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Channel Agnostic Healthcare for Resource Constrained Environments

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***Abstract*: Mobile technologies have become a social reality in large parts of the developing world in general and in Africa especially. The large scale connected representativeness of access to and often ownership of mobile devices opens many doors to innovative, far reaching mobile-based applications and services. This near ubiquitous access, however, is characterized by an entirely new set of challenges as different legacy devices and cutting edge smartphones make up a cornucopia of end user realities. In order to reach as many end users as possible through the devices that they already own and are comfortable with, channel agnostic access is needed that would support the different mobile access channels using a variety of communications protocols. This paper outlines the various technical and operational considerations associated with the conceptualization of a middleware platform for mobile enablement and its application in the health environment as a mobile health monitoring system for community health workers.**

Keywords: *Channel Agnostic; Mobile Application, Healthcare.*

I. Introduction

The current telecommunication world would be barely recognizable when looking back to the beginning of the previous decade. In a barely anticipated wave, mobile cellular technology has proliferated at a much greater rate than any other recorded technology uptake. In excess of 6.2 billion people worldwide communicate and share information through mobile cellular technology [1]. 2.3 billion of these have active mobile-broadband subscriptions with around 55% of these residing in developing countries. While most people on earth today live within reach of mobile coverage, not all networks have been upgraded to 3G technology, which is estimated to be around 50% [2]. In addition to fast growing mobile broadband subscriptions, WiMAX services, although still in infancy, are gaining traction.

This large uptake and use of services are characterized on the user side by a significant diffusion of end user technologies, ranging from die-hard, low-end phones to high-end smartphones. The impact of these technologies and their effect on the lives of ordinary people are far reaching, as they empower users with new abilities. These abilities extend from personal communication to the capacity to connect and be connected to the information society as a contributor and user of digital services and content.

A major challenge in harnessing opportunities presented by the connected individual is in providing, in a cost-effective and affordable manner, access to meaningful content, services and interactions through the technology that is already owned [3].

Chronic non-communicable diseases such as stroke, cancer, heart diseases and diabetes have been found to be the leading causes of mortality on a global scale [4] and it is expected that by 2030 they will account for five times as many deaths as communicable diseases in low- and middle-income countries. They thus pose a significant risk to public health and economic development [5]. In addition, cardiovascular diseases and hypertension were the causes of more than 10 percent of deaths in 2008. Comorbidity and multimorbidity of these non-communicable diseases is becoming increasingly prevalent in Africa [6], which exacerbates the problem.

It has been shown that hypertension [7, 8] and other non-communicable diseases have an increasing impact on people in rural communities [9, 10]. Rural communities face an additional challenge with non-communicable diseases in terms of access to health facilities through factors such as poor infrastructure, large travelling distances and limited transport [11]. Since effective treatment of non-communicable diseases depends on early diagnosis and ongoing monitoring, the inability of members of rural communities to visit health facilities for regular check-ups creates a challenge that needs to be addressed. In such resource constrained settings, in particular, it seems that community-based approaches to preventative health care and wellness promotion are suitable for addressing the risks on non-communicable diseases.

A resource constrained environment [12] for the purpose of this paper is best described as an environment where there are low-income communities and low bandwidth. These environments provide unique limitations (e.g., cultures where people are unfamiliar with or afraid of technology, environments where power and network connectivity are scarce and expensive).

This paper outlines various technical and operational considerations associated with the establishment of a middleware platform for mobile enablement and its application in the health domain to support the early diagnosis and monitoring of non-communicable diseases in a rural resource constrained setting in South Africa.

The paper is organized as follows: The use of mobile technologies in resource constrained settings is described in Section II and is followed by a brief description the South African Healthcare system in Section III. Existing interaction platforms are described in Section IV, followed by a description of the Mobi4D mobile enablement platform in Section V. The application in the health domain is described in Section VI. The paper is concluded in Section VII.

