Towards a Smart City based on Cloud of Things

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ABSTRACT

Smart City represents one of the most promising and prominent Internet of Things (IoT) applications. In the last few years, smart city concept has played an important role in academic and industry fields, with the development and deployment of various middleware platforms. However, this expansion has followed distinct approaches creating a fragmented scenario, in which different IoT ecosystems are not able to communicate between them. To fill this gap, there is a need to re-visit the smart city IoT semantic and offer a global common approach. To this purpose, this paper browses the semantic annotation of the sensors in the cloud, and innovative services can be implemented and considered by bridging Clouds and IoT. Things-like semantic will be considered to perform the aggregation of heterogeneous resources by defining the Clouds of Things (CoT) paradigm. We survey the smart city vision, providing information on the main requirements and highlighting the benefits of integrating different IoT ecosystems within the cloud under this new CoT vision and discuss relevant challenges in this research area.

Keywords

Cloud of Things, Smart Cities, Internet of Things

1. INTRODUCTION

Cities are growing steadily and urban living poses major challenges in our daily lives. As of 2007, 50% of the population of the world was living in cities. The United Nations Population Fund forecasts that by 2030 approximately 60% of the world population will live in an urban environment [15]. In this context, Information and Communication Technologies (ICT) together with local governments and private companies, play a key role for implementing innovative solutions, services and applications to make smart cities reality. In this context the Internet of Things (IoT) paradigm is playing a primary role as enabler of a broad range of applications, both for industries and the general population. The increasing popularity of IoT concept is also due to the constantly growing number of very powerful devices like smartphones, tablets and lower powerful devices like sensors, able to join Internet. In the context of Smart Cities, it makes sense to consider the scenario of the various heterogeneous devices, the Wireless Sensor Networks, interconnected to each other and to exploit these "interconnections" to activate new type of services. The ICT trends suggest that the sensing and actuation resources can be involved in the Cloud and solutions for the convergence and evolution of IoT and cloud computing infrastructures exist. Nevertheless, there are still some challenges to face such as: 1) the interoperability among different ICT systems; 2) a huge amount of data to be processed provided in real-time by the IoT devices deployed in the smart systems; 3) the significant *fragmentation* deriving from the multiple IoT architectures and associated middleware; 4) heterogeneous resources mashup, namely how to orchestrate resources of the various Clouds. Concerning the last item, the concept of IoT, with underlying physical objects abstracted according to thing-like semantics, seems a valid starting point for the orchestration of the various resources. In this context, the Cloud concept could play the role to connect the IoT with the *Internet of People* through the *Internet of Services*, by the means of an horizontal integration of various silos. We will refer to this horizontal integration and to the Cloud computing associated to the IoT as the Cloud of Things (CoT). As we will explain in the paper, this concept goes beyond the interconnection and hyperlink of things. Development of the convergence of diverse IoT platforms and Clouds goes through properly designed and implemented abstraction, virtualization and management of things. A precise design of these mechanisms will permit the development of a technological-agnostic architecture, where the integration and deployment of diverse devices and objects can be considered by neglecting their underlying architecture. We will present the VITAL project as a Cloud of Things-based architecture, able to meet many critical requirements of a smart city, and we will show how this platform can be considered to bridge different and heterogeneous IoT silos. The paper is structured as follows: Section 2 revises existing IoT platforms. Section 3 introduces the concept of CoT from the traditional Cloud computing concept. Section 4 presents the main requirements of a "smart" city. Section 5 considers IoT and CoT paradigms as potential effective solutions to make the cities smarter and more sustainable. Section 6 describes the VITAL platform as a CoT-based platform and effective solution to be applied for the realization of a smart city. Section 7 concludes the paper.

2. IoT PLATFORMS

"The Internet of Things has the potential to change the world, just as the Internet did. Maybe even more so" [13]. With this sentence, in 1998, Kevin Ashton introduced for the first time the term "Internet of Things". Some years later, in 2005, the International Telecommunication Union (ITU) formally introduced IoT, according to which: *"from anytime,*

anyplace connectivity for anyone, we will now have connectivity for anything" [12]. Since then, IoT starts to be a hot topic in academic and industry fields. 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. The main reasons behind are the capabilities offered by IoT to create a world where all the *objects* around us are connected together and to the Internet with minimum human intervention [17], making possible the development of a huge number of applications in different domains [2] as shown in Fig. 1.

