

RESEARCH ARTICLE

Towards a smart city based on cloud of things, a survey on the smart city vision and paradigms

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ABSTRACT

Smart city represents one of the most promising, prominent and challenging Internet of Things (IoT) applications [1]. In the last few years, indeed, the smart city concept has played an important role in academic and industry fields, with the development and deployment of various middleware platforms and IoT-based infrastructures. However, this expansion has followed distinct approaches creating, therefore, 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 to offer a global common approach. To this purpose, this paper browses the semantic annotation of the sensors in Cloud, and innovative services can be implemented and considered by bridging Cloud of Things (CoT) and IoT. Things like semantic will be considered to perform the aggregation of heterogeneous resources by defining the CoT paradigm. We survey the smart city vision, providing information on the main requirements and highlighting the benefits of integrating different IoT ecosystems within Cloud under this new CoT vision. This paper also discusses relevant challenges in this research area.

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1. INTRODUCTION

Cities are growing steadily, and urban living poses major challenges in our daily lives. As of 2007, 50% of the world population was living in cities rather than rural areas. The United Nations Population Fund forecasts that by 2030 approximately 60% of the world population will live in an urban environment [2]. In this context, Information and Communication Technologies (ICT) together with local governments and private companies plays a key role for implementing innovative solutions, services and applications to make smart cities a reality. In this context, the Internet of Things (IoT) paradigm is playing a primary role as an enabler of a broad range of applications, both for industries and the general population. The increasing popularity of the IoT concept is also due to the constantly growing number of very powerful devices like smartphones, tablets, laptops and lower powerful devices like sensors that are able to join the Internet. In the context of smart cities, it makes sense to consider the scenario of the various different and 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 actu-

ation resources can be involved in Cloud, and solutions for the convergence and evolution of IoT and the Cloud computing infrastructures arise. Nevertheless, there are some challenges that need to be faced such as the following: (1) the interoperability amongst 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; and (4) heterogeneous resources mashup, namely how to orchestrate resources of 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 means of an horizontal integration of various silos. We will refer to this horizontal integration and to Cloud computing associated with the IoT as the Cloud of Things (CoT). As we will see, this concept goes beyond to the interconnection and hyperlink of things. In this paper, we will explain how abstraction, virtualisation and management of things have to be properly designed and implemented in order to develop solutions for the

convergence of diverse IoT platforms and Clouds. 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 CoT-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. A preliminary description of the VITAL platform has been presented in [3] and [4], where the authors just introduce the platform and CoT paradigm. In this work, we will give more details about the services that VITAL implements, and we will describe specific use cases where the VITAL platform plays a very key role. The paper is structured as follows: in Section II, we revise the literature regarding the IoT platforms. In Section III, it introduces the concept of CoT, starting from the traditional Cloud computing concept. In Section IV, it is devoted to present the main requirements of a city to be considered smart. In Section V, we consider both paradigms, the IoT and CoT, as potential effective solutions to make the cities smarter and more sustainable, based on the specific requirements individuated in Section IV. In Section VI, we describe the VITAL platform as a CoT-based platform and effective solution to be applied for the realisation of a smart city. In the Section VII, we give some practical examples of VITAL application, by defining some use cases. In Section VIII, we describe the main ICT actors that the deployment of a smart city implies. Finally, in Section IX, it concludes the paper by investigation open research directions.

2. IoT PLATFORMS

'The Internet of Things has the potential to change the world, just as the Internet did. Maybe even more so' [5]. 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 formally introduced IoT, according to which: '*from anytime, anyplace connectivity for anyone, we will now have connectivity for anything*' [6].

Since then, IoT starts to be a hot topic in academic and industry fields. Several European (EU) projects have been launched with the goal to provide solutions for the realisation of the IoT and its integration in different application domains. The main reasons behind this interest are the capabilities that the IoT will offer. It promises to create a world where all the *objects* around us are connected to the Internet and communicate with each other with minimum human intervention [7]. These potentialities make possible the development of a huge number of applications in different domains as shown in Figure 1 according to [8].

