Future Network & MobileSummit 2011 Conference Proceedings
Paul Cunningham and Miriam Cunningham (Eds)
IIMC International Information Management Corporation, 2011
ISBN: 978-1-905824-25-0

SmartSantander: The meeting point between Future Internet research and experimentation and the smart cities

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Abstract: SmartSantander proposes a unique in the world city-scale experimental research facility in support of typical applications and services for a smart city. 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. The facility will comprise of more than 20,000 Internet of Things devices deployed in urban scenarios. SmartSantander aims at producing the following key target outcomes: 1) An architectural reference model for open real-world Internet of Things experimentation facilities; 2) A scalable, heterogeneous and trustable large-scale real-world experimental facility; 3) A representative set of implemented use cases for the experimental facility; and 4) A large set of Future Internet experiments and results. In this paper a first sketch of the experimental facility reference model will be presented. Additionally, the first deployment plans as well as the expected procedures for opening the facility to external users will be presented. A key aspect that will be addressed in the project is the inclusion of a wide set of applications to be selected based on their high potential impact on the citizens in order to attract the widest interest and demonstrate the usefulness of the SmartSantander experimental platform. Finally, such a unique platform must be maintained once the project ends so appropriate exploitation plan will be prepared.

Keywords: Future Internet, Experimentation, Internet of the Things, FIRE, Smart city

1. Introduction

Recent predictions [1] foresee the Internet of Things (IoT) to form an essential part of the Future Internet, as its connected devices will outnumber the computers and mobile devices utilised by human users by orders of magnitude. While today’s communication on the Internet is still dominated by human-to-human or human-to-machine communication, the IoT will promote Machine-to-Machine (M2M) communication to be the primary form of interaction on the future Internet. If such a scenario unfolds, it is not hard to conclude that the design of the Future Internet and its architecture will be strongly influenced by the requirements of the IoT. The scale, heterogeneity and constraints of IoT devices and the distinct nature of interactions poses challenges for their successful integration into the Future Internet architecture.

Current IoT deployments are mainly closed and vertically integrated solutions tailored to a specific application domain. In reality, they often represent disjoint “Intranets of Things”. Realising the vision of the IoT requires an agreed upon architectural reference model, based on open protocol solutions and key enabling services that enable interoperability of deployed IoT resources across different application domains and contribute to horizontal re-use of the deployed infrastructure [2][3]. This will allow transforming these Intranets of Things into federated, open and trusted platforms [4] that can be efficiently integrated with the Service, Knowledge and Network layers of a Future Internet and facilitate their organic growth into a true IoT.

A variety of different European projects have started to tackle the research challenges in various aspects of the IoT. Some of these efforts address architectures for efficient integration of the IoT into the Future Internet [5] and corresponding open protocol solutions, others target key enabling services [6], or explore the support of M2M interactions in the communication service layer of future networks [7], technologies for service layer integration [8] and services and applications [9]. WISEBED project [10] (which is dedicated to sensor network testbeds) cannot fully provide the properties required for real-world experimentation on the IoT paradigm.

Although many of the projects come up with concrete use cases and demonstrations of the developed solutions, experimentation and testing of their developed technological solutions is often limited to smaller domain specific testbeds or application specific deployments. While those may suffice as proof-of-concepts, they do not allow on the one hand conclusive experimentation with the developed technologies and architectural models to evaluate their performance at adequate scale under realistic operational conditions and on the other hand a validation of their viability as candidate solutions for an IoT. Successful evaluation and validation of suitable technologies for the IoT requires experimental facilities that allow open experimentation with the key enabling IoT device technologies from heterogeneous application domains at adequate scale in realistic settings, with the potential of involving real end-users in the experimentation process.

The non-suitability of current Future Internet Research & Experimentation (FIRE) [11] facilities for IoT experimentation has become very clear at the Real-World Internet (RWI) sessions of the Future Internet Assembly in Prague in early 2009. In [12] the requirements on IoT experimental platforms were identified to be the following:

- Horizontality – support of different application domains;
- Verticality – support for testing of different layers of the system;
- Heterogeneity – support of different sensor and actuator technologies, radios, etc.;
- Support for mobility testing (locality, appear/disappear, visibility, speed ranges);
- Support for scalability testing;
- Security, privacy, and trust;
- Confidentiality.

