Towards Sustainable Water Resource Management: a Software Architecture for Smart Water Supply Networks

Guadalupe Ortiz and Alfonso Garcia-de-Prado

***Abstract*—**The rise of the Internet of Things and smart cities together with the fall in the communications cost and the democratization of smartphones has brought new challenges for software engineering. The areas of application in which these advances can be leveraged for decision-making are endless, improving the sustainability of cities, as well as the quality of life of their citizens. Even though open issues to be solved has been explored in recent years, it is challenging to find multidomain proposals effective and efficient for each domain. In the past, we proposed software architectures for context-aware and real-time processing of IoT data in various domains, evolving with the needs of society and keeping pace with advances in technologies. In this paper we explore the needs of such architectures for intelligent management of water supply networks, aligned with some of the issues faced by the United Nations sustainable development goals.

***Keywords*—** Internet of Things, Complex Event Processing, Context-Aware Service-Oriented Architecture, Smart Water Supply.

I. Introduction

THE rise of the Internet of Things (IoT) [1] and smart cities [2] has brought a new challenge in the field of engineering in general, and software engineering in particular. This trend is due to multiple factors: the availability of the Internet 24 hours a day, 7 days a week, the fall in the cost of communications and the democratization of devices with powerful Internet access such as smartphones or tablets; as well as a strong proliferation of sensors and other data providers for the IoT. The application domains in which it is possible to take advantage of these advances are endless, supporting decision making in multiple areas, improving the sustainability of cities, as well as the quality of life of their citizens. In fact, multiple publications can be found in recent years, both exploring the open issues and challenges to be solved [3], as well as making contributions in specific application domains [4]. Nevertheless, it is challenging to find proposals that are both sufficiently broad and generic to be applied to various application domains and at the same time effective and efficient for each specific application domain where they are implemented.

On the other hand, in order to facilitate the reusability of the designed software architectures, it is desirable that they are not monolithic but rather architectures implemented through the interconnection of various components that are as decoupled as possible and that allow the necessary components to be joined together according to the specific needs of each application domain and particular scenarios. In addition, these architectures must be able to process IoT data efficiently, given the huge and growing amount of data generated; as well as being able to respond in real time, in order to meet the demand of a society in which everything is *wanted now*.

In our previous work, we have proposed a series of software architectures for context-aware and real-time processing of IoT data in various fields such as health, or efficient urban waste management. In particular, we successfully proposed CARED-SOA [5] and COLLECT [6]. The first is a Event-Driven Service-Oriented architecture (ED-SOA or SOA 2.0), supported by an Enterprise Service Bus (ESB), which enables real-time processing of data from the IoT for early warning of events of interest to citizens. In particular, the architecture is particularized for the air quality domain and contextualizes alerts to citizens based on their location, personal features and daily activity. The second, COLLECT, goes a step further, and reuses CARED-SOA as a cloud node for processing pollutant data from multiple stations and alerting in real time of air quality levels hazardous to health; but also integrates a series of nodes in the fog, where the architecture has been stripped of its heavier elements to reduce the cost of each node and to deploy them in specific locations. The application scenario in this case is a hospital where the information about patients coming into the emergencies with respiratory problems is processed in real time and such information is correlated with the poor air quality alerts coming from the cloud node. This results in new domain-specific alerts that allow on-call specialists or other hospitals to be alerted of a possible unexpected increase in respiratory conditions. As an example of the versatility of the proposed architecture, the same technologies proposed in CARED-SOA successfully addressed the needs of urban waste management in SWAT [7]. In this case, where a low-cost hardware prototype was also

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developed, the level of fullness of the containers at any given moment was detected, so that at the time of departure of the collection truck the most optimal route for waste collection was calculated, giving priority to full containers over empty ones. Additional sensors added to the prototyping station allowed the authorities to be alerted via mobile notifications about a possible fire, and the maintenance company to be alerted about a possible blockage at the container door.

The proposed architectures have been evolving with the needs of society and keeping pace with advances in technologies. For example, in scenarios where we not only want to detect situations that have occurred, but also predict those that may occur in the future in order to prevent further damage, we integrated machine learning techniques into the architecture described above [8]. In the case of non-deterministic situations in which the experience of other people can help to predict some relevant data of the situation to occur, we can integrate mechanisms for citizen collaboration; a challenge that is increasingly achievable thanks to mobile technologies and their use by almost one hundred percent of the adult population [9].

