Intelligent Agents and Wireless Sensor Networks: A Healthcare Telemonitoring System

Ricardo S. Alonso, Oscar García, Carolina Zato, Oscar Gil, and Fernando De la Prieta

Abstract. E-healthcare has acquired great importance in recent years and requires the development of innovative solutions. This paper presents a telemonitoring system aimed at enhancing remote healthcare for dependent people at their homes. The system deploys a Service-Oriented Architecture based platform over a heterogeneous Wireless Sensor Networks infrastructure. Furthermore, the information obtained by telemonitoring systems must be managed by intelligent and self-adaptable technologies to provide an adequate interaction between the users and their environment. In the proposed system, the WSNs platform is integrated with a multi-agent architecture so that information gathered by WSN nodes is managed by intelligent agents with reasoning mechanisms.

Keywords: Multi-Agent Systems, Service-Oriented Architectures, Wireless Sensor Networks, e-Healthcare.

1 Introduction

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. 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 [1]. Furthermore, over 20% of those people over 85 have a limited capacity for independent living,

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requiring continuous monitoring and daily assistance [2]. 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 healthcare will become vital.

Healthcare telemonitoring systems allow patient's state and vital signs to be supervised by specialized personnel from a remote medical center. Such systems usually consist of a home monitoring subsystem, a remote monitoring subsystem in the medical center and a network which interconnects both. A telemonitoring system for healthcare needs to continuously keep track of information about patients and their environment. The information may consist of many different parameters such as location, the building temperature or vital signs.

Most of the information can be collected by distributed sensors throughout the environment and even the patients themselves. To facilitate the deployment of these sensors, it is preferable to use Wireless Sensor Networks (WSNs) instead of wired networks [3]. In existing buildings, wiring is more uncomfortable and difficult than using wireless devices. In the case of the biomedical sensors, it could be quite bothersome for patients to wear a mesh of wires. One solution would be to use a Wireless Body Area Network (WBAN) formed by wearable sensors [4]. However, it is not enough to gather information about the patients and their environment, but that information must be processed by self-adaptable and dynamic mechanisms and methods that can react independently of each particular situation that arises. In this sense, agents and Multi-Agent Systems (MAS) [5] comprise one of the areas that contribute expanding the possibilities of these systems.

This paper presents a telemonitoring system aimed at enhancing e-healthcare for dependent people at their homes. The system utilizes the SYLPH (*Services laYers over Light PHysical devices*) [6] experimental architecture that integrates a SOA (Service-Oriented Architecture) approach with heterogeneous WSNs. The architecture provides the telemonitoring system with a flexible distribution of resources and facilitates the inclusion of new functionalities in highly dynamic environments. Unlike other SOA-WSNs architectures [7] [8], SYLPH allows both services and services directories to be embedded in nodes with limited computational resources regardless of the radio technology they use. Furthermore, SYLPH can be integrated with *Flexible User and ServIces Oriented multiageNt Architecture* (FUSION@) [9], an architecture that combines a SOA approach with intelligent agents for building highly dynamic systems. Thus, context-aware information gathered by SYLPH WSNs can be used by intelligent applications based on agents that use reasoning mechanisms [10] to adapt their behavior to the context using the collected information.

Next, the problem description is introduced and it is explained why there is a need for defining a new telemonitoring system. Later, Section 3 describes the telemonitoring multi-agent system, as well as the integration of the SYLPH platform and the FUSION@ architecture employed to implement the system. Finally, Section 4 depicts the conclusions and future work.

2 Problem Description

One of the key aspects for the construction of healthcare telemonitoring systems is obtaining information about the patients and their environment through sensors. Biomedical sensors (e.g. electrocardiogram, blood pressure, etc.) and automation sensors (e.g. temperature, light, etc.) differ significantly in how they collect data. On one hand, biomedical sensors obtain continuous information about vital signs that is important and should not be lost. On the other hand, automation sensors get information at a lower frequency than biomedical sensors [3] because it is generally less important than vital signs. In a telemonitoring scenario, it is necessary to interconnect WSNs from different technologies [4], so having a distributed platform for deploying applications over different networks facilitates the developers' work and the integration of heterogeneous devices.

