Smart Connect: Last mile data connectivity for rural health facilities

Richard Anderson[12], Eric Blantz[3], David Lubinski[2], Eleanor O'Rourke[1], Mark Summer[3], Krysta Yousoufian[1]

[1]Computer Science and Engineering
University of Washington
Seattle, WA, USA
{anderson, eorourke}@cs.washington.edu
krystay@uw.edu

[2]PATH
Seattle, WA, USA
{randerson, dlubinski}@path.org

[3]Inveneo
San Francisco, CA, USA
{mark.summer, eric.blanz}
@inveneo.org

ABSTRACT

In this paper we address the problem of providing data connection to the periphery of the health system by presenting Smart Connect. Smart Connect is a custom device that uses the cell phone network to provide limited data connectivity between a rural health facility and a server connected to the Internet. Through an analysis of the health systems in Nicaragua and Vietnam, we have identified a variety of processes that could be improved with this device. These include filing incidence reports on diseases, receiving results of diagnostic test, and providing automatic monitoring of vaccine refrigeration equipment. The main contributions of this work include a presentation of the Smart Connect requirements derived from the health care systems of Nicaragua and Vietnam, an argument in favor of facility based communication devices, and a brief discussion of the design for the Smart Connect device.

I. INTRODUCTION

In many developing countries, health care is delivered in rural areas at heath posts or dispensaries. These facilities are typically small, staffed by one or two health professionals, and offer only a limited range of services. Due to their rural locations, the infrastructure connecting these facilities is often poor. For example, many are only accessible via small roads or tracks, and some are off the electrical grid or at the periphery of cell phone service. Given that transit time is substantial and connectivity is poor, we consider how the ability to send digital data to and from these facilities could be used to support their activities. We focus specifically on providing basic data connectivity, with low bandwidth and some potential for latency.

In the following sections, we first argue the case for using facility based data communication rather than relying on personally owned mobile devices. We then discuss the types of applications that could be supported by a device that provides a small amount of bandwidth. This discussion is informed by our field visit to Nicaragua and an assessment of the vaccine distribution needs in Vietnam. Finally, we provide a sketch of the Smart Connect device that we are currently building and give an overview of the deployments planned for Nicaragua and Vietnam.

NSDR '10, June 15, 2010 San Francisco, CA

II. FACILITY BASED COMMUNICATION DEVICES

Mobile phones have rapidly become the preferred communication devices worldwide; the current global ratio of mobile subscriptions to land lines is about 3 to 1. In developing world this ratio is significantly higher. For example, in Africa the ratio of mobile subscriptions to land lines is about 32 to 1 [1]. As a result, there is an expectation that communication with health facility staff in the developing world will take place on individually owned mobile devices. We propose a different approach: the provision of a fixed, facility owned communication device that is dedicated to specific health-related applications.

A number of factors and potential advantages have led us to consider a facility based communication device:

- The device can take advantage of the facility's infrastructure, such as being connected to a permanent power source. If cellular coverage is weak, an antenna can be used to improve the signal.
- The device is owned by the facility, so it is always present and communication costs are covered by the facility.
- The device provides a fixed contact point for the facility.
- Security for the device can be improved by physically securing it, and since it may not have the full functionality of a cell phone, it will be less desirable to steal.
- The device can be restricted to running dedicated services preventing unauthorized use.
- The device can be connected to sensors.
- The device can be connected to peripheral devices.

The design of the Smart Connect device has been guided by a desire to take advantage of these proposed benefits. In order to achieve our goal of learning how a small amount of data connectivity can be used to enhance the work processes of rural health clinics, we have decided to build a custom communication device. The device is not meant to be a replacement for cell phones; in fact, several of the applications of the device could naturally be integrated with cell phone based solutions. We have chosen to build a custom device because this will give us flexibility when engineering connections with sensors and peripherals and provide us with direct access to the device hardware. Since a vaccine refrigerator is a central piece of equipment in many health facilities, one possibility is to integrate Smart Connect with the refrigerator to take advantage of its source of power. This would involve implementing Smart Connect as an embedded system, and as a result we want to have control over the device's packaging to be able to explore these types of applications. Even though it is attractive to consider using an existing mobile phone as the communication device, there are challenges in interfacing a cell phone to external sensors.