At the same time and together with the several IoT platforms, the middlewares started to gain more and more importance. Middlewares gained in the last years a lot of importance because of their major role in simplifying

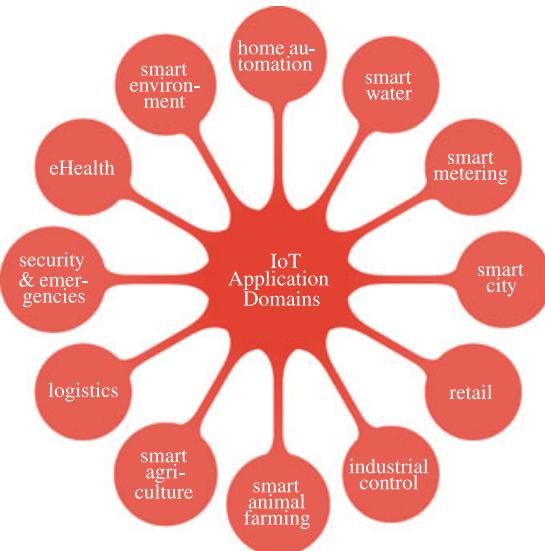


Figure 1. IoT application domains [8].

the development of new services and integration of legacy technologies into new ones [9]. In the following, we will present some of the most representative IoT platforms without pretending to be exhaustive:

GSN [10] (Global Sensor Networks) is a platform developed in Java, aiming at providing flexible middleware to address the challenges of sensor data integration and distributed query processing. It lists all the available sensors in a combo-box that users need to select the ones they need. GSN's purpose is to make the GSN applications hardware-independent and the changes and variations invisible to the application. The main limitation of GSN is that it lacks semantics to model the metadata.

LSM [11] (Linked Sensor Middleware) is a platform that brings together the live real world-sensed data and semantic web. It provides many functionalities such as wrappers for real time data collection and publishing, a web interface for data annotation and visualisation and a SPARQL Protocol And RDF (resource description framework) Query Language endpoint for querying unified linked stream and data.

Sensor-Cloud [12] is an infrastructure that aims at managing physical sensors by connecting them to Cloud. This infrastructure provides the service instances (virtual sensors) to the users in an automatic way at the same fashion as these virtual sensors are effectively part of the information technology resources. The generation of the services instances implies that the sensor devices and service templates (used to create the virtual sensors) should be firstly prepared. It uses sensor model language to describe the metadata of physical sensors. It just focuses on managing sensors via Cloud.

Open IoT [13] represents a joint effort of several contributors to IoT-based applications according to a Cloud computing delivery model. It concentrates on providing a Cloud-based middleware infrastructure in order to deliver

on-demand access to IoT services, which could be formulated over multiple platforms. Its middleware infrastructure permits to collect and filter data information from the Internet-connected objects, by means of opportunistic algorithms. It is strictly related to the FP7 VITAL project [14].

Xively [15] (formerly known as Cosm and Pachube) offers a public Cloud for the IoT that simplifies and accelerates the creation, deployment and management of sensor in a scalable manner.

As we will better explain, these approaches strengthen the vision towards the CoT, but a lot of new enhancements are still needed to realise a *CoT* platform for smart city.

3. TOWARDS CLOUD OF THINGS

Cloud computing attracts the attention from both academy and industry across the world, because it is capable of transforming service provision models over the entirely current information technology industry. It provides criterion for service provisions with reduced upfront investment, expected performance, high availability, tremendous fault-tolerance capability, infinity scalability and so on [16].

According to [17], the services can be divided in three layers (Figure 2):

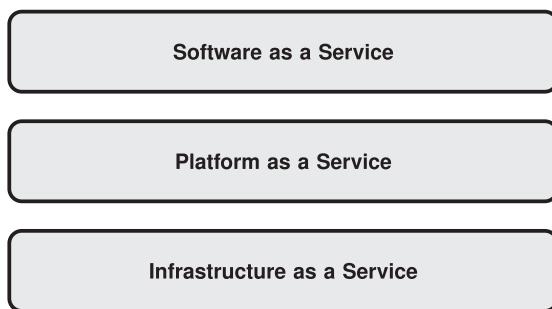


Figure 2. Cloud computing service models [17].

- *Infrastructure as a Service* that offers computing resources such as processing or storage.
- *Platform as a Service* designed for software developers, in order to allow them to write their applications according to the specifications of a particular platform without needing to worry about the underlying hardware infrastructure.
- *Software as a Service* is the most visible layer of Cloud computing for end-users, because it is about the actual software applications that are accessed and used.