These requirements were then compared to the current state of fulfilment by the existing platforms. Only few requirements such as heterogeneity, verticality, and in part horizontality can be provided by the WISEBED experimental facility or the other FIRE projects. Besides, the need for such a facility has been identified as very high.

The facility will be open to FIRE community and it is expected to influence the specification of Future Internet architecture design from viewpoints of Internet of Things and Internet of Services.

However, in order to increase the interest on the IoT concept it is equally important to project it towards the Internet of Services paradigm. In this sense, a key aspect that is typically missing in other technologically-driven initiatives is the end-users and the benefits that IoT are bringing to them in the form of added-value services. This is the main reason for setting the experimental facility into a city context. A city can serve as an excellent catalyst for IoT research, as it forms a very dense techno-social eco-system in which the necessary infrastructure of a Smart City will rely on technologies of the IoT.

Bearing this in mind, SmartSantander experimental facility includes the necessary ingredients to attract the widest interest on all the involved stakeholders:

- Future Internet *researchers* to validate their cutting-edge technologies (protocols, algorithms, radio interfaces, etc.);
- Communities of *users* and citizens; and
- Industries, *service providers* and other entities willing to use the experimental facility for deploying, validating and assessing new services and applications.

Once the main motivation of the SmartSantander project and its objectives and foreseen key outcomes have been introduced, in Section 2 we will present the reference model that addresses the already identified main requirements that must be fulfilled by the experimental facility. The deployment will be carried out following a cyclic approach. In Section 3, the plan for the deployment of the facility and the procedures that will be set up to open it to external users will be sketched. Initially foreseen use cases and services portfolio will be described in Section 4. Sustainability of the experimental facility to be deployed will be discussed in Section 5. Finally, in Section 6 some conclusions will be drawn together with the expected next steps.

2. Initial system architecture of the experimental facility

The SmartSantander experimental facility has to satisfy a variety of requirements from different stakeholders' perspective, ranging from experimenters, facility providers, service providers and system end users. A wide range of detailed functional and non-functional requirements have been derived at the beginning of the project based on a selection of use cases capturing the different stakeholders' perspective. The resulting functionality has been logically grouped into four system aspects, leading to the definition of an initial architectural model composed of the following subsystems:

- Authentication, authorisation and accounting (AAA) subsystem
- Testbed management subsystem
- Experimental support subsystem
- Application support subsystem

The *AAA subsystem* comprises functions that control and audit the access to all system features. AAA processes are common for all types of users of the facility. The AAA subsystem typically represents the first point of contact for users to gain access to other testbed functionalities. Apart from the management of user accounts on the testbed, AAA functions ensure that a user is properly authenticated and receives authorisation to access the testbed appliances according to its role. AAA system take also care that all actions carried out in the system are accounted for according to the agreed usage policies.

The *testbed management subsystem* comprises all functions that are relevant for the seamless operation and management of the testbed. The subsystem mainly caters towards the administrator users and provides many features effectively supporting this role. This includes plug and play configuration of new testbed components, monitoring, performance and fault management.

The *experimental support subsystem* provides all functional features to support the experimental life cycles of testbed users. Typically, these functions will be used by researchers, but also for service providers, as the provision of services can be in essence seen as longer lasting experiments. This includes functions to discovery availability of testbed resource and their characteristics, mechanisms for the configuration of experiments, allocation of testbed resources, control during experiments and data collection and analysis.

The *application support system* provides additional functional features that can be used by application developers and service providers to compose smart services on top of the SmartSantander facility. These are tools for easy discovery of sensor information, effective data management and other support functions that make the development and re-use of sensing and actuation capabilities from heterogeneous testbed resources easier.

