A Mobile Healthcare System for Sub-saharan Africa

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Abstract. The disparity between healthcare systems in developed countries and underdeveloped countries is huge, particularly due to the fact that the healthcare infrastructure of former is based on a sophisticated technological infrastructure. Efforts are being made worldwide to bridge this disparity and make healthcare services affordable even to the most remote areas of undeveloped countries. Recent growth of mobile networks in underdeveloped countries argues for building mHealth systems and applications on their basis. However, peculiarities of the area introduce difficulties into potential use cases of mobile devices, thus making the copying of mHealth services from developed countries inapplicable. In this paper, we present the functional requirements for a patient medical record system running partially on mobile devices and architectural choices for this system. Requirements are based on the circumstances of the Republic of Cameroon. In addition we discuss the country-level benefits that may appear after deployment of such a system.

Keywords: mHealth, Functional Requirements, Cameroon.

1 Introduction

Cameroon is a sub-Saharan African state with a population of about 20 million, according to a 2012 estimate [1]. As of 2007 about 70% of the population aged 15 and above were literate. Despite the fact that the country (and Africa in general) has a very low Internet penetration rate, the country is experiencing a mobile boom that is going through the developing and least-developed countries nowadays. As of 2011, there were close to 10 million mobile subscribers in Cameroon [1]. There are three mobile operators in Cameroon, and the coverage rate is about 80% population-wise.

The handset base consists of cheap Chinese phones, secondhand phones imported from Europe, and some new smartphones. Inflow of these phones into the market is uncontrolled. In the smartphone category, BlackBerry phones recently have shown a greater influx, as operators such as MTN have made them available to clients, along

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with the normal uncontrolled inflow. The operator offers unlimited Internet access for 15/38 €/mth if the subscription includes BlackBerry/GALAXYtab [2].

The healthcare system is very inefficient. Lack of infrastructure and competent staff makes it very difficult to provide adequate healthcare. The government allocates about 5.6% of the GDP to the healthcare sector [3]. In Cameroon, patients' medical records are stored in so-called hospital books, which are solely kept by the patients. They are small booklets issued by hospitals. Besides that, hospitals compile and keep patients' partial medical history in paper files. The hospital books are quite vulnerable to destruction and are easily lost. So a patient may not have a complete or even a partial written medical record available for future use.

Currently, a large volume of data is moved from the paper to the digital form, and digital docflow systems are widespread in developed counties. A similar system or simply camera phones might be used to move the information in the hospital books and manual cards into a digital format. One can also ponder whether the information from the hospital books could be manually typed into a new digital system in character format in a country where the labor is cheap.

In this paper we propose a system through which patients would have their medical data stored on their mobile phones, thereby eradicating the problem of vulnerability of hospital books and paper-based storage.

The paper is structured as follows. In section 2 we consider related work in this area. In section 3 we analyze the business requirements of the proposed systems, taking into consideration the existing constraints. In section 4 we propose possible variants mHealth systems and discuss shortly the deployment of our current prototype. Section 5 concludes.

2 Related Work

There is a large body of literature about mHealth in developed countries, but a general assumption is that mHealth systems augment heavily networked medical record and medical image systems, rather than act as a backbone system. Therefore, we do not handle them in this context. In [4] the authors describe a phone based mHealth system. The authors discuss problems that arose during the deployment and arrive at six core findings that should guide mobile health system designs. The results are preliminary, though.

The District Health Information System (DHIS2) project was run at the University of Oslo, Norway [5]. It aimed at the collection and analysis of health information in Vietnam. The main causes of failure were that DHIS2 was not fully implemented prior to deployment in Vietnam, and the system could not provide vital reports when needed. Besides that, problems such as lack of computers, insufficient skills of the staff, and bad management also contributed to the failure of the project.

