Implementing a Wireless Application in a Developing Country

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Abstract – **For the first time in the nation of Georgia, health facilities at the district level are connected electronically for the purposes of collecting and sharing health data for patient care and hospital administration. Legal, budgetary and infrastructure considerations as well as equipment availability complicated the design and development of a wireless, city-wide health information system in Georgia. This paper discusses these and other issues encountered by a Canadian project to implement a multi-facility electronic patient record.**

International development; Georgia; health information system; electronic patient record; wireless LAN

I. Introduction

In September 2001, the Canadian Society for International Health (CSIH) began the second phase of a project for countries in the South Caucasus region, Armenia, Georgia and Azerbaijan. This project, funded by the Canadian International Development Agency (CIDA), aims to support health reform by building sustained capacity for health planning through development and use of health information systems [1]. The project's main objectives are:

- development of model integrated health information systems (HIS),
- training in health information systems, management and planning,
- delivery and support of activities to enhance the capacity of regional stakeholders to use health information in making decisions, and
- development of health information teaching materials for regionally-delivered academic courses.

To satisfy the first objective listed above, an "HIS demonstration project" has been undertaken in each of the three countries. In the nation of Georgia, the Ministry of Labor, Health and Social Affairs (MoLHSA) and, more specifically, the Center for Disease Control and Medical Statistics and Information (CDCMSI) have been partnered with CSIH in an effort to build an integrated HIS in the city of Gori. The HIS serves four hospitals, the Public Health Department and the Regional Health Office in Gori, and enables the electronic transfer of data to CDCMSI in the city of Tbilisi.

The HIS has a central database that stores case-based patient data. Users at each of the facilities can, with proper authorization, access patient history collected by any of the hospitals. In time, several outpatient clinics will be added to the set of participating facilities. The data collected support patient care by providing medical personnel with information about previous encounters and provide management with health services utilization information. As well, the data are used by CDCMSI to generate statistical reports on the basis of which the MoLHSA can plan health programs, monitor health status and formulate health policies.

II. Background

A. The Georgian Infrastructure

Georgia was annexed by the USSR in 1922, became a Soviet republic in 1936 and ultimately declared its independence in 1991. During the Soviet era, Georgia moved from a mainly agrarian economy to an industrial one. With the collapse of the Soviet Union, much of the Georgian industry collapsed. The infrastructure, which was poorly planned and poorly built, also collapsed. Few highways are in good condition and there is a lack of available power; outages can range from a few minutes to several days. In the winter, it is not uncommon for cities, including the capital of Tbilisi, to be without power for half a day three or four times a week. In some of the outlying cities, like Gori, power outages can last for several days. Heat is also a luxury during the winter when temperatures drift around the freezing point.

B. The Physical Site

Gori, a regional capital with about 70,000 residents [2], is nestled in a flat, shallow valley. Although most of the participating facilities are at the same elevation, the Children's Hospital is on a hillside elevated about 10 m above the city center. The distances among the facilities range from approximately 50 m to a maximum distance of about three km. Many of the buildings in the city center are three storeys tall, constructed of reinforced concrete with peaked roofs made of corrugated concrete or galvanized sheet metal. The hospitals themselves are 40-year-old dilapidated concrete buildings that are three and four storeys tall. The city is heavily treed with what appear to be tall sycamores. (Fig. 1 is a map of the city center that shows the location of the participating facilities.)

C. Health Care in Georgia

The collapse of the Soviet Union also saw a decline in social and economic programs; the health care system deteriorated significantly. Hospital buildings constructed during the Soviet era are usually in a state of disrepair and

