mePHR: A Mobile Personal Health System (PHS) Framework

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Abstract: This article describes a Personal Health System (PHS) Platform, namely mePHR, for smartphones and tablet computers to provide connectivity among patients, healthcare professionals and personal medical devices. The platform is developed as a generic application framework with standard-based open interfaces as a basis for rapid development of patient monitoring services. We have demonstrated the usage of the mePHR framework in Turkey by implementing a set of basic PHR applications and the local "National clinical guideline for management and treatment of diabetes in adults" as a diabetes monitoring service. The required patient EHRs are obtained by connecting to the Turkish National Health Information System via "eSaglikKaydim" PHR system and through a number of medical devices communicating with the platform.

1. Introduction

The technologies that underlie mobile communication systems are becoming more powerful and cheaper, creating opportunities for the delivery of healthcare services and the promotion of personal health through mobile platforms. Another trend in healthcare is empowering patients through Personal Health Record (PHR) systems so that they can take a more active role in the management of their personal health. PHRs are not only electronic repositories of health information controlled or accessed by patients. They are also integrated with a wide variety of healthcare information technology systems including the personal medical devices to obtain the patient's current physiological status; the clinical decision support systems for patient-physician shared decision making; and the evidence-based medical sources on the Internet to automatically retrieve data according to the patient context.

In this paper, we describe a Personal Health System (PHS) Platform for smartphones and tablet computers, called mePHR, which provides a basis for third parties to easily develop personal health system applications by using the common services and API of the platform. The system consists of two main parts: the platform providing the services and the patient health monitoring applications developed on it (mePHR Apps). The mePHR Platform is responsible for communicating with external health information systems, connecting to medical devices, storing external patient data in a local database and providing patient data and terminologies to the mePHR Apps. The mePHR Apps, on the other hand, provide several modular patient health monitoring applications with their graphical user interfaces to allow patients to display and manage their data jointly with their physicians.

2. mePHR Software Framework

As already mentioned, the mePHR framework has a modular architecture containing two main modules: mePHR Platform and mePHR Apps; both running on the mobile device (Figure 1). It is designed and implemented as software framework to be able to provide a set of generic functionalities that can be selectively utilised by application developers, thus providing application specific software focusing on monitoring of different health problems. As part of the framework, it offers a software library providing application programming interfaces (APIs).

