

Using NFC-enabled Mobile Phones for Public Health in Developing Countries

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Abstract—One of the largest IT challenges in the health and medical fields is the ability to track large numbers of patients and materials. As mobile phone availability becomes ubiquitous around the world, the use of Near Field Communication (NFC) with mobile phones is emerging as a promising solution to this challenge. The decreasing price and increasing availability of mobile phones and NFC allows us to apply these technologies to developing countries in order to overcome patient identification and disease surveillance limitations, and permit improvements in data quality, patient referral, and emergency response. In this paper, we present a system using NFC-enabled mobile phones for facilitating the tracking and care of patients in a low-resource environment. While our system design has been inspired by the needs of an ongoing project in Karachi, Pakistan, we believe that it is easily generalizable and applicable for similar health and medical projects in other places where mobile service is available.

I. INTRODUCTION

Interactive Research and Development (IRD) is a non-profit organization based in Karachi, Pakistan working to implement a real-time electronic disease tracking system in low-resource settings. One disease they are targeting for surveillance is pneumonia in young children. Karachi’s current health system is made up of a disparate mix of private and public sector providers that almost never maintain retrievable patient records (paper or electronic). This poses several challenges, including the absence of a reliable method for patient identification or capturing illness. The inability to record visits or a brief medical history precludes continuity of care, not only as patients move across providers but frequently at the same clinic or hospital. Patients can be observed carrying old prescriptions, laboratory test results, and radiographs, and the information in these is not easily accessible and is often ignored. Additionally, since health care centers are understaffed, providers often see a large number of patients in a short period of time, and may not have the time to counsel or refer patients appropriately.

In order to overcome these challenges and facilitate pneumonia detection in young children, we have developed tools which utilize NFC-capable mobile phones to allow electronic patient identification and tracking across multiple providers. These tools allow patients to be identified by a unique radio frequency identification (RFID) tag on their person when they visit a clinic. By using a cell phone to send a patient ID and diagnosis to a central server, the physician will be able to

report pneumonia in real time. If pneumonia is diagnosed, a mobile team is alerted to pick up the sick child for further evaluation and treatment.

In presenting these tools, we note that although we focus on a particular application for this paper, the general system architecture design can be extended to many other applications in public health and other areas.

II. OVERVIEW: HOW NFC CAN BE USED TO SOLVE THE PROBLEM

A. Previous Process Design

IRD team members have previously implemented paper-based patient identification and tracking methods between 2001-2005 for pneumonia and measles surveillance in Pakistan. While this allowed for aggregation of immunization and sick visit data, it was expensive to gather in terms of manpower requirements and resulted in significant delays in cleaning and cross-linking data forms. The paper system did not allow for an immediate alert to a response team that could potentially arrive at a clinic in time to collect a blood culture prior to the administration of antibiotics.

The next iteration of IRD’s study placed a trained health worker with a smartphone in every participating clinic. The worker would shadow the physician as he or she would diagnose an infant, and enter the diagnoses and other details into the smart phone. While this method allowed for accurate data gathering, the solution is expensive to scale to a large number of clinics, as human capital is one of the most expensive parts of such an enterprise. An ideal improvement on this technological solution would not require an additional health worker at each clinic.

B. Our Solution

Our team proposes to create a fully electronic system to reduce the tracking system’s current dependence on humans and expedite the overall surveillance process.

We designed and built a mobile phone- and NFC-based patient presence alert system which identifies infants participating in the study. Patients enrolled in the study will wear or carry an NFC bracelet or anklet (in the form of a traditional amulet) or an NFC card, which the physician will scan with a cell phone during a medical encounter. Consequently, the

study participant will be identified and the physician will be prompted to select the patient's pneumonia diagnosis on the cell phone. The selection of a positive diagnosis by the physician will then alert a specialized mobile team to dispatch to the patient's location for further study and treatment.

