

Wireless Sensor Networks, Real-Time Locating Systems and Multi-Agent Systems: The Perfect Team

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Abstract—This paper presents a project aimed at combining wireless sensor networks and real-time locating systems by means of a multi-agent platform based on virtual organizations. This approach makes use of the n-Core platform to provide the basic sensing and locating infrastructure. Several case studies are presented in order to facilitate the comprehension of the goals of this project.

Keywords—Wireless Sensor Networks, Real-Time Locating Systems, Multi-Agent Systems, Virtual Organizations.

I. INTRODUCTION

Wireless Sensor Networks (WSN) are used for gathering the information needed by intelligent environments, whether in urban construction and Smart Cities, home and building automation, industrial applications or smart hospitals [1, 2]. Wireless Sensor Networks support current requirements related to the deployment of networks that cover communication needs, and flexibly in time, space and autonomy, without requiring a fixed structure [3, 4].

One of the most interesting applications for Wireless Sensor Networks is Real-Time Locating Systems (RTLS) [5]. Although outdoor locating is well covered by systems such as the current GPS or the future Galileo, indoor locating needs still further development, especially with respect to accuracy and the use of low-cost and efficient infrastructures.

However, although significant progress has been made, at present there are few platforms that efficiently integrates both automation and indoor locating capabilities in the same infrastructure. Therefore, most deployments are limited by the pre-installation of infrastructure, and integrators have to face the decision of choosing between other technologies or adapting their existing systems and infrastructure.

The approach presented in this paper combines WSN and RTLS in a single infrastructure. The infrastructure is managed by a Virtual Organization of agents which provide all the functionalities of such infrastructure.

The rest of the paper is structured as follows. Section II presents the background and problem description related to this project. Section III describes the proposed approach. Section IV introduces several case studies where the project

can be applied. An finally, Section V presents the conclusions and future work.

II. BACKGROUND AND PROBLEM DESCRIPTION

There are several wireless technologies such as ZigBee, Wi-Fi or Bluetooth that enable easier deployments than wired ones, avoiding the need to wire buildings and decreasing the costs and drawbacks of the setup phase. WSNs make it possible to build a wide range of applications, such as control of energy costs, monitoring of environmental data, security and access control in buildings, as well as industrial and home automation, among many others. In this regard, telemonitoring (or sensing) allows to obtain information about users and their environment, which is taken into account when offering them customized services in line with their environment status. The building automation and control systems market has reached in the world of standards, protocols and data distribution systems, which allows building automation systems, such as security systems, lighting systems and others, to interact and integrate with each other [6]. The building automation and control systems which started with wired technology have now entered the era of wireless technology with the advent of technologies such as ZigBee, Z-Wave, EnOcean, and others. Not only building automation and control products have increased living standards and allowed for more convenient lifestyles, they have also saved power through devices such as dimming systems and sensors. Among all the available products, security control has dominated the building automation and control market as a result of increasing concerns to enhance security. Furthermore, building automation & control systems can save up to 80% of power.

Furthermore, for the first time in human history, more people now live in cities than in rural areas, and in the next 20 years the urban population is expected to grow from 3.5 billion to 5.0 billion people [7]. The social, economic, environmental, and engineering challenges of this transformation will shape the 21st century. The lives of the people living in those cities can be improved – and the impact of this growth on the environment reduced – by the use of “smart” technologies that can improve the efficiency and effectiveness of urban systems. The smart city can be defined as the integration of technology into a strategic approach to sustainability, citizen well-being, and economic development.

While there are many innovative pilot projects and small-scale developments that are looking at the smart city from a holistic perspective, there are no examples yet of a smart city that supports hundreds of thousands, never mind millions, of people. The smart city offers a coherent vision for bringing together innovative solutions that address the issues facing the modern city, but there are many challenges still to be faced. If the smart city is to truly become a blueprint for urban development, then a number of technical, financial, and political hurdles will need to be overcome.

