Jeev: A Low-Cost Cell Phone Application for Tracking the Vaccination Coverage of Children in Rural Communities

Anas Katib
Dept. of Computer Science
Electrical Engineering
Univ. of Missouri-Kansas City
Kansas City, USA
anaskatib@mail.umkc.edu

Deepthi Rao
Dept. of Pathology &
Laboratory Medicine
Univ. of Kansas Medical Center
Kansas City, USA
drao@kumc.edu

Praveen Rao
Dept. of Computer Science
Electrical Engineering
Univ. of Missouri-Kansas City
Kansas City, USA
raopr@umkc.edu

Karen Williams
Dept. of Biomedical &
Health Informatics
Univ. of Missouri-Kansas City
Kansas City, USA
williamsk@umkc.edu

***Abstract*—Immunization saves millions of lives against vaccine-preventable diseases. Yet, 24 million children born every year do not receive proper immunization during their first year. UNICEF and WHO have emphasized the need to strengthen the immunization surveillance and monitoring in developing countries to reduce childhood deaths. In this regard, we present a software application called `Jeev` to track the vaccination coverage of children in rural communities. `Jeev` synergistically combines the power of smartphones and the ubiquity of cellular infrastructure, QR codes, and national identification cards. We present the design of `Jeev` and highlight its unique features along with a preliminary evaluation of its performance. We plan to pilot test `Jeev` in a rural population to study its effectiveness and identify socio-cultural issues that may arise in a large-scale deployment.**

***Keywords*—vaccination coverage, children, cell phones, rural communities**

I. Introduction

Immunization saves millions of lives against vaccine-preventable diseases. Through financial support from organizations such as the GAVI Alliance, and more recently the Bill & Melinda Gates Foundation, a lot of progress has been made in immunizing children since 2000 towards the Global Immunization Vision Strategy (GIVS) [28]. The number of deaths in children under 5 years of age has decreased. Yet, 24 million children born every year, do not receive proper immunization during their first year of life [28].

While the GIVS aims to achieve 90% vaccine coverage by 2015 and reduce the number of childhood deaths to 4.3 million, there are several constraints that must be overcome. According to UNICEF and WHO [28], the health care systems are weak in developing countries.[1] There is insufficient political and financial support. The monitoring infrastructure is weak and information systems are lacking. There is a shortage of trained health workers who can deliver immunization to the population. Many children live in poor, remote areas where health care facilities and public services are weak. Due to lack of information about the importance of immunization, many children do not receive the required vaccines. Unexpected deaths and side effects create fear of immunization among parents, thereby reducing the number of children who receive a full course of vaccines. [2]

UNICEF and WHO have emphasized the need to strengthen immunization surveillance and monitoring in developing countries [28]. Immunization coverage information is useful to monitor the performance of immunization programs and improve the delivery of vaccines to the population [27]. Today, the use of paper records to track the immunization status of children in countries such as India leads to inconsistencies in the way information is recorded; immunization records may be lost or damaged [17], [2], [10]. Lack of immunization coverage information can lead to wastage of vaccines due to unnecessary re vaccinations and poor forecasting of the vaccine demand [28], [10].

There has been an unprecedented rise in the use of cell phones worldwide; today, there are more than 6 billion cell phone subscribers [11]. Through cell phones, it is now possible to communicate with vast populations in previously hard-to-reach areas. The ubiquity of cellular infrastructure provides new opportunities to develop cell phone-based solutions for tracking the vaccination coverage of a rural population. In India, a middle-income economy [13], about 40% of the rural population has cell phones (or mobile phones) [20]. In Haiti, a low-income economy [13], the cellular infrastructure has grown quickly since the devastating earthquake of 2010. Haitians are using cell phones to receive relief incentives [24]. Furthermore, UNICEF has identified countries like India and Haiti as priority countries where routine immunization coverage is low and must be improved [25], [26]. (Immunization tracking is a challenge even in countries such as USA, but our focus is on developing countries.)

While tracking the vaccination coverage of a population has become a global challenge in public health[3], little research has been done in this domain. This is a timely opportunity for the health informatics community. In this work, we address

[1] The World Bank defines a country with low-income or middle-income economy to be a developing country [13].

