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The advantages of IoT and Cloud applied to Smart Cities

ClouT User Scenarios and Reference Architecture

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***Abstract*—The European Commission and the Japanese National Institute of Information and Communication Technologies (NICT) have made a big effort to promote collaboration between the IoT and Cloud communities and define a common baseline for future research. ClouT (Cloud+IoT) project is co-funded as part of the first FP7 EU-Japan cooperation call and gives life to a fruitful collaboration between six European and seven Japanese organizations. The overarching objective is to provide enhanced solutions for smarter cities by using cloud computing to overcome some of the current challenges and limitations in the IoT domain. Through the combination of IoT and cloud computing, smart cities will be able to build new and enhanced services by using the large amounts of data stored in the cloud and by processing it in quasi-real time. This paper describes ClouT Reference Architecture which was outlined by leveraging on existing works performed by established IoT and cloud Research Communities both in Europe and Japan. ClouT Reference Architecture establishes a common ground of objects, definitions and rules mapping the IoT and cloud advantages into a unique context.**

Keywords—Cloud; IoT; Architecture; user scenarios

I. INTRODUCTION AND MOTIVATIONS

The concentration of the world population in urban areas is increasing and puts the cities in the spotlight. Indeed, on 2% of the earth's surface, cities actually use 75% of the world resources [3]. These aspects inevitably make the cities important actors for the world's sustainable development strategy.

ICT has the potential to help cities to respond to the growing demands of more efficient, sustainable, and increased quality of life. Some effort is being made by the European and Japanese governments to apply ICT in the cities transforming them into Smarter Cities.

The last big improvements in the technology of sensors and actuators enable to sense many physical events and to perform more and more complex actions. The data flow related to these activities introduces several challenges regarding the storage of large amounts of data, secure access, data exploitation and application.

Interesting opportunities to address these challenges are provided by two research paths:

- **Internet of Things** (IoT), which is the set of technologies enabling the interconnection of objects by uniquely identifying them in the network. These objects can be provided with sensors or actuators and can easily make information available or perform complex actions.
- **Cloud Computing**, which provides a flexible virtual execution environment for processing any application over a potentially infinite number of resources, scaling up and down accordingly to usage behaviours. The cloud paradigm enables also new economical models based on the pay-per-use that reduces initial investments and operational costs.

The merge of these two paradigms will provide the following main benefits:

- **Economic dimension: new business models to boost economical growth in cities**. According to several market surveys, in the next decade the number of interconnected devices may reach a trillion very easily: furthermore the adoption of Wireless Sensor Actuator Networks (WSAN) will enable cost reduction and flexibility in system installation, easing the development of new applications. For these reasons, a cloud based model, that accelerates the time-to-market of innovative solutions by Public Administrations and companies, will reduce investment risks and provide factual benefits.
- **Societal dimension: increasing quality of life of citizens.** A great challenge of current City managers in EU and in Japan is to improve the

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I Introduction

ICT can contribute to a better quality of life for individuals.

IoT is the interconnectivity of different devices that are uniquely identified in the network. Those devices are often composed of sensors and actuators to collect data and perform actions

This paper emphasizes the concept of combining IoT and Cloud because cloud solutions bill depending on the amount of resources used and offer a scalable infrastructure which is important since the amount of connected devices rises significantly.

quality of life of citizens despite the increasing population in the urban environments. An approach combining cloud and IoT will enable smart cities to take optimal advantage of the data produced by billions of networked devices and millions of people. New and enhanced services will be enabled, empowered by the use and process of large amounts of data stored in the cloud.

ClouT Reference Architecture combines cloud and IoT technologies: this document describes its consolidated and final version. It starts by describing a set of User Scenarios that have been analysed by ClouT partners and that set the scene of the application contexts. Through the analysis of the selected User Scenarios and the experience of the partners involved in the project, which include four pilot cities: Genova (Italy), Santander (Spain), Fujisawa and Mitaka (Japan), a set of User/Service Requirements and System Requirements were collected.