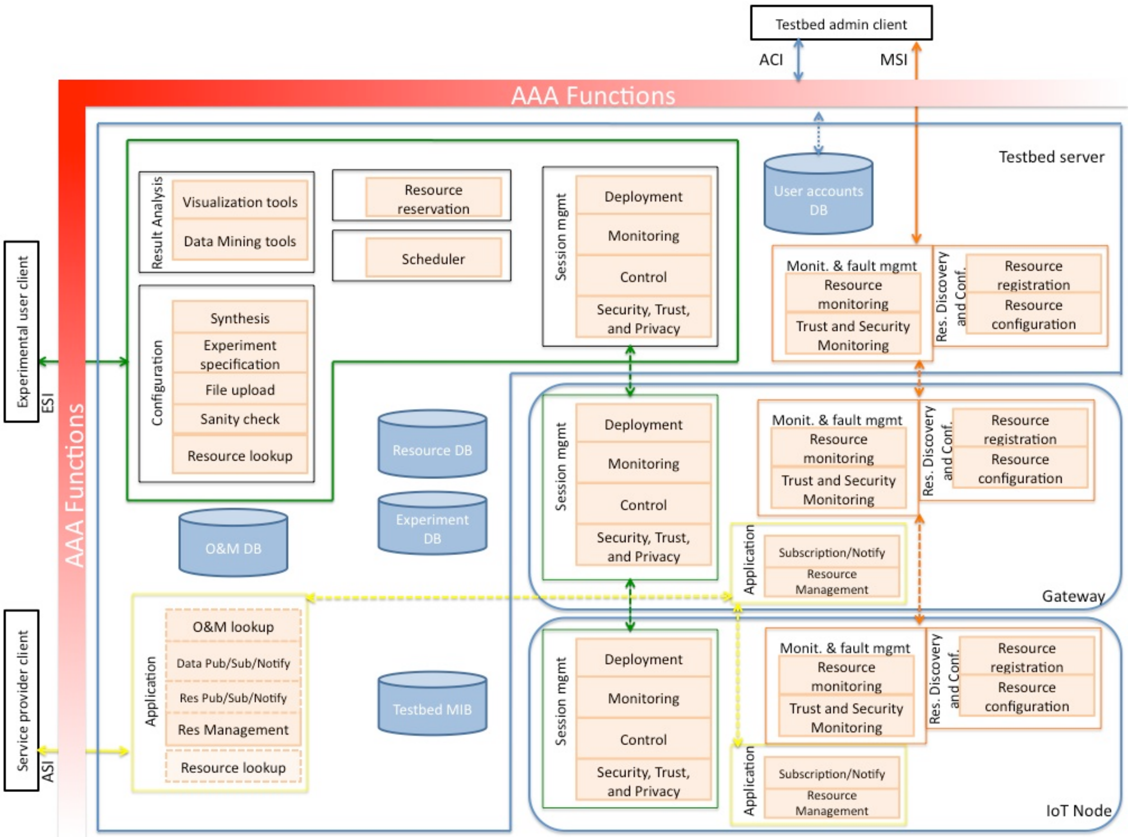

Figure 1: High level view of the SmartSantander system architecture.

Each of the subsystem exposes its functions via service interfaces, realised by a set of well defined Application Programming Interfaces (API): the Access Control Interface (ACI), the Experimental Support Interface (ESI), the Application Support Interface (ASI) and the Management Support Interface (MSI).

Besides the functional division, a physical split has also been proposed in the initial system architecture. The testbed functions will operate across the different logical testbed nodes of different characteristics and capabilities. These are:

- IoT nodes
- Gateway nodes
- Testbed server nodes

Each of the nodes provides different physical characteristics and capabilities tailored to its logical role and will host a subset of the previously defined system functions. Figure 1 provides a high level view of the SmartSantander system architecture, detailing the functional decomposition of the above described subsystems. The architecture view shows how those functions are spread across the different types of envisioned testbed nodes.

3. Facility deployment and openness

One major strategic aspect of the SmartSantander project comes with the actual implementation of a large-scale experimental facility based on a real life IoT deployment in an urban environment.

The number of devices to be deployed in Santander and its surroundings is foreseen to climb up to 12,000 devices, thus creating the basis for development of a future Smart City. Nevertheless, it is expected that the overall foreseen number of devices taking into account the contributions of other locations involved in the project (Lübeck, Guildford, Belgrade, Århus, and Melbourne) will reach 20,000 IoT devices. The deployment will be carried out following a cyclic approach. On the first cycle 2,000 IoT devices will be deployed in the city and an initial operational prototype will be ready for the first round of experiments in month 15. During the second cycle, new functionalities will be included in the experimental facility and federation will start with other IoT testbeds. It is expected that around 5,000 devices will be part of SmartSantander experimental facility at the end of this cycle, in December 2012. In the last cycle the overall amount of 20,000 IoT devices will be reached and the facility will include all the functionalities already mentioned, by September 2013.

