Zappa: An Open Mobile Platform to Build Cloud-Based m-Health Systems

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Abstract. Cloud computing and associated services are changing the way in which we manage information and access data. E-health services are not impermeable to novel technologies, especially those that involve mobile devices. At present, many patient monitoring m-health (mobile-health) platforms consist of close, vendor-dependent solutions based on particular architectures and technologies offering a limited set of interfaces to interoperate with. This fact hinders to advance in quality attributes such as customization, adaptation, extension, interoperability and even transparency of cloud infrastructure of existing solutions according to the specific needs of their users (patients and physicians). This paper presents an extensible, scalable, highly-interoperable and customizable platform called Zappa, designed to support e-Health/m-Health systems and that is able to operate in the cloud. The platform is based on components and services architecture, as well as on open and close source hardware and open-source software that reduces its acquisition and operation costs. The platform has been used to develop several remote mobile monitoring m-health systems.

Keywords: m-Health, e-Health, mobile applications, patient monitoring, SOA, open source, cloud computing.

1 Introduction

The appearance of mobile systems for e-Health has revolutionized this domain by providing tools that enable, among others, remote monitoring of patients and automate both the capture of health parameters data and its transference to remote computer systems, thereby, giving rise to so called m-health systems [1]. Furthermore, m-health systems allow patients to be under steady medical supervision so that changes in patients' health status can be tracked and notified. Unattended care is also possible, i.e., peak values in certain parameters and temporary crisis that alert of abnormal situations can be registered, which otherwise might go unnoticed, thereby affecting patients' health due to the lack of fairly relevant information in his/her medical record [2].

The challenge is not only to automate these tasks, but to also try to assure certain quality attributes of the system that support them through the application of design techniques. For instance, although there exist several monitoring systems that provide plenty of functionalities, in many ways these systems do not cover the different needs

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of a wide range of patients, since each patient requires a personalized and adaptive monitoring to be defined by physicians [3].

Likewise, physicians demand technological infrastructures that provide seamless interaction with medical systems any-where anytime through internet-operable clouds where the clouds themselves are a transparent element.

This paper presents the design of an extensible, scalable and customizable cloud platform for the development of eHealth/mHealth systems. Some key design decisions are based on the use of the recent concept for delivering resources as services over Internet (Cloud computing), open technologies (open-source software, open hardware, etc.) and additional techniques, for instance, the personal information about patients who use the platform is to be remotely managed in a customizable manner. Moreover, the platform is intended to provide uninterrupted monitoring with the goal of obtaining some information that can be subsequently analyzed by physicians for diagnosing.

This paper is organized as follows. Section II presents related work. Section III presents the platform and its features. Section IV introduces software applications and tools based on the platform. Finally, Section V summarizes the conclusions and future work.

2 Related Work

So far, several mobile systems for patient monitoring have been proposed. For space limitation, it is not possible to compare the present proposal with each one of them. Nonetheless, one common drawback of many of them is that they are designed with hardly-scalable architectures and implemented with privative software [6][10]. This not only makes it difficult for other developers to work with them, but also increases their cost and limits their adaptability to be customized for a wide range of patients [7]. In other cases, the set of services provided is limited or focused on specific services, such as information representation/visualization [4], just show the health status of one vital sign in an exact moment of time [5], are designed and devised for local monitoring of patients and, limit the number of patients that can make use of the system [12][13], or monitor just one vital sign [14][15].

3 Zappa: Cloud m-Health Platform

In the following sections it is introduced the Zappa platform, the intended properties and principles that have guided its design, as well as the constituents of its system architecture.