The overall system must guarantee scalability, availability and capability to react to load peaks. The sensors, including legacy devices, must communicate in a common data format regardless of the actual kind of data (from images to temperature). Data replication and backup must be available and security and good performances need to be guaranteed.

To meet such requirements, the resulting ClouT Reference Architecture is cloud centric, i.e. IoT features are supported by modules based on the three cloud layers, IaaS, PaaS and SaaS.

The architecture defined is finally mapped to real world scenarios conceived to involve all the modules and to show their functionalities.

Finally, some considerations are presented to demonstrate how ClouT approach, by combining IoT, Social Networks, Open Data and cloud, is an efficient and cost-effective answer which enables even small cities to become Smart.

II. Related Work

This work integrates the following concepts:

- *Sensor virtualisation*, that is the capability to integrate pieces of information coming from different physical sensors and use them as if they were produced by a single, **virtual** sensor.
- *Sensorisation*, that enables the use of mobile devices, social networks, web pages, and any kind of *information producer* as if it was a sensor.
- *Cloud*, that enables to store and compute a virtually unlimited amount of information.

Interesting papers were produced in the three domains and were taken into consideration when developing ClouT Reference Architecture. In particular, concerning sensor virtualization, in [6] the data acquired by a set of sensors are collected, processed according to an application-provided aggregation function, and then perceived as the reading of a single virtual sensor. It uses logical neighborhoods that are intended as neighborhoods associated with a higher-level, application-defined notion of proximity. In [7] it is proposed the Sensor-Cloud Infrastructure for virtualizing a set of physical sensors as a virtual sensor on the cloud computing, thus allowing users to create and use sensors without worrying about the location and the specifications of physical sensors. In [8] users are enable to automatically and dinamically add or remove physical sensors from a virtual sensor according to needs of the applications.

Concerning sensorisation, the main effort has been focused on the automation of the process of *sensorized* information sources. [14] and [10] are strictly related to the architecture proposed in sensorizer components. [13] and [15] show how semi-automatic wrapping techniques basically infer the extraction rule, and leverage human knowledge to supervise the results by providing examples or revising patterns. [11] and [15] describe some automatic wrapper generation techniques that totally remove any human effort.

In ClouT cloud computing is used to provide flexibility, elasticity, scalability and standard compliance in computing and storage. The ClouT Reference Architecture is cloud based and has been designed starting from ideas coming from consolidated work produced in other contexts. The most relevant reference architectures taken into consideration are [18] in the cloud context and [19] in the IoT one. Furthermore, with regards to the cloud Storage, which is of paramount importance considering the amount of data that a smart city produces, Vision Cloud [16] has obtained some interesting results that were taken into account, such as metadata management. Finally, the Cloud Data Management Interfaces specification plays an important role in ClouT to guarantee openness also for third party applications [17].

III. User Scenarios

This section contains the description of the actors and the user scenarios analysed within the ClouT project and that motivate the ClouT Reference Architecture. The objective of this work is to highlight those aspects and technologies of the cloud computing model that can tackle some of the challenges the IoT paradigm has to face. The combination of cloud and IoT may, in this way, improve the effectiveness of a Smart City architecture. All the results are based on real needs extracted directly from the scenarios within the pilot cities.

A. Involved actors

All the use cases presented in this section involve actors that are users or service providers in the context of a Smart City. In particular, the involved actors are:

- **Citizens**, which are users of ClouT applications and ClouT data. Additionally they can interact with ClouT by collaborating with their portable devices. They can use ClouT applications or can provide data by Social Networks such as *sensorized devices*.

- **Municipalities,** which, like common citizen, can be users of ClouT applications, they can also directly access ClouT Platform services, such as the Storage, to view raw data or provide special services.
- **Developers**, which can leverage ClouT Platform or Infrastructure capabilities to develop innovative services for Citizens and Municipalities.
- **System Administrators and Infrastructure Providers**, which own the required infrastructure and provide the related functionalities in an optimized way.

