessible via open source. On a related issue of users adopting a lesser quality tool, Camfrog had many Skype features with respect to media and temporal modalities, but was much less sophisticated in terms of security and privacy. This lack of features, however, did not deter users from adopting Camfrog.

SLED users appropriated tools like Camfrog (for SASL) and Skype (for text) into their daily activities more than DCCT users. This could be explained by the fact that the two SLED offices needed to communicate with each other because of geographic distance. Furthermore, end-users at both SLED offices had very similar RA/RI criteria attributes, e.g. education, PC literacy, PCs with web cams on their desks and broadband connectivity that encouraged the appropriation of a tool like Camfrog. On the other hand, while most DCCT participants had a PC on their desk at offices throughout the Bastion building, face-to-face contact was preferable to and more convenient than virtual contact. More importantly, DCCT-resident

[22] Thus our interest in a hands-free gesture interface.

end-users had much more ICT4D access than off-site Deaf and hearing users in their potential connectivity circle, especially with regarding to physical access to ICT. Therefore, the connectivity circle at the Bastion was artificial at best. Even though the Deaf telephony prototypes may have functioned adequately, there was no need or even genuine opportunity for DCCT participants to use the tools, as was the case at SLED. The lack of take up of research prototypes at DCCT and the simultaneous take-up of Skype and Camfrog at SLED demonstrated that the social RA/RI criteria-related considerations were fundamentally more important than the technical attributes of any ICT4D system we could devise. Thus, in order for ICT4D appropriation, RA/RI criteria had to be addressed.

Appendix B Information Sheet – Deaf Telephony

Who are we?

We are Computer Science researchers from the University of Cape Town and the University of the Western Cape. The team members are Bill Tucker, Tao Sun, Elroy Julius and Edwin Blake. Meryl Glaser is our advisor.

What do we want to do?

We want to improve communications between Deaf and hearing people. The aim is to provide a Deaf relay service to the telephone system using computers on the Internet. Our system, called SIMBA, allows Deaf and hearing people to communicate with some degree of automation. The Deaf user sits at a computer (PC) at Deaf Community of Cape Town's (DCCT) premises. We will provide the PCs. The Deaf user communicates with text. A Deaf user's text is automatically converted into speech with a Text-to-speech program. Our system, SIMBA, sends that voice to the telephone of a hearing user. When the hearing user speaks, the speech is sent to an operator that translates the speech into text. Then, SIMBA sends the text to the Deaf person's computer. Our research is primarily the development of the communication software. We will work with Deaf and hearing people to design and change the software over time. Our research runs in cycles where we introduce improvements, provide training and talk to the users to make improvements for the next cycle.

Over the past several years, we have made several attempts to build this service. We have learned that there are two main issues concerning the use of such a system: computer literacy of Deaf people and the text-to-speech and speech-to-text translation. We want to deal with these issues, because both issues introduce a lot of delay into the conversation. For example, the hearing user will have to wait for the Deaf person to type a message and also for the translation of that text into speech. Likewise, the Deaf user will have to wait while the operator translates the speech into text. We want to learn how to best deal with these kinds of delay in the conversation.

Why are we doing this?

We have already developed some software in the laboratory, but the reason we are doing this project is because we are interested in how we can use technology to help communication for the Deaf community. We are doing this as part of our research studies. We want to know things like, is the system useful, how can we make it better and how many times you use it. We will write about our experience of doing this work to help others who want to do similar work in South Africa, and even the rest of the world. We also want to show the Department of Communications the kinds of things that can be used to improve communications for the Deaf.

Who funds this project and how will it continue when we are done?

This research is funded by the Centres of Excellence at both UWC and UCT until the end of 2005. Please note that this is not a donation, and is not a commercial product. We are interested in learning how to use technology to help the Deaf communicate with the hearing over long distances. If SIMBA proves useful, we would like to convince the Department of Communications to support the project. We hope that the community will work with us to do this!

If you agree to join this project, I will ask you to sign a consent form, but you can leave the project at any time without any penalty to you at all. Participation is your free choice. You will be asked to use the system and allow yourself to be interviewed about the system at regular intervals when we visit your site.

Appendix C Consent Form – Deaf Telephony

I, _____, fully understand the Deaf Telephony project and agree to participate. I understand that all information which I provide will be kept confidential, and that my identity will not be revealed in any publication resulting from the research unless I choose to give permission. Furthermore, all recorded interview media and transcripts will be deleted after the data results have been analyzed. I am also free to withdraw from the project at any time.

I understand that the South African Sign Language interpreter who will provide the voice-sign-voice translation is bound by a code of ethics which does not allow him/her to repeat any information that is given during the discussions. This means that my identify will remain confidential within the group.

For further information, please do not hesitate to contact:
William Tucker
Dept of Computer Science
University of the Western Cape
Private Bag X17
Bellville 7535
Email: btucker@cs.uct.ac.za
Cell: 082 494 8884

Name:

Signature:

Date:

Appendix D Rural Telehealth Action Research Cycles

This appendix chronicles the action research cycles for the rural telehealth field study analysed in Chapter 7. The action research cycles were linked to a series of communication prototypes called MUTI from 2004 to 2008 and can be grouped as shown in Figure D-1. This appendix has a section for each cycle. Each cycle is reported in standard action research stages: diagnosis, plan action, implement action, evaluate action and reflection. Within the groups, the reflection and diagnosis stages of successive cycles are combined. An overview table precedes each cycle, showing the timeframe, location, local champion, intermediary, prototype name, coder(s), supervisor(s), and references to technical details. A schedule of all field trips is shown in Table D-1. These trips are cited throughout the appendix by number.

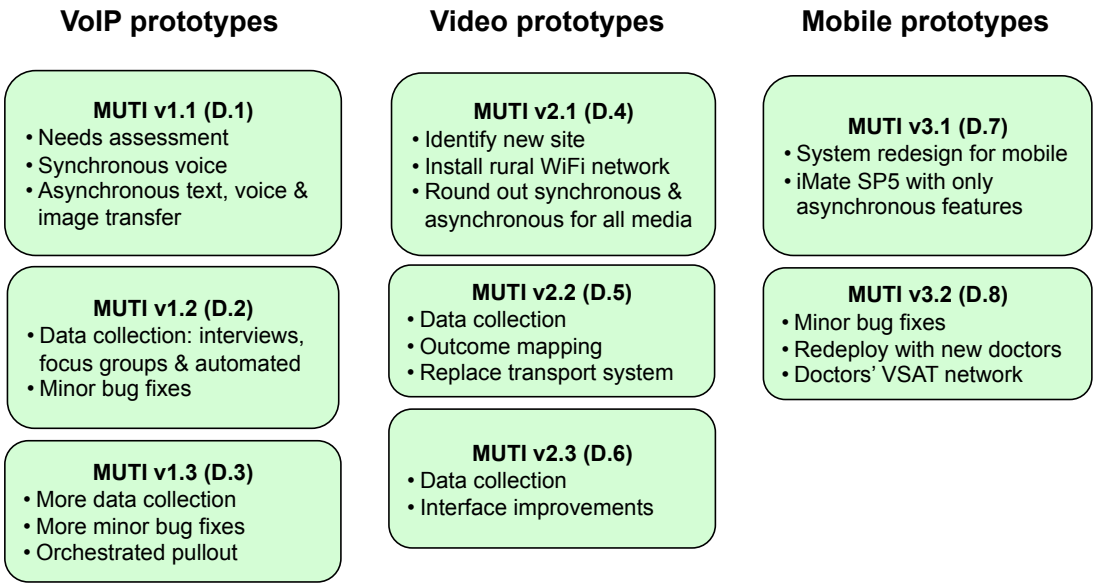

Figure D-1 Rural telehealth field study prototypes

Prototypes for the rural telehealth field study fit into three groups. Each group was associated with a particular technical orientation, location and Masters student who led the implementation of software prototypes. Marshini Chetty built MUTI v1 at Tsilitwa to explore VoIP. Xolisa Vuza deployed MUTI v2 at Canzibe with video. Andrew Maunder ported MUTI v3 to run on mobile handsets, also at Canzibe.

D.1 MUTI v1.1

The CSIR acted as an intermediary to a rural telehealth project. After an initial needs assessment and paper prototyping exercise, MUTI v1.1 was designed to address frequent power outages and brownouts that constantly disrupted the CSIR's real-time VoIP system.