Some of the applications of Real-Time Locating Systems include tracking people, assets and animals, access control, wander prevention, warning and alert systems, controlling security perimeters, or resources optimization. Companies need to use some sort of monitoring system to track their human and technical resources, and especially, to improve their security, efficiency and safety, and reduce occupational hazards. User identification is a key aspect for adequate services customization and environment interaction. This way, the system can identify each user, know where they are, and automatically provide them with services, without actually requiring the user to initiate the interaction. 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. The advantage of knowing and visualizing the location of all the resources in a company and how they interact and collaborate in the different productive processes is a clear example of the demand for a platform that integrates location and automation features in a unique infrastructure. Another good example of this demand includes emergency situations where it is necessary to locate people, such as the case of forest fires or nuclear disasters. The development of a platform for remote location and automation that integrates different subsystems demands the creation of complex and flexible applications [8].

However, although significant progress has been made, at present there is not a single platform that efficiently integrates both automation and indoor locating capabilities in the same infrastructure. Therefore, current systems are limited by the pre-installation of infrastructure, and integrators have to face the decision of choosing between other technologies or adapting their existing systems and infrastructure. There is no platform in the market that facilitates the communication and integration of the wide variety of existing sensors. The goal of this project, therefore, is to design and develop such a platform using an efficient multi-agent based architecture running on a cloud system. The proposed multiagent architecture based on organization will provide intelligence to the platform, real time response and adaptation to the needs of the application problem; and the cloud will ensure that the platform uses the required resources at all times.

There are several technologies and areas that can assist in the creation of such a platform. Such technologies are continuously evolving and it is predicted that they will have a big impact in upcoming years. For example, Cloud Computing [9], Agents Technology [10], Wireless Sensor Networks [3], Real-Time Locating Systems [5], Telecommunications, MEMS, large-scale distributed systems, workflow optimization, Decision Support Systems [11], multimodal

interfaces [12], etc. In a complex environment, such as the one proposed in this project, it is difficult to determine when and how to carry out actions that imply changes in the operation or even the structure of the network. In the area of distributed Artificial Intelligence, specifically in agent and multi-agent systems fields, one of the goals is to create systems able to make decisions in an autonomous and flexible way, and to cooperate with other systems inside an organization. Agent based technology is regarded as a potential technology to cope with the anticipated challenges of hybrid network operations. An analysis of the possibilities and benefits of implementing agents shows that it is a suitable technology for the complex and highly dynamic operation of the smart grid infrastructures, power systems or hybrid networks, among others [13].

Hybrid networks require innovative architectures with advanced functionalities. To reach this objective, it is necessary to develop new functional architectures capable of providing adaptable and compatible frameworks, allowing access to services and applications regardless of location restrictions. A functional architecture defines the physical and logical structure of the components that make up a system, as well as the interactions between those components [14]. There are SOA (Service Oriented Architectures) [15], agents' frameworks and platforms which provide tools for developing distributed systems and multi-agent systems [16]. However, these tools do not solve by themselves the highly dynamic operation of the smart grid infrastructures, power systems or the hybrid network based system's needs. For this reason, it is necessary to develop innovative solutions that integrate different approaches in order to create flexible and adaptable systems, especially for achieving higher levels of interaction with people in a ubiquitous and intelligent way.

Open multi-agent systems [17] are relatively new but tested and efficient solutions. According to this new paradigm, computation is something that occurs by means of and through communication among computational entities. In this approximation, large systems can quite naturally be seen in terms of the services offered or demanded, and consequently, in terms of the entities (agents) providing or consuming services. It should be noted that these entities may not have been designed in a joint way or even by the same development team. Entities may enter or leave different organizations in different moments and due to different reasons. Moreover, they may form coalitions or organizations among themselves to attain their current goals [18]. Obviously, the development of these types of systems is complex; therefore, it is necessary to analyze the intrinsic characteristics of these typical application environments in greater detail.

Recent tendencies have led to the use of Virtual Organizations (VOs), which can be considered as a set of individuals and institutions that need to coordinate resources and services across institutional boundaries. Therefore, a VO is an open system formed by the grouping and collaboration of heterogeneous entities; there is a separation between form and function that requires defining how a behavior will take place. Agent Technology, which makes it possible to form dynamic agent organizations, is particularly well suited as a support for the development of these open systems. Modelling open multi-agent organization makes it possible to describe structural

composition (i.e. roles, agent groups, interaction patterns, role relationships) and functional behavior (i.e. agent tasks, plans or services), and it can incorporate normative regulations for controlling agent behavior, dynamic entry/exit of components and dynamic formation of agent groups [19]. As the development of open multiagent systems is still a recent field in the multi-agent system paradigm, it is necessary to investigate new methods to model open agent-based virtual organizations, and innovative techniques to provide advanced organizational abilities to virtual organizations.

