An Ambient Intelligence Based Multi-Agent System for Alzheimer Health Care

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Abstract. This paper describes ALZ-MAS; an Ambient Intelligence based multi-agent system aimed at enhancing the assistance and health care for Alzheimer patients. The system makes use of several context-aware technologies that allow it to automatically obtain information from users and the environment in an evenly distributed way, focusing on the characteristics of ubiquity, awareness, intelligence, mobility, etc., all of which are concepts defined by Ambient Intelligence.

Keywords. Multi-Agent Systems, Ambient Intelligence, Health Care, Wireless Technologies.

1. Introduction

The continuous technological advances have gradually surrounded people with devices and technology. It is necessary to develop intuitive interfaces and systems with some degree of intelligence, with the ability to recognize and respond to the needs of individuals in a discrete and often invisible way, considering people in the centre of the development to create technologically complex and intelligent environments. This paper describes ALZ-MAS; an Ambient Intelligence based multi-agent system aimed at enhancing the assistance and health care for Alzheimer patients in geriatric residences.

Ambient Intelligence (AmI) is an emerging multidisciplinary area based on ubiquitous computing, which influences the design of protocols, communications, systems, devices, etc., proposing new ways of interaction between people and technology, adapting them to the needs of individuals and their environment (Weber, *et al.*

2005). It offers a great potential to improve quality of life and simplify the use of technology by offering a wider range of personalized services and providing users with easier and more efficient ways to communicate and interact with other people and systems (Weber, *et al*., 2005; Corchado, *et al*., 2008b). However, the development of systems that clearly fulfil the needs of AmI is difficult and not always satisfactory. It requires a joint development of models, techniques and technologies based on services. An AmI-based system consists on a set of human actors and adaptive mechanisms which work together in a distributed way. Those mechanisms provide on demand personalized services and stimulate users through their environment according specific situation characteristics (Weber, *et al*., 2005).

One of the most important characteristics of ALZ-MAS is the use of intelligent agents. Agents have a set of characteristics, such as autonomy, reasoning, reactivity, social abilities, pro-activity, mobility, organization, etc. which allow them to cover several needs for Ambient Intelligence environments, especially ubiquitous communication and computing and adaptable interfaces. Agent and multi-agent systems have been successfully applied to several Ambient Intelligence scenarios, such as education, culture, entertainment, medicine, robotics, etc. (Corchado, *et al*., 2008b; Sancho, *et al*., 2002; Schön, *et al*. 2005; Weber, *et al*. 2005). The characteristics of the agents make them appropriate for developing dynamic and distributed systems based on Ambient Intelligence, as they possess the capability of adapting themselves to the users and environmental characteristics (Jayaputera, *et al*., 2007). The continuous advancement in mobile computing makes it possible to obtain information about the context and also to react physically to it in more innovative ways (Jayaputera, *et al*., 2007). The agents in ALZ-MAS are based on the deliberative Belief, Desire, Intention (BDI) model (Jennings & Wooldridge, 1995) (Bratman, *et al*., 1988; Pokahr, *et al*., 2003), where the agents' internal structure and capabilities are based on mental aptitudes, using beliefs, desires and intentions (Bratman, 1987; Erickson, *et al*., 1995; Geogeff & Rao, 1998). Nevertheless, Ambient Intelligence developments need higher adaptation, learning and autonomy levels than pure BDI model (Bratman, *et al*., 1988). This is achieved by modelling the agents' characteristics (Wooldridge & Jennings, 1995) to provide them with mechanisms that allow solving complex problems and autonomous learning. An essential aspect in this work is the use of a set of technologies which provide the agents automatic and real time information of the environment, and allow them to react upon it.

In the next section, the problem description that motivated the development of ALZ-MAS is presented. Section 3 describes the basic components of ALZ-MAS and the most important technologies used to provide the agents in ALZ-MAS with context-aware capabilities. Finally section 4 presents the results and conclusions obtained.