The involved actors are interested in different kinds of services and do not need to be familiar with all the layers of the architecture: in particular Citizens and Municipalities are mainly interested in applications, Municipalities may be also interested in Platform Services, that can be also useful for Developers, that, by leveraging them and the Infrastructure managed by System Administrators, produce applications.

A layer based architecture enables actors to have the visibility only of the service set they are interested in.

B. *Smart Cities Applications and High Level User Scenarios*

Table 1 shows the list of categorized user scenarios, in particular the six scenarios are classified in three categories:

Category	User Scenario ID	User Scenario
Smart City Resource Management	SCRM_1	Traffic Mobility Management
	SCRM_2	IoT Device Sharing and Composing
Safety and Emergency Management	SEM_1	City Safety and Accident Management
	SEM_2	Weather Risk and Alert Management
Citizen Health and Pleasant Enhancement	CHPE_1	City Event Finder
	CHPE_2	Citizen Activity Enhancer

Table 1: ClouT User Scenarios

- **Smart City Resource Management** (*SCRM*), in which it is shown how to manage several heterogeneous resources (sensors, actuators, smartphones, cars, bus etc.) in a unified manner to share information and to improve the efficiency of a Smart City.
- **Safety and Emergency Management** (*SEM*), in which ClouT approach is used to minimize the risks due to natural events (weather, earthquakes etc.) or accidents (due by traffic, crime etc.) by combining data coming from sensors and people (acting as human sensors).
- **Citizen Health and Pleasant Enhancement** (*CHPE*), with the purpose to inform and motivate citizens to take part in public events (cultural, sports etc.) in the city, by collecting and classifying information coming from citizens and the municipality.

Each user scenario defines an associated application which is described by detailing the building blocks and the involved actors. Finally, the objectives and challenges, which are the reasons for considering these applications as pilots for ClouT, are highlighted.

The *smart traffic mobility management* (Figure 1) concept is considered as one of the solutions that would enable citizens and visitors to get access to enhanced urban mobility experience and to leverage city transportation resources efficiently. The availability of a great amount of information associated to the use of public transportation currently fosters the improvement of this concept.

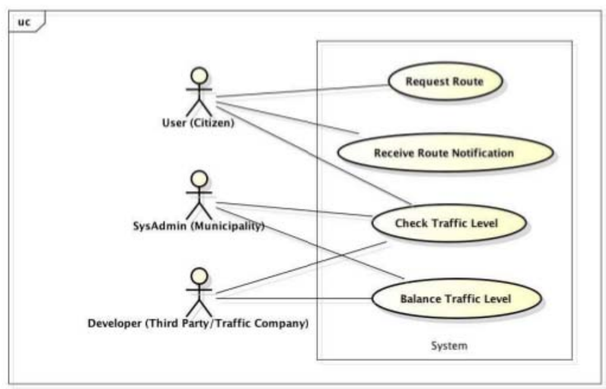

Figure 1 Traffic Mobility Management

All the information about public transportation in real time will be leveraged and combined in a single application. This application will also contain information on available taxis, available public cycles or specific friends' routes and traffic. All this data can be also combined with information regarding traffic parameters, such as speed, occupancy degree, as well as with environmental indicators such as CO 2, NO2, O3 and noise.

The information comes from heterogeneous data sources, such as sensors, social networks or webcams: it is suitably processed and provides the users (according also to their preferences) recommendations on the best route towards their

There are different scenarios that demonstrate the advantages of IoT in Smart Cities:

(See listed above)

destinations, alerts about traffic, availability of parking places in public car parks. It also provides an enhanced public transportation experience which dynamically adapts to the user's requirements and takes into consideration urban traffic conditions.

The use case diagram in Figure 1 shows how Citizens can request optimized route for travelling in the city, and the application sends results of the selected route. The SysAdmins or the Developers such as the Traffic Company can check the traffic condition in the city, so that they can understand the dynamicity of the city in real-time. In addition, they can control traffic level by controlling various actuators in the city such as traffic lights. If it is difficult to reduce traffic level only by controlling such devices, the Municipality or the Traffic Company can make a decision to increase or decrease the offered transportation service (e.g. sending off additional buses in crowded areas). Through this scenario, the city can enhance manageability of city transportation resources, and citizens can use the traffic resources efficiently.