III. PROPOSED APPROACH

The main objective of this project consists of the design and development of a new and innovative multi-agent platform based on virtual organizations that will, on the one hand, manage heterogeneous wireless sensor networks and multiple technologies (e.g., Wi-Fi, Bluetooth, ZigBee, GPS, GPRS, etc.) and, on the other hand, easily deploy real-time locating systems for indoor environments. The platform will be provided with features that facilitate interaction with outdoor location technologies such as GPS. Sensor networks fall into the category of complex, distributed, interconnected and rapidly changing systems. Multi-agent systems have been identified as one of the most suitable technologies to contribute to the deployment of sensor networks that exhibit robustness and autonomy because of their ability to provide formalisms, algorithms and methodologies that satisfy the challenging needs of sensor networks, specifically: adaptiveness, decentralized control, large scale, information uncertainty, resource boundedness and physical distribution [20].

The multi-agent platform will be built over the Cloud Computing paradigm in order to provide better flexibility and higher scalability for handling both small and large-scale projects (e.g., individual homes, large hospitals or even smart cities). Cloud Computing can offer a very powerful, reliable, predictable and scalable computing infrastructure for the execution of multi-agent systems by implementing complex agent-based applications. These applications can rely on Cloud Computing infrastructures to access and use vast amounts of processors and data. One key feature of software agents is the intelligence that can be embodied into them to solve large complex problems. That intelligence can be obtained by the collaboration of several agents running in a distributed environment. The choice of Cloud Computing meets the requirements needed by the multi-agent system providing the distributed environment by ensuring low execution times and high performance.

Moreover, the platform will make it possible to collect valuable information coming from almost any kind of sensing device that currently exists in the market, and to locate mobile devices in the same environment by using a unique platform, which will save costs in software and hardware infrastructure and open the path to a new world of possibilities in building security and automation.

The proposed research will provide unprecedented support for the dynamic adaptation and customization of applications that enable a rapid and efficient integration of technologies according to the users' needs.

As shown on Figure 1, the proposed platform will include the following components:

