SmartSantander: Experimentation and Service Provision in the Smart City

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***Abstract* — This paper describes the deployment and high-level architecture of the Internet of Things experimentation facility being deployed at Santander city. SmartSantander is a unique in the world city-scale experimental research facility in support of typical applications and services for a smart city. The testbed that has been deployed has a dual purpose. On the one hand it will allow real-world experimentation on Internet-of-Things related technologies (protocols, middlewares, applications, etc.). On the other hand it is currently supporting the provision of smart city services aimed at enhancing the quality of life in the city of Santander. Tangible results are expected to greatly influence definition and specification of Future Internet architecture design from viewpoints of Internet of Things and Internet of Services. This paper presents the physical deployment carried out in the city of Santander and the high-level architecture supporting the experimentation and service provision duality. Moreover, a brief description of the mechanisms supporting the experimentation life cycle will be done. Finally, the services that are being provided to the city will also be sketched.**

Keywords—Smart City; Internet of Things; Future Internet;

I. INTRODUCTION

Fuelled by the recent emerging of a variety of enabling device technologies on the market, the Internet of Things (IoT) is at the verge of becoming a major extension to the current fixed and mobile networking infrastructures and an integral part of the Future Internet (FI). Recent predictions [1] foresee that IoT will form an essential part of the FI, as its connected devices will outnumber the computers and mobile devices utilized by human users by orders of magnitude. If such scenario unfolds, it is not hard to conclude that the design of the FI and its architecture will be strongly influenced by the requirements of the IoT. The scale, heterogeneity and constraints of the IoT devices and the distinct nature of envisaged interactions pose significant challenges for their successful integration into the FI architecture.

However, IoT has many facets and exceeds the scope of currently available deployments mainly due to two issues. First, current IoT-like deployments are mainly closed and are vertically integrated solutions tailored to specific application domains. A major goal of IoT research is to integrate these island technologies into a globally interconnected infrastructure, moving from the currently existing Intra-net to a real Inter-net of Things [2].

On a different plane, cities are complex systems, a conglomerate of people, organizations, businesses, city infrastructures and services, and more recently deployments of smart devices like sensors and actuators. As all complex systems, cities need to be managed in order to ensure uninterrupted performance of all relevant activities and thus uninterrupted living conditions for all stakeholders. The coordination of all these activities and domains is of paramount importance to ensure efficient and effective city services management. However, in modern cities the coordination is usually not done on a daily basis, but more on a strategic level and mainly from the administrative and political perspective with poor real-time feedback. Each public service is often run as a standalone activity with (administrative) walls being built between the domains preventing efficient exchange of information and sharing of available infrastructure.

Based on these precepts, the SmartSantander project [3] main target is the creation of a European experimental test facility for the research and experimentation of architectures, key enabling technologies, services and applications for the IoT in the context of a smart city. This facility will be instrumental in fostering key enabling technologies for IoT and providing the research community with a unique-in-the-world platform for large scale IoT experimentation and evaluation under realistic operational conditions. The principle to set the experimental facility into a city context relies on four key reasons: 1) the ubiquity of IoT-based technologies that forms part of smart city infrastructures; 2) the scale as key enabler for the aforementioned broad range of experimentation needs; 3) a smart city can serve as an excellent catalyst for IoT research, as it forms a very dense techno-social eco-system that can act as invaluable source of challenging functional and non-functional requirements from a variety of problem and application domains; and 4) cities represent a strategic meeting point between the citizens (urban society) and the technology provides with an additional dimension that can be exploited for a continuous crowd-sourced creativity scenarios. This is what the authors categorize as societal innovation meaning that the human beings are immersed in a context which stimulates the conception of new ideas and quickly engages them with solutions addressing the problems related to their ecosystem.

