

Smart Municipal Systems and Services Platform Development

Anatolijs Zabasta, Kaspars Kondratijevs, Nadezhda Kunicina, Janis Peksa, Leonids Ribickis, Jelena Caiko
Riga Technical University, Faculty of Power and Electrical Engineering, Institute of Industrial Electronics and Electrical Engineering, Riga, Latvia

Anatolijs.Zabasta@rtu.lv; Kaspars.Kondratjevs@gmail.com; Kunicina@latnet.lv; Janis.Peksa@rtu.lv; Leonids.Ribickis@rtu.lv; Jelena.Caiko@rtu.lv

Abstract—Nowadays each utility allocated in municipality territory maintains usually own network of meters and sensors, own system for data collection and storage, separate customer service, inventory, bookkeeping, billing and etc. The majority of the systems are obsolete and incompatible. However, development of sensor network for monitoring and control of utilities networks and its maintenance is a challenging process due to plenty of human work related to their. During the state research program NexIT, RTU research team developed and tested multi-resource meters that are suitable for water distribution network, for installation at district heating substations and for temperature and humidity measurement in the offices and multi-apartment buildings. The gateways implement also adapter and protocols translation function for communication with other systems. Thanks to enhancing of sensors and gateway devices, it became possible to design a common architecture for a cloud of public utilities systems of a municipality that apply SOA and IoT approaches.

Keywords – Automation, SOA-based systems System-of-Systems, SOA, wireless sensor networks (WSN).

I. INTRODUCTION

Effective monitoring and control of heat energy consumption, preventing thermal energy losses in district heating networks, allocation of undetected accidents, hidden leakages, and irrational utilization in water distribution networks is an important task of public utilities in the municipalities.

Utilities (heat suppliers, water suppliers, building services providers, etc.) apply automated meter reading (AMR), smart meters and other methods for collecting metering data from sensors installed at heat, electricity and water distribution networks. However, utilities, municipalities and suppliers in their practice encounter real problems preventing introduction of smart meters: underestimated cost of technical solutions, frustration in selecting technical solutions relevant for local needs, lack of technical competences and incompatibilities between a plenty of protocols used at existing and new equipment offered by suppliers.

Despite being owned by the same owner (municipality council) each utility usually maintains own network of meters and sensors, own system for data collection and storage, separate customer service, inventory, bookkeeping, billing etc. The majority of the systems are obsolete and incompatible.

However, development of sensor network for monitoring and control of utility's networks and its maintenance is a challenging process due to plenty of human work related to their.

The aim of this research is to provide an evidence of a practical implementation of the new generation of public utility's network automated monitoring system, which complies with industrial automation framework approach:

- Development of SOA based application services as web services applying most suitable IEC standards applicable for utilities systems in municipalities.
- A modular technical solution for gateway nodes – protocol adapters.
- Development a concept of common core services for the public cloud of utilities systems.

The offered municipalities' public utilities systems pilot aims at designing a System of systems (SoS) that comprises enhanced public utility's systems, to create and to pilot application services produced by these systems. The names of the considered systems: Water supply system, District heating system and Building maintenance system.

Furthermore, a System of systems, which can be recognized as a cloud of municipalities' public utilities systems, includes several legacy systems, such as Network inventory systems, Clients billing and invoicing systems, and Bookkeeping systems, which are operated by several municipalities owned utility companies.

In a frame of the state research project NexIT and the predecessor project Arrowhead and Riga Technical University (RTU) team developed and tested municipalities' systems gateways that are suitable for water distribution network, for installation at district heating substations and for temperature and humidity measurement in the offices and multi-apartment buildings. These gateways implement also protocols adapter and translator function for communication among the systems. Thanks to enhancing of sensors and gateway devices, it becomes possible to design and implement a common architecture for Public utilities systems of a municipality.

Benefits: Since public utilities in municipalities nowadays pursue automatization of the processes but install and maintain very diverging systems, the issue of the maintenance cost

optimization becomes very crucial, and particularly, when the maintenance cost causes the growth of the tariffs for the public services. Offered approach for optimization of municipality's public utility systems demonstrates promising opportunities for systems maintenance cost saving.

The paper is structured as follows. Authors summarize related works in the area of automation advances and SOA in Section 2. Standards applicable for municipalities' systems automation are discussed in Section 3. Municipalities' systems architecture is depicted in Section 4, which describes services of the System of Systems (SoS) and an implementation of the gateway nodes. Section 5 describes core services development for the cloud of municipality' systems. The main contribution of the research, general results and possible directions for future works are discussed in the chapter Conclusions.

