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C2IoT: A framework for Cloud-based Context-aware Internet of Things services for smart cities

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Abstract

The smart city vision was born by the integration of ICT in the day to day city management operations and citizens lives, owing to the need for novel and smart ways to manage the cities resources; making them more efficient, sustainable and transparent. However, the understanding of the crucial elements to this integration and how they can benefit from each other proves difficult and unclear. In this article, we investigate the intricate synergies between different technologies and paradigms involved in the smart city vision, to help design a robust framework, capable of handling the challenges impeding its successful implementation. To this end, we propose a context-aware centered approach to present a holistic view of a smart city as viewed from the different angles (Cloud, IoT, Big Data). We also propose a framework encompassing elements from the different enablers, leveraging their strengths to build and develop smart-x applications and services.

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1. Introduction

While the world's big cities are forever getting bigger, their resources are being stretched to a maximum capacity, affecting the inhabitants quality of life in these cities. Hence, the need for novel and smart ways to manage these cities' resources, to make them more efficient, sustainable and transparent, has never been more pressing. It is with these issues in mind that the Smart City vision was initiated, leveraging several if not all Information and Communication Technology areas, to help cities' decision makers and planners make educated and well informed management policies and decisions, tailored to the specific characteristics of their cities, in order to increase the quality of life and enhance citizens' overall life experience. The effective and successful adoption of the Smart City vision depends on innovations in numerous technologies, processes and paradigms (In this paper, we call them enablers).

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One of the main enablers of this vision is the IoT (Internet of Things)[1]. The Internet of Things is eating up the world. Nowadays, be it in academia, industry or government, Internet of Things is considered by many as the latest revolution. This is mostly due to the potential impact of IoT on the way we interact with the real world. The idea revolves around making "things" (e.g. cars, refrigerators, lamps, etc.) smarter, providing them with relatively small sensory, computational and memory power in order to be able of some level of autonomy in the decision making process. In addition to smart things, IoT can also benefit from the widespread of mobile devices (e.g. smart phones, tablets, PDAs, wearables, etc.), that are already equipped with numerous sensors and an ever increasing computing and memory capabilities, as a source of rich, multi-modal data or consumable services that can help understand the user's environment and enrich his user experience (e.g. Location-aware services, activity recognition services, noise level, etc.), or they can be exposed to third parties (e.g. public records, municipals, city hall, private companies) to be used to enhance, change or adapt their policies accordingly.

However, even though IoT offers numerous benefits and holds a lot of promises, it requires colossal amount of effort to maintain and exploit the data generated by the "things". In addition to being network intensive, as the IoT requires constant communications between its infrastructure constituents, the data generated from the "things" is huge. Be it cameras, mobile phones or sensors, the billions of things will generate approximately 600ZB per year by 2020, according to Cisco's forecast. To analyze and extract valuable information from this data, novel Big data techniques and methodologies[2] must be implemented that consider not only the Big Data's 4V paradigm (Volume, Velocity, Variety, Veracity), but also, the application specific requirements with regards to response time (e.g. Real time, near real time or time insensitive) and interactions (e.g. Machine-to-machine or Human-to-Machine).

In this regard, Cloud Computing is supposed to play a monumental role in providing the resources needed to store, communicate and process the huge amount of data generated in IoT. It is defined by the National Institute of Standards and Technology (NIST) as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."[3]. Meanwhile, being highly heterogeneous, dynamic, pervasive and mobile, the IoT is highly complex, which makes the understanding and interpreting of the data generated by its constituents significantly harder. To this end, context-awareness has been explored to provide contextual information about the involved entities. Context has been best defined by Abowd and Dey[4] as "... any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves" . By taking advantage of this knowledge about the things' context, developed tools and applications are expected to make even smarter decisions and extract more specific information from the IoT data with regards to the application's goals and its users. As a result, context is not only supposed to offer better tailored and more suited services and applications to the user's needs, but also reduce the amount of data transiting over the IoT network.

This paper represents our efforts to understand the intricate synergies between the different technologies and paradigms involved in the smart city vision, to help design a robust framework, capable of handling the challenges impeding its successful implementation. To this end, we first discuss the manner in which the combination and interplay of the above defined technologies and paradigms, could benefit the successful adoption of this vision. Then, we present a framework called C2IoT, leveraging and encompassing the necessary techniques and components, to ease the deployment, development and offering of new smart services for the future smart city.