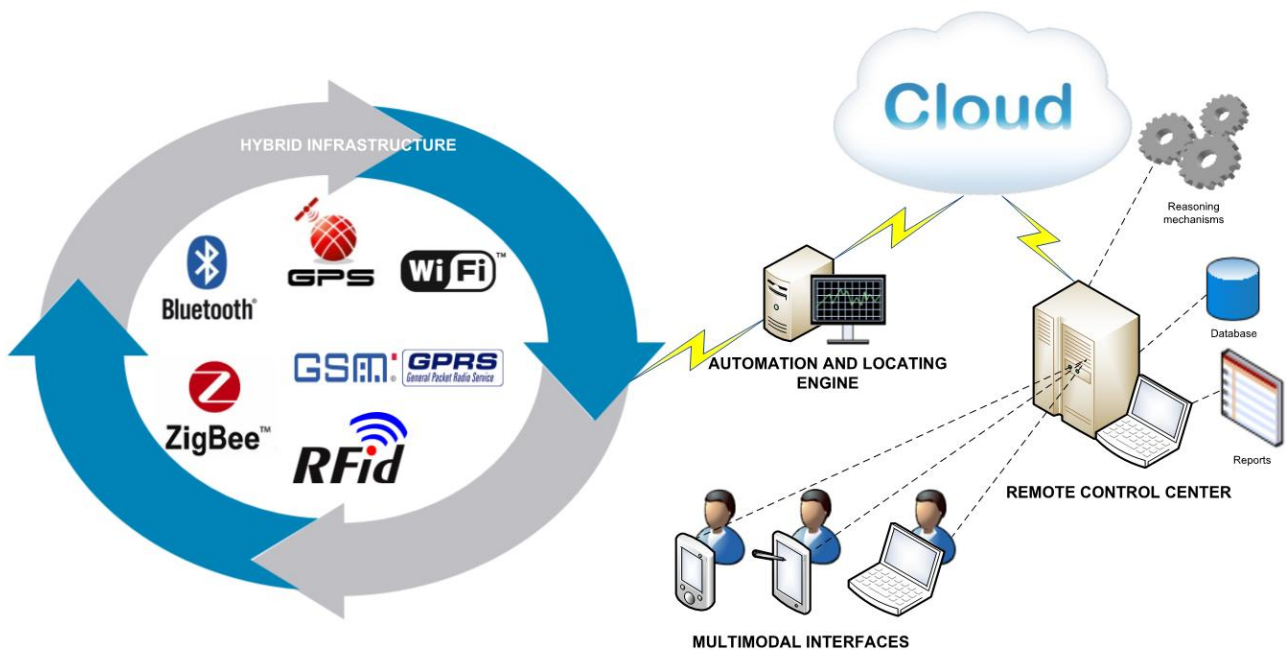


Fig. 1. Main components of the proposed platform

- A multi-agent architecture based on virtual organizations [21]. Virtual organizations are an evolution of Multi-Agent Systems and define a set of rules that govern the agents from an organizational standpoint. Virtual organizations provide a computational analogy of human organizations in which agents, both software and human, adopt different roles and interact among themselves to achieve individual and organizational goals. In other words, virtual organizations are organizational abstractions of intelligent agents that facilitate the design, development and maintenance of software applications [19]. In this project, designing the architecture of the platform by taking the virtual organizations paradigm into account is ideal, because the characteristics of the agents (autonomy, status, reactivity, rationality, intelligence, organization, mobility and learning) can be applied to the development of a platform capable of reacting intelligently to every scenario. Furthermore, the idea of modeling a distributed platform as an organization, on the basis that an organization can adapt its actions to changes in order to achieve its goals and interact with heterogeneous components, is proposed as a very effective, albeit theoretical, solution. The agents and the organizations will be structured in a way that will allow them to interact with and control the sensors and actuators. This agent-based platform will be specifically designed to be deployed at the platform level of a Cloud Computing environment. This will make it possible to use the computational and storage capabilities of the platform and to provide the services of the multi-agent architecture in an elastic way following the cloud paradigm schema. Additionally, the multiagent platform will incorporate tools to set up the system at the software level of the cloud architecture. These tools will allow for the rapid deployment of the system, including sensors and actuators, without the need for specialized personnel.
- A hybrid wireless sensor networks infrastructure that will enable managing multiple technologies. One the main problems of existing wireless sensor networks is the existence of many and various communication protocols (e.g., Wi-Fi, ZigBee, Bluetooth, GPS, GPRS, etc.) [22]. This makes the interoperability among technologies quite difficult. This project aims to develop a specific component to fuse the information provided by sensors independently of communication technology. In order to achieve this, it will be necessary to develop interoperability protocols between sensors and this specific component, besides the rapid deployment of automation and locating applications, optimizing time and costs and maximizing efficiency of the services within it [23].
- A Cloud Computing infrastructure [24] that will provide flexible and efficient services that will allow an elastic scalability and optimize associated management costs. This way, the platform will guarantee users secure and reliable access to these services. The Cloud Computing infrastructure will be

in charge of managing the system's computational resources. To accomplish this, it will use hardware abstractions, in terms of virtual machines. The services of the platform will be deployed in these virtual machines, following the principles of high availability. The redistribution of computational resources among virtual machines is usually done in a centralized way, which presents many disadvantages such as loss of availability, increment of data exchange, etc. [9]. To cope with this problem, this project will develop a new distributed model of resource allocation. This new approach will be allow each node to make autonomous decisions or negotiate with its peers regarding the allocation of resources. The aim of this infrastructure is to minimize the energy consumption (green computing) by means of switch on/switch off resources, taking into account the correct demand of the services without affecting the QoS. The infrastructure will be specifically designed to deploy the agent-based services following the cloud approach in terms of elasticity. Therefore, the platform will incorporate information fusion techniques to integrate heterogeneous data obtained from different kinds of sensors, as described in the above point; it will also incorporate decision support systems to monitor and manage the energy data obtained through the sensors and to actuate the data in order to automatically adapt the intelligent environment to the context information.

