TRESCIMO M2M-IoT Testbed

Smart Cities Solutions in Europe and Africa

Maria Barros, Anastasius Gavras
Eurescom
Heidelberg, Germany
{barros, gavras}@eurescom.eu

Andreea Corici, Ronald Steinke
Fraunhofer FOKUS
Berlin, Germany
{andreea.ancuta.corici, ronald.steinke}@fokus.fraunhofer.de

Nyasha Mukudu, Neco Ventura, Joyce Mwangama
University of Cape Town
Rondebosch, South Africa
{nyasha,neco, joycebm}@crg.ee.uct.ac.za

Daniel Nehls, Bjoern Riemer
Technical University
Berlin, Germany
{daniel.nehls, bjoern.riemer}@tu-berlin.de

Louis Coetzee, Dawid Oosthuizen
CSIR
Pretoria, South Africa
{louis.coetzee, doosthuizen}@csir.co.za

Marisa Catalan, Laura Herrera, Jacint Castells
Fundacio i2CAT
Barcelona, Spain
{marisa.catalan,laura.herrera,jacint.castells}@i2cat.net

Raviv Yatom
Airbase
raviv@myairbase.com

Hinesh Madhoo, Tiaan Willemse
Eskom
Johannesburg, South Africa
{MadhooHV, willemt}@eskom.co.za

***Abstract*— Smart City services are becoming more prevalent. These services have the potential to improve the quality of life of citizens (e.g. detecting and managing pollution) and also to make better use of resources (i.e. water and energy). The European and South African contexts vary significantly thus necessitating either different services or significant refactoring of existing services. In order to allow cross-fertilization of solutions from both continents, experimental facilities that support component federation are required.**

TRESCIMO is a project that created facilities to experiment with services distributed over continents for two IoT domain trials and developed a general solution for scaling the IoT infrastructure in a Proof-of-Concept. This paper analyzes TRESCIMO functional components and presents the results and the value added to the FIRE suite of testbeds.

Keywords— FIRE, Testbed, Experimentation, M2M, IoT, Smart City, Smart Energy, Environmental Monitoring.

I. Introduction

Smarter and greener cities are essential to address economic, social, and environmental challenges due to an increase in urbanization [1]. Informed decisions based on Internet of Things (IoT) generated data can address these challenges. A particular challenge is the unstable power supply of cities in developing countries (e.g. South Africa), thus requiring smart energy management.

One way to obtain a better view of energy demand (and thus provide insight into how the demand can be managed) is to use smart metering. Similarly, pollution is impacting the quality of life of city inhabitants, thus requiring means to understand where and why areas in cities are becoming more detrimental to a citizen's health. These aspects introduce challenges in obtaining reliable data from the environment. Environmental observations (i.e. energy or air quality) are either sent over IP networks for immediate delivery or collected in a delay tolerant manner. Appropriate power access and communication infrastructures are not always readily available and therefore a delay tolerant approach is required. In the delay tolerant mode, the data is stored locally and delivered to the destination when a suitable network becomes accessible.

Experiments in Information Communication Technology (ICT) provide a vehicle to validate functionality and test performance. It is also considered to be a good method for encouraging the uptake of open standards. Testbeds for Reliable Smart City Machine to Machine Communication (TRESCIMO) [2] is a Future Internet Experimental Research (FIRE) project [3] that focuses on enabling Smart City research through trials centred on smart energy and smart environmental monitoring, allowing academia and industry to perform M2M/IoT experiments through FIRE tools, and validates a concept for scaling IoT infrastructures.

In this paper we present the key technical requirements in section II leading to the reference architecture in section III. Section IV describes the testbed followed by section V presenting the solutions and interpreted results. Section VI concludes the paper.

II. Requirements

The Smart Energy trial aims to stabilize the power grid during peak times and to enhance the understanding of behavioural changes of those household occupants who have access to near real-time consumption data and are simultaneously able to remotely control and observe energy intensive household appliances. The Smart City Environmental Monitoring trial is focused on using wireless technologies to collect environmental data from low-power sensor devices and air quality sensors without the need to deploy dedicated infrastructure. A web dashboard is necessary to provide the municipality and potential stakeholders with a means to visualize and monitor collected data. For both trials, real world modelling is needed for access control and the interpretation of collected data. Another common requirement is energy efficiency.