[2] Recently, polio vaccines caused paralysis in 47,500 children in India [21].

[3] Recently, the Bill and Melinda Gates Foundation solicited proposals for developing low-cost cell phone applications to improve the uptake and coverage of childhood vaccinations as one of the grand challenges for 2011 [2].

the problem of tracking the vaccination coverage of children in hard-to-reach areas such as rural India, where cellular infrastructure is available. We present a low-cost cell phone application called Jeev.[4] Jeev is unique in the sense that it synergistically combines the power of smartphones and ubiquity of cellular infrastructure, Quick Response (QR) codes, and national identification cards. Jeev is based on a client-server model: the data collected by the clients are synchronized at the server; the clients and server exchange small amounts of data using low-cost SMS text messaging. (The transmitted data is always encrypted for security and privacy reasons.) We report a preliminary evaluation of Jeev using the National Immunization Survey datasets [4]. Although Jeev has not been deployed and studied in a rural community, we are planning to pilot test it in rural Haiti through Maison de Naissance [14], which is a community health care facility for delivering healthy mothers and healthy babies.

The rest of the paper is organized as follows. Section II provides the background and related work. Section III presents the design of Jeev. In Section IV, we report the performance evaluation of Jeev. Section V discusses our next steps for pilot testing Jeev in a rural community. Finally, we provide our concluding remarks in Section VI.

II. Background and Related Work

A. Cellular Infrastructure in Developing Countries

Today, there are more than 6 billion cell phone subscribers. The cellular infrastructure is ubiquitous in many developing countries and provides an easy way to connect to vast populations in hard-to-reach areas. Smartphones have become popular and affordable; they have powerful processors, several GBs of storage, high resolution cameras, several hours of battery life, and touch screen technology. SMS text messaging provides an inexpensive way to communicate small amounts of data in hard-to-reach areas. Data can be encrypted for security and privacy reasons.

B. Quick Response Codes

Quick Response (QR) codes have fast readability and higher storage capacity (up to 400 times more) as compared to standard UPC barcodes [15], [22]. QR codes are 2-dimensional and can encode any type of data and even encrypted data. They have become popular in businesses and among consumers. QR codes use advanced error correcting codes. Even with up to 30% damage, a QR code can still be decoded [7]. (See Figure 1(a).) QR codes can also be modified for artistic reasons and still be decoded. (See Figure 1(b).) They can be easily decoded using applications on smartphones [12].

C. National Identity Cards

National identity cards have become increasingly important in many developing countries to prevent voter fraud and corruption, and to take advantage of banking services, government incentives and subsidies. For example, in rural India, such cards are required to receive subsidies on food and grains [5] and open bank accounts [9]. In post earthquake Haiti, national ID cards are giving citizens access to work, banking services,

(a) (b)

Fig. 1. (a) A damaged QR code that can be decoded. (Source: Wikipedia [7]) (b) A modified QR code that can be decoded.

and voting privileges [19]. These cards are usually laminated or made of plastic and are more durable than paper records.

D. Technology Advancements in Vaccine Delivery

Closely related to our work is VaxTrac, which has received funding from the Bill & Melinda Gates Foundation. It captures and processes infant fingerprints using fingerprint readers and inexpensive netbooks [10]. However, we believe there are some potential limitations: The system may not scale in large geographical regions because images are large in size and have to be physically transferred to integrate them in a central location. This also raises the issue of how to synchronize the data on the netbooks carried by health workers. Furthermore, fingerprints of infants change in size as they grow. Infants may not be cooperative to allow health workers to take good fingerprints.

Jeev is different from VaxTrac in the sense that it relies on smartphones, which consume less power than netbooks, and does not rely on infant's biometric data. Jeev uses low-cost SMS text messaging for communication between the server and clients, synchronizes the vaccination records in real-time, and can be deployed in large geographical regions.

Abhishek *et al.* [17] proposed the notion of mobile health cards to increase the immunization rate in rural areas. They highlighted the current problems with paper based records in rural India such as lost or damaged paper immunization forms. They suggested that all activities involved during immunization should be moved to the mobile platform using cell phones. Each child would be assigned a unique id generated by the system; the authors mentioned the use of biometric technology. However, no real system has been developed using the proposed ideas.

