Cloud-IO: Cloud Computing Platform for the Fast Deployment of Services over Wireless Sensor Networks

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Abstract. In the recent years, a new computing model, known as Cloud Computing, has emerged to react to the explosive growth of the number of devices connected to Internet. Cloud Computing is centered on the user and offers an efficient, secure and elastically scalable way of providing and acquiring services. Likewise, Ambient Intelligence (AmI) is also an emerging paradigm based on ubiquitous computing that proposes new ways of interaction between humans and machines, making technology adapt to the users' necessities. One of the most important aspects in AmI is the use of context-aware technologies such as Wireless Sensor Networks (WSN) to perceive stimuli from both the users and the environment. In this regard, this paper presents Cloud-IO, a Cloud Computing platform for the fast integration and deployment of services over WSNs.

Keywords: Cloud Computing, Ambient Intelligence, Wireless Sensor Networks, Multi-Agent Systems, Real-Time Locating Systems.

1 Introduction

Nowadays the society is currently immersed in an innovator dynamics that has encouraged the development of intuitive interfaces and systems with a certain intelligence level that are capable of recognizing the users' necessities and responding to them in a discreet way, often even imperceptible [1]. Thus, is necessary to consider people as the center of the developments in order to build intelligent and technologically complex scenarios in a wide range of different areas such as medicine, domestic, academic or public administration, where technology adapts to people's necessities and their environment, and not on the contrary. Here is where concepts such as Ambient Intelligence (AmI) [2], Cloud Computing [3], agent technology [3] [4] and innovative visualization interfaces

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and techniques [5] come into play in order to achieve an improved human-machine interaction.

Systems based on Ambient Intelligence encourage technology to adapt to people, detecting their necessities and preferences and allowing them to enjoying services without need of being conscious or learning complicated operations. In this sense, agent and multi-agent systems provide these AmI-based systems with the necessary intelligence for responding to the users' preferences and needs [6]. The Cloud Computing model is centered on the user and offers a highly effective way of acquiring and supplying services. Cloud Computing defines a new economic model based on a new way of consuming services. Furthermore, all these features are performed in a reliable and secure way, with an elastic scalability which is capable of attending to sharp and a priori unpredictable changes on the demand, and at the expense of a very low increase in the management costs [7]. Likewise, Wireless Sensor Networks (WSNs) provide an infrastructure capable of supporting distributed communication needs and increase the mobility, the flexibility and the efficiency of users [8]. Specifically, Wireless Sensor Networks allow gathering information about the environment and reacting physically to it, thus expanding users' capacities and automating daily tasks [9].

There are three key functionalities that would make an AmI-based platform be a powerful tool for supporting a wide variety of situations: locating, telemonitoring and personal communication. Locating systems allow knowing the exact position of users and objects of interest [10]. This way, the platform could identify each user, know where he is, as well as provide him with services in an automatic and intelligent way, without need of him to start the interaction. Telemonitoring (or sensing) allows obtaining information about users and their environment (e.g., temperature, humidity, etc.), taking it into account when offering them customized services in keeping with the environment status [11]. Finally, personal communication, by means of voice or data, allows users to communicate among them through the platform, no matter their location or the communication media they choose. In order to an AmI-based platform can be successful regarding versatility, it should be capable of integrating these three services.

In this regard, the Cloud-IO platform is designed to provide solutions for the mentioned necessities in different environments. Thus, Cloud-IO is intended not only for covering the essential needs of society, but also for supporting the development of innovative and very specific technological solutions.

The rest of this paper is organized as follows. The next section depicts the main objectives that the development of the Cloud-IO platform intends to address. Then, the main components and services that will be integrated into the Cloud-IO platform are described. Finally, the conclusions and future lines of work are depicted.

2 Background and Problem Description

Currently, there are two main computing models that still dominate information technologies. On the one hand, the centralized computing model, which is typical in super-powerful mainframe systems with multiple terminals connected to them. On the other hand, the distributed computing model, whose the most widespread example is the client-server model, with largely demonstrated efficiency [12]. During the last years, a new model, known as Cloud Computing, has emerged with the aim of giving support to the explosive growth of the number of devices connected to Internet and complementing the increasing presence of technology in people's daily lives and, more specifically, in business environments [3] [7] [12].

