EMPIRICAL SURVEY OF HSPA NETWORKS TO DELIVER MEDICAL APPLICATIONS

Christopher I. Iyawe[1,2] and John Doucette[1,2]
[1]*Department of Mechanical Engineering, University of Alberta, Edmonton, T6G 2G8, Alberta, Canada*
[2]*TRLabs, Edmonton, Alberta, Canada*

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Abstract: Population explosion coupled with a decline in medical personnel are forcing governments in the developed and developing nations to look at new ways to deliver healthcare to their citizens. The cost of providing healthcare put so much pressure on the delivery system that many find it difficult to access the system. The most affected are often the elderly and/or those who are highly immobile, particularly those who reside in remote communities. This group is often laden with chronic illnesses and diseases requiring home care, and ambulatory services to access the healthcare system. Such services are generally quite expensive to provide. Developing an eHealth network to drive applications to deliver healthcare services to homes is very costly. Such dedicated networks will also be difficult to manage. We can observe the manner in which other industries use information and communications technology (ICT) through the public network to influence ways services are delivered to the public, and ask why the same (i.e., use of ICT applications through the public network) cannot be done for the healthcare system. In this paper, we assess the capability of local HSPA public networks to deliver healthcare applications to home care clients.

1 INTRODUCTION

It has become clear that wireless communications are almost essential to maintain an active lifestyle in today's developed countries. Economic, social and cultural activities around the world are now being driven by communications technology. The late comer to this vast access of communication networks is the healthcare industry (Fischer, 2010). Most modern healthcare communications still use 19th century technology through the *public switched telephone network* (PSTN). Although most of the patient-related information generated in the healthcare industry is still on paper, advances have been made in the implementation of *electronic medical records* (EMR) in many modern healthcare clinics and hospitals (Ludwick and Doucette, 2009). However, there is still much to be desired in the use of *information and communication technology* (ICT) to deliver healthcare services.

Many other industries have successfully used ICT to deliver services to the home for decades. For example, the banking industry uses ICT to deliver account management, bill payment, loans, and other services (Hardy, 2010). It is only natural to expect that ICT can do the same for the healthcare industry. Applying ICT to healthcare is a complex issue, because healthcare delivery may involve a variety of applications, each of which has different bandwidth and latency requirements. For the purpose of this study we will consider applications that are applicable to homes, such as vital signs monitoring, educational health services, etc.

Many healthcare applications require real-time services, and people's lives may depend on the response time of the healthcare provider, which might in turn depend on the network's latency and other technical characteristics for successful delivery of such applications (Cisco, 2007). This could have grave repercussions if the network and the applications that run on it are not designed properly; bandwidth and latency requirements for such networks and applications are of utmost importance. They have to be carefully designed and measured in order for the healthcare industry to appreciate the capability and the expediency of such applications. Where these real-time services are required, applications with even small latency can have a disproportionately adverse effect on the user's overall experience.

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1.1 Goals and Motivation

The purpose of this study is to assess the capacity of public wireless networks, more specifically local *high speed packet access* (HSPA) networks, in relation to healthcare applications requirements as they share channels with other types of public traffic. This work looks at various ICT applications with potential for use in home care, and determines their latency and bandwidth characteristics over an HSPA wireless access network.

We have chosen public wireless network technology because of its wide reach in suburban and rural areas where home care is more likely to be a major aspect of a patient's healthcare regimen. We considered HSPA in particular because it is the fastest mobile wireless network that has been widely deployed by our regional telecommunication companies. With fast data access, mobile communication can provide personal or interactive services virtually anywhere in the service area at virtually any time.

With the introduction of HSPA in WCDMA networks, *Internet service providers* (ISPs) now have the capability of offering latency sensitive and simultaneous voice, data and video services over their mobile wireless networks. We have collected empirical data over real networks, analyzed the data, and have come up with recommendations for applications that can be run through such networks.