In addition to the aforementioned main layers, some others are also introduced and discussed in literature such as Data as a Service, Network as a Service, Identity and Policy Management as a Service and so on. In [18], authors introduce XaaS (everything as a service model) that promotes the "*pay as you go*" method, allowing the consumers to consume a service from a service provider by paying only for the amount of resources they actually use. Within the IoT context, this approach gave the input to the so-called *CoT* [19], which deals to implement indexation and querying services of *things* and provides them to final users, developers and providers, as a service (Figure 3). One interesting model to enable CoT is comprehensively discussed by authors in [20]. They focus indeed, on the *Sensing as a Service* model based on IoT infrastructure, which introduces four conceptual layers:

- *Sensor and Sensor Owners Layer* that consists of sensors and how the owner manages them, allowing or not, the publication in Cloud.
- *Sensor Publishers* who detect available sensors, communicate with the sensor owners and get permission to publish sensors in Cloud.
- *Extended Service Providers* who communicate with multiple sensor publishers in order to select sensors based on costumer's requirements.
- *Sensor Data Consumers* who need to register themselves in order to consume sensors data.



Figure 3. Cloud of Things.

The advantages and benefits promised by the *Sensing as a Service* model are numerous, and just to name the majors, we have the following: *sharing and reusing of sensor data* (if someone has already deployed the sensors, others can have access to them by paying a fee to the sensor owner), *reduction of data acquisition cost* due to the shared nature and *collect data previously unavailable* (thanks to the business model, companies are stimulated to ‘sell’ their sensors data).

In the last few years, researchers have mainly focused on representing the observation and measurement data from sensor networks, according to the sensor web enablement proposed in [21] by the Open Geospatial Consortium. However, these standards do not provide facilities for abstraction, categorisation and reasoning rather offered by [22], within the World Wide Web Consortium Semantic Sensor Network Incubator group defined a Web Ontology Language2 [23], answering the need for a domain-independent and end-to-end model for sensing applications by merging sensor-focused (e.g. Sensor Model Language [21]), observation-focused and system-focused views. It has received consensus from the community and has been adopted in several projects like Spitfire EU Project[†].

Regarding the heterogeneity in communications technologies, interesting solutions for resource-constrained devices (e.g. sensors) are provided by IPv6 over Low power Wireless Personal Area Networks (LoWPAN) [24] and Constrained Application Protocol (CoAP) [25].

6LoWPAN enables the integration of sensors to the Internet, thanks to mechanisms that allow transmission of Internet Protocol (IP)v6 packets. In order to convert IPv6 packets to 6LoWPAN and vice versa, a gateway (i.e. border router) is required. It handles the necessary tasks such as header compression and enables the seamless usage of IPv6 across the heterogeneous network architectures. 6LoWPAN has been developed in an early stage for the TinyOS, Contiki and FreeRTOS operating systems for wireless sensor networks [26].

Constrained Application Protocol is an application layer protocol designed for energy constrained devices. It deals with Constrained Representational State Transferful Environments [27], providing a lightweight alternative to Hypertext Transfer Protocol (HTTP). Devices supporting CoAP provide flexible services over any IP network using User Datagram Protocol. Any HTTP client or server can interoperate with CoAP-ready endpoints by simply installing a translation proxy between the two devices [28].

Summing up, IoT devices can be connected to the Internet; their data can be annotated using a sensor ontology [i.e. semantic sensor network (SSN) ontology], can be encoded in standard web formats (i.e. RDF) and can be made available in Cloud, establishing therefore the *CoT*.