More recently, Cook Children's healthcare system, in partnership with athenahealth, Microsoft, Sanofi Pasteur and Merck, has began using QR codes on vaccine bottles [1]. This will result in easy management of vaccines, tracking of vaccination status, and allow integration of vaccination information with EHR systems. Jeev is different in the sense it uses QR codes to identify children instead of vaccines and is designed for a rural population, where the computing infrastructure is minimal.

III. The Design of JEEV

There are a few design requirements for a vaccination coverage tracking application to successfully operate in rural communities. Firstly, a child may be vaccinated at different locations and therefore, must be identified correctly to avoid missing vaccines and receiving unnecessary re vaccinations.

[4] Jeev means 'life' in the Sanskrit language.

Secondly, cellular coverage in certain areas may be lacking at times, and therefore, the application should cope with such situations. Thirdly, the application should be low-cost and easy to use and deploy in rural communities. Finally, the application should be efficient in performance and energy consumption.

We have developed a novel application called `Jeev` for tracking the vaccination coverage of children in rural communities. `Jeev` synergistically combines the power of smartphones and the ubiquity of cellular infrastructure, QR codes, and national identity cards. `Jeev` is based on a client-server model: it has a client-side software and a server-side software. (Hereinafter, we simply use the terms *client* and *server*.) The server runs on a smartphone and is responsible for storing and managing the vaccination records of children. A smartphone is a perfect choice because the computing infrastructure in rural areas is minimal; having access to devices such as netbooks with Internet connectivity in these areas would be expensive. The server can be located in a community clinic or health care facility. A health worker carrying a smartphone running the client can access the vaccination record of a child from the server and request it to update the record with new vaccine doses. The client can also request the server to create a new vaccination record for a child. [5] The clients and server communicate via SMS text messaging and do not require a data communication network like 3G. The transmitted data is encrypted for security reasons.

Figure 2 illustrates how `Jeev` operates. When a child is immunized for the first time, either at a vaccination camp, clinic, or home, a health worker will collect the name, sex, and date of birth of the child and some information about the parent (or legal guardian) from the national id card (*e.g.*, name). This information is then encrypted and a QR code is generated and printed on a sticker of 50x50 pixels in size. (Printing can be done using a portable label printer priced less than $100.) The sticker is affixed on the national id card of the parent. (Additional stickers can be printed and affixed on a paper vaccination form if available, or be provided to the parent for safekeeping at home.) Also if the parent has a cell phone, then a text message can be sent containing the encrypted string from which the QR code was generated. (Note that the parent's cell phone need not be a smartphone, which is quite realistic in rural areas.) The QR code on the sticker uniquely identifies the child during future immunization visits. It can be decoded only by authorized clients. The client sends the collected information to the server and requests it to create a vaccination record for the child. The server stores the vaccination records in a DBMS. The database schema in the current design is shown in Figure 3(a).

When a child is vaccinated in the future, a health worker will scan the QR code affixed on the parent's (or legal guardian's) id card using a smartphone running the Jeev client. Once the QR code is decoded, the child's identity is determined. The child's vaccination record is then retrieved from the server. After vaccination, the client sends a request to the server to update the child's vaccination record.

[5] In the current design, we use one server and multiple clients. If scalability and reliability become an issue, we can opt for multiple servers. We can avoid loss of data on the server by performing routine backups on inexpensive micro SD cards.

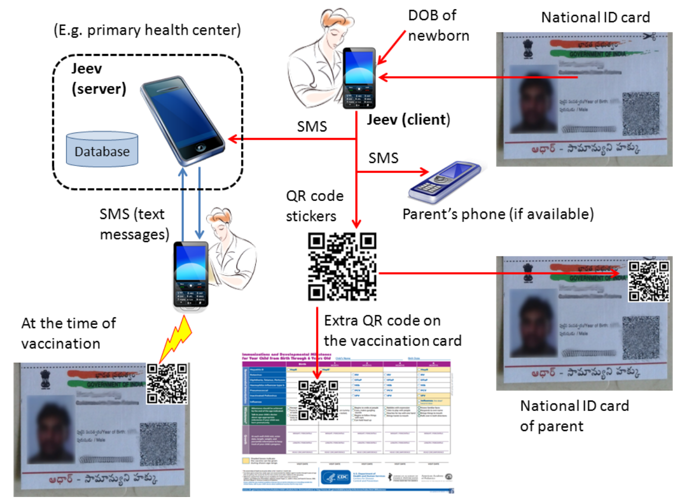


Fig. 2. Overview of `Jeev`. (Image sources: www.cdc.org, https://en.wikipedia.org/wiki/File:AadharBlurred.jpg.)

