Deploying Mobile Middleware for the Monitoring of Elderly People with the Internet of Things: A Case Study

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Abstract. The ageing population and related diseases represent some of the most relevant challenges in the healthcare domain. All that will lead to an increasing demand of innovative solutions in order to guarantee a healthy and safe lifestyle to the elderly. In fact, many researchers are studying the use of Internet of Things (IoT) technologies in the e-health field. In this paper we report a case study where a locale middleware for portable devices has been used to facilitate the development of IoT mobile application in this respect, allowing the communication among different on board sensing technologies. The mobile middleware is built on top of the WoX (Web of Topics) platform and quickly permits the deployment of innovation services thanks to its abstraction and user centric model. A validation test bed involving 31 elderly people living in Lecce (Italy) has been carried out for the monitoring of their activities, mainly those connected to positioning and motility both in indoor and outdoor scenarios. Our approach has demonstrated a practical way to replace obtrusive monitoring technique (typical of caregivers) with unobtrusive ones, in order to obtain proactive intervention strategies for a smart city.

Keywords: IoT · WoX · Middleware · Smart environment · Behavior analysis

1 Introduction

In the last years, the increase of aged people with chronic diseases will lead to a growing demand for support digital services. It is estimated that 50% of the population in Europe will be over 60 years old in 2040, while in the USA one in every six citizens will be over 65 years old in 2020 [1]. In addition, people over 75 years usually require continuous monitoring. For this reason, it is necessary to propose new solutions for healthcare that especially guarantee prevention at different levels of intervention and not only treatment of diseases.

So different e-health experiments and projects have started, and the use of the Internet of Things (IoT) paradigm is playing a key role [2]. In fact, IoT integrates all kinds of sensing, identification, communication, networking and information management devices and systems, and seamlessly links all the people and things according to their

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interests, so that anybody – at anytime and anywhere – through any device and media, can access any provided information from objects and people to obtain services more efficiently. Currently, the IoT concept is associated with the introduction of an architectural layer that integrates the data provided from many heterogeneous sources [3] (for hardware, software architecture and communication protocol used). This architectural layer is called "IoT middleware" and, besides the integration of data, it is also involved in many other IoT aspects (from networking and communication to security and context management). The union between e-health application and IoT technologies is promising to address the challenges faced by the healthcare sector. For instance, the patients of a healthcare service can be tracked and monitored by using the ubiquitous identification, sensing and communication capacities. Exploiting the global connectivity of the IoT, this information can be collected, managed and analyzed more efficiently. Furthermore, information for healthcare service can be directly provided by patient's mobile devices (smartphones, tablets, wearable devices) through Internet or IoT access (WiFi, 3G, LTE, Bluetooth, ANT, ZigBee, LoRa, etc.), guaranteeing security and authentication policy. In other words, the IoT technologies will enable the transformation of healthcare service from caregiver-centric to patient-centric, make it more efficient, proactive and ubiquitous.

In this paper, we report on how a local model-driven middleware is used to forward incoming information from patient's mobile devices toward an IoT platform in order to monitor the elderly people activities. Furthermore, the benefits of this approach are discussed and compared to other existing systems.

The paper is organized as follows: Sect. 2 briefly reports on the key related work in the area of e-health and IoT. Section 3 provides readers with a brief introduction to the WoX and L-WoX architecture, and the model on which the platform is based. Section 4 demonstrates the middleware working on a real case study in the context of a research project. Finally, Sect. 5 summarizes our key messages and sketches future research directions.

2 Related Work

In the last years, several IoT solutions have been proposed. For lack of space, in this section we limit our attention to IoT middleware applied to e-health services.

Linksmart [4] is a general-purpose middleware and it has already been tested in the e-health field as a tool to allow the easy integration of heterogeneous devices in one solution. The authors illustrate how their solution aims to solve the complexity of a pervasive environment in order to support medical care routine of patients at home. The SAI middleware [5], enabling the development of context-aware applications, is also used for an e-healthcare solution. In fact the middleware is used in a reference application scenario for patient conditions monitoring, alarm detection and policy-based handling. In [6], a solution for tracking the daily life activities, by using mobile devices and cloud computing services, is discussed. The system permits to collect heterogeneous information from sensors located in the house and share them in the cloud. The system monitors the elderly people and generates reminders for scheduled activities along with

