An IoT based reference architecture for smart water management processes

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Abstract

Water is a vital resource for life, and its management is a key issue nowadays. Information and communications technology systems for water control are currently facing interoperability problems due to the lack of support of standardization in monitory and control equipment. This problem affects various processes in water management, such as water consumption, distribution, system identification and equipment maintenance. OPC UA (Object Linking and Embedding for Process Control Unified Architecture) is a platform independent service-oriented architecture for the control of processes in the logistic and manufacturing sectors. Based on this standard we propose a smart water management model combining Internet of Things technologies with business processes coordination and decision support systems. We provide an architecture for sub-system interaction and a detailed description of the physical scenario in which we will test our implementation, allowing specific vendor equipment to be manageable and interoperable in the specific context of water management processes.

Keywords: Water management, Irrigation, OPC UA, Internet of Things

1 Introduction

Water management is defined as the activity of planning, developing, distributing and managing the optimum use of water resources. This impacts on several key matters [1] of human lives, such as food production, water consumption, sewage treatment, irrigation, purification, energy generation and utilization, etc.

The lack of water ICT (Information and communications technology) standards prevents an effective interoperability, and increases the cost and the maintenance of new products. Nowadays there are many small and local producers of specific solutions in a weak and fragmented market. The almost no adoption of complex and interoperable systems jeopardizes the control and monitoring of water distribution networks, preventing also their evolution and necessary improvements, as an adoption of IoT (Internet of Things) paradigm.

In addition, current ICT systems for water management are proprietary and packed as independent products, support all management levels from the product development to the communication with management systems. System maintenance and sustainability depends on the company providing it. This

Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, volume: 6, number: 1, pp. 4-23

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entails the SMEs (Small and medium-sized enterprises) that develop water management ICT systems and tools may not enter the water market even with powerful solutions without considering a complete system that jeopardize their strengths.

OPC (Object Linking and Embedding for Process Control) was developed by the automation and logistic industry as an open standard specification that would allow the communication of real-time plants data between control devices produced by different manufacturers. The most recent version of OPC (OPC UA), is based on web services technology, so OPC UA becomes platform-independent and can thus be applied in scenarios where classic OPC is not used.

In this work we complete the smart water management model that we proposed on [2]. In our previous work we defined an Internet of Things-based model for smart water management using OPC UA. This previous work has been extended by the provision of a detailed architecture in which we consider IoT technologies for decoupling decision support systems and monitoring from business processes coordination and subsystem implementation. This functional architecture considers several layers and interfaces to enable layer interaction. We also extended our reference model describing a practical use case defining how the MEGA architecture is used to develop a simple water management process control by using recipes, and explaining more practical aspects of our validation scenario, held in a water management experimental station in Zaragoza, Spain.

The rest of the paper is as follows: Section 2 proposed a high level architecture based on industrial challenges, water management requirements and OPC UA functionalities; Section 3 describes the integration of IoT into the water management system; Section 4 develops the reference model for smart water management, comes up with a simple use case, and finally analyses current water management scenario and future implementation.

2 High Level Architecture for effective water management

Consumers in the water sector provide a weak critical mass to influence in decisions resulting in appropriate changes. The water sector operates in a complex interaction between water resources and the socio-economic and environmental systems. The range of stakeholders is huge, public and private, from global to local companies, supported by national, regional and again local authorities. This different nature in stakeholders and also the various schemes for water governance, which are continuously evolving in every country, are the main reasons for current market fragmentation in water management solutions. An excessive market fragmentation is a severe barrier for innovation under the desirable paradigm of an Integrated Water Resources Management (IWRM), by slowing down the adoption of open reference architectures and standards. This approach could enable interoperability, making it easier for developers to upgrade current solutions and integrate and adopt innovative ones.

2.1 Challenges for defining Industrial Standards for Water Management

In order to define feasible and wider industrial standards for water management processes, two main challenges must be solved: 1) The lack of integration of current solutions and 2) the unexisting common ICT reference model for water management processes.

There is a lack of integration of current solutions. Although there are many global vendors integrating water management solutions, local solutions can be also developed and maintained. The small and local nature of these companies make them anticipate to unexpected changes and enables them to provide various solutions for intra-regional issues. However, as consumers, small businesses do not have the critical mass to influence in decisions and to foster a reference system by themselves. The definition of a common framework to canalize these efforts is required, not only to reinforce synergies among different players, but also to enable the integration and widespread adoption of specific solutions.

Global and local vendors use different standards, methods, data models and communication channels for their solutions. These solutions are often very complex and sometimes economically unsustainable for their customers. This barrier leads to monitoring issues preventing the necessary decision making process. It states the need of common understandings and consistent methodology for an effective water management.

There is not an ICT reference model for water management processes. Nowadays, there are many companies involved in water management activities, such as collection, distribution, conduction and treatment. Furthermore, companies involved in areas related to soil management or chemistry also demand suitable technologies for water support and provision.

This implies huge heterogeneity that requires various skills working together. Thousands of companies are directly active in this kind of processes. For example, 1.500 companies are involved in water technology in the Netherlands [3]. In Europe, the EUWMA (European Union of Water Management Association) represents over 8.600 organizations in eight countries. Also, in USA, companies specialized in water treatment are members of an international trade association representing over 500 companies [4].