- A set of multi-agent user multimodal interfaces that will adapt to the needs of users in an intelligent way, using enhanced interactive media [12] (e.g., voice recognition, touch, haptic technology, etc.) and 3D representation.

There are several innovative advantages over the proposed model for this platform:

- A multi-agent architecture based on virtual organizations provides hybrid networks with advanced capacities for automatic evolution and adaptation.
- The proposed platform will facilitate the deployment of a hybrid network that supports multiple services, protocols, hardware platforms and operating systems. Hybrid networks are flexible and designed to handle the varying requirements of their users and the environments. To date there has not been a platform of this type reported in literature. A hybrid network is dynamic and can suit different levels of network traffic and processing capabilities. It can also be configured in numerous ways to generate optimal results.
- Virtual organizations of agents are appropriate for handling this platform due to their heterogeneous nature, which can support different types of agents running on different types of operating systems or hardware platforms. As the hybrid infrastructure handles different technologies, the infrastructure will therefore manage several sensors and actuators. It will be possible to launch different agent based

organizations for each set of devices, and the global multi-agent architecture will facilitate the interaction between them all.

- Organizations of agents can help to distribute the workload and adapt the computational requirements to the network needs due to the autonomous and adaptive behavior of the agents included in the organization.
- With the proposed architecture, the hybrid networks will be easily extended to add more nodes and/or computer systems. The Cloud infrastructure will provide the required allocation of resources for the sensor network in execution time.
- The Cloud platform will use distributed algorithms to allocate computational resources, which provides some advantages with regards to high availability.
- Organizations of agents have the ability to include heterogeneous components, regardless of their origin, language or operating system. There will be a different organization for each type of sensor, once a new sensor needs to be connected to the network an agent will be associated to it and the inclusion will be straight forward. The platform will allow the integral management of organizations and offer tools to the end user. To achieve this goal, different protocols can be used, such as the Internet Relay Chat (IRC) standard protocol, which facilitates implementation and remains robust even with a large number of connections. An IRC server can connect with other IRC servers to expand the user network. Users access the IRC networks by connecting a client to a server.

IV. APPLICATION SCENARIOS

Hospitals, assembly lines, mines, amusement parks or homes are just a small sample of the possible areas in which the use of a real time identification and locating system can make a difference. While systems such as GPS can easily handle location problems in open spaces, these systems fail in indoor environments (e.g. tunnels and buildings).

Imagine an emergency situation, such as an accident on an oil platform or in a shopping center. The proposed platform would make it possible to help the emergency rescue team by means of a set of wireless devices in the perimeter that would act as the basic infrastructure of communication and as a set of beacons to locate the individuals in the area. The infrastructure would not require previous installation; and in the event that it were not yet deployed, it could be installed in minutes. At the same time, the beacons could include various ambient sensors to measure humidity, temperature, radiation or wind direction, and be connected to a GPS node which would provide a global reference to the geography of the region. The users would have small mobile devices (tags) with them, which would allow them to be identified and located in the area by the beacons. Deploying this infrastructure would make it possible to obtain information about an emergency situation: the real time location of each user, ambient measurements, CO₂ levels, etc. All of this information would be gathered by the platform which, because of its various processing and

visualization techniques, could display the information through an internet connection to authorized personnel on their mobile devices or a PC in a remote data center.

There are other cases of use where the users' security is critical, such as mining. In this case the protection of the staff is vital. Wireless Sensor Networks will warn of a possible gas leak, collapse or flood hazard in a gallery improving the working conditions of the miners. Moreover, in case of an accident, the RTLS may provide real-time location showing in which point of the mine is the affected personnel. The physical infrastructure necessary for this particular use case will consist of a set of beacons to be deployed along the galleries of the mine. Each of these beacons will send data of the relative position of the miners within its coverage area, so that all of them are located at all times. In addition, each of the beacons that will integrate several sensors that detect risky situations for miners. Some of these sensors are flood sensors to detect floods in galleries, gas sensors to detect the presence of toxic gases, vibration sensors to detect movements of earth and smoke sensors to detect any fire inside the galleries. Furthermore, the miners will be provided with a locating tag. This tag will steadily transmit a signal to the beacons. Through this signal the system will be able to determine the position of each miner at all times. Furthermore, the tag will have a panic button that will send alert signals in case of a miner runs into a risk or asks for help. Finally, each tag integrates an accelerometer that will detect falls of the miners and will alert the security personnel in case of an accident. Besides physical infrastructure, multi-agent architecture provides the system intelligence capabilities. With this architecture, the system can detect in advance possible risks. In this way, protection in mining is greatly enhanced since not only the circumstances in which an accident has occurred will be known, but the system will be able to anticipate risky situations avoiding such accidents.

