Remote Mobile Monitoring of Wireless Sensor Networks for Ambient Assisted Living

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Abstract

This paper presents the concept, design and implementation of a monitoring middleware for a Wireless Sensor Network based on mobile devices. A publish/subscribe mediation platform is proposed to be used as a bridge between the physical monitoring environment and the remote devices. The publish/subscribe architecture provides an inherently asynchronous, anonymous and multicasting communication infrastructure, making it especially compatible with monitoring systems based on sensor networks. The framework addressed can be easily adapted to integrate the existing healthcare technology with pervasive wireless networks, due to the system nodes can be interfaced to a variety of heterogeneous sensors. We detail the application of the proposed platform to remotely monitor a real-world habitat, and present the architecture and a prototype developed to monitor and assist the elderly.

1. Introduction

Population aging is currently having a significant impact on health care systems [1]. It has been estimated that one billion people will be over the age of 60 by the year 2025 [2]. There is an increasing need to find more effective ways of providing care and support to the disabled and elderly at home, and systems for continuous health monitoring are considered a key technology in this challenge [3]. Wireless sensor networks are one of the most promising technologies for enabling health monitoring at home, due to their suitability to supply constant supervision [4]. Indeed, the healthcare market is considered among the fastest growing markets for Wireless LAN Technologies [5].

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous sensing devices. Due to their flexibility, low cost and rapid deployment, currently sensor networks are increasingly being used in domains where ubiquitous monitoring is required [6]. Also in recent years mobile handheld devices have become more portable, powerful and affordable. With rising popularity of these devices there is a pressing need to offer computing and networking solutions while on the move [7]. The use of mobile technologies has been proved to be useful in patient surveillance settings [8]. We state that the combination of WSN with mobile networks opens up new opportunities in a variety of telemonitoring applications.

A typical setting for home-based telemonitoring consists of a wireless sensor network located in the patient environment, and connected through a gateway to the internet and a telemonitoring center [9]. The wireless sensor network can include monitoring of vital signs and other biological data, fall detection and monitoring of activities of the daily living. The home based gateway can be a dedicated device, a PC or a smartphone. Data collected at the home are transmitted to a telecare centre where they are stored and used for the follow-up of the patient. However, the way this follow-up is to be organized is an issue still under research. It is clear that having a specialist doctor devoted to the every-day follow up of the patient makes no sense from an economic point of view. It is necessary to organize the follow up in different levels, involving specialist doctors, nurses, social workers, and the family in some cases.

The framework proposed address the effective combination of WSN and mobile networks employing a publish/subscribe mediation platform. A publish/ subscribe system is a middleware communication service considered well adjusted to the needs of large-scale distributed applications [10]. The implicit and asynchronous communication that defines this scheme provides a robust and scalable type of interaction that is especially suitable for developing data-centric sensor network applications [11]. Concurrently, mobile computing involves a new style of computation that is highly context aware. The available resources are usually subject to tight constraints and communication is not only unreliable, but also very unpredictable as it strongly depends on the features of the local environment. Due to their characteristics, a publish/subscribe mechanism can provide a high degree of decoupling among the elements of a distributed application.

Therefore publish-subscribe is great platform to cope with highly variable, dynamic and unreliable environments where the set of components undergoes continuous reconfiguration as in the mobile one [12]. In recent years, several prototypes have been presented demonstrating the integration of the publish/subscribe routing mechanism either with sensor networks [13] or with mobile platforms [14]. However, no prototypes addressing the actual combination of both technologies have been found, apart from some theoretical approaches [15]. To prove the practical viability of the middleware proposed in the healthcare framework, an activity monitoring system for elderly care has been developed. Such scenario, where the follow-up is done by several health care professionals, may involve social workers and family members. In this scenario, each of these actors is interested in different pieces of the information gathered by the sensor network, and needs it in a different way: specialist doctors will access to patient data in pull for follow-up and medication triage, typically with monthly frequency, whereas family

members will be interested in receiving push mode notifications of events in the home as soon as they are detected. The whole prototype has been coded in Java language for platform and OS independency. Android smartphones have been chosen as mobile devices due to their open-source nature and easy integration capability with other Java software. Besides, the inherent non-intrusive characteristics of the WSN have been proved to suit perfectly with the home monitoring domain [16].

2. Background technologies

In this subsection we present the basic features concerning the proposed scheme. The main issues involved when adding mobility support to a system are exposed, and a detailed overview of the publish/subscribe paradigm is given.

