An Investigation into the Use of 3G Mobile Communications to Provide Telehealth Services in Rural KwaZulu-Natal

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Abstract

Background: We investigated the use of third-generation (3G) mobile communications to provide telehealth services in remote health clinics in rural KwaZulu-Natal, South Africa. **Materials and Methods:** *We specified a minimal set of services as our use case that would be representative of typical activity and to provide a baseline for analysis of network performance. Services included database access to manage chronic disease, local support and management of patients (to reduce unnecessary travel to the hospital), emergency care (up to 8 h for an ambulance to arrive), e-mail, access to up-to-date information (Web), and teleclinics. We made site measurements at a representative set of health clinics to determine the type of coverage (general packet radio service [GPRS]/3G), its capabilities to support videoconferencing (H323 and Skype™ [Microsoft, Redmond, WA]) and audio (Skype), and throughput for transmission control protocol (TCP) to gain a measure of application performance.* **Results:** *We found that none of the remote health clinics had 3G service. The GPRS service provided typical upload speed of 44 kilobits per second (Kbps) and download speed of 64 Kbps. This was not sufficient to support any form of videoconferencing. We also observed that GPRS had significant round trip time (RTT), in some cases in excess of 750 ms, and this led to slow start-up for TCP applications.* **Conclusions:** *We found audio was always so broken as to be unusable and further observed that many applications such as Web access would fail under conditions of very high RTT. We found some health clinics were so remote that they had no mobile service. 3G, where available, had measured upload speed of 331 Kbps and download speed of 446 Kbps and supported videoconferencing and audio at all sites, but we frequently experienced 3G changing to GPRS. We conclude that mobile communications currently provide insufficient coverage and capability to provide reliable clinical services and would advocate dedicated wireless services where reliable communication is essential and use of store and forward for mobile applications.*

Key words: *e-health, mobile health, telecommunications, telemedicine, telehealth*

Introduction

The problem of access to health services in remote locations in the developing world is well documented.[1] Numerous projects have described how they have attempted to overcome the limitations of the communication infrastructure in these countries through the use of mobile communications.[2] Some countries have adopted a national policy to prioritize development of the communication infrastructure in an attempt to address the problem.[3] However, there are many practical problems to be overcome: communications are managed by commercial organizations, and the requirements for health may not be commercially viable; land lines are frequently stolen; communication costs in the developing world remain high compared with GDP; communications are sparse (e.g., less than 2% have a land line); populations are sparse in remote locations; distances and geographic area coverage are large; services are not available everywhere; terrain can be hilly; and funding for projects is scarce.

Health services in remote locations can differ greatly, but there is a general desire to improve the health of the citizens of a country by increasing the capability of rural health clinics and the staff. Adoption of information communication technology can enable high-quality services to be offered and staff to be supported. Computers can support access to patient databases, administration functions, communication, education, and information. Advanced functions can include supporting teleclinics (connecting a patient with a distant physician), telehealth (forwarding physiological data), and imaging. To provide high-quality services requires good communication infrastructure. Typically, this can be provided through fixed lines, but for reasons stated, this is not always possible in the remote locations of many rural health clinics, and other communication technologies must be used.

Mobile communications are often believed to offer a universal solution to these problems. We therefore undertook an investigation into the feasibility of using third-generation (3G) mobile communications to support telehealth services in rural KwaZulu-Natal, South Africa. This article reports our investigation to determine whether 3G could be a cost-effective alternative to terrestrial communications.

Materials and Methods

We made measurements of mobile communication service provision at a representative set of rural health clinics in KwaZulu-Natal, in order to ascertain coverage, type of service available, capability to support clinical services, and characteristics of the communication.

COVERAGE

Measurements were made at representative sites around KwaZulu-Natal to determine coverage at different types of health organizations,

			SIGNAL	STRENGTH		SKYPE		SPEED (KBPS)	
SITE	TYPE	DATE	TYPE	(BARS)	VIDEO	AUDIO	VIDEO	UPLOAD	DOWNLOAD
A		August 29, 2010	None						
B		July 19, 2008	2G	4	No	Barely	No	23	45
B		September 9, 2010	2G	4	No	No		79	70
C	Clinic	July 19, 2008	2G	4	No	Does not send	No	31	73
C	Clinic	September 9, 2010	2G	4	No	Yes		95	42
D	Clinic	July 19, 2008	2G	3	Very low bandwidth	Barely	No	31	45
E		July 20, 2008	2G	4	No		No		
F	Clinic	July 21, 2008	2G	4	Yes	Poor	No	33	55
G	Clinic	July 21, 2008	2G	Unreliable	No	No	No	0	0
H	Clinic	July 22, 2008	2G	3		No	No	16	27
I	Clinic	September 4, 2010	2G	4	No	No			28
J		September 6, 2010	2G	4	No				250
K	Hospital	September 9, 2010	2G	3	No	No		45	
L	Hospital	September 10, 2010	2G	4	No	No		35	
M	Hospital	September 10, 2010	2G	4	No	No		100	67
N		September 10, 2010	2G	4	No	No			
O	Hospital	July 16, 2008	3G	4	Yes	Yes	Yes	230	230
O	Hospital	September 10, 2010	3G	4	Yes	Yes		352	
P	Hospital	July 18, 2008	3G	4	Yes	X	X	X	X
P	Hospital	September 10, 2010	3G	4	Yes	Yes		312	460
Q		August 27, 2010	3G	3	Yes	Yes		370	400
R		September 1, 2010	3G	3	Yes	Yes		386	400
S		September 4, 2010	3G	4	Yes	Yes			740
T	Hospital	September 9, 2010	3G	4	Yes	Yes		333	
U	United Kingdom	September 17, 2010	3G	4	Yes	Yes		222	
V	United Kingdom	September 17, 2010	3G	4	Yes	Yes		667	
2G									
Mean								44	64
SD								33	65
3G									
Mean								331	446
SD								56	185