II. Resource constrained mobile user

The total number of mobile phones in the world surpassed the number of fixed telephones in 2002 and by the end of 2008, it is estimated that there were 4 billion mobile phones globally [11]. "No technology has ever spread faster around the globe [13]." This rapid diffusion has resulted in mobile phones representing the largest distributed platform in the world [13]. The most significant growth has been in the developing countries where close to 40% penetration was reached at the end of 2007, up from 44% in 2002. These statistics imply that in more than 70% of all the world's mobile subscribers are currently from developing countries.

The use of mobile phones reported from a European and/or developed country scenario experiences mobility as the next step; embedding virtuality in reality [14], contextualizing access [15-17] and, generally, extending already available desktop computing to a mobile platform [18]. However it is suggested that mobile technologies, mostly in the form of mobile cellular technology, not only provide mobility, but also empower the user with *ability* [19-22]. This 'ability' refers to the user's capacity to connect to the information society as a contributor and a user. As " [m]obile technology is changing the way many Africans live and work [23, 24]", this ability to connect and be connected is of primary advantage in the areas where other means of access are not available as a result of various infrastructure and physical realities. The use of networked personal computers being extended to the mobile platform for the added dimension of mobility and contextual access depicts the trajectory that is evident in Europe, the Pacific Rim and North America. Here access to the information age is predominantly gained through desktop computing. Africa and other developing regions are, however, testing or contradicting this conventional thinking and entering the information society from a mobile centric perspective.

Van Biljon and Kotze [25, 26] identify determining factors and mediating factors that influence mobile phone adoption.

A. Determining Factors

They identify the following six determining factors:

- Social influences: Denoting the social pressure exerted on an individual with regard to the opinions of other individuals or groups. Social influence is extended to include cultural influences, perceived usefulness and ease of use.
- Facilitation conditions: These conditions refer to the stability and availability of the mobile phone infrastructure. By implication this includes variables such as system service, system quality, cost of handset and service.
- Perceived usefulness: The extent to which a user believes that there is a benefit from using the phone.
- Perceived ease of use: The extent to which a user deems the use of the mobile device effortless.
- Attitude: Defined as the individual user's positive or negative feelings about performing behaviour.
- Behaviour intention: denotes the behaviour of mobile phone interaction.

B. Mediating factors

Three mediating factors have been identified as having an influence on mobile phone adoption.

- Personal factors: Personal factors refer to the user's personal preferences and beliefs about the benefit of the technology. It includes relative advantage, compatibility, trialability, observability, image and trust.
- Demographic factors: Denotes the age, gender, education and technological advancement.
- Socio-economic factors: Described by variables like job status, occupation and income.

These factors highlighted above; combine the influences of mediating factors and determining factors on behaviour intention [25, 26]

Love highlights the following characteristics that could have a significant effect on the user's use and perception of mobile phone devices, services and applications [27]. The characteristics are the user's spatial ability, personality, memory, verbal ability, previous experience, and age. Each of these is briefly outlined:

Characteristic	***Implication for Mobile Use***
Spatial Ability	Users with low spatial ability may find it difficult to visualise the systems they are accessing, especially if there is a drill down of several levels.
Personality	• User's personality affects the perception of the system they are interacting with, projecting personalities onto computing systems. • Manipulating the screen text changes the user's perception of the personality of the system.

Characteristic	Implication for Mobile Use
	• Users become emotionally attached to their mobile devices
Memory	As mobile devices often present a single channel of serial communication that cannot be browsed or scanned the user needs to memorise the service structures, menu options and their location within the service hierarchy.
Verbal Ability	Large impact when user needs to comprehend verbal information in order to use the system effectively. Compounded when there are limited or no visual prompts.
Previous Experience	Previous experience in using information and communication technology has emerged as an important predictor of performance with a new system.
Age	Older users have different requirements and expectation from younger groups. Inherent device limitations are challenging for older users.