The primary requirement of the Proof-of-Concept (PoC) is to enable large scale infrastructures for smart cities applications from multiple domains using a Platform-as-a-Service (PaaS) approach. The same functionality is required for the federated testbed in order to rapidly establish an environment in which M2M/IoT solutions can be developed, new devices experimented with, and applications or cross-domain applications developed.

III. Reference Architecture

Informed by the requirements of the two trials and the experiments, a reference architecture was designed (Fig. 1). In this architecture, the device layer includes smart meters and actuators, energy efficient sensors, and Delay Tolerant Network (DTN) gateways. Together, the M2M Gateway and M2M Platform components provide communication management functionality and are oneM2M standard compatible. The Smart City Platform (SCP) supports real-world modelling and a specific application was built for each domain. By selecting either one of the trials, the PoC, or the experiments, a set of requirements was extracted. The subsequent architectural implementation for a trial consists of a subset of components taken from the reference architecture.

The Smart Energy trial (executed in Gauteng, South Africa) utilizes as building blocks smart energy management devices, gateways, and the Smart City Platform. Energy consumption observations from smart energy management devices communicate directly to the Smart City Platform (SCP) where the User Mobile Application for Smart Energy processes the data. This application monitors the consumption and actuates individual devices by switching them on or off according to the user's need.

The Smart City Environmental Monitoring trial (executed in Sant Vicenç dels Horts, near Barcelona, Spain) integrates additional functional blocks and elements of the TRESCIMO architecture. The trial links the DTN-based gateway and enhanced radio wake-up [4] sensor devices, Airbase air quality devices, the OpenMTC M2M platform [5], and the Smart City Platform from where the dashboard is instantiated. Observations received from the environmental sensors are communicated to the M2M middleware (Gateway and Platform) by means of Delay Tolerant Networks. The M2M middleware links with the Smart City Platform which hosts the Smart City Application – Green City. The Green City application dashboard visualizes observations that are associated with environmental monitoring.

The PoC integrates the smart energy and smart environmental monitoring domains. It uses the Open5GMTC platform [6] to control the communication of the end devices (these being smart meters-and-actuators and DTN gateways) in order to enable end-to-end scalability and resilience of the infrastructure.

To allow the testbed to support FIRE experiments, FITeagle [7] was introduced to model software components as resources that can be provisioned as a topology consisting of M2M gateways, M2M platform, SCP and emulated and physical devices. The OpenSDNCore orchestrator [8] was used for both the PoC and testbed to instantiate virtualized resources and interweave components according to topology defined relationships.

In the last years there were other Smart City project rolled in the European Union. One of the most remarkable is SmartSantander that encompassed several usecases including environmental monitoring and smart parking. The architecture focused on AAA, Testbed management, experimental support (using virtualized devices) and application support (via well-defined API to Applications). In respect to SmartSantander, the TRESCIMO project introduced the DTN and radio wake-up infrastructureless Smart CIty approach, approached AAA using the real world model for validation of device discovery and targeted flexibility through communication management using PaaS as the first step towards reliable IoT infrastructure.

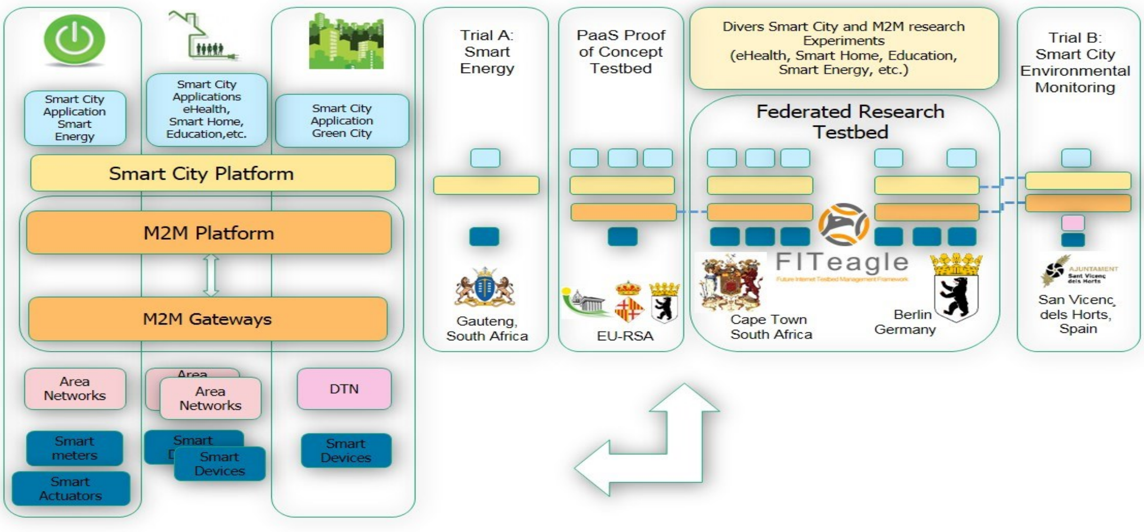

Fig. 1. TRESCIMO Reference Architecture [9].