MUTI provided store-and-forward of mixed voice, text and image messages in addition to VoIP, and ran on laptops rather than PCs. Table D-3 provides an overview.

2003	
V1 Aug 19-21	Tsilitwa #1 first site visit with CSIR
V2 Dec 8-11	Tsilitwa #2 conducted needs assessment and paper prototype
2004	
V3 Apr 19-20	Tsilitwa #3 installed MUTI v1.1
V4 Jun 21-22	Tsilitwa #4 installed MUTI v1.2
V5 Sep 1-4	Tsilitwa #5/Canzibe #1 MUTI v1.3 and new site feeler
V6 Oct 20-22	Tsilitwa #6/Canzibe #2 withdrawal and new clinic identification
V7 Nov 8-11	Canzibe #3 planning
2005	
V8 Mar 16-22	Canzibe #4 more planning and established commitment
V9 May 8-21	Canzibe #5 built network and installed MUTI v2.1
V10 Jul 12-19	Canzibe #6 installed MUTI v2.2 with training
V11 Sep 1-9	Canzibe #7 installed MUTI v2.3 with more training
2006	
V12 Mar 20-24	Canzibe #8 paper prototype for mobile interface
V13 Aug 7-13	Canzibe #9 left I-mates with participants
V14 Sep 18-27	Canzibe #10 floods and prototype bugs delayed deployment
V15 Oct 4-8	Canzibe #11 installed MUTI v3.1
2007	
V16 Mar 12-18	Canzibe #12 installed MUTI v3.2
V17 Jun 18-24	Canzibe #13 joined MUTI and VSAT networks
2008	
V18 Nov 25-27	Canzibe #14 shifted emphasis to network expansion and NGOs

Table D-1 Rural telehealth travel schedule

Cycle overview	*Description*
Timeframe	Early 2004
Community	Nessie Knight hospital (Sulenkama) and Tsilitwa clinic
Local champion	Patricia Madikane (head nurse at Tsilitwa clinic)
Intermediary	CSIR
Prototype	MUTI v1.1
Coded by	Marshini Chetty (UCT)
Supervised by	William Tucker (UCT/UWC), Edwin Blake (UCT)
Technical details	(Chetty et al., 2003; bridges.org, 2004c)

Table D-2 MUTI v1.1 cycle overview

D.1.1 Diagnosis

The project commenced in 2003 with the idea that VoIP, as opposed to the PSTN, could help bridge the digital divide. At the time, VoIP was illegal in South Africa (DoC, 2001). We wanted to demonstrate the usefulness of VoIP in a digital divide environment to influence South African telecommunication policy. Chetty (2003) gave a short talk at a conference with the hope of finding someone with a community project interested in our ideas. Subsequently,

the CSIR invited us to their rural telehealth project involving a clinic in Tsilitwa and Nessie Knight hospital in Sulenkama (CSIR, 2002). On the first visit (V1), we met the CSIR project coordinator, the head nurse at the clinic, and some of the technical support staff. Hereafter, we refer to this project as Tsilitwa because the local champion was resident in that village.

The CSIR (2002) designed and built a wireless network between Tsilitwa and Sulenkama. The network had a single repeater, or relay, on a hill between the two villages. The network used standard 802.11b at 2.4GHz. The network was powered by mains electricity. According to the clinic head nurse and support staff, the power was very erratic, often down for two or more days at a time. We witnessed this ourselves, but more often we arrived and power was up, but the wireless network was down. The relay between the two villages also had dedicated mains power because the original solar infrastructure had been burgled. Its UPS suffered from continuous brownouts and often required a manual reset. Reset required a 7km walk from either village. This meant that the network was often out of commission, and consequently real-time communication was impossible.

The VoIP system was based on an H.323 software PBX with a server in the Multi Purpose Community Centre (MPCC). Unfortunately, the MPCC was the most likely node to have no power. Each network node had a Soekris biscuit PC router with several RJ-45 ports for access devices (www.soekris.com). The devices were PCs and handsets. The handsets were regular PSTN telephones connected to the Soekris via a Cisco VoIP adapter. The PC in the clinic also had a web cam for one-way viewing by a doctor at the hospital. The nurse and doctor were not happy with the video quality, and preferred to use a digital camera for higher resolution pictures. The VoIP and web cam supported real-time communication only.

Because the system was frequently unusable, the nurse tended to fall back on hand-written patient referral to the hospital. When the nurse did manage an online consultation, it took about 2-3 times longer than normal, due to translation (from isiXhosa to English) and the delayed nature of tele-consultation, with the patient communicating with the doctor via the nurse. Language was an issue because the patients spoke isiXhosa, and the doctor could not. He was Cuban; yet spoke English, as did the nurse.

Soon after that first site visit, we attended a 'First Mile' workshop in Pretoria. We were invited to join a group of ICT4D projects across southern Africa, organised by the IDRC and the CSIR. Most of the projects concerned the 'last mile' of connectivity to a customer

premises. We stressed the importance of including the user and the user's needs before providing connectivity infrastructure, and that became known as the 'First Inch'. After we joined the group, it became known as FMFI (First Mile First Inch, www.fmfi.org.za).

D.1.2 Plan Action

FMFI interaction informed us that unreliable power and network downtime was a common theme for many ICT4D projects and provided impetus to store-and-forward ideas for communication. We visited Tsilitwa again (V2), accompanied by a bridges.org representative, and met with the nurses and support staff. True to form, the power was down, but when it returned we were able to use the VoIP system and were impressed by how well it worked. The nurse and doctor had scheduled weekly appointments to use the system with actual patients, but the power outages interfered with that plan. We sketched out some store-and-forward ideas on paper, using cell phone voicemail as an analogy, and it was well received.

Our idea was to have real-time calls when the network was up, but use store-and-forward messages when it was down. A message would consist of text, voice and pictures taken from a digital camera. Because the power issue also affected the use of the PC, we suggested using a laptop that could run on its own batteries. We also preferred P2P VoIP to get rid of the dependence on a VoIP server. We would also choose SIP. We could also have used H.323 for P2P, but at the time, SIP was emerging as the preferred VoIP API.

The head nurse told us that the system had previously provided email (via GSM dial-up) and she had been able to send the doctor pictures of patients taken with a digital camera. However, the email (dial-up) system had been discontinued because it was too expensive. Furthermore, the digital camera was broken and the rechargeable batteries were leaking acid.

At a subsequent FMFI workshop, we spoke more with our CSIR partners. They informed us that of all of their rural initiatives, Tsilitwa was the most difficult because of the village headman. They cautioned us to avoid meeting him on site. Thus, from very early on, we were aware of local power relations, but not necessarily cognizant of the details. We also met with the lead support technician again who stressed that we should meet the local DoH district manager. We spoke with CSIR about adding our laptops to their network, and they were concerned that our laptops not replace the existing PCs.

D.1.3 Implement Action

Marshini Chetty, a UCT Masters student, coded the initial prototype, MUTI v1.1 (see Figure 7-7). We returned to Tsilitwa (V3) to install it. MUTI v1.1 supported synchronous voice. An asynchronous message component allowed for a combination of text, voice and digital images. A Softbridge representation is shown in Figure D-2.