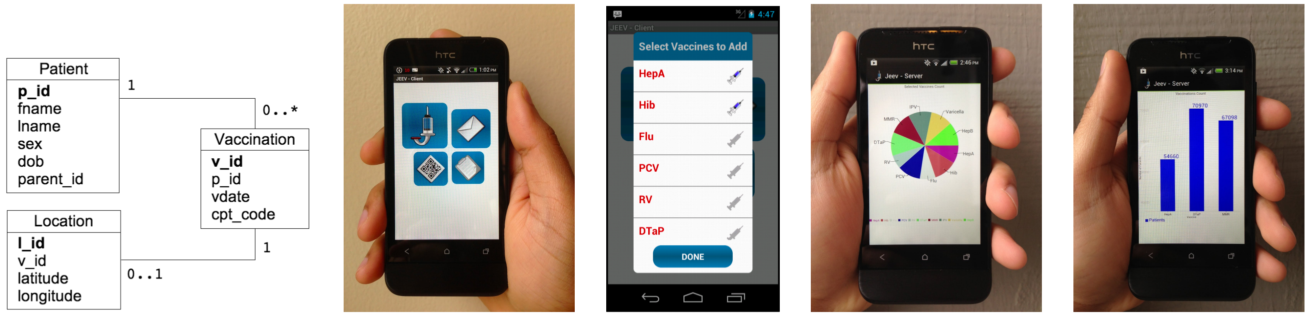
`Jeev` has intuitive user interfaces for health workers and officials both on the client- and server-side. A few screenshots on the client-side are shown in Figures 3(b) and 3(c). A few screenshots on the server-side are shown in Figure 3(d) and 3(e), where the vaccination coverage information is displayed. If client-side smartphones have GPS capability, then the vaccination coverage of children can be mapped and visualized on an interactive map.

It is possible for a parent to lose or misplace her national id card; the QR code sticker on the id card may be damaged and therefore, cannot be decoded by a client. Then the parent can bring the extra QR code stickers provided during the first visit to identify the child correctly. A health worker can also print a new sticker with the same QR code and affix it to the parent's new or old id card. Another way is to have the health worker receive the text message stored on the parent's cell phone (provided during the first visit) and regenerate the original QR code. If none of the above is possible, the health worker can ask relevant questions to the parent and try to identify the child and locate its vaccination record on the server. Because vaccination records are stored in an RDBMS on the server, appropriate SQL queries can be posed to retrieve the record using partial information provided by the parent. In the worst case, a new QR code has to be generated and printed.

When cellular coverage is not available, a client can store the vaccination data locally. Once coverage is available, the data can be pushed to the server. Vaccination records can be downloaded ahead of time from the server if needed.

IV. Preliminary Evaluation

We implemented the `Jeev` client and server using the Android SDK. We used SQLite to store the vaccination records on the server, Zxing [12] for QR code processing on the client, AChartEngine [6] for visualizing the vaccination coverage information on the server, and PowerTutor [29] for measuring the power consumption of the client- and server-side smartphones. For the experiments, we used two HTC One V smartphones with 5.0 MP camera, 1.0 GHz processor, 512



(a) (b) (c) (d) (e)

Fig. 3. (a) Database schema on the server-side. (b)-(c) Screenshots of `Jeev` on the client-side. (d)-(e) Screenshots of `Jeev` on the server-side.

RAM/4 GB ROM built-in memory, and running the Android 4.0.3 operating system. The smartphones used Sprint's 3G network in Kansas City. The data in the text messages were encrypted using the 256-bit key AES encryption.