IV. Federated Testbed

TRESCIMO created a FIRE federated testbed [10]. Experiments are supported by an SFA client that requests resource actions via FITeagle. TRESCIMO test sites have been established across countries and continents (Fig. 2) with one in Berlin, Germany, one in Cape Town, South Africa and a remote node in Pretoria, South Africa. Here, the focus is on linking developed and developing countries. In this way, Future Internet Research Experimentation (FIRE) is expanded and offers Smart Infrastructures as a Service and thereby providing a reliable and standard compliant Smart City software stack as a Service for evaluation purposes based on European and South African Smart Cities requirements. It also provides a research environment for investigating and experimentally validating highly innovative and revolutionary ideas. The federated testbed allows researchers to effectively prototype, develop, deploy and thus validate new applications and services. It also supports experimentation using new hardware and standards.

The testbed integrates software-based cross-industry horizontal M2M frameworks with real world sensors and IoT device deployments. In addition, the testbed applies autonomic communication methods for end-to-end M2M communication in Smart Cities by focusing on smart energy management and environmental monitoring.

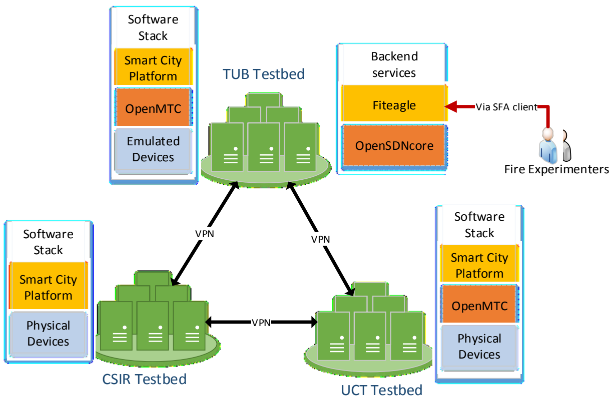

Fig. 2. Testbed interconnection.

V. Solutions and Results

To validate the utility of the testbed a three pronged approach was followed: execution of two trials and the creation of the PoC

A. Smart City Environmental Monitoring Trial: Spain

The Smart City Environmental Monitoring Trial is deployed in Sant Vicenç dels Horts, near Barcelona, Spain.

The trial consists of the deployment of a Delay Tolerant Networks (DTN) based system for Environmental Monitoring in Smart Cities and does not require dedicated infrastructure for interacting with the sensors which are distributed through the city. It is an energy-efficient solution based on enhanced radio wake-up system mechanisms and bidirectional communication with the sensors to support monitoring and configuration functions.

More than 35 low-power sensor devices were deployed city wide. To save energy, these units are “asleep” most of the time and only transmit data when a mobile collector (a gateway) approaches and “wakes” it. This gateway is installed in a bus to demonstrate how the available public transportation infrastructure can be innovatively exploited to collect not only passengers but also valuable data from the city [11]. Furthermore, Airbase air quality devices have been integrated in the trial to provide the municipality with interesting pollution figures.

The trial provides real data to experimenters and verifies:

- The possibilities and performance of an integrated M2M architecture deployed in the TRESCIMO project.
- The integration with the OpenMTC platform and the Smart City Platform (SCP) as the main blocks of the TRESCIMO architecture.
- The viability of applying Delay Tolerant Networking and wake-up Technologies to deploy energy-efficient Smart City solutions when real-time data acquisition and network interaction is not a relevant issue.

A key performance indicator for the deployment is the distance at which sensors can be woken up by the bus. Fig. 3 illustrates the average wake-up distance and the standard deviation (in meters) for the sensors involved in the Smart City Environmental monitoring trial. The sampling period ranges from the beginning of November 2015 to the end of January 2016. As observed, the deviation is considerable in all the cases; however, this is an expected result in a realistic mobile scenario and communication performance can be affected by a multitude of external and variable factors. In particular, most sensor devices show effective wake-up distances greater than 20 meters. Only a few devices show poor behaviour and this can be attributed to these being positioned on street edges, turnarounds.

