Sustainable smart city IoT applications:
Heat and electricity management & Eco-conscious cruise control for public transportation

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Abstract — **In a world of multi-stakeholder information and assets provision on top of millions of real-time interacting and communicating things, systems based on Internet of Things (IoT) technologies aim at exploiting these assets in a resilient and sustainable way allowing them to reach their full potential. In this paper we present two innovative smart city IoT applications: the first one refers to heat and energy management, and aims at utilizing different resources (such as heat and electricity meters) in order to optimize use of energy in commercial and residential areas. The second application refers to cruise control for public transportation, and aims at utilizing different resources (such as environmental and traffic sensors) in order to provide driving recommendations that aim at eco efficiency. We also highlight the IoT challenges as well as potential enabling technologies that will allow for the realization of the proposed applications.**

Internet of Things; Smart cities; Electricity management; Transporation; Eco-efficienty;

I. INTRODUCTION

According to CISCO [1], during 2008, the number of things connected to the Internet exceeded the number of people on earth and by 2020 there will be 50 billion, shaping a rich digital environment. Sensors, intelligent fixed and mobile platforms (e.g. smartphones, tablets and home gateways), massive scale cloud infrastructures and other network-enabled devices will all need to cooperate and interact to create value across many sectors in smart cities. This digital environment creates a treasure trove of information, which is the key enabler for embedding wisdom into objects. The added value in a city context is that by making objects smarter cost savings and increased efficiencies will be created, thus allowing for long-term economic growth [2].

Realizing the vision of sustainable smart city applications requires for enhancing Internet of Things (IoT) technologies with new ways that will enable things and objects to become more reliable, more resilient, more autonomous and smarter. As highlighted in [3] humans evolve because they communicate, creating knowledge out of data and wisdom based on experience. Applying this metaphor to the IoT domain means enhancing objects with technologies that would enable them to evolve based on the knowledge derived from the data streams and the experience of their exploitation and of other objects exploitation by IoT applications. To this direction, current research approaches focus on allowing objects to exchange information in order to enhance their capabilities, targeting more sustainable and green smart city applications [4]. Thus and according to a report by Economist [5], future smart cities will base IoT service provision on the digital reflection of things and citizens, which will bring much greater efficiency. Towards this direction, approaches have been already proposed as for example through the use of using intelligent parking reservation policies [6] or decision support systems for environmental crisis management [7].

Nowadays, cities become smarter and smarter by going digital: they deploy digital equipment that is utilized by various applications (e.g. street cameras for traffic jam control, sensors for transportation times, etc), while there are also enterprises that use objects to provided added-value services (e.g. Google street views). Moreover, there is a multitude of mobile devices used by individuals contributing services and information. In this rich digital - but diverse in terms of objects characteristics, security rules, contributors' motivations, served applications, etc. - city environment several questions arise on:

- How to exploit the multitude of objects in ad-hoc defined, on demand applications?
- How to manage the volatility and uncertainty introduced due to real-world dynamics and ensure quality of information?
- How to make existing objects smarter?

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- How to enable objects to adapt to different situations and contexts?
- How to address by design considerations related to security, trust and privacy?
- How to minimize data movement given the number of objects and the data generated by each one of them?

In this paper, we present two representative sustainable smart city IoT applications (i.e. smart heat and electricity management, and eco-conscious cruise control for public transportation) along with the challenges and enabling technologies for their realization. These applications highlight the need for techniques that incorporate trust and security and provide built-in privacy support to the applications, as well as mechanisms to overcome limitations in the management and exploitation of millions of unreliable, non-autonomous things and of the corresponding data and information flows.