II. RELATED WORKS

Widely accepted that automation is driven by industrial requirements on sustainability, flexibility, efficiency and competitiveness. These in turn are driven by big societal questions like environmental sustainability, availability of energy and other raw material and rapidly changing market trends. These drivers are pushing for much larger and greater number of automation systems compared to current state of the art. While automation is a key driver of the technology, its development is prevented by the high engineering costs for large and complex systems. This is a reason on moving from the ISA-95 automation pyramid to an Internet cloud paradigm based on Service Oriented Architectures, SOA [1], [2]. Here cheaper hardware and expectations on reduced engineering costs have been strong motivators for the developments.

Model driven engineering in the domain of mechatronics and industrial control is not a new discipline at all; various approaches have been researched such as Intelligent Mechatronic Components [3], Model-Integrated Mechatronics [4]. In collaborative automation, model driven engineering is mostly used to support the design of System-of-Systems (SoS), hence it is based, at least on the system level, on loosely coupled open loop service oriented control principles [5]. A framework, which enables standards based development of end points, secure interoperation of modularized and distributed applications and utilizing global cloud and local cloud concepts is depicted in [6].

Application of Wireless Sensor Networks and SOA development for optimal control of legacy power grid was researched in [7]. City transport automation and maintenance issues have been considered in [8]. Transport simulation model was built for each considered transport access alternative according to the four stages of transport planning model with additional restriction – level of service for each model to meet SLA.

Recently, a number of open platforms have also emerged (e.g., Arrowhead Framework, IoTivity, FiWare, OMA-LWM2M [9]. A Reference Architecture Model Industry 4.0 (RAMI 4.0) [10] creates, what has been called a "smart factory". Within the modular structured smart factories, cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions.

A number of automation technology gaps has been identified to support internet technologies [11], [12]. Some of the identified automation technology gaps are:

- Interoperability of a wide range of IoT and legacy devices.
- Automation requirement on latency guarantee and prediction for communication and control computations.
- Scalability of automation systems enabling very large integrated automation systems.
- Multi stakeholder integration and operations agility.
- Security and related safety of automation systems.

The local automation cloud concept is implemented by the Arrowhead Framework [11], [13]. The implementation of a local automation cloud for a local climate control automation has been used to verify the local cloud concept. Interoperability between devices or software systems joining a local cloud is proposed to be addressed at a service level. It is proposed to use DNS-SD as a basis for such service registry [14], [15].

Every service produced within the local cloud shall be registered with the service registry. Arrowhead Framework open source implementation of a DNS-SD based service registry for local automation clouds is depicted in [11], [13]. Interoperability between devices exposing service through different SOA protocols should be supported using a protocol translation service [16]. The protocol translator acts as a participant of the local cloud and is monitored for QoS.

III. STANDARDS APPLICATION FOR MUNICIPAL SYSTEMS

Heterogeneous public utilities systems apply different standards. For example, ISO 4064-1:2014 specifies the metrological and technical requirements for water meters for cold potable and hot water. These water meters incorporate devices, which indicate the integrated volume. Many electricity meters are equipped with an IEC1107 compliant optical interface. This gives a convenient method for the electricity companies to access all manner of information held in the meter using a hand terminal.

Technical Committee CEN/TC 294 "Communication systems for meters and remote reading of meters", prepared series of standards details requirements for interoperable gas meters, water meters and heat meters that can interoperate with Home Area Network (HAN) products that conform to this standard through a Smart Energy Profile application layer. The scope of CEN/TC 294 Remote meter reading and communications for non-electricity meters allows the data produced by utility meters to be read by a WAN communications hub, another meter, a separate meter display unit or any other device implementing this Smart Energy Profile standard.

The standard EN 13757-1 "Communication system for and remote reading of meters" - Part 1 describes data exchange, but in turn EN 13757-4 "Communication Systems for Meters and Remote Reading of Meters - Part 4 is devoted to Wireless

Meter Readout (Radio Meter Reading For Operation In SRD Bands). This series of standards specifies how a mesh networking radio specification applies within the scope of European standards at the application layer, networking layer and also MAC/PHY. There are references to the IEEE 802.15.4:2003 standard on which the MAC/PHY for this standard is based.