Table 1. User characteristics [27]

Table 1 reflects the characteristics cited by Love that could have a significant effect on mobile use and perception. He argues that the dimension of mobility and use in context further accentuates these characteristics [27]. The "on the go [28]" nature of mobile user give rise to users that are [18]

- Mobile: The users are navigating the real world and moving between instances of interaction with the device, alternating between tasks in the physical world and tasks in the virtual world. The location-free nature of the device establishes a shift from place-to-place communication in favour of person-to person connection [29-32]. The portable and private nature of the device allows the user to occupy multiple social spaces simultaneously (Virtual space of the conversation and physical space of the device and user) [14].
- Interruptible and easily distracted: The mobile user contends with all the interruption that a desktop user has but without the social cues to signal his unavailability. The user is interacting in the physical world with all its complexities while navigating the device with limited display and input modalities.
- Available: The mobile user is available to networks, communities, social and family connections as the device ports with the user. "[A] characteristic of mobile users is that they are present and immediately available [18]" This implies that users answer their phones, either with voice or text, even in situations that might be inappropriate. This ambient availability allows applications to communicate with remote platforms.
- Sociable: Social mobile users handle several micro-contexts simultaneously. In situations where phones are shared the device can become the focus of the social interaction [33, 34].
- Contextual: The user's environment affects how the device is utilized.
- Identifiable: The user stores information that is unique to the user as well as owning the mobile cell number. The personal nature of the device brings about a large degree of personalization, with users selecting personal ringtones1, screensavers2 and wallpapers3.

Having investigated the mobile user, the following outlines considerations related to the South African health system.

III. Health in South Africa

According to the official 2014 mid-year population estimates [35], South Africa has an estimated population of 54 million, with a life expectancy at birth of 59.1 years for males and 63.1 for females. This remains well short of the Millennium Develop Goals (MDG) target of 70 [36]. Statistics South Africa report an infant mortality rate in the country of 34.4 per 1000 live births [35] well below the MDG target of 18 [36].

Healthcare in South Africa is divided between the public and private sectors, which significant inequities evident between the two systems. According to the National Health Insurance Green Paper [37], almost half the national expenditure is in the private sector, which only covers 16.2% of the population, while the remainder of the population is served by the under-resourced public health sector.

This inequity in the health system is seen as a major inhibitor slowing progress towards universal health coverage in South Africa [38].

As a result of this inequity, and despite high national expenditure on health (8.5% of GDP in 2011 against a World Health Organization recommendation of 5%), health outcomes in South Africa remains poor in comparison to other middle income countries [37].

To address this under-performance in the delivery of health outcomes, the South African health system is being reformed to have a greater focus on primary healthcare and preventative care through the use of community outreach programs, and supported by a national health insurance [37]. The strategy is to bring healthcare closer to patients' home through the use of dedicated teams, including:

- An integrated, district-based teams of clinical specialists, initially including an obstetrician and gynaecologist, a paediatrician, a family physician, an anaesthetist, a midwife and a professional nurse;
- School-based primary care and health promotion services (e.g. Immunization, physical and mental health and well-being, family planning, etc.) Delivered by teams led by professional nurses; and
- Municipal ward-based primary healthcare workers who work with allocated households to identify health problems and to promote active involvement in good health practice by communities.

Non-communicable diseases, although often associated with the aging populations of many developed countries, are

1 Sound made by a mobile handset to indicate an incoming call or text message.
2 Dynamic image that runs when the mobile phone is idle for a user defined period of time.
3 Background image on entrance screen of a mobile phone.

already considered a significant issue in South Africa. Even though South Africa has a relative young population, its aged population is expected to increase from 7% to 10% by 2025 [35]. Furthermore, there are many individual, behavioural, social, cultural, structural and environmental determinants of non-communicable diseases that are prevalent in South Africa [36], particularly in resource constrained environments, which indicate that community-based approaches to preventative health care and wellness promotion are suitable.

IV. Existing Interaction Platforms

An overview of existing enablement platforms that provides the sought after broad range of interaction opportunities has identified the following common characteristics [39, 40]. These technology solutions on offer are frequently *quick and dirty* solutions that follow a route of least resistance with minimum concern for long term cost-effectiveness and cross platform integration. The solutions tend to be point-to-point implementations that have limited or no access channel interoperability or integration. It is frequently observed that the proffered solutions consist of numerous disparate technology platforms and have multiple network integration points that results in limited reusability. These result in a medium to high level of skill needed to integrate or develop extensions and to maintain relevance. The highly contextual nature of the solutions results in little or no economies of scale. In addition there is limited specialization, scalability or inter-project synergies.