The Cloud-IO platform is aimed to offer locating, telemonitoring (sensing) and voice/data transmission (personal communication) services using a unique wireless infrastructure and supported by a Cloud Computing model. Furthermore, the platform is focused on supporting applications based on Ambient Intelligence paradigm and that are conscious of the location of the users and the environment state, as well as allowing them to keep intercommunicated through the platform.

Wireless Sensor Networks are identified as one of the most promising technologies by different technological analysts and specialized journals [8] [9] [11], because of they give support to the current requirements related to the deployment of networks that cover the communication needs flexibly in time, space and autonomy, without need of a fixed structure. The user identification is a key aspect for an adequate services customization and environment interaction [13]. In this sense, knowing the exact geographic location of people and objects can be very useful in a wide range of application areas, such as industry or services [10]. The advantage of knowing and visualize the location of all the resources in a company and how these interact and collaborate in the different productive processes is a clear example of the demand for a platform as Cloud-IO. Other good example of this demand are all those emergence situations where is required to locate people, such as forest fires or nuclear disasters. Whether in home automation, healthcare telemonitoring systems or hospitals, WSNs are used for collecting information from the users and their environment [9]. Nonetheless, the development of software for remote telemonitoring that integrates different subsystems demands the creation of complex and flexible applications. As the complexity of an application increases, it needs to be divided into modules with different functionalities. There are several telemonitoring developments based on WSNs [14]. However, they do not take into account their integration with other architectures and are difficult to adapt to new scenarios [15]. Furthermore, even though there are some existing approaches that integrates personal communications, such as voice, over WSNs [16], current wireless sensor technologies have inter-operability, manageability and mobility deficiencies [17]. In this regard, all these issues can be addressed developing a new platform that integrates locating, telemonitoring and personal communication services in a unique wireless sensor infrastructure.

In the last years, several approaches aimed at merging WSNs and the Cloud model have been proposed [18] [19] [20]. Nevertheless, many of these proposals are not realistic or scalable enough, which results in not much practical approaches. Moreover, many of the research done until the date do not consider desirable features such as fault-tolerance, security and the reduction of the communication response times, and, when they are considered, they are usually achieved at the expense of energy efficiency. Furthermore, these approaches do not consider the integration of locating, telemonitoring and personal communication in the same infrastructure.

3 The Cloud-IO Platform

This section describes the main components of the Cloud-IO platform. First, the basic functioning of the platform is depicted. After that, the different modules that make up the platform are described. As this is a research work that will be finished in Q4 2013, this paper presents a preliminary description that will be extended and published further on.

The main objective of this work is to revolutionize the interoperability, accessibility and usability of systems based on WSNs through a new platform based on Cloud Computing services. Therefore, the Cloud-IO project consists of the development of a modular, flexible and scalable platform that integrates, on the one hand, identification/locating, telemonitoring and personal communication services in a unique network infrastructure, and, on the other hand, the creation of interactive and customized services managed from a Cloud infrastructure. In addition, most of its multiple functionalities must be accessible through 3D virtual scenarios generated automatically by a new graphical environment integrated in the own platform.

It is worth mentioning that this project is not only aimed at integrating pre-existing technology, but also designing and developing innovative hardware and software in order to build a unique platform. Therefore, it will be developed a new specific hardware, both for the network infrastructure and the services implemented over it. Moreover, it will be developed a new middleware that manages all functionalities of the platform, making use of techniques and algorithms based on Artificial Intelligence [21] [22] on practically each of these functionalities: dynamic routing, real-time locating [10], 3D virtual model automatic generation, as well as self-configuring and error-recovery, among many others. This way, it will be achieved a platform that will not only make use of existing technology, but also perform important and relevant improvements on the current state of the art of different technological areas. The basic architecture of the Cloud-IO platform, shown in Figure 1, is formed by the next main components:

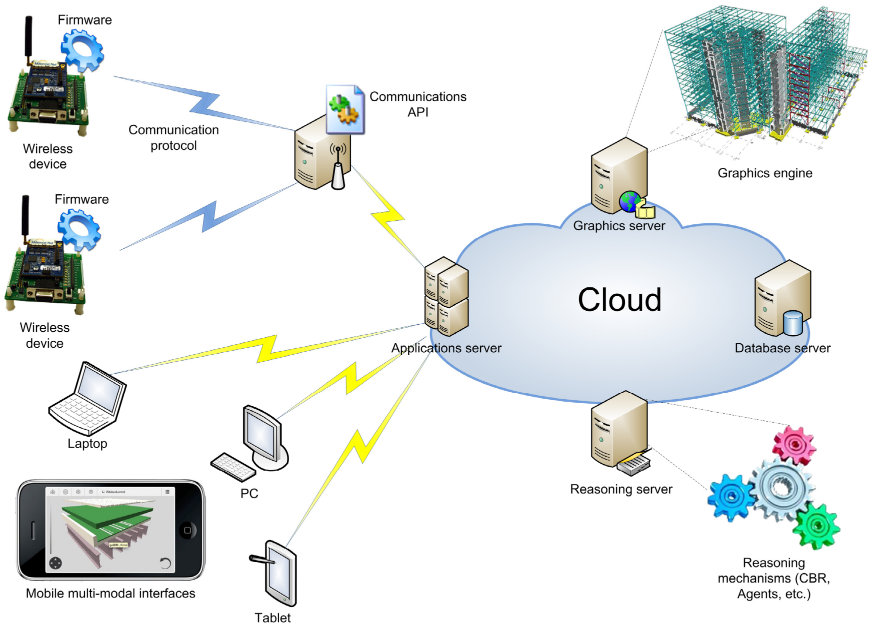

Fig. 1 Basic architecture of the Cloud-IO platform

- **Wireless sensor infrastructure.** The main components and services of the Cloud-IO platform are based on this infrastructure. This infrastructure consists of a set of wireless physical devices over which part of the low-level middleware, described below, will run. This low-level middleware allows the rest of the platform to access to their functionalities.
  - **Wireless devices.** They form the hardware layer of the wireless sensor infrastructure. In this sense, a set of wireless devices with reduced energy consumption and physical size must be developed. Each of them should share a common architecture made up of a microcontroller, a radio transceiver and a set of physical interfaces for the data exchange between the device itself and the sensors and actuators connected to those interfaces [15]. According to the application, these devices must be able to be supplied by batteries or an extern source. Moreover, and also according to each application or system to which they can belong, these devices should include Digital Signal Processors (DSP) [23], for the personal communication service, or physical interfaces intended for the intercommunication with sensors and actuators, for the telemonitoring service [15].
  - **Low-level middleware.** Over the wireless sensor infrastructure it must be developed a low-level middleware formed by different layers aimed at allowing the data exchange among the wireless devices and the rest of the components of the Cloud-IO platform. This low-level middleware is

formed by the firmware embedded in the wireless devices, a communications API (Application Programming Interface) for accessing the features of the devices from any extern machine (e.g., a PC), as well as a communications protocol for the data exchange between the firmware and the communications API.

- **Firmware.** It consists of code that can run on each of the wireless devices. By means of this firmware the devices can connect automatically among them, thus building a network topology for the data exchange among devices. Likewise, the firmware must implement the required functionalities for each of the three main services of the platform (i.e., telemonitoring, identification and locating, personal communication) and respond to the received commands remotely from the communications API by means of the communications protocol. Regarding the devices intended for the personal communication service, it must be also developed the firmware specific to be run over the Digital Signal Processors [23] in order to implement the voice codecs required for that service [16].
- **Communications protocol.** It must be developed a communications specific protocol that allows transporting the required data among the devices, as well as between the devices and the communications API. This protocol must allow transporting data with different quality-of-service, network latency and data throughput rate. This way, the different necessities of the main three services (i.e., telemonitoring, locating and personal communication) must be covered in an optimal way.
- **Communications API.** The communications API allows the rest of the components of the Cloud-IO platform to interact with the wireless devices in order to collect information from the sensors connected to them, as well as send and receive voice/data streams. In addition, this API must incorporate a set of innovative locating algorithms [10] in order to provide the rest of the components of the platform with accurate and real-time position of people and objects that carry the wireless devices focused on being used by the identification and locating service. The communications API should run over a server in the entity that acts as consumer of the Cloud-IO services.