4. SMART CITY REQUIREMENTS

Before to relate the IoT and CoT paradigms to what is considered as a very emerging and important application domain, namely Smart City, it is useful to identify the main requirements, in terms of ICT-based services and solutions that a city presents. To this purpose, by following the same approach introduced in [29], we make reference to two different types of requirements that are as follows: (1) *service/application*, considered from the point of view of the citizens and (2) *operational*, seen from the city authorities and administrators of the networks viewpoint. Concerning the *service/application* aspects, the end-users devices equipped with multiple radio technologies and several 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 the following: (1) *user-centric*: based on the specific context and preferences of the users; (2) *ubiquitous*: reachable everywhere and from any devices; and (3) *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, health care and public safety providers, governmental organisations and so on 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 network providers are translated into a network infrastructure that is as follows: (1) *highly-interconnected*: by overcoming the heterogeneity of the devices and the IoT platforms, it is possible to provide ubiquitous connectivity; (2) *cost-efficient*: the deployment and organisation of the network should be as much automatic as possible and should be independent from human intervention; (3) *energy-efficient*: able to realise an efficient resource utilisation, in order to meet the main requirements of *green* applications; and (4) *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 characterised with a high level of *fragmentation* of technologies and lack of ubiquity in terms of both connectivity and coverage, due to the plethora of technologies and devices present in a city. This *fragmentation* is mainly due to the presence of many access networks usually managed by different operators (i.e. Universal Mobile Telecommunications System and Worldwide Interoperability for Microwave Access—WiMAX, WiFi etc.). Even if some steps ahead have been moved, thanks to some projects, most of these initiatives are related to specific cities and do not consider general architectures. By considering the main IoT platforms and CoT concept, we will try to explain how the main requirements of a city to become a smart city can be fulfilled,

[†]<http://spitfire-project.eu>

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 take advantage from the IoT platforms, the smart city concept received in the last few years a significant research effort and technological development. The most notable reason for these attentions is attributable to the population growth and urbanisation trend. According to the United Nations, the urban populations will grow to an estimated 2.3 billion over the next 40 years, whilst as much as 70% of the world's population will live in cities by 2050. 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 emission. 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 [30].

Although there is not a formal and universally accepted definition of 'Smart City' yet, in [31], authors try to delineate the concept, defining a smart city as a city that functions in a sustainable and intelligent way, by integrating all its infrastructure and services into a cohesive whole and by using intelligent devices for monitoring and control, to ensure sustainability and efficiency. This interpretation makes evident, therefore, that smart city concept (Figure 4) needs *interoperability* between the different IoT deployments that are, today, mainly closed and vertically integrated to specific application domains [32].

These solutions are, indeed, based on multiple architectures, standards and platforms, which have led to a highly fragmented IoT landscape and make challenging the realisation of smart city concept. According to [33],

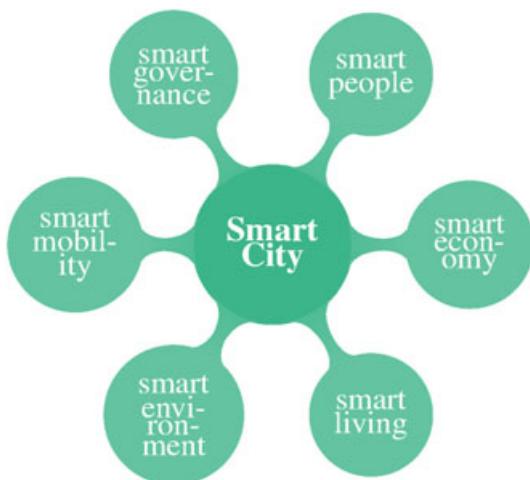


Figure 4. Smart city concept.

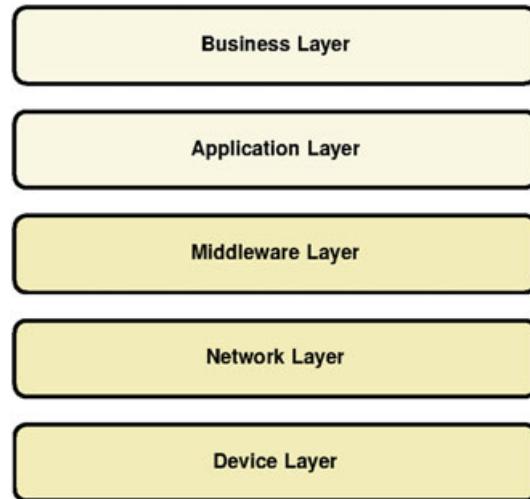


Figure 5. The IoT architecture [33].

we can recognise the IoT structure divided into five layers (Figure 5):

- *Device Layer* that deals with the identification and collection of objects specific information by the sensor device;
- *Network Layer* used to send data collected by the device layer to the information processing system;
- *Middleware Layer* that performs information processing and ubiquitous computation and takes automatic decision based on the results;
- *Application Layer* that provides global management of the application based on the information processed through Middleware;
- *Business Layer* that is responsible for the management of overall IoT system.

