Distributed Management of Pervasive Healthcare Data through Cloud Computing

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Abstract. This paper presents a distributed platform based on Cloud Computing for management of pervasive healthcare data. Pervasive applications through continuous monitoring of patients and their context generate a vast amount of data that need to be managed and stored for processing and future usage. Cloud computing and service-oriented applications are the new trends for efficient managing and processing data online. The *Cumulocity* cloud platform utilized in this work is especially developed for the support of sensors and machine-to-machine (M2M) communication infrastructures. This paper presents an integrated system for managing sensor data related to the detection of disabled or elderly citizens falls. Wearable sensors collect the fall related data, which are then handled by the Cumulocity Cloud Platform.

Keywords: Cloud Computing, Wearable Sensors, Sensor data management, Fall Detection, Distributed programming, web services.

1 Introduction

The proper delivery of healthcare services among with patient monitoring are considered key issues for improving the quality of life and ensuring efficient health and social care. Mobile pervasive healthcare technologies can support a wide range of applications and services, including mobile telemedicine, patient monitoring, location-based medical services, emergency response and management, personalized monitoring and pervasive access to healthcare information, providing great benefits to both patients and medical personnel ([1], [2]). The realization, however, of health information management through mobile devices introduces several challenges, like 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. One potential solution for addressing all aforementioned issues is the introduction of Cloud Computing concept in electronic healthcare systems. Cloud

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Computing provides the facility to access shared resources and common infrastructure in a ubiquitous and pervasive manner, offering services on-demand, over the network, to perform operations that meet changing needs in electronic healthcare application.

In this context, a distributed platform based on Cloud Computing for management of pervasive healthcare data has been developed. The platform contains the appropriate mechanisms for collecting sensor data. It is based on *Cumulocity*, a horizontal Machine-to-Machine (M2M) Cloud Solution platform provided by Nokia Siemens Networks (NSN). It contains a comprehensive set of tools for managing meters and sensors, collecting and validating data and providing it to enterprises back-office applications. A use case regarding the collection and management of pervasive motion data for fall detection is demonstrated. The rest of the paper is organized as follows; Section 2 discusses related work in distributed pervasive healthcare data management. Section 3 introduces briefly the Cloud computing framework, while Section 4 presents the proposed architecture that utilizes the Cumulocity platform. Section 5 describes the developed use case and, finally, Section 6 concludes the paper.

2 Related Work

The application of mobile devices for pervasive healthcare information management has already been acknowledged and well established ([1], [8]). Authors in [3] present the benefits of using virtual health records for mobile care of elderly citizens. The main purpose of the work is to provide seamless and consistent communication flow between home health care and primary care providers using devices like PDAs and Tablet PCs. Smart cards and web interfaces have been used in [4] for storing patient records electronically. The MADIP system [5] is a distributed information platform allowing wide-area health information exchange based on mobile agents. In [2] authors present a mobile platform for exchanging medical images and patient records over wireless networks using advanced compression schemes.

The majority of the aforementioned works is based on proprietary architectures and communication schemes and requires the deployment of specific software components. Furthermore, these works focus mostly on 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 healthcare systems. The usage of Cloud Computing provides data management and access functionality overcoming the aforementioned issues as discussed in previous sections. The concept of utilizing Cloud Computing in the context of healthcare information management is relatively new but is considered to have great potential [9].

3 Cloud Computing Utilization

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.

A number of Cloud Computing platforms are already available for pervasive management of user data, either free (e.g., iCloud [28], ¬Okeanos [31], Pithos [32] and DropBox [30]) or commercial (e.g., GoGrid [27], Amazon AWS [29] and Rackspace [33]). 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 sensor-based applications.

3.1 The Cumulocity Cloud Computing Platform

Cumulocity is a horizontal Machine-to-Machine (M2M) Cloud Solution platform provided by Nokia Siemens Networks (NSN). It contains a comprehensive set of tools for managing meters and sensors, collecting and validating data and providing it to enterprise back-office applications. In addition to this, Cumulocity contains a set of tools for building sensor-based and M2M applications. The platform is used both for integrating sensors and meters into enterprises back-office applications and processes, as well as a stand-alone environment for deploying and running a number of innovative M2M applications. The primary benefit of this integration is increased visibility into the real assets of enterprises and thus improved performance of business processes as well cost reduction.

The Cumulocity based solution consists of three layers: (1) Connected meters and sensors, (2) the management platform, and (3) the integrated vertical applications and enterprise processes. Any meter or sensor can be integrated to the platform through its open smart device integration API. The platform itself consists of device and sensor management functionalities like data collection and validation, fulfillment, monitoring, performance management, configuration management, inventory, identity service, tenant management and open northbound interfaces for application integration. Users can manage and monitor all of these components and features through the embedded management dashboard.