There are several telemonitoring healthcare developments based on WSNs [4] [11]. However, they do not take into account their integration with other architectures and are difficult to adapt to new scenarios. This is because such approaches do not allow sensors and actuators to communicate directly with one another, and instead gather data in a centralized way. Excessive centralization of services negatively affects system functionalities, overcharging or limiting their capabilities. However, distributed architectures such as SOA [12] look for the interoperability amongst different systems, the distribution of resources and the independency of programming languages. Some developments try to reach integration between devices by implementing some kind of middleware, which can be implemented as reduced versions of virtual machines, middleware or multi-agent approaches [13]. However, these developments require devices whose microcontrollers have large memory and high computational power, thus increasing costs and size. These drawbacks are very important regarding healthcare scenarios, as it is essential to deploy applications with reduced resources and low infrastructural impact.

One of the most prevalent alternatives in distributed architectures is agents and Multi-Agent Systems. An agent can be defined as anything with the ability to perceive its environment through sensors and respond in the same environment through actuators, assuming that each agent may perceive its own actions and learn from the experience [5] [10]. The development of agents is an essential piece in the analysis of data from distributed sensors and gives them the ability to work together and analyze complex situations, thus achieving high levels of interaction with humans [14].

There are different technologies for implementing WSNs. The ZigBee standard allows operating in the ISM (Industrial, Scientific and Medical) band, which includes 2.4GHz almost all over the world. The underlying IEEE 802.15.4 standard is designed to work with low-power limited resources nodes. ZigBee adds network and application layers over IEEE 802.15.4 and allows more than 65,000 nodes to be connected in a mesh topology WSN. Another standard to deploy WSNs is Bluetooth. This standard also operates in the 2.4GHz band and allows creating star topology WSNs of up to 8 devices, one acting as master and the rest as slaves, but it is possible to create larger WSNs through devices that belong simultaneously to several WSNs. However, it is not easy to integrate devices from different technologies into a single WSN [15]. The lack of a common architecture may lead to additional costs due to the necessity of deploying interconnection elements amongst different WSNs.

The architecture for the telemonitoring system presented in this paper tackles some of these issues by enabling an extensive integration of heterogeneous WSNs and providing a greater simplicity of deployment, optimizing the reutilization of the available resources in such WSNs. The architecture integrates a SOA approach for facilitating the distribution and management of resources (i.e. services). Unfortunately, the difficulty in developing a distributed architecture is higher. It is also necessary to have a more complex system analysis and design, implying more time to reach the implementation stage. There are several developments to integrate WSNs and a SOA approach [8]. However, those developments do not consider the necessity of minimizing the overload of the services on the devices. In contrast, our solution allows the services to be directly embedded in the nodes and invoked from other nodes either in the same WSN or another WSN connected to the former. Furthermore, it specifically focuses on using devices with small resources to save energy, CPU time and memory size.

3 System Description

The proposed telemonitoring system makes use of SYLPH (*Service laYers over Light PHysical devices*) [6], an experimental architecture developed by the BISITE Research Group at the University of Salamanca, Spain. This architecture integrates a SOA approach over WSNs for building systems that combine devices from different network technologies, such as ZigBee or Bluetooth. A node in a WSN of a specific technology can then be connected to a node in another WSN of a different technology. In this case, both WSNs are interconnected through a set of intermediate gateways connected simultaneously to several wireless interfaces. SYLPH allows applications to work in a distributed way and does not depend on the lower stack layers related to the radio transmission (i.e. data link and physical layers) and the WSN formation (i.e. network layer). A SOA approach was chosen because such architectures are asynchronous and non-dependent on context (i.e. previous states of the system) [12]. Thus, devices do not continuously take up processing time and are free to perform other tasks or save energy.