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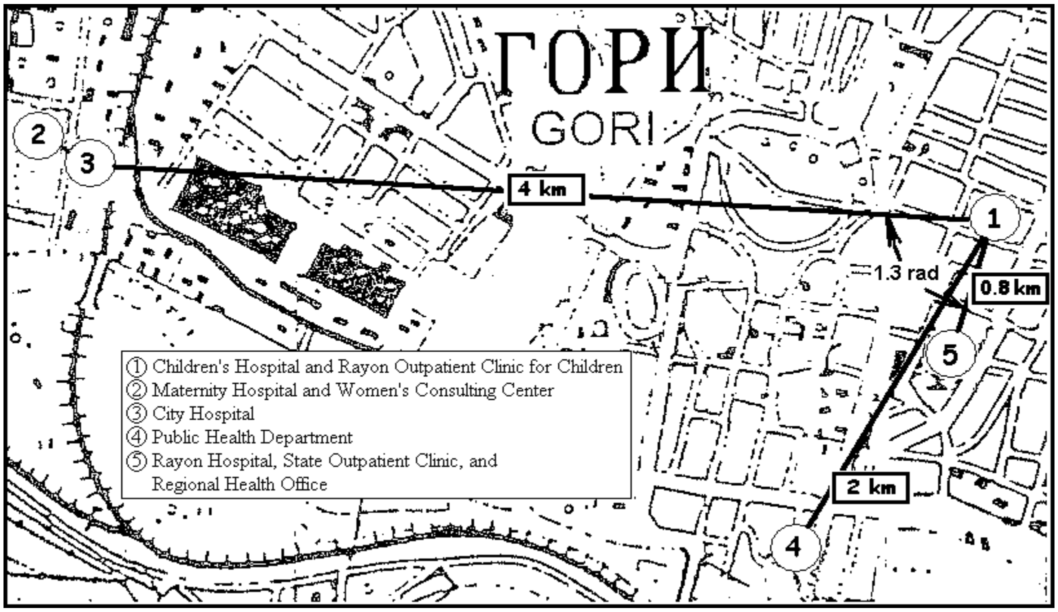

Fig. 1. Map of Gori, Georgia showing the locations of demonstration project facilities [3].

there are no funds to build new buildings or to renovate the existing ones. The Soviet approach to health care resulted in a large number of specialized hospitals, such as those designated specifically for trauma, pediatrics, or obstetrics. City hospitals are nearly empty; an occupancy rate of 25% is high, 10% is normal. The hospitals have no budget for capital equipment and very small budgets for operating expenses, including the salaries of nurses and doctors.[1]

Facility administrators are not empowered to make more than short-term localized operational decisions. Facility budgeting and strategic planning are managed at either the regional or national level where decisions tend to be less sensitive to the needs of the patient population. Because hospitals and clinics make few significant decisions that have an effect on the care they deliver, they have become information producers not information consumers. Furthermore, the reliance on largely paper-based data collection tools, which are cumbersome to manipulate and often inaccurate, limits the usefulness of information for decision-making at all levels.

It was important to make the best use of the country's existing resources because of the country's severe budgetary constraints and the project's limited funds.[2] To ensure continued operation of the HIS beyond the end of the project in 2005, operating expenses had to be minimized. This had implications for the choice of the personnel, training, software, hardware, and network.

D. Health Information System Requirements

Software was required for storing and reporting the case-based data that would be collected at inpatient, outpatient, and clinic facilities. The application software would be used to capture data about patients and their families, patient encounters, admissions, symptoms, signs, diagnoses, procedures, immunizations, medications, laboratory tests, consultations, pregnancies, and deliveries. At the inception of the project, most of this data were entered only on paper forms although there were some simple stand-alone DOS-based computer applications that were used to collect principal diagnoses and maternal health data for the Ministry and for the World Health Organization (WHO).

A central on-line database would be needed so that patient and client histories could be shared among hospitals, outpatient facilities, and women's reproductive health clinics in the region. Not only would the system provide some information for physicians and nurses to make clinical decisions but it would also be a tool for data analysis and management decision support at participating hospitals, clinics and government authorities.

The HIS programs would have to present screens written in the vernacular. Each of the countries has a unique language and alphabet; the Russian language, which is the

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[1] To place costs in perspective, the gross domestic product (GDP) per capita of Georgia is estimated to be $2,500 US. The GDP per capita in the United States is 15 times greater at $37,800 US [4]. In 2000, Georgia's budget for state spending on health was approximately US $11 per person; the average salary for health care staff was approximately US $15 per month in 1999 [5].

[2] CIDA's contribution to the SCHIP budget is $3.4 million CAD (approximately $2 million US). This is supplemented by significant in-kind contributions (donations of time, equipment, or other resources) by all project participants [1].

most frequently used second language, is not an acceptable alternative.