In this paper we explore the needs of a major new application domain, the management of water supply networks, which is aligned with the United Nations Sustainable Development Goals (SDGs). In particular, SDG 6 focuses on clean water and sanitation aiming at increasing water use efficiency in all sectors and implementing integrated water resources management at all levels, with the support and strengthening of local communities' participation. In addition, in working towards this goal, we also collaborate with SDG 11: sustainable cities and communities.

The rest of the paper is structured as follows: Section II presents the background on the technologies and software architectures mentioned in the proposal. Then, Section III describes the case study for which we seek to provide a solution. Besides, Section IV examines the related work, highlighting the existent gap for real time intelligent water supply network management. Afterwards, Section V outlines the proposal presented in this paper. Finally, Section VI briefly summarizes the conclusions and draws future work.

II. Background: Technologies and Architectures to Process IoT Data in Real Time

Service Oriented Architecture (SOA) represents a paradigm for the design and implementation of loosely coupled distributed systems in which services are the primary implementation tool. These architectures facilitate interoperability between existing third-party distributed applications in a flexible and loosely coupled manner, so that the developer can focus on the business process without having to be tied to specific technologies for implementation. Thus, costs are reduced when system modifications or enhancements are required, as the system will be easier to maintain and evolve [10]. Consequently, the concept of service-orientation is based on the notion of providing a well-defined interface offering communications based on a standard protocol, where the provider and consumer implementations will thus remain fully decoupled.

On the other hand, the microservice architecture pattern provides an alternative implementation for service oriented architecture [11]. A microservice architecture is based on the concept of building an application as a set of small interconnected services, which communicate through light protocols [12], where each service is expected to implement an identified function of the server application. The communications are expected to be developed through Hypertext Transfer Protocol/ REpresentational State Transfer (HTTP/REST) synchronous requests or asynchronous message queueing protocols.

One step further, ED-SOA, or SOA 2.0, evolves from traditional SOA by replacing remote procedure calls with event-driven communications [13]. Despite all the advantages offered by an SOA 2.0, it requires other complementary software to be able to analyze and correlate large amounts of data in real time. For this purpose, Complex Event Processing (CEP) [14] is integrated into SOA 2.0, a technology that allows capturing, analyzing and correlating a large amount of heterogeneous events with the objective of detecting relevant situations in a given domain [15]. What we do is to define a set of event patterns that specify the condition that must be met from the event content of one or more incoming data streams for a situation of interest to be detected. These patterns are deployed in the CEP engine, which analyzes the incoming events to the system and alerts about the patterns that have been detected based on these.

In addition, when receiving large amounts of events to be processed by the system, it is convenient to integrate a message broker that facilitates such communications and the management of the input data. A message broker implements an asynchronous mechanism that allows complete decoupling of source and destination messages.

III. Case Study

Environmental degradation and lack of clean water pose fundamental challenges to sustainable development. Socio-economic progress cannot be sustained without clean air to breathe, clean water to drink, healthy soil for agricultural production, and a clean and stable environment in which work and life can be sustained.

Water is a scarce and vital socio-economic resource. The growing demand for water for both domestic and industrial purposes threatens the sustainability of groundwater, affecting our societies sustainability, too. This situation is being further aggravated by hidden leaks, i.e. leaks that go undetected until the meter is read, leading to excessive water consumption and customer billing. In addition, water supply fraud is another current problem. It is therefore essential that water resources are managed strategically, securely, efficiently and sustainably.

At present, most municipalities do not have smart meters, which would allow us to obtain data in real time; instead, most of them have traditional meters through which a company employee has to go in person to read the consumption of the meter. This situation would make efficient management of water supply networks unfeasible. Although smart meters are not cheap and replacing all the meters in a city would be unaffordable, more and more localities are starting to implement smart meters in some parts of the city.

We are currently working with the company Grupo Energético de Puerto Real (GEN) in the town of Puerto Real, which is already installing smart meters in several areas of the town. These meters will provide us with various data about the consumption of each meter, for example. The data can be obtained with more or less frequency; but a very high frequency can also lead to a high battery consumption, so it is necessary to reach a balance between frequency of data collection and battery consumption.

IV. Related Work

There are not many proposals that manage water supply networks in an intelligent way; and even less, that have the capacity to do so with the data obtained in real time and therefore generate alerts in time to prevent a waste of water, with its consequences for the environment and the economy, due to a non-localized leak or an undetected fraud.

