Towards Experimentation-Service duality within a Smart City scenario

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Abstract—**Smart City concept and applications domains are taking a prominent position in nowadays innovation trends. Future Internet and ICT in general are considering the Smart City as the key concept for the future technological developments. In particular, Wireless Sensor Networks (WSN) and Machine to Machine (M2M) communications are some of the basic enablers for fulfilling the Smart City concept requirements. In this paper we are describing the SmartSantander experimental facility. This Smart City testbed has been envisioned on a twofold approach: experimentation support experimentation and service provision. The paper not only describes the main features of the deployed testbed but also showcases the supported experimentation-service duality by showing how it is possible to run a routing protocol experiment while a service is provided to the citizens over the same network.**

Keywords- FIRE; IoT; Living Lab; Smart City

I. Introduction

The FIRE (Future Internet Research and Experimentation) initiative [1] was set on the Seventh Framework Programme, as an experimentally-driven approach for challenging the mainstream perceptions for the Future Internet development, in a twofold approach:

- Experimentally-driven long term research on new paradigms for the future internet.
- Build a large scale experimentation facility by federating existing and new testbeds, for future internet-related technologies.

The first set of projects in the FIRE initiative already started to create general-purpose experimental facilities for the Future Internet. In this sense, projects like OneLab2 [2], PII [3] and Federica [4] (and the smaller Vital++ [5]) were essentially not designed for IoT experimentation. However, the area of the Internet of the Things (IoT) was initially not tackled. as WISEBED [6] project is dedicated to sensor network testbeds but not specifically to IoT on its wide sense thus it cannot provide all the properties expected for experimenting on all IoT technological enablers.

The FIRESTATION [7] portfolio study has observed a need to enhance user support and user involvement, which is considered a new and untested concept. In this sense, the Living Labs community has brought together a rich variety of experiences on user engagement in ICT-based innovation. This has led to the creation of important areas of application, such as Smart Cities, considered as excellent playgrounds for Future Internet research and experimentation.

In the light of these recent studies, apart from the general-purpose environments developed in FIRE, there are a few initiatives to create Smart City environments. Some of these examples are Oulu in Finland [8], Cambridge, Massachusetts [9], or Friedrichshafen, Germany [10]. While these are all interesting approaches, they are usually not intended to be an experimental platform for Future Internet research. Furthermore, they are not very large-scale and are not designed to be open for all kinds of researchers.

In order to achieve the aforementioned remaining challenges and fill the existing gap, SmartSantander project proposes a unique in the world city-scale experimental research facility in support of typical applications and services for a Smart City. This unique experimental facility will be sufficiently large, open and flexible to enable horizontal and vertical federation with other experimental facilities, and stimulates development of new applications by users of various types, including experimental advanced research on IoT technologies as well as realistic assessment of users' acceptability tests.

SmartSantander differentiating characteristic is that it has been designed not only for addressing the pure experimentation on IoT technologies, but also for bringing these technologies closer to its end-users. The so-called experimentation-service duality.

In order to fulfil all the requested requirements, SmartSantander architecture heavily relies on existing components which have been complemented by so far missing building blocks that are specific for SmartSantander singularities. The most important platforms, the experimental facility have been built on come from:

- FP7 Integrated Project SENSEI [11].
- FP7 STREP WISEBED.
- Telco 2.0 Open Platform [12].

In order to step forward in terms of the deployment size, the facility will consist of more than 20,000 IoT devices. 12000 nodes are being deployed in the city of Santander and its surroundings while around 8,000 devices are expected to come from the deployments in, Belgrade, Guildford and Lübeck.

This paper results come from a first pilot deployed in Santander comprising 300 IEEE 802.15.4 devices.

The paper is structured as follows: Section II shows the scenario posed by SmartSantander to support, so-called experiment and service planes, in a simultaneous way. Section III focuses on the way the network management together with service provision as well as experimentation are supported by the platform. In Sections IV and V, an exemplifying experiment, including corresponding measurements associated to them, as well as user-addressed services provided to the Santander citizens are detailed. Finally, Section VI presents the main conclusions derived from the deployed infrastructure.

