Innovative smart metering-based applications for water utilities

Smart metering is already being used in many utilities to manage water loss and customer consumption, but there is also the potential to improve network planning and operation and the overall system's water-energy efficiency. **PAULA VIEIRA, DÁLIA LOUREIRO, JOSÉ BARATEIRO, RITA RIBEIRO, MARGARIDA REBELO** and **SÉRGIO TEIXEIRA COELHO** discuss the development of a new ICT tool, iWIDGET, which brings together a set of applications for smart metering data.

Current smart meter technologies installed in water networks and in customer households that provide real-time and high resolution data raise several challenges for water utilities, but also provide an opportunity to improve a utility's business based on real and highly valuable data.

Smart meter technologies grant access to data about water and energy consumption that allows for the identification of opportunities for improvements in efficiency. In water distribution systems, energy may account for a very high proportion of running costs for companies, principally being used for abstraction, treatment and transportation of water. In Latin America and the Caribbean, energy is often the greatest cost component, corresponding to 30-40% of utilities' operational costs (UNESCO, 2014). An example of an extreme situation is California, where the consumption of energy for water treatment and pumping in supply systems, plus consumer water use, is around 20% of the state's total electricity need (Elkind et al., 2011).

The identification of applications that explore the potential of high resolution data in energy utilities using smart meters has been widely explored in the last years (Capone et al., 2009; ESMIG, 2012; Han and Lim, 2010). However, for water utilities, the potential of high resolution water-energy data collected from smart meters has been much less explored until now (Hajebi et al., 2013; Boyle et al., 2013; Top, 2010).

In spite of the fact that numerous water utilities already explore smart metering systems, the main focus has been on water loss management in the network and monitoring of large consumers. In addition, most of the smart metering technologies that serve the above mentioned objectives do exist and are proven, but are often used in isolation. Therefore, there is a need for a more integrated and complete approach that covers non-current applications and that benefits from the cross analysis between smart metering data collected from network flow meters and water meters installed in households.

In order to produce value from an integrated approach that takes advantage of smart metering technologies, it is necessary to analyse and design a set of applications that are relevant for the stakeholders (ISO/IEC/IEEE 42010, 2011). Such an approach has been commonly used in software engineering, where systems are analysed (gathering and unifying all relevant requirements) and designed (defining how the systems must behave) before starting the system construction (software coding and development).

The work presented in this paper identified, characterised and validated a set of relevant applications derived from smart metering real-time data, which are valuable for water utilities as they will, after implementation in an ICT tool, allow for the better planning and operation of networks and an overall increase of water-energy efficiency. This was done through the definition of use cases (OMG, 2011), which are a relevant modelling technique from the Unified Modelling Language that is commonly used for systems analysis (Somé, 2006; Massila. et al., 2010), but can also be used to model the behavioural part in a system's design (Ratcliffe and Budgen, 2005).

Finally, the developed systems must be checked in order to validate if they conform to what was specified during the system analysis and design. In ICT tools, this validation is done through a set of software tests, including white-box tests (internal details of software applications) and black-box tests (how the systems behave for their users) (Graf et al., 2007). A method to test the ICT tool development is therefore also presented.

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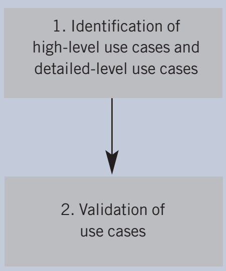
Figure 1: Method for the definition and validation of smart metering-based applications

Step



Key actions

Preparation of high-level use cases list
Description of high-level use cases
Harmonisation of high-level use cases
Preparation of detailed-level use cases list
Description of detailed-level use cases
Harmonisation of detailed-level use cases
Initial validation and prioritisation of use cases by stakeholders
Validation of use cases through full-scale offline testing
Validation of use cases through full-scale online testing

