Developing an IoT Smart City Framework

Evangelos Theodoridis, Georgios Mylonas and Ioannis Chatzigiannakis
Research Unit 1, Computer Technology Institute & Press “Diophantus”
Patras, Greece
{theodori, mylonasg, ichatz}@cti.gr

Abstract — In this paper, we discuss key findings, technological challenges and socioeconomic opportunities in Smart City era. Most of the conclusions were gathered during SmartSantander project, an EU project that is developing a city-scale testbed for IoT and Future Internet experimentation, providing an integrated framework for implementing Smart City services.

Smart City, IoT, Future Internet, Socioeconomic Impact.

I. INTRODUCTION

The last few years, a significant research effort and technological development have been devoted to the IoT domain targeting smart city concepts, for various reasons. The primary one is the exponential growth of devices/smart objects that can participate in an Internet of Things (IoT) infrastructure. According to recent reports [1], the number of interconnected devices will grow over 50 billion in the next 10 years. Adding on top of this number wearable devices and all kinds of smart objects that carry inherent sensing and data processing capabilities, it is expected to face trillions of connected things being added to the Internet [2, 3].

The second most notable reason is the population growth and the urbanization trend. According to the United Nations, the urban populations will grow by an estimated 2.3 billion over the next 40 years, while as much as 70% of the world’s population will live in cities by 2050 [4, 5]. The rapid growth of cities became the main driver of global environmental changes, as cities, occupying only 2% of the earth landmass, consume about 75% of the world’s energy and produce 80% of its greenhouse gas emissions [6]. Moreover, cities consume approximately 60% of all water allocated for domestic human use, while human demand for water is expected to increase six-fold in the next 50 years, as some municipalities may lose up to 50% of precious water resources through leaky infrastructures [7]. Such a dramatic expansion of the cities has brought to focus the need to develop cities in a sustainable manner, while also making the quality of life in the cities better. Due to these factors, a wide range of problems have been tackled by exploiting IoT and Future Internet (FI) technologies and their use in the Smart City concept has matured significantly.

Cities consist of very complex systems of different types: civil engineering infrastructures, ICT infrastructures, societal networks, financial networks, etc. All these systems require enormous management effort (monitoring, reporting, and interventions) to ensure uninterrupted performance of all relevant activities. Examples of such systems are public transport systems, electric energy provision, water and gas distribution systems, waste management and maintenance of the city infrastructure, such as roads and public parks. At a societal and economic plane, there are systems for the management of school buildings, sites of historic and touristic interest, for commerce, for medical and elderly care etc.

Management of the aforementioned functions of a city is usually delegated to appropriate entities/companies of private or public sector. The coordination of the activities between all these entities is usually very difficult and inefficient due to various technical, administrative and political reasons. Often, bureaucracy and lack of intra-communication among these entities leads to poor performance in many of these city activities.

The wide adoption of IoT and FI technologies brings in high potential to overcome many of the handicaps of the traditional “analog” city operation. The ability to automatically share data, interact and combine services whenever and wherever is required, will be an inherent feature of the smart cities. With the integration of the actual with the digital world, it will be possible to efficiently connect, integrate and utilize information generated by an ever increasing number of city actors, items and events. Having the above in mind, it is clear that cities serve as an excellent ecosystem for IoT research, as they represent a very dense techno-social economic system that can act as an invaluable source of challenging functional and non-functional requirements from a variety of application domains.

Over the last few years, several EU projects have been launched with the goal to provide solutions for the realization of the IoT and its integration in different application domains. A number of EU initiatives and projects are targeting innovation and technological breakthrough in several research areas such as cloud computing technologies (EPIC [10]), service integration (Peripheria [11], SmartCities [12]) and e-governance (OpenCities [13]). Regarding smart city services, urban performance is currently [14] measured by assessing from the one side the city's deployment of hardware infrastructure and on the other hand on the availability and quality of knowledge communication and social infrastructure. The latter form of capital is crucial for urban competitiveness and highlights the growing importance of ICT. Smart City services in general can be categorized along several categories like economy, mobility, environment, living of people and governance that are factors that express urban growth and development. Urban growth and development usually incorporates also developments in competitiveness, transport and ICT.
economics, natural resources, human and social capital, quality of life, and participation of citizens in the governance of cities. A number of different approaches and scenarios for urban applications and services are included in [15].