II. SMARTSANTANDER TOPOLOGY

Since experimentation-service duality represents the key feature of the SmartSantander platform, it is necessary to define an infrastructure that enables the execution of experiments and user-addressed services in a concurrent manner. The platform has to be flexible enough for researchers to try their applications and techniques on the testbed while at the same time a service aimed at improving citizens' quality of life is being provided using the same devices. To handle this concurrency in an efficient way, a solution (developed by the Spanish company Libelium [13]), based on hardware independency between experiment and service data, is posed within the first pilot of the SmartSantander project.

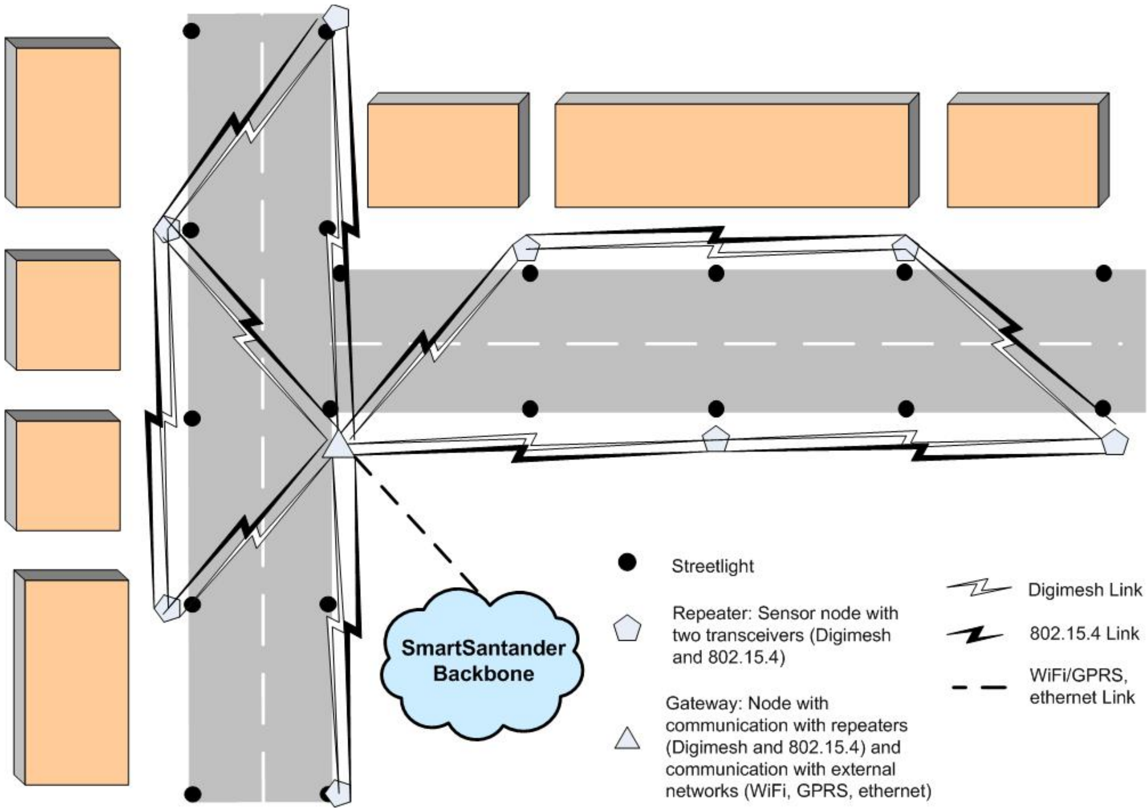

Figure 1. SmartSantander Architecture for concurrent service provision and experiment testing

As it can be shown in Figure 1, the network presents three levels of hierarchy:

- **IoT node**: These nodes only participate on the service provision aspect of the facility and in those experiments that do not require the nodes to be reprogrammed. This is the case for the parking sensors buried under the asphalt. These devices are battery-powered only and its duty cycle is optimized for the service they are deployed for. They communicate with nearby repeaters on a peer-to-peer fashion. They are not shown in Figure 1 as only service-related experimentation (i.e. using the observations generated on the service provision task) might be possible with them.