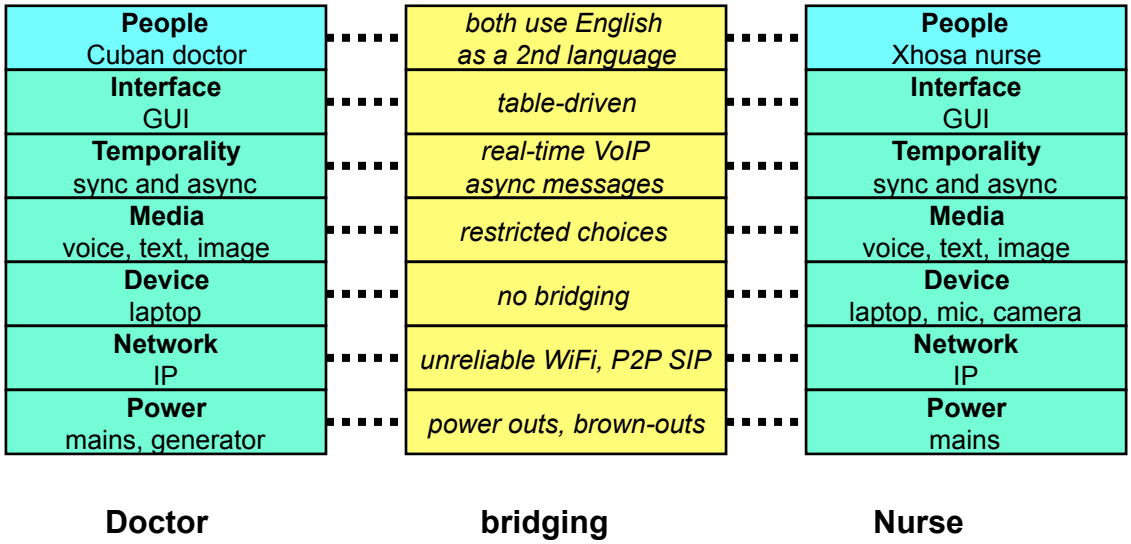

Figure D-2 MUTI v1.1 Softbridge stack

The initial MUTI prototype used a store-and-forward approach to bridge unreliable power. MUTI v1.1 was installed in parallel with the CSIR real-time system, but provided its own real-time VoIP component.

We held a group meeting at the hospital to introduce the MUTI prototype. This was the first time that the head nurse actually met the doctor face-to-face. We handed out a one-page summary (Appendix E) and asked them to signed participation consent forms (Appendix F). We conducted a semi-structured questionnaire/interview to collect their impressions of the CSIR system. They told us that the CSIR system had been in operation since November/December 2003, but was rarely used because the doctor was too busy and the system was often not working. They claimed that the web cam was more reliable than the voice handsets. [23] After the interview, we demonstrated the MUTI software to them on two laptops.

[23] We learned this was the case because the VoIP server was placed in the MPCC in the school. Apparently, the power bills were often not paid by the village headman, who was also the school superintendent. Thus, the VoIP server was often down while the network was still up.

Even with power on in the school, we had to physically reset the network at the relay tower in order to get the network up and going. A rural wireless specialist, Murray Pearson, from CRCNet (www.crc.net.nz) in New Zealand had accompanied us. Pearson (2004) determined that the CSIR network performance was not optimal.

We met briefly with the district manager of the Qumbu District DoH. She told us that they would soon increase the staff at Nessie Knight and improve the road. We tried to emphasize the advantage of having Internet for the doctors, to allow them to get online, but she dismissed this idea as pointless.

Then we went back to Tsilitwa/Sulenkama to provide hands-on training for MUTI v1.1. The power was out at the clinic, so we held the training at the MPCC, still without informing the headman. The head nurse was very curious about our relationship with the CSIR. We explained the research agenda as best we could. We left with the MUTI v1.1 system software and hardware in working order.

D.1.4 Evaluate Action

We attended a FMFI research methodology workshop and met with CSIR partners to discuss problems and issues about the collaboration. The CSIR were not happy about a bridges.org (2004c) report that had criticized their rural telehealth system. We found it increasingly difficult to communicate with the CSIR about the research agenda. At the workshop, the CSIR proposed the same research questions as ours, yet we were not actually working on the solution together. We had two entirely different solutions.

During the training at installation time, the feedback on the user interface was generally positive. We visited the site again (V4) to collect data on system usage. We brought together the doctor, nurse and technical support at the hospital to conduct interviews. The doctor and nurse did not use MUTI at all, but they did start the software 15 times. No calls were made by either party, and neither were messages sent. We suspected it was because the doctor's laptop was locked in a room that he rarely visited. We encouraged them to use MUTI, and brainstormed possible features that would help them use it more often. One idea was SMS notification from the nurse to let the doctor know she had left a MUTI message.

The next day, there was a large meeting at the clinic including the CSIR, the district DoH district manager, all of the clinic nurses, technical support and the village headman. This

was the first time we had met the headman. At one point, it seemed as if the DoH district manager were going to ask us to leave because she claimed we were confusing the nurses with technology. Then the headman, who was frustrated with the CSIR for not providing him with Internet access, invited us to stay. We also met the hospital superintendent and the DoH information officer, who suggested we use our system to track referral statistics. However, she never replied to follow-up emails.

D.1.5 Reflection/Diagnosis

We had been told that the CSIR system was not used very often. Unfortunately, we had no way of knowing how much that system was used other than what the participants told us verbally because the system was not instrumented for data collection.

We were disappointed that MUTI had also not been used very often. We thought that the doctor and nurse would use the system in store-and-forward mode to overcome the power and network problems. During the interview, the nurse told us that she had used MUTI several times, but the logs revealed that there was no activity. That taught us that the end-users might not always say what really happened. Perhaps she was telling us what she thought we wanted to hear or perhaps she interpreted merely turning on MUTI as using the system.

Yet even when the power, network and VoIP system were functional, there was still the problem of the other party not being there to answer. The doctor told us the most difficult problem was to schedule a meeting with the nurse, since he was so busy. He was the only doctor at the hospital. Furthermore, the VoIP phone and laptop were locked up in a seldom-used room. We reasoned that the doctor could go to the laptop when he had time, and deal with the nurse's inquiries. He could either send a message back, or call her using MUTI (or even the CSIR system). The doctor could even take the laptop home with him and use the system completely offline.

It appeared that even though MUTI was intended to relieve the work burden of the nurse and the doctor, the opposite was true. It took more time to deal with remote tele-consultation, in real-time or store-and-forward mode, than for the nurse or doctor to just deal with the patient alone with the old paper-based referral system. The benefit of a tele-consultation system, then, was actually for the patient, who would benefit by possibly not having to travel to the hospital to get care. We noted that the care at the clinic was free, while care at the

hospital required a small fee and a very long distance to walk or take expensive public transport.

We also had to consider theft of research equipment. We used simple security wires to lock the laptops to a desk. If participants took the laptops home, they would assume personal responsibility for them. We were forced to consider who would pay for research equipment that went missing. That impacted on the long-term sustainability of the project. We hoped that by demonstrating utility to the DoH, they would take responsibility for funding the project. We realised that in order to pursue that aim, we also needed the village headman's support. It was beneficial that we met the village headman against the CSIR's recommendation because his buy-in meant approval to participate for all involved.

We tried to encourage the head nurse to train other nurses. This would also improve her capabilities. In practice, however, the head nurse did not train the others and she was the only one to use the system.

D.2 MUTI v1.2

MUTI v1.2 fixed several bugs, improved the user interface according to user feedback and added more automated data collection. The users started using MUTI for both synchronous and asynchronous calls. The CSIR, however, asked us to leave the site so we could compare the two different telehealth approaches. Table D-3 provides an overview.

Cycle overview	*Description*
Timeframe	Mid 2004
Community	Nessie Knight hospital (Sulenkama) and Tsilitwa clinic
Local champion	Patricia Madikane (head nurse at Tsilitwa clinic)
Intermediary	CSIR
Prototype	MUTI v1.2
Coded by	Marshini Chetty (UCT)
Supervised by	William Tucker (UCT/UWC), Edwin Blake (UCT)
Technical details	(Chetty et al., 2004a, 2004b)

Table D-3 MUTI v1.2 cycle overview

D.2.1 Plan Action

We obtained initial feedback during the demo of, and training for, MUTI v1.1. User interface feedback included: use colour to denote online status, replace popup notifications with a status bar, and rearrange buttons. The doctor also asked for a 'reply to' function because the interfaces for viewing and receiving involved two different windows. He also wanted to print images. Users also requested improvement of the CSIR's video. We could address all of

these suggestions except the video (later added to MUTI v2). We also planned to fix several bugs in the system found with actual users, and to add more logging. Since the CSIR's digital camera was broken (V3), we decided to supply another camera rather than wait for the CSIR to provide one.

D.2.2 Implement Action

Most of the issues identified in the previous section were coded between visits V3 and V4. The most significant bug fix was to the asynchronous file transfer subsystem. Some minor user interface modifications were made according to feedback from users. The initial user interface was simplified by removing user profiles and login, since only the doctor and the head nurse were using the software. Several modifications to the logging system increased the detail recorded for both synchronous and asynchronous calls, including timestamps and duration.