We considered also IEC 61850, a communication standard for electrical substation automation systems. The abstract data models defined in IEC 61850 can be mapped to a number of protocols. These protocols can run over TCP/IP networks of substation LANs using high speed switched Ethernet to obtain the necessary response times below four milliseconds for protective relaying. However, IEC 61850 offers too complex models and features for simple scenarios maintained at public utilities systems.

We have proposed a mapping of the IEC 62056 standard functionalities to a RESTful approach. IEC 62056 is a set of standards for Electricity metering data exchange by International Electrotechnical Commission. The IEC 62056 standards are the International Standard versions of the DLMS/COSEM specification. DLMS or Device Language Message Specification is the suite of standards developed and maintained by the DLMS User Association that has been adopted by the IEC TC13 WG14 into the IEC 62056 series of standards. COSEM, or Companion Specification for Energy Metering, includes a set of specifications that defines the Transport and Application Layers of the DLMS protocol.

The IEC TC13 WG14 groups the DLMS specifications under the common heading: "Electricity metering data exchange - The DLMS/COSEM suite". DLMS/COSEM protocol is not specific only to electricity metering, but it is also used for gas, water and heat metering:

- IEC 62056-5-3:2013 DLMS/COSEM application layer
- IEC 62056-6-1:2013 Object Identification System (OBIS) [17]
- IEC 62056-6-2:2013 COSEM interface classes
- The last one IEC/TS 62056-9-1 accepted in 2016 [18] depicts use cases for DLMS with Web services and SOAP (Simple Object Access Protocol) interface. According to the standard COSEM messages are represented in XML format. IEC/TS 62056-9-1 is based on IEC 61968-1 and 61968-100 (TC57).

Based on M/441 European Commission Smart Metering Standardization Mandate DLMS User Association coordinates its efforts with Technical Committees TC 294, TC13 and TC 57.

The DLMS/COSEM offers three step approach that provides "orthogonality" such as separation of a model and protocols:

- Data model, to view the meter functionality at its interface(s) for COSEM objects and OBIS Object Identification System

- Messaging method to communicate with the model and to represent data as a series of bytes (APDUs)
- Transportation method to carry the messages over the media between the meter and remote parties

Object modelling assumes that any real-world things can be described by some attributes, when the attribute' name identifies the data, hence each attribute has a meaning, a data type and a value range. Methods in its turn allow performing operations on attributes, furthermore, attributes and methods constitute an object (Fig.1). Using the object means one can read or write the attributes and to invoke the methods.

The COSEM server model can be structured into three hierarchical levels: Physical device, Logical device and Accessible COSEM objects.

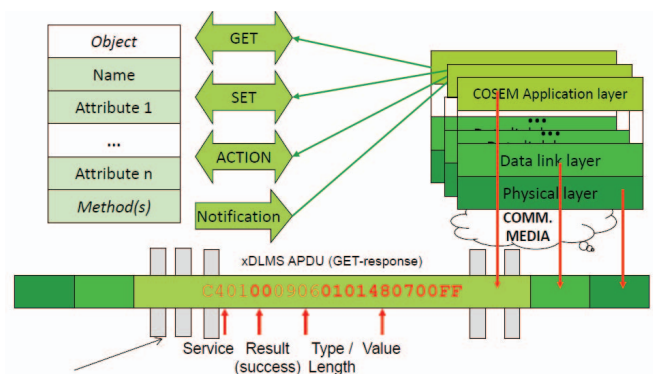


Figure 1. Building the messages services to access the objects and protocols to transport the information [19]

Therefore, we have proposed a mapping of the IEC 62056 standard functionalities to a RESTful approach. Due to the paths resemble a fully qualified file-name notation, they can be mapped to a URL, which makes the data model suitable for REST, therefore a REST URL could look something like <http://hostname/device/node/class/attribute>.

The proposed solution for communication as a part of public utility's system contains a multi-interface modular platform with two main node components. Metering node – connects to a meter via switchable/selectable interfaces (current loop, IEC1107 optical interface etc.). Metering nodes have rechargeable batteries for operation during a power outage and for long-term standalone operations. Inter-system communication is possible using selectable interface modules (e.g. IEEE 802.3, ISM radio interface, GSM/GPRS).

Gateway node – has a selectable inter-system and a backend communication' interface architecture. A gateway node provides requests, readouts pre-processing, secure data delivery, queuing protocols. Furthermore it implements adapter and translator function for communication among the systems (see Fig. 2).