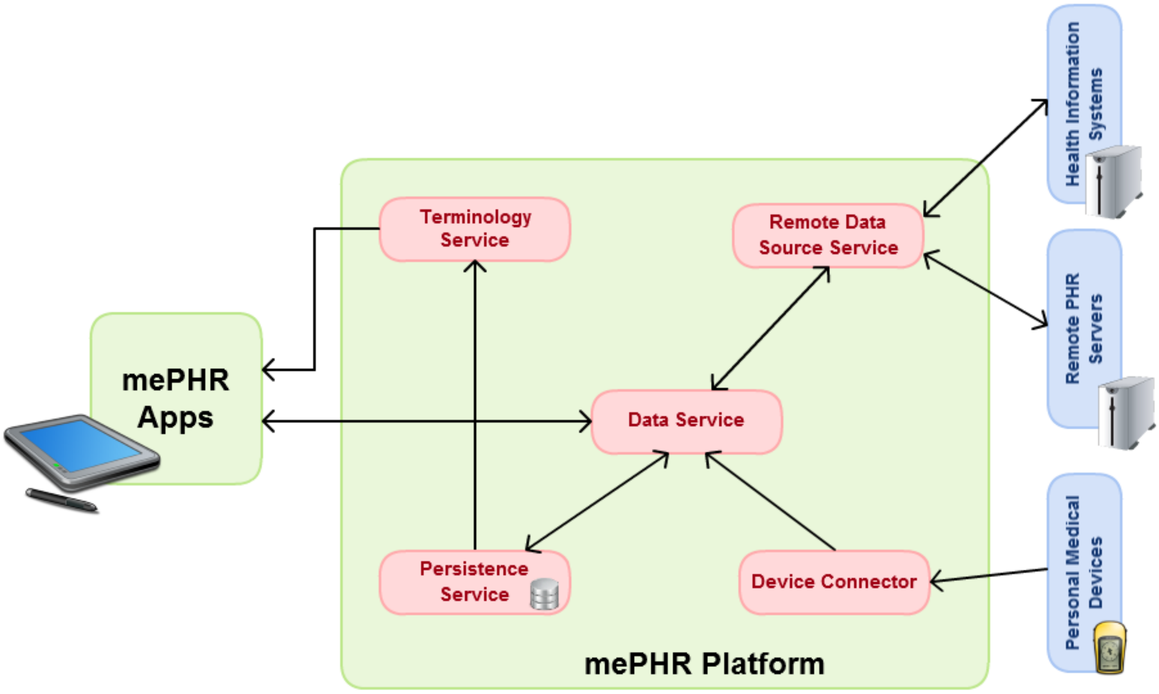

Figure 1 Overall Architecture of the mePHR Software Framework

The mePHR Platform provides five main interfaces (Figure 1), each realising some core functionalities for the whole system:

- **Data Service** manages record exchanges between mePHR Apps and mePHR Platform. It handles four operations:
    1. **getRecords** operation is used for retrieving patient records from Remote Data Source Service, which could be health information systems or PHR servers. Then the Persistence Service synchronizes these records with the internal database. When there is no Internet connection, **getRecords** operation retrieves synchronized records from the internal database.
    2. **addRecord** operation creates a new patient record in the remote PHR server and synchronizes this record with the internal database. When there is no Internet connection, the new record is added directly to the internal database and synchronized with the remote server when Internet connection is available; this synchronization process works similarly for the remaining operations presented below.
    3. **updateRecord** operation updates an existing patient record in the remote server and synchronizes this patient record with the internal database.
    4. **deleteRecord** operation deletes an existing patient record in the remote server and synchronizes this operation with the internal database.

- **Terminology Service** is responsible for providing terminology lists to the mePHR GUI. End user applications form their patient records with these terminology entries. These terminology lists are in fact subsets of original medical code systems and kept in separate XML files to facilitate maintenance, update and also multi-language support. When the mePHR Platform runs for the first time, these XML files are parsed by the Persistence Service and tables of the internal database are populated by the extracted terminology information. An example terminology subset from the SNOMED CT code system for status codes is given in Figure 2.

```
<Vocabulary
    id="7a4a5c2b-58bb-4596-af0e-2bf2d1b960dc"
    version="1.0"
    description="PHR General Status Codes">

    <UnderlyingCodeSystem
        id="2.16.840.1.113883.6.96"
            description="SNOMED CT"/>
    <VocItem>
        <Code>55561003</Code>
        <Designation lang="en">Active</Designation>
    </VocItem>
    <VocItem>
        <Code>73425007</Code>
        <Designation lang="en">Inactive</Designation>
    </VocItem>
    <VocItem>
        <Code>90734009</Code>
        <Designation lang="en">Chronic</Designation>
                    ⋮
```

Figure 2 Status codes terminology subset from SNOMED CT

  There is a separate root element for each terminology system denoted by the term “Vocabulary” and each “Vocabulary” item indicates the related international or national code system in the “Underlying Code System” node. Actual terminology codes are listed as “VocItem”s. Multiple languages can be supported by adding different “Designation”s in a VocItem through the use of "lang" attribute.
- **Remote Data Source Service** is used for securely connecting to the remote health information systems or PHR servers. It also handles remote authentication and record operations when mobile device is connected to the Internet. In the mePHR Platform, patient medical summaries are represented and stored in a model based on the ASTM Continuity of Care Record (CCR) [1]. The data format used during data exchange between the mePHR Platform and remote PHR servers or health information systems is HL7 Clinical Document Architecture Release 2 (CDA) [2]; so for each of the remote record operations, the CCR objects are mapped to the CDA format and vice versa. For each record type, there is a mapper that can perform the necessary mapping in both directions.
- **Persistence Service** is responsible for the encryption (of private data), synchronization and persistence of patient records, user accounts, and medical terminology lists within the mobile device. It acts as a cache for the remote PHR servers, and mePHR Platform is able to respond to requests on PHR records even if the mobile device has no Internet connection. The Persistence Service is implemented on top of an SQLite database instance and the relational tables stored. The number of tables is minimized, since mobile devices have limited computing resources. Each PHR record is serialized into JSON format and persisted in an encrypted way. When a PHR record is requested, corresponding JSON string is decrypted and deserialized into CCR object model and returned to the calling component easily.
- **Device Connector** listens for Bluetooth connections with the personal medical devices. The data is retrieved from these devices as a sequence of bytes and interpreted into the corresponding CCR format with a parser that implements IEEE