2. Problem Description

Dependence is a permanent situation in which a person needs important assistance from others in order to perform basic daily life activities such as essential mobility, object and people recognition, and domestic tasks (Costa-Font & Patox, 2005). There is an ever growing need to supply constant care and support to the disabled and elderly, and the drive to find more effective ways of providing such care has become a major challenge for the scientific community (Nealon & Moreno, 2003). The World Health Organization has determined that in the year 2025 there will be 1 billion people in the world over the age of 60 and twice as many by 2050, with nearly 80% concentrated in developed countries (WHO, 2007). Spain will be the third “oldest country” in the world, just behind Japan and Korea, with 35% of its citizens over 65 years of age (Sancho, *et al*., 2002). In fact, people over 60 years old represent more than 21% of the European population (WHO, 2007), and people over 65 are the fastest growing segment of the population in the United States of America (Anderson, 1999). Furthermore, over 20% of those people over 85 have a limited capacity for independent living, requiring continuous monitoring and daily assistance (Erickson, *et al*., 1995). The importance of developing new and more reliable ways of providing care and support for the elderly is underscored by this trend, and the creation of secure, unobtrusive and adaptable environments for monitoring and optimizing health care will become vital. Some authors (Nealon & Moreno, 2003) consider that tomorrow’s health care institutions will be equipped with intelligent systems capable of interacting with humans. Multi-agent systems and architectures based on intelligent devices have recently been explored as supervision systems for medical care for dependent people. These intelligent systems aim to support patients in all aspects of daily life (Cesta, *et al*., 2003), predicting potential hazardous situations and delivering physical and cognitive support (Bahadori, *et al*., 2003).

Ambient Intelligence based systems aim to improve quality of life, offering more efficient and easy ways to use services and communication tools to interact with other people, systems and environments. Among the general population, those most likely to benefit from the development of these systems are the elderly and dependent persons, whose daily lives, with particular regard to health care, will be most enhanced (Corchado, *et al*., 2008a; Van Woerden, 2006). Dependent persons can suffer from degenerative diseases, dementia, or loss of cognitive ability (Costa-Font & Patox, 2005). In Spain, dependency is classified into three levels (Costa-Font & Patox, 2005) Level 1 (moderated dependence) refers to all people that need help to perform one or several basic daily life activities, at least once a day; Level 2 (severe dependence) consists of people who need help to perform several daily life activities two or three times a day, but who do not require the support of a permanent caregiver; and finally Level 3 (great dependence) refers to all people who need support to perform several daily life activities numerous times a day and, because of their total loss of mental or physical autonomy, need the continuous and permanent presence of a caregiver.

Agents and multi-agent systems in dependency environments are becoming a reality, especially in health care. Most agents-based applications are related to the use of this technology in the monitoring of patients, treatment supervision and data mining. (Lanzola, *et al*., 1999) present a methodology that facilitates the development of interoperable intelligent software agents for medical applications, and propose a generic computational model for implementing them. The model may be specialized in order to support all the different information and knowledge-related requirements of a hospital information system. (Meunier, 1999) proposes the use of virtual machines to support mobile software agents by using a functional programming paradigm. This virtual machine provides the application developer with a rich and robust platform upon which to develop distributed mobile agent applications, specifically when targeting distributed medical information and distributed image processing. While an interesting proposal, it is not viable due to the security reasons that affect mobile agents, and there is no defined alternative for locating patients or generating planning strategies. There are also agents-based systems that help patients to get the best possible treatment, and that remind the patient about follow-up tests (Miksch, *et al*., 1997). They assist the patient in managing continuing ambulatory conditions (chronic problems). They also provide health-related information by allowing the patient to interact with the on-line health care information network. (Decker & Li, 1998), propose a system to increase hospital efficiency by using global planning and scheduling techniques. They propose a multi-agent solution that uses the generalized partial global planning approach which preserves the existing human organization and authority structures, while providing better system-level performance (increased hospital unit throughput and decreased inpatient length of stay time).

To do this, they use resource constraint scheduling to extend the proposed planning method with a coordination mechanism that handles mutually exclusive resource relationships. Other applications focus on home scenarios to provide assistance to elderly and dependent persons. RoboCare presents a multi-agent approach that covers several research areas, such as intelligent agents, visualization tools, robotics, and data analysis techniques to support people with their daily life activities (Pecora & Cesta, 2007). TeleCARE is another application that makes use of mobile agents and a generic platform in order to provide remote services and automate an entire home scenario for elderly people (Camarinha-Matos & Afsarmanesh, 2002). Although these applications expand the possibilities and stimulate research efforts to enhance the assistance and health care provided to elderly and dependent persons, none of them integrate intelligent agents, distributed and dynamic applications and services approach, or the use of reasoning and planning mechanisms into their model.