C. Goals of the Technical Implementation

The ultimate goal of our technical solution is to provide 100% accurate automatic identification of a participating infant once that infant enters a clinic. There are several cost and design constraints that bar us from initially implementing this goal by means of automatic identification, and our initial design goal is to provide 100% accurate identification that is not automatic, but requires minimal physician and patient interaction. Our budget is USD 2 per bracelet, which does not allow us to utilize active RFID technology given its current cost ($>$ USD 10) and battery concerns (size and lifetime). Moreover, active RFID is not currently approved by the Food and Drugs Administration in the United States for use in identifying patients in medical scenarios [6], and active RFID tags are too large to fit in a small bracelet. While we eliminated the option of using active RFID for now, it may be a potential option in the future as the size and cost of such devices are reduced further.

An additional advantage to using mobile phones is the ability to use Bluetooth communications as well and interface to other devices. By adding modularity, other identification devices and methods can be added in the future. One of IRD's original ideas, for example, was to place a long-range passive RFID reader in the doorway of a doctor's office and communicate with the doctor's mobile phone over bluetooth, thus achieving the goal of completely passive automatic patient identification. However, due to limitations of cost and electric power, we have built a more integrated lower-cost option, which employs an RFID reader that is embedded in the Nokia 6131 NFC [8] phone to identify the patient. Passive RFID technology will require human initiative to identify study participants, but will allow us to test the remainder of the system and stay within the cost constraints of the design.

D. Constraints

In order to determine the appropriateness of our design, it also helps to study the constraints imposed by the environment. There are two primary locations to concentrate on: the clinic locations at which the NFC-capable phones help identify and diagnose study participants, and the central hosting facility containing the server that stores the study's medical records.

At clinic locations, we need to expect unreliable electricity and little or no wired internet availability. However, all of these locations have reliable cell phone signals and sufficient GPRS connectivity to support basic web-based applications. As such, a cellphone-based approach would be ideal for such locations, as the battery on the phone would be resilient to power outages, and the GPRS connection on the phone would support all data transfer needs.



Fig. 3. The physician is presented with the option to scan an NFC tag or enter a patient ID manually.

The hosting facility is in a safer and more developed part of Karachi. Electricity is dependable, and additional power backup technology ensures resilience to outages. Since the facility is dedicated to hosting web servers, web connectivity at the server is stable and can handle the bandwidth requirements of several concurrent clinics reporting statistics.

E. System Design

The system architecture can be seen in Figure 1. It features two components: a cell phone and a centralized web server.

A dynamic interpretation of the operation of the system architecture of our implementation is presented in the interaction diagram in Figure 2.

For the cellphone component, we use the Nokia 6131 NFC running a J2ME midlet. The implementation allows the user to scan a passive NFC tag that has previously had a patient ID written to it. We use Mifare Standard proximity tags [7], which implement the ISO14443A RFID protocol. The tags themselves are small enough to fit on a bracelet for the eventual implementation. Our software reads and writes NDEF tags through the JSR-257 API. Thus, our solution should work for NDEF compatible tags in general, not just Mifare.

F. User Interface

We now present a walkthrough of the user interface presented to the physician diagnosing a patient in the study.

The first screen, shown in Figure 3 on the phone asks the doctor to scan an NFC tag using the NFC module on the phone. Note that if a new patient enters the study, the doctor has the option of writing a new card for the patient using the phone. There is also an option to enter the patient's ID manually, which is prone to human error, but required since a patient may lose their tag, or have a broken tag.

If the doctor elects to scan a card, he or she is prompted to place the phone to the card, as shown in Figure 4. Both NFC