This paper presents an architectural reference model for open real-world IoT experimentation facilities that copes with the plethora of devices and application domains associated with this concept. It is important to note that IoT experimentation facilities must attract the widest interest and demonstrate the usefulness besides the research community. To that end, a key aspect that has been addressed when defining the presented architectural model is to make the platform attractive for a wide range of involved stakeholders, namely Internet researchers to validate their cutting-edge technologies; entities that are willing to use the experimental facility for deploying, validating and assessing new services and applications; and communities of users generating insights into the acceptance of IoT-based services deployed in a live environment.

The description of the actual physical deployment process is another key contribution that is highlighted in this paper. In particular, the steps taken for the set-up of a large-scale heterogeneous infrastructure over the city of Santander will be detailed.

The IoT experimentation support framework relies on the integration of existing components from SENSEI [4] and WISEBED [5] projects and Telefonica Ubiquitous Sensor Networks Open Platform [6]. However, singular challenges of the SmartSantander facility have made it necessary to design and implement additional mechanisms to address support for large-scale, horizontality, heterogeneity, mobility testing, as well as resource reservation and management. Presenting the solutions adopted for addressing these singularities and making the facility usable for the experimenters is the another contribution of this paper.

The last contribution of the paper is presenting four services that are currently being provided in the city of Santander based on the deployed facility. These services create a showcase demonstrating the potential for smart services development on top of the platform described in this paper.

The paper is organized as follows. Section 2 presents the SmartSantander platform high-level architecture highlighting the main requirements and testbed singularities that have been considered for the realization of the experimental facility. It also describes the IoT infrastructure that is deployed nowadays at the city of Santander. The mechanisms that have been implemented for experimentation support are described in Section 3. Section 4 presents four service developed for engaging citizens in the SmartSantander paradigm. Finally, Section 5 concludes the paper presenting some of insights on how SmartSantander will be further developed on the two axes FI experimentation and smart city service provision in the near future.

II. TESTBED ARCHITECTURE AND DEPLOYMENT

A. High-Level Architecture

This section provides an overview of the architecture of the SmartSantander testbed and explains in more detail how its features and underlying design choices contribute to provide a richer IoT experimentation environment that is suitable to support experimental research addressing many of the open research challenges in this area as well as to enable smart city services provision at the same time.

In previous work [7] some of the gaps of existing research facilities to provide an adequate support for the emerging requirements of experimental IoT research. The SmartSantander facility offers a variety of properties and features to overcome many of these shortcomings and integrates them into a holistic experimentation environment. These main gaps are as follows: Realism of experimentation environment, scale, heterogeneity in terms of devices and application domains, mobility, user support and user involvement.

As depicted in Fig. 1, SmartSantander is realized by a three tiered network architecture, which consists of an IoT device tier, a gateway (GW) tier and server tier.

The IoT node tier provides the necessary experimentation substrate consisting of IoT devices. As IoT experimentation is the primary focus for SmartSantander, the IoT node tier accounts for the majority of the devices utilized in the testbed infrastructure. In order to satisfy the expected heterogeneity the IoT node tier consists of a variety of IoT device types, such as diverse mote platforms, RFID readers and tags as well as more powerful platforms such as mobile phones with short range communication capabilities.

The gateway node tier links the IoT devices at the edges of the network to a core network infrastructure. The nodes of the GW tier are also part of the programmable experimentation substrate, in order to allow experimentation for different inter-working and integration solutions of IoT devices with the network elements of a current or FI.

The server tier provides more powerful server devices, with high availability, which are directly connected to the core network infrastructure. External users access the platform through these servers.

The architecture distinguished between four subsystems: 1) Authentication, Authorization and Accounting (AAA) 2) Testbed Management 3) Experimental Support and 4) Application Support.