alerts for critical situations to caregivers and family members, so reducing the health expenditures. In [7], an IoT based architecture for providing healthcare services to elderly and incapacitate individuals is proposed. As the underlying technology for implementing this architecture, 6LoWPAN is used for active communications, and radio frequency identification (RFID) and near-field communications (NFC) are used for passive communications. Another platform based on the IoT is proposed in [8]. This platform resolves different limitations (for example interoperability, security, the streaming quality of service). Its feasibility has been verified by installing an IoT-based health gateway on a desktop computer as reference implementation. A solution for monitoring patients with specific diseases such as diabetes using mobile devices is discussed in [7]. This system provides continuous monitoring and real time services, collecting the information from healthcare and monitoring devices located in the home environment and connected to mobile devices. Always in this area, in [9] is discussed the potential benefits of using m-IoT in non-invasive glucose level sensing and the potential m-IoT based architecture for diabetes management.

The above quoted related work is more focused on the technological aspects and they do not seem to pay a primary attention to the user's needs. Despite them, the advantage of the solution we propose is directly connected to the model-driven approach due to a user centered design. The user, in this case the patients' needs have guided, since the beginning, the design process in order to easily develop unobtrusive scenarios starting from geriatric parameters.

3 WoX and L-WoX Model and Reference Architecture

Web of Topics (WoX) [10, 11] is a model-based middleware for the IoT, specifically aimed at minimizing the language distance between people (end users, developers) and technology, while at the same time abstracting the multifaceted complexity of the considered IoT hardware and communication protocols.

Based on a hierarchical publish/subscribe approach, where every entity within the WoX conceptual framework can also be considered as a broker for other WoX entities, the Web of Topics makes the development of scalable applications easier by hiding the heterogeneity of the underlying IoT communication protocols, thus acting as an intermediate abstraction layer between the Web of Things (WoT) and consumer applications (Fig. 1). In particular, a WoX entity can generically refer to a wide range of both IoT hardware nodes and consumer applications (varying from mere single-user applications to enterprise systems for machine learning and Big Data Analytics), and it can be modeled as a set of {role; topic} couples. WoX delegates to entities the responsibility of interacting with topics, both in terms of capabilities towards a given topic (which is equivalent to providing a service) and needs (which is equivalent to requesting a service). In this context, the role concept is used to express the entity's technological (source/executor/function) and collaborative (capability/need) dimensions within the considered scenario.

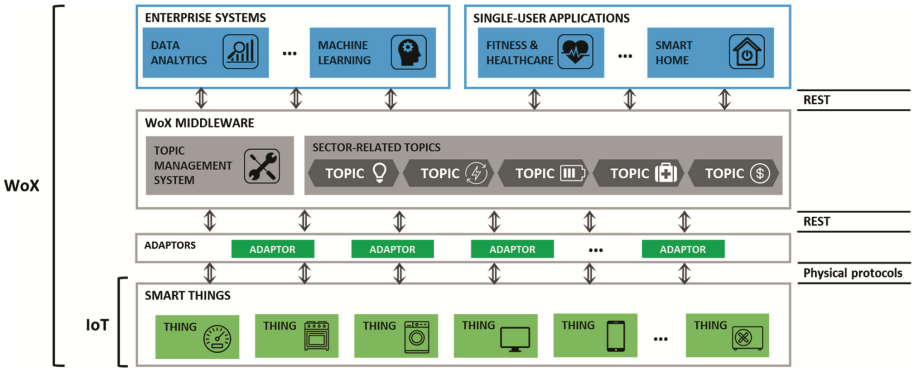

Fig. 1. WoX reference model

The topic concept, which is at the heart of the WoX approach, is used instead as a carrier for meaningful information concerning IoT capabilities exchanged between entities acting as providers and consumers. Furthermore, WoX topics can be grouped into three macro-domains:

- Cloud WoX, which includes all the topics residing in Cloud-based environments;
- Local WoX (L-WoX), which includes all the topics residing on mobile devices;
- Embedded WoX (M-WoX), which includes all the topics residing on embedded systems as, for example, wearable devices, micro-controllers, actuators, weather stations, etc.