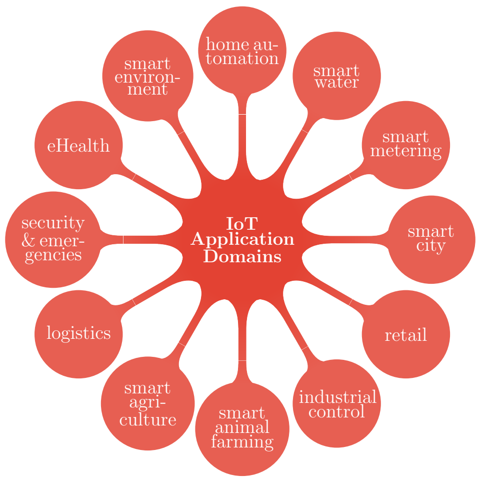

Figure 1: IoT application domains.

Simultaneously together with the several IoT platforms, the middleware started to gain more and more importance since simplifying the development of new services and the integration of legacy technologies into new ones [3]. We present some of the most representative IoT platforms without pretending to be exhaustive:

GSN[1], provides a flexible java middleware to address the challenges of sensor data integration and distributed query processing. It lists all the available sensors in a combo-box which users need to select. GSN's purpose is to make applications hardware-independent and the changes and variations invisible to the application. Its main limitation is a lack in metadata semantics.

LSM[2](Linked Sensor Middleware) is a platform that bridges the live real world sensed data and the Semantic Web thanks to many functionalities such as, wrappers for real time data collection and publishing; data annotation and visualization; and a SPARQL endpoint for querying unified Linked Stream Data and Linked Data.

Sensor-Cloud [22] aims at managing physical sensors by connecting them to the cloud, providing the service instances (virtual sensors) in an automatic way in the same fashion as these virtual sensors are effectively part of the IT resources. The generation of the services implies that the sensor devices and service templates (used to create the virtual sensors) and metadata should be firstly described by using SensorML.

OpenIoT[3], a joint effort of several contributors to IoT-based applications according to a cloud computing delivery model, provides a cloud-based middleware infrastructure to deliver on-demand access to IoT services issued from multiple platforms. It can opportunistically collect and filter data from the Internet-connected objects. It is closely related to the FP7 VITAL project.

Xively[4](formerly Cosm and Pachube) offers a public cloud that simplifies and accelerates the creation, deployment and management of sensor in scalable way.

These approaches strengthen the vision towards the CoT, but a lot of new enhancements are still needed to realize a *Clouds of Things* platform for Smart City.

3. TOWARDS CLOUD OF THINGS

Cloud Computing attracts the attention from both academy and industry across the world, thanks to its ability of transforming service provision models over the entirely current IT industry with reduced upfront investment, expected performance, high availability, tremendous fault-tolerance, infinity scalability, and so on [23]. The services can be divided in three layers [16]:

• *Infrastructure as a Service (IaaS)* which offers computing resources such as processing or storage;
• *Platform as a Service (PaaS)* to allow software developers to write their applications according to the specifications of a particular platform independently of the underlying hardware infrastructure;
•*Software as a Service (SaaS)*, the most visible layer for end-users, focuses on the actual software applications accessed and used.

In addition to the above main layers, some others are also introduced and discussed in literature such as Data as a Service (DaaS), Network as a Service (NaaS), Identity and Policy Management as a Service (IPMaaS). In [4] authors introduce XaaS (everything as a service model) that promotes the "*pay as you go*" method, allowing the consumption of a service by paying only for the amount of resources used. Within the IoT context, this approach gave the input to the so called Cloud of Things [10], which deals to implement indexing and querying services of *things*, and provides them to final users, developers, provides, as a service (Fig. 3). One interesting model to enable CoT [18] focuses on the *Sensing as a Service (SeaS)* model based on IoT infrastructure, relying on four conceptual layers:

• *Sensor and Sensor Owners Layer:* sensors and how to manage them with possible publication in the cloud.
• *Sensor Publishers* to detect available sensors and get permission to publish them in the cloud.
• *Extended Service Providers* to select sensors from multiple publishers based on customer's requirements.
• *Sensor Data Consumers* that need to register to consume sensors data.