3.1 Desired Features

E-health and m-health platform must comply with certain desired features that foster their acceptance by the different group of users that interact with them (patients, relatives, physicians, etc.). The proposed platform aims at providing certain monitoring services for medical purpose and intends to achieve the following characteristics:

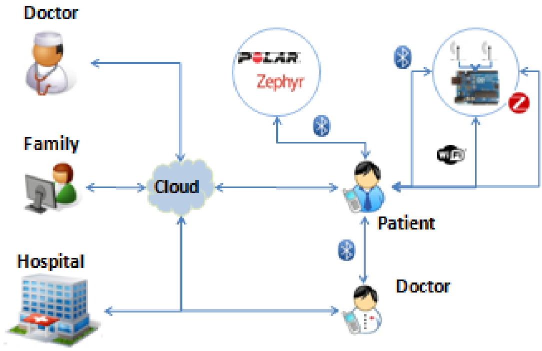

Fig. 1. Local-Remote monitoring scenario

1. System adaptability, which allows the customization of the application in order to meet heterogeneous and changing patients' needs. Integration of user profiles that are used to set up the application (i.e., determine the biosensors to be used, peak of values for triggering alerts, etc.). This information is internally represented in XML to foster interoperability.
2. Timely alert, when a peak value in certain patient clinical parameter is registered, the system should react in the predefined interval of times to safely notify about abnormal situation to professionals and caregivers. Besides, this value will be stored in the patient medical record.
3. Self-configuration, the system which must adapt to changing needs of clinical conditions of patients, their profiles, and their dynamic environment, without external tools or expert knowledge.
4. Cost-reduced system, by making use of:
   - Open Source software, so that system modules can be reused by developers and extended without paying for licenses, and thus, reduce costs.
   - Open Hardware, which required the different elements to be based on open hardware, to reduce the costs for customers [3][8].
5. Dynamic System. M-health scenarios are dynamic in nature. This means that not only new components (software components and hardware devices, like biosensors) are able to automatically connect and disconnect to the system at run-time, but also new patients can become part of a scenario and interact with the system on the fly. Fig. 1 shows a generic local-remote scenario where the patient is being monitored locally and remotely (family, doctor, hospital).
6. Interoperable system, in order to overcome the heterogeneity of system devices and enable the system to communicate and integrate with other systems. XML-based representations of data in conjunction with some extensible and adaptable communication protocols are used to achieve this goal.
7. Seamless clouds, i.e., users (either physicians or patients), are not aware that they are interacting with a cloud infrastructure.
8. Use of medical devices. The system should be able to use different medical devices based on different technologies. This feature guarantees the use of commercial and

close-source hardware devices of popular vendors, such as Polar or Zephyr (Bluetooth), and custom/research devices based in open-source hardware as Arduino (ZigBee, Bluetooth, Wifi).

3.2 Architecture

According to the characteristics enumerated in the previous section different concerns of mHealth systems can be identified, e.g., communication with and between devices, data representation, formatting and storage, wireless protocols, cloud access, etc. These concerns are supported by means of a component-based (modular) architecture design so that changes in one system component do not alter system behavior and do not affect the configuration of other system components either [11]. Fig. 2 shows the Zappa platform