Table 1: Examples of smart metering based applications for the water utilities

High-level application	Description of high-level application Examples of detailed-level applications (DL apps)	Portugal	Overall rating UK	Greece
WU_UC01: Obtain water and related energy consumption data	The water utility has access to near real-time data about metered water and associated energy consumption. Water consumption data comes from SCADA, smart metering and includes network inflow, total metered consumption and total metered consumption per category of consumer. Energy consumption data comes from SCADA and is related to network pumping if present in the system.	2.7	2.6	2.4
	DL apps *WU_UC01.1: Obtain inflow (and associated energy consumption) and total water consumption per network sector using real-time data* *WU_UC01.2: Obtain water consumption data per category of consumer using real-time data*			
WU_UC02: Understand water consumption	The water utility gets near real-time information on the different components of metered water consumption and water losses (real losses, apparent losses, unmetered consumption).	2.9	2.1	2.5
	DL apps *WU_UC02.1: Obtain water balance data* *WU_UC02.2: Benchmark water losses against reference values* *WU_UC02.3: Obtain information on consumption profiling* *WU_UC02.4: Obtain detailed information on operational inefficiency*			
WU_UC03: Understand energy associated with water consumption	The water utility gets near real-time information on the different components of metered energy consumption associated with network pumping.	2.3	1.7	2.1
	DL apps *WU_UC03.1: Obtain information on energy consumption associated with pumping*			
WU_UC04: Get support to increasing operational efficiency	The water utility gets near real-time information on the effects of pressure control on consumption components, adaptive pumping scheduling regarding energy costs and consumption profiles and optimal placement of valves and flow meters in network.	2.9	2.6	2.4
	DL apps *WU_UC04.1: Receive warnings about faults (leakages, bursts) and unusual water consumptions in the network* *WU_UC04.3: Obtain information on the effect of pressure control on leakage components and consumption* *WU_UC04.5: Receive customised suggestions about pumping scheduling*			
WU_UC05: Get support to increasing the quality of service	The water utility gets information on billing, complaints and residential leakage.	2.2	2.7	2.3
	DL apps *WU_UC05.1: Receive information to make billing more accurate and flexible* *WU_UC05.2: Receive information to improve the management of complaints*			
WU_UC06: Get support to improve consumer efficient water use	The water utility receives customised suggestions on adaptive pricing schemes and awareness campaigns.	1.8	2.4	2.3
	DL apps *WU_UC06.1: Receive customised suggestions about adaptive pricing schemes* *WU_UC06.2: Receive customised suggestions about awareness campaigns*			
WU_UC07: Get support for system planning and design	The water utility gets information on reliable demand forecasts considering context factors (e.g., socio-demographic, tariffs) to support decisions on network expansions and on optimal replacement period of equipment.	2.6	2.0	2.6
	DL apps *WU_UC07.1: Obtain water consumption trends* *WU_UC07.2: Get support to decision-making on water network expansions* *WU_UC07.4: Determine optimal placement of valves and flow meters in the network*			

the aim of which is to advance knowledge about smart metering in order to develop novel, robust and cost-effective ICT tools both for the water utilities and the consumers. Applications for the consumer domain are presented in Loureiro et al (2013) and in Loureiro et al (2014). The focus of this paper is the water utility domain.

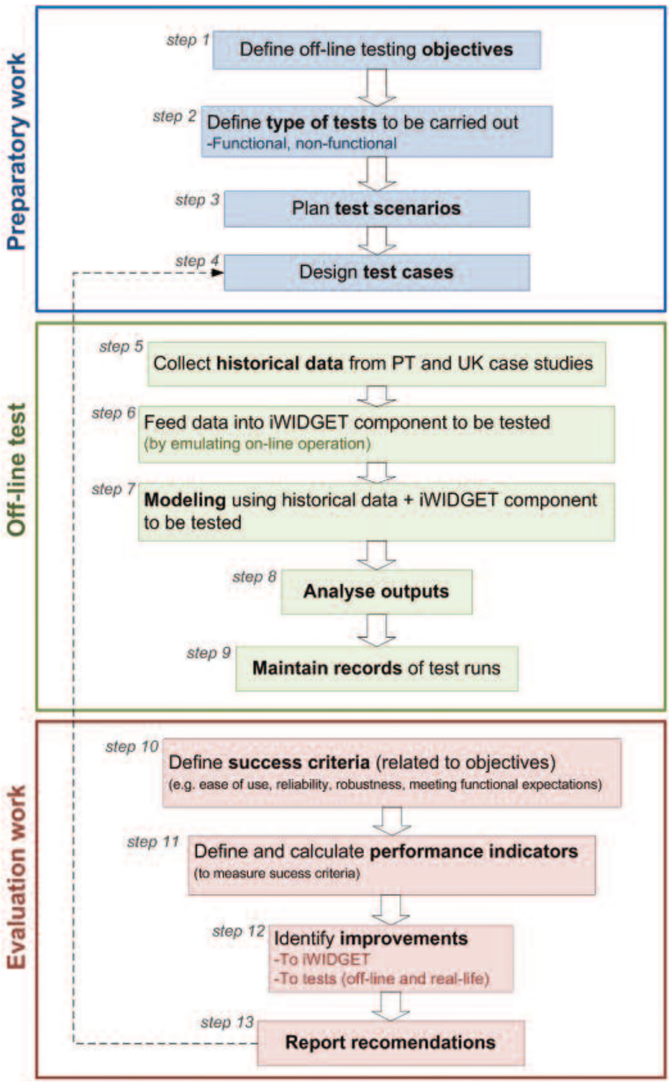


Figure 2: Validation of smart metering-based applications through full-scale testing
a) (above) Method for off-line testing; b) (below) Design of off-line tests (example of a functional test)