Moreover, there are quite a few research works that are trying to stimulate and multiply the development of the aforementioned urban performance factors by exploiting IoT, FI and ICTs. The SmarterCity [16] and CityScience [17] projects respectively provide a set of research solutions and pieces of software for supporting application in mobility, governance, buildings, energy etc. Furthermore, cities themselves are investing on IoT technologies and development of services. Indicative examples are the Cities of Oulu [18] and Barcelona [19] that have deployed and developed services spanning across the aforementioned topics. Regarding mobility and traffic management there are also some industrial products. Products like DYNAC ATMS [20], Siemens COMET [21] or TransSuite [22], provide highway monitoring, traffic light management, and traffic management functionalities. Finally, there are also projects based on crowdsourcing paradigm, where users exchange vehicles, share rides or sharing parking spots. Some applications in this category falls: Cacherry [23] and Spothero [24] respectively.

Aiming at leveraging such an environment for the advancement of IoT/FI research on smart cities, the SmartSantander project [9] is creating a large-scale experimental facility across 4 European countries (Spain, Germany, UK and Serbia). The project started in September 2010 and plans to deploy up to 20,000 sensors. The main deployment site is the city of Santander in Spain. Deployed devices combine a range of hardware platforms, communication technologies and sensing capabilities appropriate for a wide range of city services. The main goal of the project is to develop a testbed for city scale IoT/FI experimentation and provide a framework for implementing Smart City services on top of it.

II. INFRASTRUCTURES

SmartSantander [9] is currently a prominent project that tries to build a city scale testbed that will support experimentation using IoT technologies along with Smart City services provision, e.g., parking monitoring, environmental monitoring, precise irrigation in parks and augmented reality using Near Field Communication (NFC) tags. End users of SmartSantander platform are researchers (of various disciplines like Computer Science, Sociology, transportation science etc.) who want to run IoT experiments using the facility and citizens who use the provided services. Apart from the deployment of IoT devices all over the city of Santander, the installation of a large number of Gateways and Servers was required in order to ensure connectivity of all devices, uninterrupted multipath communication, continuous data flow and exchange, and service execution. As depicted in Figure 1, SmartSantander is realized by a three tiered network node architecture, which consists of an IoT device tier, a Gateway (GW) tier and a Server tier.

The IoT node tier consists of the deployed IoT devices deployed in the extent of the city on light poles, under parking spots, parks, etc. These devices are typically resource-constrained (in terms of power, memory and energy availability). In order to target a wide variety of application and experimentation use cases, the IoT node tier consists of a wide variety of IoT device types, such as diverse sensor node platforms, RFID readers and tags, smartphones, thus supporting a wide range of communication capabilities. The gateway node tier interconnects the IoT devices with a core network infrastructure and the Internet. The devices of the GW tier are also part of the programmable experimentation plane, in order to allow experimentation for different inter-working and integration solutions of IoT devices with the network elements. The GW tier devices are typically more powerful with larger computational and memory capabilities, large number of network interfaces and continuous power supply (GW node devices are embedded servers, PCs or netbooks). The server tier provides more powerful server devices with high availability and large processing and storage capabilities. The servers are used for the operation of IoT data repositories, services for the management of the infrastructure and various Smart City application servers.

A major design decision has been the separation of the architecture into 3 planes: a) Infrastructure Management, b) IoT experimentation and c) Smart City services. The Infrastructure Management plane consists of software components and APIs that are responsible for the overall operation and performance of the infrastructure. Functions like IoT node reservation, node/GW registration and configuration, user authorization and authentication, observation and measurement data exchange and storage and security are supported by this plane. The IoT experimentation plane consists of modules responsible for managing an experiment using components from different tiers. Functions supported in this plane are: deployment of experimentation code, retrieval of experimentation data and
management of the deployed experiment. Finally, at the Smart City plane there are several software components and APIs at all tiers that guarantee the continuous flow of data to Smart City services.