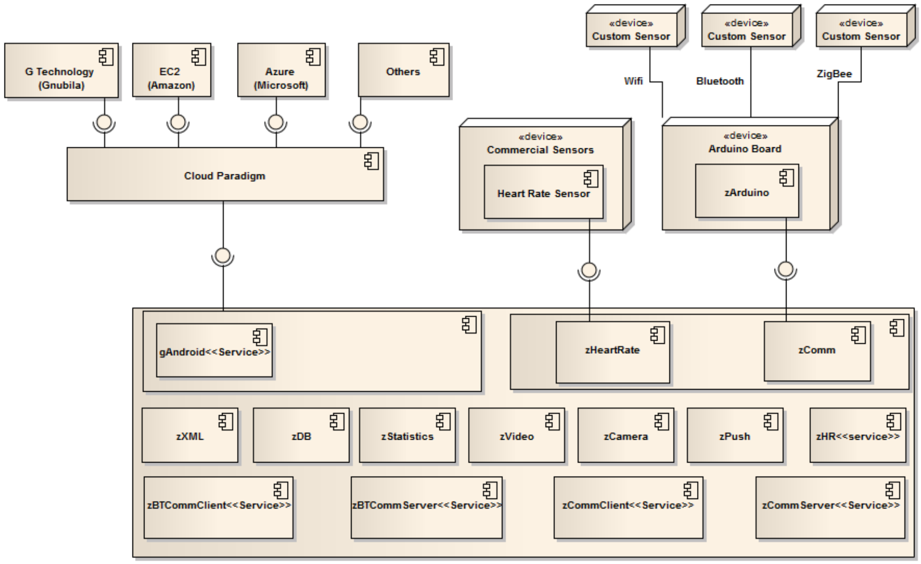

Fig. 2. Zappa Component-based Architecture

architecture. There exist different components that encapsulate and abstract all functionalities related to information management (e.g., zXML, zDB), communications (zComm, ZBTServer) and cloud technologies (gAndroid for G Technology), as well as biosensor devices, among others. These components could be used in eHealth/mHealth systems (Android). Some design decisions, such as the management of the communication between different devices with different components(zComm for Wifi and zHeartRate for Bluetooth) or separate the cloud management in different components, have been adopted in order to foster higher extensibility of the mechanisms and functionalities the platform permits to:

1. Connect a new biosensor or disconnect a biosensor at run-time. The status of biosensors will be detected and updated automatically, thanks to zComm (for custom biosensors) and zHR (for Bluetooth heart rate sensors) components.

2. Establish the communication between two devices (i.e., between two mobile devices or between a mobile device and a biosensor) with any of usual communication protocols, like Bluetooth and Wifi. This is achieved using different components (zHeartRate with Bluetooth and zComm/zArduino with Wifi) which are used in services that are executed in the background to provide a full time support. Thanks to message passing communication protocols implemented in zComm and zArduino components, the developer can add new functionalities and specify new types of notification messages, without changing the behavior or performance of the system.
3. Interact with cloud infraestructures. For example, the gAndroid component has been explicitly designed to work with G-Technology IaaS (Infrastructure as a Service). If interoperation with other IaaS vendors is required, new components can be added to the platform seamlessly.

4 Example Applications

In order to show the applicability of the platform, several m-health applications based on the Zappa platform are introduced. These applications use different components (Fig 2) of the platforms to provide the corresponding functionality.

4.1 Zappa App

Zappa App is an m-Health system used to monitor the heart rate, temperature and blood pressure of the patient. In addition, the system is able to save the vital sign values, detect health problems and share information with a doctor or medical staff that are in the same place that the patient (Bluetooth).

Currently, Zappa App consists of four software applications. Three of these applications have been built for mobile devices (Android) and the last one (desktop application) has been built to support the information exchange between mobile devices and the biosensors connected to Arduino boards (an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software), which makes use of the Zigbee technology for communication. The different mobile applications are the following:

- Setting Application (Zappa App Setting): It is the application installed on the patient's mobile devices. It is used to manage all the different elements of the system. It allows the user to manage sensors (zComm component), statistics (zStatistics component), profiles and patients (Fig. 3 - left).
- Monitoring Application (Zappa App Patient): This application (Fig. 3 - center) shows the obtained values from the biosensors through the communication service (zComm and ZCommService components). Each monitorization is customized and varies depending on the selected user profile. This application has been built as an Android service. In this manner the system (alert notifications, real-time biosensors connection/disconnection, information storage and other tasks, can be executed even when the application is running in background. In addition, this application starts the different components that allow sending and receiving information from the cloud. In this manner, the application can receive requests and act accordingly.

- External request application (Zappa App M.D.). This application could be installed in any mobile device and it able to search, via Bluetooth, different patients in the same location and to obtain personal in-formation or monitoring values. This is possible using zBTCommClient component in this app, and the component zBTCommServer in the mobile device of the patient (Fig. 3 -right).