3. An Ambient Intelligence Based Multi-Agent System for Alzheimer Health Care

ALZ-MAS (*ALZheimer Multi-Agent System*) (Corchado, *et al*., 2008a; 2008b) is a distributed multi-agent system designed upon Ambient Intelligence and aimed at enhancing the assistance and health care for Alzheimer patients living in geriatric residences. The main functionalities in the system include reasoning and planning mechanisms (Glez-Bedia & Corchado, 2002) that are embedded into deliberative BDI agents, and the use of several context-aware technologies to acquire information from users and their environment. As can be seen on Figure 1, ALZ-MAS structure has five different deliberative agents based on the BDI model (BDI Agents), each one with specific roles and capabilities:

- *User Agent*. This agent manages the users' personal data and behaviour (monitoring, location, daily tasks, and anomalies). The *User Agent* beliefs and goals applied to every user depend on the plan or plans defined by the super-users. *User Agent* maintains continuous communication with the rest of the system agents, especially with the *ScheduleUser Agent* (through which the scheduled-users can communicate the result of their assigned tasks) and with the *SuperUser Agent*. The *User Agent* must ensure that all the actions indicated by the SuperUser are carried out, and sends a copy of its memory base (goals and plans) to the *Admin Agent* in order to maintain backups. There is one agent for each patient registered in the system.

- *SuperUser Agent*. It also runs on mobile devices (PDA) and inserts new tasks into the *Admin Agent* to be processed by a reasoning mechanism (Corchado, *et al*., 2008b). It also needs to interact with the *User Agents* to impose new tasks and receive periodic reports, and with the *ScheduleUser Agents* to ascertain the evolution of each plan. There is one agent for each doctor connected to the system.
- *ScheduleUser Agent*. It is a BDI agent with a planning mechanism embedded in its structure (Corchado, *et al*., 2008b). It schedules the users' daily activities and obtains dynamic plans depending on the tasks needed for each user. It manages scheduled-users profiles (preferences, habits, holidays, etc.), tasks, available time and resources. Every agent generates personalized plans depending on the scheduled-user profile. There is one *ScheduleUser Agents* for each nurse connected to the system.
- *Admin Agent*. It runs on a Workstation and plays two roles: the security role that monitors the users' location and physical building status (temperature, lights, alarms, etc.) through continuous communication with the *Devices Agent*; and the manager role that handles the databases and the task assignment. It must provide security for the users and ensure the efficiency of the tasks assignments. There is just one *Admin Agent* running in the system.
- *Devices Agent*. This agent controls all the hardware devices. It monitors the users' location (continuously obtaining/updating data from sensors), interacts with sensors and actuators to receive information and control physical services (temperature, lights, door locks, alarms, etc.), and also checks the status of the wireless devices connected to the system (e.g. PDA or Laptops). The information obtained is sent to the *Admin Agent* for processing. This agent runs on a Workstation. There is just one *Devices Agent* running in the system.