II. Smart Heat and Electricity Management

Within the boundaries of London Borough of Camden, the Brunswick Centre and Ampthill estate, an interconnected IoT-based system (using as a basis an energy platform) is required for smart heat energy management while addressing the retail domain in the specific area. The application will leverage the existing energy IoT infrastructure (owned by London Borough of Camden) to exploit sources, sinks and mediation of sensors, actuators and processors of IoT data. As already mentioned, the application will use as a basis an energy platform, namely EnergyHive [8] (designed and implemented by Hildebrand [9]) for smart heat and electricity management. The specific geographic area will be used as a living lab to build upon existing energy IoT infrastructure deployed by the Council and operated by Hildebrand. The iconic Brunswick Centre has approximately 50 retailers and restaurants, 500 domestic properties owned by Camden Council and a public square attracting hundreds of thousands of people a year. Currently there are 300 properties each having a connected heat meter, Wi-Fi router and 7" Android tablet displaying real-time energy consumption from the Council's district heating system. This system is designed, built and maintained by Hildebrand. The application will be used by retailers, residents and visitors as end users. Streams will include real-time: 1) energy production and demand, 2) shopper dynamics from Wi-Fi signal triangulation, 3) environmental and energy data from retail and restaurants. A pop-up shop on site called the Brunswick Hive [10] will serve as a focal point for citizens providing heat and electricity information. The pop-up shop will be opened and operated by Hildebrand including a directory service, proxy and mediation for streams akin to a SIP, in that there are two bands for communication, a) for messaging through TCP and b) for pure signal data through TCP/UDP.

Following the implementation of the EU Energy Performance of Buildings Directive and complying with EC Directive 2006/32/EC on Energy End-use Efficiency and Energy Services [11] (which sets out that the energy bills for household customers have to be sufficiently detailed and served frequently enough for customers to be aware of their energy consumption and control it accordingly), this application will allow for reducing electricity demand, by communicating real-time electricity usage about the energy consumption of buildings (including the consumption of the individual appliances) to the end users. Smart meters will be used to enable automatic energy management through the recording and real-time reporting of accurate consumption information automatically and remotely. Through the corresponding heat and electricity sensors as well as the environmental sensors, IoT technologies will utilize this information at real-time (e.g. through the real-time analysis of streaming data for situational awareness) in order to enable adjustment of the energy consumption based on various conditions within the building (such as temperature and lighting). Technologies are required to allow things to communicate in order to share their experiences and enable runtime adaptation of the communicating devices (i.e. network of things) as well as things' cognitive control for example predictive control of heating based on how external temperature affects specific heat systems deployed in a building. IoT technologies enabling event detection and correlation with other events and actions will also be applied enabling the identification and analysis of things behavior that may have caused specific events for example in the case of a fire. Furthermore, based on IoT technologies for information reliability and volatility identification, users will be promptly informed in the case of abnormal appliance consumption, damage or non-standard conditions. Tools for analysis on storage will provide knowledge regarding the consumption patterns to the end users in order to promote energy saving through optimization of appliances usage. Built-in security, privacy and trust will allow for more peer based interactions and integration of various sensors and actuators within the Brunswick Hive so as to have a more complete picture at any time of the city heat and electricity information, thus allowing energy companies to innovate buy offering at real-time to their customers new types of tariffs that will allow customers to take advantage of cheaper deals at off-peak times. Furthermore, in the future, smart metering is expected to play an increasingly important role besides residential also in commercial buildings. Thus this application will explore how energy semantics affect retail marketing and operations, providing valuable information to the Camden Council in order to put in place the corresponding rules and regulations. The application is expected to engage a big number of participants / volunteers (residents, visitors and retailers), referring to more than 500 residents, 5000 visitors and 50 retailers. Education, awareness, end user engagement are all enhanced by having a physical showcase through the physical Shop, allowing for close interaction with end users in a truly collaborative way.

In terms of infrastructure, the application is expected to utilize more than 300 heat meters, 250 electricity meters, an environmental monitoring station, 350 Wi-Fi mesh units, 300 Android tablets, a mobile application for personal location sensing, London transportation data, 150 wireless sensors for temperature, motion and light, 250 low power wireless sensor access points and EnergyHive platform. The information hub (the Hive) is a system that supports messaging, device management, persistence, basic stream processing, analytic execution, end point consumption and control event generation with the characteristics of large scale throughput (300,000 messages per second), layering (open APIs at various levels) and domain specific semantics.