E. Transaction Volumes

Four of the sites are hospitals that primarily enter and review encounter data. The two remaining sites, the Public Health Department and the Regional Health Office, use the system to generate reports. Table I gives estimates of the daily number of concurrent sessions, transactions, and average bandwidth requirements. Although clinics such as the Rayon Outpatient Clinic for Children are not yet participants in the project, in Gori there are seven such outpatient facilities that may join the HIS in the future. Each of these clinics processes approximately three times the number of transactions as do the hospitals. The average bandwidth requirement throughout a six-hour day is 8.3 kbps and the estimated maximum bandwidth requirement, based on each session submitting a complete transaction within a period of five minutes, is approximately 120 kbps. The average transaction size is based on an estimate of the size of the web pages to be displayed at a workstation, the amount of data entered, and the size of the reports.

TABLE I. ESTIMATED DAILY TRANSACTION VOLUMES

Type of Site	Active Sessions	Number of Transactions per Session	Average Transaction Size (kB)	Bandwidth Requirement (kbps)
Hospital	4	15	300	2.1
Office	2	10	100	0.6
Clinic	7	40	300	5.6
Summary	13	65	270	8.3

III. MATERIALS AND METHODS

A. The Platform

The system makes use of a private TCP/IP network, web clients and a single Linux server. Most of the client computers are either Intel 80486DX 33 MHz or Pentium I 100 MHz computers. At this time, there are approximately 10 workstations in all that are accessing the server. The server, which has a 2 GHz Celeron processor with 256 MB of memory, two 40 GB hard disk drives, and a CD-RW drive, is running the Mandrake Operating system. Apache and MySQL provide web and database services, respectively. Programs written in PHP generate the application web pages in HTML and javascript.

As shown in Fig. 2, there is an IEEE 802.11b wireless local area network (WLAN) between the Children's Hospital and each of the City Hospital, the Public Health Department and the Rayon Hospital. A shielded twisted pair (STP) wired connection has been made between the City Hospital and the Maternity Hospital. Within each building a rudimentary IEEE 802.3 local area network (LAN) was installed using unshielded twisted pair (UTP) cable. Table II shows the types and manufacturer's models of the wireless equipment installed.

Not shown in the schematic is a small training center that has been built in the Rayon Hospital. The training center, which is connected to the LAN in the Rayon Hospital, has two workstation clients and its own Linux server.

B. The Application Software

A number of techniques have been used to minimize the amount of data that is exchanged between the server and its client workstations. The most significant are: a) tightly written HTML web pages are transmitted to the clients, b) web pages are small and semantically complete - this reduces the page transmission time and the amount of HTML code that is transferred, c) few images are displayed and these are cached by the client, d) data validation edits are applied wherever possible by the client, e) "novice" and "expert" modes are available for data that require database validation – novices can invoke a new screen to submit queries to the database engine; experts need merely to identify the database entity, f) reports can be displayed in segments rather than in their entirety, g) filtering criteria can be specified on every database inquiry to minimize the query set and to reduce the number of records that are displayed, and h) reports can be transferred to the workstation as compressed files.

TABLE II. WIRELESS EQUIPMENT BY SITE [6]

Site	Device	Model	Maximum Range (km)
Children's Hospital	Bridge Amplifier Antenna	SMC-2482W SMCAMP-1000 (1000 mW) SMCANT-DI105 (10.5 dBi gain, 0.87 rad beam width at -3 dB)	19
All other sites	Bridge Amplifier Antenna	SMC-2482W SMCAMP-500 (500 mW) SMCANT-DI145 (14.5 dBi gain, 0.45 rad beam width at -3 dB)	43

IV. DISCUSSION

Georgia is just beginning to embrace computer and network technologies. Prior to its independence, there were few computers and almost no networks. Over the past decade, the country has relied heavily on nongovernmental organizations (NGOs) to fund the purchase of new computers and to donate used ones. For example, during the first phase of this project which began in 1999, CSIH donated approximately 40 used Intel 80486 PCs to various maternity and child health facilities to support the collection of data to promote maternal health. Indeed, some of these computers are still being used as client workstations in the second phase of this project. The political and cultural climate, budgetary constraints, lack of local expertise and a weak infrastructure interact to make a complex and unwelcoming environment for these computer network technologies.