Paper [6] examines the use of mobile devices, particularly Android-based tablets, in rural healthcare. Paper [7] discusses mWash mobile phone applications, which aim at helping the people who do not have access to safe water and sanitation by mainly using mobile phones for the collection and dissemination of information regarding water sources. Though the application domain differs from the one proposed in this paper, the environments are similar (cf. below).

FrontlineSMS and RapidSMS are frameworks that allow two-way data exchange between a computer and a mobile device. FrontlineSMS [8] is an appropriate solution for some remote areas with GSM network coverage for the transfer of data directly between residents of those areas and service providers. These frameworks are considered here since most of Sub-Saharan Africa, and Cameroon in particular, relies solely on two GSM networks, although 3G license competition is ongoing [9].

Berg et al. [10] implemented an application that allows the storage of outgoing data on a mobile device if there is no network connection and sends those data when the connection is reestablished. Similar functionality might be desirable for the system proposed in this paper for the same reasons.

Paper [11] describes a project carried out at the University of Botswana to improve learning facilities and bring healthcare provision closer to the rural population. Relevant material about projects under resource-poor settings in low-and middle-income countries was traced referring to various mHealth projects at different stages of implementation in several countries in [12]. Some of these projects are reviewed here, but others, such as [13], Expedited Results System to Improve Early Infant Diagnosis [14], and Fitun Warmline AIDS Hotline [15] are also relevant. Paper [21] describes a mobile system aimed at collecting the data from a sensor measuring blood glucose. Software is installed on a cellphone, and the sensor is sending the information via Bluetooth. Paper [22] describes the progress of telehealth projects in Sub-Saharan Africa and concludes that many projects are up and running. Some of them are in a pilot phase, and the future of mHealth is hard to predict in general. Paper [23] discusses applications of mHealth systems in Botswana and concludes that the success of mHealth projects demonstrates the potential of the technology. Paper [24] discusses mHealth in resource-limited settings, and describes an mHealth project in Kenya: patients would get SMS messages reminding about the need to take their medicine and enquiring about their health status. Paper [25] discusses the TRACnet system in Rwanda. Its architecture and use experiences are of high relevance for our work, although the goal of the system is different. Its success shows that mHealth is possible in Africa. Paper [26] discusses general barriers for mHealth in Africa.

3 Requirements for a Patient-Centered System

3.1 Stakeholder Identification

In this section we discuss the requirements for the proposed mHealth system, taking into consideration the peculiarities of the Sub-Saharan region. According to [16], getting stakeholders involved in the requirements-elicitation process of a system eliminates the need for two of the most ineffective requirements-elicitation techniques: clairvoyance and telepathy. When identifying the stakeholders of the proposed system, we referred to stakeholder-identification models presented in [17, 18]. From these works the following stakeholders were identified: patients who are the users of the system, doctors, nurses, developers of the system, and maintenance personnel of the system. Apart from these basic stakeholders, other stakeholders such as the government of Cameroon represented by the Ministry of Public Health, the Medical Council, local hospitals, clinics, and health centers are relevant. Some individual stakeholders were included in the elicitation process of the requirements, but not all categories had their say.

3.2 Business Requirements and Constraints

Medical records of patients are not only very important for medical staff and the patients, but to a greater extent can be useful to the government as a whole. Although a paper-based version of the storage is simple and reliable, many of the developing countries or at least some private hospitals are moving to the usage of special information systems aimed at the storage of the medical data. An example of a special-purpose system is TRACnet in Rwanda [25].

In general, information system architecture always spans certain power relations between the stakeholders. The developed countries started to develop their medical information systems during 1960s, first based on the available mainframes. This was typically a top-down endeavor, where government and public and private hospitals were controlling the development. Patients were not at all included as stakeholders, or they had a minor role. Hospitals and governments controlled the structure the information systems and the information stored into the medical record systems. In Finland, healthcare districts and municipal health centers were allowed to decide for themselves during 1990s what kind of systems they would use. This led to large interoperability problems between different healthcare units. One argument was the privacy legislation that imposes strict rules upon the transfer and use of the patient's data that are at the same time owned by the government or private enterprises, not by the patient.