SYLPH implements an organization based on a stack of layers [3]. Each layer in one node communicates with its peer in another node through an established protocol. The SYLPH layers are added over the application layer of each WSN stack, allowing SYLPH to be reutilized over different WSN technologies. SYLPH implements the *SYLPH Message Layer* (SML), the *SYLPH Application Layer* (SAL) and the *SYLPH Services Directory Sub-layer* (SSDS) [6]. The SML offers the upper layers the possibility of sending asynchronous messages between two nodes through the *SYLPH Services Protocol* (SSP). Such messages specify the origin and target nodes and the service invocation in a *SYLPH Services Definition Language* (SSDL) format. The SAL layers on two different nodes can directly communicate each other using SSDL invocations and responses which will be delivered encapsulated in SML messages through SSP. The SSDS is used by nodes for locating services on other nodes in the WSN. *SYLPH Directory Nodes* (SDNs) acts as directories of the services offered by other nodes. Thus, any node in the network can request a SDN for the location of a certain service by sending it a SSDL search request embedded in a SML message over SSP. As mentioned above, several heterogeneous WSNs can be interconnected using SYLPH. For this, special nodes called *SYLPH Gateways* are used. Thus, they can forward messages amongst the different WSNs to which they belong. From the SAL layer's point of view, there is no difference between invoking a service stored in a node in the same WSN and invoking another one stored in a node in a different WSN.

3.1 Integration of SYLPH and FUSION@

In order to interact with a SYLPH network from a system that is not made up of WSNs, it is proposed to use FUSION@ [14], a Multi-Agent architecture for distributed services and applications. FUSION@ (*Flexible User and ServIces Oriented multiageNt Architecture*) proposes a new perspective, where Multi-Agent Systems and SOA-based services are integrated to provide ubiquitous computation, ubiquitous communication and intelligent interfaces facilities. The FUSION@ framework defines four basic blocks: *Applications*, *Services*, *Agents Platform* and *Communication Protocol* [14]. Besides, there are seven pre-defined agents that provide the basic functionalities of the architecture: *CommApp*, *CommServ*, *Directory*, *Supervisor*, *Security*, *Admin* and *Interface*. *Interface Agents* were designed to be embedded in users' applications and are simple enough to allow them to be executed on mobile devices, such as cell phones or PDAs.

This way, we have designed two agents in SYLPH to interact with FUSION@: *SylphInterface* and *SylphMonitor*. The *SylphInterface Agent* allows the rest of agents to discover and invoke services offered by SYLPH nodes. Moreover, the *SylphInterface Agent* can offer services to the SYLPH nodes. To do this, the WSN node in the FUSION@–SYLPH gateway stores services entries on its SSDS table. As can be seen in [9], the *SylphInterface Agent* performs as a broker between SYLPH and FUSION@. The *SylphMonitor Agent* allows the agents platform to monitor the state and operation of the SYLPH network. Thus, *SylphMonitor Agent* monitors all the traffc (i.e. service invocations, responses, registrations or searches) in the SYLPH network. The node gathers all the invocations and forwards them to the *SylphMonitor Agent* running on the agents' platform. The same process is done for service responses, searches and registrations. The *SylphMonitor Agent* makes it possible to observe when a node is searching for a certain service in the network, the services offered by the nodes, and the contents of the SSDS entries tables stored in the SDNs.

3.2 Implementation of the Healthcare Telemonitoring System

The proposed telemonitoring multi-agent system makes use of several SYLPH WSNs for obtaining context information in an automatic and ubiquitous way. In

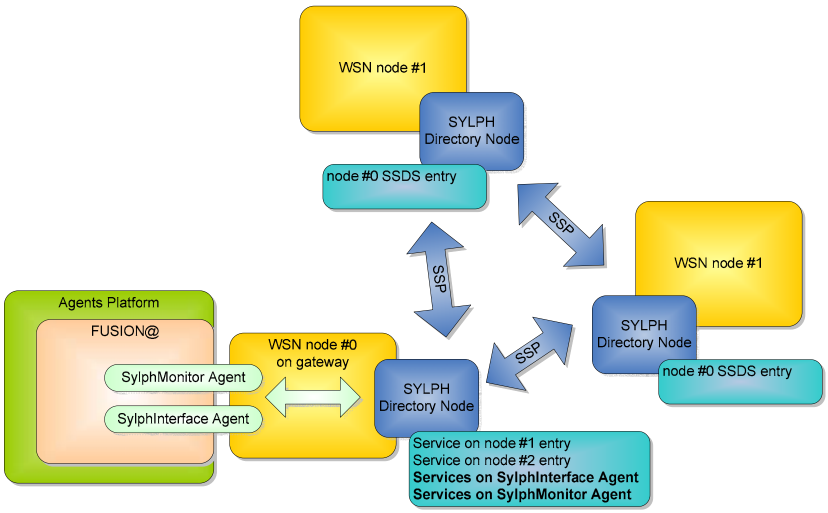

Fig. 1 Interaction between SYLPH and FUSION@

addition, the information gathered by the SYLPH nodes is managed by intelligent agents running in the system by means of the FUSION@ multi-agent architecture.