Cumulocity has mainly three different exposure Application Programming Interfaces (APIs): Functional REST, batch data and near-real time publish/subscribe. The first one is RESTful exposure API for northbound applications to use its functionalities. The batch interface is used for exporting large datasets. It is used for example in billing integration, where meter readings are transferred to a billing system. The Event API is a Publish/Subscribe interface that allows for receiving event information from a device or set of devices in near real time. This allows for the creation of independent event driven applications. Through the latter APIs, the interconnection and interoperability with pervasive healthcare applications is direct and straightforward. The sensors can be connected directly through their wireless interfaces to the platform and use simple REST calls for sending and retrieving data. Alternatively, appropriate s/w gateways with similar functionalities can be developed for the sensors that cannot connect directly to this platform. Regarding the caregivers, treatment experts and monitoring personnel, appropriate web applications will be developed giving them access to collected data and events.

The following section presents the proposed architecture for utilizing the M2M platform as a means for distributed management of pervasive healthcare data.

4 The Proposed Architecture Utilizing the Cumulocity Cloud Computing Platform

Fig. 1 presents an illustration of the proposed architecture for managing pervasive healthcare data over the Cumulocity Cloud platform. A variety of pervasive sensors can be utilized for monitoring the patient status and context. The latter can be wearable and textile sensors that monitor vital biosignals and patient motion and generate alerts in cases of stroke or fall detection. Contextual sensors like overhead cameras and microphone arrays can provide more information about the patient condition, context and location and assist with the better assessment of an emergency situation. All sensors are equipped with appropriate networking interfaces (e.g., WiFi, Bluetooth or ZigBee) for communicating directly with the Cloud platform or through intermediate nodes, e.g., like a smartphone. Software interfaces are developed that can act as the intermediate nodes for forwarding the data to the Cloud using REST web service calls. Web applications have been developed that are also hosted by Cumulocity and visualize the data to the caregivers providing them the ability to retrieve information anywhere and anytime. Mobile applications can also be developed especially for alert management, in cases of fall event detections (utilizing the Event API).

An example of a REST web service call for storing a sensor value to the Cloud is the of the following form: *https://<tenantname>.cumulocity.com: port/ webapplication/storevalue?=sensorvalue&key=xxx*

'Sensorvalue' represents the reading from the sensor and 'key' is a secret key for authenticating the sensor to the system. Sensors that communicate directly with the platform can make the REST call which can also very easily be embedded to the intermediate nodes and/or mobile applications.

The communication between the sensors or the intermediate nodes and the Cloud is performed over the SSL protocol providing the essential encryption of the data over transmission. The Cumulocity platform, is deployed on top of the Amazon AWS infrastructure, and is HIPAA compliant. The latter means that all appropriate security techniques and technologies have been adopted in order to store data safely and at the same time maintain the appropriate data anonymity.

Fig. 1. The proposed architecture for managing pervasive healthcare data in the Cloud

5 Managing Fall Detection Data through Cumulocity Cloud Platform

A use case of pervasive healthcare data management through the Cumulocity platform is presented in this Section. Fall-related injuries are among the most common, morbid, and expensive health conditions involving older adults ([1] – [13]). Falls account for 10% of emergency department visits and 6% of hospitalizations among persons over the age of 65 years and are major determinants of functional decline, nursing-home placement, and restricted activity (14 - 17). The most common and way to monitor patients for fall detection and emergency management is through wearable motion sensors – accelerometers.

In previous works ([21] – [25]) several sensors have been used for collecting motion data. The Arduino microcontroller ([18]) equipped with 3-axis accelerometer and tilt sensor has also been widely utilized. Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It supports a variety of extensions (shields) that provide additional functionality (e.g., collecting motion data) and networking capabilities (ZigBee, Bluetooth, WiFi, 3G/UMTS, etc.). It exists in various forms with different sizes. It also exists as wearable solution (LilyPad Arduino [19]) that can be sewn to fabric and similarly mounted power supplies, sensors and actuators with conductive thread.

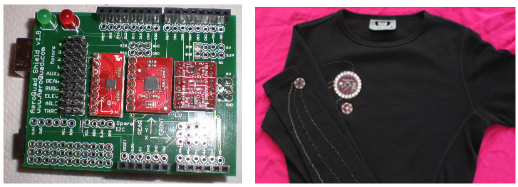

Fig. 2. Arduino sensor board equipped with WiFi module, accelerometer and tilt sensor the LilyPad Arduino sewed on cloth along with accelerometer textile sensors

Fig. 3. Screenshot of the web-based application hosted on Cumulocity for monitoring the output of sensors

By using the appropriate network interface (e.g., WiFi and/or 3G/UMTS), Arduino can collect and transmit motion data, wirelessly in both indoor and outdoor environments maximizing this way the availability of the platform. Additionally, the recently introduced Google's Android Open Accessory Development Kit (ADK) [20] provides an implementation of Android USB accessories that are based on the Arduino open source electronics prototyping platform. This allows Arduino to easily interface with android-enabled mobile phones, providing better means of data communication between the sensors and the cloud platform especially in cases where user is located outdoors.

Arduino with the appropriate libraries can make directly calls to the REST API of Cumulocity. An appropriate web-based application has been developed on the platform (see Fig. 3) that receives and displays the sensor data. Through the same

REST API, external applications like in [22] can retrieve data for further analysis and fall detection.

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.

6 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. In this paper we have presented a system for managing fall detection data from wearable sensors using the Cumulocity M2M Cloud Platform. Future work includes the deployment of the service in a wide range of sensors and the further evaluation of the system in terms of sustainability, availability and energy efficiency.

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