We connected the two laptops back-to-back with both users in the same room. We showed them how MUTI was usable during both power and network outages by unplugging the power cables, and how the system delivered messages when the network returned. We gave them a revised user's guide. After the training session, we installed the laptops in the hospital and clinic and tested out all of the functionality with the end-users. We also provided a new digital camera along with new rechargeable batteries.

D.2.3 Evaluate Action

We collected usage data during a subsequent visit (V5). The logs showed that the clinic used (not just turned on) MUTI 31 times, and the hospital 13 times. We conducted semi-structured interviews individually with the doctor and nurse. We had hoped that the head nurse would train other nurses to use the system, but she did not. The doctor and nurse had agreed to set up weekly meetings with MUTI. The nurse told us that about 4 patients were helped during those weekly meetings. This was the same as when they had used the original CSIR system. The nurse had learned how to use the presence feature, to see if the doctor was online or offline, and she recognized the benefit of being able to leave a message when the doctor was not there to answer her call.

According to the interviews, they usually exchanged about 3-4 asynchronous messages per week. The doctor usually replied the next day. The doctor had begun to take the laptop

home with him, and said he could answer MUTI messages with greater convenience because of that. The nurse preferred leaving a voice message to using text.

The users said they preferred the headsets to the handsets because they could listen, talk and type at the same time. The spare laptop batteries were unused. Apparently, the power outages were not such a problem during winter. Unfortunately, this doctor was on his way back to Cuba, and there was no replacement in the pipeline.

D.2.4 Reflection/Diagnosis

In order to support the participants to use the system more often, we needed to contact them while we were not on site and encourage them to use the system. We could do this with SMS and voice calls.

After deploying MUTI v1.2, the CSIR insisted that we terminate the project in Tsilitwa. The problem was that MUTI was interfering with the use of their system. We had misunderstood our invitation to the site. We thought we had been asked to rectify the system because it was underutilized and came up with the store-and-forward enhancements. We did, however, agree with the CSIR that it would be better to have different sites using different solutions for the sake of comparison. So we had to find another site, and contemplated our withdrawal from Sulenkama and Tsilitwa.

With respect to system design, the custom message transfer system was still misbehaving and we thought it should be replaced with FTP-based delivery. The nurse had suggested an SMS notification to the doctor to alert him that a MUTI message had arrived. So we put that suggestion on an improvement list. Also on that list was an automatic handover to store-and-forward mode when a real-time call was not answered (similar to voicemail).

D.3 MUTI v1.3

MUTI v1.3 fixed minor bugs, and was used half-heartedly by users because we had informed them that we were asked to leave the research site. We orchestrated withdrawal from the site during this cycle. Table D-4 provides an overview.

Cycle overview	*Description*
Timeframe	Late 2004
Community	Nessie Knight hospital (Sulenkama) and Tsilitwa clinic
Local champion	Patricia Madikane (head nurse at Tsilitwa clinic)
Intermediary	CSIR
Prototype	MUTI v1.3
Coded by	Marshini Chetty (UCT)
Supervised by	William Tucker (UCT/UWC), Edwin Blake (UCT)
Technical details	(Chetty, 2006; Chetty et al., 2006)

Table D-4 MUTI v1.3 cycle overview

D.3.1 Plan Action

We had to inform the users that we were leaving the site. This would be easier with the doctor, since he was leaving the country. The CSIR wanted to continue with their system, so we had to remove all of the MUTI hardware, including laptops and the new digital camera. We planned to spread the pullout over two visits.

D.3.2 Implement Action

During the first of those visits (V5), we informed the users of our intention. We also met with the village headman. At first he was upset, but when we explained our conflict of interest with the CSIR, he understood and supported our decision to go. The nurse was not so supportive. She felt that the project was a community decision, and that our research conflict with the CSIR was not her problem. She also felt that MUTI was a better solution than the CSIR system. We installed MUTI v1.3 (V5) that addressed minor bugs that emerged from the previous cycle. We withdrew all of the equipment on the subsequent visit (V6).

D.3.3 Evaluate Action

We had one last chance to collect data on the final visit (V6). We conducted informal interviews, but did not record them. We obtained very little data since most of the discussion was about termination. Since the doctor was on his way back to Cuba, it was already a farewell. He invited us to dine with him, and it was a jovial parting. On the other hand, the communication was a bit tense with the nurse since she was not happy about us leaving.

The automated data collection revealed that they had used the system a few times, but not as much as with MUTI v1.2. The nurse had created 20 patient records, but for some reason only sent three to the doctor. Even though we had provided a new digital camera, and some pictures were taken, none were sent to the doctor for examination. The doctor had not

responded at all. Several call attempts were made from both sides, but none had been answered. We suspected that the presence indicators were not working properly.

D.3.4 Reflection

Multiple sources of data were beneficial since the automated logs often conflicted with what was reported during interviews. The participants, especially the nurse, often reported inflated usage of the system. Both users preferred to use synchronous communication. We also learned that the network had been down for two weeks. Also, the nurse had been on leave for two weeks. Therefore, after the initial upturn in usage with MUTI v1.2, overall usage declined with the last prototype.

Pulling out of the Tsilitwa project was very difficult. We had established a good rapport with the head nurse, the support staff and the doctor. The most difficult farewell was with the head nurse who had been the local champion. To her, the project equipment belonged to the community. We painstakingly explained that the equipment belonged to the university as it would at the next site. More importantly, she was angry that we were taking away a solution that she wanted to use. While we were gratified that she liked MUTI, her reaction indicated that we had not successfully conveyed our research agenda to her.

D.4 MUTI v2.1

We moved the project to a new site in the Libode District, also in the Eastern Cape. There we built our own rural wireless network. The next series of MUTI prototypes introduced real-time two-way video and IM. We quickly engaged stakeholders and met with them multiple times before committing to building the wireless network. Table D-5 provides an overview.

Cycle overview	*Description*
Timeframe	Early 2005
Community	Canzibe hospital and Lwandile clinic
Local champion	Arjan van der Sar, Transcape chairman and doctor's husband
Intermediary	Transcape
Prototype	MUTI v2.1
Coded by	Xolisa Vuza (UWC), Murray Pearson (CRCNet)
Supervised by	William Tucker (UCT/UWC)
Technical details	(Vuza & Tucker, 2004)

Table D-5 MUTI v2.1 cycle overview

D.4.1 Diagnosis

Xolisa Vuza, a Masters student from UWC and a native isiXhosa speaker, had been assisting with the Tsilitwa visits in 2004. Speaking isiXhosa was a key asset for the project. He also conducted the needs assessment to continue the project into the next phase. He was the principle programmer for the MUTI v2 prototypes.

Our introduction to Canzibe hospital and Lwandile clinic came from a chance encounter with members of the Transcape NGO (www.transcape.org) that ran a backpackers called Mdumbi. They were interested in our work at Tsilitwa and told us about a rural hospital close to them. After the hardware removal from the Tsilitwa site, we made a foray to Mdumbi (V5) to see if they were still interested in the project.

A Transcape member accompanied us to Canzibe hospital to meet with the hospital superintendent and one of the doctors. They welcomed to the idea of MUTI and invited us to continue the project with them. We also scouted a communications tower behind the hospital because we had to build our own network for this site. We returned the next month (V6) to conduct a more formal needs assessment, and to choose a clinic.

We held a large group meeting at Canzibe hospital with four doctors and the nurse matron. The matron had been working in the area for over two decades and told us about the area. Canzibe hospital was the central referral point for ten rural clinics. In the 1990s, a CB radio system had linked the hospital and all of the clinics. Unfortunately, the system had fallen into disrepair and disuse. The system had not been used for patient referrals, but for requests for supplies, ambulance and clinic-to-clinic communication.

We chose to connect the hospital to Lwandile clinic for two main reasons. Firstly, Lwandile clinic was close to Transcape at Mdumbi and they would help support the project. Secondly, Lwandile appeared to be the most difficult clinic of the 10 to deal with. If we could get MUTI working for Lwandile, we could get it working for the other clinics as well.