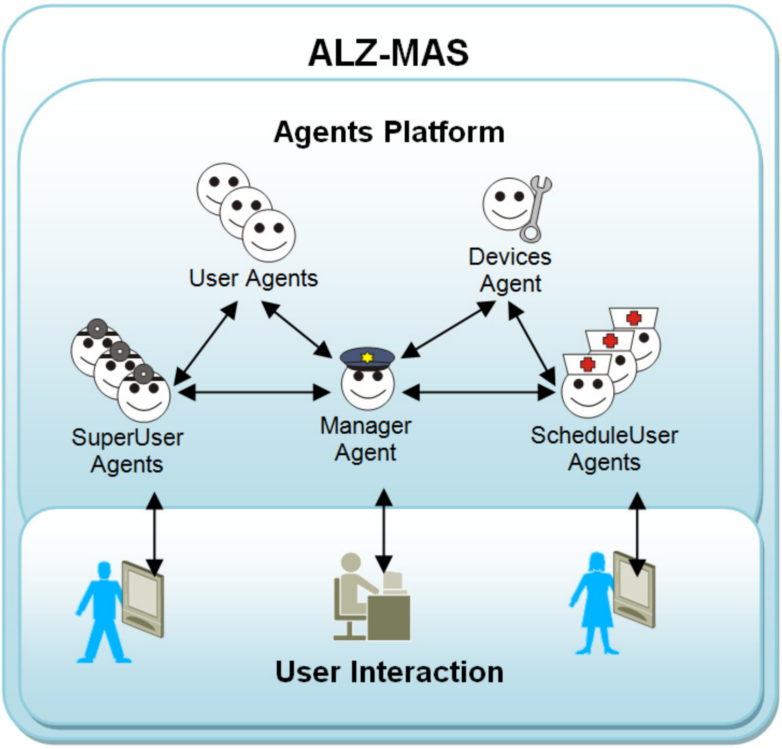

Fig. 1. ALZ-MAS basic structure

Next, the main technologies used in ALZ-MAS to provide the agents with context-aware capabilities are presented.

3.1. Technologies Used in ALZ-MAS for Context-Awareness

The agents in ALZ-MAS collaborate with context-aware agents that employ Radio Frequency Identification, wireless networks and automation devices to provide automatic and real time information about the environment, and allow the users to interact with their surroundings, controlling and managing physical services (i.e. heating, lights, switches, etc.). All the information provided is processed by the agents, specially the *Devices Agent* which is a BDI agent that that runs on a Workstation. The *Devices Agent* monitors the users' location (continuously obtaining/updating data from the RFID readers), interacts with the ZigBee devices to receive information and control physical services and also checks the status of the wireless devices connected to the system (e.g. PDA). The information obtained is sent to the *Admin Agent* to be processed. All hardware is some way integrated to agents, providing automatic and real time information about the environment that is processed by the agents to automate tasks and manage multiple services. Next, the main technologies used in ALZ-MAS are presented.

Radio Frequency Identification (RFID) technology is a wireless communications technology used to identify and receive information about humans, animals and objects on the move. An RFID system contains basically four components: tags, readers, antennas and software. Tags with no power system (e.g. batteries) integrated are called passive tags or “transponders”, these are much smaller and cheaper than active tags (power system included), but have shorter read range. The transponder is placed on the object itself (e.g. bracelet). As this object moves into the reader’s capture area, the reader is activated and begins signalling via electromagnetic waves (radio frequency). The transponder subsequently transmits its unique ID information number to the reader, which transmit it to a device or a central computer where the information is processed and showed. This information is not restricted to the location of the object, and can include specific detailed information concerning the object itself. The most use is in industrial/manufacturing, transportation, distribution, etc., but there are other growth sectors including health care. The configuration used in ALZ-MAS consists of a transponder mounted on a bracelet worn on the users’ wrist or ankle, and several sensors installed over protected zones with an adjustable capture range up to 2 meters, and a central workstation where all the information is processed and stored. Figure 2 shows two Sokymat’s Q5 chip 125KHz RFID wrist bands (left) and a RFID USB Desktop Reader (right) used in ALZ-MAS for people identification and location monitoring.

Fig. 2. RFID Technology used in ALZ-MAS: two RFID wrist bands (left); a USB Desktop Reader (right)

Wireless LAN (Local Area Network) also known as Wi-Fi (Wireless Fidelity) networks, increase the mobility, flexibility and efficiency of the users, allowing programs, data and resources to be available no matter the physical location. These networks can be used to replace or as an extension of wired LANs. They provide reduced infrastructure and low installation cost, and also give more mobility and flexibility by allowing people to stay connected to the network as they roam among covered areas, increasing efficiency by allowing data to be entered and accessed on site (Hewlett-Packard, 2002). New handheld devices facilitate the use of new interaction techniques, for instance, some systems focus on facilitating users with guidance or location systems (Corchado, *et al*., 2005) by means of their wireless devices. ALZ-MAS incorporates "lightweight" agents that can reside in mobile devices, such as cellular phones, PDA, etc., and therefore support wireless communication, which facilitates the portability to a wide range of devices. Figure 3 shows the user interface executed in a PDA emulator. The Wi-Fi infrastructure in ALZ-MAS supports a set of PDA for interfaces and users' interaction; a Workstation where all the high demanding CPU tasks (planning and reasoning) are processed; and several access points for providing wireless communication between distributed agents.