As it has been already mentioned, the facility will be open to the scientific community and service providers so that they can perform their tests and research whether on the algorithms, protocols and mechanisms that will compose the Future Internet or on the creation and provision of services based on the IoT paradigm. This openness will be orchestrated through Open Calls where selected external users will be funded to run research experiments using SmartSantander facility. They will be managed as described in the ICT FP7 Work Programme, following the rules indicated by the EC. Two Open Calls will be issued during the whole duration of the project. The first one will be published on July 2011, and will use the initial version of the facility. The second one will be published on July 2012.

4. SmartSantander use cases

The use cases developed within the project try to cover the three envisioned user groups previously defined: Future Internet *researchers, service providers* and *end users*. In this sense, the use cases associated to researching are mainly related to the FIRE perspective, while those targeting end users are connected to the smart city paradigm.

4.1 Researchers use cases

According to the FIRE perspective tackled by the project, several scenarios will be aimed at researchers for evaluating and testing different experiments, covering different aspects.

On the one hand, a facility for researchers to test a wide portfolio of *protocols* as well as different *data processing* techniques is provided. Within the protocols to be implemented, the testbed enables the testing, among others, of typical ad-hoc routing protocols (on demand or on periodic routing table update), innovative algorithms based on geographical position provided by Global Positioning System (GPS) modules and, even, protocols handling nodes with mobility. Pertaining to the data processing techniques, implementation and test of network coding as well as data mining schemes over a real and large testbed facility imply many interesting points from the research perspective.

On the other hand, once applications and experiments are running over the testbed, a plethora of use cases emerge focused on the estimation of *traffic impact* through the measurement of Key Performance Indicators (KPI) (latency, throughput, packet error rate…), thus characterizing the behaviour of the whole network and the effect of several applications executing simultaneously over the network.

Finally, aforementioned experiments together with other specific ones, impose challenges from the monitoring and network management perspective that has not been so far addressed due to the fact that such a large facility has not been previously deployed.

Most of the use cases previously mentioned have been already analysed, either in small-size testbeds or through the use of simulation tools, but none have been challenged in a so large real deployment as the one offered by the SmartSantander facility.

4.2 Service provider specific use case,

IoT offers Service Providers a huge opportunity to create new revenues by providing a new wave of services; however, it also represents a risk, since most of them rely on a set of challenges that are not fully solved. SmartSantander must provide the tools that help providers to evaluate the *technical, societal and economical viability* of their potential solutions.

One of the most critical aspects the IoT Services has to achieve is the *acceptability* by the users. Being able to test them with real end-users is not an add-on but a basic need. SmartSantander enables the Service Providers to get access to end-users feedback.

More often users are demanding to have access to their services every time and everywhere. It is not valid anymore to provide services just for the PC; mobile phones and other mobile and embedded devices will play a key role. For this new paradigm the *support heterogeneous devices and environments* has become crucial. For this reason, SmartSantander will provide heterogeneous infrastructures (Internet, Operator networks, etc.) that will allow users and providers to determine the best ways to communicate each other (e.g. phone calls, SMS, e-mails, etc.).

Internet of Things infrastructures are expensive to create, deploy and maintain. Service providers need to accurately *estimate the real costs* associated to their services. SmartSantander must help them to answer questions like: the number of IoT devices that are required, their deployment and maintenance costs, the technological viability, if the infrastructure can be shared to deploy other services, etc.

4.3 City service, use case

Several services aiming at bringing a more sustainable city have been already explored in SmartSantander. Among them, the most promising in terms of future development are:

- Outdoor parking management, providing real time parking information to the citizens.
- Traffic management based on the elaboration of dynamic maps updated every 15 minutes approximately.
- Monitoring of environmental control parameters, such as:
  - CO_2, CO, SO_5, $PM_{2,5}$, PM_{10}
  - UVA, UVB, O_3
  - Noise levels

In the first phase of the project, Santander City Council (a partner in the project) jointly with the citizens, have considered that outdoor parking area control, considering also the provision of real time information related to the status of loading/unloading areas; as well as CO_2 measurement have a priority. In this sense, once the infrastructure of wireless sensors has been deployed, the Municipality will provide information to the citizens about the areas where they may find free places to park.