2G, second generation; 3G, third generation; SD, standard deviation.

including hospitals, rural clinics, and some other selected locations. Technical performance measurements were conducted to determine the type of mobile service available and to determine the capabilities of the service at selected sites. Measurements were made during two periods: July 2008 and August 2010.We made repeated measurements at several locations to determine if the service had been upgraded over time.

CAPABILITY AND CHARACTERISTICS

A laptop was configured with a 3G/general packet radio service (GPRS) modem on the Vodacom mobile network in KwaZulu-Natal. Wireshark[4] was used to capture and analyze network traffic to determine throughput for applications. Iperf[5] was used to determine sustained throughput for transmission control protocol (TCP) traffic. As 3G and GPRS are asymmetric in bandwidth, throughput in both the up and down direction was determined. Polycom (San Jose, CA) PVX™ was used as the videoconference application (H323), with a connection being made to a Sony (Tokyo, Japan) video-conference system in the Nelson Mandela School of Medicine, Durban, South Africa. Skype™ (Microsoft, Redmond, WA) was used as an example of an Internet-based video/voice application. Skype was tested by making an audio connection to the Skype echo service. Web access to typical Internet sites was used as an example network application.

Results

Several measurements were taken at each site. Results were consistent for each site regarding the service available (3G or GPRS) and its characteristics and are presented in *Table 1*.

COVERAGE AND PERFORMANCE

For sites with 3G, the results were consistent between sites and between the results from 2008 and 2010. Upload speed for the network was determined to provide a sustained throughput of around 331 Kbps for TCP traffic, and download speed was determined to be around 461 Kbps. This was deemed sufficient to support video services at 256 Kbps and provide good access to Web sites that did not have significant image content.

Videoconference sessions held with the Department of Telehealth of the Medical School in Durban, using a bandwidth of 256 Kbps, were found to be consistently good. Jitter and loss for video and audio packets were consistently low, demonstrating the network is capable of sustaining video as an application. Higher connection speeds did not provide sustained good performance, with loss and jitter increasing rapidly with higher connection speeds, as is consistent with measured throughput. Access to Web services was good and consistent with measured throughput.

Coverage of 3G was limited to urban areas, business areas, or popular tourist destinations. There was no 3G coverage in any of the rural areas, unless close to a tourist destination.

We measured GPRS as a means of providing network access for rural clinics. Average upload speed was 44 Kbps, and average download speed was 64 Kbps. We noted that bandwidth was significantly improved from measurements in 2008, when these were 30 Kbps as upload speed and 40 Kbps as download speed. We would expect this as a result of the introduction of EDGE (2.5 generation) to the network to enhance GPRS (second generation).

Some remote clinics had no mobile service at all. These typically were in locations far from the nearest town and in radio shadow from masts due to the local terrain.

EXPERIENCED PERFORMANCE

We experienced unreliable communication and performance with Web applications in all sites. When investigated, we determined that round trip times (RTTs), as measured with ping, were around 300 ms for 3G and over 750 ms for GPRS. This compares with 20 ms for typical terrestrial networks. Several applications had timeout problems and would sever the connection. Although these speeds should

Table 2. Current Cost of the Kwazulu–Natal Telehealth Network Based on Integrated Services Data Network										
SITES (*N*)	LINE SPEED (KBPS)	SITE RENTAL (ZAR)[a]	CALLS	CALL DURATION (S)	SITE CALL COST (ZAR)[b]	SITE TOTAL COST (ZAR)	TOTAL RENTAL COST (ZAR)	TOTAL CALL COST (ZAR)	TOTAL COST (ZAR)	DATA AMOUNT (GB)
Clinics (19)	128	286.55	8	3,600	376.13	662.68	5,444.45	7,146.43	12,590.88	0.46
District general (1)	256	573.10	8	3,600	752.26	1,325.36	573.10	752.26	1,325.36	0.92
District general (6)	384	859.65	12	3,600	1,692.58	2,552.23	5,157.90	10,155.46	15,313.36	2.07
Tertiary care (3)	512	1,146.20	25	3,600	4,701.60	5,847.80	3,438.60	14,104.80	17,543.40	5.76
Teaching hospital (2)	768	1,719.30	5	3,600	1,410.48	3,129.78	3,438.60	2,820.96	6,259.56	1.73
Monthly cost							18,052.65	34,979.90	53,032.55	
Annual cost									636,390.65	

[a]With cost per 128 kilobits = 286.55 (Zar).