There are many design points that could be considered when developing a custom communication device. We have chosen to look at what should be the least expensive: supporting a very small amount of data, maybe a few kilobytes *per day*. At that level, one option is to use the cellular network and send data encoded in SMS messages, which can accommodate 161 characters per message. However, the cost of sending SMS messages varies dramatically around the world, ranging from a small fraction of a cent up to 20 cents in some locations. If low cost messaging is not available, then limiting the messages to a small number is important for a cost realistic solution.

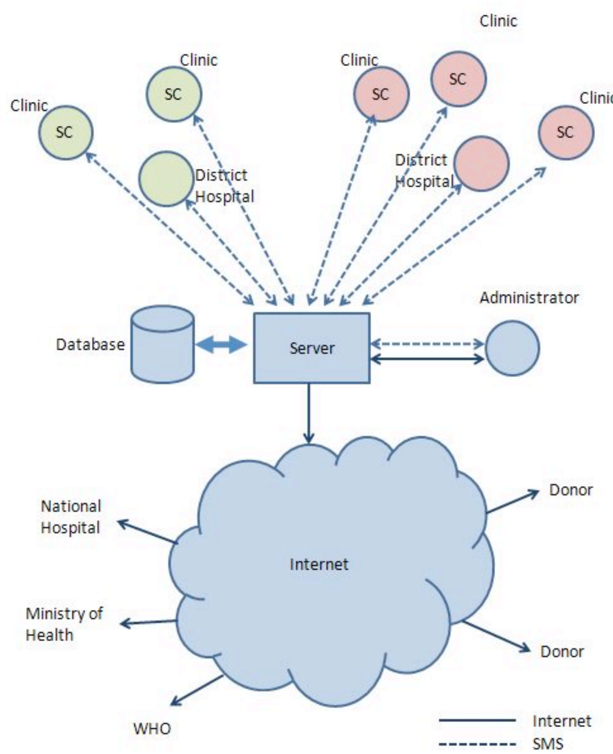

Figure 1 A schematic overview of a countrywide deployment of Smart Connect.

Prior to developing the device, we conducted a study of the communication needs associated with rural medical facilities and the vaccine distribution process. This study consisted of a field visit to Nicaragua to look at the data needs at the facility level, and an assessment of logistics in vaccine distribution in Vietnam.

III. NICARAGUA

In the initial planning stage for the Smart Connect device, we developed basic use cases including temperature monitoring, reporting vaccine stock levels, and notifying clinics of deliveries. To evaluate these use cases, we made visit to Nicaragua to get an overview of the public health system. The visit focused on assessing information needs at all levels, including surveillance data and immunization. At this stage, Nicaragua had been selected as the likely country for a field deployment.

Nicaragua is a low-income country in Central America with the second lowest per capita income in the Americas. In spite of the low level of income, the country has a moderately strong public health system. The health system is organized in the standard tiered model, with the National, District (SILAIS), Health Center and Health Post levels. A reform several years ago shifted some of the responsibilities from the national level down to the district level. In rural regions, health centers are located in towns, and staffed by about 6 doctors, and 6 nurses. Health posts are in more remote locations, staffed by one or two medical professionals, who can be either doctors or nurses. Basic services provided at health posts include vaccinations, maternal health checkups and well baby care. Efforts are made to send serious cases and births to health centers.

The visit covered all levels of the health system, including two departments at the Ministry of Health, and visits to 6 district offices, 5 health centers and 6 health posts. The visit focused on the rural central area of the country and did not include the sparsely populated lowlands on the Atlantic coast.

We now present a summary of our findings, which generally represent information gathered from multiple informants. We organize our findings by application area.

A. Cold Chain Monitoring

The country has a very strong immunization program, which successfully implements procedures recommend by the Pan American Health Organization (PAHO) and the World Health Organization (WHO). Nicaragua has pioneered the introduction of new vaccines, such as being the first developing country to introduce the Rotavirus vaccine. The "Cold chain" refers to the refrigeration infrastructure used to manage national vaccine distribution from the national store to the delivery point. One of the candidate use cases for Smart Connect was to provide regular reports of temperature and alerts on out of range temperatures. The visit provided validation for this use case.