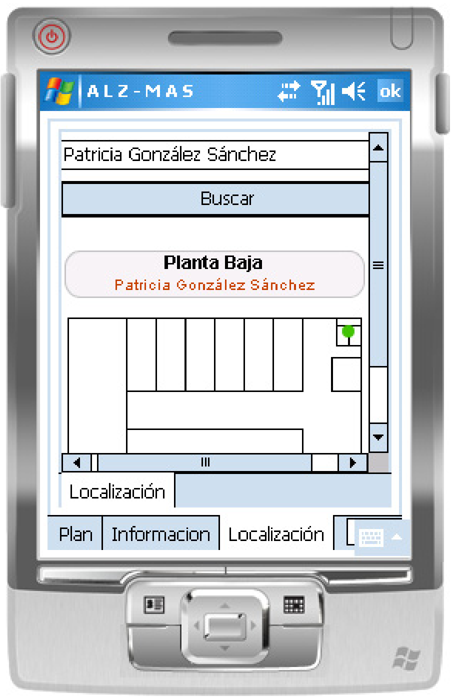

Fig. 3. ALZ-MAS' PDA user interface showing the location of patients and nurses

ZigBee is another important technology used in ALZ-MAS. ZigBee is a low cost, low power consumption, two-way, wireless communication standard, developed by the ZigBee Alliance (ZigBee Standards Organization, 2006). It is based on IEEE 802.15.4 protocol, and operates at 868/915MHz & 2.4GHz spectrum. ZigBee is designed to be embedded in consumer electronics, home and building automation, industrial controls, PC peripherals, medical sensor applications, toys and games, and is intended for home, building and industrial automation purposes, addressing the needs of monitoring, control and sensory network applications (ZigBee Standards Organization, 2006). ZigBee allows star, tree or mesh topologies. Devices can be configured to act as: network coordinator (control all devices); router/repeater (send/receive/resend data to/from coordinator or end devices); and end device (send/receive data to/from coordinator). Figure 4 shows a Silicon Laboratories' C8051 chip-based 2.4GHz development board which controls heating, lights, door locks, alarms, etc. It is necessary a mesh of these boards to control all these services.

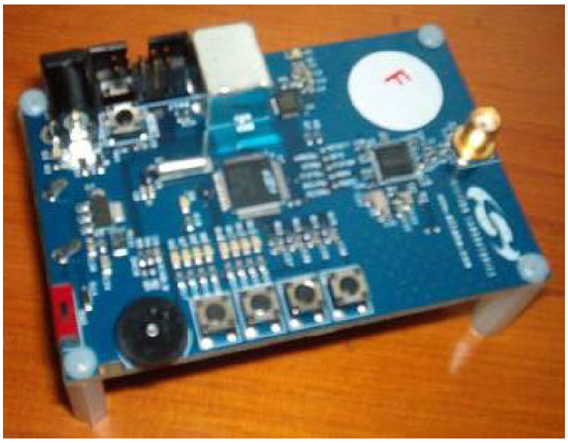

Fig. 4. A ZigBee device used in ALZ-MAS

All information obtained by means of these technologies is processed by the agents. Figure 5 shows the main user interface of ALZ-MAS. Depending of the system requirements, several interfaces can be executed. The interfaces show basic information about nurses and patients (name, tasks that must be accomplished, schedule, location inside the residence, etc.) and the building (outside temperature, specific room temperature, lights status, etc.).