A. Challenges

While developing the aforementioned infrastructure we have identified many technical challenges, as city scale applications face many multimodal contexts and large volumes of data.

**IoT Middleware Design and Development**: IoT is characterized by the need to integrate large numbers of heterogeneous and non-interoperable real-world objects. In order to address this, middleware solutions provide an appropriate level of abstraction to applications from devices and offer multiple services, acting as a bond joining the heterogeneous domains of applications. Operations that these middleware systems should solve are service interoperability, device heterogeneity, device discovery, device self-management and auto configuration etc. Solutions such as SensorGrid4Env [38] and OutSmart [39] have proposed different approaches; SensorGrid4Env presented a semantic sensor web architecture that comprises a core collection of services that form a service-oriented architecture for data publication, discovery and integration. OutSmart addresses five essential smart city services, namely water and sewage, smart metering and street lighting, waste management, water and environment, based on an open and standardized infrastructure.

Furthermore, the concept of virtualization has been a key research topic (e.g. Vitro EU project [42]), presented as a promising solution towards reusability of information and resources, hiding platform heterogeneity from end-users and solving issues related to resource and service isolation, manageability and flexibility. In this way, virtualization promises to provide a clear separation of services and infrastructures and accommodate novel business models, irrespective of the administrative control, communication paradigms and different economic interest of multiple vendors, thus exploiting the full fledge of IoT advantages.

**Semantics**: There are efforts to lift sensor data to a semantic level, e.g., by the W3C Semantic Sensor Network Incubator Group [25], and projects like Semantic Streams [26], Semantic System [27], and the Semantic Sensor Web [28], all aiming at making sensor data available as Linked Stream Data [29], i.e., sensor data available following the Linked Data principles. The Linked Open Data (LOD) cloud is a growing a collection of interlinked public datasets (encoded in RDF) that currently consists of more than 200 datasets with 25 billion facts connected with over 200 million links and is doubling in size every 10 months since 2007 [30]. The key success factor of LOD is the simplicity of its underlying principles: the main tasks are to publish data as Linked Data in order to: 1) assign consistent URIs to data items, 2) generate links, and 3) publish metadata which facilitates further exploration and discovery of relevant datasets. Integration of Social Networking, Semantic Web and Sensor Web technologies promises the ability to meaningfully access, discover, and query the Web of sensors and observations. Through meaningful semantic annotation, advantages brought in by virtualization, integration with existing spatial knowledge bases, and support for current Sensor Web services, it is possible to provide a middleware software component for processing semantically annotated, capable of providing the ability to access, discover and query IoT objects and their related data streams and provide services in a more intuitive and efficient manner. There are projects like Spitfire EU project [42] following this direction.

**Big Data Management and Cloud Computing**: The management of large data streams produced by the IoT is a topic of growing importance. There are some software prototype implementations like Cosm [31] and IDAS [32], Cosm connects devices and products with applications to provide real-time control and data storage. It focuses purely on the storage and exchange of data, with no specific capabilities in other fields, and so far offers support for a limited number of hardware platforms. IDAS provides support for a set of IoT services to various categories of users; it offers essentially a set of APIs to easily integrate existing applications and use it for storing and exchanging information. IDAS is currently utilized on the SmartSantander project and tested with a large IoT research facility. sMAP [33] is a RESTful web service which allows instruments and other producers of physical information to directly publish their data. Its strengths are that it is easy to consume, easy to implement for new device types, and simple to process. Finally, SenseWeb [34] is a system by Microsoft providing a set of services to developers for publishing and storing data from various kinds of sensors. Applications using SenseWeb can initiate and access sensor data streams from shared sensors across the entire Internet. Future storage solutions have to employ and combine advanced spatio-temporal and caching storages in order to realize a centralized storage for sensor data, which is capable of answering bursts of spatial and temporal queries efficiently. There is a need for designing novel data storages for indexing and caching semantically annotated datasets at various system levels like gateways and servers.