The power supply at Canzibe hospital was more stable than at Sulenkama. Telecommunications, however, were comparable to the Tsilitwa site. Canzibe used DECT technology that provided Internet dial-up at 9600 baud. Several cellular providers including MTN, Vodacom and Cell-C served Canzibe, but it was necessary to walk about to find a strong signal. GPRS worked on both cellular networks and was much faster than dial-up over DECT. Canzibe's administration building had a 128kbps Diginet line that linked the hospital

to a DoH intranet, but without Internet access. There was also fibre between that building and the OPD. We found several network cabinets filled with equipment, all switched off.

Figure D-3 Lwandile clinic

Four nurses staffed Lwandile clinic. The clinic had solar power. There was no cell coverage at the clinic, and it had no DECT line. As the crow flies, the clinic was only about 15km from the hospital. Driving on poor winding (and flood-prone) dirt roads, however, was about 30km and took about 45 minutes to drive.

Lwandile clinic (see Figure D-3), on the other hand, had a solar power system donated and constructed by Dutch missionaries in the late 1990s. The batteries periodically dried up and required distilled water that was just as hard to come by in the closest city, Mthatha, as in the rural areas. The clinic had no telecommunication connectivity at all, neither DECT or GSM. The clinic was in a GSM 'hole', surrounded by hills. This meant that the MUTI network would provide the only communication the nurses had with the hospital since the CB radio system.

D.4.2 Plan Action

Based on our experience from Tsilitwa in getting to know the key players too slowly, we sought out and met with most, if not all, of the new stakeholders immediately: provincial DoH, district DoH, hospital doctors and management, village headmen, clinic nurses and local technical support. The provincial level DoH was aware of the CSIR's work in Tsilitwa, and we told them how ours differed in terms of semi-synchronous communication and multiple communication modalities. They told us about their ISDN video conferencing

systems in several far-flung hospitals in the Eastern Cape, but said the doctors were not really using it.

The district level DoH managers were very receptive to the project. They knew of the previous CB radio system. They offered the prospect of technical support and also computer literacy training for the nurses (alas, this never materialized).

We met again with the doctors at the hospital. The nurse matron accompanied us to Lwandile clinic where we met the nurses for the first time. Just up the hill from the clinic, we visited the village headman. His home had line of sight to the communications tower behind the hospital. He was very supportive of the project, and offered the use of his home to mount a relay station. The village headman near the tower gave his consent as well.

Unlike in Tsilitwa, we had to build the Canzibe network from scratch. Since Murray Pearson from CRCNet had accompanied us to Tsilitwa earlier that year and had expressed interest in the project, we asked him to help design the network. Together we planned the network over a period of several months, including the following:

- Designed the basic network topology (see Figure 7-5)
- Mapped the area and verified line of sight between network points
- Worked out a power provision with both solar and mains
- Chose hardware, especially spare parts
- Identified the installation tools and materials, especially spares
- Designed network details: IP addresses and routing, WiFi segmentation and channels
- Dealt with ICASA[24] about legality issues

We designed the network to take advantage of a communications tower owned by Eskom (herein referred to as the Eskom tower, as shown in Figure D-5). We visited Eskom in East London (V7) to request placement of research equipment on their tower. Eskom was willing, but was concerned that the long-range 802.11b network in 2.4GHz spectrum was illegal. They were happy to let us use the tower if we could obtain permission from ICASA, the regulatory authority. We were aware of other rural WiFi projects in South Africa, but to our knowledge, no one had bothered to obtain permission from ICASA. The application process was lengthy because of bureaucracy, personnel changes (at ICASA) and poor

[24] ICASA is the Independent Communications Authority of South Africa, the watchdog for telecommunications policy.

response to email and telephone calls. We finally submitted an application for a test license in person in Pretoria on April 5, 2005.

Figure D-4 Eskom tower relay station

The Eskom tower was protected by a wired fence enclosure. The tower was 22m high and used for Eskom communications, not for power distribution. It had its own mains power supply. Eskom agreed to let us place equipment on the tower providing we obtained permission from ICASA. They also provided us with free power. We used that power to trickle charge a 12v bakkie battery (shown in Figure 7-4).

We visited Canzibe again to ensure that everyone was still committed to participating in the project (V8). There was a new doctor at Canzibe assigned to visit each of the ten clinics in three-week intervals. We were lucky enough to visit Lwandile clinic on the day she was there. Her husband had joined Transcape and was very interested in providing technical support. He quickly became our main ally in the project. We met with three of the four nurses, and they were excited to begin the project. As became customary, when we visited the clinic, we also visited the Lwandile village headman.

We held a large group meeting at the hospital, and drove the clinic nurses to and from the meeting (about 45 minutes one way). The district level DoH managers attended, as did the hospital manager and both clinic supervisors. Two doctors were also there along with the technical support from Transcape. We demonstrated the MUTI software to everyone. The consensus of the meeting was that the MUTI software would be beneficial for

communication, remote consultation and also for possibly getting test results from the hospital back to the clinic faster. They were also marginally interested in adding video functionality. The plan was to start PC literacy training by leaving a laptop with them. We stayed at the hospital for a couple nights to get to know the doctors better, and also to observe how the hospital handled referrals. Their system was entirely paper-based.

D.4.3 Implement Action

We coded substantial extensions to the existing MUTI v1.3 prototype. In summary, MUTI v2.1 provided both synchronous and asynchronous functionality for text, voice and video (see Figure D-5). Images were still catered for in asynchronous mode.

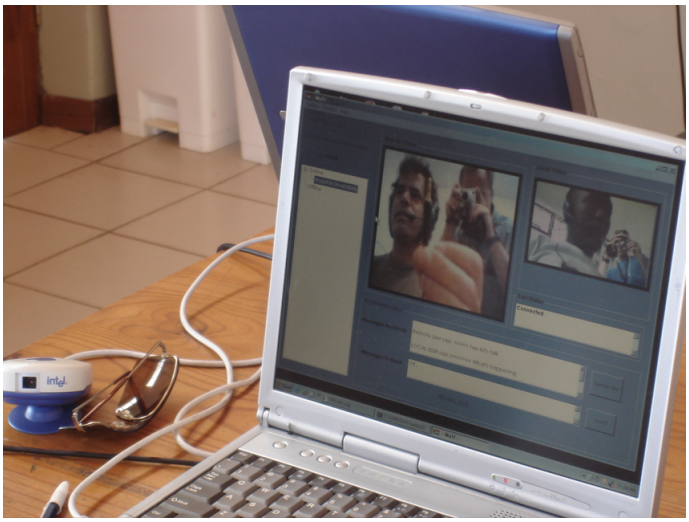

Figure D-5 MUTI v2.1 video interface

MUTI v2.1 added video to the previous version of MUTI. The web cam can be seen on the table on the lower left. A simple Instant Messaging facility is beneath the video windows.

We sourced the long-range WiFi equipment locally in Cape Town, and Murray Pearson of CRCNet flew out from New Zealand to help us build the network. Fortuitously, ICASA granted approval for the network during the (16 hour) drive out to Canzibe from Cape Town. The test license was for three months only.

It took less than one week to physically install the network and get MUTI v2.1 running (V9). A Softbridge analysis of MUTI v2.1 is shown in Figure D-7. We stayed an additional week to conduct training sessions with the nurses and doctors. Transcape offered to help with training while we were not on site. The chairman helped with training and also hired a young local Xhosa woman with computer experience to train the nurses.