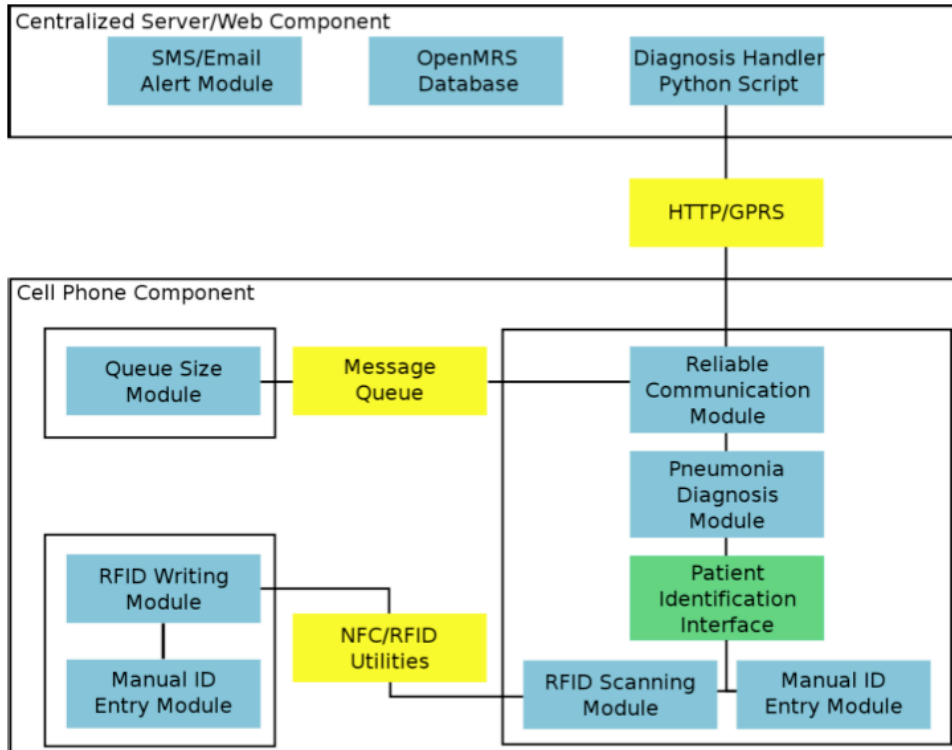


Fig. 1. System architecture. Web server side (top), Nokia 6131 NFC cell phone side (bottom).

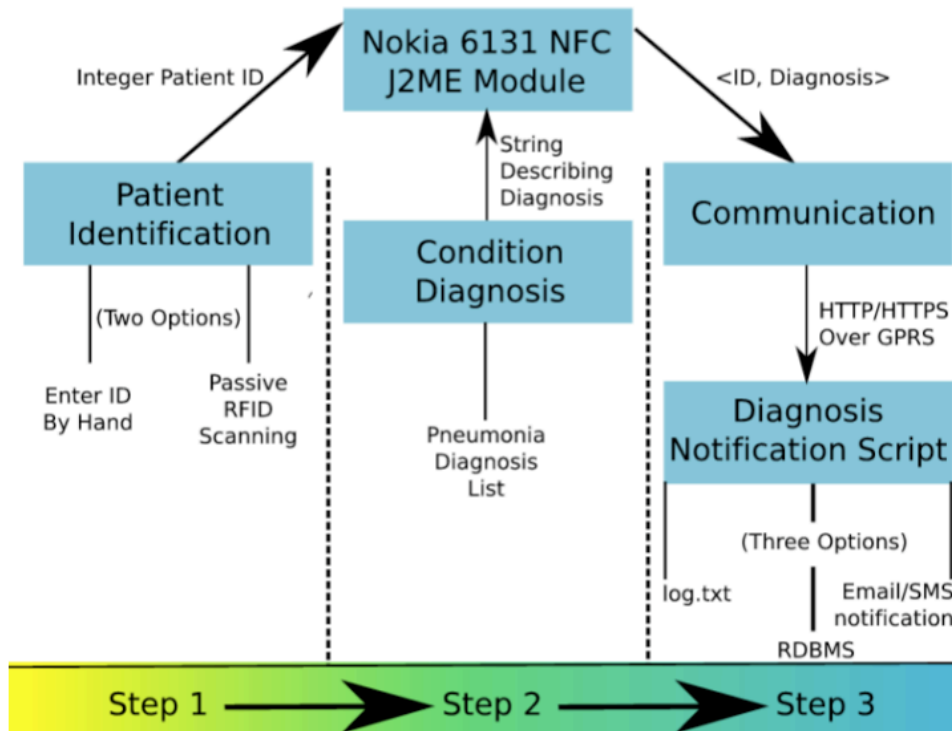


Fig. 2. The dynamic architecture of the developed system. J2ME - Java Micro Edition, HTTP/S - Hypertext Transfer Protocol (over Secure Socket Layer), GPRS - General Packet Radio Service, SMS - Short Message Service, RDBMS - Relational Database Management System



Fig. 4. If the physician selects the option of scanning the NFC tag, he or she is prompted to tap the NFC tag onto the cell phone for reading.