Within the context of smart city [34], the *CoT* is expected to play a significant role. *CoT* indeed, can make better use of distributed resources, puts them together in order to achieve higher throughput and be able to tackle large scale computation problems [35], enabling therefore, the horizontal integration of various (vertical) IoT platforms and so the smart city vision. Moreover, it allows users to express the service they want providing the relevant data back to them quickly without asking the users to manually select the sensors that are relevant to their requirement.

Certainly, *CoT* needs to deal with several challenges, but the major in terms of research regards the heterogeneity in sensor types [e.g. temperature, near field communication (NFC) and radio frequency identification (RFID)] and protocols and communications technologies (e.g. Wi-Fi and ZigBee), interoperability among different sensors hardware and cloud solutions. It is therefore important to define an *abstraction level*, in order to bridge the gap between the disparate technologies. Regarding the various sensor type, the use of the technologies developed in the semantic

web [36] such as ontologies, semantic annotation, linked data [37] and semantic web services has recently gained momentum in this field. These technologies promote interoperability among IoT resources, information models, data providers and consumers and simplify effective data access and integration, resource discovery, semantic reasoning and knowledge extraction[38].

6. VITAL AS A CoT-BASED SMART CITY PLATFORM

One of the most important objectives of VITAL is about the integration of inter-connected objects (ICOs) among multiple IoT platforms and ecosystems. The project explores the convergence and federation of multiple IoT platforms by taking account of cost efficiency of the deployments. In the context of VITAL, a very key factor is represented by the virtualisation of interfaces that in combination with cross-context tools that enable the access and management of heterogeneous objects supported by different platforms and managed by different administrative stakeholders let us define the VITAL platform as a CoT architecture. In Figure 6 we show an overview of the VITAL platform.

As we can observe in Figure 6, the data and services access of the heterogeneous objects involved in VITAL are based on the implementation of the Virtualized Universal Access Interfaces (VUAI)s 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 Cloud platforms and enables heterogeneous mashup. The VUAI's 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' paradigm. In this sense, the VITAL as CoT platform is something that goes beyond the interconnection and hyperlinking 'things' of the IoT paradigm. VITAL also includes a datastore 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 optimisation 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 and etc.). Moreover, the CoT concept explicitly has to consider mechanisms to abstract, virtualise and manage things as performed in VITAL. It is worth outlining that VITAL is

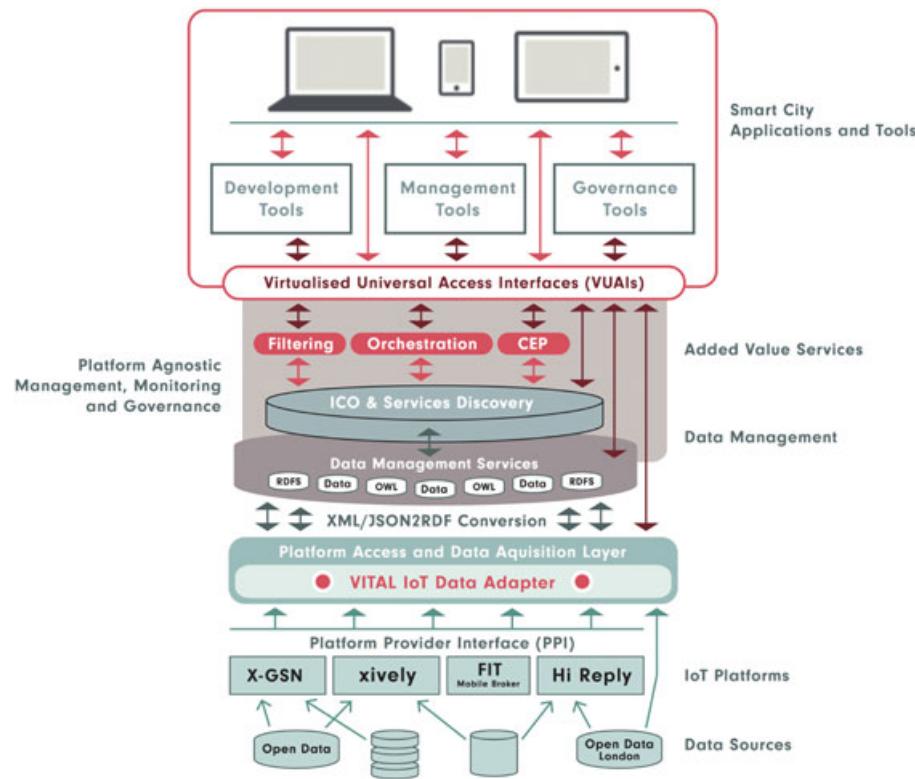


Figure 6. VITAL platform.