- **Repeaters**: The majority of them are also equipped with a sensing device for a given physical parameter (temperature, CO, noise, light, etc.). These nodes are high-rise placed (with heights ranging from 3 to 5 meters) in lamp posts, semaphores or information panels. In order to provide the aforementioned hardware independency, these nodes are equipped with two different communication interfaces, both running over 2.4 GHz. The first on implements IEEE 802.15.4 protocol in a native way. The other one implements, on top of IEEE 802.15.4 a proprietary routing protocol called Digimesh. This protocol automatically creates a meshed network among all the nodes allowing them to be addressed in an easy and straightforward way. All nodes can act as forwarders as well as end points, thus allowing multihop communications from the source to the destination node.

- **Gateways**: These devices are connected to the Internet and provide the door for having access to the information generated at the IoT nodes and Repeaters. In this sense, both repeaters and IoT nodes send the retrieved information to the gateway node they are associated to.

Figure 2 shows the hardware associated to the Repeater (IoT node is similar but with a single radio interface) and Gateway.

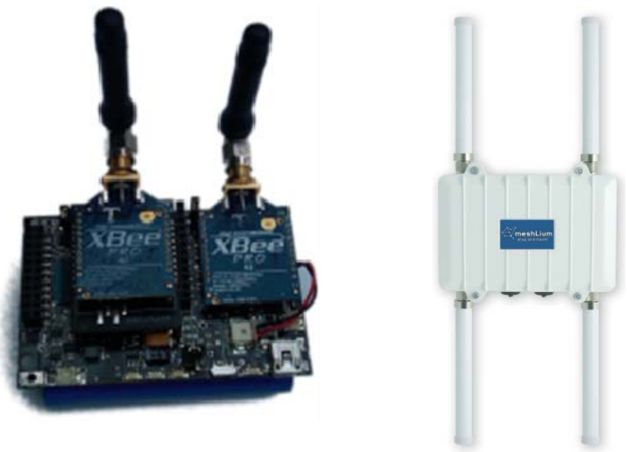

Figure 2. IoT node/repeater (left) and Gateway (right) architecture

The IoT node/Repeater can be divided on the following parts:

- Main board: This board (called *waspmote*) is in charge of processing and memory issues, providing a set of interfaces for attaching different types of sensors (both analog and digital), as well as to plug several radio modules to communicate with other nodes. The waspmote is equipped with a ATmega1281 microcontroller, and several types of memory, 8KB SRAM, 4KB EEPROM, 128KB FLASH and an extra storing SD memory with 2GB capacity. Moreover, 7 analog and 8 digital interfaces are available for external sensor connection, as well as 1 PWM, 2UART, 1 I2C and 1 USB interfaces for attaching different communication modules.
- Two XBee-PRO radio modules: Both modules manufactured by Digi [14] company, run over 2.4 GHz. Native IEEE 802.15.4 one is dedicated for the experimentation while the one that includes the Digimesh protocol is reserved for the service provision related data and for control and management related traffic.

Gateway device (called *meshlium*) offers higher capacity in terms of processor (500MHz) and memory (256MB RAM and up to 32GB hard disk), and is also equipped with both Digimesh and IEEE 802.15.4 interfaces. Additionally, it also provides WiFi, GPRS and Ethernet interfaces for connecting to the Internet. Once the information from the Repeaters and IoT nodes network is received at this node, it can be made globally available.