Another approach is public cloud infrastructures, which implies that improved techniques for data management and structuring are necessary if future demands shall be met. In the cloud databases of major providers, there are various data
management services like managing and retrieving structured data. Current solutions provide either a classic database system inside a virtual machine (e.g. Amazon RDS or Microsoft SQL Azure) or a massively distributed key-value store (so-called NoSQL systems) where data is organized in buckets (Amazon Dynamo) or in tables of records (Bigtable) which allow flexible schema evolution. However, the latter support only simple query interfaces, i.e., key-based access or single-table queries requiring that the application developers have to implement more complex operations such as joins themselves. There is a need for developing a cloud-based infrastructure optimized for streamed data, which will allow advanced sensor-cloud service abstraction. The cloud infrastructure has to support fine-grained provisioning and management of resources.

III. SERVICES

Several services have been deployed on the SmartSantander platform targeting Smart City applications. The development of the services performed both with installation of specialized hardware and software in all tiers and planes of the SmartSantander architecture.

Outdoor parking management: The Outdoor Parking Management use case implies provision of a Limited Parking Space Management service in the city of Santander. To achieve this, several hundred parking places in the city centre of Santander are equipped with ferromagnetic wireless sensors (buried underneath the asphalt). Collected information is pushed to the main storage and then to end-user applications (web/smartphone) and to public displays installed on the main city junctions informing drivers about the number of free parking places in different areas.

Environment monitoring: A large number of environment monitoring devices have been installed on lamp posts at several areas of Santander. Deployed devices contain air pollution sensors as well as noise sensors. To further increase the coverage of the environment monitoring network, a number of devices are being deployed on the public transport buses, police cars and municipality vehicles.

Participatory sensing: In this service, users utilize their mobile phones to send physical sensing information, e.g. GPS coordinates, compass, environmental data such as noise, temperature, etc. This information is stored to the SmartSantander platform providing useful data from areas where no deployments have been done. Furthermore, with the same smartphone application, users can subscribe to a special service named the “Pace of the city”, where they can get alerts for specific types of events (traffic jams, car accidents, concert, protests, etc.) that are currently happening in the center of the city. Moreover, users themselves can register in the system an event. The users receive notifications about the occurred events via their smartphones or SMS/mail.

Precision irrigation and garden monitoring: The precision irrigation and garden monitoring service provides real-time information to the gardening authorities and parks technicians regarding the status of parks, allowing them to assess remotely the current conditions. IoT devices have being deployed (underground for measuring the soil moisture and other parameters and above ground with weather stations) in two parks in the city of Santander. Apart from providing tools for the gardening authorities, there is also an alert module that notifies users when irregular conditions are detected. Moreover, users of this service can remotely...
monitor the water consumption and utilize estimations of important performance indicators like water absorbed, water waste, energy and labor cost.

**Augmented reality:** This service enables the “tagging” of points of interest (POIs) in the city like touristic points, monuments, parks, beaches, public services and shops. Using smartphone application users can get additional information about the tagged locations as well as leave feedback to the city administration and to other users. Furthermore, the service records and analyzes how users visit the POIs and extract common and frequent patterns of their movement. This knowledge facilitates the authorities to reorganize resources (adjust public transportation, garbage collections etc.).

**Smart metering:** The main goal of this service is to monitor energy consumption of building and office environments. Apart from collecting metrics concerning the energy consumption of devices, the system also recognizes the corresponding context of consumption (such as employee presence at his work room, utilization of a meeting room etc.).

**Challenges**

As many of the Smart City services interact directly with citizens there are certain challenges that have to be explored.