The advantages and benefits promised by the *SeaS* model are numerous and to name a few: *sharing and reusing sensor data* (if some sensors are already deployed, one can access them by paying a fee to the owner), *reduction of data acquisition cost* due to the shared nature, *collect data previously unavailable* (companies are stimulated to "sell" data).

[1]`https://github.com/LSIR/gsn`
[2]`http://lsm.deri.ie`
[3]`http://openiot.eu`
[4]`https://xively.com`

4. SMART CITY REQUIREMENTS

Before to relate the IoT and CoT paradigms to the very emerging Smart City concept, it is useful to identify its main requirements in terms of ICT-based services and solutions. To this purpose, by following the same approach introduced in [1], we make reference to two different types of requirements: 1) *citizen-centric service/application* and 2) *operational*, seen from the city authorities and administrators of the networks point of view. Concerning the *service/application* aspects, the end-users devices, sensors and actuators deployed all over the cities, make possible the individuation of novel services and applications for the citizens. These services will have specific features, like: a) *user-centric*: based on the specific context and the preferences of the users, b) *ubiquitous*: reachable everywhere and from any devices, and c) *highly-integrated*: based on the integration of services and data from several and different applications or on the social cooperation of multiple users. Of course, beyond the citizens, also the stakeholders of a city, like educational institutions, healthcare and public safety providers, governmental organizations, etc. will be in conditions to exploit the key features of these new services that make the city more sustainable. On the other hand, the Smart City concept considered from the point of view of the administrations and the providers of the networks are translated in a network infrastructure that is: a) *highly-interconnected*: by overcoming the heterogeneity of the devices and the IoT platforms, it is possible to provide ubiquitous connectivity, b) *cost-efficient*: the deployment and organization of the network should be as much automatic as possible and independent from the human intervention, c) *energy-efficient*, able to realize an efficient resource utilization, in order to meet the main requirements of *green* applications d) *reliable*: that connectivity, the ubiquity of the network should be guaranteed above all in the case of exceptional and adverse conditions. The real scenario we can observe at the moment, is characterized with an high level of *fragmentation* of technologies, lack of ubiquity in terms of both connectivity and coverage, due to the plethora of technologies in a city. This *fragmentation* is mainly due to the presence of many access networks usually managed by different operators (i.e. LTE/UMTS, WiMAX, WiFi, etc.). Even if some steps ahead have been moved, most of these initiatives are related to specific cities and do not consider general architectures. By considering the main IoT platforms and the CoT concept, we will try to explain how the main requirements of a city to become a smart city, can be fulfilled and at the end we will show how the VITAL platform can play the role of "interconnecting" heterogeneous ICT silos and devices.

5. IoT AND CoT FOR A SMART CITY

Among all the domains that can benefit from the IoT platforms, the Smart City concept received a significant research effort, notably because of the population growth and the urbanization trend. ONU predicts that the urban populations will grow by 2.3 billion over the next 40 years, while as much as 60 % of the world's population will live in cities by 2030. Such as a dramatic expansion requires to develop cities in a sustainable manner, while also improving the quality of life [21].

Despite no formal and universally accepted definition of "Smart City", in [11], authors try to delineate the concept, defining a Smart City as *a city which functions in a sustainable and intelligent way, by integrating all its infrastructure and services into a cohesive whole and using intelligent devices for monitoring and control, to ensure sustainability and efficiency*. This interpretation makes evident, therefore, that a Smart City (Fig. 2) needs *interoperability* between the different IoT deployments that are, today, mainly closed and vertically integrated to specific application domains [20].