Fig. 5. After tapping the NFC tag, the physician is asked to enter the patient diagnosis on the cell phone.

tag scanning and manual entry are described in Step 1 of the interaction diagram in Figure 2.

The diagnosis interface allows the doctor to select the diagnosis of a patient. This is step 2 of the architecture diagram, and is depicted in Figure 5. Once the doctor enters the diagnosis, he or she is prompted to send the diagnosis over a GPRS connection by way of the HTTP protocol. The system sends a request to the web server which takes the patient ID, diagnosis, and the location of the phone. This represents Step 3 of the interaction diagram. The communication with the HTTP server may be encrypted over SSL to protect sensitive patient information (although in reality, an adversary spying on the communication would only receive the patient's integer identifier and diagnosis with no other identifying information). In order to ensure that the entry is legitimate, further protection can be provided with public/private key encryption, so that the doctor's identity can be verified at the central server.

One implementation hurdle of the system is that HTTP over GPRS is unreliable, and we have seen diagnosis messages hang or be dropped. To ensure reliable delivery, and to avoid locking the doctor's screen while the transmission (which may take several seconds) is processed, we instead utilize the J2ME records system to create a record for each diagnosis, which is safely and transparently written to the local file system of the phone. A background thread will be woken up when a new record is added to the file system, and will loop continuously until a successful response is confirmed by the HTTP GET. In this way, all messages will be sent as soon as a connection allows, and the doctor will not be forced to wait while transmitting the message. We also have a version of the midlet which uses SMS to send the data from the phone to the central server.



Fig. 6. A bracelet with an NFC tag.

G. RFID Chips Used

We aimed to fit the cost of each bracelet within our budget of USD 2, including the RFID chip. Because there are several applications of RFID technology in medical identification applications, we had a variety of passive RFID bracelets in the 13.56 MHz range within our budget [11], [9], [14]. Figure 6 shows one form of NFC-enabled bracelet that IRD is considering for use in the project.

III. DISCUSSION: METRICS, LIMITATIONS, FORESEEABLE PROBLEMS, AND THE FUTURE

A. Metrics for Success

The following outcome measurements would be interesting to pursue in order to assess the utility of this technology in the study conducted by IRD:

- Accuracy. Use a special team of health workers along a specific and limited geographic area for some time to control if the results being reported through the new technology are accurate. This would allow us to determine how many false positives and negatives exist. Moreover, we can compare the accuracy of this study to that of previous studies (pre-test vs. post-test).
- Speed. Did the time employed to report sick patients, assist sick patients, and the time of the study as a whole improve with the use of the technology?
- Human Resources. Did the usage of the technology decrease the need of human resources for tracking and assessing patients, as compared to previous methods?
- Cost effectiveness. The total number of beneficiaries (or participants) per dollar of total budget money would be a measure of improved cost effectiveness of using this NFC/cell phone technology over past studies.
- Cell phone breakdowns. Diagnosis would be stalled any time the cell phone fails to operate, so keeping track of the total number of instances of when the cell phone breaks down (measured by the number of times the physician calls for help) would help measure the robustness of the technology.
- NFC tag breakdowns. How often do bracelets need to be replaced? The number of times NFC tags get damaged, measured by the number of times bracelets need to be replaced, would be another measurement of the technology's durability.
- Medical issues with bracelets. How many clinic visits are due to bracelet-related concerns? The introduction of any extraneous medical issues (e.g. rashes) by the NFC bracelets would call for the need to rethink the use of the NFC system or the form factor of the bracelet.

B. Forseeable Problems

We are aware that there are some limitations to our system that need to be addressed when used in real practice. Currently, there is no way to track keep track of participants if they do not visit clinics. A guardian can opt out of the study simply by removing the NFC bracelet on the child or not mentioning it to the physician. We recommend that IRD follow up on participants, such as by phone calls in intervals, or in subsequent vaccination clinic visits. It is paramount that this is done professionally and delicately so that the participants will not feel offended.