The second User Scenario of Table 1 is focused on *IoT Device Sharing and Composing*. By sharing IoT devices owned by end-users, we can easily increase the sensing and actuation scope in a city. This can allow collaborative detection of important city events or the provision of more precise information by exploiting the multi-source information coming from various devices. This user scenario provides the sharing function of IoT through the cloud computing platform.

As shown in Figure 2, Users, SysAdmins and Developers can freely share their devices and use shared devices by protecting their security and privacy. They can get sensor data from shared devices, or control actuators such as street light with appropriate accessibility rules. In addition, composing functions for using data coming from multiple shared IoT devices are provided: SysAdmins and Developers can define a set of shared devices as virtual and composite IoT devices.

Thus, it will be easy to manage and create their original smart city applications with this use case.

Besides, the municipalities can also monitor the physical devices (sensors, actuators, gateways, but also infrastructure components) by using this functionality. In particular the SysAdmin can watch and map all the sensors and actuators in order to have a complete view of the current status of the IoT devices.

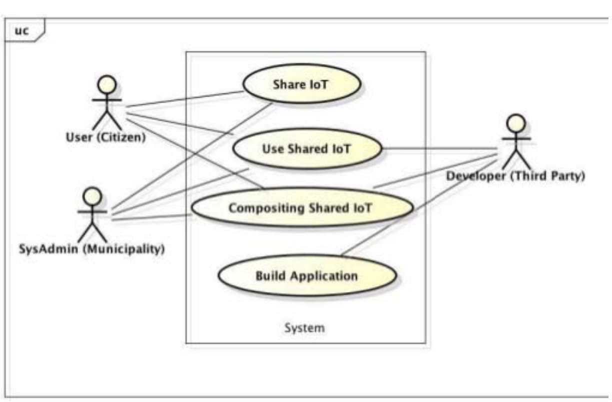

Figure 2: Device Sharing and Composing

An overview of what is happening inside the devices can also prevent potential failures: in this way it is possible to avoid physical gateways overcomitting that could disrupt data gathering and communication between the connected devices and all the related services.

Such monitoring capabilities can be extended to virtual and composite IoT devices via custom monitoring scripts that are capable of sending alerts if errors occur. This kind of tools are necessary in order to manage a complex system with many devices connected.

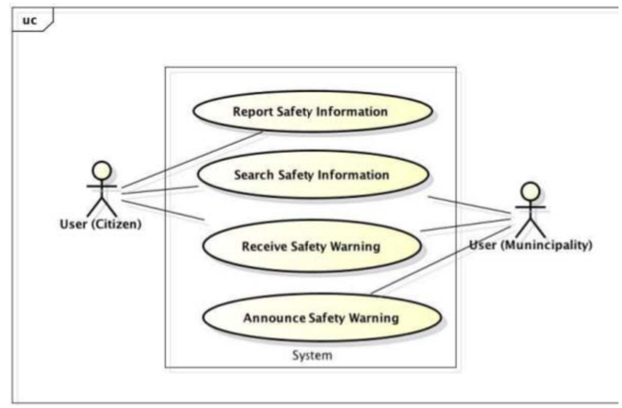

Figure 3: City Safety and Accident Management

The user scenario shown in Figure 3 is about *City Safety and Accident Management* and concerns non-natural risks. The Citizen can search for safety information such as criminal information in the city. In addition, the Citizen can act as human sensor (participatory sensor) which reports actual accident or self-feeling about risks in the city. Another important risk factor is traffic accidents such as car accidents (both car-car accident and car-human accident): this may have a very high risk factor, for example in narrow roads where both people and cars can go throughp, which is very common situation in Japan, but also in some European cities. This user scenario takes care of such situations by including use cases in which alerts to pedestrians are sent in order to take care of passing cars detected by the system. At the same time, car drivers can also learn of the existence of pedestrians in the same street. The status of the street is detected by various sensors and street lights and smartphones can be used to control the traffic and send alerts.

