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Bringing IoT and Cloud Computing towards Pervasive Healthcare

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***Abstract*—Pervasive healthcare applications utilizing body sensor networks generate a vast amount of data that need to be managed and stored for processing and future usage. Cloud computing among with the Internet of Things (IoT) concept is a new trend for efficient managing and processing of sensor data online. This paper presents a platform based on Cloud Computing for management of mobile and wearable healthcare sensors, demonstrating this way the IoT paradigm applied on pervasive healthcare.**

Keywords: Internet of Things (IoT), Cloud Computing, Patient Monitoring, Wearable Sensors

I. INTRODUCTION

The introduction of the pervasive healthcare paradigm has enabled the awareness towards the independent living of elderly people and the need for constant medical supervision of chronic patients or habitants at remote, isolated or underserved locations. In this context, advanced electronic healthcare services are required to be made available through a network anytime, anyplace and to anyone. A medical assistive environment on the other hand concerns the utilization of pervasive and ubiquitous technologies for delivering the above services. Wireless technologies enable the real time transmission of data about a patient's condition to caregivers. Numerous portable devices are available that can detect certain medical conditions—pulse rate, blood pressure, breath alcohol level, and so on—from a user's touch.

However this development and deployment of health information management through mobile devices introduces several challenges: data storage and management (e.g., physical storage issues, availability and maintenance), interoperability and availability of heterogeneous resources, security and privacy (e.g., permission control, data anonymity, etc.), unified and ubiquitous access are a few to mention One potential solution for addressing all aforementioned issues is the introduction of Cloud Computing concept in electronic healthcare systems. Cloud Computing provides the facility to access shared resources and common infrastructure in a ubiquitous and transparent way, offering services on-demand, over the network, and performing operations that meet changing needs. Figure 1 illustrates the Cloud Computing concept.

Figure 1. An illustration of the Cloud Computing concept. All kinds of computing and communication devices are able to interact with the Cloud and share the same data resources. Embedded - sensor devices and microcontrollers are such way a part of the Cloud.

In addition, the advance of machine-to-machine communication (M2M) enables the direct interaction of pervasive healthcare sensors with the Internet and by extension with Cloud Computing systems. This communication with the Internet has been recently introduced as the 'Internet of Things' (IoT). IoT utilizes specific protocols for inter-device and Internet communication, provides real time access to device information and allows the remote management of the devices. It also features web applications that are scalable, accessible globally and provide communication interfaces to external applications. In the case of healthcare monitoring the IoT has already been proposed as an infrastructure for medical sensor communication ([23] - [24]).

In this context we have developed a Cloud-based system that manages sensor data. Wearable – textile sensors collect biosignals from the user (like heart rate, ECG, oxygen saturation and temperature), motion data (through accelerometers) and contextual data (like location, ambient temperature, activity status, etc.). Depending on the wireless technology used, the data can be forwarded to a mobile phone or directly to the Cloud infrastructure utilizing established techniques for IoT communication. Appropriate

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interfaces enable the data dissemination to external applications (like medical record systems or emergency detection platforms) and a web-based application provides the essential data real-time monitoring and management.

In this work we present a prototype implementation, which has been evaluated using both wearable and mobile sensors that acquire patient data and forward them on the Cloud platform. Initial results are quite promising. The rest of the paper is structured as follows: Section 2 presents related work and Section 3 discusses the context of Cloud computing and healthcare. Section 4 describes the proposed architecture and Section 5 presents an initial evaluation of the system using mobile and wearable sensors. Finally, Section 6 concludes the paper.

II. Related Work and Background Information

There is a great number of research works on pervasive healthcare sensors. Most of them deal with data management on the devices (e.g., using storage means like SD cards) or utilize intermediate nodes (e.g., mobile phones) or store the data directly on computer nodes. Only few works exist however that address the issue of data storage and management directly on the Cloud. Authors in [3] present a sensor-oriented cloud infrastructure. The presented platform is proprietary and the initial evaluation results do not include actual devices, but they are based on simulated sensors. On the other hand a number of Cloud-based services dedicated for storing sensor-based data are nowadays available. Pachube [12], Nimbits [15], ThingSpeak [13] and iDigi [14] are a few that could be mentioned.