11073-xxxxx specifications [3] where xxxxx stands for the 5-digit identifier of the medical device (e.g. 10407 is used for blood pressure monitors). When a Continua Health Alliance [4] compliant medical device based on 11073 Data Exchange Protocol starts working, it immediately sends an “Association Request” to this interface. That means the medical device is ready to send measurements. To be able to receive measurement data from the medical device, this interface sends a response to Association Request in a specific format defined in IEEE 11073-xxxxx specifications.

When a measurement is ready by the personal medical device, it sends the actual data in an “Agent Data” message, and the Device Connector parser extracts the measurement data and converts it to the corresponding CCR format. Then, the Device Connector sends a response to medical device to denote that it successfully read measurements from the medical device.

Finally, the Bluetooth connection is released after both the Device Connector and the medical device send an “Association Release” message to each other.

Based on this modular platform we have implemented different mePHR Apps, namely:

- *Basic Health Information Management*: Enables patients to manage basic information such as weight, height, blood type, etc.
- *Medical Summary Management*: Enables patients to access and manage (save, update, delete) allergies, problems, test results, encounters, medications and procedures that are pertinent to patient's current or past medical history.
- *Life Style Management*: Enables patient to manage his diet and exercise program.
- *Chronic Disease Management*: Different chronic disease management applications have been implemented including diabetes management that provides decision support and helps patient to manage his care plan; high blood pressure management; and cholesterol management.
- *Baby Health & Immunization Tracking*: Enables parents to track the immunizations and other care activities for their babies.
- *Pregnancy Monitoring*: A tool that provides decision support and information for pregnancy and help patients to improve their healthcare during gestation period.

3. The Standards Used in the mePHR Platform

Given the existing semantic and technical diversity of eHealth systems, each integration effort with a new system will be an expensive process unless standard models and interfaces are used for data representation and exchange. Therefore, all the interfaces developed in the mePHR system are based on the relevant international standards as explained in the following sections.

3.1 Content Model and Format Standards

In the mePHR platform, to define the PHR summary data, the E2369-05 Standard Specification for Continuity of Care Record (CCR) by ASTM International is used [1]. CCR is one of the most widely used standard that defines a core data set for the most relevant administrative, demographic, and clinical information facts about a patient’s healthcare, covering one or more healthcare encounters. It contains various sections such as patient demographics, insurance information, diagnosis and problem list, medications, allergies and care plan.

In real life settings to exchange data for a specific application, content templates are used. Content templates are built on top of the well-accepted content standards to further refine these standards by: (i) restricting the alternative hierarchical structures to be used within the instances, (ii) constraining optionality and cardinality of some elements, (iii) defining the code systems and codes used to classify parts of the document and also (iv) describing the specific data elements that are included. One of the most prominent PHR content templates, namely ASTM/HL7 Continuity of Care Document (CCD) [5], is defined by constraining HL7 CDA EHR content standard [2] with requirements set forward in CCR. In the mePHR platform, the content templates are based on ASTM/HL7 CCD. Hence, the PHR records of a patient from a backend (remote) data source are retrieved over a secure connection based on HL7 CDA standard.