A. Datasets

We did not have access to vaccination records of children from a rural population, and therefore, we used the National Immunization Survey datasets [4], [8] for the years 2008, 2009, 2010, and 2011. They were created through a random-digit-dialing telephone survey of households in the United States for children between the ages of 19 to 35 months. The vaccines that we selected were DTaP (diphtheria and tetanus toxoids and acellular pertussis vaccine), poliovirus vaccine, MMR vaccine (measles, mumps, and rubella vaccine), Hib (Haemophilus influenzae type b vaccine), Hep A (hepatitis A vaccine), Hep B (hepatitis B vaccine), varicella zoster vaccine, PCV (pneumococcal conjugate vaccine), and influenza vaccine.

We uploaded the vaccination records of 102,508 children into SQLite on the server. The vaccination table and location table contained 1,692,024 records each. Indexes were built on three attributes: p_id in the Patient table, v_id and p_id_patient in the Vaccination table, and l_id in the Location table. The total database size including the indexes was 187 MB.

B. Workload

We tested `Jeev` by running the client and server on two smartphones for three different workloads, namely, W_1, W_2, and W_3. Workload W_1 is shown in Table I and was used to measure the performance of data storage and retrieval on the server. The operations in the workload were SQL SELECT and INSERT statements, which were executed directly on the server. (See Appendix.)

Workload W_2 is shown in Table II and was used to measure the performance of `Jeev`'s client-server model in a real-world cellular network. Each operation in the workload was initiated by the client by sending a text message (to the server) containing the information encoded in a QR code. Based on the request, the server executed one or more SQL statements, and if required returned a particular vaccination record. The text messages exchanged by the client and server are shown in Table II. Operations O_8 and O_9 retrieved a vaccination record from the server and were different in the number of text messages sent by the server to return the vaccination record to the client. Operation Q_{10} updated a vaccinated record on the server with five vaccines. The communication between the server and client was made secure by encryption.

TABLE I. WORKLOAD W_1

	Operation
O_1	Find the total number of children in the patient table
O_2	Find the total number of children who received at least one dose of a particular vaccine
O_3	Retrieve the id of a child using first name and date of birth
O_4	Update the vaccination record of a child with 5 vaccines along with the date of vaccination
O_5	List the vaccines and dates of vaccination for a particular child
O_6	Find all vaccines taken by a child with a particular first name and date of birth (join between the patient and vaccine tables)
O_7	List all the female children who have received at least two doses of a particular vaccine (join between the patient and vaccine tables)

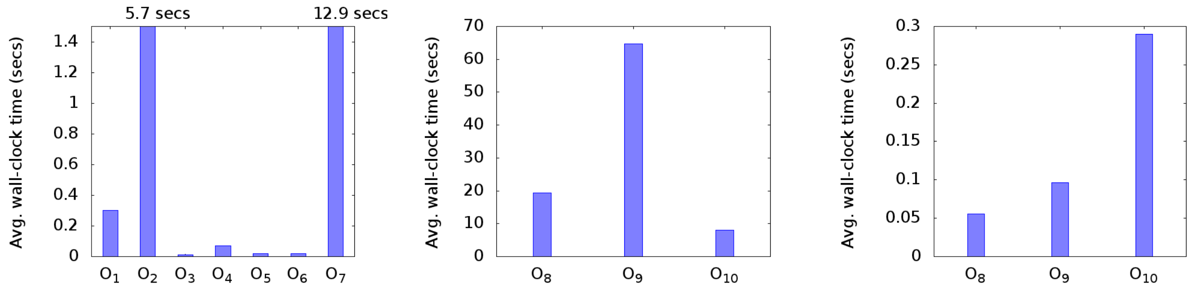
TABLE II. WORKLOAD W_2

	Operation	SMS message exchanges	
		client	server
O_8	Retrieve the vaccination record of the child identified by a QR code (the vaccination record was within 160 characters)	① $\Longrightarrow$ ② $\Longleftarrow$	
O_9	Retrieve the vaccination record of the child identified by a QR code (the vaccination record was within 320 characters)	① $\Longrightarrow$ ② $\Longleftarrow$ ③ $\Longleftarrow$	
O_{10}	Update the vaccination record of the child identified by a QR code with 5 vaccines	① $\Longrightarrow$	

Workload W_3 is shown in Table III and was used to measure the energy consumption of `Jeev`. Each operation in the workload was initiated by the client by scanning a QR code through the phone's camera, communicating with the server and retrieving the vaccination record of a particular child, and finally updating the vaccination record with new information on the server. O_{11} and Q_{12} were different in the number of text messages sent by the server to return the vaccination record to the client. The text messages exchanged by the client and server are shown in Table III. As before, the communication between the server and client was made secure by encryption.