The new arrival of ICT technologies in the water management field has to deal with the large variety of processes and functions required to understand the water management cycle (urban and rural consumption, weather and climate change, water resources, agriculture, ground water, forest, river basins, environmental areas of special interest, etc). This complex cycle results in the lack of a reference model for the use of ICT and the absence of a clear leader on ICT technologies that covers the entire water management process. There are some European initiatives [5] for defining common frameworks for water policies, but *there is not any international organization promoting the definition of ICT standards to foster effective interworking of water management infrastructures and components*. This is mainly due to two reasons:

Little appreciation for interoperability: water management processes are performed by specific technologies coming from other sectors, such as automation, energy, etc. The control of such technologies is provided by proprietary solutions. One reason for the lack of effective interworking of water management infrastructures and components is that there is not any requirement, demand or legal regulation that imposes the interconnection of such systems.

Water management companies locally oriented: most of the water management solutions currently used are provided by SMEs. Those companies provide simple solutions for very specific problems with local markets that needs close relationships, but they usually find problems to expand their business top other areas or countries due to different regulations, and low equipment interworking. The problem for the end-users is that they are engaged with local providers which can even disappear and the existing infrastructure cannot be maintained and updated by any other. Therefore they are forced to start from the scratch with a big reinvestment.

To overcome these problems, Tragsa [6] is promoting the MEGA [7] model as an specific initiative in Spain that can be translated to European and International levels. Tragsa is a public company that belongs to Spanish Ministry of Agriculture, Food & Environment deals with all aspects of water management. In Mediterranean countries water consumption for agriculture represents the 70% of the total and higher energy consumption than a big city like Madrid, Rome, Paris, or Athens. The MEGA model considers a functional decoupled architecture to allow interoperability between specific vendor equipment.

2.2 Requirements for a reference Architecture

We define the following requirements that must be fulfilled to develop a standard water management model:

REQ #1: The system should cover these water management functions: remote management of physical elements and operation of basic units; identification of resources in the water network, definition of operations and conditions over the network.

REQ #2: It should support interoperability with other applications such as geographic information systems and also databases containing information regarding soils, weather forecast, environment, farming, etc.

REQ #3: It should provide a flexible and extensible architecture for the integration of various systems. To do that, it must define open interfaces among communication and process control layers, and also integrate IoT systems for a direct access to individual water management devices.

REQ #4: It should support integration with legacy systems, controlling current equipment. Water management infrastructures currently deployed in the countryside consist of many interconnected and simple devices that must be managed using legacy systems. They integrate communication functions, data models, and protocols dependent on an specific technology of the manufacturer. Overriding these systems with new ones is not always a feasible solution.

2.3 Requirements for a reference Architecture

OLE for Process Control (OPC), which stands for Object Linking and Embedding (OLE) for Process Control, is the original name for a standards specification developed in 1996 by an industrial automation industry task force. The standard specifies the communication of real-time plant data between control devices from different manufacturers[8] .

As of November 2011, the OPC Foundation has officially renamed the acronym to mean ”Open Platform Communications”. The change in name reflects the applications of OPC technology for applications in process control, discrete manufacturing, building automation, and many others. Initially, the OPC standard was restricted to the Windows operating system. This specification, which is currently known as OPC Classic, enjoyed widespread adoption across multiple industries, including manufacturing, building automation, oil and gas, renewable energy and utilities.

With the introduction of service-oriented architectures in manufacturing systems new challenges in security and data modeling arrived. The OPC Foundation developed the OPC UA (OPC Unified Architecture) specification to address these needs and at the same time to provide a feature-rich open-platform architecture to be future-proof, scalable and extensible.

OPC UA, released in 2008, consists of the following parts: Concepts, Security Model, Address Space Model, Services, Information Model, Mappings, Profiles, Data Access, Alarms and Conditions, Programs, Historical Access, Discovery and Aggregates. It also defines a platform independent service-oriented architecture that integrates all the functionality of the individual OPC Classic specification into one extensible framework. The multi-layered approach of OPC UA accomplishes these original design goals:

- **Functional equivalence:** all COM OPC Classic specifications are mapped to UA
- **Platform independence:** from an embedded micro-controller to cloud-based infrastructure
- **Secure:** encryption, authentication, and auditing
- **Extensible:** ability to add new features without affecting existing applications
- **Comprehensive information modeling:** for defining complex information

The OPC UA information-modeling framework turns data into information. With complete object-oriented capabilities, even the most complex multi-level structures can be modeled and extended. Datatypes and structures are defined in profiles. For example, the existing OPC Classic specifications were modeled into UA profiles, which can also be extended by other organizations.

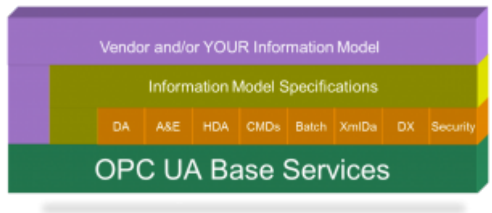

Figure 1: OPC UA information Modeling

OPC UA offers a set of Base Services, which is complemented with optional services (Data Access, ASE, Historical Data Access, Commands, Alarms and Events, Data Exchange and Security), as shown on Figure 1. Over Base Services and using some of the optional services, the OPC UA standard can be applied to any specific domain by the definition of the Information Model Specification. In the top level vendors can define their own specific Information Model.

The new functionalities provided by OPC-UA specification (support for Web applications to access OPC-UA servers, OPC-UA cloud computing service) are aligned with the requirements of the proposed water management architecture. Thus, we decide to use this standard for the communication between MEGA interfaces.