III. Eco-conscious Cruise Control for Public Transportation

With transportation being one of the main activities of daily living – Europeans spend on average an hour per day travelling [12], cities aim at providing various modes of transportation (e.g. buses, trains, trams, metros, "rentable" bikes, etc) while considering the environmental effects given that 12% of global CO2 emissions are caused by transportation means [13]. According to a study of UK air quality [14], road pollution is more than twice as deadly as traffic accidents, while car pollution causes severe heath damage and risks in premature deaths [15]. On the other hand, one needs to take into consideration the emerging landscape: cities going digital by deploying various sensors and additional information is provided by individuals through their mobile devices. In this context, Internet of Things (IoT) as an underlying technology aims at creating smart environments / spaces for energy and mobility (as described by the European Research Cluster on the Internet of Things [4]). The aforementioned facts and figures as well as the IoT underlying technologies highlight the need and the potential for IoT environments that will aim at addressing the domains of smart transport and smart energy, which have been identified amongst the main IoT applications in the EU Strategic Research Agenda [16]. The goal of this application is to enhance public transportation systems in order to increase their efficiency while tackling environmental aspects.

Taking for example the city of Madrid, EMT [17] operates the city bus lines (in total 215 lines) through a fleet of 2095 vehicles, which have an average age of 6.04 years. In 2011, EMT operated a total of 7.11 million hours and 95.45 million kilometres, with an average operating speed of 13.43 Km/h. Given the big number of vehicles and their operation the goal of the scenario is to optimize the driving conditions of the buses in order to minimize air pollution. The buses are equipped with GPS devices providing information regarding their location and speed. Moreover, City of Madrid has deployed sensors in the streets regarding the traffic lights, the environmental conditions, the traffic congestion, etc. In this scenario we propose to take into consideration the available information from mobile sensors deployed in the busses regarding the routes, vehicle information such as car speed, road slope, location information from GPS devices, as well as from static city sensors such as street cameras, traffic lights location and changing intervals, speed of cars, road lights, temperature and in general weather information (e.g. ice, rain, etc). Additional information may be provided by citizens from their mobile devices (such as smartphones and tablets) offering views from the devices' cameras regarding road conditions or potential accidents. Through this information an innovative scenario refers to enhancement of buses cruise control in order to take into account various aspects (i.e. eco-efficiency, weather, traffic jam, etc). The proposed cruise control application will offer eco-saving considering the location of the bus, the road slope and the speed of other vehicles in the route (e.g. no need to increase speed and thus consume gas when in 1km the speed of the cars is 40% less than the cruising speed or when a traffic light will turn red). IoT technologies will manage the reliability of the things and the corresponding information flows and will extract knowledge at real-time out of the data streams contributing to the situational awareness both regarding the buses and other vehicles (e.g. position, CO2 emissions, schedule, etc) as well as regarding the environment (e.g. traffic congestion, traffic lights, CO2 emissions, temperature, humidity, etc). Moreover, safety will be increased by utilizing information regarding the location and speed of the buses, the road lights, slippery and potholes, the weather conditions (e.g. ice) and the speed of other vehicles. IoT technologies will allow things to learn from the experiences of others and thus adapt to real-time situations. For example and in order to achieve optimum breaking, things used to locate and identify the bus movement will provide information regarding the bus systems (e.g. breaks or tires) reaction for specific situations such the weather, the driving conditions, the temperature, etc. This information will be communicated to other buses with the same characteristics (in this case with same breaks or tires) in order to optimize their cruising.

In Madrid, the current technological infrastructures for mobility users include, on the EMT's side, Wi-Fi hotspots on the 2.000 buses (with M2M Communications), 350 Street Information displays (with M2M Communications) and over 4.500 Bus Stops. Parking facilities for car sharing with electric vehicle charging slots (67 slots) and traffic management information systems could also be exploited by the application. Besides these, the current technological infrastructures in Madrid city and similar smart cities include real-time information on buses' locations, arrival times, average velocity on streets, etc with over 3.000.000 of EMT's App users per month. What is more, parking facilities can be used for accessing the car sharing vehicle fleet, and parking lots with the charging infrastructure needed for electric vehicles.