Another scenario in which the platform presented in this paper has special relevance is telemonitoring and wander prevention. In the case of Europe, declining birth rates and growing life expectancy reflect a clear aging. The care of the elderly is one of the areas in which society and governments are more aware and where more efforts and investments are being made. In this case, the platform helps to improve the independence of elderly through a range of services that will enable them to be protected at all times. Thus, the elderly can live independently for longer. In this implementation the elderly will be monitored at all times through a device that will allow them to be located both at home and anywhere else outdoors. In addition, this device will allow the elderly to make requests for help through a panic button that the device integrates. In this case the device also integrates an accelerometer to detect falls in the elderly, so the platform will emit automatically emergency calls in these situations. The house of the elderly will become a smart home. A physical infrastructure will be deployed on it. This infrastructure is formed by several beacons that will locate the elderly. Moreover, they also get data from the environment through a wireless sensor network that is deployed with the same infrastructure. The location of the elderly allows collecting data from their customs and habits such as time spent

watching television, sleeping hours per day or what time it is usual to get out of bed. Moreover, the sensor network will make the home safer. Smoke, humidity, temperature, opening and closing doors and windows or other sensors are integrated to achieve not only a safer home, but a home more energy efficient. All the data collected by the wireless sensor network and the real time locating system will be stored in the cloud. This information will be used by the platform to determine parameters of each user's behavior and so anticipate potential problems that may arise. It will be handled by the multi-agent architecture, responsible for identifying potential risk and anticipate them. One example is that of an elderly who opens

the door to his balcony when the temperature at home rises to 25 Celsius degrees. The system will be able to detect this behavior and regulate the air conditioning system to never exceed that temperature, avoiding the risk of an open door. In addition, elderly's family members or caregivers will benefit from the use of this platform. Besides having the reassurance that the elderly's house has a secure monitoring system, they can check at any time the recorded information: where he or she is at this moment, if they have had any problem in a given period of time, etc., All through any Internet-connected device. Moreover, family members and caregivers can receive alerts that occur in real time on any mobile device.