Only in the recent years governments have begun to change their policies and open access for patients to their own data. In Finland this will happen by 2014, when KanTA [19] will be taken into full use. The e-prescription service is now almost fully functional, and by 2014 complete copies of citizens' electronic medical records will be stored into the central repository. They can be accessed by the patients and healthcare personnel over the Web using PCs or smartphones. Usage of such an IS as KanTA provides obvious benefits such as access to a rather complete medical record of a patient that is currently lacking, soon a rather complete picture of the current medication of the patient, enabling easy searching of the data, simple data transfer, and so on. However, deployment and maintenance costs of such systems might be rather high, since they require a number of computers, large data storage, expensive software support, and skilled personal for maintaining the system. KanTA is maintained by KELA—The Social Insurance Institution of Finland, which has a long record of massive population-wide insurance and social benefit systems.

Deployment of the massive country-wide health information systems in underdeveloped countries might become almost completely insuperable. The first problem is the lack of funding and skilled personnel. The second problem is the almost complete lack of the ICT infrastructure, so the hospitals can only provide basic facilities and it would be difficult to equip computer and server rooms. This would also require a lot of electricity that should be constantly supplied. The third problem is a frequent occurrence of electricity shortages, and the lack of Internet connections. Thus, an important business requirement and a constraint is the usage of very cheap infrastructure, e.g., mobile phones, since currently they are very widespread and the government would not need to pay for them. A further requirement is making the architecture of the system reliable, taking into account all the realities of Cameroon, including harsh conditions for the ICT equipment that has to operate under constant high temperatures of about 30–35 degrees Celsius during the dry season, high humidity during the rainy season, and dust from the roads that in rural areas are not paved.

3.3 Central Functional and Non-functional Requirements

The system consists of a number of mobile handsets and a central component that can communicate over mobile telecom networks (2G–4G) or fixed Internet using SMS, MMS, or data services. The central component can further be implemented as one entity running on one site (one or several server computers), or it can be implemented as a distributed system consisting of several components running on fixed servers at various sites, communicating over wireless or wireline data connections with each other. “The system” consists of mobile handsets controlled by the patients, and the central component is controlled by the hospital(s) and possibly by the central government.

- F1 The system shall facilitate storage and manipulation of patient medical records on mobile phones. Rationale: Patients can carry digital medical records with them all the time, and presumably phones are less often lost than hospital books.
- F2 Medical records of a certain person are stored into a mobile phone controlled by him or her. Children’s medical records can be stored into mobile phones under the control of their parents. Rationale: In this way the privacy is maintained
- F3 Medical records of a certain person can be stored and manipulated at the central component. Rationale: This component is hosted by the hospitals (and government) and storage and manipulation are dictated by their needs. The central component also acts as a backup point for the medical data.
- F4 The system shall provide the capability for medical personnel to access the Internet and transfer the data using a wireless data connection. Rationale: The transfer of medical data can easily be done via the Internet.
- F5 The system shall provide the possibility to transfer medical data using SMS as a bearer, in addition to GPRS, HSPA, and WLAN. Rationale: In the absence of an Internet connection medical data can still be transferred—at least important extracts such as blood type and diseases (cf. TRACnet).
- F6 The system shall be equipped with the capability of handling images. Rationale: Doctors could improve diagnosis with image files, and patient records can be images.
- F6.1 The system shall support the transfer of images from a mobile phone to the central component. Rationale: The doctor could improve diagnosis if he is supported with images from past treatments.
- F6.2 The system shall support the transfer of images from a computer to a mobile phone. Rationale: The patient would be able to take home images such as X-rays or ECG-plots needed for future diagnosis and treatments.