This paper is organized in the following order. The methodology used in the survey is described in Section 2. The test setup is given in Section 3. Survey results are presented in Section 4. Network evaluation for medical data sets is considered in Section 5, and the paper finishes with some concluding remarks in Section 6.

2 METHODOLOGY

We chose Strathcona County, near Edmonton, Alberta as our test site, as that region covers a good mix of suburban and rural residential areas. We first mapped out the test area as illustrated in Figure 1. The survey area is representative of the population density distribution in the suburban and rural areas of Strathcona County. We drove through the indicated route (highlighted in red) and collected *global positioning system* (GPS) data, and wireless information such as *received signal strength indication* (RSSI). We also carried out bandwidth testing at numerous points in the area to simulate healthcare applications through the network.

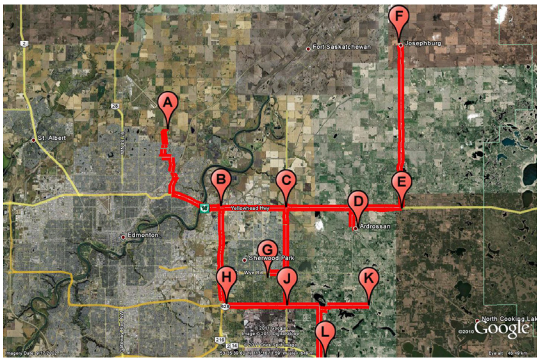

Figure 1: Area of interest for Wireless measurement.

3 TEST SETUP

Figure 2 illustrates our HSPA network setup. We connect to the *radio access network* (RAN) with an access service network antenna to create the data path between the mobile station and the core network. Detailed network characteristics and configurations of the core network are unknown to us, as the local service providers do not like to divulge this information. All data presented herein is based on the data we were able to collect through our own experimental apparatus.

We had the ability to measure the network performance from two end points, in the field and in our office in downtown Edmonton In the field, we measured the upload speed and latency as well as the download speed and latency through the network. We set up a laptop computer (denoted as "Server PC" in the figure) to act as a fixed server running Darwin streaming server and IxChariot endpoints (Ixia, 2010) at our Edmonton office. The Server PC communicated with our field apparatus (the lower half of the figure) through the HSPA network. We deemed the Server PC to represent a doctor's office or hospital server and the field apparatus to represent a patient home. The Server PC has an external IP address to by-pass the office firewall and also to free it from our office's network traffic. This ensures that our test is isolated from whatever is happening within the office network.

The "Test PC" is the main computer in the field apparatus (set up in the lead author's vehicle), and ran VLC application software and IxChariot endpoints. VLC was used in the field to stream video files from the Server PC. IxChariot was used to test the upload and download speed through the network. The Test PC was also fitted with a Logitech QuickCam and a Polycom PVX. This enabled us to do video conferencing with our office's video conferencing system via the Server PC. Video files of various sizes, frame rate, resolution, and bit rates recorded in MPEG-4 format were loaded on the Server PC. We deemed the video files represent medical data images such as radiographs, MRI, etc. These files were used to test the network from Test PC in the field.