It is very important to note that SmartSantander ultimate beneficiaries of the services must be understood in its wider sense bearing in mind the very different natures of the potential end-users of the SmartSantander facility. Three main profiles can be highlighted:

- The technicians responsible for the various subject areas who analyze the data obtained from the information sensed by the infrastructure.
- The city authorities who receive reports aimed at the highest level decision making and based on the analysis performed by the technicians in the previous section.
- And finally, the citizens itself who are the ultimate beneficiaries of the decisions taken by the authorities and / or directly from services that are provided from the SmartSantander facilities.

This heterogeneous nature of the end users will influence in the implementation of the different use cases in order to satisfy the different information needs.

5. Exploitation plans

One of the main challenges SmartSantander will face is the maintenance of the facility over the project lifetime in its two facets: as an infrastructure for research and for providing services to end-users. For this reason, a Business Plan is being developed aiming at not only ensuring the sustainability of the project but also at providing the economical bases for the viability of the future services that will be developed in a Smart City environment.

From a business standpoint, the SmartSantander facility can be considered as a service offered to different kind of potential clients: researchers, service providers and end-users. Therefore, the business models that are being conceived foresees two main blocks, the analysis of the *cost structure* and the analysis of *potential incomes* that can be generated.

For analysing the *cost structure* an initial value chain has been generated as shown in Figure 2, where we model the providers of the SW and HW components of the sensor nodes (including Gateways); the responsible of deploying and maintaining the nodes; the provider of the communication infrastructure that allows the sensors to communicate to the portal; the provider of the portal that allows to run experiments, manage the sensors, etc.; the service platform provider that facilitates the development of final services; and finally, the one that runs the services or the experiments using the infrastructure.

Figure 2: Value chain for the SmartSantander infrastructure

For each of these elements, the cost structure they have associated (like for example HW, SW, licenses, personal, etc.) is being analysed. These costs are also being coupled to the services using them: for example, if a particular sensor network is just used to provide a service to the municipality this cost is assigned to it. Alternatively, if one infrastructure is shared among several applications (or experiments), the cost is shared accordingly. All this information will enable coming out with an accurate prizing schema.

From the *incomes* point of view, we are developing specific plans targeting three groups: researchers, service providers and public administrations. For the first group, we are creating plans that facilitate their access to our infrastructure; more specifically how new research projects can use SmartSantander. For the second group, we will focus in two areas: using the facility to create new services and using it as a benchmark to test/research future services. For public administrations, we are considering applying for public funding in order to expand the current facility.

6. Conclusions

SmartSantander aims at the creation of an experimental test facility for the research and experimentation of architectures, key enabling technologies, services and applications for the IoT. The envisioned facility is conceived to provide the European research community with a one-and-only platform of its characteristics, suitable for large scale experimentation and evaluation of IoT concepts under real-life conditions.

SmartSantander will enable a broad range of experimentations mainly targeting but not limited to the following activities:

1. Evaluation of key building blocks and enablers of the IoT architecture;
2. Assessment of the impact of the IoT on future networks to facilitate design and testing of required network capabilities;
3. Evaluation of service layer integration technologies;
4. Application of existing distributed data mining solutions and knowledge engineering for exploitation of real world information and cross-domain knowledge in the FI knowledge layer;
5. Assurance of citizen privacy and establishment of trust in IoT deployments;
6. Evaluation of social acceptance of IoT technologies and services in the framework of a smart city.

Taking this into account, it is clear that the deployment of such an experimental facility and the rang of experimentations that it enables, is of key importance for the Future Internet research as long as the design of the Future Internet and its architecture will be strongly influenced by the requirements and necessary enablers for the IoT concept.

Besides the actual deployment of such a large facility, the project is facing key challenges such as using the deployed experimental research infrastructure to assess a carefully selected set of IoT based services that provides better understanding of both the usability of the experimental facility and the potentials of IoT to improve the quality of life in cities by increasing the efficiency of important city services. In this sense, SmartSantander is closing the gap between technology development and social acceptance of the technology which on the one hand imposes big challenges but on the other enables an assessment of the cutting-edge technology into real-world scenarios.

Finally, another important aspect that is being considered is the sustainability of the facility beyond the project lifetime. Being a unique-in-the-world asset, the facility must be considered for its continuous development and bearing this in mind a thorough business plan is being developed for assuring that the facility is prepared for the future.

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