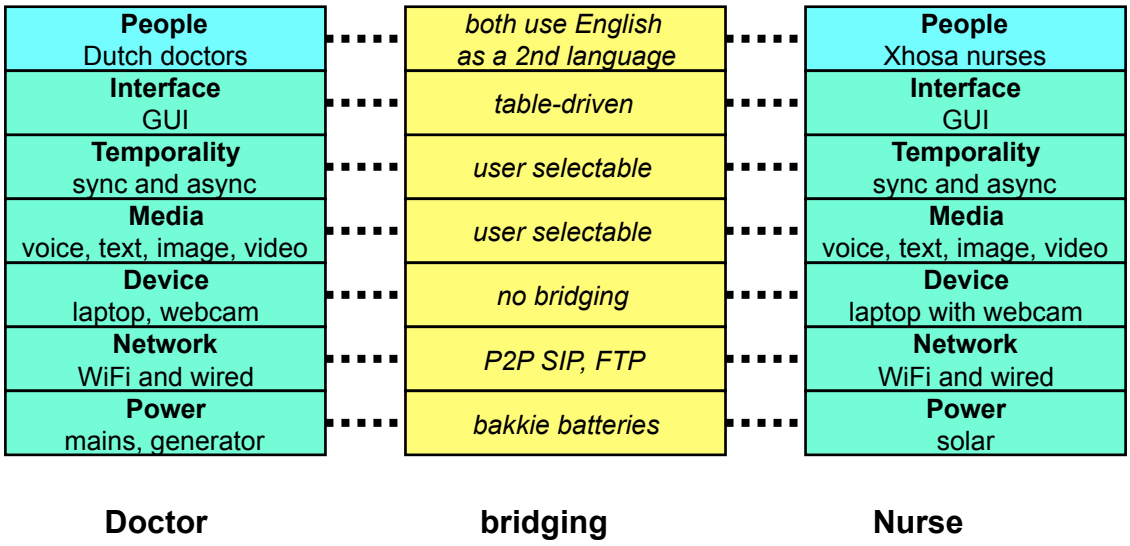

Figure D-6 MUTI v2 Softbridge stack

Canzibe hospital and the Eskom tower had grid power. At both nodes, we trickle charged a bakkie battery instead of using a UPS. Other network points used solar power. Each node had a waterproof enclosure that contained a WRAP PC and an integrated 16db flat panel antenna. The two relay stations used a second radio card with a 24db grid antenna for the long link. We used the same end-user devices from the Tsilitwa site. Asynchronous and synchronous video modalities were added, along with textual IM. The user interface changed very little from MUTI v1.3 because the application was enhanced rather than redesigned.

D.4.4 Evaluate Action

The local technical support team had many suggestions for the MUTI interface during the installation and training. We put them onto a list of improvements for the student programmer. After the network was installed (V9), we held another large meeting including everyone from the previous meeting plus the tele-medicine group from the provincial DoH (a total of 17 people). Initial results were encouraging: real-time text, voice and video were working, but the store-and-forward system was hanging. A follow-up visit (V10) confirmed that the network was working perfectly, but MUTI's asynchronous functionality was not.

D.4.5 Reflection/Diagnosis

Even though the synchronous components were working properly, we knew that a dysfunctional store-and-forward subsystem would hinder take up. There was also a lengthening list of improvements to the interface because we got a lot of feedback from the ICT-literate technical support. We had received very little feedback at the previous site, so this feedback was valuable and made us feel like the project was moving forward.

We addressed the issue of who owned the equipment at a group meeting. We made it very clear to the DoH and the participants that the equipment was not a donation. The equipment belonged to the universities (UCT and UWC) and was being lent to the DoH.

D.5 MUTI v2.2

The wireless network was reliable, but MUTI's store-and-forward system had become unstable. We redesigned the store and forward system, but it remained problematic. Table D-6 provides an overview.

Cycle overview	*Description*
Timeframe	Mid 2005
Community	Canzibe hospital and Lwandile clinic
Local champion	Arjan van der Sar, Transcape chairman and doctor's husband
Intermediary	Transcape
Prototype	MUTI v2.2
Coded by	Xolisa Vuza (UWC)
Supervised by	William Tucker (UCT/UWC)
Technical details	(Tucker, 2005)

Table D-6 MUTI v2.2 cycle overview

D.5.1 Plan Action

The store-and-forward subsystem required attention. There was also a list of interface improvements recommended by technical support. We also wanted to continue training the local Xhosa trainer and the nurses. We also planned another group meeting to get more feedback since more users had exposure to the system.

D.5.2 Implement Action

We reviewed the design of the asynchronous subsystem and identified thread synchronisation issues. We decided to redesign the asynchronous transfer system. After the re-implementation, executables were sent via email to Canzibe technical support (Transcape members).

We trained Transcape trainers and nurses (V10). We held another focus group with the nurses and doctors. We also approached the lab test services technician at the hospital to enquire about sending lab results back to the clinic with MUTI. The lab technician and his boss rebuffed us. They mistakenly thought we wanted to reconfigure their computer.

We drafted a letter for the hospital manager to explain that the equipment belonged to the project, but the DoH would put the equipment on their asset register to take financial

responsibility in case of theft. We also left the information sheet (Appendix E) and consent forms (Appendix F) with Transcape to get the nurses and the rest of the doctors to sign.

D.5.3 Evaluate Action

The main outcome of the focus group was agreement by the nurses and doctors to leave the system on everyday. Apparently, the users would only boot up when they felt the need to use MUTI. That made it difficult to use the system. The doctors and nurses told us that store-and-forward was not as useful as real-time communication. They did not really miss that component while it was broken. They also established that the best time to call was between 11:00-13:00 Monday through Friday.

Transcape agreed to follow up on the lab results issue: there must be a handover from that private company to the hospital at some point to get results back to the doctors and nurses. They needed to identify that person and get that person to use MUTI.

When we visited next (V11), the asynchronous messaging in MUTI v2.2 had been fixed. One of the doctors had sent a few messages to the nurses, but the nurses had not initiated any messages at all. On the clinic laptop, MUTI was running the processor at 99% trying to send a message, so there were still technical problems with the implementation.

D.5.4 Reflection/Diagnosis

We were concerned that the doctors and nurse felt that the store-and-forward component was not useful for them. We reasoned it must be because the system just was not working most of the time. We also realized we had to spend more time with the users; not just to support them, but to also learn more about their expectations for the technology. As for the software, there was still a growing list of problems to fix concerning asynchronous delivery, system logging and the human computer interface.

D.6 MUTI v2.3

The wireless network was still solid, but MUTI was not. The nurses told us they thought we were using the system to spy on them. MUTI was so cumbersome to use that it was clear it required a major overhaul. Table D-7 provides an overview.

Cycle overview	*Description*
Timeframe	Late 2005
Community	Canzibe hospital and Lwandile clinic
Local champion	Arjan van der Sar, Transcape chairman and doctor's husband
Intermediary	Transcape
Prototype	MUTI v2.3
Coded by	Xolisa Vuza (UWC)
Supervised by	William Tucker (UCT/UWC)
Technical details	(Vuza, 2006)

Table D-7 MUTI v2.3 cycle overview

D.6.1 Plan Action

To encourage the users to use MUTI more often, Transcape configured both laptops to automatically turn on in the morning, and to conserve battery, off in the afternoon. We also wanted to check on the network to ensure strong signal strength on all of the links using utilities on the routers. We planned to collect usage information from MUTI and compare it with claimed usage from users. Also, we wanted to collect feedback on the system from the users to find out exactly what was wrong with MUTI so we could fix it.

D.6.2 Implement Action

On the next visit (V11), we saw irregularities in ping times across the network, particularly across the long link. We re-aligned the grid antenna at the headman's home to solve that problem. We fixed some pathname-oriented bugs that were causing MUTI to crash. We also added some useful features like notification of arrival of new messages and a few other minor improvements.

D.6.3 Evaluate Action

We held another group meeting and learned that it took one of the nurses about 20 minutes to create a message. She typed very slowly and had a noticeable lack of confidence with the system. She insisted on more training. Upon closer inspection of the system's idiosyncrasies, e.g. having to exit records and come back to queue another for delivery and lack of audio with the video at the hospital, it was clear that the system was difficult to use.

We also found that the logs were much too large, measured in gigabytes. There was too much extraneous information written into the logs. We also found out that the presence was not working properly, so users could not really tell when someone was online or not.

The main findings of the group focus meeting (V11) were that the system had not become part of the nurses' routine and the interface was still extremely hard to use. However, it was noted that there were many uses for the system including test results, booking patients in Mthatha, supply requests, and emergency vehicle requests. One doctor suggested these alternatives, and said she would try to use the system herself from the clinic.

D.6.4 Reflection

Aside from the technical difficulties with the system, the (clinic-visiting) doctor, Transcape and our team discussed issues with the clinic nurses' work ethic. They were often only at the clinic about 20 hours per week. One of the nurses mentioned something to us about the system being used to spy on them. Transcape suggested that we move to and/or add another clinic near the hospital to take advantage of a better work ethic. We felt that until we demonstrated that we had a viable application, we should not expand the project and risk a larger failure. It was easy to fault the interface or the nurses' work ethic, but overall we failed to achieve rapid take-up because we over-emphasized patient referrals and not enough on the generic communication functionality that the system offered.