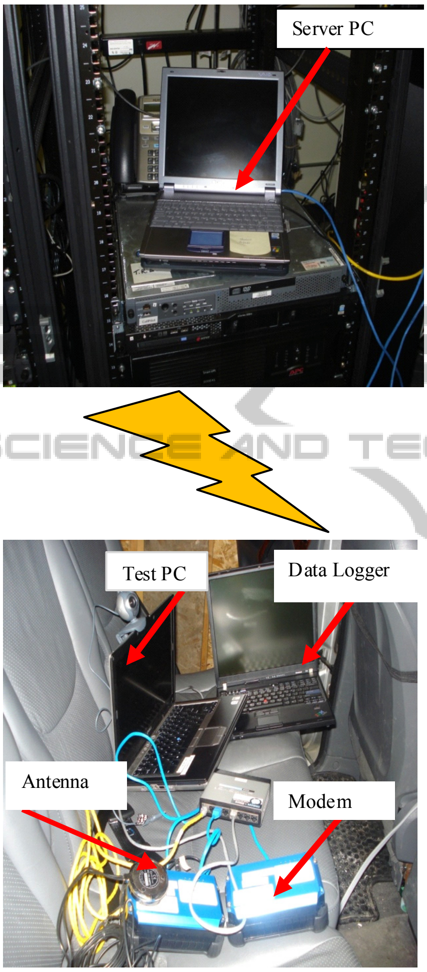

Figure 2: HSPA Network test setup.

The Test PC was also connected to a Cypress CTM-152 cellular modem, shown in Figure **2**. Embedded in the CTM-152 is a Sierra Wireless AirPrime MC8700 HSPA+ module that accepts an approved data card from local ISPs. The CTM-152 is equipped with antenna (also shown in the figure) and GPS inputs so that data could be mapped to the corresponding GPS coordinates at the time of collection. Low-level diagnostic information about the network was also collected and logged in MySQL database.

The measurement route is shown in Figure 1. Starting at point A in northeast Edmonton, we drove to the hamlet of Sherwood Park, which is the suburban area bounded by rectangle B-C-H-J in Figure 1. Then, we proceeded to point D (Ardrossan), and ended at point F (Josephburg). At the noted points and intersections along the route, we became stationary and ran our battery of network tests: IxChariot FTP-get and FTP-put, VLC video streaming and Polycom Video Conference sessions. These points were chosen to coincide with community boundaries, community centres, and places that represent the population distribution in the area. We followed this route on two different dates (28 May 2010 and 04 June 2010), and simultaneously collected data for each of two main wireless carriers in the region (we will simply refer to them as Carrier 1 and Carrier 2). We could not find a convenient place to stop and collect data at point C as there was construction on the road way at the time of our measurements.

4 RESULTS/DISCUSSION

4.1 Network Performance – Suburban

We used IxChariot, and VLC to assess the capacity of the network of the two carriers and we measured the performance of their networks. We configured IxChariot to download data files from the server using FTP-get. These measurements were done on the networks of both carriers at pre-determined locations. The first measurement location was at point B in Figure 1. The RSSI recorded at this location was -81 dBm for carrier 1. We completed the first test by downloading a 100 kb data file in real time. The average download speed was 0.557 Mbps. Figure 3 through Figure 5 give a graphical view of TCP throughput, transaction rate, and response time for our FTP-get test on Carrier 1. The average transaction rate and response time were 0.697 per second and 1.436 seconds, respectively. As expected, we can observe that a high throughput tends to correspond to high transaction rates and low response time. For example, Figure 3 shows a fall in throughput at about 51 seconds into the test, and there was a corresponding low transaction rate and high response time at that time stamp in Figure 4 and Figure 5. The fall in throughput below the application bandwidth requirement threshold may necessitate packets drops, just as in the video streams test. These are important facts to note about the network when designing an eHealth application because round trip time of an application will depend on the network response time, which is the delay through the network. Also, the delay through the network will depend on the network throughput. The ideal for a high capacity network will be a high throughput, high transaction rate, and low response time. This will ensure minimal delay between a doctor's office and a patient's home.

Similar values were obtained for FTP-put throughput, transaction rate, and response time at point B, where we uploaded a 100 kb data file from the field to the Server PC. We deem this to represent a patient sending personal or medical data from home to a doctor's office.