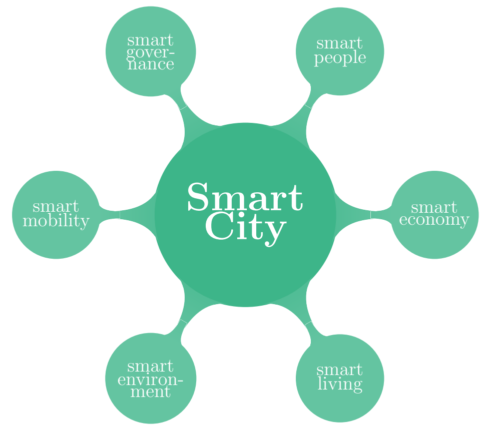

Figure 2: Smart City concept.

These solutions are, indeed, based on multiple architectures, standards and platforms, which have led to a highly fragmented IoT landscape and making challenging the realization of the Smart City concept. According to [14], the IoT structure is divided into five layers:
- *Device Layer* deals with the identification and collection of objects specific information by the sensor device;
- *Network Layer* sends data collected by the Device Layer to the information processing system;
- *Middleware Layer* to process and compute ubiquitous information and take automatic decision accordingly;
- *Application Layer* to globally manage the application based on the data processed through the middleware;
- *Business Layer* to manage the overall IoT system.

In Smart City [9] context, CoT is expected to play a significant role making a better use of distributed resources, achieving higher throughput and tackling large scale computation problems [19], to enable the horizontal integration of various (vertical) IoT platforms and the Smart City vision. Moreover, it allows users to express their expected service to provide them relevant data without a manual selection of relevant sensors.

Certainly, CoT needs to deal with several challenges, but the major relies on the heterogeneity in sensor types (e.g., temperature, NFC, RFID), and in protocols and communications technologies (e.g. Wi-Fi, ZigBee); interoperability among different sensors hardware and clouds. It is thus important to define an *abstraction level* to bridge the disparate technologies. Regarding the various sensor types, the use of the technologies developed in the semantic web [7] such as ontologies, semantic annotation, linked data [6] and semantic web services have recently gained momentum. These technologies promote interoperability among IoT resources, information models, data providers and consumers to simplify effective data integration, resource discovery [5].

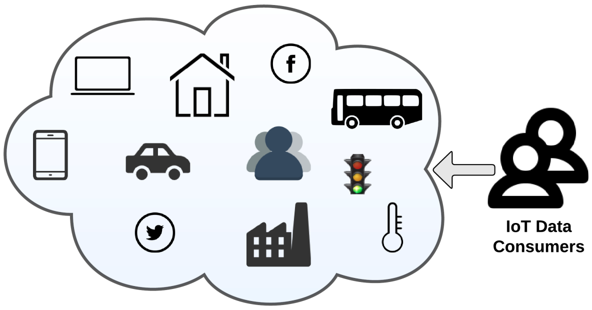

Figure 3: Cloud of Things.

6. A CoT-based SMART CITY PLATFORM

One of the major VITAL objectives is the integration of sensors and interconnected objects among multiple IoT platforms and ecosystems. The convergence and federation of multiple IoT platforms is based of the deployment cost. In the context of VITAL, a very key factor is the virtualization of interfaces that in combination with cross-context tools enable the access and management of heterogeneous objects supported by different platforms and managed by different administrative stakeholders.

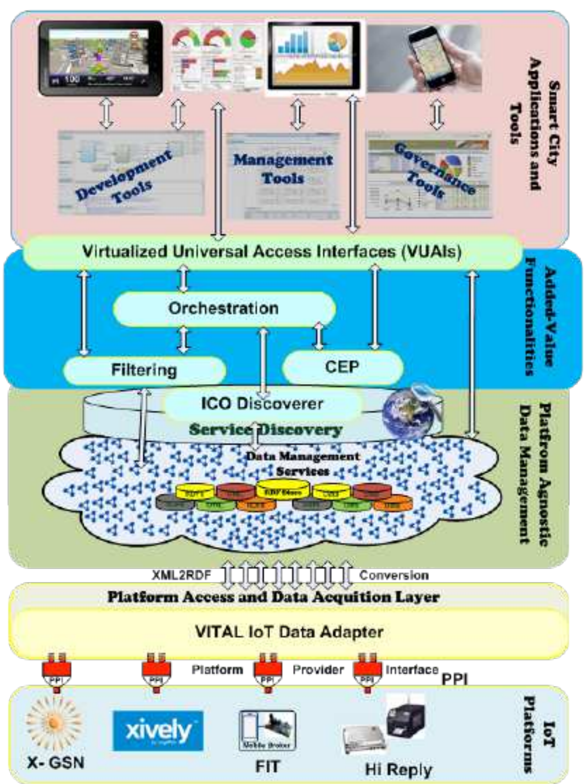

Figure 4: VITAL Platform.