C. Performance Results

First, we present the results for workload W_1. Note that the SQL statements were executed directly on the server. We report the average wall-clock time taken (over three runs) to execute operations O_1 through O_7 in Figure 4(a). O_2 performed duplicate elimination and required more time to finish. O_7



(a) Time spent by the server to process operations in workload W_1

(b) Time taken to process requests from the client in workload W_2

(c) Time taken by the server for processing operations in workload W_2

Fig. 4. Performance evaluation of `Jeev`.

TABLE III. WORKLOAD W_3

	Operation	SMS message exchanges (client / server)
O_{11}	Client scans the QR code and sends information to the server; server returns the vaccination record of the child; client adds new vaccines and sends an update to the server; server completes the update (the vaccination record was under 160 characters)	① ⟹ ② ⟸ ③ ⟹
O_{12}	Client scans the QR code and sends information to the server; server returns the vaccination record of the child; client adds new vaccines and sends an update to the server; server completes the update (the vaccination record was under 320 characters)	① ⟹ ② ⟸ ③ ⟸ ④ ⟹

performed a join, followed by grouping and counting, and as expected had the highest execution time, *i.e.*, 12.9 secs.

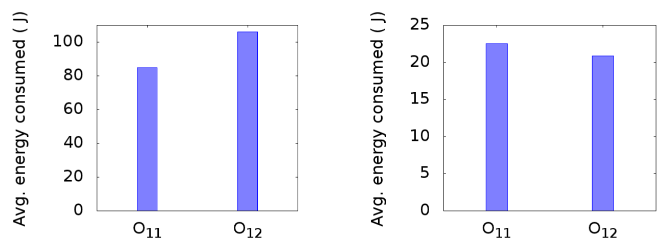
Next, we present the results for workload W_2. For O_8 and O_9, we measured the average wall-clock time taken (over three runs) to process the client's request. This included the time to send a text message to the server, decrypt the message and process the SQL statements on the server, and return the (encrypted) vaccination record to the client and decrypt the vaccination record on the client. For O_{10}, the client did not receive an acknowledgment, and therefore, the completion time was when the server finished updating the vaccination record.[6]

The performance results are shown in Figure 4(b). Interestingly, most of the time was spent in communicating between the client and the server via text messaging. O_9 required more time than O_8 because its vaccination record was sent using two text messages by the server. The time taken by the server to process all the SQL statements in each operation was under 0.3 secs and is shown in Figure 4(c). Clearly, the response time seen by the client was dominated by the communication latency through the cellular network.

D. Power Consumption

We measured the end-to-end energy consumption of `Jeev` using workload W_3, beginning with scanning a QR code using the client's camera to completing the update of a vaccination record on the server. We included the energy required for CPU, LCD, GPS, SMS, and system services. (In O_{12}, the size of the vaccination record returned to the client was larger than in O_{11} and therefore, required two text messages.) The average energy consumption (over 3 runs) on the client-side is shown

[6]It is possible to provide an acknowledgment to the client via a text message.



(a) Client-side

(b) Server-side

Fig. 5. Energy consumption of `Jeev`.

in Figure 5(a) and each operation consumed less than 110 Joules. The average energy consumption on the server-side is shown in Figure 5(b) and each operation consumed less than 25 Joules. On the client-side, the user interfaces were active and therefore, led to higher energy consumption compared to the server-side. (The LCD/display on the server was turned off.) Note that each phone had a 4.1V, 1500mAh battery capable of storing 22,140 Joules of energy.

V. DISCUSSION

Haiti is an ideal country to test `Jeev` because it has low vaccination rate, high infant mortality rate, and is an under-resourced country. Since the catastrophic earthquake in 2010, the cell phone market has grown considerably in Haiti through relief initiatives [3]. Two-thirds of Haitians have access to cell phones [24]. Cell phones and SMS messaging have become popular among Haitians for mobile banking and access to other services [3]. We plan to pilot test `Jeev` in rural Haiti through Maison de Naissance (MN). MN is a modern, community health care facility in Haiti dedicated to delivering healthy mothers and healthy babies in rural areas [14]. MN aims to make innovative use of technology for providing high-quality care to mothers and children. Its existing infrastructure is ideal for pilot testing `Jeev` [16].