• **Cloud Computing infrastructure.** This infrastructure is, along with the wireless sensor infrastructure, the other main pillar of the Cloud-IO platform. Thanks to this, the tasks requiring an elevated computational cost can be moved to remote powerful machines, as these tasks are very difficult to be implemented in the machines and devices, often mobile, used by the client users of the platform. This infrastructure should be basically formed by a set of high-performance hardware machines, as well as a data communications network infrastructure for the interconnection between the client machines and the remote high-performance machines.

- **Hardware.** The hardware infrastructure that must support the Cloud Computing components should be formed by a set of high-performance machines that will be sited, generally, remotely with regard to the client machines infrastructure (i.e., the wireless infrastructure connected to the client machine, as well as the set of multimodal interfaces [1]). This set of high-performance machines are responsible for executing the tasks with elevated computational cost that, otherwise, could not be feasible to be done in the client machines, which usually have a low or moderate performance.
- **Data communication networks.** Consist of a set of data communication networks, either public, private or public-private partnered, aimed at the data transmission between client machines and the remote high-performance machines where the software of the Cloud Computing infrastructure will run. These networks could be from a public network based on cable, ADSL or 3G, until a local intranet based on Ethernet or Wi-Fi, or even a mixed solution (e.g., a Virtual Public Network or VPN). On the one hand, the information gathered by the wireless sensor infrastructure are transmitted from the client machines to the remote high-performance machines. On the other hand, all the information processed by the reasoning mechanisms, as well as the rendered tridimensional images, are transmitted from the remote high-performance machines to the client machines, including the multimodal interfaces. This way, client machines are freed from a great part of the computational load.
- **Software components of the Cloud Computing infrastructure.** These components make up the software layer that run over the Cloud Computing hardware infrastructure and are responsible for performing remotely a great part of the high-cost computational load, which, otherwise, would be difficult to be done by the client machines, especially mobile multimodal interfaces.
  - **High-level middleware.** This middleware layer must make possible the data exchange among the different Cloud software components, as well as the interaction among those components and the client machines, such as the mobile multimodal interfaces [1]. This middleware should offer its functionalities through protocols similar to Web Services [24]. This will allow the remote access to them from practically any kind of device which includes an adequate web browser.
  - **Graphics engine.** The graphics engine is an essential part of the Cloud-IO platform. It should be based on a set of certain APIs and a well-defined list of functionalities. It must run over the hardware infrastructure mentioned before and allow, remotely, performing the tridimensional objects modeling, the layout and animation of them, and, lastly, the rendering of the scenarios and the objects. This graphics engine is a high-complexity component that should

contemplate multiple and different technologies, such as techniques for lighting, shadowing, culling (i.e., saving time when rendering objects hidden by the presence of other objects in the scenarios, as, for example, the use of Binary Space Partitioning or BSP [25]), etc.

- **Reasoning mechanisms.** Integrated with the Cloud Computing infrastructure itself, it will be implemented a set of complex and innovative reasoning mechanisms based on agent technology [4]. This way, all the tasks related to alerts management, tracking and patter recognition can run on the Cloud itself, thus freeing the client machines, and especially the generally light multimodal interfaces, from performing these tasks. These reasoning mechanisms include the algorithms intended for managing the call routing and queuing required by the personal communication service.
- **Databases.** Optionally, these databases could be remotely stored, so that all the information and the important data required for the different services (i.e., telemonitoring, locating and personal communication) in the Cloud-IO platform could be provided by machines more secure and powerful than those that could have the clients of the platform.