Pachube has been one of the first on-line database service providers that allow developers to connect sensor data to the Web. It is a real-time data Cloud-based infrastructure platform, which supports the Internet of Things (IoT) paradigm. More specifically it could be described as a scalable infrastructure that enables users to build IoT products and services, and store, share and discover real-time sensor, energy and environment data from objects, devices & buildings around the world. The main features of the platform are: managing real time sensor and environment data, graphing and monitoring and controlling remote environments. In addition there is a great number of interfaces available for building sensor or mobile-based applications for managing the data on the Cloud infrastructure. One of the important features of Pachube that have facilitated its penetration as a IoT cloud service is that the basic usage if free, it is based on an open and easy accessible API and has a very interactive web site for managing sensor data.

Nimbits is a data processing service for recording and sharing sensor data on the Cloud. It is a free, social and open source platform for the Internet of Things. Within Nimbits sensor data are stored as data points using textual, JSON or XML values. Data points can also be configured to perform calculations, generate alerts, relay data to social networks and can be connected to SVG process control diagrams, spreadsheets and web sites. Nimbits offers a data compression mechanism, an alert management mechanism, and data calculation on the received sensor data using simple mathematic formulas.

ThingSpeak is also an open source "Internet of Things" application that provides developers with APIs to store and retrieve data from sensors and devices using HTTP over the Internet. With ThingSpeak, users can create sensor-logging applications, location-tracking applications, and a social network of things with status updates. In addition to storing and retrieving numeric and alphanumeric data, the ThingSpeak API allows for numeric data processing such as time scaling, averaging, median, summing, and rounding. Each ThingSpeak Channel supports data entries of up to 8 data fields, latitude, longitude, elevation, and status. The channel feeds support JSON, XML, and CSV formats for integration into applications. The ThingSpeak application also features time zone management, read/write API key management and JavaScript-based charts.

The iDigi system is a machine-to-machine (M2M) platform-as-a-service. iDigi platform lowers the barriers to building secure, scalable, cost-effective solutions that seamlessly tie together enterprise applications and device assets. iDigi platform manages the communication between enterprise applications and remote device assets, regardless of location or network. It makes connecting remote assets easy, providing all of the tools to connect, manage, store and move information across the near and far reaches of the enterprise. The platform includes the device connector software (called iDigi Dia) that simplifies remote device connectivity and integration. It allows the management (configure, upgrade, monitor, alarm, analyze) of products including ZigBee nodes. The application messaging engine enables broadcast and receipt notification for application-to-device interaction and confirmation. There are also cache and permanent storage options available for generation-based storage and on-demand access to historical device samples.

These services however, focus mostly on the visualization of the data and usually lack of secure data access and provision of interfaces for linkage to mobile or external applications for further processing.

The majority of the aforementioned available systems is based on proprietary architectures and communication schemes, which requires the deployment of specific software components. Furthermore, these systems deal mostly with delivering data to healthcare applications and do not address issues of data management and interoperability issues introduced by the heterogeneous data resources found in modern electronic healthcare systems. The introduction of Cloud Computing infrastructure may provide data management and access functionality overcoming the aforementioned issues as discussed in previous lines.

Cloud Computing is a model for enabling convenient, on-demand network access to a shared group of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. Resources are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., smart phones). Examples of resources include storage, processing, memory, network bandwidth, and virtual machines. Given the characteristics of Cloud Computing and the flexibility of the services that can be developed, a major benefit is the agility that improves with users being able to rapidly and inexpensively re-provision technological infrastructure resources. Device and location independence enable users to access systems using a web browser, regardless of their location or what device they are using (e.g., mobile phones). Multi-tenancy enables sharing of resources and costs across a large pool of users, thus allowing for centralization of infrastructure in locations with lower costs. Reliability improves through the use of multiple redundant sites, which makes Cloud Computing suitable for business continuity and disaster recovery. Security typically can be improved, due to centralization of data and increased availability of security-focused resources. Sustainability comes about through improved resource utilization, resulting in more efficient systems. The concept of utilizing Cloud Computing in the context of pervasive healthcare information management is relatively new but is considered to have great potential [4], motivating us to deal with this important field.

A number of Cloud Computing platforms are already available for pervasive management of user data, either free (e.g., iCloud [6], ¬Okeanos [9], Pithos [10] and DropBox [8]) or commercial (e.g., GoGrid [5], Amazon AWS [7] and Rackspace [11]). Most of them, however, do not provide substantial developer support, to create custom applications and incorporate Cloud Computing functionality, apart from Amazon AWS. None of them is optimized for the provision of services to healthcare-based applications.