3.2 Medical Device Measurement Standards

Although some of the Personal Health Device vendors still use proprietary formats and protocols for communicating their devices with external systems, important standards that have emerged are gaining wide-spread acceptance, such as the ISO/IEEE 11073 standard set and Continua Health Alliance guidelines [4]. ISO/IEEE 11073 standard set is based on an object-oriented domain information model called the Domain Information Model (DIM) [6], and Continua Health Alliance guidelines detail the use of ISO/IEEE 11073 standard set for specific medical devices by exploiting ISO/IEEE 11073 Device Specializations. In the mePHR Platform, a Bluetooth medical device connector, based on the IEEE 11073 Personal Health Devices standard and the Continua Health Alliance guidelines, has been implemented. The connector reads the measurements from medical devices and integrates them into the PHR records of the patient. The mePHR Platform also provides basic user interfaces for this component to manage its functionalities and present the device measurement to users.

3.3 Communication Protocol Standards

In the mePHR platform, RESTful Web Services [7] are implemented for communication between mePHR Platform and the remote data sources. REST (REpresentational State Transfer) corresponds to a stateless client-server architecture in which the Web services are viewed as resources and can be identified by their URLs. Web service clients consuming these services access them over HTTP or HTTPS by transferring application content using a small globally defined set of remote methods that describe the action to be performed on the resource.

3.4 Security and Privacy Standards

For the data to be stored in the smartphone and tablet, security mechanisms are essential in order to protect the patient information. For this purpose, the mePHR Platform encrypts the data to be stored in the internal database by using 128-bit Advanced Encryption Standard (AES128) encryption algorithm [8]. AES128 encrypts and decrypts patient data by using SHA-1 (security hash algorithm) [9] cryptographic hash function. The data exchange between mePHR Platform and remote PHR server is performed over secure HTTPS protocol. mePHR Platform also provides three different levels of session security mechanisms: low, medium and high; according to the selected level, user session is kept infinitely, kept for 10 minutes or not kept at all.

3.5 Mobile Platform Standard

Android is a Linux-based software stack for smartphones and tablets that includes an operating system, middleware and key applications developed by the Open Handset Alliance [10] led by Google. It is a frequently updated platform and each update comes out with a new version that contains new functionalities and revisions. Therefore, it is important to designate a minimum version that a framework can run on. In the mePHR platform, the minimum required versions are Android version 2.2 and API level 8 for smartphones; and Android version 3.0 and API level 11 for tablets, as long as medical device connections are not needed. If medical devices are used, Android version 4.0 is necessary for both smartphones and tablets.

3.6 Terminology Systems

In medicine, the clinical data structures such as EHR and PHR content templates refer to controlled vocabularies or terminologies to express semantics; i.e., the meaning of the terms used. For example, the observation for a patient can be expressed as a “heart attack” or a “myocardial infarction”, and these mean the same thing to medical professionals. But unless the term is associated with a unique code from a code system, automated processing of the exchanged term is very difficult because an application, programmed to use “heart attack”, would not understand “myocardial infarction”. When the observation refers to a medical terminology system such as SNOMED CT [11] and a code like “22298006 (Myocardial infarction)” is used to represent the observation, the meaning can be shared in a consistent and automated way as long as all involved applications use this code.

Therefore, there are many terminology standards such as Systematized Nomenclature of Medicine - Clinical Terms (SNOMED-CT), Logical Observation Identifiers Names and Codes (LOINC) [12], International Classification of Diseases - 10th Revision (ICD-10) [13] and these terminologies are used for classification of different types of patient data like diseases, laboratory results, procedures, etc. In the mePHR Framework, in order to facilitate interoperability with external systems, the patient data is coded with relevant terminology systems to the extent possible, e.g. apart from free text notes.

4. Diabetes Monitoring through the mePHR framework in Turkey

The mePHR platform is being used to develop a pilot diabetes monitoring application in Turkey within the scope of the FP7-ICT-288209 EMPOWER Project [14]. The EMPOWER Project aims to support patient empowerment by an intelligent self-management pathway for patients. The pathway is being developed based on the Turkish “National clinical guideline for management and treatment of diabetes in adults” [15].