The VITAL platform is a CoT architecture as illustrated by Fig. 4. The data and services access of the VITAL heterogeneous objects, is based on the implementation of the VUAIs (Virtualized Universal Access Interfaces), that makes possible to consider a single virtual access by making the architecture platform-agnostic. These key features of VITAL make this platform able to embrace the CoT philosophy. The VUAI layer is built upon a so-called meta-architecture and migration layer and includes several connectors to communicate and interconnect different IoT platforms and clouds. In practice, this module deals with issues related to the management of the overall VITAL infrastructure, built on top of existing IoT architectures and clouds platforms and enable heterogeneous mashup.

The VUAIs allow the implementation of a kind of abstraction, where *objects* handler that point to physical items, can be discovered, selected and filtered and also allocated by following a Things as a Service (TaaS) paradigm. In this sense the VITAL as CoT platform is something that goes beyond the interconnecting and hyperlinking *things* of the IoT paradigm. VITAL also include a data-store for data like geographical information and smart city stakeholders. Of course, it is expected that the management of this kind of information giving location awareness and other context related information can be effectively exploited in the optimization of computing and sensing of the management of the various clouds. The CoT paradigm implies the implementation of querying services and indexing of things, the aggregation of heterogeneous resources based on a given thing-like semantics and provided to the final stakeholder (final user, developer, etc.). Moreover, the CoT concept explicitly has to consider mechanisms to abstract, virtualize and manage things as performed in VITAL. It is worth outlining that VITAL relies on W3C SSN ontology, that is considered ideal for unifying the semantics of different IoT platforms, since it is domain independent and extensible. Several additional concepts have to be considered to enhance the ontology starting from information about city-wide, stake-holders, IoT system, etc. The ontology update with additional functionalities will allow the migration of smart city application across different urban environments.

7. FUTURE CHALLENGES

In this paper we have considered the IoT platforms as a viable solution to make cities smarter. We have shown how the proliferation of ICT represents new opportunities for the development of novel services, contributing to make the cities more sustainable. The different IoT platforms, the various IoT clouds and the several IoT applications and services have resulted in different and heterogeneous IoT ecosystems, that introduce a significant degree of fragmentation. In this paper we presented several IoT platforms that can be efficiently considered in the context of Smart City, but in order to bridge the gap between the different IoT platforms it is necessary to consider a convergence of these platforms and ecosystems. In this paper we envisaged in the Cloud computing a valid bridge of the IoT, Internet of people through the Internet of Services. This novel perspective allows the realization of an horizontal integration of various vertical platforms. Through the implementation of a specific virtualization level, the VITAL platform in the context of the corrispective FP7 EU project, ensures the semantic interoperability of various and different IoT platforms. The Virtualized Unified Access Interfaces (VUAIs) implements a meta-architecture and migration layer, with different connectors and drivers to permit the communication among the various platform. In this way, VITAL CoT-based platform can be considered as a very promising solution for the fragmentation issues in the context of Smart Cities.

Several challenges related to the Cloud of Things in smart cities, from technical and privacy view arise:

Big Data. The overall IoT data produced by *things* is growing up fast, becoming really *big data*. Within this context, the challenges can be divided in two main categories [8], *engineering* in order to perform data management activities such as query, and storage efficiently; and *semantic*, in order to extract the meaning of the information from massive volumes of data.

Privacy & Security. Privacy and Security issues exist for a long time in the computing literature, and many law acts have been published to protect users [23]. Certainly the main problematic within the CoT context is to define mechanisms in order to let "sensor owners" the decision to publish or not the data. Other issues may come from the cybercrime, indeed the system can be prone to cyber-terrorism and cyber-vandalism.

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