- F6.3 The system shall support the transfer of images from mobile phone to mobile phone. Rational: This is helpful for clinics equipped only with mobile devices.
- F6.4 The system shall support transfer of image files from a computer to a computer. Rationale: This is helpful for the interaction between hospitals equipped with computers.
- F7 The system shall enforce authentication through PIN codes and passwords at least. Rationale: This is useful for security and privacy reasons, for both doctors and patients.
- F8 Patients shall have access to their own medical data residing at the central component. Rationale: The patient might not have complete medical data on her mobile phone or she might have lost the mobile phone and needs to access medical data remotely or locally from the central component.
- F9 Patients and healthcare personnel must have a unique identity inside the system. Rationale: This is necessary for enforcing access control and protecting the privacy of the data.
- F10 Special infrastructure and interfaces shall exist that would allow the transfer of currently existing medical data (in form of paper-based hospital books) to a digital format into the mobile handsets and central component. Rationale: This is useful for patients who still have hospital books during the transition period.
- F11 The system interfaces should be designed so that illiterate people can also use the system.

In addition, we describe the following *non-functional requirements* (NF):

- NF1 The system must not lose data when electricity shortage takes place in the hospital or the handset runs out of power.
- NF2 Core functions of the system should still run even without Internet connection
- NF3 The system must provide high enough performance for hospitals and patients.
- NF4 The system design must minimize software and communication costs.

4 Architectural Solutions

In this section we present two architectural solutions that correspond to the described requirements. The "system" that is required is inherently distributed, because we want the mobile phones be part of "the system."

4.1 Decentralized Solutions

In theory, we might base the entire distributed system on the portable terminals, without any central components. The data would be carried in the terminals of the patients, doctors, and nurses, and replicated for safety and availability reasons into other terminals. Obviously, the smartphones/tablets/laptops of the doctors and nurses should contain their patients' data, but data could be further replicated. This kind of architecture would have many unsolved challenges, though. Evident ones are data privacy issues (e.g., a patient's data could be copied to other patients' phones), synchronization costs (e.g., who pays the network transmission costs?), and reliability and availability issues (e.g., in spite of copying, the data might be lost and unreachable when needed by the doctor for various reasons).

The individual patient's data is placed on his or her own mobile terminal in any case (Fig. 1.). Data storage and its user interface are implemented as an application on top of the mobile operating systems. Data can be uploaded to the terminal from another fixed or mobile terminal over various network bearers (SMS, GPRS, HSPA, etc.) and short-range links (USB, IR, BT, ZigBee, WLAN). The terminal can be handed over to a doctor or nurse, and he/she can find out the data him/herself and update it. The application on the terminal should provide the necessary interfaces.

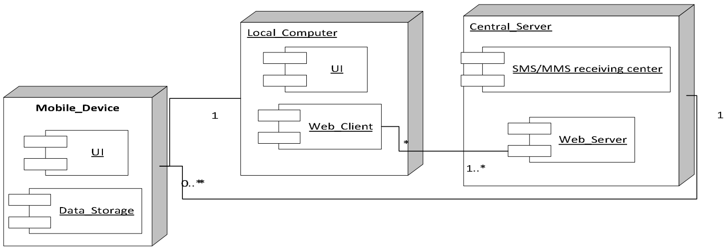

Fig. 1. Decentralized system

For the processing of SMS and MMS messages on patients' and doctors' terminals, it is necessary to have special software (possibly deployed at the mobile operator's central location), which would handle the received SMS or MMS messages. The mobile phone would send an encoded message to a defined number, and later this message would be received and processed. This is similar to TRACnet functionality.

The main benefit of this kind of system is perhaps that it does not cost anything or almost anything for the government, because it does not need to invest in the infrastructure. The patients would pay for the infrastructure. A challenge is the communication of the patient data from the handset to the doctor and vice versa. Another issue is that the data on the cell phone might be lost. This can be remedied by copying the data to a memory card, for example. This might be necessary also when the phone is changed and the medical data need to be moved to a new phone.