For this pilot application, the mePHR Platform is integrated with the “eSaglikKaydim” PHR system in Turkey as well as with the Turkish National Health Information System (NHIS) [16] and the Family Medicine Information System (FMIS) [17].

National Health Information System of Turkey became operational on January 15, 2009. As of February 2012, 98% of the public hospitals and 60% of the university hospitals and private hospitals are connected to the NHIS sending the EHRs of their patients daily. The total number of connected healthcare organizations is around 1200 and currently there are more than 650 million EHRs in total. The Family Medicine Information System, on the other hand, is another national infrastructure for the exchange of primary care records among general practitioners and the Ministry of Health. Both systems have service based architectures implementing Web services to store and retrieve EHRs. eSağlıkKaydım is a modular and flexible PHR system allowing access to personal health records of a patient with proper security mechanisms in place.

We describe diabetes monitoring through a case scenario which is about Ms. Aymaz diagnosed by Type II diabetes in May 2009 during one of her visits to the hospital. The treating physician, Mr. Simsek recommends her to use the mePHR platform so that they can jointly monitor her case and develops her care plan which is accessible from the mePHR platform (Figure 3-a). After that, her EHRs are retrieved from NHIS so that her physician can decide on the co-morbidities; her twice-daily glucose measurements from the glucose meter device and her dietary information from her PHR (eSaglikKaydim) system that she uses to enter her daily food intake. Fortunately for Ms. Aymaz, the mePHR system provides a single point of access and control to all this information from her smartphone or tablet because the mePHR platform is interoperable with all the mentioned systems based on relevant standards. The system also enables her to keep track of all her scheduled and recorded activities by providing a calendar based user interface (Figure 3-b). Additionally, the consent management mechanism of her PHR controls access to this data according to her privacy consent. After a while, she manages to get her blood glucose level under control. At a later appointment, it is discovered that she has become pregnant. Mr. Simsek develops a new care plan for Ms. Aymaz that indicates the dates for her additional check-up dates to monitor the possible complications that her diabetes might have on her pregnancy (Figure 3-c). Additionally, because oral anti-diabetes medication cannot be used during pregnancy, Mr. Simsek recommends her to use an insulin pump (Figure 4-a) and sets the glucose level goals for her (Figure 4-b) by also setting the necessary reminder alerts (Figure 4-c).