2.4 High level Architecture for effective water management

The MEGA architecture is described in Figure 2. The proposed high level model identifies three layers (from bottom to top): the *Subsystems layer*, the *Coordination layer* and the *Management - Exploitation layer*. These layers deal with a common *Water Management Model* that considers the definition of *Entities*, *Recipes*, *Procedures*, *Planned processes*, and *Alarms*. The water management model is the key element for enabling MEGA to provide a common behavior framework. Between the Subsystem layer and the Coordination layer there is a *Coordination - Subsystems interface* and between the Coordination and the Management - Exploitation layer there is a *Common Communication* interface. It is also considered an Administration layer that manages the information provided by the Coordination layer through the *Administration Interface*.

We describe the main elements of the MEGA architecture:

Management and Exploitation layer: this layer hosts the main applications and services responsible for the efficient management of water infrastructures, and supports the definition and management for the processes applied to those infrastructures. In this layer the Operators (big service companies, and end-users associations among others) drive management processes abstracting from the specific final systems deployed in the real environment. Services can be executed on local hosts, cloud services or whatever other service environment provided by current state of the art technologies.

Coordination layer: this layer supports the interoperability among different management and exploitation systems and the underlying hardware and software subsystems. Based on the definition of a water management model, the Coordination layer perform the following functions:

- **Entity management:** The coordination layer defines and associates entities to physical objects. Entities can be *Real Entities* when they directly correspond to physical devices or *Virtual Entities*,

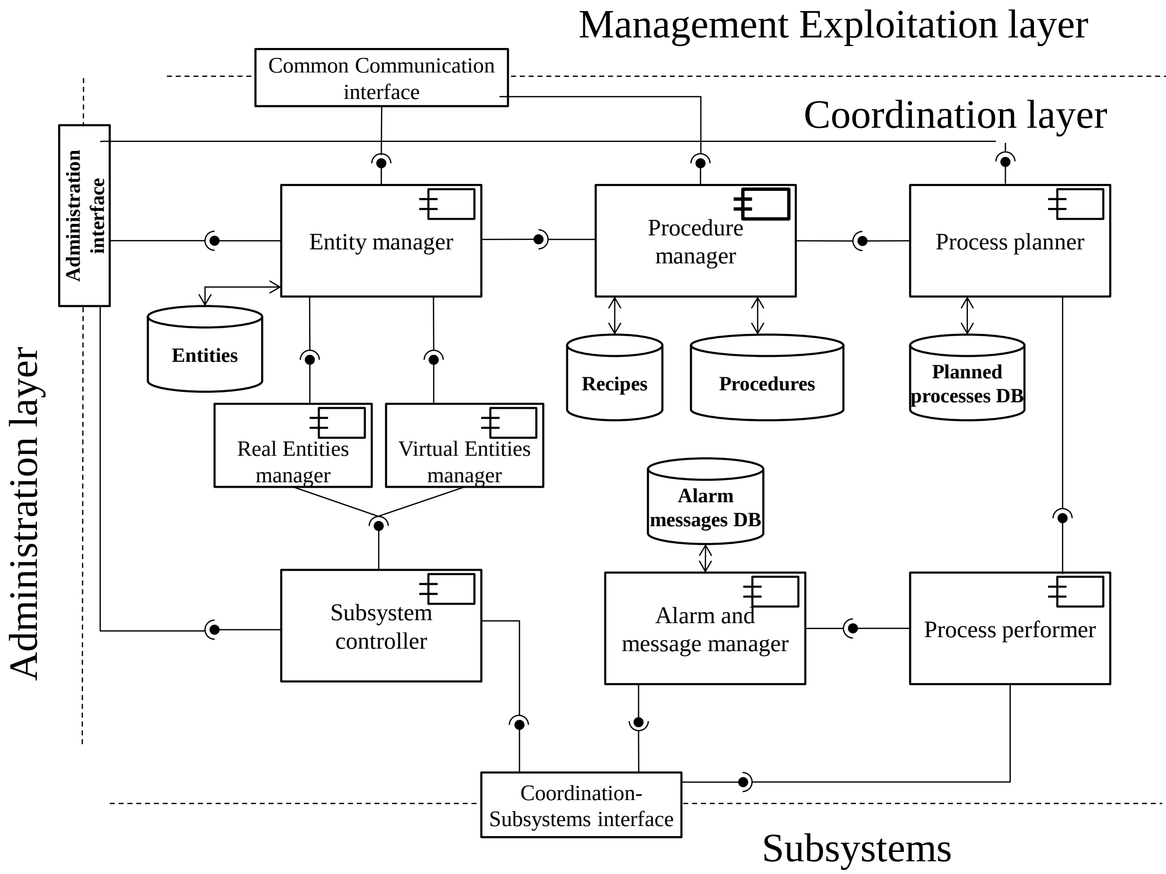

Figure 2: MEGA High level Functional Structure

when they correspond to a functionality that can be either covered by multiple devices or part of a single device.

- **Procedure management:** A *procedure* is a high level water management use case that is performed in one or many subsystems. Procedures defined by the Management and Exploitation are collected and delivered to the Subsystem layer. The coordination layer interacts with the subsystems taking into account the topology of the water system, and the interface of each subsystem.

- **Recipe management:** *Recipes* specify the sequence of activities to be executed in subsystems. They are associated to procedures. The *Procedure manager* binds recipes with defined procedures.

- **Process planning:** Processes are atomic activities that are executed inside a subsystem. Recipes are composed by processes. The *Process planner* defines processes and delivers them to the *Process performer*, which is in change of its execution.

Subsystems layer: the subsystems layer contains the different subsystems integrated into the Water Management System. Each subsystem is independent from others and manages the lifecycle of the operations that are executed. Subsystem can be heterogeneous and dependent from proprietary technologies. In order to achieve interoperability they must implement the methods defined in the Coordination-Subsystems interface.