Also, if a bracelet is broken, or lost, a guardian can contact IRD for a replacement. However, if the guardian chooses not to act on it, the participant is essentially dropping out of the study. As mentioned in the previous section, tracking and reminding participants will help, yet there is no guarantee that this will be 100% effective.

Furthermore, even if the participant is wearing the bracelet properly, there is a chance that it is not scanned. For instance, the participant might be brought to the clinic by a relative who does not know about the study; the physician might be pressed for time and not notice the bracelet. One option would be to

have posters and pictorial reminders put up in the clinics to ensure that both the literate and the illiterate will be reminded about the study. Again, this method is not entirely foolproof. We suggest that IRD raise the profile of this study, such as by promoting this initiative through the media, to raise interest in the study and in pneumonia in general.

There is currently no contingency plan in the case when the one and only phone in a clinic is out of order or being repaired. IRD should maintain some backup phones in case this need arises.

Given that our application has an intuitive and user-friendly interface, we do not expect physicians to have difficulties interacting with it. Rather, we anticipate that most of the problems will be technical issues arising from everyday use of the cellphones and bracelets. Although it is a robust cell phone, the Nokia 6131 NFC is going to be repeatedly used to read NFC tags, select pneumonia diagnosis of patients, and to transmit patient information over GPRS. It is the single most important piece of equipment in the data collection process that our project entails. Without appropriate care and maintenance of these cellphones, the study results could be drastically affected. Hence, it is very important to keep the phones and their batteries in optimal conditions. At this point we do not know if technical support exists for this specific phone in the area where the study is being conducted or if there will be in the future.

As with all medical studies, security of the data is of primary importance. Because smart cards can easily be read by various devices, we must ensure that the information on them is secure, perhaps by encrypting the NDEF records stored on the phone. Currently, the only data stored on the smart card is a numerical patient identifier, which is of little value to an adversary with no access to the central server, and so securing the GPRS communication and central database are more important than smart card security.

C. Interference with Medical Devices

Although there have been some reports claiming that RFID devices may interfere with medical equipment, it is important to point out that the NFC readers embedded in the mobile phones are relatively low-power (drawing a few tenths of a Watt) and not a threat to medical devices. Recent work by Christe and colleagues demonstrated that at these low power levels, neither Near-Field nor Far-Field antennas altered medical equipment [2]. Furthermore, NFC in particular has the added advantage that the coil antenna used in NFC readers is indeed "near-field" with negligible radiated power beyond a range of 10 centimeters.

We note that the radiated power of most mobile phones is significantly greater than the power from an embedded NFC RFID reader. If the cell phone operation itself is a concern to medical equipment, it would also be possible to design the system so that the NFC reader could be used independently and the data stored on the phone for later transmission.

D. Other Health and Medical Uses of the Technology

Aside from tracking patients more efficiently, this technology could and should also be used for the collection of statistics that show how often pneumonia occurs, which in turn helps to identify disease trends, track disease outbreaks, and help control future outbreaks. Similarly, the same platform could be used to report outbreaks of any other reportable diseases with public health importance (HIV, hepatitis, syphilis, etc.). Additionally, the technology could be used for other epidemiological studies or clinical trials that need to keep track of participants using an inexpensive but efficient method.

In related work, Karim and Muhammad have explored utilizing NFC to identify patients and process their records on a computer within the range that a bluetooth connection affords [5]. Lahtela et. al describe how NFC can identify patients for the automatic application of medical care through a medication dispenser [15]. Gordon and Sarmenta proposed and presented a proof-of-concept demonstration of the use of NFC-enabled mobile phones for patient and inventory tracking as part of the Medi-SIM platform using SIM cards [4]. In the Philippines, PhilHealth, an insurance provider, is exploring the use of NFC-enabled phones to store patient record information [1]. Our project is novel in that it combines NFC technology and mobile phone applications to facilitate identification, diagnosis, and messaging with a central server over an unreliable connection medium. Whereas previous work has focused on storing data on an NFC-enabled device or informing a nearby device about the state of the patient, we explore using inexpensive smart cards at scale for identifying and diagnosing patients, and storing this information at a remote location.