The user scenario described in Figure 4, *Weather Risks and Alert Management*, concerns risk management for natural accidents such as typhoons, earthquakes, heavy spot-raining and so on. Risks are calculated on the basis of two kinds of data sources – participatory sensing and IoT devices. Thus citizens can report weather conditions by using their smartphones (text and photo/video media). In addition, users can both search for information on weather risks and receive "push" warnings from the service.

In addition to these basic functions, the scenario enables municipalities to set original participatory sensing tasks which can ask citizens to report the current situation by using a questionnaire format. Thus, the system can alert risk information in real-time.

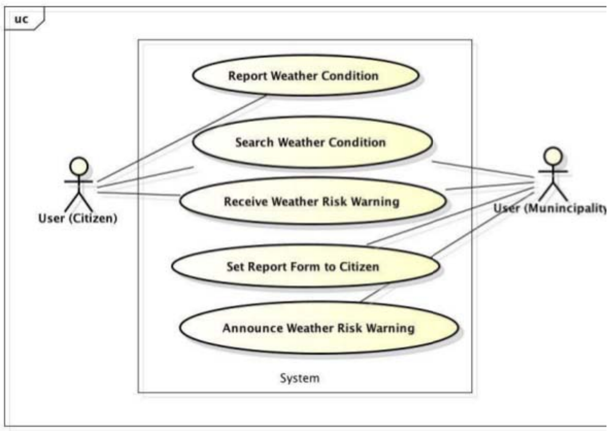

Figure 4: Weather risks and alert management

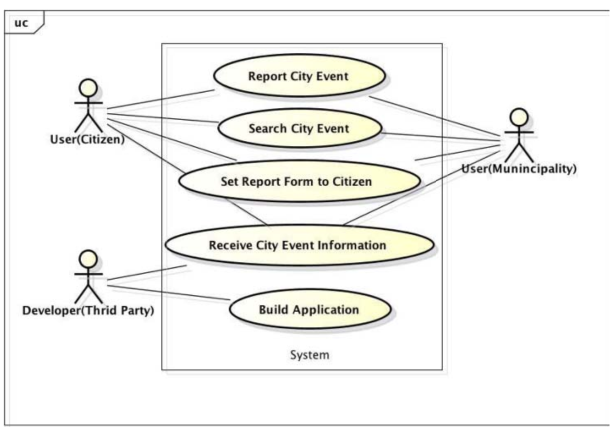

Figure 5: City Event Finder

City Event Finder User Scenario is described in Figure 5: it concerns the possibility for Citizens to report event information through the sensing functions of the ClouT platform. In addition, similar to the SEM_2 scenario, Municipalities can set original participatory sensing tasks by defining report forms. Users (both Citizens and Municipalities) can get city event information by search functions. In addition, by using the event classification functions of the ClouT platform, Users can receive recommended events according to their profile. Developers can use that information about events to build their original application.

Citizen Activity Enhancer user scenario enables users to share their personal activity with other citizens. Users (citizens or municipalities) can register their activity such as private sports activity or shopping activities (Figure 6). Developers can also register more complex activities by using several sensors. Users can then search and participate in activities around them and can receive certification of participation. The number of certifications can be used as achievements, so that users can be motivated to participate in more events by gamification effects, and developers can also use the certification for further application development.