Administration layer: the administration layer enables the configuration of the different entities defined in the Coordination layer. It provides a user interface that can be consumed by platform administrators to perform administration and monitoring functions.

Three main interfaces are defined in this high level architecture, the Administration Interface, Common Communication Interface and the Coordination-Subsystems Interface:

Administration Interface: The Administration interface enables the monitoring of the entities defined and stored in the coordination layer. Specifically it monitors entities, procedures, and processes, and how these processes a being executed into subsystems.

Common Communication Interface: This bidirectional interface provides a common solution in order to handle messages from business processes in the management and exploitation layer and process them in the coordination layer by using industry driven standards such as ISA-95/88 and OPC UA, as explained in Section 2.3.

Coordination-Subsystems Interface: this interface enables the execution of water management processes in the subsytems. The Coordination layer does not know precisely the internal structure of each subsystem (which is implemented by each company), but can delegate processes and monitor their execution and the status of the physical systems requesting relevant information. This information is collected, processed and further translated to the Management and Exploitation layer.

These layers and interfaces rely on how water management elements and processes are defined. Data analysis, collection, process distribution and system behavior are defined into a physical model and a process model.

Physical Model: The physical model enables the definition of the equipment integrated in the water management systems in a hierarchical way. This model identifies in an unique way the entities participating in the subsystem, how the are related and grouped. As subsystems can be heterogeneous and dependent from proprietary technologies, it allows SMEs, which do not have the resources to implement a whole reference system on their own, to develop o reuse a single subsystem.

Process Model: based on the physical model and knowing the process each subsystem is able to perform, simple or complex processes are defined and (i) loaded into the system; (ii) validated according to internal information; (iii) distributed to the suitable subsystems; (iv) executed and monitored; and finally (v) stopped and reported.

OPC UA is defined for controlling processes assigned to physical entities. Due to the specific nature of water management systems, MEGA identifies the "virtual entities" as a concept that is defined for facilitating the water management over one specific water system. The virtual entities can be defined as "logic devices generated by the logic operation of an hydraulic entity". The use of virtual entities enables the definition of processes for such elements that do not correspond to real devices, instead they correspond to a functionality that can be either covered by multiple devices or part of a single device.

Due to the virtual nature of such entities, their functional behavior and states will be determined in the Coordination Layer, instead of in the Subsystems. Then, control recipes including procedures for such virtual entities are going to be executed by the Control Layer, as such those recipes are not going to be transferred to any subsystem.

MEGA provides a reference Architecture for water management process using OPC UA. Figure 3 shows how the MEGA reference architecture fits into the automation pyramid, and uses OPC UA for communication between the Coordination Layer and the Subsystem Layer.

The first version of MEGA defined the two interfaces based on OPC UA: the Common Communication Interface and the Coordination-Subsystem Interface. Nevertheless the interface between the Process Control Level and the Control & field Level is not defined in MEGA at all. This is because the nature of water management system for irrigation in the field. MEGA reference architecture identifies the subsystems for covering the Process Control Level and the Control & field Level, so each manufacturer company can provide on the box solutions using the most suitable process and communication tech-

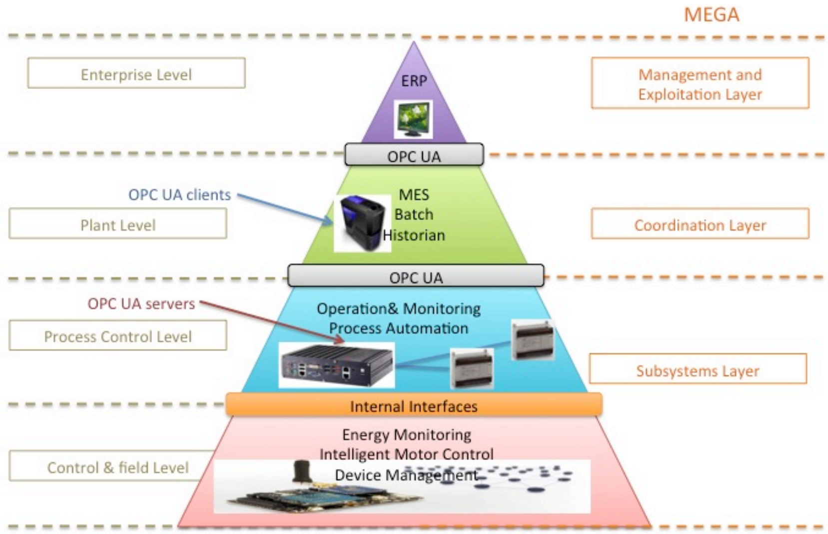

Figure 3: OPC UA in the automation pyramid for MEGA

nologies according to the state of the art and the requirements imposed by such kind of systems. In the water management process the equipment has to be deployed into an hostile environment (open air, bad weather conditions, unattended or difficult access equipment, etc.) Therefore it is a key issue for every provider that their system is able to solve such difficulties even with specific interfaces.

3 Integrating IoT in water management

Contributing to solutions that integrate the Internet of Things paradigm into water management processes can be beneficial to address expected solutions. The rest of this Section describes the main benefits of adopting IoT and the IoT characteristics that are considered in the proposed MEGA model, considering new advances on ICT technologies for creating feasible and commercial systems [9].