III. NETWORK MANAGEMENT, SERVICE PROVISION AND EXPERIMENTATION SUPPORT

In addition to the experimentation support and service provision, it is also critical for the SmartSantander facility to be remotely managed. This management does not only refers to network monitoring, fault detection and self-healing, but also to experimentation management and control.

- **Network Management**: It is carried out through the Digimesh interface and consists of the transmission/reception of commands from the gateway to the repeaters in order to configure them or ask for certain information retrieval. A key Network Management feature for fully supporting the experimentation is the ability for nodes to be flashed from the gateway in a wireless way, the so called Over The Air Programming (OTAP) and Multihop OTAP (MOTAP). The nodes store the received codes in the SD memory, being possible to have several programs in the same node. Afterwards it is possible to send a command from the gateway to indicate the program to be executed by a node at a certain time. Besides, it is also possible to control the WSN topology or monitor the status of all the IoT nodes and Repaters.
- **Service Provision**: Digimesh interface is also used for sending information related to the services offered to the citizens. In this sense, the Digimesh protocol directly routes all the information from the repeaters to the gateway.
- **Experimentation Support**: Native IEEE 802.15.4 is reserved for experimentation. Experimenters can use this interface to send and receive all the data associated with the different experiments executed over the network.

Hardware independency is just one of the necessary legs to support simultaneous execution of management, service and experimentation. In this sense, Repeaters are flashed with a default program (so-called Golden Image), which carries out the functionalities associated to the service provision, as well as all the management issues needed for the correct network operation. This image is loaded in the nodes at the network start-up, and re-flashed when a node must be restored to its default state (e.g. after an experiment has ended).

The default program is standalone and running when no experiment is making use of the node, thus supporting service provision as well as network management. However, this support has to be kept when nodes are being used as part of an experiment. In this sense, the golden image has been also created as software libraries that can be linked to the experiment program. This way both functionalities, this is, those supported by the golden image and those related with the experiment, are merged into a single program image. This guarantees that nodes are accessible and manageable at any moment.

From the gateway point of view, information associated to the service is received through the digimesh interface, whilst the information associated to the experimentation arrives to the 802.15.4 interface. The data associated to the service is processed and stored in a database, in order to serve as basis for the development of different applications and services. On the other hand, the packets received at the experimentation interface are processed by the corresponding controller associated to each experiment.