The registration of gateways can be performed automatically or manually, with the following parameters specified: device name, group, type, network settings, gateway dynamic loadable modules, VPN configuration, Wi-Fi settings,

encryption settings, the working mode registration server/service (WMRS) and working mode data submission server/service parameters (WMDSS). The WMRS and WMDSS parameters allow the gateway control functions delegation to other servers for load balancing or third party service operators by allowing them to perform all parameter and control functions as the FTRS.

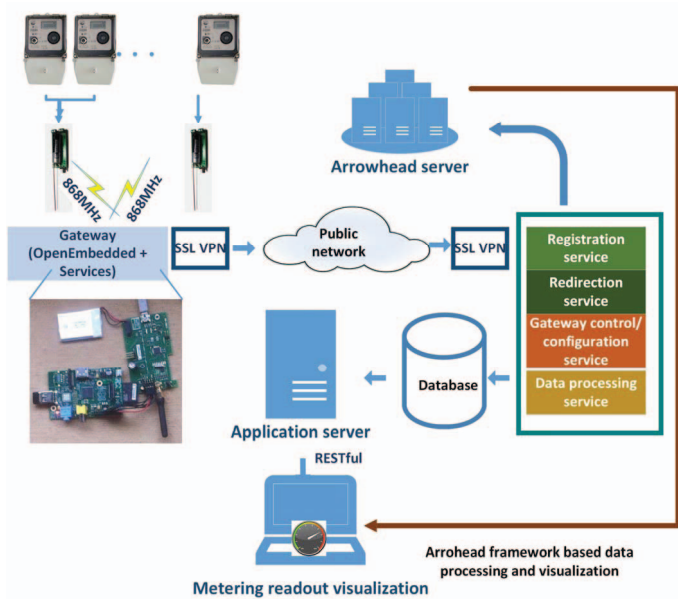


Figure 2. A block schema of the “Smart municipal System-of-Systems” (SoS) and its comprising systems

All gateways initiate a SSL VPN based on FTRS or WMRS VPN setting parameters to the data processing service that receives the gateway data through the encrypted VPN tunnel and stores them in a database. For the prototype application and further integration into any of the third party network and standalone, a service agent at the data processing service or the gateway itself has to be integrated. In the prototype case, a web service demonstrating configuration and data reception/visualization (charting) is used. The querying has been implemented using RESTful web services. The described communication part of public utility’s system has been piloted at the water supply network in city Ventspils (Water utility “Udeka”).

IV. APPLICATION SERVICES

A view at Fig.3 shows the “Smart municipal SoS” (System-of-Systems) as a model comprising three application systems: Water supply, District heating and Building maintenance systems. Three core systems operating as sharing systems for the local cloud of municipalities systems provide Authorization, Service registry and Orchestration services. More detailed research of core services implemented in Arrowhead project one can find in [13]. Legacy systems such as Client billing and Inventory system comprise a part of the overall Municipality system, and to be integrated using protocol adapters, however it is out of the scope of this work.

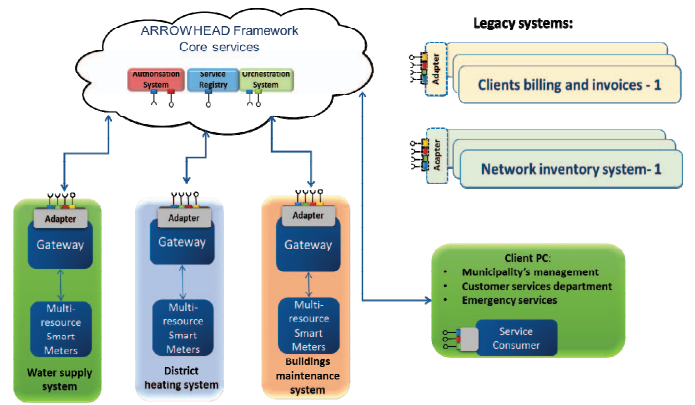


Figure 3. A model (Arrowhead) view of the “Smart municipal System-of-Systems” (SoS) and its comprising systems

In our research we used approach developed in Arrowhead project [13] and then applied in NexIT project [20] for documentation of SoS. A practical implementation is depicted in Fig. 4, which shows the links between the documents describing SoS. Due to the lack of space, only a part of the documentation chart is displayed on Fig. 4. A model view of the “Smart municipal System-of-Systems” (SoS) and its comprising systems is defined in the System-of-Systems Description (SoSD) and System-of-Systems Design Description (SoSDD) documents.