With these limitations in mind it would be advisable for mobile enablement environments to have a single access point to various network communication channels and resources, to enable mobile access offered on Software as a Service basis, and to enable device and access agnostic service development. The ideal would be a single standards-compliant technology platform that enables a *drag and drop* service creation environment. This type of environment would require a lower level of skill to create mobile applications. It is further advisable to improve synergies and economies of scale with mobile as a specific focus area and to provide 24/7 availability.

From this overview an argument can be made for an extendible mobile enablement platform offering reusable communication and shared resource components as part of an extensible, IP-centric services framework with a primary objective of reducing the effort, time, skills level and financial requirements for developing mobile services in order to consolidate mobile requirements and benefit from future or existing economies of scale.

V. Mobi4D mobile enablement platform

With this in mind, the *Mobi4D Mobile enablement Platform* was developed to be scalable, standards-based, and able to support interoperability in the mobile environment. The platform is device agnostic and supports the following capabilities:

- Text using technologies such as SMS (text messages) and USSD (session-based text menu systems);
- Mobile web;
- Mobile chat protocols, such as MXit, XMPP, Google Talk and Cloud Tutor;
- Mobile applications using cell phone development frameworks such as J2ME, Windows Mobile, Symbian and Android; and
- Various communication and telephony protocols such as GSM/GPRS/3G.

In addition it meets the following functional and non-functional requirements:

- Minimal total life cycle cost - built using low cost open source components that require minimal upfront expenditure with limited ongoing operating expenses in the form of licensing and support fees;
- It is a standards-compliant solution that ensures interoperability as it is based on open standards and widely-used design principles; examples include the adoption of a Service Oriented Architecture (SOA) and the use of the Java API for integrated networks service logic execution environment (JSLEE) etc.
- Bearer & device agnostic that allows for the same service to be accessed from different mobile devices using different access mechanisms;
- Ease of use and accessibility to make it easier to create, operate and maintain specific mobile services and, in so doing, reduce the required minimum skills levels and resulting costs, thus leveraging existing available skills;
- Synergies and interoperability to extend to and integrate with external ICT solutions; Modularity provides the ability to develop mobile services using new as well as existing, reusable modules;
- Flexibility and extensibility with reference to the addition of further communication mechanisms e.g. Near Field Communication (NFC), multimedia message service (MMS), session initialization protocol (SIP), additional chat protocols, etc.
- Flexibility and extensibility with respect to adding new reusable service building blocks (SBBs) and incorporating existing standalone mobile applications;
- Scalability through ensuring that the mobile delivery platform can be scaled up to meet the anticipated concurrent user load; and
- Robustness, ensuring that the platform operates reliably and performs well under normal and abnormal conditions; and
- Availability through ensuring that the platform is architected as a high availability solution that remains operational and available to and usable by platform and service users.

The value proposition for this JSLEE-based platform is that because of it uses a Resource Adaptor architecture; it allows integration with legacy telecommunication networks, thereby allowing telecommunication operators returns on their investment in these infrastructures. Also, the next generation networks are envisaged to still place the network operator at the centre of the architecture, with standard-based signalling protocols such as SIP forming a service control overlay onto the infrastructure layer.

Having delineated the Mobi4D mobile enablement platform, the following section outlines an application of the Mobi4D mobile enablement platform in the health domain as a Mobile Health monitoring system for community health workers.

VI. Health application

This section describes the application of the Mobi4D platform in the health domain.

A. The opportunity

One of the initiatives of the primary healthcare reform in South Africa described above is the deployment of community health workers in the field [14] as part of ward-based outreach teams [15]. The aim of this initiative is to extend the reach of primary healthcare to communities. The task of community health workers is to provide assistance in health care by visiting community members in their homes or at schools and performing tasks such as home-based care, health education, assessment and counselling [41]. While community health workers do not have medical training and are not allowed making a diagnosis or providing treatment, their reach in the rural communities creates a perfect opportunity to enable early detection of possible non-communicable diseases and ongoing monitoring of patients in their homes.