We plan to study the effectiveness of `Jeev` in terms of the durability of QR code stickers, the robustness of our scheme in correctly identifying infants at different geographical locations and times, cost of operation, scalability, and ease of use by health workers. We will recruit families with infants and newborns under MNs coverage and track their vaccination status for a period of one year. We will measure the vaccination drop out rates for these families. We will also study how `Jeev` can cope with cellular coverage in hilly areas of Haiti and identify socio-cultural issues that must be addressed for large-scale deployment of `Jeev`. We are aware that there will be challenges in developing mobile interfaces for low-literacy, rural population [23], [18].

VI. Conclusions

We presented a low-cost cell phone application called `Jeev` to track the vaccination coverage of children in rural communities. Jeev synergistically combines the power of smartphones and cellular infrastructure, QR codes, and national identification cards. `Jeev` does not use any biometric data. It is based on a client-server model and uses low-cost text messaging. Data captured by different clients can be synchronized on the server in real-time. We presented a preliminary evaluation of `Jeev`'s performance and energy consumption using the National Immunization Survey datasets to show its efficiency.

Acknowledgment

We thank the reviewers for their suggestions. This work was supported in part by King Abdullah Scholarship Program (Saudi Arabia), UMKC Women Council's Graduate Assistance Fund (GAF), and National Science Foundation Grant No. 1115871.

References

[1] Cook Children's Pioneers 2D Barcode System For Vaccines. http://www.healthcareitnews.com/news/cook-children's-pioneers-2d-barcode-system-vaccines, 2011.

[2] Create Low-Cost Cell Phone-Based Solutions for Improved Uptake and Coverage of Childhood Vaccinations. http://www.grandchallenges.org/MeasureHealthStatus/Topics/CellPhoneApps/Pages/Round7.aspx, 2011.

[3] Mobile Technology Creates New Opportunities In Post-Earthquake Haiti. http://www.huffingtonpost.com/2011/01/12/mobile-technology-creates_n_808333.html, 2011.

[4] National and State Vaccination Coverage Among Children Aged 19-35 Months - United States, 2010. *Journal of the American Medical Association*, 306(13):1434–1437, 2011.

[5] A Tale of Two Villages. http://www.economist.com/blogs/feastandfamine/2012/10/rural-india, 2012.

[6] AChartEngine: Charting library for Android. http://code.google.com/p/achartengine/, 2012.

[7] Damaged QR Code. http://en.wikipedia.org/wiki/File:QR_Code_Damaged.jpg, 2012.

[8] Datasets and Related Documentation for the National Immunization Survey, 2005 to Present. http://www.cdc.gov/nchs/nis/data_files.htm, 2012.

[9] Indian Government Pushes Banks To Go Rural, But Will It Pay? http://news.yahoo.com/indian-government-pushes-banks-rural-pay-014713348–business.html, 2012.

[10] VaxTrac. http://vaxtrac.com/blog/2012/03/what-is-the-vaxtrac-system/, 2012.

[11] World Has About 6 Billion Cell Phone Subscribers, According To U.N. Telecom Agency Report. http://www.huffingtonpost.com/2012/10/11/cell-phones-world-subscribers-six-billion_n_1957173.html, 2012.

[12] Zxing: Multi-format 1D/2D barcode image processing library with clients for Android, Java. http://code.google.com/p/zxing/, 2012.

[13] How We Classify Countries. http://data.worldbank.org/about/country-classifications, 2013.

[14] Maison de Naissance. http://www.maisondenaissance.org, 2013.

[15] QR Code. http://en.wikipedia.org/wiki/QR_code, 2013.

[16] Through personal communications with Stan Shaffer and Jim Grant from Global Birthing Home Foundation. Kansas City, 2013.

[17] R. Abhisek, S. Raman, M. Mukhtar, E. Ohri, S. Saha-Mitra, and A. D. Sood. Mobile Health Card How to Use Mobile Phones to Increase Rural Immunization Rates. http://www.mgovworld.org/libra/mhealth/casestudies/document.2010-04-16.7743909927, 2010.