There are many other areas in healthcare where NFC and RFID technology could be useful. Dr. Dzik, co-director of the blood transfusion service at Massachusetts General Hospital (MGH) demonstrated that RFID could be used for safer blood transfusions [12]. This high-risk procedure requires healthcare staff to read blood and patient labels several times in order to check that the correct blood is given to a patient. As distraction and errors are common in stressful situations, frequent automated ID checks would be useful.

Another promising application for NFC and mobile RFID is administering medications to pediatric or adult patients during surgery or in intensive care units (where patients are usually sedated and/or intubated and cannot respond to questions). RFID bracelets can help alert the nurse in case the wrong medication is administered. AstraZeneca's anesthetic drug Diprivan is an example of medication delivery using RFID. It is a pre-filled syringe that features a recognition tag designed to be used with a target controlled infusion system[10].

Surgical intervention is another area where this technology could be utilized. It could help reduce the unfortunate but common problem of wrong-site surgery[3]. Finally, RFID bracelets could be used to avoid newborns being abducted or switched during their hospital stay [13].

IV. CONCLUSIONS

We have presented an NFC-based mobile medical patient tracking and diagnosis system that features low cost and ease of deployment. In addition to the original project in Karachi, Pakistan that inspired this solution, we believe that this system architecture can be used for similar health projects in any geographic location where mobile phone service is available. As prices for mobile phones equipped with NFC readers and writers come down, more such applications will come to light, reducing medical spending, avoiding human error, increasing medical team response times, while improving information flow in previously information-poor environments.

V. ACKNOWLEDGEMENTS

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REFERENCES

- [1] Casiraya, Lawrence. PhilHealth pilots mobile and RFID-based medical system. Inquirer.net., May 9, 2008. <http://technology.inquirer.net/infotech/infotech/view/20080509-135616/PhilHealth-pilots-mobile--and-RFID-based-medical-system>
- [2] Christie B, Cooney E, Maggioli G, Doty D, Frye R, Short J. Testing potential interference with RFID usage in the patient care environment. *Biomed Instrum Technol.* 2008 Nov-Dec;42(6):479-84.
- [3] Clarke JR, Johnston J, Finley ED. Getting surgery right. *Ann Surg.* 2007 Sep;246(3):395-403, discussion 403-5.
- [4] Gordon M, Sarmenta L. Medi-SIM: Medical Tools and Applications using SIM cards. Gemalto SIMagine 2008 Final Presentation. Mobile World Congress, Feb. 2008. <http://medi-sim.mobi/>
- [5] Karim, M. Muhamad, R. Integration of near field communication (NFC) and Bluetooth technology for medical data acquisition system. *ISCGAV* 2006.
- [6] Levine M, Adida B, Mandl K, Kohane I, Halamka J. What are the benefits and risks of fitting patients with radiofrequency identification devices. *PLoS Med.* 2007 Nov 27;4(11):e322.
- [7] Mifare Standard Proximity Cards. <http://www.mifare.net/about/standards.asp>.
- [8] Nokia 6131 NFC. <http://www.nokiausa.com/A4409108>.
- [9] Precisions Dynamics Corporation (PDC). <http://www.pdcorp.com/en-us/rfid-hc/smart-band-wristbands.html>
- [10] The RFID Knowledgebase - Sample Case Studies. <http://www.idtechex.com/pdfs/en/k3807f3934.pdf>
- [11] Synometrics. http://www.synometrix.com/china_taiwan_rfid_bracelets.shtml
- [12] System targets blood-type mix-ups. http://www.boston.com/news/globe/health_science/articles/2005/02/24/system_targets_blood_type_mix_ups/
- [13] VeriChip Touts Xmark Infant-Protection Systems. Feb. 12, 2008. <http://www.rfidnews.org/weblog/2008/02/12/verichip-touts-xmark-infantprotection-systems/>
- [14] Zebra. http://www.zebra.com/id/zebra/na/en/index/industry_solutions/applications/patient_safety/patient_wristbanding.html
- [15] Lahtela, A. Hassinen, M. Jylha, V. RFID and NFC in healthcare: Safety of hospitals medication care. *PervasiveHealth* 2008. Jan. 30 2008-Feb. 1 2008.