For this purpose, a mobile health monitoring system was developed for use by community health workers [42]. This system provides community health workers with light-weight backpacks containing wearable health monitors such as ambulatory blood pressure monitors, blood glucose meters, weight scales, and cholesterol test sticks. This enables the community health worker to register a household member, perform the health assessment through the devices and send the profile and measurements to a centralized application for monitoring and reporting purposes.

This addressed the need for health monitoring, reporting and planning on a district level, but there was still a need to enable rapid response and follow-up when the health measurements collected from an individual indicates a health risk. The problem of limited connectivity in rural areas added to the challenge since many rural clinics do not currently have access to the Internet and would not benefit from a web based alerting solution.

The proliferation of the use of mobile phones in rural and resource constrained areas created an opportunity to use mobile communication technology to address these challenges. The constraint however was to provide a service that would be adaptable to support a range of network and phone capabilities in resource constrained environments and will be usable by the complete range of mobile telephones from low-end devices to high-end smart phones.

The following section describes how the Mobi4D was used to address this constraint.

B. The communication solution through Mobi4D

The Mobil4D platform provides the functionality to receive instructions from the Mobile Health Monitoring System though an Enterprise Service Bus and send SMS messages out to specific recipients. It also enables members of the community to request and access information on certain conditions and diseases via channels such as USSD, Google Talk and MXit. Lastly, it also provides a facility to collect information from community members regarding their health status. Due to the power of the Mobi4D mobile enablement platform, the establishment of these services was performed with minimal software development in a short time frame.
The conceptual architecture of the integrated solution including the Mobile Health Monitoring System, a health data vault for reporting and analytical purposes and the Mobi4D platform is depicted in Figure 1.

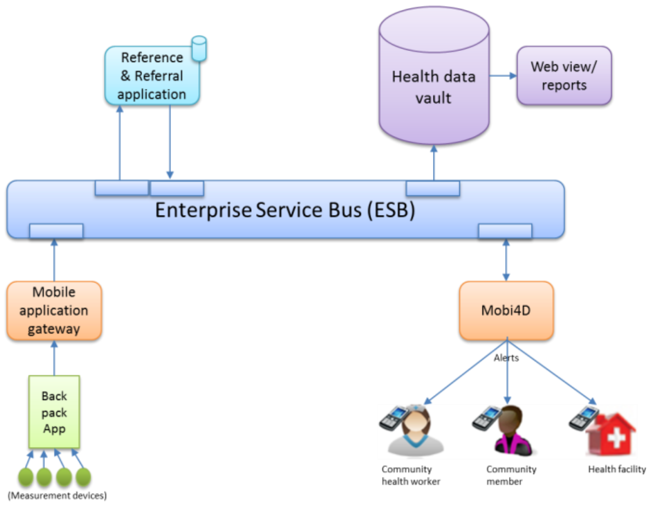

Figure 1: Conceptual architecture of the mobile health monitoring system

The picture shows the technical components of the solution including the integration of the Mobi4D platform. The measurements from the health measurement devices such as the ambulatory blood pressure monitors, blood glucose meters, weight scales, cholesterol test sticks are entered into the Mobile health monitoring application that is deployed on the mobile phone of the community health worker. The information regarding the community member and his/her associated health measurements are uploaded from the community health worker's mobile phone as soon as he/she is in an area with Internet connectivity. The information is passed though as mobile application gateway that provides authentication and data transformation services. This information is passed to the Enterprise Service Bus that delivers it to the Reference and Referral application. This application evaluates the measurements against a rule based engine and initiates alerts to be sent if measurements are found to be outside the normal range. The alert message instructions are transported to the Mobi4D platform where the mobile communication functions are performed, using the most appropriate messaging channel. The information is also recorded in a data warehouse (the health data vault) that is used for reporting purposes.

C. User scenario

A typical user scenario is as follows:

- A community health worker visits a community member in his/her home.
- If the person already exists in the system her/his record is retrieved with the application on his/her

mobile phone. If not, the community health worker registers the person.