Mark Weiser defined a "Smart Environment" [10] as - the physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network. There are many research works that contributes to solve various issues in *Smart Environments*, such as seamless access to resources and devices [11], distributed service executions [12], social choice techniques [13], etc. Other works explains how IoT is based on three paradigms - internet-oriented (middleware), things oriented (sensors) and knowledge-oriented (semantics) [14]. Although this type of delineation is required due to the interdisciplinary nature of the subject, the usefulness of IoT can be unleashed only in an application domain where the three paradigms intersect.

3.1 IoT for Water Management

The provision of Internet of Things capabilities in water management scenarios can be achieved if we consider some considerations from the business, social and technical point of view. Here we list the main benefits of providing IoT in water management scenarios:

Efficiency increase: water management companies and associations can use real-time operational control to make smarter business decisions and reduce operating costs. They use real-time data from sensors and actuators to monitor and improve water management infrastructures, making them more efficient, reducing energy costs and minimizing human intervention.

Cost savings: water management costs can be reduced through improved asset utilization, process efficiencies and productivity. Customers and organizations can benefit from improved asset utilization (e.g., smart water irrigation units that eliminate manual operation) and service improvements (e.g., remote monitoring of irrigation conditions)

Asset utilization: with improved tracking of assets (machinery, equipment, tools, etc.) using sensors and connectivity, companies can benefit from transparency and visibility into their assets and supply chains. They can easily locate assets and run preventive maintenance on critical pieces of infrastructure and machinery.

Productivity increase: Productivity is a critical parameter that affects the profitability of any organization. IoT allows real-time control, new business models, process optimization, resource conservations, service time reduction, and the capability to do all of this globally, reducing the mismatch of required vs. available skills and improving labor efficiency.

Expansion of new and existing business models: IoT is beneficial in any of the three defined layers. In the *subsystem layer*, IoT subsystems are able to execute processes and communicate using a standard communication interface; in the *coordination layer*, it can be useful to enable SMEs to design new coordination applications, with the purpose to orchestrate the management and exploitation layer with the subsystem layers; and finally, in the *management and exploitation layer*, IoT identification capabilities contribute to provide tailored information services for an specific water distribution network community.

As we explained before, IoT builds on three pillars [14]: *Internet orientation, thing orientation, and knowledge orientation*. We link these pillars with the ability of objects to (i) be identifiable (anything identifies itself), (ii) communicate (anything communicates) and (iii) to interact (anything interacts), either among themselves, building networks of interconnected objects, or with end-users or other entities in the network. The proposed MEGA model considers these properties:

Internet-oriented: the proposed MEGA model identifies three layers (see Figure. **??**). These layers are communicated with two web interfaces enabling the definition of a flexible and scalable communication system for controlling the huge amount of subsystems to be required for a complete water management system.

The *Coordination* and *Management - Exploitation* layers are defined as Cloud services. IoT, as a broader vision of the previous concept of machine-to-machine (M2M) communications, is gaining support by current Cloud computing infrastructures, which begin to provide so called cloud-based IoT solutions.

Furthermore, subsystem capabilities (i.e. sensing, actuating, computing and communication technologies) depend on the specific conditions of the scenarios in which they are deployed. A seamless access to subsystems will require that the **Subsystems layer includes homogenization through a large diversity of communication paradigms and higher granularity**, to deal with many communication technologies.

Thing-oriented: Due to previous experiences of the development of systems for water management, the most granular element to be accessible is the subsystem. It is expected higher granularity in the coming years, as subsystems are composed by many devices and interrelations, as we describe in the physical and process models of Section 4. These elements can be redefined as *Smart Objects*, being objects which are able to describe its own possible interactions. Smart Object may provide the following information: Object properties (physical properties and a text description), behavior (different behaviors based on state variables) and, also, interaction information (current state of dials, gauges, switches, etc.).

It is important to define how subsystems as smart object containers fulfills the features identified by [14] and [15]. Subsystems defines and provides object identification, to do that they must incorporate

Unique system identification features. Also, they publish subsystem capabilities, as a list of functions supported by them, considering the capabilities of integrating objects.

Knowledge-oriented: due to the large heterogeneity of subsystems for water management it is important to model the characteristics that these subsystems have in common, and their behavior. In this work we provide a physical model, defining the physical elements executing water management processes in a hierarchical way, and also a process model, organizing the execution of particular processes in water management subsystems. Based on these models, smart execution of water management processes is supported through collaboration between subsystems and the Coordination layer, based on the interchange of information among them (see Figure. 3). Thanks to knowledge provision systems can be monitored to facilitate public entities tracking the fulfillment of regulations. **Information to be monitored is autonomously provided by the subsystems** based on sensor capabilities. These models can be enriched with semantics to describe, share, and integrate information, inferring new knowledge related to water management and irrigation processes. Semantics also helps to create machine-interpretable and self-descriptive data in the IoT domain. Semantic descriptions can support data integration by enabling interoperability between different data sources (sensors, devices); however, analysis and mapping between different semantic description models is still required to facilitate the IoT data integration with other existing domain knowledge.

4 Reference model for smart water management

This Section describes the water management model that is being developed. This model consist of three main elements, the Water Management Model, Common Communication Interface and Coordination-Subsystems (C-S) Interface.

4.1 Water Management Model

The water management model includes the physical model and the process model.

The physical model follows standards EN 61512 [16] and EN 62264 [17]. As proposed by EN 61512 a layered structure is defined and represented in Figure 4. The three upper layers (Company, Location and Area) are modeled as in EN62264, representing companies organization. The Process Cell and Unit represent entities in which processes are executed. Examples of process cells and units are an Irrigation Sector and a Pump Management Station (PMS) respectively. Finally, the Equipment Module and Control Module are elements belonging to the subsystem and can not be directly accessed by the Coordination layer. Due to the current advance in the state of the art in IoT these elements will become *Smart Elements* in a future and they will be directly identified and accessed. Hydrants, filtering stations and pumping lines are examples of equipment modules. Valves engines and meters are examples of control modules.