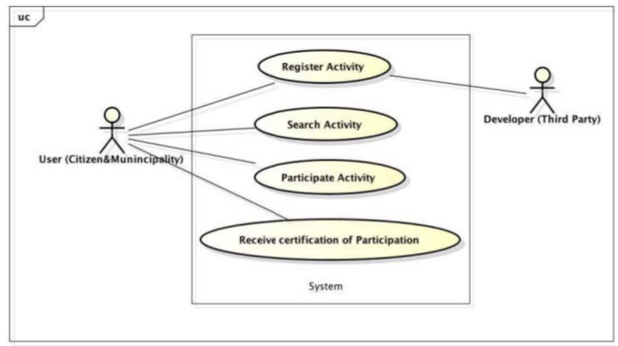

Figure 6: Citizen Activity Enhancer

IV. *REFERENCE ARCHITECTURE*

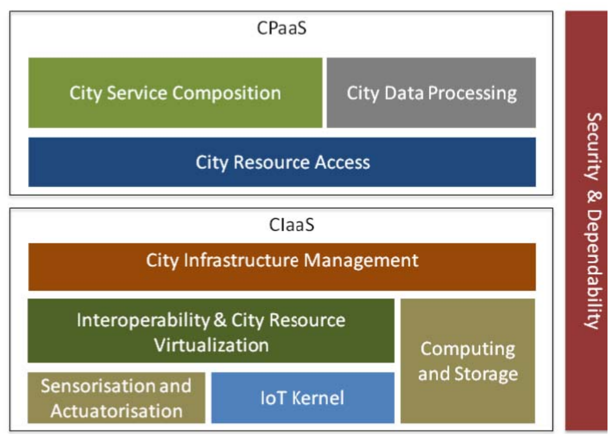

Figure 7: ClouT Reference Architecture overall view

Figure 7 shows a high level view of the ClouT Reference Architecture, its layers, functional blocks and models.

As exposed in section II.A, the vision of the Reference Architecture is cloud-centric. In particular it is based on the cloud service models (IaaS, PaaS and IaaS) that support modules providing both cloud specific services (such as Service Composition or Storage) and IoT specific services (such as Sensorisation).

A. CIaaS functional models and components

Figure 8 shows the logical representation of the main functional blocks within the City Infrastructure layer.

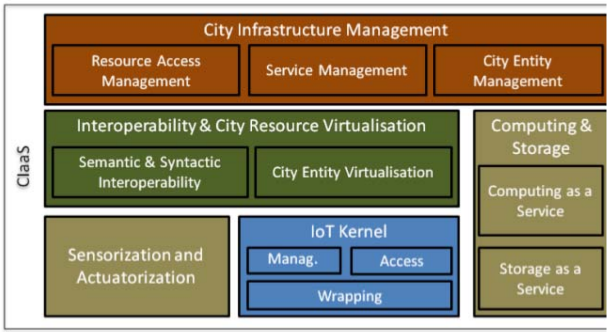

Figure 8: City Infrastructure as a Service Layer

City Infrastructure as a Service Layer (CIaaS) provides all the required facilities to exploit the computing and sensing resources available to the City, while making it easier to extend such infrastructures through the adoption of cloud technologies, standard protocols and interoperability facilities.

Here is a brief breakdown of its main subcomponents:

- The **City Infrastructure Management** offers centralized search capabilities and event management on the discovered city resources. It keeps track of all the available city resources, detecting changes in state and offering information on the availability of devices and services.
- The **Computing and Storage** offers all the physical and virtualized computing, networking and storage resources that are required to store, retrieve and elaborate city data. It has load balancing, high availability and scalability qualities that are typical of the cloud. It is the foundation on which the other city service models lay.
- The **Interoperability & City Resource Virtualisation** component is in charge of validating and converting data gathered from both IoT and sensorised devices. Its duty is to transform raw, unstructured city data into meaningful context data. It offers both syntactic and semantic interoperability capabilities. Moreover it includes the sensor/actuator virtualisation capabilities, offering extended sensor/actuator abstraction functionalities.
- The **Sensorisation and Actuatorisation** component is responsible for the "sensorisation" of legacy devices, making such resources IoT-compliant sensors and/or actuators. This sensorisation/actuatorisation process applies to both physical legacy devices and Internet of People's selected sources such as social networks. This component includes the facilities required to transform legacy resources into smart objects, the noise reduction functionalities required to extract meaningful data from external web data sources and it offers access to the sensorised resources via APIs.
- The **IoT Kernel** comprises all the IoT resources available to the City. It includes a multiprotocol IoT Gateway that is in charge of gathering heterogeneous IoT devices data streams. On the one hand it offers a multiprotocol compatibility layer that complies with all IoT transmission protocol standards, on the other hand it offers a uniform access to the connected resources. It has discovery and management functionalities that enable the remote management of the bound IoT sensors/actuators.