Use Case	Test scenario	Test case	Test case steps	Requirement	Success criteria	Key Performance Indicator
WU_UC02.1: Obtain real-time water balance data	#1 Obtain real losses for a specific month	#1.1	1. Log on to iWIDGET using a password	Logon	Successful logon without errors	Pass/fail
			2.Select network sector	Network sector selection	Successful selection of option	Pass/fail
			3. Choose a time period from a calendar	Time period selection	Successful selection of option	Pass/fail
			4. Select the components of the water balance to be calculated	Water balance components selection	Successful selection of option	Pass/fail
			5. iWIDGET calculates the result	Execute calculations	Correct result is calculated	Pass/fail
			6. iWIDGET presents a table and a report with the results	Display information	Correct display of results	Pass/fail
			7. Print the report	Print	Successful print of report	Pass/fail
			8. Save data	Download	Successful data saving	Pass/fail

Defining and validating smart metering-based applications

The method used for the definition and validation of smart metering-based applications (Figure 1) includes two main steps: the definition of high-level applications and the corresponding detailed-level applications; and validation of the applications by water experts.

In the first step, in order to define the smart metering-based applications, a use case approach was followed. A list of high-level use cases was compiled and a characterisation of each use case was made, including the following: ID code, goals, actors, description, pre-conditions, post-conditions, triggers, constraints, main flow, alternative flow, issues and relationship with other applications. These use cases are aligned with the stakeholders' concerns and business areas. A final analysis of the high-level use cases was undertaken to balance the level of detail between use cases and to find overlapping or conflicting use cases.

Subsequently, based on the sub-processes of each high-level use case, a list of detailed use cases was prepared, exhaustively described and harmonised in a similar way to the first step.

The initial validation of the previously identified applications included a prioritisation according to predefined criteria accounting for their relevance in terms of improvement of water loss control, network water-energy efficiency, data management and integration of information systems, new services to the consumer, billing systems, and pricing schemes and sustainable planning. This prioritisation was made, at dedicated workshops, by water utilities that operate drinking water systems and by other drinking water experts (researchers, regulators, technology providers, consultants, professional associations, government organisations).

Finally, validation of the applications also occurs after their implementation in a software prototype (the iWIDGET system). This validation is made by water utilities in Portugal, UK and Greece through extensive full-scale testing. Within the project, specific procedures have been developed to carry out this task.

Catalogue of applications for the water utilities

A catalogue of the most relevant applications to improve efficiency in water use and related energy consump-

Table 2: Examples of requirements related to smart metering-based applications

Use case ID	Requirement ID	Requirement type	Requirement short description	Requirement details
WU_UC07.2	Fn.137	FR	Select parameter time horizon and scenarios	The user shall be able to choose a menu to select the time horizon and the scenarios for the analysis
WU_UC04.3	Fn.115	FR	Output results in user interface	The utility shall be able to visualise the results in terms of variation in water losses and metered consumption due to pressure control
all	Fn.085	FR	Save report	The system shall save a report created based on the output graphics
WU_UC02.2	Fn.090	FR	Allow comparison to reference data	The system shall allow comparison to reference data provided by the user
WU_UC07.2	Fn.140	FR	Display alternatives	For each consumption scenario, the system shall display the optimal solution and alternatives as well as respective performance and costs
all	Nfn.002	NFR	Ease of use	The system shall have an easy-to-use design for the user
all	Nfn.005	NFR	Responsiveness	The system shall be responsive in displaying graphics
WU_UC04.3	Dfn.006	DR	Allow input of data describing the network	The system shall allow the utility to input data describing the network (e.g., network model, pipe material), acceptable pressure values and valve characteristics, dwelling and family characteristics
WU_UC04.3	Dfn.009	DR	Store water network data	The input data describing the water network components shall be stored in a database for future use and analysis

FR: functional requirement, NFR: non-functional requirement, DR: data requirement

tion in water utilities through the use of smart metering technologies was developed. Seven high-level applications were identified (Table 1). High-level applications describe major processes in the systems and are largely business-oriented. These applications take into consideration smart metering data collected from network flow meters and water meters installed at the household level, and cover the whole range of possible use cases that can be drawn out of detailed water and energy consumption data. Based on the high-level applications, a set of 20 detailed-level applications was identified, providing information on specific system services.