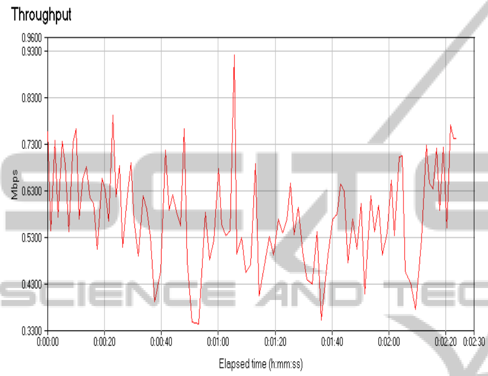

Figure 3: FTP-get throughput for Carrier 1 at junction of Trans Canada 16/Hwy 216 (point B).

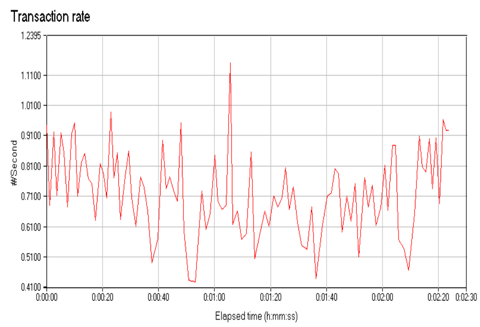

Figure 4: FTP-get transaction rate for Carrier 1 at junction of Trans Canada 16/Hwy 216 (point B).

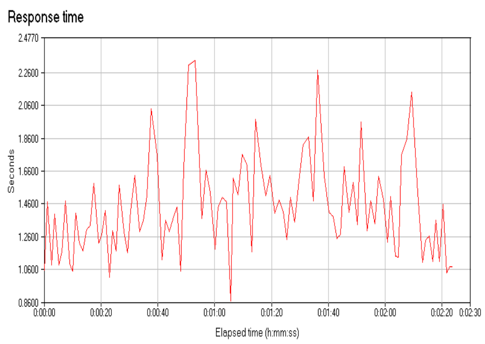

Figure 5: FTP-get response time for Carrier 1 at junction of Trans Canada 16/Hwy 216 (point B).

We note here that although Figure 3 through Figure 5 correspond to only a single point in our tests, the results shown are typical of data collected at other locations, and so for space considerations we omit figures showing the data for those tests. That said, we show summary data for some location in Table 1.

The packet size for IxChariot was set at a constant 4096 bytes, with no dynamic variation in packet size. *Real time streaming protocol* (RTSP) was used in VideoLAN (VLC) streaming of the pre-recorded MPEG-4 video clips. These files were created using FFmpeg on a pre-recorded video clip varying the key parameters as detailed in Table 2. During the test, the received video streams were recorded and the video quality evaluated subjectively by noting audible and visual artefacts in the audio and video streams that are not present in the originals.

At point H, we repeated the video streaming tests and observed that here, we were able to successfully stream files 1-7 on Carrier 1 without noticeable degradation, but could only do so with files 1-4 on Carrier 2. In fact, the video bit rate of Carrier 1 was 5000 kbps, approximately 6 times that of Carrier 2, which was 750 kbps. We can also note that at this location, throughput for carrier 2 was much lower than for Carrier 1. For instance, Carrier 1 averaged 1.084 Mbps throughput for FTP-get while Carrier 2 averages 0.441 Mbps. The average transaction rate for Carrier 1 was 1.378 per second, and the average response time was 0.726 seconds, while the average transaction rate for Carrier 2 was 0.551 per second, and the average response time was 1.816 seconds. Given Carrier 2 transaction rates this low, response times this high and a low throughput rate, it took almost twice as long to run this test in carrier 2 than in carrier 1. This suggests that depending upon choice of carrier (i.e., its network configuration, number of active users etc.), will greatly impact the type of eHealth application that can be deployed in such a network. We show all video streaming summary data in Table 3, below. In the entire suburban area, we found out that at a minimum, we can stream video file 3, a video recorded at 15 frames per second with a bit rate of 500 kilobits, and screen resolution of 720 X 480. We conclude that at least based on these findings, we can expect a home care application including video with those characteristics to be functional over the two HSPA wireless networks we tested.