Even so, we can mention some of the following works. Shahanas et al. proposed a smart water management system to generate alerts when water levels are below certain limits. They deploy water level sensors along with an Arduino board to perform the task of data collection, which is sent to a Raspberry Pi for analysis and send alarms when the water level falls below a certain threshold [16]. Narendran et al. presented a system designed for sustainable water management which distributes information about water sources collected by sensors and provides a warning system to notify the local community of alerts regarding water level [17]. In addition, Salvi et al. proposed an architecture to monitor and analyze a multi-tier smart irrigation system. This architecture collects information from irrigation sensors, and performs communication between them and a cloud server; the latest provides functionalities to analyze and visualize the collected data [18]. More recently, Mezni et al. proposed a framework with the aim of controlling and optimizing water quality through a set of intelligent corrective measures and thanks the use of machine learning techniques. Their proposal was validated with a real dataset [19].

All these proposals suffer from not being able to process the data in real time as they are taken in the smart meter; this prevents a quick decision making, which in their systems should be postponed to an analysis a posteriori, when they already have a series of stored data and too much time may have passed since the incident.

V. The proposal in a Nutshell

To meet the previously introduced challenges we propose the development of a platform, composed of a software architecture and several additional tools, for the intelligent management of water supply networks. Although we will focus on the GEN group networks, it could be extended to other water supply networks or other IoT domains.

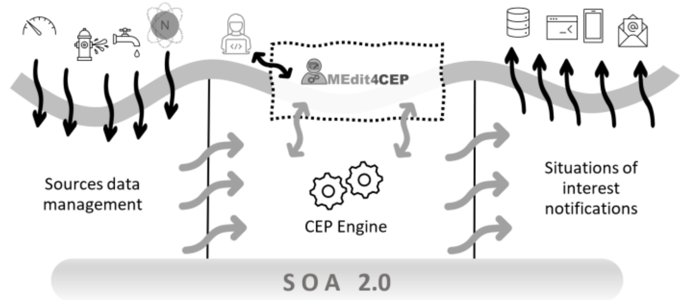

Fig. 1. Software Architecture for Smart Management of Water Supply Networks.

To this end, we propose the use of an SOA 2.0 integrated with CEP, which in our experience allows real-time detection of situations of interest from IoT data; it will be necessary to analyze how to adapt this integration of SOA and CEP to the specific needs of water supply network companies. It will also be necessary to evaluate various alternatives regarding the implementation of SOA 2.0 and the use of the CEP engine. SOA 2.0 could be supported by the use of an ESB or articulated through a pure microservice-based architecture [20]. In turn, CEP could be used with traditional or flow-based programming [21]. All these design decisions should be evaluated according to the needs of the system in question and always in favor of better performance and efficient use of resources.

In this scenario, it will be possible to obtain data from local and remote heterogenous data sources such as sensors and IoT platforms, we will have to define a set of patterns to detect the different situations of interest from the data received and we will provide a set of mechanisms for alerting interested consumers of the detected situations of interest. In particular, the platform, represented in Fig. 1, is expected to receive data from the company's meters, detect the patterns required by the company and make the appropriate notifications to consumers according to their needs.

On the other hand, since there is usually no programming expert in this type of companies, it is considered essential to integrate the aforementioned architecture with a graphical interface and an IoT data simulator, which allows defining and testing the data to be received, the patterns to be detected and the notifications to be made graphically, and which automatically generates and deploys the code to be executed on the servers. For this purpose, we will extend nITROGEN [22], an IoT synthetic data generator, and MEdit4CEP [17], a tool for the graphical definition of CEP patterns, to be characterized according to the domain in question.

In addition to the extension of these tools, a series of clients will be created to receive events of interest, such as a monitoring console where company employees can quickly visualize the alerts detected and a series of mobile applications where, for example, the subscriber can see if there is any incident in his meter readings.

VI. Conclusion

Thus, we can conclude that based on our previous experience, a software architecture based on the SOA 2.0 model and complemented with a CEP engine; as well as a series of tools for its management, testing and alert notification, is suitable for the needs of a water supply network management company. With the use of this architecture and tools we will make a more sustainable consumption of water resources and save costs for both the supplier and the subscribers, contributing towards the SDG 6 and 11 described by the United Nations.

Of course, the platform could be more ambitious and integrate and correlate data from other application domains to provide more functionality; such as alerting caregivers of an elderly person living alone that he/she has not consumed water for a whole day or that he/she has not left the bedroom for 24 hours.

In our near future work we want to take the last design decisions previously mentioned and test a prototype of the platform with the company GEN in some of the sectors of Puerto Real that already have smart meters. Subsequently we would like to integrate different verticals of the city to give a better service to the citizens moving towards more sustainable and intelligent cities.

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