Moreover, each topic consists of:

- A feature of interest (e.g., *temperature*, which refers to the temperature measured in a given place).
- A specific URI-identified location associated with the previously mentioned feature of interest (e.g., *italy:apulia:lecce:school:lab:desk1*, which refers to a desk situated in the science laboratory of an ordinary high school in Lecce, Apulia, Italy).
- The current value of such feature (e.g., *64 °C*, referring to the temperature example), which can be updated by any entity capable of providing additional information.

Any concrete or virtual property of the domain that is perceivable, definable, measurable or controllable – from raw sensor data to more abstract concepts, such as mathematical functions or human behaviors – can be used as a feature. Since WoX entities are allowed to decide whether forwarding topic updates to parent entities or not, entities at the edge of the architecture will deal with relatively few, very specific topics, while entities near the core retain a higher level of knowledge through their access to more abstract topics. In particular, the L-WoX middleware, being an extension of the cloud WoX platform, replicates the topic-based, model-driven approach of the Web of Topics on a local level, and manage the lifecycle of topic instances available for any WoX-enabled application running on mobile devices. It also mediates the communication between different on-board sensing technologies (with their heterogeneous, native APIs) and client applications through a set of plugin adaptors used to update specific topics

with the incoming data. As a consequence of this approach, topic management responsibilities are effectively distributed among the involved nodes, thus turning mobile devices into aggregators for L-WoX entities. Furthermore, in several circumstances it may also be more efficient to keep low-level topics locally on the device, such as:

- Multiple mobile apps querying or updating the same shared topic;
- Multiple mobile apps referring to different topics, which are updated by the same on-board sensor.

4 Case Study: The H2020 City4Age Project

The City4Age project [12, 13] is a research project co-funded by the European Commission under the H2020 program that utilizes data from smart cities and ad-hoc sensors for the prevention of Mild Cognitive Impairment (MCI) and frailty of aged people. In particular, behavior change detection and 1-to-1 communication for IoT-enhanced intervention are some of the project's key features, following two main areas of strategic importance for the project:

- **Social dimension:** through the involvement of urban communities in conjunction with health services, smart cities can provide an invaluable support to the growing number of families facing Mild Cognitive Impairment (MCI) and frailty of the elderly, especially in these times of demographic imbalance and ageing populations afflicting most of the European countries. Prevention of MCI and frailty-related risks through early detection of dangerous situations and timely interventions will play a pivotal role in guaranteeing, in the least-obtrusive possible way, the well-being of the elderly people, as well as providing a more empathic communication between the social ICT services and the involved people.
- **Technological dimension:** City4Age pursues the creation of a highly-innovative framework of already existing technical components – such as wearable and mobile devices, sensor networks, systems for data analytics and machine learning – in order to collect large amounts of potentially heterogeneous data pertaining individuals that will be used, after several processing phases, to identify large segments of population at risk as well as to closely monitor few individuals, thus promoting more effective observing procedures and proactive interventions. This requires the ability to assign a geriatric meaning to the raw data gathered by the sensors, and to infer knowledge about the monitored subjects and their behaviors over the time.

The Lecce's pilot for the City4Age project, which involves the cooperation of 31 volunteer individuals of proper age and situation, focuses on monitoring their activities, with particular attention paid to those features connected to positioning and motility both in indoor and outdoor scenarios, and demonstrates a practical way to replace obtrusive monitoring techniques (typical of caregivers) with unobtrusive ones (typical of the IoT context), while at the same time achieving a high level of proactive intervention strategies for a smart city.

For the Lecce's pilot, an IoT Android application, enabling the communication among different on board sensing technologies (accelerometers, GPS, etc.) and paired

sensors (SensorTag, smart plug, BLE - Bluetooth Low Energy - beacons, etc.), has been developed on top of a local middleware (L-WoX), which is part of the Web of Topics platform and allows a fast deployment of innovative services thanks to its abstraction and user-centric model. The main objective of the developed architecture is to turn the smartphone into a gateway between the environment and the rest of the WoX platform, collecting motility and positioning events related to a person that is moving inside a BLE-monitored location.