- Refrigeration is available at almost all health posts with a wide range of refrigerators available. Most refrigerators use grid power, but some in remote areas use solar. A few facilities rely on a freezer, icepack, or cold box solution.

- There is a universal practice of recording refrigerator temperature by hand twice a day. Standard forms for doing this are posted on all refrigerators.
- Alerts by text message for out of range temperatures were deemed as a useful idea. One informant said that alerts on power outage would be more useful than high temperature, since the failures were caused by loss of power. WHO provides guidelines on when alerts should occur [2]. (10 hours above 10 degrees C, or 1 hour below -1 degree C).
- Each district has a cold chain officer who is responsible for visiting all facilities on a regular basis to maintain the equipment. This is significant since there is someone who is responsible for fixing equipment and could receive alerts.
- Health centers and district facilities have refrigerator rooms with multiple vaccine refrigerators. Thus, a single device that could monitor up to six refrigerators would be useful.

B. Surveillance

There is a strong national epidemiological reporting system that sends statistical information from the base of the health system up through the hierarchy to the Ministry of Health.

- The standard form lists 67 different conditions which are reported by age group and gender.
- A range of mechanisms are used to pass information up the hierarchy including hand delivered paper forms and radio call in.
- Quality control procedures are in place throughout the system.
- There is a desire for faster data reporting at the national level, a ministry official expressed the desire to get data reported "on the weekend as well." Full reporting of surveillance data seemed to take about two weeks.
- Most remarkable finding was that the surveillance data was used at all levels. Almost all of the health centers and district offices visited had a wall with charts produced summarizing the area's statistics. These were produced in the facility.

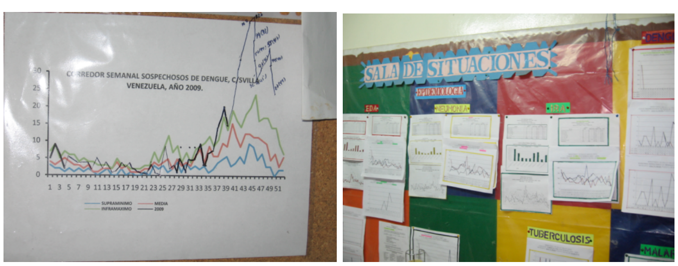

Figure 2 Charts showing local epidemiological data posted at health facilities.

C. Incidence Reporting

Incidence reporting involves sending in details of individual disease cases, as opposed to surveillance reporting which just gives the number of events. Incidence reporting may give additional information about particular conditions of interest.

- A pilot program using Frontline SMS had been introduced in one district for reporting cases of dengue fever. This program has since been extended to three more districts.
- The cell phone based approach seemed to work very well, so if Smart Connect were to take on this functionality, it should be integrated with the cell phone system, and not attempt to replace it.

D. Diagnostics Results

The analysis of diagnostic tests is often done at higher levels of the health system and then results are sent back to the facility.

- Other work has established that it can take a long time for diagnostic results to be returned to patients, even if the test results are done within a day of the sample being collected.
- Treatment is often independent of test result, with treatment for suspected cases of diseases such as malaria beginning before test results are received. It has been argued that a benefit of returning the test results is to help educate the staff.
- Reporting test results to the clinic is a simple process, it is just necessary to send a test identification number and the result.
- The ability to print test results would be valuable.
- An assessment needs to be done do determine which diagnostic tests are done in remote labs and send back test results.

E. Stock management and reporting

We investigated mechanisms for reporting stock outs on commodities and reporting inventory levels. We did not get any demand for this functionality in Smart Connect from our visit in Nicaragua. The existing mechanism for replenishing stock was to pick up supplies on a weekly visit to the health center and this was considered adequate. Phone calls could always be used as a backup mechanism for reporting running out of supplies.

F. Infrastructure

As a low income country, there are infrastructure challenges in rural regions. These observations apply to the central, mountainous region.

- Cellular phones are in wide use by the rural population. Most health workers were carrying a cell phone.
- Nicaragua has two phone companies, Movistar and Claro, with Claro dominant in rural area.
- It was common to have a significant area of marginal cell coverage, meaning that signal could only be received in certain spots, or some cell phones would work, while others would not.
- The electrical grid generally extended further than cell phone coverage. This was a bit of a surprise, and ruled out one of the deployment scenarios we had been thinking of: Smart Connect integrated with a solar refrigerator.
- Internet was only available at the district level, even though health centers often had PCs. Communication with the disconnected computers was done by flash drive.