• **Multimodal interfaces.** Last but not least, the platform will include a set of innovative multimodal interfaces [2] that should allow showing in an enhanced way all the information provided by the platform from the data received from the Cloud Computing services. This way, all the information and services of the platform will be able to be accessed by almost any device that can execute a web browser. Specifically, the design and development are focused on those mobile multimodal interfaces that can be implemented in devices so light as a mobile phone or a tablet PC.

3.1 Telemonitoring, Locating and Communication Services

Therefore, three main differentiated services must be developed over the Cloud-IO platform. These services must be fully integrated among them and work simultaneously over the platform. These services (telemonitoring, locating and personal communication) are shown in Figures 2, 3 and 4, respectively:

1. **Telemonitoring service.** This service allows gathering information about the context and the users in the defined application scenarios, as well as acting consequently managing alerts and other relevant situations. In order to do this, the design and development of this service should make use of specific functionalities of the wireless devices, which, through different physical interfaces (hardware) could be connected to different home automation sensors (e.g., temperature, humidity, gases, smokes, etc.) [15], biomedical sensors (e.g., breath rhythm, body temperature, fall detection, etc.) [14], biometric sensors (e.g., recognition of faces, eyes or fingerprints) and actuators (e.g., light alarms, sound alarms, data delivery through the platform, etc.).

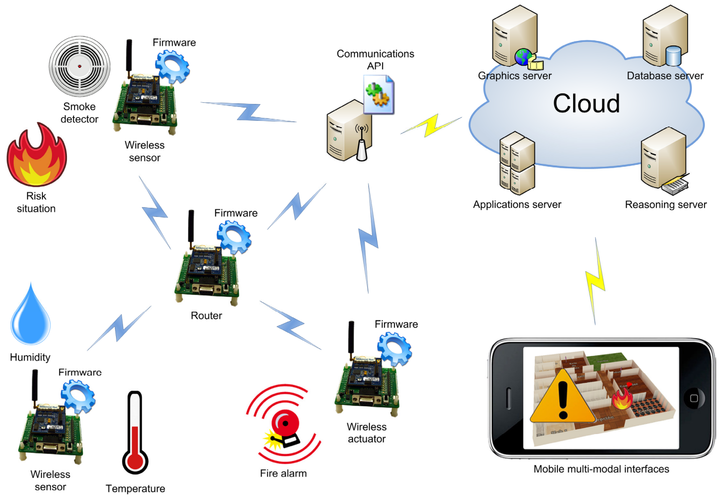

Fig. 2 Telemonitoring service in the Cloud-IO platform

2. **Real-time identification and locating service.** This service allows identifying and estimating the position of users and objects in every moment. As the other services, this service must also allow utilizing algorithms for managing alerts derived from the position of the users and objects according to the area where they are, they permissions, etc. In this sense, the service must make use of an innovative set of locating algorithms [10] that will be developed. The main objective of the development of these algorithms is to achieve a much better accuracy than with existing locating systems when locating people and objects, as well as allow its adequate operation both outdoors and indoors.
3. **Personal communication service.** This service allows the transmission of voice and instant messaging through the wireless devices in the platform. To do that, it must be used an innovative architecture of wireless devices that puts together microcontrollers, transceivers and Digital Signal Processors [23], along with the implementation in the devices and the platform of voice codecs [16] and reasoning mechanisms based on agent technology [4] and focused on the personal communications routing, as well as the implementation of optimized queuing algorithms.