Table 1: Summary of FTP-get and FTP-put data at all suburban locations.

Location	Carrier	RSSI (dBm)	FTP-get Throughput (Mbps)	FTP-get Transaction Rate (sec^{-1})	FTP-get Response Time (sec)	FTP-put Throughput (Mbps)	FTP-put Transaction Rate (sec^{-1})	FTP-put Response Time (sec)
B	1	-81	0.557	0.697	1.436	0.805	1.009	0.991
G	1	-75	0.956	1.198	0.836	0.764	0.957	1.044
H	1	-76	1.084	1.378	0.726	0.845	1.059	0.944
J	1	-91	0.890	1.114	0.897	0.777	0.973	1.028
B	2	-81	0.456	0.561	1.798	0.351	0.438	2.289
G	2	-91	0.425	0.532	1.891	0.341	0.429	2.304
H	2	-76	0.441	0.551	1.816	0.349	0.346	2.293
J	2	-91	0.417	0.522	1.915	0.348	0.435	2.297

4.2 Network Performance – Rural

As mentioned earlier, our test region includes a large area with a higher concentration of people in the suburban (Sherwood Park) area, and a more moderate population density in the acreages and rural areas, with the exception of a somewhat higher density of people in the immediate vicinity of points D and F in Figure 1 (the rural hamlets of Ardrossan and Josephburg with populations just over 400 and 200, respectively). With this in mind, we chose test points in the acreages and rural areas (points E, K, and L) and in the two above-mentioned hamlets. For expediency, we will discuss our findings on Carrier 1 here. We could not obtain any useful data for carrier 2 at point E, K and L. Also, Carrier 1 has poor signal reception at point E and L. At those points, we could not run our battery of test. FTP-get test executed for carrier 2 at Josephburg, but the signal reception was so poor that FTP-put could not execute. We summarize the above data and the other collected data in the rural locations in Tables 4 and 5.

Table 2: Characteristics of MPEG-4 video files used.

File #	Frame Rate (frames per sec)	Audio Bit Rate (kbps)	Screen Resolution	Video Bit Rate (kbps)
1	10	16	320x240	250
2	10	64	320x240	1000
3	15	64	720x480	500
4	15	64	720x480	750
5	15	64	720x480	1500
6	15	64	720x480	2000
7	15	64	720x480	5000
8	24	128	1920x1080	3000
9	24	128	1920x1080	4000
10	24	128	1920x1080	15000

5 NETWORK EVALUATION FOR CLINICAL DATA SETS

One of the purposes of conducting this study was to determine what sort of capability exists in local HSPA networks (Palola et al., 2004) to accommodate potential healthcare applications. Table 6 shows various sizes of data files produces by some medical applications and the average transmission time based on our measured averages. Medical application file sizes are well documented in various peer-reviewed articles the file sizes used in Table 6 were adapted from (Rafael et al., 2006).

The frequency of monitoring vital signs, the number of patients being monitored and the number of monitoring devices may generate large amounts of data and traffic for the network. The extent of monitoring and the frequency of monitoring will depend on the medical history and medical problem of the patient (Varshney, 2006). The results of our measurements show that HSPA has system resources that are sufficient to handle a shared transport channel. Vital signs monitoring, which has a low bandwidth requirement, may easily be transported through this medium to a server at the clinician or hospital system. Vital signs devices that are real-time or near-real-time, running store and forwarding protocols may work well with this transport system. Specific tests may still be done to properly size the number of users on the shared channel. Bandwidth-hungry applications such as radiographs can best be served by store and forwarding systems. As shown in Table 6, it may take some time to upload or download 100MB file through the system.

Table 3: Summary video streaming results at all suburban locations.