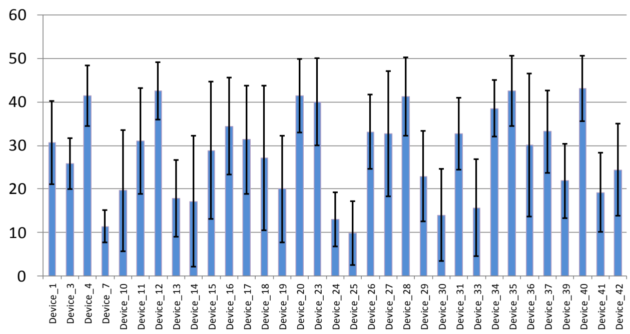

Fig. 3. Average wake-up range (in meters) per sensor. November-January. EU Trial.

The trial demonstrates that solutions based on radio wake-up systems and DTNs support city-wide information collection while minimizing the number of deployed and maintained devices. Furthermore, improvements due to the enhanced wake-up system lead to communication ranges of more than 28 meters on average and it has been shown to be sufficient for data to be retrieved by a moving vehicle. Finally, the implemented device addressing techniques permit to univocally determine the sensor device to be woken up. This opens up the possibility to deploy differentiated services in the city without real-time requirements (e.g. trash recollection, environmental monitoring, water irrigation) using the same approach. The results have been presented to the municipality of Sant Vicenç dels Horts, Spain and were well received.

Fig 4. is a screenshot of the Smart Environmental application. This figure demonstrates how the information collected by the TRESCIMO framework is presented to the

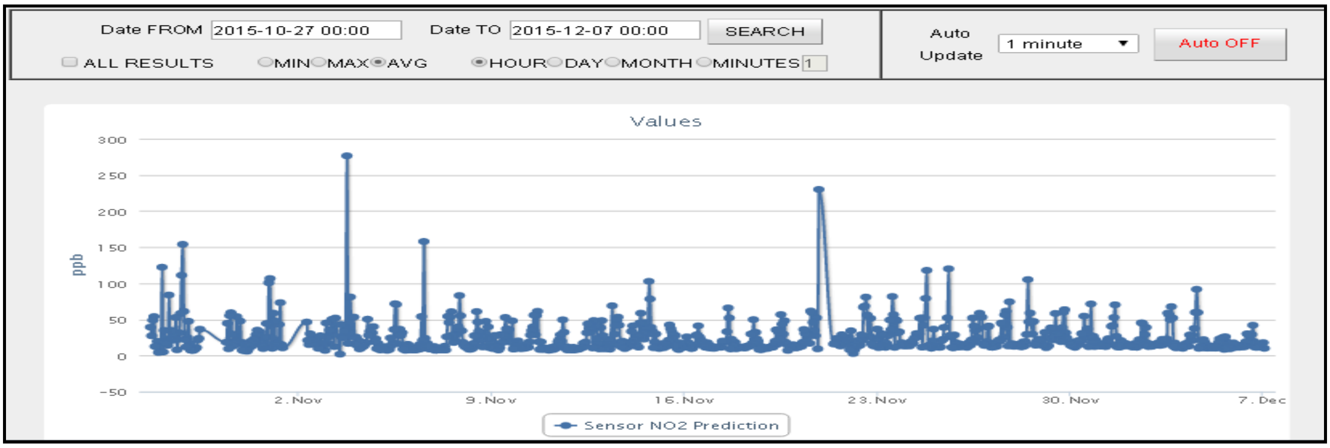

Fig. 4. Smart Environmental web application: NO_2 measurements.

end user. NO_2 measurements illustrate the pollution due to city traffic. Additional trial results are available in [12].

B. *Smart Energy Trial: South Africa*

The Smart Energy trial is deployed in the Gauteng region of South Africa. The trial uses a collection of intelligent energy management devices and links a number of households to the Smart City Platform. The aim of the trial is to establish a demand-side energy management mechanism; that is, data is acquired, communicated, processed and the result communicated to a device as an automatic actuation command or alternatively to a person. The interface (a mobile application) to the person is of particular interest.