2.1. Mobility issues

Currently, mobile computing promotes a novel style of computation where new trends in distributed applications demand not only scalability, but also a high degree of adaptability to dynamic conditions [17]. Clearly, there exist several application domains, such as healthcare, that can benefit from the integration of this novel paradigm with traditional Wireless Sensor Networks [18]. Mobile computation poses several new challenges. An appropriate mobile computing model must deal with the variability of the wireless environment and the low reliability of mobile networks. Moreover, the communication among the entities of a mobile system becomes harder since they typically form an unknown set of elements. As result, resources and services available to mobile applications are not fixed, rather they usually change according to the current location of the user. Thus, in general terms, mobile computation offers a form of distributed computing with very different connectivity assumptions than in traditional distributed systems.

The traditional request/response paradigm most mobile applications are based on is not really suitable for a data-centric system in which the message delivery is focused on the data produced by nodes. The habitual mechanism for a mobile application which requires instantaneous updates of information is to poll periodically for the data. This approach is highly inefficient, as it leads to server resource contention and network overload and congestion. Moreover, mobile devices rely on a finite energy source, so unnecessary information requests should be avoided.

The alternative is a more advanced and efficient method: the server push. Push technology is a style of communication that automates the information delivery process without requiring clients to request the data they need. The data sources (sensors in our case) notify the events and initiate the data transaction. A very well-known push bearer deployed on mobile networks is the Short Message Service (SMS). Push services are usually based on information preferences expressed in advance, also known as the publish/subscribe paradigm [10]. These systems are a simple way to communicate both static and mobile clients when a traditional client/server model is required.

2.2. Publish/Subscribe pattern

A publish/subscribe system is a middleware communication model where the involved entities can be primarily divided into two roles: publishers and subscribers [19]. Publishers produce the information and do not program the messages to be sent directly to specific subscribers, instead they publish the information in one or more available data channels. Similarly subscribers consume the information and only receive messages that are of interest from the channels they are subscribed to. The mediation element that coordinates subscriptions and manages the queues to ensure the data are published and received correctly is usually an event brokering entity. Figure 1 shows the schematic of a basic topic-based publish/subscribe system.

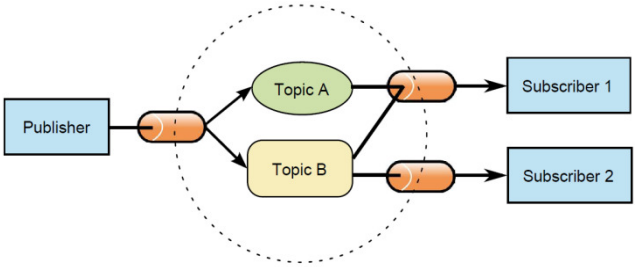

Figure 1. *Topic-based publish/subscribe design pattern.*

The one-way message transmission that characterizes publish-subscribe models provides an asynchronous communication among the different elements. Publishers are not blocked while producing events, and similarly subscribers can receive data asynchronously while performing other concurrent task in the meantime. The form of decoupling this paradigm supports is considered well suited to environments demanding flexible and dynamic network topology. Indeed, the scalability and robustness provided by this type of interaction make the publish/subscribe paradigm particularly suitable for creating data-centric sensor network applications [11], hence simplifying particularly the integration of WSNs with other distributed applications. The inherently anonymous communication and dynamism of publish/subscribe models enable the development of flexible systems quickly adaptable to frequent connections and disconnections of mobile nodes, characteristic of a mobile network [20].

3. Architecture

In this section we detail how the described technologies have been merged into a general architecture. Next we present the instance of the publish/subscribe protocol selected as mediation platform of the system. Also, a more detailed description of the approach and its core components is given.

3.1. MQTT (“*Message Queuing Telemetry Transport*”)

MQTT is an open publish/subscribe protocol [21] designed for environments where a lightweight messaging model is required. This protocol is commonly used by specialized applications on constrained devices that

require low bandwidth communication, typically for remote data acquisition and process control. A major advantage of MQTT is that most of the system complexities reside on the broker implementation, enabling light and simple clients.

A relevant aspect of distributed information systems is reliability. The broker supervises the liveliness of the client connection by a keep-alive mechanism, which establishes the maximum time interval that may elapse between two messages received from the client. This protocol is suitable for mobile applications due to its small size, minimized data packets, low power usage and efficient distribution of information to one or many receivers. MQTT has been proven useful and well adapted to the peculiarities of a wireless communication environment [22].

3.2. Modules description

The basic design of the framework is divided into three main modules or areas: the nodes network, the centralized management server and the mobile monitoring environment.