The process model organizes the execution of particular processes in water management subsystems, following a predefined strategy. Examples of processes are irrigation, tank filling, or water consumption measurements. The process model identifies the *Procedure*, as the basic element to be executed by the Process Cell. Procedures are composed by *Unit Procedures*, as the basic element to be executed by one unit, and finally, the *Operations*, as atomic instructions executed inside units. For example, an atomic instruction to be executed in a pump management station can be to execute a periodic cleaning process to optimize the performance of the station. The definitions of elements and operations in the physical model and process model respectively enable the operation and remote management of water management elements, as REQ #1 demands

4.2 Common Communication Interface

The Common Communication interface is composed by a set of web services that are consumed by applications belonging to the Management - Exploitation layer, in order to operate on entities defined by the physical model, identify the current state of the systems and also send water management operations to control the water consume.

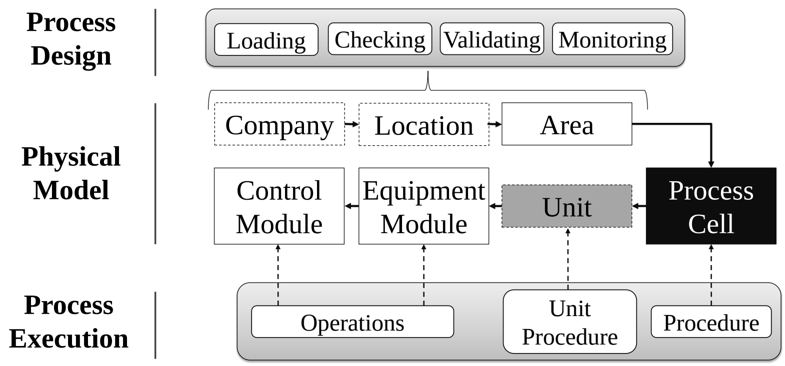

Figure 4: Layers of the physical and process models

The Common Communication interface handles messages from the business processes (GIS-based applications, services providing information about soils, meteorology, as REQ #2 demands), in XML format, and transforms them to ISA-95/88-compliant OPC UA information models. OPC UA (IEC 62541) is an industry driven standard which provides unified communication and interaction means for Service Oriented Architectures and Web Services. It is often used to implement different profiles for automation systems [18] such as home and industrial automation and also water management systems. OPC UA contributes to fulfill REQ #3, as it enables the integration of different systems based on specific technologies.

OPC UA defines an information model that enables the creation of device instances and device types. We implemented the physical model in OPC UA defining control messages in the Management - Exploitation layer, and enabling the execution of these messages in the Coordination layer. In order to be compliant to ISA-9588, we define recipes, which specify the sequence of activities in the form of procedural steps. Thus, control messages contain recipes that will be executed in the subsystems, by the physical components located inside. Using recipes becomes the solution to manage subsystem elements, which are not directly accessible by the Coordination layer, as the sequence of activities to be performed must be decoupled from the specific technology in the subsystems, as REQ #4 demands.

There can be some problems if more that one recipe is executed on the same entity at the same time. To solve that we define recipes with execution restrictions, which prevent multiple recipe executions over the same physical element. To check which elements are used by a recipe the Coordination layer retrieves the list of operations to be done by the recipe and gets the identifiers of the process cells and units which perform these operations. If any of these process cells and units are used by other recipe that must be executed at the same time the coordination layer finds an incompatibility, which must be solved in the Management - Exploitation layer by user intervention.

Figure 5 describes the defined model for recipes. The control recipe has a *RecipeID* that uniquely identifies it. Also, it *Header* identifies the procedure in which the recipe is included with the *ProceduralID*, and the type of recipe to execute (*RecipeType*). The *Formula* includes the set of actions to be performed over the entity *EntityID*. Depending on the recipe type, the formula applies to either the active elements (monitoring recipe), irrigation elements (irrigation recipe), hydrants of the entity (hydrant

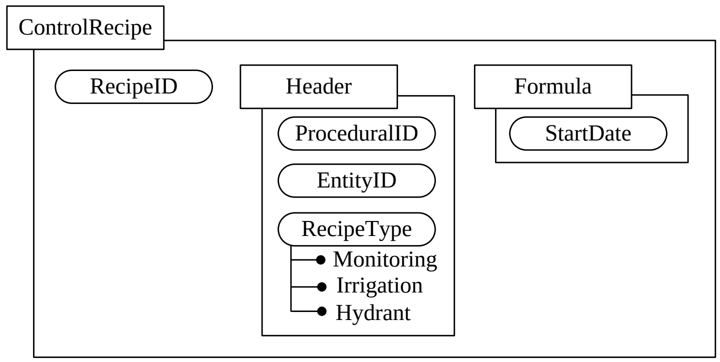

Figure 5: Control recipe model

recipe), etc.

4.3 Coordination-Subsystems interface

The Coordination-Subsystems (C-S) interface exchanges OPC-UA messages between the *Coordination layer* and the *Subsystems*.