IV. Challenges and Enablers

A. *Challenges*

The realization of the aforementioned indicative sustainable applications in a smart city context, raise a number of challenges with respect to IoT-based systems. One of the challenges refers to embedding intelligence into things by enabling things and devices to learn and become smarter and more autonomous through the description, sharing and exchange of experiences with other things, as well as by managing the things reliability following the volatility introduced due to real-world dynamics. Another challenge refers to the management of heterogeneous device platforms in a decentralized way, by coordinating the devices exploiting their "social-behavior" in terms of relationships with other devices, goals, location, administration rule, and by adapting the network of things based on the evaluation of events impact and the anticipated IoT application requests. Furthermore, pertinent issues with respect to end-to-end security, privacy and trust need to be addressed. Techniques are required within and across different levels of IoT-based systems: hardware-coded security at the devices level, security and privacy in storage at the data level, reputation, trust and privacy profiling of things and providers as well as techniques to minimize data movement in order to prevent information inference. Additional challenges refer to the support for scalable data and information management, through rich metadata structures that capture the social-aspects of things, allow for real-time analysis of data to obtain the potentially valuable knowledge from the information flows, while managing the exponentially increasing amount of generated data.

B. Enablers

The representative challenges described previously can be addressed by architectures, models and enabling technologies that aim at tackling challenges on different levels: information, data, devices and management. On the information level, technologies are required to obtain valuable knowledge from the data (either stored or at real-time through the analysis of streaming data based on complex event processing techniques), to identify reliability and volatility patterns, to evaluate the information provided by the devices and enabling mechanisms to be put in place in order to overcome the volatility of the information provision, thus enhancing the corresponding Quality of Information (QoI). Technologies will enable events to be detected from the corresponding data flows and their impact to be assessed in order to deliver additional knowledge to the management mechanisms so as to perform the corrective actions at runtime. On the things level, technologies will enable description and sharing of experiences, thus allowing things to learn based on their experiences and the experiences of others (with the same characteristics and operating under the same conditions) with respect to spatial-, societal-, application- and situational- related aspects. Experiences will capture functional (e.g. performance, response time, availability, reliability, accuracy) and non-functional properties (e.g. trust, users experience, expectations, motivations) of things, allowing things to adapt to different situations based on their / others experiences and thus acting in a more autonomous way. Security, privacy and trust considerations will also be tackled through IoT technologies.

Furthermore, IoT technologies will allow for the decentralized management of the things exploited in such applications, enabling efficient management and coordination of the big number of things. Overcoming the management limitation for the exponentially increasing number of things requires for techniques that base management and coordination decisions on goal-, administration-, service-, interaction-, proximity-, location- and reputation-oriented principles. What is of major importance regarding the enhanced and autonomous management technologies is their ability to adapt to reality. Analyzing raw data will provide a snapshot of the network of things behavior and state at any time, triggering actions with respect to resources and data management. Finally and given that things follow the administrative rule of their owners / operators or of a community with specific goals, techniques will allow for developing security, privacy and trust profiles of things and the potential linkage with the corresponding administrative domains, the contexts, conditions and events associated with their operation.

V. CONCLUSIONS

We are experiencing a second historical surge of population movement from rural areas to urban areas. The latest UN report on the subject of Smart Cities suggests that the world will need to create 10.000 new cities by 2040, and the Chinese are already committed to building 100 new cities to accommodate the 385 million people reported to be moving from the countryside to the city. There are to be seven new cities in Korea, six are being planned for Saudi Arabia, and there are private sector developments underway such as PlanIT Valley in Portugal and Lavasa in India. The Digital Agenda for Europe [18] establishes that "Smart use of technology and exploitation of information will help us to address the challenges facing society", and in Europe more than 70% of the population concentrates in urban environments, with a clear tendency to increase this percentage even more in the near future. Most society challenges must then be addressed and answered from those urban conglomerates, usually with scare resources and complex political organizations in which decision-making becomes a cumbersome and awkward process with lack of transparency.

The term "Smart City" can be understood as a shorthand for technology-enabled services in communities, which means that a smart city is not just about ICT, but ICT is critical. In fact, the smart use of ICT technologies is being invaluable to deal in an effective way with the city challenges mentioned before. In this context, in this paper we have presented two indicative sustainable smart city IoT applications (i.e. heat and electricity management, and eco-conscious cruise control for public transportation) along with a set of challenges and enabling technologies for their realization.

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