This particular visit (V11) was arranged 2 months in advance, but was ill timed because three of the doctors were not there. The trainer was pregnant so we had to train a new trainer for the clinic. This was advantageous, however, because now there would be two locals involved. However, these types of issues indicated we had to try and stay longer in the field, or make more frequent visits in the future.

When training the nurses, we found ourselves repeating the instructions again and again. One suggestion, from Transcape, was that we send a trainer to the clinic every single day instead of once a week. Unfortunately, the travel time for the trainer was 2 hours one way via public transport to the clinic. So daily training was a difficult proposition.

We were surprised that it took the nurses so long to create a message. One way to shorten that time was to automate the picture attachment process. MUTI also needed to fall over into message mode when a real-time call did not go through. We could also encourage nurses to only type the patient's name and use the voice for the rest of the information (to save on typing time). We could also simplify/unify the inbox/outbox interface, serialize the

message creation steps for the nurses with dialogs, and possibly create a different interface for doctors who could handle a more complex interface.

Perhaps the most significant realisation during this cycle was that this project did not originate from the participants, nor did we have a champion at the clinic. The champion for this project was a foreigner at Transcape, not at the hospital or in the clinic. Because of this, we had to support the nurses even more. If they did not make calls or leave messages, no one would use the system. We also had to emphasize non-referral functionality. It was possible that the nurses felt offended that we suggest they call the doctor for every patient, even though that was not what we intended.

We had lingering problems with system implementation. The store-and-forward system was faulty for far too long, the user interface was cumbersome, the presence did not work and the logging system logged too much data. It was not hard to see why the users struggled to use MUTI. We had to treat the system like the prototype it was, throw it away, and come up with a whole new approach.

Another emergent issue was that the group meetings might not be the best way to collect information. One of the doctors suggested that the Xhosa nurses could not effectively participate when surrounded by white people. Another doctor cautioned us to not bring up the nurses' poor work ethic because it would cause problems with their supervisors. Also, language issues made for misunderstanding. There were usually at least three mother tongues amongst the group members. Also, the terminology for health care and computer science disciplines was strikingly different. Our discussion of technical issues (of how we wanted to change MUTI) was couched in terms unfamiliar to the participants. Likewise, we found it difficult to understand their acronyms and processes. It was difficult to find common ground.

D.7 MUTI v3.1

We explored a mobile handset version of MUTI to address interface issues. Despite a user-friendlier interface on the cellular handset, MUTI usage remained low. The nurses may have shunned MUTI because they perceived it caused them to lose face in the community to ask for help from a doctor in front of patients. Table D-8 provides an overview.

Cycle overview	*Description*
Timeframe	2006
Community	Canzibe hospital and Lwandile clinic
Local champion	Arjan van der Sar, Transcape chairman and doctor's husband
Intermediary	Transcape
Prototype	MUTI v3.1
Coded by	Andrew Maunder (UCT)
Supervised by	William Tucker (UCT/UWC), Gary Marsden (UCT)
Technical details	(Maunder et al., 2006)

Table D-8 MUTI v3.1 cycle overview

D.7.1 Diagnosis

Before our next visit (V12), one of the clinic nurses died. Since another one was on official retirement, the clinic had only two nurses left. Due to the patient load, it was even more difficult for us to find time to train them, and for them to use the system. It meant we really had to make the system quick and easy for them to use. We decided to throw aside previous MUTI prototypes and redesign the system from scratch. We would port MUTI to a cellular handset.

D.7.2 Plan Action

The nurses were already familiar with cell phones. Each nurse had her own cell phone. The DoH also provided them with a clinic cell phone because they had persuaded MTN to adjust their equipment to provide coverage to the clinic. We would choose a WiFi-enabled cell phone that could participate on the MUTI network. We would install an AP at the clinic and also at the hospital. Another reason for porting the application to the cellular device was to simplify the interface. We also planned to give doctors a more comprehensive interface on the PC, but also allow them to share and carry around a MUTI cell phone.

In order to work out the interface, we conducted a paper prototyping exercise with the users (V12) that appeared unproductive. The nurses and the trainer were reluctant to move to a new interface because it meant more work for us (to produce a new version), and more training for them (to learn a new interface). We also felt that the participants did not understand the abstraction of the paper prototyping exercise. The only real change they wanted concerned attachments. That seemed the most difficult part for the nurses. They felt comfortable with picture attachments because of the associated thumbnails, but the voice and video attachments were difficult to visualise. Thus, the nurses wanted some kind of visual feedback.

D.7.3 Implement Action

We searched for a cell phone with the following features: GSM, GPRS, 3G and WiFi connectivity; form factor similar to a common cell phone, e.g. not like a PDA (Personal Digital Assistant) with a stylus; high-resolution digital camera that could also support video; software library support for SIP and RTP; and availability in South Africa. We chose the rather expensive iMate SP5 (about R4000) shown in Figure 7-8. We did not consider price to be an issue at that point because we knew prices would drop in the future. We were not able to find any phone that had the full SIP and RTP library support that we needed. Even though many phones came with SIP clients, they did not come with the libraries necessary to build custom real-time VoIP applications. Therefore, MUTI v3.1 could not implement the real-time features. We planned to add that in the future. The Softbridge stack for this prototype is shown in Figure D-7.

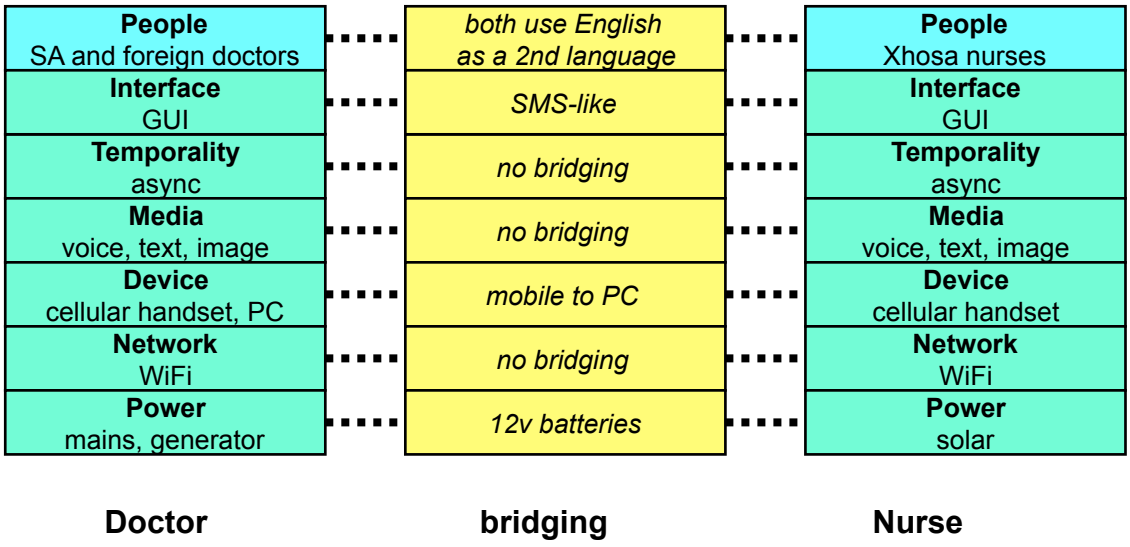

Figure D-7 MUTI v3 Softbridge stack

The main goal for MUTI v3.1 was to port MUTI to a handheld device and simplify the store-and-forward interface. MUTI v3.1 supported the creation of messages comprised of text, voice and images. The interface was very similar to creating an SMS, and would therefore be familiar to the nurses. Unfortunately, MUTI v3.1 was not compatible with prior versions of MUTI, and did not include real-time voice or video.

We installed APs at the clinic and hospital (V12), but had to reconfigure them on two subsequent visits before the hotspots worked well. We left three iMate SP5s with the trainers (V13) so they could get accustomed to the devices and start training the nurses to use them. We visited again with the intention to install MUTI on all three phones, but were flooded out

by the weather (V14). We finally installed MUTI on the phones and tested them on the MUTI WiFi network on a subsequent visit (V15).

D.7.4 Evaluate Action

It was not possible to evaluate the new system because the nurses simply were not there to use it. Apparently, they left over the Christmas/New Year's holidays and did not return to work for several months. It should be noted that the nurses came from far-flung villages.