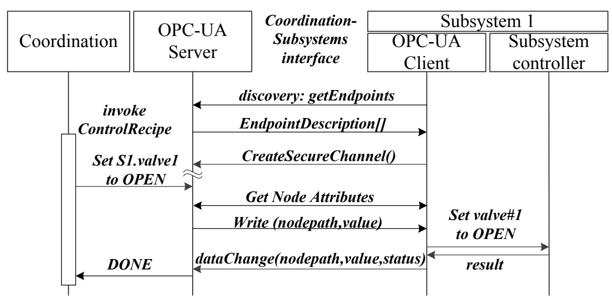

Figure 6: Invoking a simple control recipe

This interface considers the water management elements (Units, Process Cells, etc) as a set of nodes, which can be monitored and accessed by OPC-UA clients. A modification of these nodes, due to the execution of a recipe formula, results in changes in the behavior of physical elements. Recipe formulas are transfered from the coordination layer to subsystems that can execute them. To do that, the coordination layer must know the subsystem capabilities. OPC-UA supports the definition of *Profiles*, which describes the supported features by an OPC-UA compliant product. Mandatory features that must be supported by clients and servers are defined in profiles, along with other non-required functionalities that are negotiated between entities. Currently, the OPC Foundation has published more than 60 OPC-UA profiles [19].

Figure 6 describes an interaction diagram of the use case *'Invoking a simple control recipe'*. The diagram reflects the interaction between Coordination layer and Subsystems, which includes an OPC-UA server and an OPC-UA client respectively. Subsystems must discover supported profiles by getting the server endpoints. Then, a secure communication channel is created with the server. A modification of a property in a subsystem device (such as opening a valve) is transmitted through the C-S interface using the OPC Get Node Attributes command, to retrieve the name, type, description and permissions (read and/or write) of the node, and finally, using the OPC write command to change the node value.

When the change is performed in the physical system (e.g. a valve is opened), the element responds with a *dataChange* event that is delivered to the Coordination layer, with the result of the action.

4.4 A simple Use Case

In this Section we illustrate by the use of a simple example how MEGA can be used. We describe a simple but realistic scenario, we show how the data are defined for loading into MEGA, and finally we outline how MEGA performs the process control.

1. *Scenario description*

   The proposed scenario contains "a single subsystem with a hydrant and a water deposit that provides water to the system". Figure 7.A shows the scenario schema.

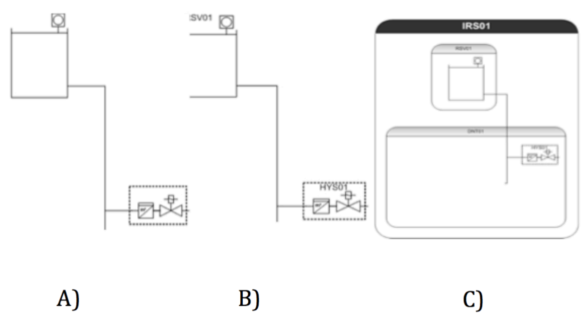

Figure 7: Physical Model

   For such Hydraulic Network we want to define the next process, direct expressed by the farmer: "to irrigate the 27th of September at 12.00 finishing at 12:30 and using 800 liters as maximum volume".

2. *Definition of the Physical Model*

   Based on the real equipment described on Figure 7.A the next step is the definition of the Physical Model according to MEGA specifications. Figure 7.B depicts the component identification, and Figure 7.C describes the physical model for this use case. MEGA does not define any standard procedure for loading the physical model into MEGA System. The table of Figure 8 is elaborated from Figure 7.C and loaded into the Coordination Layer.

WMD01
WDM01.IRS01
WDM01.IRS01.RSV01
WDM01.IRS01.DNT01
WDM01.IRS01.DNT01.HYS01

Figure 8: Physical Model loaded into the Coordination Layer

4.5 Definition of the Master recipe

As described in Section 4.2 MEGA requires the definition of a Master recipe. The translation of the informal process to a semi-formal recipe is as follows:

- It is required to execute the process *Irrigation_recipe_1* over the simple hydrant *HYS01*
- Starting time for initiating the execution of the recipe: 27th of October of 2013, at 12:00
- End of the execution of the recipe: 27th of October of 2013, at 12:30
- Max water used for irrigation: 800 liters

MEGA does not specify how to define the recipes. In our case, the following elements apply:

- The target entity for the recipe is: WMD01.IRS01.DNT01.NBU01.HYS02
- The conditions that apply to this recipe are:
  - StartDate (201312011200) according to ISO8601
  - Two conditions for finishing:
    - MaxVolume $->0.8(m^3)$
    - MaxDuration $->1800(seg.)$

In order to illustrate how a water management procedure recipe looks like Figure 9 presents the XML description of the example of Master recipe given above.

```
<procedure>
   <Procedure_Operation>
      <proceduralID>
          PROC001
      <proceduralID>

      <entityID>
          WMD01.IRS01.DNT01.HYS01
      </entityID>

     <RecipeType>
         Irrigation_recipe_1
     </RecipeType>
  </Procedure_Operation>
  <formula>
     <StartDate>
          201312011200
     </StartDate>

     <Maxvolume>
           0.8
     </Maxvolume>

     <MaxDuration>
        1800
     </Maxduration>
   </formula>
</procedure>
```

Figure 9: Operation Process over a single Entity

The final element to be loaded into the MEGA system is the Master Recipe, which encloses the process defined in Figure 9 into several “administrative” envelops, which detailed description is beyond the scope of this paper.

The Master recipe is transferred to the Coordination Level, where the following functions are performed:

1. **Identifiers Mapping:** Identifiers of the Master recipe are mapped into identifier of the subsystems. The identifiers mapping algorithm is not defined by MEGA, neither current version of OPC UA. In MEGA this functionality is left for manual or semiautomatic implementation according to developer's preferences. Currently there is an initiative of OPC UA standardization in order to be able to support automatic identification of entities with OPC UA, we expect that next version of MEGA can incorporate this enhancement.