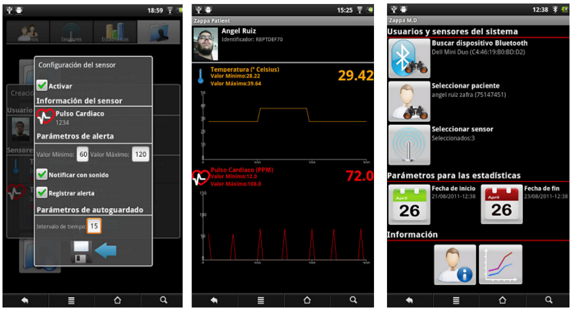

Fig. 3. Zappa App

4.2 Cloud Rehab

Cloud Rehab is a full m-Health system that is used to monitor the daily activities of patients with severe brain damage. This kind of patients can evolve faster performing certain activities, such as having lunch, dressing, etc., if these activities are monitored (in real-time) by physicians or medical specialist. The doctors can define new activities, called sessions, according to the evolution of the patient.

One session is made up of a training video of a patient performing an activity in a training process, a set of audio and image files used when the heart rate value of the patient reach a certain value, the recorded video of the session, the heart rate values, and alert triggered, among others. The doctor can define new sessions with new training activities and, once the patient has completed them, review the session's information to evaluate patient progress. The system includes two applications.

- Web Application: The web application (Fig. 4 left) is used by the medical staff to manage patients' medical information. This application is used to manage sessions, monitor patients values, real-time monitoring, etc. The application can be also used by the relatives of the patient to check if she/he has completed all the sessions, her/his medical progress and/or check if the doctor has defined a new session.
- Android Application: This application (Fig. 4 right) is used by the patient to perform the sessions. The application monitors heart rate in background (zHR component as a service) and stores the values in a cloud server (gAndroid component as a service) and in a local database in real-time (zDB component). If the heart rate value is above or below some predefined thresholds, the patient can use relaxation options.

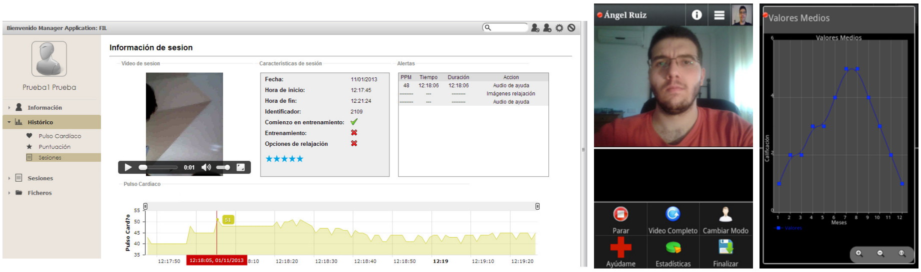

Fig. 4. Cloud Rehab Web Application (left) and Android Application (right)

5 Conclusions and Future Work

Health monitoring systems can help patients in many different ways [3]. Normally the control of the status health of the patient is good enough, but thanks to mobile devices and their hardware and software evolution it is possible to provide more functionality to them like remote at home monitoring.

An m-health cloud-transparent platform, called Zappa, for developing systems intended to monitor patients remotely and in real time has been described. Its design is based on an open architecture and made up of components based on standard technologies that allow a higher extensibility and support the management of different patients, being able to customize the systems to be developed to their needs. The platform aims also at saving implantation and economic cost through open source hardware and software. The platform enables systems to operate in hybrid monitoring scenarios and offers robust communication capabilities by enabling to switch between different protocols seamlessly and on the fly depending on availability, efficiency, etc., issues.

Zappa supports the construction of m-health cloud-based systems so as to provide functionalities fulfilling non-functional properties that foster patient acceptance of such systems. Several sample applications have been shown in order to illustrate the applicability of the proposal.

We are currently working in the improvement of the proposed platform. Plans for future work include: 1) the development of an expert system¸ so as to improve diagnosing; 2) the improvement of the main web server, in order to incorporate new functionalities such as external remote calls to public emergency services (112, 911, etc.), security and privacy control; and 3) the development of additional components to adapt the platform with other cloud platforms such as EC2 or Windows Azure will be designed and developed in the future.

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