The mobile application that links to the platform stack was implemented and provides a view into a resident's household. The trial aims to provide energy consumers with the ability to both monitor and control specific appliances in the home. This function is especially useful during peak energy demand periods and uses IoT and M2M technologies. Another aim is to test the impact on consumer energy patterns when a customer is provided with comprehensive and timeous individualised household energy usage statistics.

The trial aims 1) to gauge an individual customer's response to the technology presented and 2) to determine the impact the energy management technology has on a customer's perception of energy management and consequently also their willingness to make use of smart technologies to elicit a change in their energy usage patterns. To this end pre-trial and post-trial questionnaires were compiled and the rate at which the customer used the system monitored. The questionnaires revealed:

- A large number of the participants mentioned that they actively track their energy consumption.
- Residential consumers respond substantially to Power Alert, a national broadcast notification system developed to reduce energy consumption during system constraint periods.
- The majority of respondents indicated that load could be shifted by controlling pool pumps, air conditioners and hot water geysers.
- The majority of consumers indicated that they would prefer to shift load themselves instead of the utility doing so on their behalf.

To identify behavioural changes that can be ascribed to residential installations, half-hourly energy consumption data was retrieved from an existing and parallel independent smart metering system and analysed.

Fig. 5 compares the average daily energy consumption of a participant during the trial with the same period 12 months earlier. From the graphs it is evident that a significant correlation exists with regards to environment-driven increases and decreases in the average daily energy consumption. However, a significant reduction in average energy consumption is observed during the trial. For this customer, the average energy consumption was calculated as being 45% less than the same period in the previous year.

The reduction in energy consumption can be attributed to a

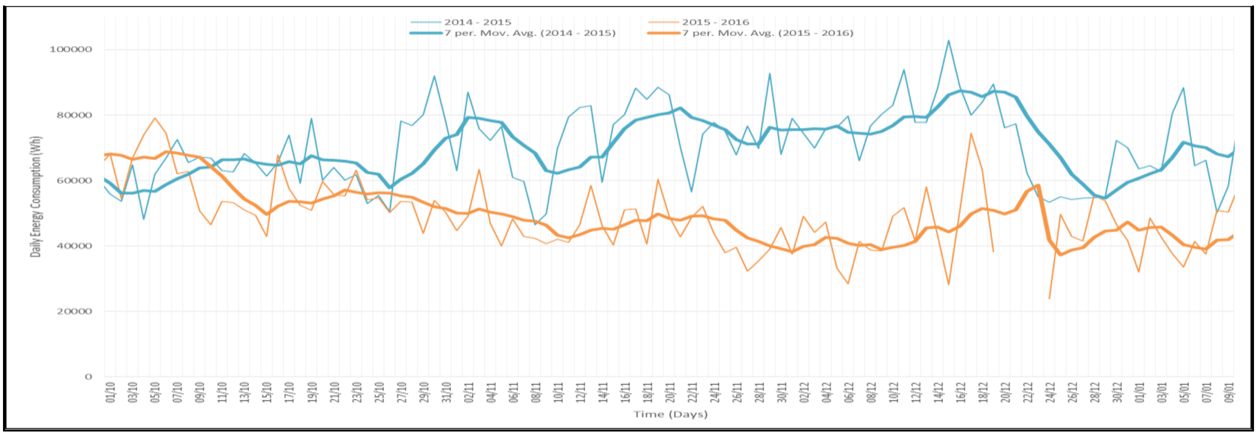

Fig. 5. Daily energy consumption comparison of a household.

number of factors and these are as follows: the customer actively used the system to manage their energy usage, the customer replaced one or more appliances for more efficient models or non-electrical appliances (solar or gas), or the customer dramatically changed their household lifestyle (i.e. a child leaving the residence). The following are responses received from the trial participants when asked what they would like to see changed or improved concerning the functionality provided by the mobile application:

- The mobile application did not always open when logging in and it would require multiple attempts to log in and be able to use the application.
- The ability to schedule the control of an appliance so that it happens automatically.
- The ability to have total energy consumption would be useful.
- Historical consumption should be displayed in daily, weekly and monthly increments.