For better reliability it would be possible to make a hybrid system, which would contain central backup storage, in addition to the data on cell phones. Thus, if data from phone were lost, it would be possible to recover the data from the central backup system. This could be maintained even by a telecomm operator.

We can also consider that there is a central component that can be hosted by one hospital or by the government (centralized central component) or by many hospitals and government agencies (decentralized central component).

4.2 Single Central Component Solution

First, we discuss a centralized system, i.e., one in which medical data are stored on a central server (cf. Fig. 1). Central storage on the server would contain a copy of the medical data of all the patients in the country. This would be a massive centralized solution with all relevant data up- and downloadable from/to the mobile phones and other networked computers and mobile terminals. This kind of solution is now emerging in Finland in the form of KanTA. Only a government could host such a component due to the high costs. In a country with 20 million people, this could require a datacenter, placed where the power supply in the country is most stable. This kind of architecture would mean a single point of failure. Access to the server farm should be possible from fixed and mobile terminals. TRACnet [25] seems to have this kind of architecture.

4.3 Multitude of Central Components

The above can be modified so that the country is divided into regions and each region has a central component, as in Fig 1. It would be hosted by a suitable hospital. In this basic setting, not all the central components would be interoperable. The patient data would be stored into the handsets of the patients and into the local hospital data repositories. Each component would contain data of the patients registered to the area of the hospital in question. Such a component would be one server-level installation with a suitable data management and Web access software (e.g., LAMP stack). In each hospital there could be several computers or mobile devices used by the doctors for downloading patients' data from the server storage and uploading the data there. This kind of central component architecture would require a LAN or WLAN in the hospital. The architecture would correspond to the current situation as concerns the healthcare organization. A strong point is that patients could carry their medical records in their phones and if treated outside the region still have the data with them. The data could also be fetched to another hospital, if the patient allows it or accesses the data him or herself with his or her phone. This scheme works better in cases where fewer people need treatment outside of their region.

The main part of a central component is a DBS, e.g., a PostgreSQL database.

4.4 Loosely Coupled Central Components

The above architecture can be developed further into one in which the central components exchange and replicate data regularly. It could also be developed in a direction in which there is one central component that hosts all the data (cf. KanTA above). This would be in that respect similar to the first choice, that the problems with establishing the central component would be the same. Local storage contains a subset of the data from the global data storage, which can also be implemented as a PostgreSQL database. A synchronization module allows interchange of the data with the central data storage. Local storage also provides user interface (UI), which can be used by the clients. Local storage does not need to communicate with central storage persistently, and might carry out data refresh at rather long time intervals, e.g., overnight. This would function under the assumption of low inter-hospital mobility.

4.5 Envisioned Deployment

The Kumba District Hospital is a "district reference" hospital for an estimated population area of about 300,000 inhabitants (The Kumba Health District) [20]. It is the largest health district in the southwest region of Cameroon. The hospital has 148 beds and is run by six physicians of various specialties: ophthalmology, obstetrics and gynecology, general surgery, radiology, and general medicine (family practice) [20]. The hospital receives daily about 150 patients for consultation and supports about 145 deliveries in a month. Supervisory reports produced by the Kumba Health District reveal that there are many unauthorized medical settings in the health district, with a huge quantity of drugs sold in clandestine "medicine stores" in the central market [20]. The most prevalent medical condition is malaria infection with *Plasmodium falciparum*, and all clinical variants are reported.

5 Conclusions

The current paper describes requirements for the medical data storage system for Cameroon. The paper aims at elaborating the requirements via designing potential scenarios and subsequent requirements elicitation. The paper considers the realities of Cameroon such as frequent electricity shortages and low Internet penetration rate and high mobile handset penetration. In addition, we present and discuss two architectural solutions: centralized and decentralized. Further we plan to verify and validate requirements using surveys of potential user groups in Cameroon. In addition, we plan to pilot a prototype of the system in a Kumba local hospital, applying the most suitable architecture option above.

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