B. CPaaS functional models and components

The City Platform as a Service layer (Figure 9) includes the development and processing tools offered by the ClouT platform. It lays the foundations upon which the end-user services are built.

- The **City Service Composition** aims at both technically oriented and un-experienced users to mash-up and aggregate data and services offered by deployed applications. It has a graphical user interface to enable an accessible interaction with the composition services. It also caters for the experienced developer with Platform as a Service cloud capabilities via the Development and Deployment Platform, enabling the swift instancing of customized development environments and the shipping of the developed applications on auto-scalable, self-balancing virtualised instances.
- The **City Data Processing** component enables the analysis and extraction of the data archived inside the cloud storage. It offers querying interfaces that are exposed to the overlaying services. Moreover it includes an event/decision making engine that analyses requested queries and takes actions based on a configurable rules directory. Finally it has a data fault corrector that analyses and rectifies faulty sensor data.
- The **City Resource Access** offers the middleware software that enables the storing and retrieval of the collected city data, together with the associated metadata, from and into the backend storage via a uniform data access layer. It is a gateway to the City Infrastructure as a Service layer.

C. Security and Dependability transversal Module

The Security and Dependability module is not considered as part of any layer, since its functionalities are provided by every described block. For this reason the Security and Dependability module is a logical module that brings all the required security functionalities, included the protocols used, needed to check and authorize the access to all the modules, including CSaaS. In particular CSaaS applications can leverage Security and Dependability functionalities provided by ClouT at platform level (e.g. for the Storage) or use their own Identity and Access Management systems.

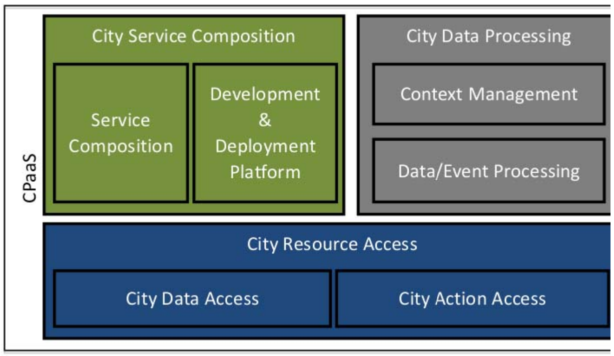

Figure 9: City Platform as a Service Layer

V. INTERACTION OF THE ACTORS WITH THE REFERENCE ARCHITECTURE

In order to better understand the interaction of each actor (defined in section II.A) with the ClouT Architecture the Traffic Mobility Management use case is taken as an example. Figure 10, shows the interaction among the different users with the ClouT Reference Architecture in a real world scenario:

- The citizens access different applications (within the CSaaS) that provide route planning according to certain user requirements and needs, and to the monitoring of the urban events that occurred in the city. As it can be observed in the figure, these types of applications could be developed by external third party users using their own security mechanism and accessing the Security and Dependability block, as a trusted application.
- The traffic company and the Municipality will use the traffic management application (in the CSaaS layer) for monitoring and managing the available resources that provide data to the upper layers. In this sense, considering that this application is tightly dependent on the ClouT architecture, the access will be carried out through the Security and Dependability block. Apart from that, they access the CIaaS in order to add new IoT devices, sensors and actuators to provide the corresponding data for the traffic mobility use case. All this data will be processed and stored in the Computing & Storage block, formatting this data accordingly in the Interoperability & City Resource Virtualisation module, which make them available to the City Infrastructure Management block.
- Third Party service providers will enter the platform through the Security and Dependability block, thus accessing the Service Composition in order to generate the different applications of the CSaaS layer. In this sense, the City Service Composition will be fed by the data and events processed by the City Data Processing block and will be able to access and manage the different cities and services/resources using the City Resource Access.