D.7.5 Reflection

Because of the resistance to new features or versions of the software, we decided to avoid paper prototyping and just go to the field with a new prototype. When we showed up with the software on the iMate, the users appeared very receptive to the new prototype.

We described the status of the MUTI project at another FMFI workshop. One of our partners told a story about students in Mozambique being so much better at PCs than the teachers that the teachers told their superiors that the computers were useless. This was because they felt disempowered. We may have had a similar situation at the clinic: the nurses were community leaders and using MUTI meant they lost power because they were seen to request help from elsewhere. A similar power struggle may have emanated from providing training with locals because the trainers had less formal education than the nurses.

There were also work-related issues. The nurses did not need to talk to the doctor all of the time. They only needed to talk to the doctor in severe circumstances. What they needed most was quick turnaround on test results and to make bookings at the city hospital and for an ambulance. The DoH cell phone resolved the latter two issues. We approached the test lab management again (V15) and submitted a formal request, but never heard from them again.

A Transcape member suggested that the clinic nurses might prefer to talk with other nurses at the hospital and other clinics, as with the old CB radio system. The nurses also wanted to communicate with the test result people. The nurses wanted to talk to the hospital in Mthatha, and to the ambulance service, but not with the doctors. From the very beginning, our emphasis had been on communication with the doctors. It had taken several cycles to discover what the nurses really needed. By conducting cycles, we learned more about user needs by making mistakes than by getting things right.

D.8 MUTI v3.2

The doctors pooled resources to install a VSAT to provide Internet for their personal use. We helped our local champion design the network, but he bought and installed it entirely himself. We made some bug fixes to MUTI v3.1, but mostly encouraged users to explore Internet-based tools once the MUTI network was connected to a VSAT connection. Lwandile clinic was vandalised and we removed all research equipment from the clinic. The rural network terminated at the headman's house, whose son recently returned from the UK. We hoped that the son would emerge as a local champion to use the Internet connectivity available at his home, and a colleague visited to help him. Table D-9 provides an overview.

Cycle overview	*Description*
Timeframe	2007-8
Community	Canzibe hospital and Lwandile clinic
Local champion	Arjan van der Sar, Transcape chairman and doctor's husband
Intermediary	Transcape
Prototype	MUTI v3.2
Coded by	Andrew Maunder (UCT)
Supervised by	William Tucker (UCT/UWC), Gary Marsden (UCT)
Technical details	

Table D-9 MUTI v3.2 cycle overview

D.8.1 Diagnosis

There were minor glitches with MUTI v3.1. Despite the mobile interface, the nurses were not using the store-and-forward MUTI messages. Interestingly, even though the DoH provided a cell phone to the clinic, the nurses continued to use MUTI v2 on the laptop to contact doctors in real-time, although not very often. The doctors had connected themselves to the Internet with VSAT. We could connect the MUTI network to the Internet via their link. Burglary of the clinic's solar panels effectively halted the MUTI telehealth project.

D.8.2 Plan action

Before the burglary, we planned to fix minor glitches in MUTI v3.1 and also to hook up the MUTI network to the doctors' VSAT network. That would provide Internet connectivity to the clinic and we could encourage the nurses to explore the Internet and use Internet-based communication tools.

D.8.3 Implement action

We deployed MUTI v3.2 (V16). On a subsequent visit, we connected the MUTI network to the doctors' VSAT network (V17). Transcape continued with weekly visits to train the nurses how to use the new phone, the new version of MUTI and the Internet until the burglary occurred. During that visit, we also met the Lwandile village headman's son who had recently returned from the UK. Subsequently, a research colleague interested in ICT4D, Nicola Bidwell, leveraged our presence in the area and began ethnographic observation by staying in Lwandile village for extended periods of time in 2008 (her work is beyond the scope of this thesis). It was also notable that Transcape also built another VSAT plus WiFi network at the Mdumbi backpackers, also in 2008.

D.8.4 Evaluation action

Even with the bug fixes, there was very little use of MUTI v3.2. When the clinic's solar panels were stolen, Transcape removed all MUTI equipment from the premises to prevent it from being stolen. We returned late in 2008 (V18) to evaluate the state of affairs. Network usage appeared to be beginning at Lwandile village with the headman's son, and also burgeoning at Mdumbi; both were completely unrelated to telehealth.

D.8.5 Reflection

MUTI had effectively failed to take root with nurses at both Tsilitwa and Lwandile clinics. However, at the second site, the doctors, NGO and village headman's son recognised the value of having wireless Internet connectivity in the rural area. The doctors built their own WiFi network to share a VSAT connection at their homes. The Transcape NGO did the same at their base in Mdumbi. The village headman's son contributed to the purchase of an expensive Nokia E61i handset in order to use his home as a hotspot. The nurses were clearly the bottleneck for the MUTI project. As with the other field study, social issues appeared to influence the adoption of technology more than the performance of the technology.

Appendix E Information Sheet – Rural Tele-consultation

Who are we?

We are Computer Science researchers from the University of Cape Town and the University of the Western Cape. The teams members are Bill Tucker, Xolisa Vuza, Marshini Chetty and Edwin Blake. Hyman van Zyl of the Mdumbi Trust is our local technical support. We also work with Murray Pearson (University of Waikato) and Rudi Westerveld (Technical University of Delft).

What do we want to do?

We want to improve communications between the Lwandile clinic and the Canzibe hospital in the Libode area of the Eastern Cape to help with patient referrals. The aim is that patients only have to travel to the hospital if necessary. Our system, called MUTI, allows doctors and nurses to communicate with text, voice and video messages. It also allows sharing of high resolution pictures (taken with a digital camera). To use MUTI, we install a Wireless Ethernet (aka WiFi and 802.11b) network. Our research is primarily the development of the communications software. We work with doctors and nurses in rural areas to design and change the software over time. Our research runs in cycles where we introduce improvements, provide training and talk to the doctors and nurses to make improvements for the next cycle.

Over the past year working elsewhere, we have learned that there are two main issues concerning the use of such a system: dealing with power problems and the incredibly busy schedules of doctors and nurses. MUTI is designed to deal with these issues. We use laptop computers to run the MUTI system. When the power and network are working, the nurse and doctor can call each other just as with a telephone (but without the cost). When the power goes down, a laptop computer can run on battery power for several hours. When a patient comes in, the nurse can take pictures and/or video of the patient, record measures like blood pressure and record a voice mail for the doctor. The MUTI system stores this information and automatically sends it to the doctor when the power returns. The doctor can then look at the messages and either call the sister about the patient or send a message back. The doctor can also do this when the power is down. This does not mean that they can talk to each other when the power is out. It means they can create and process messages at any time. Messages are only delivered when the power and network are up. This is similar to voicemail or email, but allows the message to consist of any combination of text, voice, video and images.

Why are we doing this?

We could easily develop this software in the laboratory, but the reason we are doing this project is because we are interested in how we can use technology to help communication in rural areas. We are doing this as part of our research studies. We want to know things like, is the system useful, how can we make it better and how many times you use it. We will write about our experience of doing this work to help others who want to do similar work in the Eastern Cape and other rural areas. We also want to show the Departments of Health and Communication the kinds of things that can be used to improve health in areas with few phones and poor electricity.

Who funds this project and how will it continue when we are done?

This research is funded by the IDRC, SANPAD, and the Centres of Excellence at both UWC and UCT until the end of 2005. Please note that this is not a donation, and is not a product. We are interested in learning how to use technology to communicate in rural areas. If MUTI proves useful, we would like to convince the Department of Health to support the project. We hope that the community will work with us to do this!

If you agree to join this project, I will ask you to sign a consent form, but you can leave the project at any time without any penalty to you at all. Participation is your free choice. You will be asked to use the system and allow yourself to be interviewed about the system at regular intervals when we visit your site.

Appendix F Consent Form – Rural Tele-consultation

I, _____, fully understand the MUTI project and agree to participate. I understand that all information which I provide will be kept confidential, and that my identity will not be revealed in any publication resulting from the research unless I choose to give permission. Furthermore, all recorded interview media and transcripts will be deleted after the data results have been analyzed. I am also free to withdraw from the project at any time.

For further information, please do not hesitate to contact:
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Name:

Signature:

Date:

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