- The community health worker performs the health assessment with the health measurement devices.
- The health record of the community member including all the health measurements is uploaded to the central system as soon as the community health worker is in an area with Internet connectivity.
- The health measurements are analysed in the central system.
  - If the measurements are found to be out of the normal range, appropriate messages will be sent to the community member, the community health worker and in severe cases to the local clinic. If the person's blood pressure is slightly elevated, the system will send a message to the community member informing him/her that his/her blood pressure is elevated. The message will also contain information on a USSD service, Google Talk service and MXit service available where the person can find more information related to the dangers of high blood pressure and how to change their lifestyle to address it.
  - If the person's blood pressure is high, the systems will send out a message to the community member and the community health worker advising them that the person's blood pressure is high and should go to the clinic urgently. The message is also sent to the community health worker to enable him/her to follow up with the community member.
  - If the person's blood pressure is critically high, the system sends a message to the community member and the community health worker indicating that the person's blood pressure is dangerously high and he/she should go to the clinic immediately. A message is also sent to the clinic enabling them to send an ambulance to collect the member if possible.
- The system also enables follow-ups via SMS. If a community member was advised to visit a clinic, a massage will be sent to him/her a week after the encounter asking if he/she visited the clinic. Via a USSD service, the member can indicate if he/she went to the clinic or not. If not, a follow-up message will be sent indicating that he/she should visit the clinic. If he/she indicates that he/she went to the clinic, the system will ask him/her if he/she received treatment or medication. If the member indicates that he/she did not receive treatment or medication, he/she is referred back to the clinic. If he/she indicates that he/she did not receive treatment or medication, they are referred back to the clinic.

D. Implementation and evaluation

The system was developed according to design science research and was evaluated in a simulated clinic environment to evaluate the efficiency and effectiveness of the system. Feedback from the simulated evaluation was fed back into the development of the system and the system was refined accordingly.

A pilot roll-out of the system is planned in one clinic and catchment area in South Africa in the near future. This pilot will be used to evaluate the effectiveness of the system in a real life setting.

VII. Conclusion

The Mobi4D platform allows users who are not ICT experts to use the cell phone as a crucial ICT tool for empowerment and development in Africa. It enables a standards- and framework-based approach to creating mobile services via re-usable, scalable and integrated components and approaches, utilising the various functionalities of cell phones, in ways that make sense in Africa.

The Healthcare system in South Africa is under strain and is not achieving the desired health outcomes. This is due, in large part, to the inequitable division of healthcare service and expenditure between the public and private sectors. This is particularly evident in the high incidence and impact of non-communicable diseases.

In order to address this problem, the South African health system is being reformed to have a greater focus on primary healthcare and preventative care through the use of community outreach programs.

Community health workers are being deployed in South Africa to provide ward-based primary healthcare to citizens in their homes. To improve their ability to monitor the health of members of the communities they serve, a Mobile Health Monitoring system that is deployed on mobile phones and supported by backpacks containing portable health monitors was developed. Data collected using these monitors are combined with data captured on a mobile device and transmitted to a centralized health information system. This system is used for health monitoring, reporting and planning on a district population level.

This system was extended using the Mobi4D platform, which allowed the central health information system to communicate back with community members and health workers, to engage them directly, and to provide them with alerts and information about their health. The use of Mobi4D proved appropriate and effective, as it provided a mechanism to reach and engage health beneficiaries directly, taking into account the technologies they already possess and the access networks and channels they already use.

Through the utilization of the mobile messaging and information delivery abilities of the Mobi4D platform, early warning signs of non-communicable diseases can be identified and affected people, community health workers and clinics can be appropriately alerted. This mechanism can also be utilized for ongoing follow-up visits by community health workers for monitoring purposes.

Future work will include (1) the deployment and assessment of the Mobile health Monitoring system in the field; and (2) the use of the Mobi4D platform for other health related communication services such as SMS reminders of appointments at clinics, SMS reminder services for medication adherence and mobile health information services for health education and awareness.

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