**Privacy and Trust/Anonymity:** As individuals interact directly with the platform and huge amount of data are being recorder and then shared, aggregated, annotated, stored, processed and finally consumed, the privacy and anonymity of users has to be ensured. Toward this, there are mainly two approaches: security mechanisms and privacy-trust mechanisms. Regarding security cryptography techniques and key management (like Elliptic curve cryptography-ECC and Pairing-based Cryptography-PBC) are computationally feasible in resource-constrained devices in the IoT, allowing on top of them more complex security methods as Identity-based encryption (IBE) [35] and Attribute-based encryption (ABE) [36]. Moreover, privacy methods can be classified into: data-oriented privacy and context-oriented privacy. Furthermore, a number of privacy schemes have been recently proposed for wireless sensor networks which can be applied to IoT objects. Simple Anonymity Scheme (SAS) and Cryptographic Anonymity Scheme (CAS) enable establishing anonymity in clustered WSNs by using dynamic pseudonyms. Data privacy protections within the sensor network can be also reached by encryption techniques or with aggregation/randomization of the datasets.

**Crowdsourcing/ User Engagement:** Innovation is no longer the result provided solely by single entrepreneurs or groups; instead, collaborative efforts by researchers, companies, municipalities and end-users are equally important sources for social and technological innovation. Moreover, participating in smart city experiments and services requires users to become active and to download and install an application on their personal smartphone, granting access to users’ personal data collected by smartphone integrated sensors. Most users will be quite reluctant to install such an application without any clear benefits. In order to persuade users to participate, some kind of incentivisation is often required. In the optimal case, incentivisation schemes are compatible with a user’s needs and interests; moreover, they can also relate to social networking schemes and pursue to maintain the interest in participating in such a project. Building upon more traditional means of end-user engagement, the intermixing of physical and digital domains to produce e.g., “serious” games is an increasingly popular approach, also utilizing results from the pervasive gaming area. Use of such concepts in public spaces to promote “common-good” activities, or in corporate environments to promote energy-conscious practices has already given encouraging results in terms of user engagement. The combination of moral incentives, as outlined above, seems a very promising approach on building and also sustaining end-user communities of all sorts, e.g., supporting air quality participatory sensing initiatives, etc.

**IV. SOCIAL AND FINANCIAL INNOVATION**

In many cases, participatory applications and services can lead to novel value-added meta-applications and can create new opportunities for novel entrepreneurship and business growth. Nowadays, with Web 2.0 and mobile phones, users are not only consumers but also producers (a.k.a. prosumers) of content, leading to a new stage of Web evolution, the Web of data with the emergence of data-centric applications and services based on open data. The growth of available data, their potential for value-added services and the availability of standards seem to set the conditions for new cycle of
network effects and innovation. Governments can make datasets available for use by citizens or organizations, who can then add value to them. The research community can share datasets and facilitate research collaboration. Businesses can publish datasets to enable and participate in open supply chains. Datasets originated from sensors and devices can be published for use by applications for transport, health, the environment and business.

The potential of Open Data is already established in a number of sectors in government and business. The European Union has adopted an open data strategy to support transparency and to create a €32 billion a year market for public data [39]. Published datasets can cover a number of areas of activity including transport, health, agriculture, business, law and education. The role that SMEs can play innovating in the Web of open data is significant. It is estimated that the Internet contributes as high as 7% to GDP growth in some countries, most of which is coming from small businesses [40]. SMEs can innovate by adding value to open available information, adding value to company data, participating in open supply chains or by providing solutions to enable more efficient publication and use of open data.

V. CONCLUSIONS

In this paper, we highlighted the current developments of a project that designs a Smart City framework. Based on this, we presented some key technological findings, technological ICT challenges and socioeconomic opportunities of an IoT Smart City ecosystem.

ACKNOWLEDGMENT

This work is funded by research project SmartSantander (www.smartsantander.eu), under FP7-ICT-2009-5 of the 7th Framework Programme of the European Community. Authors would like to acknowledge the entire consortium of the project for SmartSantander developments leading to argumentation presented in this paper.

REFERENCES

[14] http://www.opencities.net/content/project
[29] http://lod-cloud.net/
[33] H. Ahmadi, N. Pham, R. Ganti, T. Abdelzaher, S. Nath, and J. Han, “Privacy-aware Regress Modelling of Participatory Sensing Data”, in the Proceedings
http://www.sensorsgrid4env.eu
http://www.fi-ppp-outsmart.eu/
http://www.ubiuoliu.fr/
http://www.ubiuoliu.fr/