This project represents a small step taken to demonstrate how a twentieth century technology can be fruitfully applied to the benefit of the population. The equipment and software development budgets have been frugal and CDCMSI, CSIH staff and CSIH consultants have donated a significant amount of their time to implement the HIS. Many of the project activities, design decisions and equipment choices have been influenced by constraints imposed by the environment which differs dramatically from those of North America and Europe.

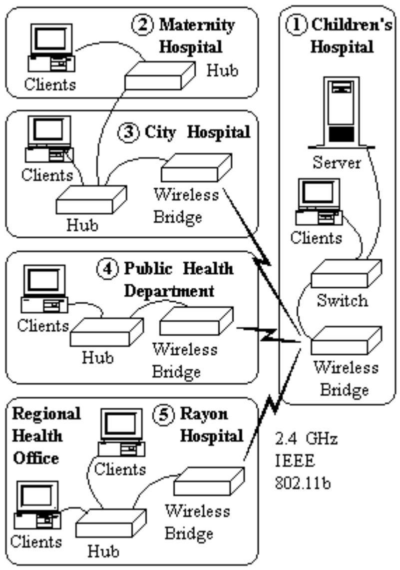

Fig. 2. Abbreviated schematic of the network topology.

The network in Gori is a good example of how choices have been thus influenced. The telephone company was contacted to determine whether or not it was practical to install leased lines between the hospitals. It was determined that the monthly charges were 15 Georgian Laris (GEL) or approximately $7 US per termination but that the data rate would probably not exceed 9600 bps due to line noise. Given the slow data rate, the typical 20 kB web page would take a prohibitive 25 seconds to transmit. Faster services, such as that provided by Integrated Services Digital Network (ISDN), are not available. The maintenance service provided by the telephone company would be unreliable, particularly given the outdated telephone exchange equipment that is currently being installed.

Telecommunication lines could be installed but the distances are too great to be convenient; permission from the local authorities would be necessary in order to use the telephone poles; and the lines would have to be maintained by the project. This clearly was an expensive, non-sustainable solution.

The network could be foregone entirely and CD-ROMs could be used to exchange data. This solution would work but it would a) increase the time delay for data exchange from a few seconds to a week or more, b) fail to be an exemplary demonstration of the project concepts, c) increase the system administration load, and d) increase the equipment cost – although the applications can run with both client and server on the same computer, the computer would have to be a modern one.

A wireless network was chosen to join the most distant sites because it was most likely to have a lower operating cost, be easier to install and be easier to maintain. This choice, however, introduced a number of problems.

The Georgian National Communications Commission required the project to purchase a radio license at a cost of 500 GEL ($250 US). The Radio Committee, whose stated purpose is to monitor the frequency, required an application for use of the 2.4 GHz band at a cost of 1700 GEL per year ($850 US). This fee, rather than subscribing to a service, is a form of taxation; the one other wireless network known to the project, located in Tbilisi, was disbanded because of lack of official monitoring and enforcement.

The hospitals' roofs are in such a bad state of repair that it was difficult to convince the chief executive officers (CEOs) to permit the installation of antennas there. Indeed, it was possible to do so at only two of the sites. At the Public Health Department, another site, the antenna could only be installed on an exterior wall of the building by passing through a privately owned apartment on the third floor.

Wiring in the hospitals is haphazard and has no breakers for protection. Because remedial costs are too great to be borne by the project, computer and wireless equipment is installed without adequate electrical grounding. Even poor grounds such as hot water radiators and washroom fixtures are lacking as they are often disconnected or missing entirely. Although there are generators at three of the four sites, there is no money to purchase fuel for the generators. Surge suppressors, network surge suppressors and uninterruptible power supplies (UPSs) have been purchased in order to compensate for the poorly conditioned and unreliable power but these operate to specification only if they have a good ground connection.