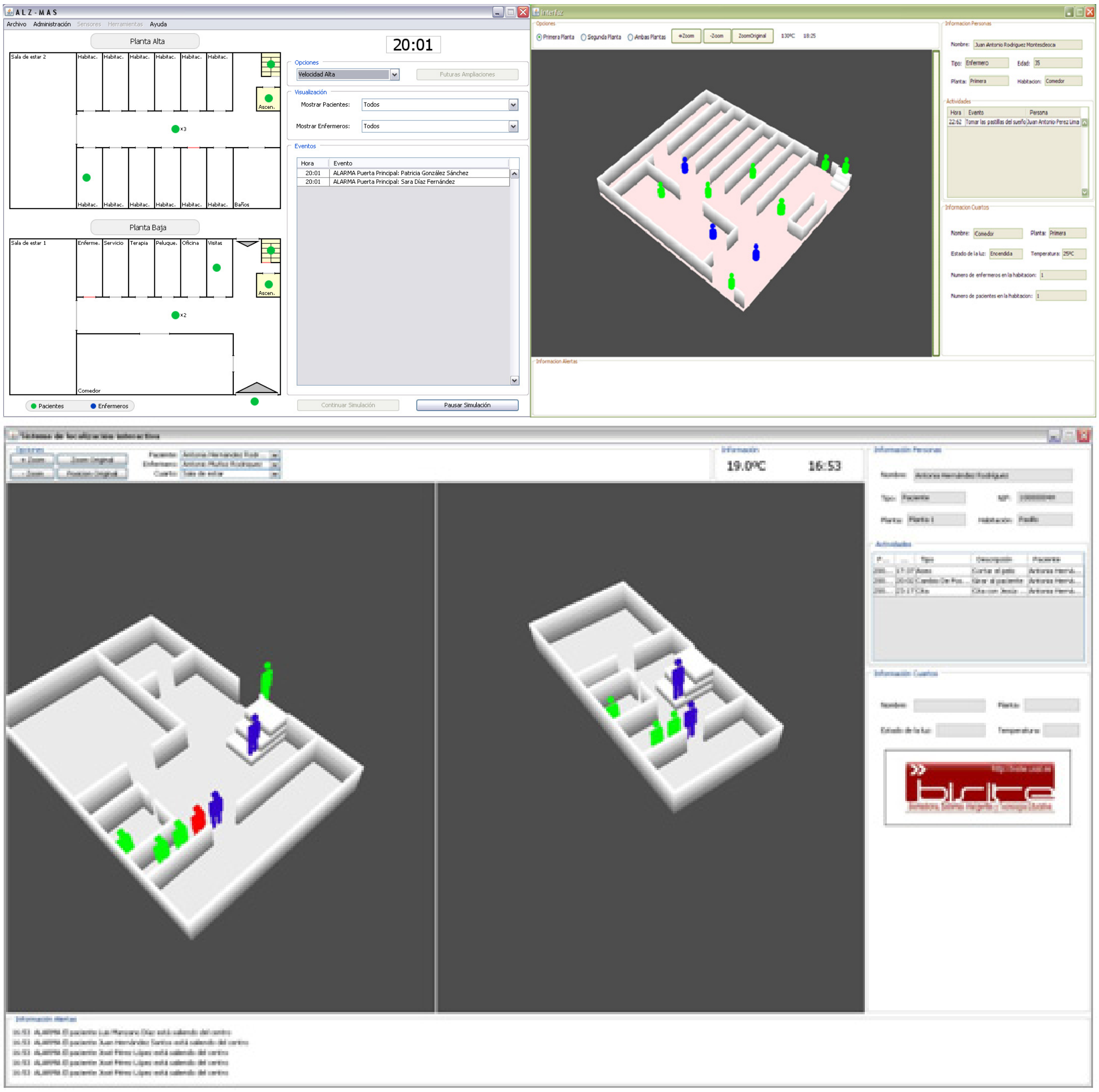

Fig. 5. ALZ-MAS main user interfaces: a 2D representation (upper left); a 3D representation with a single floor view (upper right); and a 3D representation with multiple floors (down)

4 Results and Conclusions

ALZ-MAS is an Ambient Intelligence based multi-agent system aimed at enhancing the assistance and health care for Alzheimer patients. ALZ-MAS takes advantage of the cooperation among autonomous agents and the use of context-aware technologies providing a ubiquitous, non-invasive, high level interaction among users, system and environment.

One of the most important features in ALZ-MAS is the use of complex reasoning and planning mechanisms. These mechanisms dynamically schedule the medical staff daily tasks. Figure 6 (left) shows a window with the general planning process result. It contains the date, time to initiate the task, task description, priority of the task, length of the task, and the patient associated with each task. To generate a new plan, a *ScheduleUser Agent* (running on a PDA) sends a request to the *Agents Platform*. The request is processed by the *Manager Agent* which decides creating a new plan. Then, the solution is sent to the platform which delivers the new plan to all *ScheduleUser Agents* running. The planning mechanism creates optimal paths and scheduling in order to facilitate the completion of all activities defined for the nurses connected to the system. As can be seen on Figure 6 (right), the information is provided to all nurses and doctors in a user-friendly format using mobile devices (PDA) to see their corresponding tasks.