Table I. VITAL ontologies

Prefix	Ontology-language	Namespace
dcn	Delivery context ontology	http://www.w3.org/2007/uwa/context/deliveryContext.owl#
dul	DOLCE+Domain Name System (DnS) ultralite ontology	http://www.ontologydesignpatterns.org/ont/dul/DUL.owl#
geo	Basic Geo (World Geodetic System 84) ontology	http://www.w3.org/2003/01/geo/wgs84_pos#
hrest	hRepresentational State Transfers ontology	http://www.wsmo.org/ns/hrests#
msm	Minimal service model ontology	
owl	Web Ontology Language	http://www.w3.org/2002/07/owl#
rdfs	RDF schema ontology	http://www.w3.org/2000/01/rdf-schema#
sawsdl	Semantic annotations for Web Service Description Language and XML schema ontology	http://www.w3.org/ns/sawsdl#
ssn	Semantic sensor network ontology	http://purl.oclc.org/NET/ssnx/ssn#
time	OWL time ontology	http://www.w3.org/2006/time#
vital	VITAL ontology	http://vital-iot.com/ontology#
wsl	Web service modeling ontology-lite ontology	http://www.wsmo.org/ns/wsmo-lite#
xsd	XML schema definition	http://www.w3.org/2001/XMLSchema#
qudt	Quantities, units, dimensions and data types ontologies	http://qudt.org/schema/qudt#
foaf	Friend of a friend	http://xmlns.com/foaf/
s4ac	Social semantic SPARQL (SPARQL Protocol And RDF Query Language) security for access control	http://ns.inria.fr/s4ac/v2#
otn	Ontology of transportation networks	http://www.pms.ifilmu.de/reverse-wga1/otn/OTNOTN.owl

XML, Extensible Markup Language; RDF, resource description framework; DnS, Descriptions and Situations; DOLCE, Descriptive Ontology for Linguistic and Cognitive Engineering.

based on World Wide Web Consortium SSN ontology that is considered ideal as a basis for unifying the semantics of different IoT platforms, because 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 and so on. The ontology update with additional functionalities will allow the migration of smart city application across different urban environments.

6.1. VITAL ontologies

The main challenge of VITAL is to integrate in a platform agnostic way a multitude of heterogeneous data and functionalities produced and offered by different sensors and IoT systems managed along by disparate (independent) organisations and entities. This can be achieved, thanks to linked-data functionalities, which aim to describe and integrate data provided by different organisations in an interoperable way [39]. VITAL indeed relies on linked-data standards (i.e. RDF, JavaScript object notation for linked data and ontologies) for modelling and accessing data; in particular, ontologies are used to specify data formally. As shown in Table I, we reuse as many ontologies as possible, while new ontologies need to be exploited to model relevant smart cities entities and for describing the VITAL system itself.

The VITAL ontologies can be grouped into four main areas—sensors and sensor measurements, smart cities, IoT systems and services, VITAL systems and services that we describe in the following.

Sensor and sensor measurements represent a crucial part of the VITAL data model. Many ontologies have been

already developed in the field and are based on multiple layers of abstraction [40]. It is important to clarify that because there are many application-specific cases, it is impossible to specify a single ontology that defines the semantics of all possible data items. VITAL combines several ontologies. It uses SSN [22] as a generic sensor ontology because it permits to describe sensors, including their accuracy and capabilities, observations, methods for sensing, concepts for operating and survival ranges and deployments. Beyond this, in order to describe other basic concepts like time, location and unit of measurement, VITAL uses well-known ontologies [41–43].

Smart cities have many capabilities that must be modelled as part of a smart city ontology. According to the VITAL use case as defined in Section 7, the most relevant producers of data come under the following headings:

- *transport* - for example dynamic route calculation informed of accidents and congestion;
- *energy* - for example reporting of faults;
- *emergency services* - for example detection of accident and crimes;
- *waste management* - for example detection of full bins;
- *air and water* - for example reporting of air and water pollution;
- *recreation* - for example produce data on large events such as concerts to inform public transport.