- An important communication asymmetry exists between the health post and the health center. It is much easier for the health post to call the health center than for the health center to call the health post. This is because the health center generally has a known phone number, while to call the health post, one needs to know the number of someone at the health post. This motivates a "call me" or paging function for Smart Connect.

The overall conclusion from the visit was that a facility based device could enhance existing processes by supporting temperature monitoring of refrigerators, submission of clinic data to higher levels, and allowing receipt of messages at the clinic. The importance of incoming messages had not been recognized prior to the visit. One of the potential advantages of a clinic based device is that reception can be improved through an antenna.

IV. Vaccine Stock Management In Vietnam

One of the application domains for Smart Connect is supporting vaccine distribution. We assessed the role that Smart Connect could play in supporting logistics management by studying requirements derived for the vaccine supply chain in Vietnam. These requirements came from the Optimize project, a collaboration between PATH and the WHO. They were derived in a series of collaborative requirements workshops in five different countries including Vietnam.

Vietnam also has a tiered health system, with national, regional, province, district and commune levels. Vaccines are distributed in a top down manner, with requests made to the level above. Refrigerated vaccine storage occurs at the district through national levels. The communes receive their vaccines from the district and use them immediately for scheduled vaccinations. The basic vaccine inventory problem is to keep a count of on hand vaccines by type and lot number, and to track vaccines entering and leaving the facility. The number of vaccines is fairly low – there are between eight and twelve vaccines on the national schedule. Vaccines are purchased at the national level and receive a lot number. There will only be a small number of lots present in the system at a given time, since the vaccines use is based on expiration date.

The logistics requirements for vaccine stock management are defined by the business processes identified in the reference requirements for logistics management. The four key business processes are:

- BP1: Requisitioning, the placement and receipt of orders for vaccines between levels of the health system.
- BP2: Receiving, accepting an order of vaccines.
- BP3: Storage, managing the inventory while vaccines are at a facility.
- BP4: Dispatch, sending vaccines to another facility.

Each process is broken down into a collection of requirements that cover the updating of the inventory and sending notifications. A review of these requirements brings out a number of points relevant to this investigation:

- The amount of data required to represent the inventory or an order is small. This is because of the small number of vaccines.
- Information flow is bidirectional. Requests go "up", dispatch notifications go "down", and receipt acknowledgements go "up".
- On receipt of an order, the received stock is confirmed with respect to the dispatch notification, avoiding data entry.
- Alerts can be generated on order discrepancies, product shortages or expiration.
- Temperature monitoring is a requirement of the storage business process.

These requirements indicate the need for a bidirectional means of communication that would transmit small amounts of data between health facilities. Additionally, a system that could handle alerts and temperature monitoring would be beneficial.

The requirements highlight the possibility of integrating barcode reading and printing into the vaccine stock management process. At this stage it is not clear if the vaccine packaging has appropriate bar codes to enable scanning for updating the inventory, however with the correct packaging a bar code scanner could be instrumental in improving the inventory process. Printing could be valuable as a means of integrating the production of shipping documents and receipts into the vaccine stock management process. It would likely be easier to work from a printed inventory rather than viewing inventory information on a small display. A receipt or label printer would probably be the most appropriate type for this application.

V. Device Overview

A component diagram showing the basic design for the Smart Connect device is given in Figure 3. The design involves connecting a microprocessor to a cell phone radio. The key component of the device is the communication module, which will most likely be the Telit GM862 GSM/GPRS unit, while other components include a low cost microprocessor and interface components. The communication module dominates all of the other components in terms of cost: the basic GM862 is available for about $100 (or $80 in quantity above 100), while the total cost of the remaining components should be less than $60.