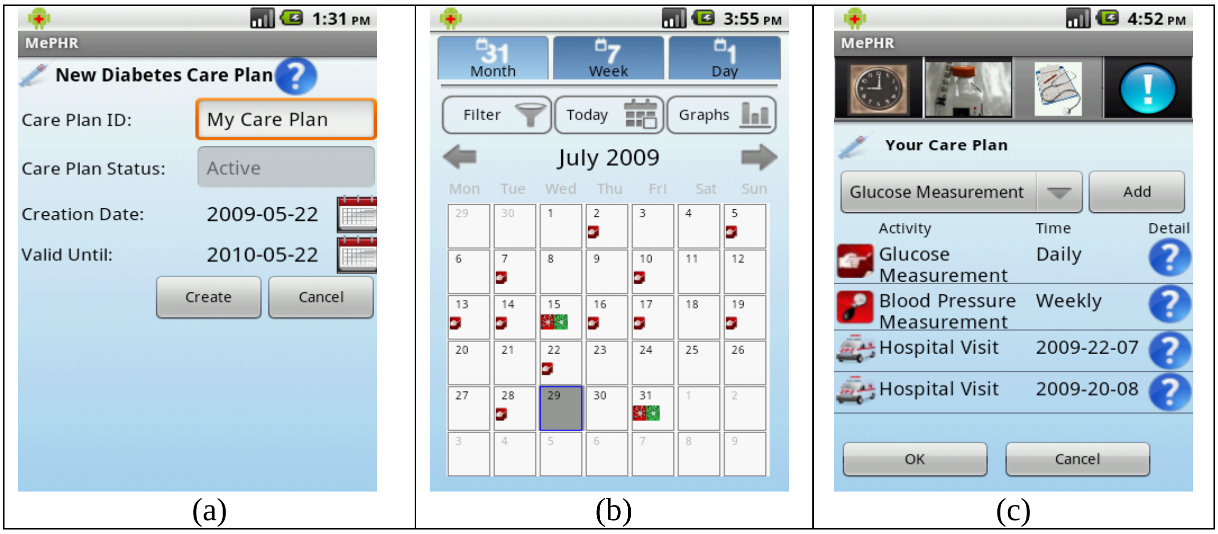

Figure 3 Screen Shots from the Mobile Diabetes Monitoring Application on the mePHR Framework

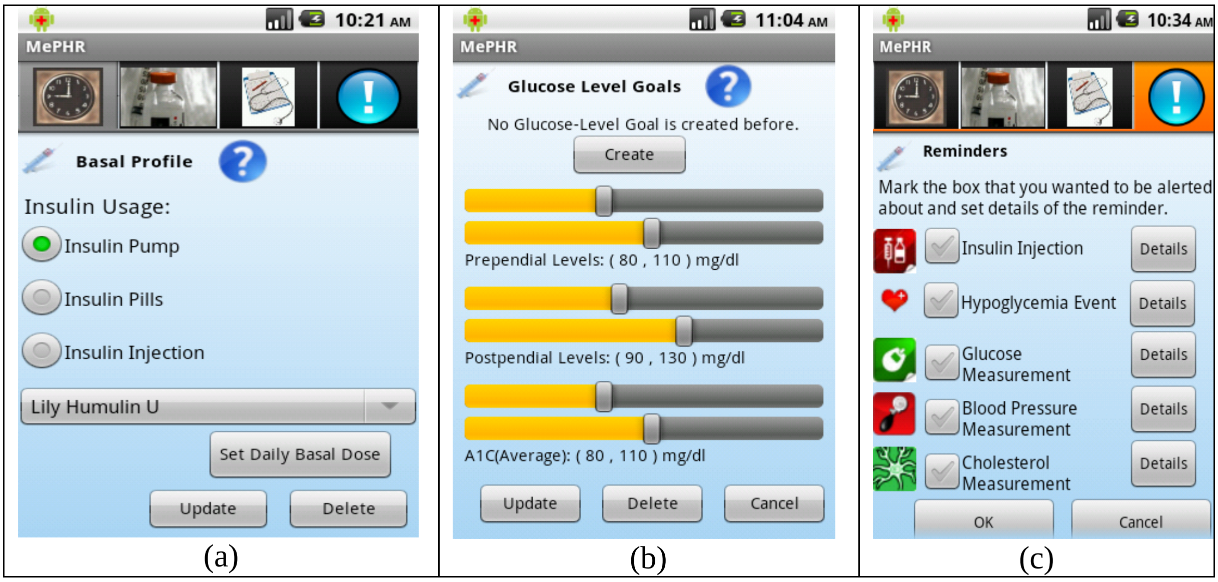

Figure 4 Screen Shots from the Mobile Diabetes Monitoring Application on the mePHR Framework

5. Conclusions

The aim of developing the mePHR system is to provide an application framework that helps rapid development of standards conforming, secure mobile health monitoring applications. The standards based open interfaces of the mePHR Platform facilitate implementations of personal health monitoring services by providing connectivity with personal health record systems, a variety of measurement devices and health information systems.

The mePHR Platform is being used to develop a pilot diabetes monitoring application in Turkey within the scope of the FP7-ICT-288209 EMPOWER Project. The diabetes patient pathways are developed based on the Turkish "National clinical guideline for management and treatment of diabetes in adults".

Turk Telekom intends to make the mePHR Platform and the applications running on top available through the smartphones and tablet computers.

Acknowledgements

The work done for the mePHR Framework was supported by Turk Telekom. The research leading to the diabetes monitoring through the mePHR Framework has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement no ICT-288209 EMPOWER Project (Support of Patient Empowerment by an Intelligent Self-management Pathway for Patients).

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