The majority of the VITAL semantic information on cities are obtained via the classic databasepedia[‡] dataset.

[‡]<http://dbpedia.org/>

However, modelling smart transport is a non-trivial task because it covers a wide range of domains (e.g. tracking pedestrian congestion, smart traffic light systems etc.). Therefore, VITAL uses, again, a combination of ontologies, and the core of them are the ontology for transportation networks [44] that allows an easy modelling of a transport network graph with connections between infrastructures (e.g. bus) and dynamic events such as accidents and blocked passages. It is important to emphasise that VITAL is not restricted to smart transport scenarios; a user who would like to adopt VITAL for other smart city aspects can do so by specifying additional ontology elements. Thanks to the nature of linked data indeed, additional elements can be added at any time without the need to redesign the whole system.

The integration of heterogeneous IoT systems and services represents another challenging point for the VITAL consortium. In order to model them, and in particular, the four platforms so far chosen—GSN [10], Reply H1, Future Internet of Things IoT-lab [45] and Xively [15]—VITAL uses the SSN ontology. In this way, an IoT system is modelled as a subclass of *ssn : System* with a number of additional properties (e.g. operator, status etc.). In addition, an IoT system may specify a set of *IoT services* offered.

Above the IoT systems aforementioned, we need also to model the VITAL system itself and its services. From the semantic point of view, a VITAL system is similar to an IoT system; therefore, we decided to model it as a subclass of *IoTSystem*.

7. VITAL'S USE CASES

In this section, we describe a potential VITAL use case, where the concept of the different services that characterise VITAL (i.e. discovery, filtering, orchestration and complex event processing (CEP)) plays a key role. Note that more use cases are available on the project web sites and in the project deliverables.

7.1. Use case 1: VITAL for smart street management

An effective management of the roads would make easier the citizens' life and would also have an economic impact. Just as an example, we could consider public lighting management, which represents a significant source of energy wasting. In this context, the VITAL platform 'reinterprets' every light source (each equipped with sensors) as an ICO. The VITAL services (e.g. discovery, filtering, orchestration and CEP) allow an efficient management of the information, through the interconnection of data originated from different Clouds. This intelligent manipulation of the data will be exploited in several ways such as the following: (1) it will be translated in 'actuation' for an automatic regulation of the luminous intensity; (2) it will be used to infer useful information such as the actual schedule of public transportation (e.g. if a bus is incoming and the exact number of the bus); (3) it will be

used for the intelligent management of the trash containers (e.g. if a trash container has to be emptied), and so on. Concerning the intelligent management of the trash container, the VITAL platform could be very effective. In fact, the *discovery* of the areas where the trash containers are deployed, and the *filtering* of the zones where an immediate intervention is necessary (e.g. a trash container that needs to be emptied), represent just an example of intelligent and dynamic manipulation and actuation deriving from the VITAL architecture. From this very simple use case scenario, it is also possible to understand that data in Cloud could help the stakeholders, by redefining the deployment of the trash containers dynamically. In practice, the concept of services as defined in the VITAL platform is to allow the manipulation and management of data coming also from zones that are geographically far to each other through the definition and implementation of complex algorithms.

7.2. Use case 2: VITAL for smart traffic management

In the last years, the technological advancements allowed a very deep diffusion of complex Global Positioning System (GPS) navigators. Several drivers make use and exploit these tools that give very valuable information on the traffic conditions also in real time. They are also very valuable in the case of accidents alerts. Anyway, also in this context, the VITAL platform, through the definition and implementation of its CoT paradigm, is able to play a key role. Let us refer to a scenario where an accident is broadcasted/'alerted' (e.g. through the use of a GPS navigator). Normally, after such an alert occurs, the 'minor' roads are taken as viable alternative solutions, with the side effect that they will be soon overcrowded. Moreover, this type of navigators do not take special events into consideration, such as concerts or festivals. The elaboration of data coming from different ICOs allows a smarter elaboration of different kinds of information. In this sense, the VITAL platform does not limit its 'intervention' to a simple alert and alternative roads, but the VITAL services will output alternatives that consider many different 'aspects', and the final user will play an active and aware role by choosing based on different type of information.