III. Materials and Methods

This section presents the proposed system architecture, the software and hardware modules needed to implement and deploy the pervasive monitoring infrastructure and also demonstrates the implementation of an initial prototype that proves the functionality of the system.

A. Proposed System Architecture

This section discusses the proposed IoT based architecture for acquiring and managing sensor data on the Cloud.

The main components of the proposed architecture are:

- The wearable and mobile sensors that acquire patient biosignals, motion and contextual information.
- The sensor gateway that collects all the signals from the sensors and forwards them to the Internet. It can be a mobile phone or a microcontroller platform capable of communicating with the Internet. It also forwards information about the status of the sensors (e.g., proper operation, power source levels, etc.).
- The communication APIs that are provided by the Cloud platform. The latter are lightweight interfaces (like REST Web Services) than can be used by the sensor gateways for sending sensor data and retrieving information. The API can also be utilized by external applications for data processing, alert management, billing, etc.
- The managing application consists of a web-based application that is updated real time and provides visualization of the sensor data (in graphs, etc.) and important information about the patient's context (like location, activity status, etc.).
- The Cloud infrastructure that hosts the interfaces and the managing application. It provides the essential resources (like CPU, storage and application servers) for deploying the web application and the interfaces that enable the communication with the sensors and the various external systems.

Figure 2. The proposed architecture: Appropriate APIs and web-based applications deployed on the Cloud provide the essential communication channels for sensors, caregivers and business stakeholders.

Every communication that takes place between the Cloud infrastructure and the rest of the components is secure by applying appropriate authentication and data encryption mechanisms. Sensors can be authenticated by unique id and data can be encrypted using symmetric encryption techniques ([19]). Users and external applications can be authenticated using more sophisticated mechanisms like PKI and digital signatures ([20]).

The major features of the proposed architecture are its scalability, interoperability and lightweight access. It is scalable due to the fact that it relies on a Cloud infrastructure that provides resources based on utilization and demand. More users, sensors and other data sources can be added without affecting the functionality of the system or without the need for further maintenance or expansion. The web-services based interfaces ensure the maximum interoperability with external applications. The Representational State Transfer (REST) API is very lightweight and can be easily accessed and implemented by wireless sensor and mobile platforms. REST has also been proposed as a communication mechanism for IoT applications ([25], [26]) and is the basic interfacing technology behind established IoT platforms like Pachube, Nimbits and ThingSpeak.

B. Case based implementation

In order to evaluate the proposed architecture we have implemented a part of it in the context of a simple real time telemonitoring system. The developed system consists mainly of two parts: the sensors that collect and transmit signals like temperature, motion and heartbeat data and the cloud infrastructure for storing and managing the data.

For the signal acquisition part we have developed two solutions; a wearable one and a mobile one. For the wearable solution we have used textile accelerometers, a temperature sensor and a heartbeat chest strap by Polar ([16]). The latter sensors are connected to a textile version of the Arduino open hardware microcontroller platform ([18]), called LilyPad ([17]). Arduino is an open-source single-board microcontroller. An Arduino board consists of an 8-bit Atmel AVR microcontroller with complementary components to facilitate programming and incorporation into other circuits. For the connection between the Polar monitor and the microcontroller, the Polar HeartRate Module has been utilized. Lilypad collects data through the appropriate embedded software and transmits them on an Android-based mobile phone through a Bluetooth interface. An appropriate application has developed for the Android that collects the data and forwards them to the Cloud. All textile sensors and the microcontroller have been sewed on a sock that can be worn easily by the user (see Figure 2).

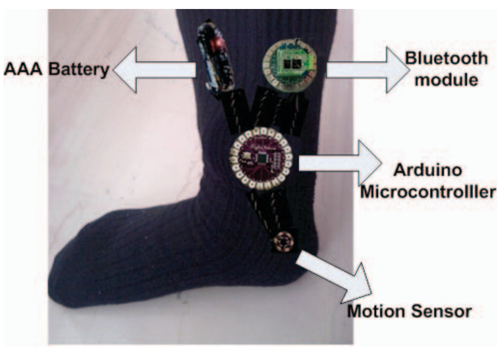

Figure 3. The CloudSensorSock and the main hardware modules as sewed on the final prototype.