2. **Recipe validation:** The validation of the recipe sent by the Management and Exploitation Layer requires to check that the corresponding subsystem is able to execute the process contained in this Recipe. MEGA defines a procedure for deciding when it is not going to be concurrency problems related to the assignation of more than one process to the same entity at the same time period. In our simple scenario HYSO1 does not have any other process assigned for execution, so there is not any scheduling problem.

3. **Process transfer to the suitable subsystem:** The process to be executed for each entity is going to be transferred to the subsystem where the entity is located, and alarms and values can be monitored from the Control Application using standard mechanisms of OPC UA. In this case there is no alarms or values to be monitored.

4. **Control and monitoring of the process execution:** The transferred process is monitored from the Control application, while the process is autonomously executed at the subsystem level. The Coordination Layer provides information to the Management and Exploitation Layer about the execution of each Recipe.

4.6 Water management scenario description

Scenarios for water management consider natural environments, cities and rural regions. Systems deployed in these scenarios are controlled by applications that access to subsystems. It is necessary to consider various conditions, ranging from the number of subsystems to be deployed to the business models that must be considered for subsystem control, exploitation services and information exchange. This Section describes the deployment scenario we have defined for validating the MEGA model, that is developed in *Aula Dei*, an experimental station in Zaragoza, Spain. We also enumerate the list of functions that we are going to test in this station.

The Aula Dei experimental station is focused in the water management cycle, specifically in irrigation. A complete irrigation system is modeled, from the water intake to the distribution to the latest elements (i.e. hydrants). One irrigation system works by gravity and the other one works by artificial pressure, to cover all the situations that can be presented in a real setting. From the point of view of the automation and control elements, the execution of various procedures is allowed in the same hydraulic element. Specifically, the installation is divided into:

1. Upper network with two water tanks at different levels and a lifting station with two pumps in parallel and level control function.

2. Pressure network with automatic pumping station, three pumps in parallel. Two of them with variable speed drive. The network is composed by 20 hydrants, grouped into 4 lines that return water to the tank, closing the cycle.

3. Control center with the necessary computer equipment for proper control and installation, as well as for conducting some tests over the management applications.

4. Channel with regulation elements for downstream water, regulation gate for upstream water, mixed regulation gate and flow controlled regulation gate.

Figure 10: Deposit and three pumping stations in Aula Dei

Figure 11: Irrigation system in Aula Dei

Figure 10 shows the deposit and the three pumping stations that are installed in Aula Dei. Figure 11 shows the irrigation system composed by 20 hydrants and the corresponding regulation elements.

The following tests were performed to verify the proper operation of the installed equipment:

- Tests on remote systems, checking the correct operation of the installed equipment based on required settings. Also checking the interoperability between equipment and the control center.

- Water regulation flow tests, checking the optimal functioning of various control algorithms, both in pumping stations operating in conjunction with tanks and in regulation control points for hydrants.
- Tests on management applications, checking the correct operation and interoperability with the installed systems. Multiple computers are installed in order to perform parallel tests to check equipment coordination and detect interferences.

We enumerate a list of functions that we are going to test in the described scenario:

- Loading and configuration of the elements of the physical model. Mapping of hydraulic entities and association to subsystem controllers. Monitoring and listing of the elements of the physical model registered in the Coordination layer.
- Collection and consolidation of data from subsystems. Subsystem coordination and data integration, i.e. integration of hydrants' aggregated data for branch surveillance.
- Execution of control recipes in virtual entities, assigning to associated subsystem the corresponding actions. Creation of normalized history registries for virtual entities.
- Reception, interpretation, allocation and delivery of elements from the process model. Monitoring and listing of these elements.
- Storage, publication, and distribution of the hydraulic topology to applications that require it. Storage and publication of sensor data (weather conditions, humidity, temperature) collected by legacy subsystems, adapted to the MEGA model.

5 Conclusions and Future Work

Water management impacts on several key matters of human lives and several scenarios, such as cities, natural areas, agriculture, etc. Some works focus in the lack of ICT services and tools for water management, which would enable information reuse (goal of the PSI Directive [20]), easier fulfillment of policy regulations and resource monitoring.

In this paper we presented the MEGA initiative for defining a reference architecture for water management based on integrating IoT capabilities to achieve a scalable and feasible industrial system. We define the management exploitation layer, coordination layer, subsystems layer and administration layer and the interfaces that enable layer interaction. We also consider the physical model, which defines the physical elements executing water management processes in a hierarchical way, and also, the process model, which organizes the execution of particular processes in water management subsystems.

Processes are defined based on automation principles and using the widely used standard OPC UA. We illustrate how such architecture can be used for controlling real water management systems, but still we need to clearly define operation procedures for dealing with many real problems such as physical network definition or identifiers mapping.

Finally, we describe the deployment scenario we have defined for validation the MEGA model, developed in Aula Dei, an experimental station on Zaragoza, enumerating the list of functions that we are going to test in this station.

We can conclude that the adoption of IoT and OPC UA facilitates water management companies the access to a wider global market and incorporates new benefits to decisions support systems, monitoring, water governance and also water-energy nexus. Future work will describe the performed test and will focus on the contribution to solve coordination problems when executing multiple recipes over the same physical resources, considering priority and conditional executions and also process optimization.

Acknowledgments

This work is partially supported by MEGA, a join research effort of Tragsa and UPM. It is also supported by CALISTA project, TEC2012-32457, awarded by the Ministry of Economy and Competitiveness in Spain.

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