In the considered case study (as exemplified in Fig. 2, which describes the overall architecture of the WoX ecosystem), the user updates a specific topic moving close to a beacon (e.g., the *MOVING_START* or *MOVING_STOP* topics), which sends to the user's smartphone a BLE message (referring to the correct feature of the topic) telling any WoX-compliant listener its current position (e.g., the *room-id*). The L-WoX service installed on the smartphone is then able to detect the BLE beacon and forward the local topic information to any local mobile app subscribed to the considered topic. Furthermore, the mobile app can update (through 4G connection) the corresponding global topic located in the Cloud, where the WoX module redirects the data to several repositories for temporary event persistence, according to their macro-category. Then, a specifically designed Data Aggregation Module, which continuously listens for WoX Topic updates, extracts and aggregates the sensors' data on a daily basis in order to generate a set of high-level measures (e.g., *TM*, which refers to the *total amount of time spent moving* by the monitored subject) indicating how the user is performing according to certain criteria.

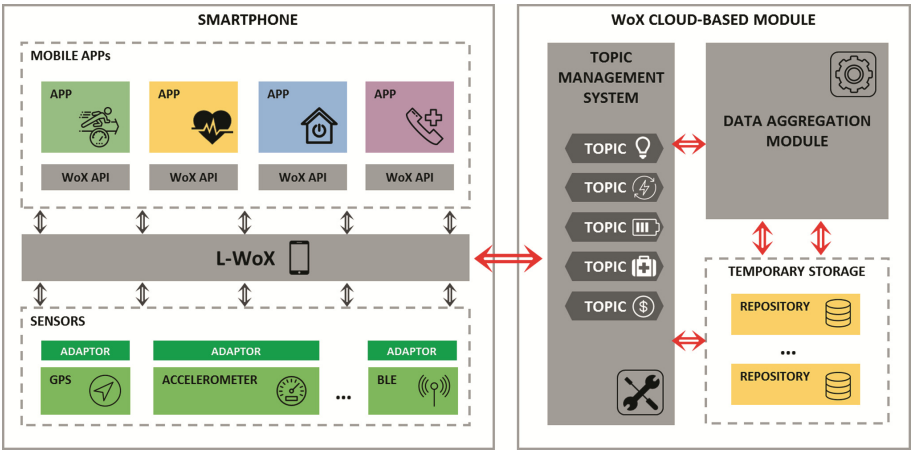

Fig. 2. WoX ecosystem for the Lecce's pilot

It is worth noticing that the model-driven approach characterizing the Web of Topics paradigm is inherently well suited for the intervention strategies laid down within the framework of the City4Age initiative. These set of strategies and procedures are in turn based on a hierarchy defined according to the following concepts:

- Geriatric Factors (GEF), such as *Motility*.
- Geriatric Sub-factors (GES), such as *Moving*.
- Measures, such as the previously mentioned *TM* aggregated measure.
- Gathering Method, which can refer to a wide range of sensors and devices, such as BLE beacons or built-in GPS sensors.

The Data Aggregation Module finally loads the resulting measures in the City4Age repository for further processing, where a central engine is used to detect and predict behavioral patterns. The early detection of risks related to a specific health condition can help geriatricians and caregivers to enact appropriate interventions that can slow down the progression of the condition itself, with beneficial effects on both the patients' quality of life and treatment costs. In fact, late diagnoses are known to decrease the chances of recovery, while at the same time increasing the costs of medical treatments. Furthermore, as a result of their behavioral pattern analysis, the monitored subjects can receive timely interventions – in a healthcare sector where medical protocols are less precisely established and prevention is usually left to the families and carried out via direct human contact – aimed at improving or avoiding behaviors known for their potentially detrimental effects on their health. The final aim of the test bed is to establish an empathic and persuasive relationship with the individual through a tailored, one-to-one communication, capable of convincing the subject to modify his/her behavior in a positive way, in order to prevent further decay.

5 Conclusion

In this paper, we proposed a mobile middleware able to monitor elderly people in their daily activities. Our solution allows important benefits: (i) compared to other solutions and the related work, it permits to progressive deliver unobtrusive techniques for elderly supervising in the e-health field; and (ii), more in general, it can be easily extended in order to develop innovative services in the smart city context for active and healthy ageing starting from defined geriatrics factors. Furthermore, the WoX middleware is able to transparently collect sensor data coming from heterogeneous devices and forward them to the remote reasoning server, in order to trigger appropriate alarms, generate notifications, and activate interventions.

As part of future activities, the project will start its testing phases and this will lead to apply risk detection algorithms on real data related to elderly behaviors. Furthermore, the WoX platform could be enhanced with a complex reasoning in order to handle the communications arising from various sources, and conflicting data that need to be normalized.

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