This way, thanks to the integration of these three services in a unique wireless infrastructure of fast deployment, the Cloud-IO platform will be able to deploy applications as the next example. Let's imagine a scenario when a natural disaster has happened, such as a possible leak in a nuclear power station. The Cloud-IO platform will allow facing this situation in the next way. As a previous stage, operators will place a set of wireless devices along the perimeter of the zone. These devices will act as basic communications infrastructure and as beacons when locating the operators themselves throughout the environment. This infrastructure will not require previous calibrating and will be deployed in a few minutes. Simultaneously, these beacons will incorporate different environmental

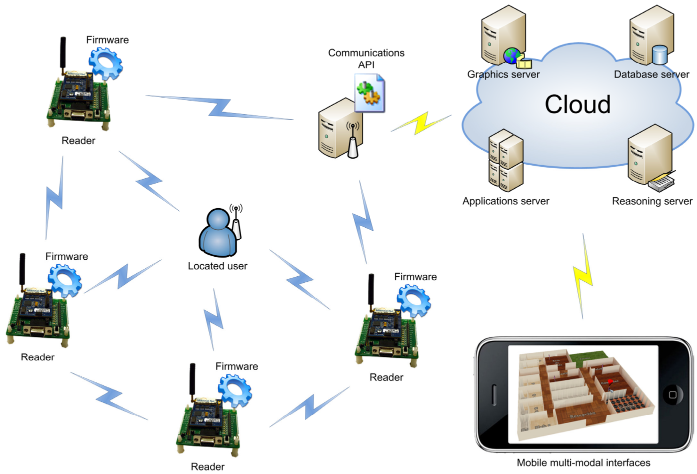

Fig. 3 Real-time identification and locating service in the Cloud-IO platform

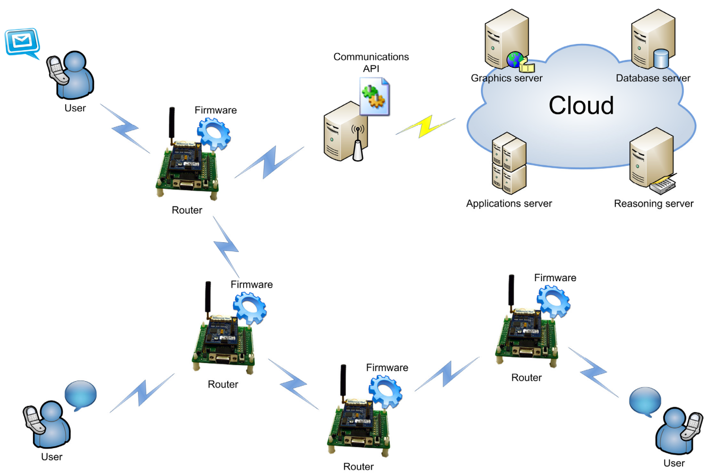

Fig. 4 Personal communication service in the Cloud-IO platform

sensors for measuring humidity, temperature, radiation, wind direction, and will be connected to a GPS receiver in order to have a global reference. Operators will carry small wireless devices (i.e., tags) to be identified and located throughout the environment by the beacon devices, as well as communicate among them via voice.

This way, deploying a unique infrastructure in a few minutes, the services in the platform will provide a complete information about the emergence situation: real-time location of operators, environmental and radiation measurements, as well as the information that operators will transmit among them via voice in real-time. All the information will be collected by the platform, which, thanks to different techniques of object modeling and tridimensional representation [25], will show it to those authorized users that want to watch this information in a mobile device, a PC or a remote control center, all of this through Internet.

4 Conclusions and Future Work

This work presents Cloud-IO, a Cloud Computing platform for the fast integration and deployment of services over Wireless Sensor Networks. The Cloud-IO platform integrates in a unique wireless infrastructure three main services that are key for the implementation of AmI-based applications: telemonitoring (sensing), locating and personal communication (voice and data transmission among users). Furthermore, the platform makes use of agent technology for implementing reasoning mechanisms aimed at routing and queuing data and voice transmissions, as well as a new graphics engine and multimodal interfaces in order to enhance the interaction between users and the applications deployed using this platform.

Future work includes the full development of all the projected functionalities. This includes the production of the first hardware prototypes for the wireless devices. At the software level, the firmware embedded in the devices, the communications API and the high-level middleware in the Cloud infrastructure will be developed. Then, the graphics engine and the agent-based reasoning mechanisms will be designed and developed. At a further stage, the three main services (telemonitoring, locating and personal communication) will be implemented over the platform. Finally, the system will be implemented in two real scenarios related to elderly care and a fire department in order to test its actual performance.

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