As it can be derived from this Traffic Mobility Management use case, the different users interact with the different layers of the platform producing and/or consuming the information provided by the subjacent platform.

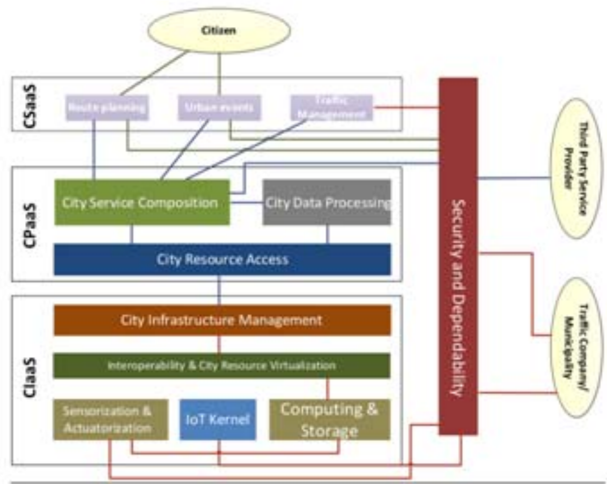

Figure 10: Interaction with ClouT reference architecture in the traffic mobility management use case

VI. CONCLUSIONS AND FUTURE WORK

ClouT approach defines how cloud and IoT can cooperate to obtain significant benefits in offering services for Smart Cities.

The proposed user scenarios show how the ClouT approach can be applied in different contexts, such as resource, emergency and pleasant management. The common aspect of all the contexts is the management of a large amount of data in quasi-real time. By large amount of data it is intended both a large quantity of data and a burst of data concentrated in a limited time slot. In general modern cities, especially if willing to offer several high quality services, may have to face the issues related to the management of large amounts of data. For example a simple traffic jam may produce a sudden increase in the access to smartphone applications from involved drivers, looking for information on the traffic jam itself and on alternative routes to take. Similarly, special public events such as exhibitions or sporting events or even natural disasters may bring to a wide increase in the amount of data processed and used for a certain period of time. This may occur not only for very short periods but also for longer ones. The issues raised by these aspects are not the only ones taken into consideration by ClouT use cases. The efficiency of public services for young and old people and the emergency management or healthcare are strictly related to the quantity and the quality of the information shared between municipalities and citizens and among citizens themselves.

For all the user scenarios considered the data must be collected as fine-grained as possible: sensors managed by gateways provide a continuous flow of information that should be stored, processed, aggregated with other data to produce new sets of information that, in turn, need to be stored. Moreover, time limited data burst, lasting from few seconds to a few days, should be managed and processed in quasi-real time. Furthermore, an implementation of reactions to either simple or very complex alerts must always be supported by the city's infrastructures.

One of the solutions could be to buy the hardware needed to store the required data for an appropriate amount of time and to face the load peaks in the best way possible. The costs are enormous, unaffordable for small municipalities, but also very difficult to sustain for big cities, especially if a good quality of service is requested.

Another solution is the use of cloud technology. ClouT's approach demonstrates that cloud technologies can be specialized for SmartCities applications. In particular the infrastructure layer (CIaaS) provides an unlimited and secure storage capability and enables the abstraction of the concept of sensor, taking into account also social networks which are a very precious data source. The platform layer (CPaaS) enables the composition of services and data processing, enabling the developers of the software layer (CSaaS) to offer innovative services. The cloud technologies provide these features with elasticity and cost effectiveness, enabling small (but also big) municipalities to provide services always dimensioned as required and to pay only for the resources used.

For these reasons ClouT approach has the potential of making small municipalities willing to make a first step into the Smart City world in a easy and cheap way, while supporting cities already smart to become even smarter.

Currently ClouT project is work in progress: in particular the modules of CIaaS and CPaaS layers have been almost completely defined and the implementation of some of them has started.

VII. Acknowledgment

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