[b]With cost per second per channel = 0.00653 (Zar).

Kbps, kilobits per second.

Table 3. Estimated Cost of the Kwazulu–Natal Telehealth Network Installed in All Clinics and a 50% Increase in Use Based on Integrated Services Data Network

SITES (*N*)	LINE SPEED (KBPS)	SITE RENTAL (ZAR)[a]	CALLS	CALL DURATION (S)	SITE CALL COST (ZAR)[b]	SITE TOTAL COST (ZAR)	TOTAL RENTAL COST (ZAR)	TOTAL CALL COST (ZAR)	TOTAL COST (ZAR)	DATA AMOUNT (GB)
Clinics (59)	128	286.55	12	3,600	564.19	850.74	1,6906.45	33,287.33	50,193.78	0.69
District general (1)	256	573.10	12	3,600	1,128.38	1,701.48	573.10	1,128.38	1,701.48	1.38
District general (6)	384	859.65	18	3,600	2,538.86	3,398.51	5,157.90	15,233.18	20,391.08	3.11
Tertiary care (3)	512	1,146.20	25	3,600	4,701.60	5,847.80	3,438.60	14,104.80	17,543.40	5.76
Teaching hospital (2)	768	1,719.30	8	3,600	2,256.77	3,976.07	3,438.60	45,13.54	7,952.14	2.76
Monthly cost							29,514.65	68,267.23	97,781.88	
Annual cost									117,3382.58	

[a]With cost per 128 kilobits = 286.55 (Zar).

[b]With cost per second per channel = 0.00653 (Zar).

Kbps, kilobits per second.

support Web applications, the large RTTs of GPRS result in poor perceived performance due to the slow start-up algorithm of TCP.

RTT does not affect video traffic as it is based on the user datagram protocol of the Internet protocol.

In areas with 3G, we noticed that service would occasionally downgrade to GPRS for periods of time.

FINANCIAL CONSIDERATIONS

We developed a model of the KwaZulu-Natal telehealth network that is currently based on Integrated Services Data Network (ISDN) in order to compare cost with provision through other technologies. We selected dedicated wireless (microwave) links. We also considered cost assuming 50% increased use of the network.

The first scenario (*Table 1*) presents the actual use of the current network based on ISDN. The second scenario (*Table 2*) considers extending the network so that all hospitals and clinics in the state are connected based on the same ISDN and assumes that this leads to increased use of 50% in the district hospitals (equivalent to an increase from 2 h to 3 h of use per week).

The third scenario (*Table 3*) considers using fixed wireless technology (microwave link) to provide reliable network infrastructure for all sites (in practice, fixed links are already available in the large hospitals). Not only is the third scenario reliable, it can provide improved bandwidth and access at lower cost. Furthermore, all services (e.g., telephony) can be provided over the same connection, thereby providing savings from eliminating multiple connections (in some cases, satellite phone).

Discussion

We have undertaken an investigation into the feasibility of using 3G/GPRS to support telehealth services in KwaZulu-Natal. Performance measurements confirm that 3G can support sustained throughputs of

at least 250 Kbps in the upload and download directions and did support good-quality videoconferencing at 256 Kbps.

However, 3G was only available in urban areas (where terrestrial communications are also available), with no coverage in rural areas. GPRS was widely available, and measured bandwidth should support e-health applications. However, experience in KwaZulu-Natal revealed excessive RTTs that caused many e-health applications to fail.

We also determined several locations with extremely poor or no mobile service.

We accept that mobile communications can be an excellent solution in rural areas, but care has to be exercised in the choice of application and implementation. Mobile communications can provide ideal solutions to mobile workers under the condition that applications can work offline in situations where there is no signal, so that the application has sufficient information to be useful and can

Table 4. Estimated Cost of the Kwazulu–Natal Telehealth Network Installed in All Clinics and a 50% Increase in Use Based on Microwave Links

SITES (*N*)	SITE COST (ZAR)	TOTAL COST (ZAR)
Clinics (59)	855	50,445
District general (1)	855	855
District general (6)	855	5,130
Tertiary care (3)	1,200	3,600
Teaching hospital (2)	855	1,710
Monthly cost		61,740
Annual cost		740,880

store data for later upload and synchronization. There are numerous examples of this approach.[2,6]

However, in the context of this research, telehealth was to be provided in the rural clinics and, therefore, with fixed and static installation of the communication infrastructure. We conclude that the mobile network is currently not suitable to provide the infrastructure for a telehealth network that must provide reliable health services and would advocate use of dedicated wireless links in this case. This could also lead to cost savings (*Table 4*).

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Disclosure Statement

No competing financial interests exist.

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