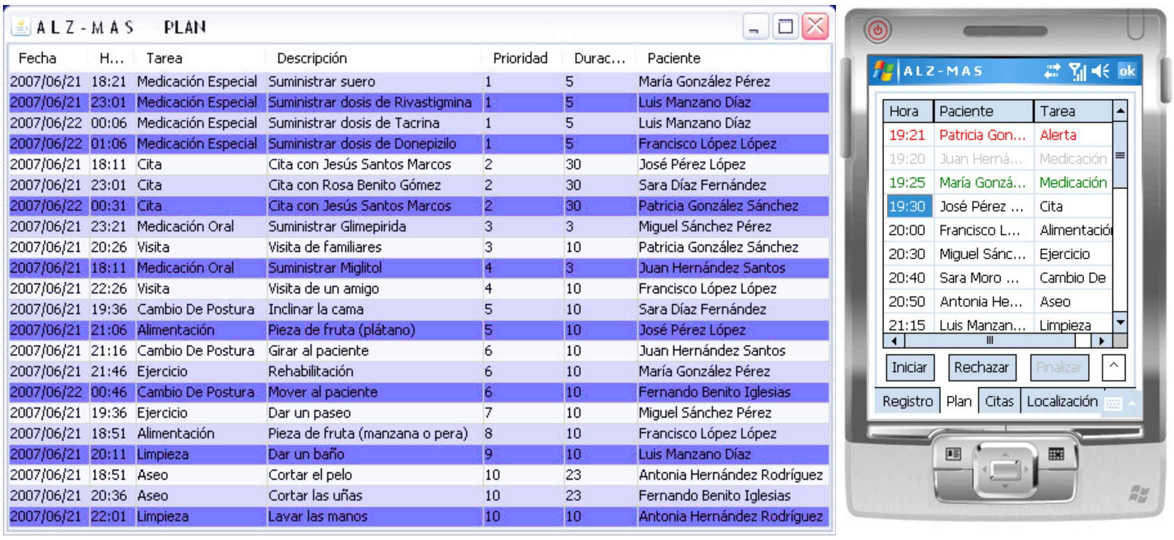

Fig. 6. Interface window showing the result of a general planning

Several tests have been done to demonstrate the efficiency of ALZ-MAS which consisted on collecting data regarding the time spent by the nurses on routine tasks and the number of nurses working simultaneously. The prototype was adopted on June 12th, 2007. The tasks executed by nurses were divided in two categories, direct action tasks and indirect action tasks. Direct action tasks are those which require the nurse acting directly on the patient during the whole task (medication, posture change, toileting, feeding, etc.). In the indirect action tasks the nurses do not need to act directly on the patients all the time (reports, monitoring and visits). We focused on indirect tasks because ALZ-MAS can handle most of them, so nurses can increase their productivity and the quality of health care.

Figure 7 shows the average time spent on indirect tasks by all nurses before implementation, with the previous release of ALZ-MAS and finally the release presented in this paper. ALZ-MAS continues reducing the time spent on indirect task. For example, the average number of minutes spent by all nurses on monitoring patients has been reduced from more of 150 daily minutes (before ALZ-MAS implementation) to approximately 90 daily minutes. Furthermore, this new release of ALZ-MAS performed slightly better than the previous release.