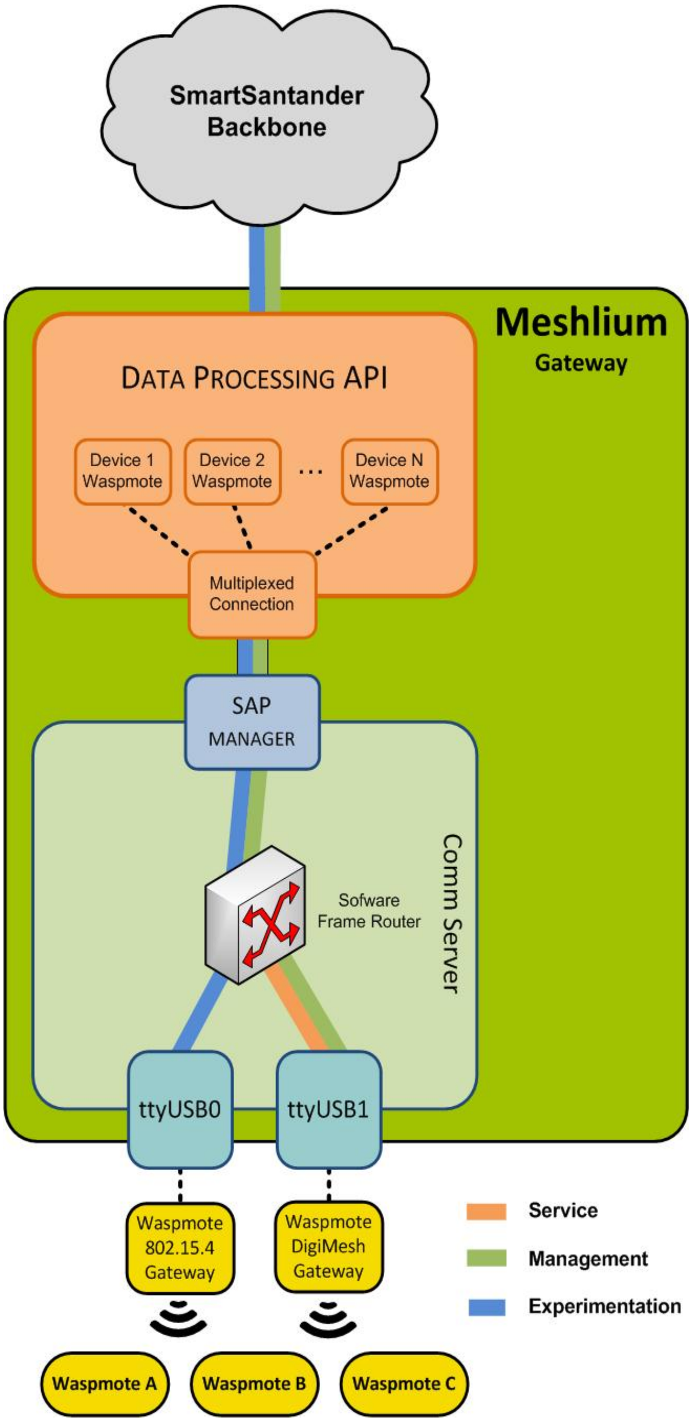

Figure 3. Architecture for integration of Waspmote-based WSN

Figure 3 illustrates this mux/demux functionality to support communication with Waspmote devices. The hatched boxes in the figure, namely CommServer, Multiplexed Connector and Waspmote Driver, implement the mux/demux functionality in order to support the wireless Waspmote devices.

- **CommServer:** The CommServer module is responsible for directly handling with the physical radio interfaces in charge of wirelessly interacting with the WSN and of providing a unique interface for the access to/from the rest of the system.
- **Multiplexed Connector:** As it just exists a unique interface (one for Digimesh and another one for 802.15.4) for interacting with all deployed nodes, the Multiplexed Connector will manage the message and forward it to the CommServer, which will subsequently send it through the appropriate physical interface in order to make it available to the corresponding connector associated with the sender IoT Node.
- **Waspmote Driver**: Functionalities and message formatting that are specific for the Waspmote devices are implemented in this module. As it is assumed one connector per IoT Node in the WSN, there is one of these modules per device in the WSN.

The first two modules are generically-applicable and IoT device-independent, whilst the WaspMote driver is device-specific i.e. a new driver needs to be implemented for each new device type.

IV. SERVICE-RELATED USE CASE: ENVIRONMENTAL MONITORING

Once presented the main features of the SmartSantander experimental facility, a service-related use case is presented in this section.

The implemented service is meant to measure different environmental parameters like temperature, CO, light and present this information within a web interface.

In Figure 4, it can be observed one of the deployed clusters with the gateway and the Repeaters associated to it. These repeaters generate observations of different environmental parameters: light, CO level and temperature (all sensors retrieve temperature values). Deployed parking sensors, showing the free (blue) and occupied (grey) parking sites can also be observed. All these values are sent through the Digimesh-based network. Once packets are received by the gateway, these are processed and the retrieved information stored in a database and made available for the SmartSantander backbone.

In Figure 5 and Figure 6, they are observed the corresponding values of temperature, luminous intensity and battery charge for a determined node. The measurements are taken every few minutes giving a complete picture of the variations during the day.