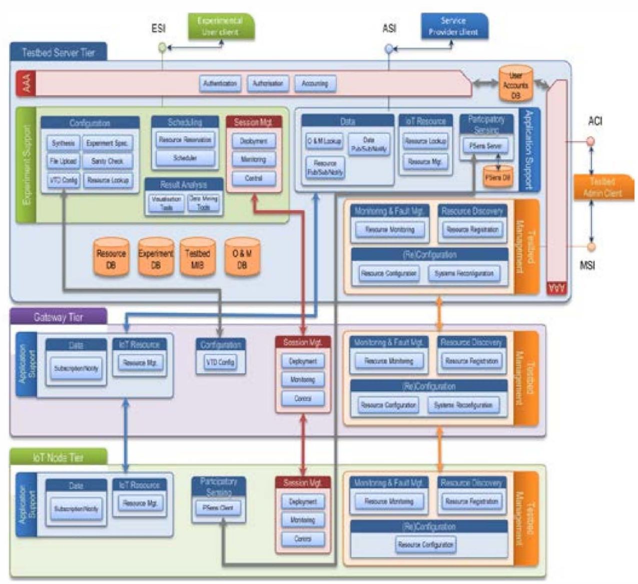

Fig. 1. High-level SmartSantander architecture

The AAA subsystem is common for all user groups and controls the access to the testbed functions. Its services are exposed via the Access Control Interface (ACI). Depending on user privileges the other subsystem functions can be invoked.

The management support interface (MSI) exposes the service functions of the management subsystem and is typically used by the system administrators of a testbed deployment. It provides access to functions such as user accounts, testbed resource discovery and configuration as well monitoring and fault management.

The experimental support interface (ESI) is mainly used by the experimental researcher and provides access to the service functions of the Experimentation Support Subsystem which assist the user in the entire experimentation life-cycle. This includes functions for testbed resource selection, specification of experiments including resource configurations, reservation of testbed resources, scheduling of experiments as well as functions for the deployment and execution control of experiments and data collection and data analysis.

The application support interface (ASI) offers a wide range of data management functions that can operate on information retrieved from the deployed sensors of the IoT node tier including citizen provided information through participatory sensing on mobile phones.

B. Physical Deployment

In order to attract the widest interest and demonstrate the usefulness of the SmartSantander experimental platform, a key aspect that has been addressed is the deployment of the IoT experimentation infrastructure around the most interesting and impact-generation use cases. This testbed goes beyond the experimental validation of novel IoT technologies. It also aims at supporting the assessment of the socio-economical acceptance of new IoT solutions and the quantification of service usability and performance with end users in the loop.

Thus, the objectives of the deployed IoT infrastructure are two-fold as well as concurrent. On the one hand it enables experimental assessment of cutting-edge research and on the other hand it simultaneously supports the provision of an impact-generating smart city service. Application areas have been selected based on their high potential impact on the citizens, thus enabling the execution of extensive experiments to obtain insights into the uptake of IoT-based services deployed in a live environment. Also taken into consideration in the selection of application use cases are the diversity, dynamics and scale of the IoT environment, that increase the potential of the testbed for the evaluation of advanced protocol solutions to be evaluated through the platform.

The following kinds of devices have been installed:

- *Fixed sensor nodes:* they have been placed attached to public lampposts or to building facades. Apart from the typical low-capacity microcontroller and multi-modal sensing unit, a distinguishing feature of these devices is that they have been equipped with two radio transceivers operating at 2.4 GHz frequency. One of the modules implements IEEE 802.15.4 protocol in a native way, and the other one runs IEEE 802.15.4 protocol modified with the proprietary routing protocol Digimesh. This way it is possible to support that these nodes concurrently supports experimentation and service provision as both functionalities are physically separated on each of the networks created. Multimodal sensing units includes a wide range of observed physical magnitudes: light intensity, noise, carbon monoxide, air temperature, relative humidity, solar radiation, atmospheric pressure, soil moisture, soil temperature, wind direction, wind speed and rainfall. It goes without saying that not all nodes are able to provide information about all these magnitudes but a subset of them on each case. In total more than 2,000 sensing points are available through this kind of nodes.
- *Mobile sensor nodes:* Equivalent to the fixed ones in terms of micro-controller and radio transceivers, these nodes are installed on top of public transport buses, taxis and other municipal services vehicles. These nodes are also equipped with GPS and a GPRS interface so that they can geo-position each of their observations and be permanently reachable respectively. The sensing capabilities of these nodes are focused on air quality monitoring: nitrogen dioxide, ozone, particles in the air, air temperature, carbon monoxide, relative humidity. GPS also allows them to report speed and course of the vehicle. Some of the nodes installed on public buses have been connected to the CAN-bus so they can monitor a plethora of parameters related to the vehicle status and behavior. 150 vehicles are equipped with this kind of nodes.
- *Parking monitoring sensor nodes:* These nodes are buried under the asphalt on outdoor parking places at Santander downtown area. A total of 350 parking lots are monitored with this kind of nodes.
- *Traffic monitoring sensor nodes:* These nodes are buried under the asphalt on the main entrances to the city of Santander. They are monitoring the number of vehicles, the level of occupancy of the lanes, the average speed of vehicles and the average queue length both inward and outward.40 sensor nodes of this kind have been deployed.
- *QR and NFC tags:* Located at city Points of Interest (POI) (e.g. monuments, bus stops, local administration premises, shops, etc.) these tags include both a QR code and a Near Field Communication (NFC) tag. They are a key asset for the Augmented Reality service as they provide information related to the POI. 2,500 of these tags have been placed all around the city.
- *Embedded PCs:* They act as Gateways for the fixed sensor nodes. These nodes are arranged in multihop meshed clusters that depend on one of these Gateways. They are connected to the IoT Nodes through the IEEE 802.15.4 Digimesh interface and to the testbed server tier through WAN interface (e.g. Ethernet, 3G, optical fiber, etc.)

Fig. 2. Excerpt of the infrastructure deployment at Santander's downtown

Fig. 2 presents a portion of the devices deployed overlaid over a map of Santander downtown. Each icon represents one of the devices previously mentioned. Different icons are used for each kind of device.

Apart from the aforementioned devices, two Apps have been developed and made freely available to the citizens. These Apps transform citizens' smartphones into yet another sensing device which is connected to the platform, thus supporting both experimentation and service provision with the data generated through these Apps. Description of the Apps and what information they generate is provided in Section IV. Nine months after the public release of these two Apps, they have jointly had more than 20,000 downloads.

III. Experimentation Support

A. *Testbed Monitoring*

Three non-trivial management processes are performed dynamically by the Management and Fault-Monitoring Subsystem, namely: resource discovery, resource monitoring and testbed reconfiguration. The resource discovery process involves detecting new IoT resources in the testbed, registering them for use and recording the resource descriptions using standard data models to facilitate the query and retrieval of these resources. The heterogeneity of devices/resources is such that the selection of suitable IoT devices to run an experimenter's software code remains a crucial step in the deployment and execution of research experiments. Similarly, service-applications require subscriptions to sensor data streams with particular context attributes such as locality or sampling frequency and that capture certain phenomena occurring in the environment; IoT-resource selection is also an important step in the deployment of service-applications. Hence, to support this level flexibility for resource-selection, resource discovery should include the use of information models to uniformly describe their attributes, capabilities and roles.

The resource monitoring process concerns the dependability of the testbed platform i.e. its robustness with respect to software component or equipment failure. Under normal operation, the SmartSantander platform is in a constant state of flux. New sensor devices are detected and registered with the platform. The context status parameters (battery level, CPU utilization, memory consumption) of existing devices change whilst they run experiments generate experiment traces or sensor data streams and execute data transformation functions. Each experimentation node can be reserved, flashed with an experimenter's code, reset or enter an 'idle' state of service-observations reporting. IoT devices can run out of battery power, be subjected to hardware failure, accidental damage or vandalism. Ensuring the correct execution of the IoT testbed's services in the face of such dynamicity and ensuring the testbed's resilience to failures, therefore, requires continuous monitoring of the state of its IoT resources.