The system uses a network of ZigBee devices placed throughout the home of each patient to be monitored. Figure 2 shows the basic schema of the system. The patient carries a remote control (a small ZigBee device embedded in a wristband) that includes an alarm button which can be pressed in case of the need for remote assistance. There is a set of ZigBee sensors that obtain information about the environment (e.g. light, smoke, temperature, etc.) and react to changes (e.g. light dimmers and fire alarms). There are also several Bluetooth biomedical sensors placed over the patient's body. Each patient carries an Electrocardiogram (ECG) monitor, an air pressure sensor acting as respiration monitor, and a triaxial accelerometer for detecting falls. All ZigBee and Bluetooth devices can offer and invoke services within the network.

There is also a computer connected to a remote healthcare center via Internet for forwarding possible alerts to caregivers and allowing them to communicate with patients. This computer acts as a ZigBee coordinator and as master of the Bluetooth network formed by the biomedical sensors as slaves. At the SYLPH level, the computer works as a SYLPH Gateway so that it connects both WSNs each to other. In the other hand, there is a telemonitoring application based on the FUSION@ multi-agent architecture running on the computer in order to gather information from the SYLPH sensor nodes and send commands to the SYLPH actuator nodes. Such application is also the responsible for transfer the information between the SYLPH network and the other parts of the system.

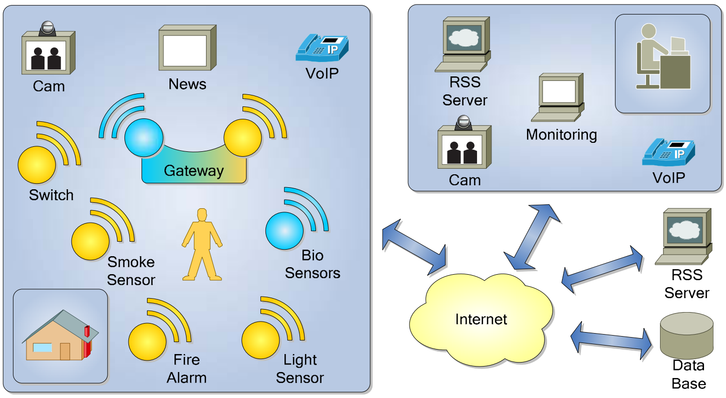

Fig. 2 Infrastructure of the telemonitoring system using SYLPH and FUSION@

4 Conclusions and Future Work

The integration of SYLPH and the FUSION@ multi-agent architecture allows developing highly-dynamic e-healthcare applications where context information gathered by heterogeneous WSNs is managed by intelligent agents. These intelligent agents can use reasoning mechanisms and methods in order to learn from past experiences and to adapt their behavior according the context. The use of a SOA-based approach provides a flexible distribution of resources and facilitates the inclusion of new functionalities in highly dynamic environments. Thus, functionalities are modeled as independent services offered by nodes in the network. These services can be invoked by any node in the SYLPH infrastructure, regardless the physical WSN which they belong. In addition, SYLPH nodes do not need large memory chips or fast microprocessors. The easy deployment of SYLPH-based systems reduces the costs in terms of development and infrastructure support.

Future work on SYLPH includes the development of nodes based on several WSN technologies (e.g. ZigBee and Bluetooth), as well as SYLPH Gateways for interconnect such kinds of WSNs. Other of the main aims is to achieve the integration of FUSION@ and SYLPH through the development of the *SylphInterface* and *SylphMonitor Agents* described above. We are also currently exploring alternative case studies for applying this platform and demonstrate that the approach presented is flexible enough to be implemented in other scenarios. However, one main issue to be taken into account is that the platform is still under development so it is necessary to define it through formal analysis and design methodologies and *Agent-Oriented Software Engineering* (AOSE) tools, such as Gaia or SysML.

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