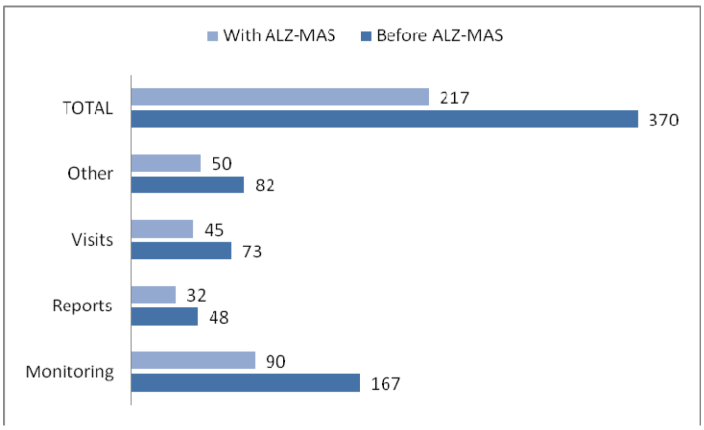

Fig. 7. Average time (minutes) spent on indirect tasks

Figure 8 shows the average number of nurses working simultaneously each hour of a day before and after the implementation of ALZ-MAS. In these set of tests, there were selected 50 patients and 12 nurses. According to the times spent by the nurses carrying out their tasks before the implementation, it can be seen how ALZ-MAS facilitates the more flexible assignation of the working shifts. The number of nurses working simultaneously before and after the implementation of the system is reduced substantially, especially at peak hours in which the indirect action tasks are more prone to overlap with the direct action task. For instance, from 13:00 to 15:00 there is a reduction of 5 nurses working simultaneously. This is achieved because there is an optimal distribution of tasks using ALZ-MAS.

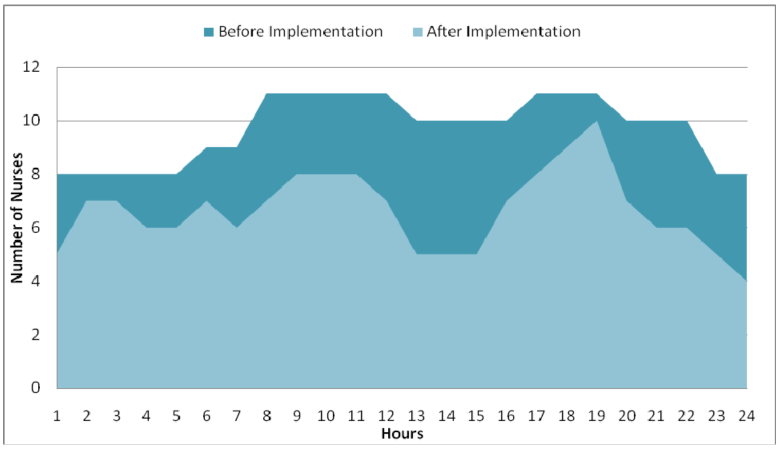

Fig. 8. Number of nurses working simultaneously

The security of the centre has also been improved in two ways: the system monitors the patients and guarantees that each one of them is in the right place, and secondly, only authorised personnel can gain access to the residence protected areas. Figure 9 shows the number of accesses to restricted zones detected before and after the implementation of ALZ-MAS. As can be seen, there were detected almost twice unauthorized accesses. This is an important data because it can be assumed that several accesses were not detected in the past and most of them could lead to risky situations.

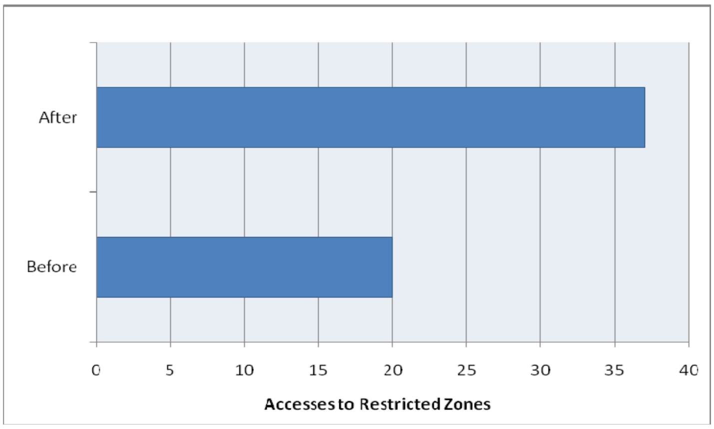

Fig. 9. Number detected accessed to restricted zones

It is demonstrated that ALZ-MAS can improve the security and health care efficiency through monitoring and automating medical staff's work and patients' activities, facilitating working shifts organization and reducing time spent on routine tasks. RFID, Wi-Fi and ZigBee technologies supply the agents with valuable information about the environment, contributing to a ubiquitous, non-invasive, high level interaction among users, system and the environment. Future work consists on improving ALZ-MAS by adding more features and increasing its performance.

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