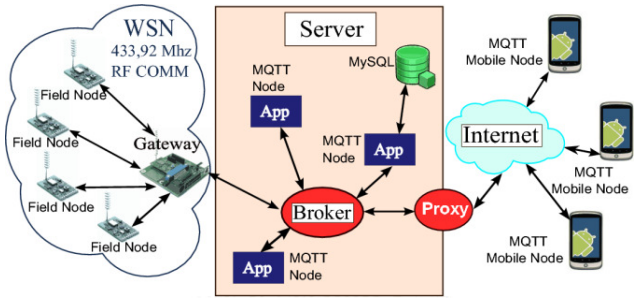

***Figure 2**. General architecture of the framework proposed.*

The nodes network is configured in a star topology (see Figure 2), where the access point is a central gateway attached to the management server and all field nodes are within radio range. The network is highly flexible, it can be configured to measure and monitor a great variety of physical parameters. All data collected are transferred to the management server using wireless communication. Due to the good reliability and accuracy this sensing network offers, other similar systems had been previously developed based on such technology [23].

In the centralized management server several components coexist. This module can be understood as the required bridge between the sensing network and the mobile terminals. Different key functionalities of the system are addressed by this module, having each component a well defined role. One of the components is used as an interface between the computer server and the sensing network, this component autonomously emits beacon messages for time synchronization. The broker component provides the publish/subscribe service to the application. As mentioned, the communication of these different components is always based on the publish/subscribe mediation model. The server software was implemented under a Unix environment.

4. Prototype implementation

A real prototype is useful to demonstrate that a generic design can be implemented under the particular constraints of the target domain. To this end, in addition to the design of the service, we have developed a reference implementation of the framework proposed. Such prototype will prove how the architecture proposed here enables the configuration of a telemonitoring environment where all the actors involved can access the information gathered in the home in the way that best suits their specific needs.

A real-life home environment was selected for testing the effectiveness of the prototype. Such domain allowed us not only to evaluate the overall performance of the whole system, but also to assess the degree to which users are likely to accept our sensing network. Our purpose was to investigate the application of this technology to monitor the movements and activities of elderly residents living independently, in order to foster their autonomy. In situations where users have lack of knowledge to use technology or it is complex to be handled, obtaining information about the context can be very valuable.

The proposed prototype required the use of several event based sensors: infrared IR motion sensors, passing sensors and operation detectors were added to the testing environment. These sensors captured raw measures of the movement of the user. The type of sensors employed to monitor the user movements was an important aspect of designing the system. The sensing network employed was chosen according to two main criteria: ease of installation and minimal intrusion. Sensors that need to be worn on the body may be considered intrusive by the user, and sensors that are easy to install can increase the acceptance of the system.

***Figure 3**. Scheme of the prototype implementation..*

In the testing setting, a collection of various sensors to measure different things were included: pressure mats to measure sitting on a couch or lying in bed; passive infrared sensors to detect motion in a specific area; contact switches for open-close states of doors and cupboards, and float sensors to measure the toilet being flushed (see Figure 3). Basically any kind of event based sensor can be combined with the framework proposed. The full extent of the sensor network deployed in this prototype was 14 nodes; which was the number of sensors required to fully monitor the testing environment, and consequently also the number of real publishing nodes.

5. Conclusions

In this paper, we described the architecture of a mobility support platform for remote monitoring of Wireless Sensor Networks, and a real prototype to supervise the activities of elderly residents has been presented. Based mainly on a publish/subscribe mediation model, the proposed approach provides a complete and dynamic infrastructure to effectively integrate a mobile operating environment with traditional sensor networks. As mediation platform, the light MQTT publish/subscribe protocol was chosen. The decoupling among information producers and information consumers this protocol provides has been shown to address most of the design requirements requested by mobile computing. To illustrate how the framework can be implemented under the particular constraints of a target domain, we developed a prototype to remotely monitor elderly people in a real home environment. Such prototype was explained by presenting the three main modules it comprises: the sensing network, the centralized management server and the mobile monitoring environment. The performance and adaptability of the architecture proposed makes this monitoring middleware suitable to be used in a variety of domains, including ambient assisted living. A noticeable shortcoming of the implemented prototype is the absence of a robust security layer. To meet the necessary privacy and security requirements, some mechanism that permits nodes to have private message exchanges must be included [24]. In future deployment scenarios, the presented middleware will be required to operate in untrusted environments. To address this issue, we have already begun to explore some proposed extensions in which client authentication and access control are considered [25].

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