On the detection of hardware failures, fault-remediation strategies require that the testbed is reconfigured to omit the faulty nodes from future experimentation or service-provisioning. Reconfiguration for testbed management is not confined to only executing fault-remediation strategies. As dynamic variation in the platform execution context occurs, reconfiguration of the platform's components is required to deliver optimal performance at all times. The reconfiguration strategy usually involves changing control parameters to optimize the operation of running components and communication protocols. Parameter-based reconfiguration is also required when application requirements change; for example the temporal granularity of sensor data can be dynamically adjusted to suit the requirements of service applications.

B. Experiment Life-cycle

While testbed management is the most critical part for testbed administrators, the main aim of SmartSantander testbed is to be open and ready to be used by experimenters. In this sense, experiment lifecycle has been defined for SmartSantander testbed and corresponding mechanisms have been implemented in order to address each of the different phases defined.

During specification phase, mainly dealing with the resource selection, the user is assisted with an exploration of available testbed resources and their static and dynamic properties and topological interdependencies. The user is able to formulate queries for specific resource properties in order to satisfy the requirements for a particular experimentation scenario which are matched against the testbed resources descriptions in order to provide the user with a selection of testbed resources fulfilling the desired properties. Furthermore, during setup phase, dealing with actual reservation and scheduling, ESS assures that experiments do not collide in time. Finally, on the Execution phase experimenter is empowered with experiment execution control, experiment monitoring, data collection and logging.

C. Resource Reservation

ESS implementation architecture [8] was designed with generality in mind and at the architecture's core a set of standardized web service APIs allows a technology-agnostic standardized way for users to access a testbed's resources. The so-called Testbed Runtime (TR) is the reference implementation of the APIs for testbed management and experiment execution defined in the WISEBED project. It creates an overlay network for easy node addressing and message exchange independent from the actual underlying network connections.

One of these APIs is the Reservation System (RS) API, which allows users to reserve a set of resources (i.e., IoT devices) for experimentation. This API allows experimenters to select a subset of resources, uniquely identified by a URN, based for example on device type, attached sensors, mobility support, etc. As it has been introduced in the previous section, resource management solutions that have been put forward in SmartSantander testbed aims at improving the efficiency of the allocation of resources to the experiments and will ensure proper condition for all simultaneous experiments as well as the services running on the platform.

After successful authentication, experimenters can reserve, by sending the set of URNs to the RS web service, the devices that best fit their requirements for a certain period of time. The RS then checks authorization and reserves the devices if they are available for the desired time period. As return value the user receives a secret reservation key which he uses to access his experiment through the WSN API. This secret key is called the reservation key in the following. As a result of this invocation, users obtain a so-called secret reservation key which is used later on to identify the user as the owner of this reservation.

IV. SERVICE PROVISION

As it has been already said, the infrastructure installed and the software platform deployed to support it had a dual purpose. In this sense, besides the supporting the experimentation on IoT technologies, this facility has to be the basis for providing smart city services. Four services are currently being provided based on IoT engaging the citizens and other city stakeholders (authorities, companies, entrepreneurs, etc.) into the smart city concept.

A. Environmental Monitoring

The current solutions for environment monitoring in urban settings are based on a handful of measurements stations at fixed locations. Although the accuracy of the measurement equipment in these units is high, the cost of these units obviates a large-scale deployment to obtain measurements at finer granularity feasible.

With the introduction of the IoT technology, it is now possible to deploy a large number of low cost sensors for a fraction of cost of the current technology. These IoT sensors do not provide the same degree of accuracy as modern environment measurement stations. However, using a large number of measurement points and intelligent processing of the measurements it is possible to obtain sufficiently accurate measurements that can be used as the initial indicator of the status of the environment pollution. Another use case related to this scenario is the use of luminosity sensors spread around the whole city to infer a more accurate knowledge of the current situation of the artificial street illumination service.