	Carrier 1				Carrier 2			
Location	Best File	Best File Frame Rate (fr/sec)	Best File Screen Resolution	Best File Video Bit Rate (kb/sec)	Best File	Best File Frame Rate (fr/sec)	Best File Screen Resolution)	Best File Video Bit Rate (kb/sec)
B	5	15	720x480	1500	4	15	720x480	750
G	7	15	720x480	5000	-	-	-	-
H	7	15	720x480	5000	4	15	720x480	750
J	7	15	720x480	5000	3	15	720x480	500

Table 4: Summary FTP-get and FTP-put data at all rural locations.

Location	Carrier	RSSI (dBm)	FTP-get Throughput (Mbps)	FTP-get Transaction Rate (sec^{-1})	FTP-get Response Time (sec)	FTP-put Throughput (Mbps)	FTP-put Transaction Rate (sec^{-1})	FTP-put Response Time (sec)
D	1	-90	0.899	1.127	0.888	0.820	1.027	0.973
F	1	-97	0.523	0.657	1.522	0.682	0.854	1.172
K	1	-71	0.932	1.166	0.857	0.723	0.905	1.105
L	1	-102	0.054	0.068	14.722	0.075	0.093	10.742
D	2	-91	0.163	0.204	4.902	0.098	0.123	8.160
F	2	-92	0.059	0.075	13.415	-	-	-

Table 5: Summary video streaming results at all rural locations.

	Carrier 1				Carrier 2			
Location	Best File	Best File Frame Rate (fr/sec)	Best File Screen Resolution	Best File Video Bit Rate (kb/sec)	Best File	Best File Frame Rate (fr/sec)	Best File Screen Resolution	Best File Video Bit Rate (kb/sec)
D	6	15	720x480	2000	None			
F	3	15	720x480	500	None			
K	7	15	720x480	5000	None			
L	none				None			

Table 6: Medical files upload times in select areas.

File Type	File Size	Point G (Mean TX: 0.845Mbps)	Point D (Mean TX: 0.820Mbps)	Point F (Mean TX 0.682Mbps)
Sonogram	2MB	18.9 sec	19.5 sec	23.5 sec
Angiogram	70MB	11.05 min	11.38 min	13.69 min
SPECT	10MB	1.58 min	1.63 min	1.96 min
MRI	30MB	4.73 min	4.88 min	5.87 min

Polycom PVX software was used to test the link between the video conferencing system at our downtown office and the Test PC video conference in the field. Polycom implemented an enhanced video (H.264) standard. We observed that at the low bandwidth setting of 384 Kbps, the frame drop and the video jitter were at a minimum. For example, in Ardrossan, where RSSI was -90dBm, we recorded a frame rate of 15 fps, a video jitter of about 7ps, an audio jitter 14, and a packet loss of 1 for the entire 5 minutes of video calls. This was typical of most sites on our test route.

6 CONCLUSION

We were able to characterize the RSSI in the study area and did some channel condition testing in the predetermined sites. The fact that HSPA is a highly deployed technology shows the acceptance of the technology in the wireless community, which would easily permit a means to obtain high speed data connection to homecare patients. With this technology, ISPs have been able to boost their bandwidth for better delivery of content through their network and better user experiences with the wireless technology. We were able to establish a threshold for video conferencing (384Kps) given the same channel conditions and same setting on the Polycom PVX, that good reception and communication is possible over the HSPA network.

Our study indicates that it is plausible to set up patient remote monitoring using the public HSPA wireless network; high quality medical data may be delivered over the network with the existing network resources. The low response times we obtained from our measurement will work with live monitoring applications such as ECG, SpO_2. With live monitoring application, the most important service requirement will be the response time or latency which affects the quality of the eHealth application over the network. The network will perform better with a *store and forward application*, where medical information is stored at the time of collection and then later forwarded to the server at a convenient time (e.g., when there is sufficient network resources to do so). This provides value to the patients and the clinicians in the sense that the clinician can still monitor the patient and have a sense of the patient's wellbeing. Using the system relieves and frees up clinical resources that would otherwise have been tied up in the process of gathering these medical information.

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