The rest of the paper is organized as follows : Section 2 provides a review of related works that are proposed in literature. In Section 3, we present our project's motivating scenario. Then, we propose and explain our C2IoT framework in Section 4. Finally, we draw our conclusions and outline our future works.

2. Related Works

The smart city vision is associated with numerous scientific research areas from different disciplines (Natural sciences, formal sciences, social sciences and applied sciences). Being interested in the smart city from an ICT (Information and Communications Technology) perspective in general and a services computing view in particular, we noticed that a wide range of technologies, methods and paradigms were linked and expected to play a role in the foundation of the smart city. In this paper, we investigate the synergies between different smart city enablers; namely IoT, Cloud Computing, Big Data and Context-awareness; to provide a robust framework, capable of handling the challenges related to the smart city vision. To that end, we review, in this section, some of the works that cover at least two of the above mentioned topics. After reviewing the works pertaining to the above mentioned enablers, we have noticed that, generally, IoT and Cloud Computing are very disruptive technologies and thus they are more covered in literature, and their integration was thoroughly investigated through numerous research proposals and surveys. In their paper, the authors in[5] survey this integration under a new paradigm they called "CloudIoT", highlighting the complementarity of Cloud and IoT on many levels (e.g. displacement, reachability, components, computational ability, etc.) that lead to the adoption of this paradigm in many applications, and providing a view of the applications that would benefit from this integration and already existing projects leveraging the new paradigm. The authors also discuss the main challenges (e.g. reliability, heterogeneity, privacy and security, large scale, social and legal aspects, etc.) that this integration faces.

Context-awareness and big data were covered in direct relation to these paradigms (Cloud Computing and IoT) to provide more information and knowledge to address their related challenges. In particular, context-awareness has been widely investigated to provide more insight to deal with the challenges of ubiquitous environments (e.g. scalability, heterogeneity, resource scarceness, requirements, personalization, etc.); and thus was linked to IoT more than Cloud Computing. In order to understand and contextualize IoT sensor data, the authors in[6] survey 50 existing works dealing with context-aware computing, to provide a set of value added features needed by IoT middleware solutions on every stage of the context life cycle (e.g. thing management, context sharing between things, reasoning about accuracy of data, accessibility, etc.).

Because big data deals with the storage, processing and analysis of large size data that resides mainly in the Cloud, its issues were more investigated and linked to Cloud Computing[7,8]. However, due to the data getting more varied and volatile, big data is becoming more and more associated with the Internet of Things, considered as its biggest source, as a mean to assist policy makers in making informed decisions.[9].

Dobre and Xhafa[10] leveraged context-awareness and big data to provide new smart services in the cloud. They proposed several contributions related to the management of context information from collection and aggregation using the CAPIM framework to large scale storage using the Context-Aware Framework. Also, they presented challenges related to the development of future and intelligent big data application in large scale context (e.g. smart cities). Their work was tested on a real case study relevant to the transport domain.

In a nutshell, numerous works have studied the integration of some pairs of enablers to serve and address some specific problems and applications. While very little research was done to integrate more than a pair of enablers, none, to the best of our knowledge, tried to define a methodology to integrate all of them. In the following, we present a framework for our vision aiming at the integration of several technologies and methods, that we consider essential to the successful adoption of the "smart" vision.

3. Motivating scenario

This work is part of the SMARTROAD project under the French/Moroccan Hubert Curien Partnership 'Toubkal' (PHC Toubkal)[1], aiming at the fluidification of traffic through the provision of smart services, to the betterment of user experience in travel. Researchers from different backgrounds are interested in the transport domain. To provide a clear view of future research directions in this area, the authors in[11] present a survey where they have reviewed and classified the existing context-aware applications in transport use cases, using three dimensions (environment, system-and-application, and context-awareness). Fleet management, transport sharing (Cabs, Uber, etc.), road security management and others, are all examples of services and applications that are in need of innovative ways to follow the ever changing market landscape and address the challenges of the city's development. As metropolitan cities grow bigger with each passing year, travellers take more time in transit to get to their work places. To take advantage of this transit time, while improving the travellers social life, we propose the following scenario inspired from an OrganiCity use case[2]: *"Soufiane needs to travel from home to his work. There are different means of transportation that are available to him and include walking, biking, scooter (own, shared, electric/petrol), car (own, ride sharing, taxi),*