As an alternative deployment to support the environmental monitoring use case, a number of devices have also been installed on public transport buses, police cars and municipality vehicles to allow a much more efficient coverage of the whole city. This deployment serves multiple application domains; for instance it enables the provision of additional services like smart public transportation management and traffic conditions assessment.

B. Traffic Management

Nowadays, the counting and classification of vehicles on the roads is accomplished by inductive loops placed under the asphalt. However, these systems have several problems and disadvantages like their deployment, maintenance and high cost, among others. In this sense, within the SmartSantander project a solution based on Wireless Sensor Network has been deployed.

The objective of the deployment is to monitor traffic volume, road occupancy, vehicle speed and estimation of queues length on the two main entrances to the Santander city, as well as to get knowledge on how the traffic is distributed over the main city avenues arising at these main roads.

Additionally, information on vehicle speed and route times available from the nodes installed on public buses and taxis will allow creating a congestion map on the inner streets of the city.

Finally, one of the key contributors to city traffic is precisely drivers looking for parking. In this sense, wireless sensors buried under the asphalt allows parking occupancy information to be disseminated instantaneously to drivers, the relevant traffic control management organizations in the city or local authorities. Several panels have been installed in the city center showing the amount of free lots available in the direction indicated by the panel.

C. Augmented Reality

The Augmented Reality application augments the city scape or locations in the city with IoT endpoints to provide context-sensitive information and services at these locations. Using the tags deployed at POIs in the city as well as the information generated by the sensing infrastructure and other open data sources available, the App developed for citizens' smartphones expose services or information relevant to the location or context to the site visitors. As an example, the site-visitor's mobile-phone display is overlaid with relevant services or tourist-targeted information, depending on their location or direction of vision. For instance, the augmented reality App provides tourists with a "stroll in the city" experience by supplying them with location-sensitive information such as description of monuments in their preferred language.

D. Participatory Sensing

In this scenario, users utilize their mobile phones to send physical sensing information, e.g. GPS coordinates, compass, environmental data such as noise, temperature, etc. Depending on the sensors embedded in a particular phone. This information is fed to the SmartSantander platform. Users can subscribe to services such as "the pace of the city", where they can get alerts for specific types of events currently occurring in the city. Users can themselves also report the occurrence of such events, which will subsequently be propagated to other users that are subscribed to the respective type of events, etc.

The users receive notifications about the occurred events via a smartphone application, phone calls, SMS and e-mails in the preferred language.

All the users that are interested in receiving the notifications have to subscribe the service, defining their personal profile (including e.g., the preferred language), selecting the information they are interested to. This subscription can be done via web interface; if the Council wants to provide the service also to users without web access, it can provide a phone number of a help desk to be called in order to subscribe the service with operator support.

V. Conclusions and Outlook

SmartSantander architecture has been presented in this paper. On the one hand it will allow real-world experimentation on Internet-of-Things related technologies (protocols, middlewares, applications, etc.). On the other hand it is currently supporting the provision of several smart city services aimed at enhancing the quality of life in the city of Santander. Tangible results are expected to greatly influence definition and specification of Future Internet architecture design from viewpoints of Internet of Things and Internet of Services. Innovative solutions for supporting the experimentation and service provision duality have been described.

Future evolution currently being specified targets the federation of the SmartSantander facility with other FI testbeds. The objective is to allow holistic experimentation on FI scenarios composed by heterogeneous technological enablers. In this sense, solutions supporting Slice Federation Architecture (SFA), Orbyt Management Framework (OMF) and OMF Measurement Library (OML) are being defined.

Last but not least, it is important to mention that local administration policies are being tuned to foster the smart city concept. In this sense, the municipality is demanding to public utilities to include IoT technologies and to incorporate the information generated at the public services they are managing into the SmartSantander platform. Thus, experimentation as well as service provision capabilities of the platform will be continuously upgraded.

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