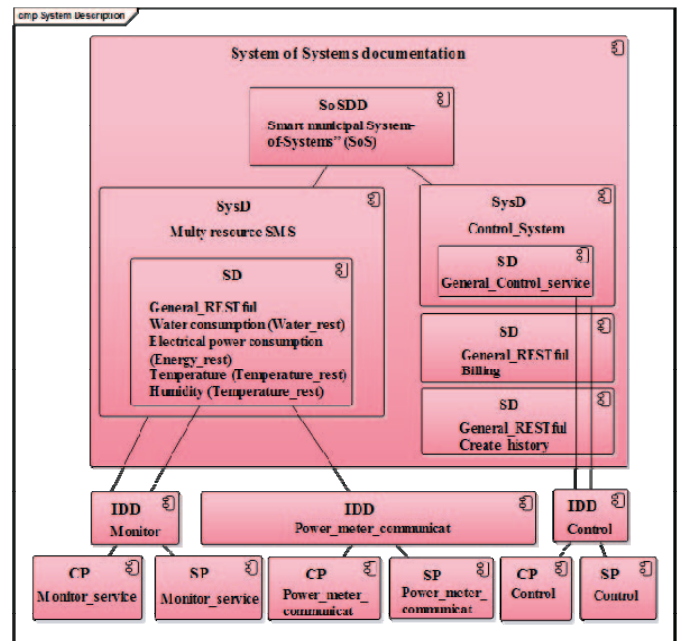


Figure 4. System-of-Systems documentation approach

The correct way of working of each system comprising “Smart municipal SoS”, is represented by three systems in the System Description (SysD) documents. At the chart SysD are depicted as Multi-resource meter Service Description documents, because we applied single gateway nodes for all three application systems, which operate as multi-resource meters, gateways and protocol adapters. Therefore, each

“system type” can talk to each other or identify the gateways/protocol adapter needs.

A proper description of Systems in the SysD document requires a listing of all provided and consumed services with references to their Interface Design Description (IDD). At the Service level, the IDD describes how to realize the service identifying explicitly the technologies to be used. This document refers to the Communication Profile (CP), the Semantic Profile (SP) and the Service Description (SD). The CP is composed by the transfer protocol (e.g., HTTP, CoAP), security for the transportation of data and the data format. The SP contains information about how a specific measurement (e.g., a temperature value or a consumption volume) is coded (e.g., in a standard such as XML or SenML).

Four application services have been created as RESTful services:

1. Water consumption (getMeasureConsumptionWater)
2. Heat energy consumption (getHistoricalEnergyData)
3. Temperature (getMeasureTemperature)
4. Humidity (getMeasureHumidity)

The first one is produced by Water supply system, the second one by District heating system, but the last two one by Building maintenance system.

The semantic profile of the services in the documentation is presented as the JSON [21] information model, which allow to share measurement data through the real time global data space

In the example (see Table 1) the web service getMeasureConsumptionWater returns water consumption measurement of a particular meter in a particular interval, additionally, the web service getHistoricalEnergyData returns energy consumption data of a particular meter in a particular building, room, time interval etc.

TABLE I. TABLE 1 BUILDING CONDITION MATERING DATA STRUCTURE

Web Service	JSON format
getMeasureConsumptionWater	{ "consumption": value, "water": value, "unit1": m3 "start date period": Date, "end date period ": Date, "prior period consumption": value "unit2": m3 }
getHistoricalEnergyData	[{ "meterId": value, "buildingId": value, "roomId": value, "roomName": value, "name": value, "consumption": value, "meterTypeId": value, "measureDate": " Date ", "meterCategoryId": value, "meterCategoryName": value, "meterTypeName": value, }

Web Service	JSON format
	"periodInitialDate": value, "periodFinalDate": value, "periodConsumption": value, "hour": value, "hourConsumption": value, "hourConsumptionWithoutNullValues": value, "quarterHourConsumption": value, "quarterHourConsumptionWithoutNullValues": value, "arrayDates": value, "arrayMeasures": value, "arrayMeasuresWithoutNullValues": value, "model": value }]