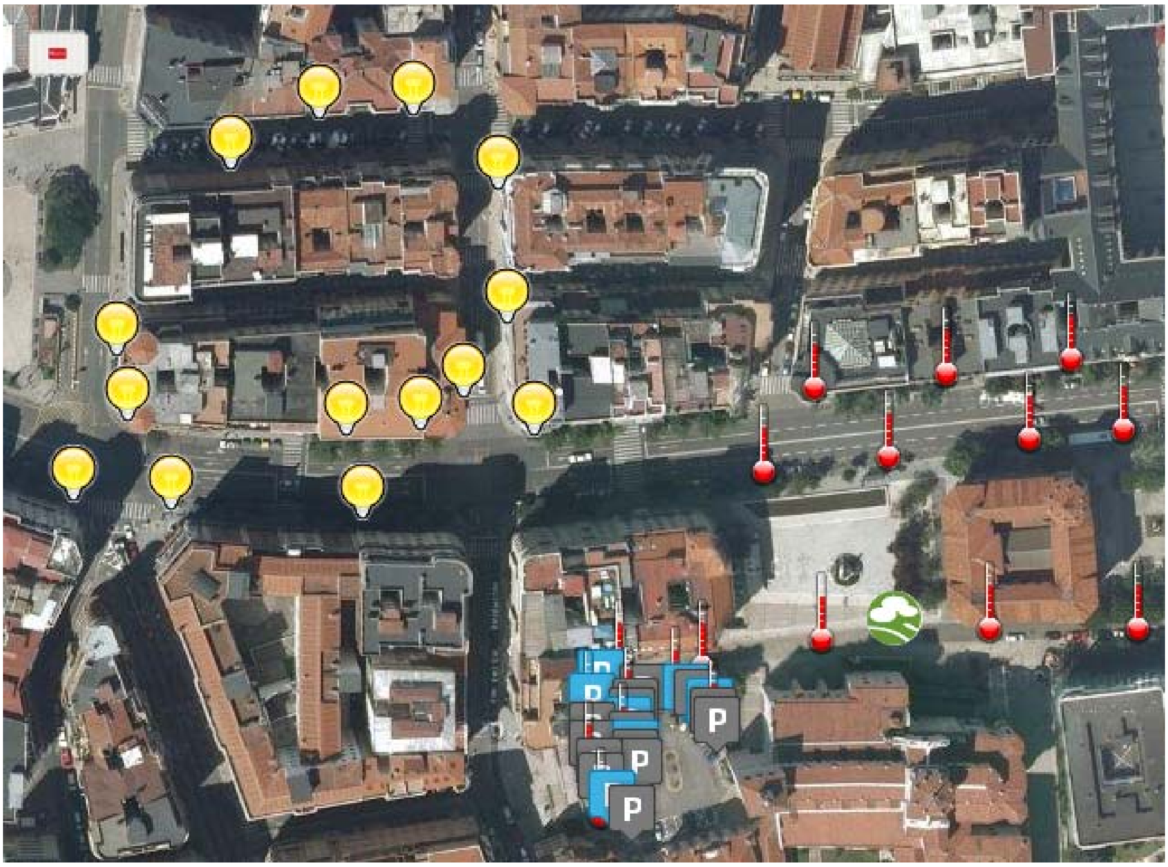

Figure 4. Part of network deployment in Santander city centre

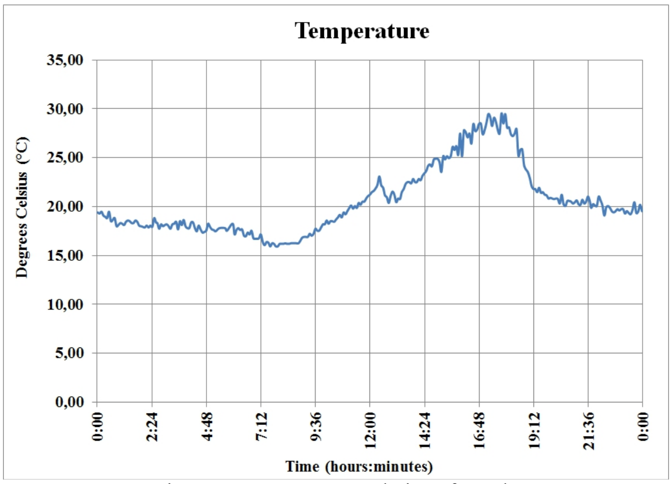

Figure 5. Temperature evolution of a node

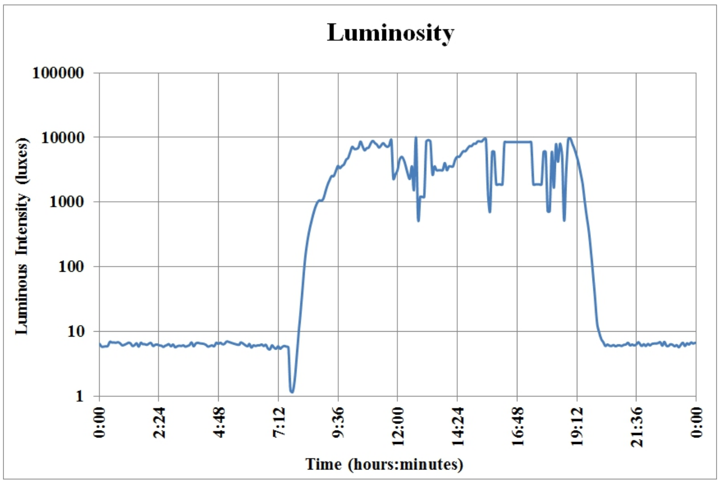

Figure 6. Luminous intensity evolution of a node

In Figure 5, it is depicted the temperature evolution during a whole day, observing a logical behavior as temperature decreases at night and in early morning, and grows during morning and afternoon. If it is compared with the Luminosity graph, shown in Figure 6, the hours with the highest temperatures match with those presenting larger luminosity values. For the temperature values, they are observed low intensity peaks than for luminosity, where peaks can be due to clouds or shades. Moreover, observing the graph, it is possible to conclude how the dawn in this day was at 08:00 and the sunset at 20:00, approximately.