8. TECHNOLOGIES

Deploying a smart city is a multi-disciplinary task that involves various stakeholders from different thematic areas like politics, finance, city management and organisation and ICT. From the ICT perspective, the number of devices, technologies and standards involved is huge; therefore, it is necessary to have an overall view. In the next subsections, we summarise the main technology's actors.

8.1. Devices

Sensors represent an essential component of any intelligent control system. Thanks to technology advances today,

a multitude of different sensors is available, enabling applications that were unimaginable in the past. From the perspective of the requirements for smart cities, wide availability of these technologies translates to a large number of opportunities in terms of sensing, that is, meters to determine gas, electricity, water and so on. Sensor nodes are usually scattered in a sensor field; each of these scattered sensor nodes has the capabilities to collect data and routes data back to a special node called *sink* by a multi-hop infrastructureless architecture [46]. Currently, most of commercial wireless sensor networks are based on the IEEE 802.15.4 standard, which defines the physical and Medium access control (MAC) layers for low-power, low bit-rate communications in wireless personal area networks. However, IEEE 802.15.4 does not include specifications on the higher layers of the protocol stack, which is necessary for the seamless integration of sensor nodes into the Internet [9]. The role of sensor network (SN) in the IoT is crucial and well examined in [7], wherein authors point out on the relation between IoT and sensor networks: *SN can exist without the IoT; however, the IoT cannot exist without SN.*

Smartphones represent another interesting sensing scenario. Indeed, the ever increasing number and presence of a mixture of sensors such as GPS, gyroscopes, accelerometers and compasses, enabling a variety of crowd-sourcing applications, which will eventually be augmented by the IoT. For instance, as users regularly update their location status on social networks like Twitter and Facebook, based on this location information, it is possible to aggregate this data, enabling tasks to be dispatched to people in specific locations [31].

Regarding to short range communications, two interesting technologies in the smart cities context are RFID and NFC.

RFID is a method of identifying unique items using radio waves. Typical RFID systems are made up of two major components: *readers* and *tags*. The reader sends and receives radio frequency data to and from the tag via antennas. The tag is made up of the microchip that stores the data, an antenna and a carrier to which the chip and antenna are mounted [47]. RFID can be used to develop a large number of smart city applications, to name a few: smart parking [48], traffic monitoring [49], library management [50], transportation tickets and so on.

NFC is a contactless wireless communication technology based on RFID and Internet technologies [51]. It supports the communication within 20 cm, and it represents a prominent technology in the smart city scenario, enabling a range of applications in order to make people's life more convenient and fast, that is, the digital wallet introduced in [52] or building access control.

8.2. Networking

Integrating resource-constrained devices into the Internet is difficult because ubiquitously deployed IPs such as HTTP,

Transmission Control Protocol or even IP are too complex and resource-demanding [53].

6LoWPAN [24] defines mechanism that allows the transmission of IPv6 packets. CoAP [25] is an application layer protocol designed for energy constrained devices. It deals with Constrained Representational State Transferful Environments, providing a lightweight alternative to HTTP. CoAP and 6LoWPAN allow sensor nodes to be integrated into the web, through the use of proxies for HTTP to CoAP conversion.

However, the short range transmission problem still exists. Regarding the link layer, smart city system requires a set of link technologies that can easily cover wide geographical area and support, at the same time, a possibly large mount of traffic.

9. CONCLUSION AND 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, various IoT Clouds and several IoT applications and services have resulted in different and heterogeneous IoT ecosystems that introduce a significant degree of fragmentation. 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 realisation of an horizontal integration of various vertical platforms. Through the implementation of a specific virtualisation level, the VITAL platform in the context of the correspondent FP7 EU project, ensures the semantic interoperability of various and different IoT platforms. The VUAI implement 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.

There are different challenges related to the CoT in smart cities, from both technical and privacy points of view.

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 [54], *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 and Security. Privacy and security issues exist for a long time in the computing literature, and many law acts have been published to protect users [16]. Certainly,

the main problematic within the CoT context is to define mechanisms in order to let the decision to publish or not data to ‘sensor owners’. Other issues may come from the cyber-crime; indeed, the system can be prone to cyber-terrorism and cyber-vandalism.

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