The mobile solution (see Figure 3) consists of an Arduino sensor board equipped with accelerometers, tilt and air quality (CO2) sensors. It has also a WiFi communication module that allows it to connect directly to the Cloud infrastructure when there is a wireless network available. The communication module can also be replaced by a GPRS/3G module, extending its connection abilities. The two versions can be considered both complimentary (allowing users to add additional sensors that are not available for the wearable platform) and alternative, depending on the available wireless connectivity and on user convenience.

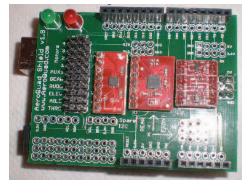

Figure 4. Arduino sensor board equipped with WiFi module, accelerometer, tilt and air quality sensors

The Cloud part consists of a Java EE application that provides both the management graphical interface and the interfaces for the communication with the sensors. As a Cloud infrastructure the Jelastic platform has been selected. The Jelastic [21] is a Platform as a Service (PaaS) Cloud provider that allows users to deploy Java-based applications providing all the essential components (application server instances, databases, load balancers, etc.) and all the appropriate scalability. Jelastic provides full access to the application server runtime environment, which enables the deployment of additional Java extensions like encryption and authentication libraries. For the specific application the Tomcat application server among with a MySQL database have been utilized. Data encryption has been achieved using the java cryptographic extension implementing a symmetric (AES) data encryption. AES has been also implemented on the Arduino so that sensor data are encrypted upon acquisition.

The following Section presents the initial evaluation of the proposed architecture.

IV. Initial Evaluation

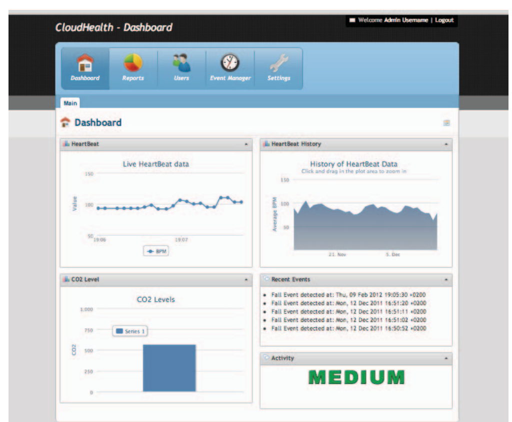

Figure 5. An instance of the Web application deployed on the Cloud that presents real time information about the acquired sensor data.

The web based front-end of the developed system is illustrated in Figure 4. The graphical interface utilizes HTML5 techniques for real-time sensor data visualization. More specifically, the average heartbeat rate, the CO2 levels and the user activity are illustrated. The user activity (e.g., medium, low, high) is calculated from the accelerometer sensors using classification of the latter sensor data by utilizing a platform similar to [22].

During the initial experimentation with the system, a drop packet rate of 20-30% has been detected. This fact is either due to the Arduino low resources for high rate sampling of sensors and transmitting the data at the same time, or due to network congestion because of the repetitive REST calls at such a high sampling rate (i.e. 10 acceleration samples per second). In order to address this issue, a memory buffer has been introduced on the Arduino side that collects motion data during a 10 second time frame and then transmits the latter to the Cloud. This way the drop rate has been minimized between 2-5%, which is quite acceptable for the application.

V. CONCLUSIONS

Pervasive healthcare applications generate a vast amount of sensor data that need to be managed properly for further analysis and processing. Cloud computing through its elasticity and facility to access shared resources and common infrastructure in a ubiquitous and pervasive manner is a promising solution for efficient management of pervasive healthcare data.

The presented system is unique as a dedicated solution for managing patient-related data on the cloud and that utilizes both open hardware and open software resources for developing the hardware and software parts of the platform. Based on IoT functional principles and design it allows direct communication of the sensor devices with the Cloud application, uses a lightweight REST-based API used and at the same time it is highly scalable in the context of data stored, users and sensors supported.

Open issues that need to be addressed are the security of privacy of data and the energy efficiency of the textile sensors and microcontroller platform, in order to extend the system autonomy. Future work will also include the investigation of integrating alternative wireless technologies like 6LoWPAN and DASH7 for assessing power consumption and communication improvement.

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