In Figure 7, it is depicted the evolution of the level of a rechargeable battery during a whole day. All the repeaters placed in the streetlights are fed with this kind of batteries. In this sense, as street lights are only electrically powered at night (when they are turned on), then batteries will also recharge at this period of time, working in autonomous way the rest of the day. As it can be observed, the level of the batteries grows at night and decreases during the day, but at the end of a 24-hour cycle the level remains the same, so ideally the battery life will be infinite.

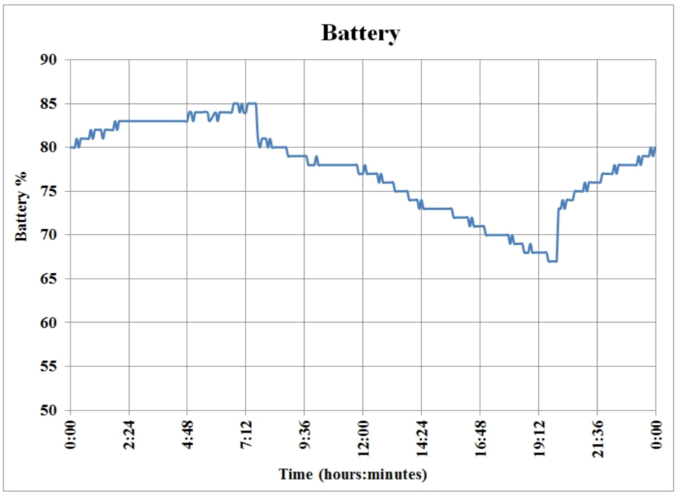

Figure 7. Rechargeable evolution of a node

All these measurements are oriented to fulfill the citizens' requirements, just offering a dense network with several type of sensors.

V. EXPERIMENTATION-RELATED USE CASE: BASIC ROUTING PROTOCOL

It is important to highlight that although presented in different sections both service-related and experimentation use cases are running simultaneously.