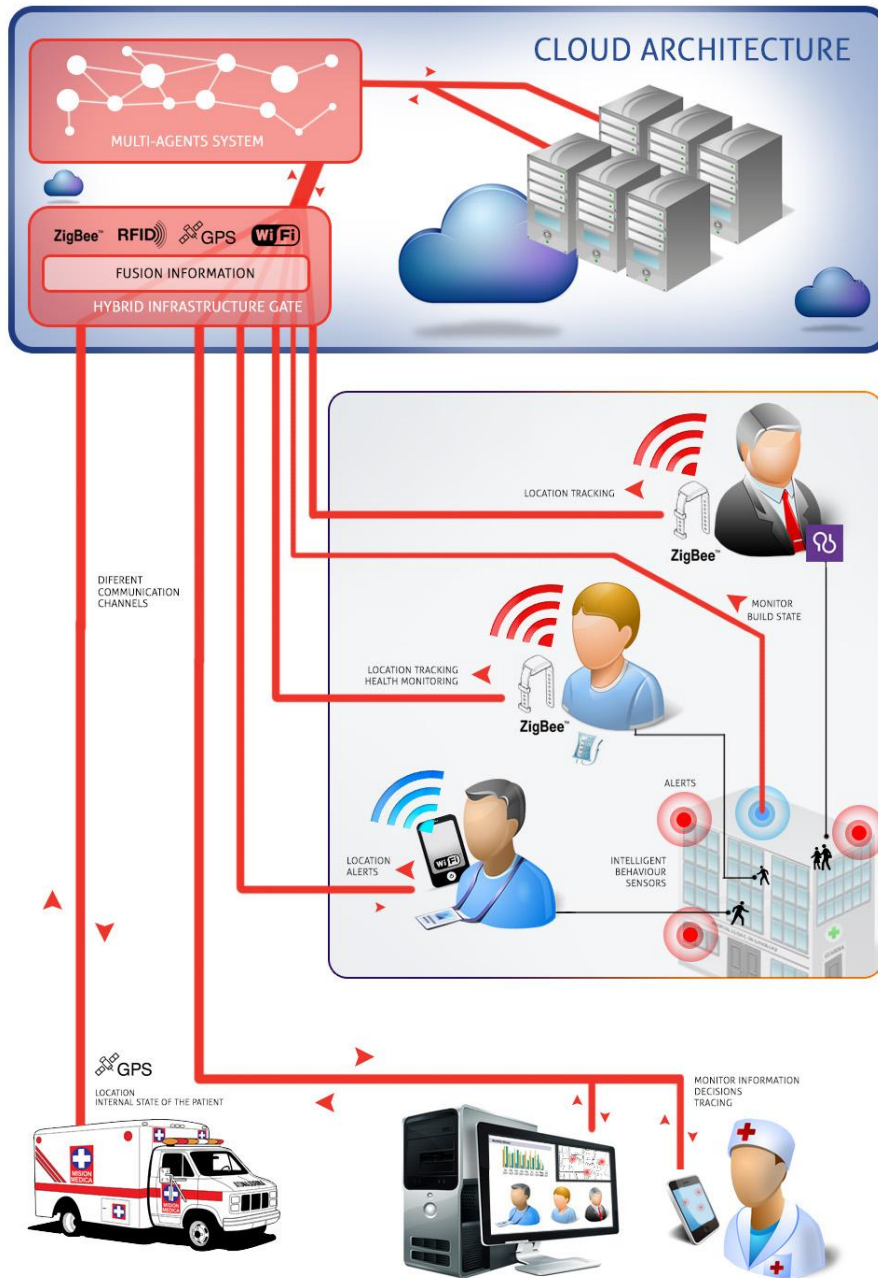


Fig. 2. The platform used in an emergency scenario.

The last scenario presented in this paper is related to education. The ability to characterize and customize the context that surrounds a learning situation at a certain time and place provides flexibility in the educational process. This way, currently learning does not only occur in classrooms, but also in a museum, park or any other place. A better understanding of environment through technology allows teachers to customize the content provided to students. Similarly, technology facilitates the interaction with the environment and between students. In this scenario the platform provides contextual information to be used by the teachers to deploy a learning activity anywhere. Contextual information is useful in the educational process, facilitating the acquisition of new knowledge and training. The use of contextual information allows a better understanding of the environment surrounding the learning and student in a given time. With this knowledge, the information received by the students can be dynamically optimized, customized and adapted to their needs and requirements. To provide contextual information the platform offers indoor and outdoor location capabilities. Thus, the system knows when and what information should be provided to students based on knowledge of their positions. Moreover, if some contextualization involves physical measurements, the platform offers it through its wireless sensor network

infrastructure. The sensors form a mesh network through which data are sent to the access point that sends information to the cloud. Students will be able to receive data from sensors as they approach them as its position is known. Furthermore, the system is aware of which student has approached, so that the information provided can be customized or filtered. For that, the platform uses a multi-agent architecture that make easier decision making. Moreover, the real time locating system is useful to determine where each student is. Once the position and the identity of the student are known the platform will be able to provide the student the information he or she need through any mobile device. The area where the tracking system is deployed is equipped with a set of beacons. These beacons are able to communicate and send information about the location of a student to the network access point. Each student has a “tag” that communicates with the beacons closest to his position. Beacons collect different types of signals sent by mobile devices and send them to the access point. The access point sends all information to the activity server where a location engine calculates the position of the student. The combination of a wireless sensor network and a real time locating system can benefit the learning process and improve learning using novelty techniques in informal scenarios.