Comments from the trial participants alluded to challenges in continuously accessing the system. The Smart Energy trial used 3G mobile connectivity to connect active devices to the back-end platforms. For the trial 33 sets were developed of which 29 were deployed. Fig. 6 depicts the average uptimes per household. Each household had three devices. Excellent end-to-end data throughput per device was obtained from numerous households (i.e. House #2, #25, #31 and #32). However, this was not the case for all households (i.e. #13, #14 and #15). The drop in end-to-end data flow reliability is attributable to two factors: where a device in the low-power network was no longer active (Device #2 for house 24 has a much poorer uptime compared to the other two devices) and the case where the 3G connectivity was insufficient (e.g. #1, #4, #20 and #29) leading to intermittent or very poor data flow caused most of the times by walls between the devices.

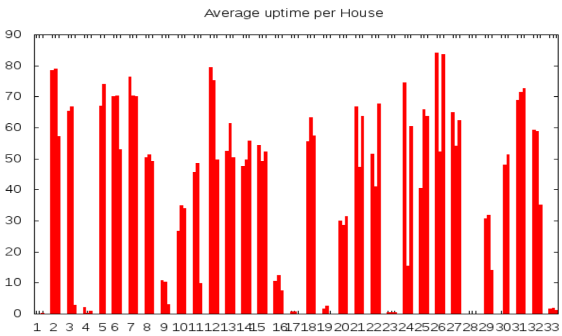

Fig. 6. Uptime (in percentage) per household (1-33)

C. *PaaS Proof-of-Concept (PoC)*

The PoC integrates technology building blocks into an end-to-end future internet experimental platform with communication management platform by adapting the communication handling of the end device (in this case the smart meters-and-actuators and DTN gateways) based on the available service instances in the cloud [13].

Experimental applications using the current resources (and new resources which can easily be integrated) provide a rich opportunity for exploitation towards a large scale deployment where the infrastructure has to evolve and scale as more and more customers enter.

VI. Conclusions

TRESCIMO outcomes encourage the development of affordable technologies for Future Internet. It enables research activities on delay tolerant networks and opportunistic communications as well as developments supporting innovative applications for social integration. It improves the capabilities of testbeds on Future Internet technologies in Europe and in South Africa. The validity of TRESCIMO has been established through its ability to support experiments on different domains (energy and environment).

With respect to future smart grid, both at national level as well as at municipality level, TRESCIMO contributes to increased awareness at citizen level and encourages behavioural change leading to energy savings in public and private buildings and homes. Similarly, TRESCIMO has shown that it can provide a detailed view of pollution in a city which can lead to improved quality of life of its citizens.

An important project achievement is the potential to cross-fertilize solutions and concepts across hemispheres: The European smart environmental monitoring utilised the South African SCP for real world modelling whereas the South African trial made use of the European tools for communication control and PaaS concepts as a solution for scaling the infrastructure. The technology developed for the TRESCIMO project can also support existing initiatives and anticipated programs in other domains for example smart city programs dealing with water, waste, healthcare, education, transport, and logistics.

Acknowledgments

The TRESCIMO project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 611745, as well as from the South African Department of Science and Technology under financial assistance agreement DST/CON 0247/2013.

References

[1] UN-HABITAT, "Cities for All: Bridging the Urban Divide - State of the World Cities 2010/2011," no. 004/14E. 2011
[2] TRESCIMO Website: http://trescimo.eu/
[3] FIRE Website: http://www.ict-fire.eu/
[4] J. Oller et. All. "Design, development, and performance evaluation of a low-cost, low-power wake-up radio system for wireless sensor networks," *ACM Trans. Sens. Networks*, vol. 10, no. 1, pp. 1–24, 2013
[5] OpenMTC, www.openmtc.org
[6] Open5GMTC, www.open5gmtc.org
[7] FITeagle, www.fiteagle.org
[8] OpenSDNCore, www.opensdncore.org
[9] TRESCIMO Deliverable D3.3. Architecture, http://trescimo.eu/wp-content/uploads/2015/11/D3.3_v1.0.pdf
[10] https://federation.trescimo.eu
[11] M. Catalan et. All.. "How buses can collect more than passengers: The Sant Vicenç dels Horts experience". TRESCIMO Workshop on "New strategies and solutions for Smart Cities". June 2015
[12] TRESCIMO Deliverable D4.3. Experiment Results. http://trescimo.eu/wp-content/uploads/2015/11/D4.3-TRESCIMO_final.pdf
[13] A. Corici et. All, "Towards Programmable and Scalable IoT Infrastructures for Smart Cities", MUCS Workshop, Percom, March 2016.
[14] SmartSantander Project, "Second Cycle Architecture Specification"