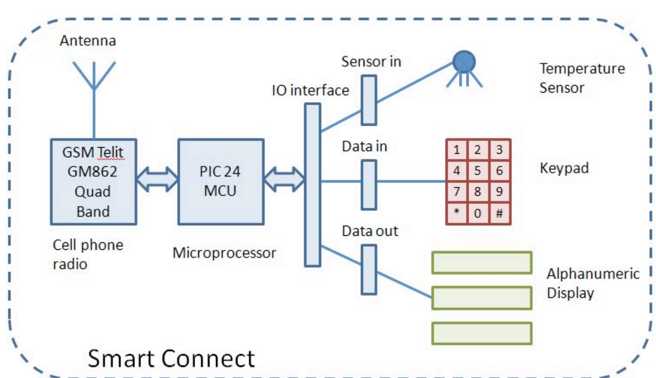

Figure 3 Smart Connect component diagram

The device will communicate with an SMS server running on a PC with a standard GPRS modem. The current plan for the server is to use RapidSMS, an open source framework for data collection and communication which runs on both Linux and WindowsXP.

The goal of this version of Smart Connect is to produce a device that can be built with a modest engineering budget and that can be deployed in the field quickly. As a result, a number of tradeoffs emerged during the requirements stage. Most important was to constrain the scope of the project. For example, one interesting scenario for Smart Connect is to utilize other communication mechanisms for use in areas outside of cell phone coverage, however this has been deferred to future versions. The basic communication unit supports both GSM and GPRS, but we have decided to focus solely on GSM in this version since including GPRS would require an investment in programming for a second communications stack. Interfaces for external devices are planned, including support for connecting low cost printers and bar code readers, although it is not guaranteed that they will be available in the first version.

Although it is natural to focus on the physical device that is being built, critical to Smart Connect's success is software. The Smart Connect software is split between the firmware of the device and the server side, and there will also be application level software running on the device and the server. Beyond managing the SMS communication the software needs to accommodate configuration updates, localization, server side device monitoring, message authentication, and device registration. The device will also provide simple, menu based interface that we will need to implement.

The engineering and development of Smart Connect started at the end of March when the requirements document was given to the development partner. We hope to have an initial prototype of the device available in May for testing and application development, so that field trials can take place in August-September 2010.

VI. Application Development

Two separate field tests of the Smart Connect device are planned, one in Nicaragua, and the other in Vietnam. The deployments will differ substantially in setting and applications.

A. Nicaragua

In Nicaragua we will deploy the device in one health center and roughly five of its associated health posts. The goal of the deployment is to evaluate the proposed use cases as well as the engineering and usability of the device. While the location for the field test has yet to be finalized, rural districts at the boundary of cell phone coverage are under consideration. Two candidate districts are Jinotega, in the coffee country in the north, and Nueva Guinea in cattle country in the south. This deployment will allow us to evaluate the device as a means of supporting the delivery of basic health services in rural areas.

The field visit allowed us to refine our use cases and prioritize the operations to implement for our initial deployment. Three core use cases will be implemented for this field test.

1. Refrigerator monitoring. A sensor will record the temperature of a vaccine refrigerator at regular intervals.
    a. Report temperature data to the server twice a day.
    b. Send a text message to a supervisor if the temperature is out of range for an extended period of time.
    c. Send a text message to a supervisor if power goes off.
2. Message sent to the device. The server will send a message to the device which can be displayed. The device will indicate receipt with an alarm.
    a. Display a paging message with a phone number to be called.
    b. Report diagnostic results. The server sends a message with a test ID and a result. The device will need to allow storage of at least 10 results and scrolling through them for viewing.
3. Data sent to the server. The device will support menu based data entry and sending the data to the server.
    a. Incidence reporting for new cases of dengue fever. The server will forward these reports to the regional system.
    b. Submission of a simplified version of the surveillance report.

While these three use cases are the central focus of this version of Smart Connect, several extensions of these scenarios are under consideration. One extension would involve sending the health post surveillance data directly to the health center device, in addition to having the server relate the data to the top of the hierarchy. Additionally, we may support the monitoring of multiple refrigerators. This would be useful for the larger health centers, which may have several vaccine refrigerators. Finally, if we are able to support a printer, we will add functionality to allow the printing of diagnostic results and surveillance data that are sent to health centers.