Each application is targeted to specific users within the water utility: billing and customer management staff, maintenance staff, network operation staff, public relations and communication staff and utility planning staff.

Table 1 presents some examples of detailed-level applications and the description of each one can be found in Loureiro et al. (2013).

Initial validation of the applications by water utilities and water domain experts

Workshops were conducted in Portugal, the UK and Greece with the main objective of validating and ranking the set of identified use cases. Each expert rated the relevance for the water utilities by assigning a priority to each application using a three-point Likert scale (3 = highly relevant, 2 = relevant, 1 = not relevant). Based on individual classifications, average overall ratings were obtained for each category of experts (water utilities, researchers, regulators, technology providers, consultants, professional associations, consumer organisations, government organisations) and for each country.

As shown in Table 1, the applications regarding the access to water and related energy consumption data, understanding water consumption, getting support to increase operational efficiency and for system planning and design (UC01, UC02, UC04 and UC07) were assigned as being of higher priority (2.6–2.9) by the experts of at least two case studies, which indicates the consensual relevance and priority given to these use cases. Applications that provide support for water utilities to increase their quality of the service were also highly rated by the UK experts (2.7). UK and Greek experts considered the applications related to understanding energy associated with water consumption to be less relevant (1.7–2.1), whereas the Portuguese experts assigned the lowest level of priority (1.8) to supporting the improvement of customers' water use efficiency. Further details of this initial validation can be found in Loureiro et al. (2013) and in Rebelo et al. (2014).

Validation of the applications after implementation in a software prototype

In order to further validate the applications in the catalogue and implement them in a software prototype, requirements for each application have been derived, an overall architecture of the prototype has been defined (Cleverley et al., 2013) and, at the moment, the data management and analytical components of the prototype are being developed. This process is critical to drive the software development and to ensure the usability of the software components.

Within the scope of product development, a requirement describes an individual need that the product has to fulfil. It defines an action the product has to take in order to be useful to its users. Requirements are usually classified in functional requirements (things the product must do to comply with users goals), non-functional requirements (qualities and properties that the product must have) or data requirements (information users need or want, covering aspects such as required data for the system and access to information). Based on the use cases, 140 functional requirements, six non-functional requirements and 11 data requirements were identified for the iWIDGET system. Some examples of the requirements are presented in Table 2.

Once individual components (data management and analytical) have passed unit testing and are integrated in a prototype, testing takes place at full-scale in three cases studies located in Portugal, the UK and Greece. The first phase of testing consists of comprehensive off-line tests of the prototype, i.e. using historical smart metering data as opposed to online testing that uses near real-time data (second phase of testing).

Validation through off-line testing follows a standardised method (Figure 2a; Vieira et al., 2013) that includes functional and non-functional testing. Functional tests verify whether or not the functional requirements are met (if the software does what it is supposed to do), by feeding input to the functions and examining the output. Non-functional tests verify compliance with non-functional requirements (if the software does what it is supposed to do in an adequate way) and, in the case of iWIDGET, assess the quality of the software in terms of loading, performance, compatibility, scalability, usability, documentation, security and availability. The off-line testing method is considered itself to be a result of this work since it was specifically designed and optimised for the iWIDGET project.

For each application to be validated, test scenarios were designed as well as the corresponding test cases. In each test scenario, the functionality of the system that is to be tested was specified. Each test case specifies how that functionality is going to be tested in detail (sequence of steps) and gives information on the tester profile required. Success criteria for determining whether an observed behaviour of the system is or is not correct and key performance indicators to assess the achievement of success criteria were also defined for each test case step. Figure 2b shows examples of all these results. The complete set of test scenarios and test cases can be found in Vieira et al., 2013.

Conclusions

Smart metering technologies provide the potential to improve current procedures and enable new applications to support a water utility's business and increase the overall water-energy efficiency of supply systems. Within the FP7 project iWIDGET new applications for smart metering data were incorporated into the iWIDGET ICT tool and an offline testing method based on test scenarios and test cases was specifically developed and optimised to evaluate and test the adequacy of the proposed smart metering data applications. This test method besides being used to validate the results also drives the software development process.

In this work, ICT formalisms and methods used to define applications, corresponding requirements and to validate them were applied in a new domain – the water-energy in distribution systems. In this new domain, these methods have proved to be adequate in identifying functionalities useful for the efficient management of water and energy in supply systems equipped with smart metering and have also shown advantages for the project consortium by providing a common and clear understanding of project objectives, as well as defining indicators to measure the critical success factors of the iWIDGET applications. ●

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