The elevation of the Children's Hospital made it the logical site for the central node in a point-to-multipoint network but its elevation is only 10 m above the city center. The farthest distance is three km, which makes reception problematic due to the Fresnel zone [7]. Fig. 3 shows the envelope that is 60% of the radius of the first Fresnel zone and its position relative the surrounding buildings and trees. The diagram indicates that it should be possible to maintain a communications link between the sites but there would be some interference due to diffraction. In fact, interference and the wide-beam, but lower-gain, antenna installed at the central node resulted in signal attenuation that was much greater than what was anticipated based on the manufacturer's specifications.

The network equipment was chosen using the following criteria which in order of their importance are: availability, reliability, cost, and simplicity of installation and management. Wireless network equipment is difficult to obtain in Georgia; nearly all such equipment is shipped via Moscow where it must first receive a Russian certificate of compliance. Only a few products are available and none were inventoried in Tbilisi when the order was made. Equipment from only two reputable manufacturers was available: Cisco and SMC. Both manufacturers provide reliable equipment but the SMC equipment costs significantly less and is simpler to manage. Each of four SMC-2482W kits, which included cable and high-gain antenna, cost $1000 US and the delivery time on the equipment was approximately two months. There were few options available from the distributor in Moscow and amplifiers, additional cables and 14.5 dBi antennas had to be purchased in North America. The total price of the wireless equipment was approximately $2000 US per network node.

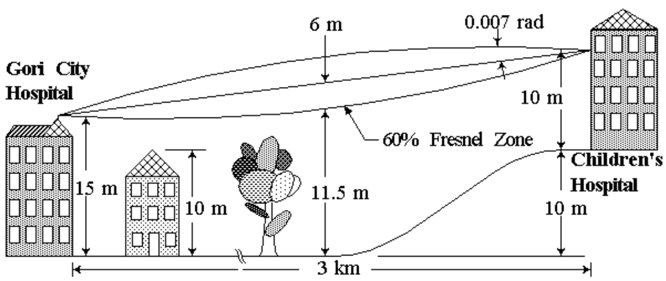

Fig. 3. Elevation showing the Fresnel zone for the greatest transmission distance.

An attempt was made to consult with Georgian telecommunication and wireless experts before the equipment was purchased. Because there are so few wireless networks in Georgia, there is a dearth of experts who specialize in WLANs. Instead, the network was based on our own experience, common sense and good luck. In retrospect, it seems unlikely that the outcome could have been improved through expert consultation.

Due to budgetary restrictions, the computer equipment that already existed in Gori is being used. The result is a system that runs on older less-powerful client computers but that supports all of the features that any sophisticated information system does. As well, the number of clients and facilities can be readily increased. The bandwidth requirements shown in Table I fall easily within the capabilities of the IEEE 802.11b wireless bridge: the average bandwidth requirement is 8.3 kbps, with an estimated peak requirement of 120 kbps, and the central node is capable of operating at 22 Mbps. The seven outpatient clinics can be added to the network by simply adding three bridges and extending the IEEE 802.3 LANs at four existing sites.

V. Conclusion

A health information system has been built successfully in the city of Gori. It makes use of a wireless local area network and demonstrates how the technology can be used. It presents a showcase example of a functioning practical on-line multi-facility HIS. Although the system is installed only in Gori, the software can be installed in other cities and regions in Georgia at a minimum cost. The Linux operating system and tools are "open source" and carry no licensing cost. The installations are in not-for-profit public institutions that will not be marketing any part of the operating software or HIS application software.

Installation of the wireless network was not technically difficult but, rather, made difficult because of the conditions imposed by the environment. It took a year to build this comparatively simple wireless network. Equipment was hard to obtain and had long delivery times. Licenses had to be purchased for a bandwidth that is usually unlicensed. (It is expected that the Radio Committee's fees will be waived in the future.)

The hospital buildings are old, made of concrete and in a state of poor repair. Power is unreliable and badly conditioned; wiring is inadequate and the power circuits are unprotected. Building walls that are opaque to microwaves make wireless communication within the buildings impossible. Opaque and reflective roofs increase the amount of diffraction of wireless communication between buildings. Access to good antenna mount points is problematic, sometimes impossible.

Despite its implementation problems, the outcome of the demonstration project is favorable. The network is sustainable at a minimum cost. System maintenance should be easy because the equipment and software are robust and simple to use. This HIS demonstration project is a good lesson in capacity-building and a reference for future initiatives.

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