B. Vietnam

The deployment of Smart Connect in Vietnam is designed in response to a particular business process: the distribution and tracking of vaccines. In contrast to our deployment in Nicaragua, this deployment is driven by a customer's needs and requirements, and not just our analysis of user needs. The plan is to gradually scale our deployment, starting initially with a few districts and then expand in scale to include provincial and possibly regional facilities as well. A PC based system for logistics tracking will be developed by a software firm in parallel with our Smart Connect application. This will allow a comparison of the logistics tracking across a number of different types of devices: PCs, Netbooks, and our custom device. It may also be possible to include a pure cell phone implementation for an additional point of comparison.

The device deployed in Vietnam will include applications for both refrigerator monitoring and stock management. The refrigerator monitoring is the same as for the Nicaragua deployment, so we just discuss stock management here.

All four of the business processes that appear in reference requirements for logistics management will be implemented for Smart Connect. The following points delineate how Smart Connect will address each business process.

1. BP1: Requisitioning. Send and receive messages on Stock Request. Display a list of received stock requests.
2. BP2: Receiving. Receive a dispatch notification message. Allow user to check off received goods according to dispatch notification. Notify user of discrepancy.
3. BP3: Storage. Display inventory information. Update inventory with additions and removals of stock. Display notification of expiring stock.
4. BP4: Dispatch. Send a dispatch notification. Update stock on shipment.

Additionally, if printing is available then paper receipts can be generated to track operations performed using the device. SMS notifications indicating the receipt of goods and dispatch of stock are also possible.

VII. Discussion

The goal of the Smart Connect project is to understand the impact that a data connection can have on the quality and efficiency of service delivery in peripheral health facilities. We hypothesize that if we establish an initial data connection between health facilities, various processes will take advantage of the connection. This will produce demand for a higher quality of service, which will then lead to better integration of the health system. Our emphasis in this work is on a facility based device – even though we rely on cellular technology we are pursuing a usage model that differs from the model afforded by traditional mobile devices. A range of questions can be asked about how facility based devices compare with mobile devices for different types of applications. These include whether they are more robust, if the financial model is more attractive, and whether users prefer a fixed location when completing tasks or if they would rather have the flexibility of mobile access.

Our primary focus when designing the Smart Connect device was to build something that would have the flexibility needed to support varying hardware deployments and that could be adapted and used as an embedded device. Additionally, we wanted to design a device that could be completed and taken into the field quickly. Considering these motivations, it is not surprising that the resulting Smart Connect device is more expensive than a cell phone. Even though the parts used in Smart Connect and cell phones are roughly the same, there is a big difference in price, primarily because of the cost of Smart Connect's radio chipset. It seems quite likely that the price of the radio chip set will drop in the future, making this approach more price competitive. An alternate approach in developing a device that integrates cell phone communication with sensing and computing is the FoneAstra project by Chaudhri et al.[4]. They add an external device to a low cost phone that has a microprocessor and connections for sensors. This allows SMS messages to be sent from the processor by patching into the phones communication mechanism. Their device does have a substantially lower cost than ours, and is suitable for some, but not all of the use cases that we outline.

VIII. Summary and Future Work

In this paper, we have outlined a case for a facility based data communication device, and described in detail the use cases that we are targeting and our work in validating the use cases with projects in Nicaragua and Vietnam. The outcomes of this process included requirements for a hardware device and server and requirements for the application software. We are now starting to build the device and develop the software, which should be ready for field testing by summer.

There are many possible directions for future work. An important extension of the Smart Connect project would be to develop a compatible version of the device using other radio technologies that could be used outside of cell phone coverage. In countries such as Nicaragua, short wave radios have been used for communication with clinics – these are still important for locations that cannot be reached by cell phones. The long term goal of this work is have impact on delivery of health services by making data connections available at peripheral facilities. This will entail both developing appropriate technology that allows for scaled deployment and the creation of information based services for supporting public health services.

References

[1] International Telecommunication Union, Information Society Statistical Profiles, 2009 – Africa. //www.itu.int

[2] WHO Immunization Standards. http://www.who.int/immunization_standards/en/

[3] RapidSMS, http://www.rapidsms.org/

[4] Chaudhri, R., Borriello, G., and Thies, W., "FoneAstra: Making Mobile Phones Smarter", 4th ACM Workshop on Networked Systems for Developing Regions (NSDR), June 2010