JSON information model is selected, because it implies an open standard format that uses human-readable text to transmit data objects consisting of attribute–value pairs. It is used primarily to transmit data between a server and web application, as an alternative to XML at resource-constrained devices. Originally derived from the JavaScript scripting language, JSON is a language-independent data format. Code for parsing and generating JSON data is readily available in many programming languages. Here is an example of JSON code for a temperature service:

```
200 OK
Allow: GET,PUT,OPTIONS
Content-Type: application/json
{ "rt" : "urn:building:temperature:room",
  "description" : "A room temperature service",
  "content-type" :
"application/senml,application/senml-json",
  "url" : "https://host.services/1",
  "data-points" : [
    [
      "name" : "Room Temp",
      "content-type" :
"application/senml,application/senml-json",
      "url" : "https://host.services/2",
      "rt" : "urn:building:room:temp",
      "allow" : "GET,OPTIONS"
    ]
  ]
}
```

Therefore, the enhanced public utilities systems of municipality are able to consume published services inside of the cloud. However, potential service consumers outside of the municipality cloud will be able to consume application services only after core services functionalities will be implemented.

V. CORE SERVICES FURTHER DEVELOPMENT FOR THE CLOUD OF MUNICIPALITY’ SYSTEMS

Previously core services, such as authorisation and orchestration has been implemented as “built in” inside of the each of utilities system. It is the challenge for our team to transform them according to the Arrowhead Framework, therefore, as core system for the public utilities systems cloud. The mandatory core systems such as Authorisation and Orchestration have been simulated at Arrowhead Test Tool G2

(developed by Arrowhead project partners BnearIT and Lulea Technical University) [13]. In addition, part of the functions of Orchestration system has been tested at Ventspils water distribution network, namely, gateway and sensor nodes registration and reconfiguration.

The next core system, Data repository – History (locally accumulated for billing and trend analysis), has been developed in the project and piloted at Ventspils water distribution network and for building maintenance systems in Riga. Sensor data related to water flow, water pressure, temperature, heat consumption, humidity in the building etc., using semantic encodings like JSON, SenML [22], are stored, automatically decoded and processed. The data are automatically recorded with their timestamp and meta-data. Decoded sensor data can later be processed and filtered for analysis and visualization purposes. The encoded data and its visualization are available for Clients PC represented by different groups of users. Each of them needs a particular format of data: for example, municipality management needs aggregated data as tables and charts, which are refreshed by day, week of month, but the emergency services need data input in the network monitoring system at least each 10 minutes (Ventspils water utility). Data repository – History system provides services to PC clients via web interface.

The challenge still is services provision to municipality's legacy systems. It is planned to develop adapter and to test at least at one of the systems. As a preliminary solution, a semi-automated translator is tested between Data repository and Billing system at Ventspils water utility, which converts data in a required format. Billing system operator calls the Data repository and the service loads data to the Billing system on request.

VI. CONCLUSIONS

Since public utilities in municipalities nowadays pursue automatization of the processes but install and maintain very diverging systems, the issue of the maintenance cost optimisation becomes very crucial, and particularly, when the maintenance cost causes the growth of the tariffs for the public services. The offered approach for optimization of municipality's public utility systems demonstrates promising opportunities for systems maintenance cost saving.

- Opportunity for sharing of application services among public utility's companies may reduce requirements for functionality of their systems, for example, if one of the system provides Temperature service, it is not necessary to measure and collect temperature data by the other systems at the same territory.
- Since the information describing the different tasks and configurations is stored in a network connected storage area, i.e. in the core system accessible from all locations, where devices are to be installed and in a format that the devices are able to interpret, the network nodes installation, configuration and reconfiguration process becomes faster and less human time consuming. Additionally, the cost of transport of technicians visiting of the sites can be reduced.

- The data provided by Data repository – History system, filtered and processed in a required dimension, granularity and frequency, is an invaluable asset for Client PC and other specialised systems-clients, which interpret and use them. For example, legacy systems as SCADA, EPANET etc., can effectively utilise data for damage, leakages, burst of the pipes or theft cases identification and localisation.
- Acquisition of the core services for municipality systems cloud encourages a transition from multiply legacy systems, which belong to different utility companies, to the restricted number of shared systems that are able to collaborate within the cloud of SoS. For example, only one billing system instead of three or four is sufficient to serve the same clients base at a municipality territory.

At this time, the evaluation of benefits (savings incurred by using the overall solution and potential return on investment) is ongoing, however, the first evaluation about the saving by different public utilities looks encouraging.

Further research efforts should be devoted to security issues for authentication and authorisation of different systems in the municipality SoS cloud, as this issues have not been considered in this research. Furthermore, the research team will look for the most efficient way of different protocols translation across the systems taking into account that a majority of utility systems apply metering devices with appropriate protocols and interfaces.

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