[18] B. M. Chaudry, K. H. Connelly, K. A. Siek, and J. L. Welch. Mobile interface design for low-literacy populations. In *Proceedings of the 2nd ACM SIGHIT International Health Informatics Symposium*, pages 91–100, Miami, Florida, USA, 2012.

[19] CIDA. In Haiti, Having an Identification Card Means 'Having a Say'. http://www.acdi-cida.gc.ca/acdi-cida/ACDI-CIDA.nsf/eng/NAD-11316214-SNX, 2012.

[20] IAMAI. Internet In Rural India. http://www.iamai.in/Upload/Research/9320123264601/ICube_2012_Rural_Internet_Final_62.pdf, 2012.

[21] P. Louis. Untested Vaccines Causing New Wave of Polio-like Paralysis Across India. http://www.infowars.com/bill-gates-and-47500-cases-of-paralysis/, 2012.

[22] Mcloone. Numbering/Bar Coding/QR Codes By Mcloone. http://www.mcloone.com/numbering-barcoding-qr-ppc/, 2011.

[23] I. Medhi, S. Patnaik, E. Brunskill, S. N. Gautama, W. Thies, and K. Toyama. Designing Mobile Interfaces for Novice and Low-Literacy Users. *ACM Transactions on Computer Human Interaction*, 18(1):2:1–2:28, May 2011.

[24] E. Powell. In Haiti, Restoration Through Cell Phones. http://sutradharsmarket.wordpress.com/2012/10/24/in-haiti-restoration-through-cell-phones/, 2012.

[25] UNICEF/WHO. Expanding Immunization Coverage. http://www.unicef.org/immunization/index_coverage.html, 2011.

[26] UNICEF/WHO. Immunization Summary. http://www.childinfo.org/files/immunization_summary_en.pdf, 2012.

[27] WHO. WHO vaccine-preventable diseases: monitoring system - 2010 global summary. http://www.who.int/immunization/documents/who_ivb_2010/en/index.html, 2011.

[28] WHO, UNICEF, and W. Bank. *State of the World's Vaccines and Immunization*. 3rd Edition, WHO Press, 2009.

[29] L. Zhang, B. Tiwana, Z. Qian, Z. Wang, R. P. Dick, Z. M. Mao, and L. Yang. Accurate Online Power Estimation and Automatic Battery Behavior Based Power Model Generation for Smartphones. In *Proc. of the 8th IEEE Intl. Conference on Hardware/Software Codesign and System Synthesis*, pages 105–114, Scottsdale, Arizona, USA, 2010.

Appendix

Below are the SQL statements for workload W_1. Note that the actual values for attributes are not shown.

```
O1: SELECT COUNT(*) FROM Patient_Table;

O2: SELECT COUNT(DISTINCT p_id) FROM Vaccination_Table
    WHERE cpt_code = xxxxx;

O3: SELECT p_id FROM Patient_Table
    WHERE fname ='xxxxx' AND dob='yyyy-mm-dd';

O4: INSERT INTO Vaccination_table (p_id, vdate, cpt_code)
    VALUES (xxxx, 'yyyy-mm-dd', codex),
           (xxxx, 'yyyy-mm-dd', codey),
           (xxxx, 'yyyy-mm-dd', codez),
           (xxxx, 'yyyy-mm-dd', codez),
           (xxxx, 'yyyy-mm-dd', codew);

O5: SELECT cpt_code, vdate FROM Vaccination_Table
    WHERE p_id = xxxxx;

O6: SELECT cpt_code FROM Vaccination_Table as VT
    INNER JOIN Patient_Table AS PT ON VT.p_id = PT.p_id
    WHERE PT.fname = 'xxxxxx' AND PT.dob = 'yyyy-mm-dd';

O7: SELECT VT.p_id FROM Vaccination_Table as VT
    INNER JOIN Patient_Table AS PT
    ON VT.p_id = PT.p_id  AND PT.sex = 'f'
    WHERE VT.cpt_code = xxxxx
    GROUP BY VT.p_id HAVING COUNT(*) > 1;
```