From the experimental point of view, a simple flooding routing protocol running over the 802.15.4 interface has been implemented for the sake of exemplifying SmartSantander service-experimentation duality. The operation of the implemented protocol is described next:

- The protocol also implements a neighbour discovery mechanism, thus any node can discover its neighbours at a determined distance (in number of hops), determined by the TTL specified in the discovery packet.
- Packets are sent from the Gateway in a broadcast fashion, such that the packet floods the network until it reaches the target node. Once this node receives the packet, it stops forwarding it in order not to flood network unnecessarily.
- To assure that a packet does not stay endlessly travelling within the network, it is assigned a time to live (TTL) parameter to each packet. When a packet crosses a node, its TTL value is decreased, so when TTL value is zero, packet will be discarded and not forwarded any more by the node.
- In order to avoid the reception of duplicated packets, each packet will be provided with a sequence number. Once a node receives twice a packet with the same sequence number, the packet is discarded as it has been already received previously.

Regarding to the protocol operation of the protocol, four nodes have been loaded with this code (using (M)OTAP), thus retrieving the following results shown in next figure:

```
Timestamp              : 2011-10-07T22:17:48.381+02:00
NodeID (dec)           : 60
Last 802.15.4 hop      : 00:13:A2:00:40:65:1A:E4
Number of hops         : 1

Timestamp              : 2011-10-07T22:17:48.397+02:00
NodeID (dec)           : 50
Last 802.15.4 hop      : 00:13:A2:00:40:65:1A:E4
Number of hops         : 0

Timestamp              : 2011-10-07T22:17:48.380+02:00
NodeID (dec)           : 70
Last 802.15.4 hop      : 00:13:A2:00:40:6C:A5:38
Number of hops         : 0

Timestamp              : 2011-10-07T22:17:49.380+02:00
NodeID (dec)           : 80
Last 802.15.4 hop      : 00:13:A2:00:40:60:8F:AB
Number of hops         : 0
```

Figure 8. Gateway Neighbours Table

In Figure 8, it is shown the neighbor table associated to a gateway node for 802.15.4 native interface (for the other interface, Digimesh protocol will find the neighbours automatically). As it has been observed in the figure, from the four nodes, three of them located within gateway coverage area (0 hops away), whilst the other one is one hop away. For this last node, it is also indicated the node corresponding to the last hop.

It is important to take into consideration that this discovery protocol triggered by gateway node, operates (through the 802.15.4 interface) at the same time than these nodes are sending (through the digimesh interface) environmental parameters to the same gateway. The use of the different communication interfaces assures no disturbance among both applications.

VI. CONCLUSIONS

Smart Cities stands as the meeting point to align the creation of large scale experimentation facility fostered by FIRE initiative and the user involvement in ICT-based innovation targeted by the Living Labs community. This paper has shown a real deployment of WSN within a city (Santander) scenario, as a first pilot within the SmartSantander project.

The deployed pilot represents the first step towards a Smart City scenario aiming at addressing a twofold approach. On the one hand, it offers an experimental facility for the researchers to try their own developments within a real-world environment. On the other hand, over the same infrastructure, SmartCity-like services are provided to the citizens.

A third facet of utmost importance, namely large-scale WSN management, has been also tackled. To ensure the accessibility and manageability of the testbed, nodes are provided with a *golden image* that allow the nodes to transmit/receive configuration commands at any moment and more importantly, nodes can be flashed as many times as needed with the corresponding code images so that new services can be added on the fly and a plethora of experiments can be tested over the same nodes.

Last but not least, it is important to highlight that both service-oriented and experimentation-related applications are simultaneously executed over the same physical network, without interfering among them. In this sense, a service to monitor different environmental parameters (light, temperature, CO level), and an experiment to test a flooding protocol have been implemented, thus showcasing the concurrent execution of both of them assessed by the completion of different measurement campaigns.

ACKNOWLEDGMENT

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