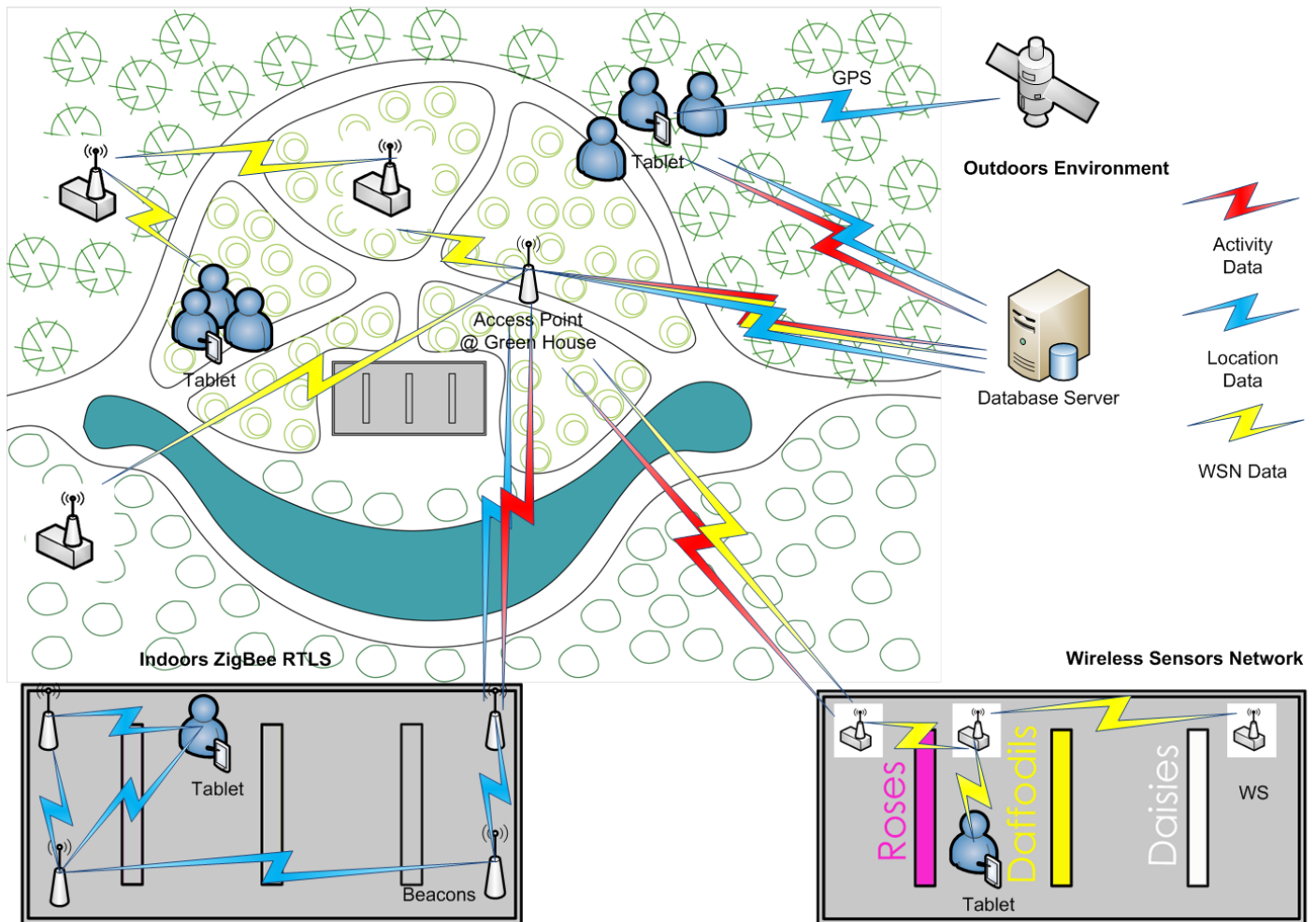


Fig. 3. The platform used in a learning scenario.

V. CONCLUSIONS

This work presents a Cloud Computing platform for the fast integration and deployment of services over Wireless Sensor Networks. The platform integrates in a unique wireless infrastructure two of the main services that are key for the implementation of AmI-based applications: telemonitoring (sensing) and locating. Furthermore, the platform makes use of agent technology for implementing reasoning mechanisms, as well as multimodal interfaces in order to enhance the interaction between users and the applications deployed using this platform.

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