[1] http://www.campusfrance.org/fr/toubkal
[2] https://scenarios.organicity.eu/scenarios/325cf80f-322d-48ef-84dd-6bb9a2347331

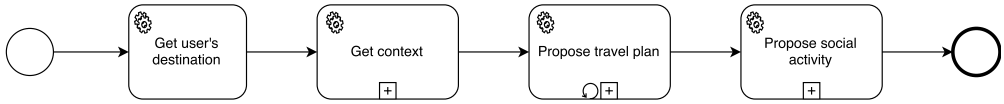

Fig. 1. Abstract Process for a travel planning system

public transportation (bus, metro, train, ferry). Transportation can be optimized to Soufiane's preferred travel time, convenience, total cost, environmental impacts, scenic route and personal health. Factors that impact this optimization include conditions of the different transportation modes (road, weather, maintenance works, traffic intensity, parking availability, pollution, air quality, irregularities in traffic schedules, road tolls, seating availability, accidents, etc.). Soufiane will be presented with his ideal route and will be able to select each leg of the journey based on concurrent and projected aggregated conditions. Recalculation of his chosen route(s) can happen if conditions or preferences change, and will adapt to any detour of own choice. But, because Soufiane is a student who lives far from his university, he mainly uses public transportation. To make his travel experience more enjoyable, the system matches him with other travelers taking the same route to meet and converse about different topics, the matches have a purpose (friendship, dating, help, chat, etc.) and can be based on different criteria (shared interests, preferences, common friends, etc.)."

Figure 1 shows the process that the system takes to deliver pertinent services to the user, relevant to his travel plans. In the first step, the system receives the destination of the user (through a map, coordinates or address). After that, the system recovers the context related to the user (e.g. his preferences mentioned above, weather conditions, infrastructure conditions (roads, Internet connection, etc.)). These elements of context are used in the third step to propose travel plans to the user, among which the user chooses his favorite route. Once the route's confirmed, the system combined the selected route with the collected context to further offer the user a social activity to profit most from his travels.

4. C2IoT : A framework for Cloud-based Context-aware Internet of Things services

In our efforts to contextualize our research with regards to the smart city vision from an ICT perspective, and after reviewing the existing related works, we have noticed the lack of a clearly defined view of the technologies and paradigms involved in the foundation of the future city. Therefore, we present in this section a holistic view reflecting our vision for the integration of several technologies and methods, that we consider essential to the successful adoption of the "smart" vision. We also propose a framework encompassing elements from the different enablers, leveraging their strengths to build and develop smart-x applications and services (e.g. smart health, smart agriculture, smart grid, smart mobility, etc.).

Our approach to tackle the above mentioned integration is centered on Context and Context-Awareness. From linguistics to computing, context is a crucial element. The Cambridge dictionary defines 'context' as "the situation within which something exists or happens, and that can help explain it"; adding to that Abowd and Dey's definition of context stated in our introduction, we believe it becomes clear that context and context-awareness would play an important role in the understanding and interpretation of the situation of any given entity. Context-aware computing is defined by Gartner[3] as "a style of computing in which situational and environmental information about people, places and things is used to anticipate immediate needs and proactively offer enriched, situation-aware and usable content, functions and experiences.". The life cycle of context management systems spins generally across four stages, (1) Collecting and Aggregating Phase, (2) Modeling and Storing Phase, (3) Reasoning and Processing Phase and (4) Dissemination and Integration Phase. The first phase concerns the ways of acquiring the context data around an entity and aggregating it to provide more accurate data. The second phase deals with the representation of the collected data (Key-value, ontology, etc.) and how to store it (Relative Databases, NoSQL Databases, XML files, etc.). The third phase is responsible for processing the data stored to harvest better knowledge and more meaningful information. The fourth phase specifies the way the context information gathered is provided to the interested parties (e.g. services, events, reactions, etc.).

[3] http://www.gartner.com/it-glossary/context-aware-computing-2

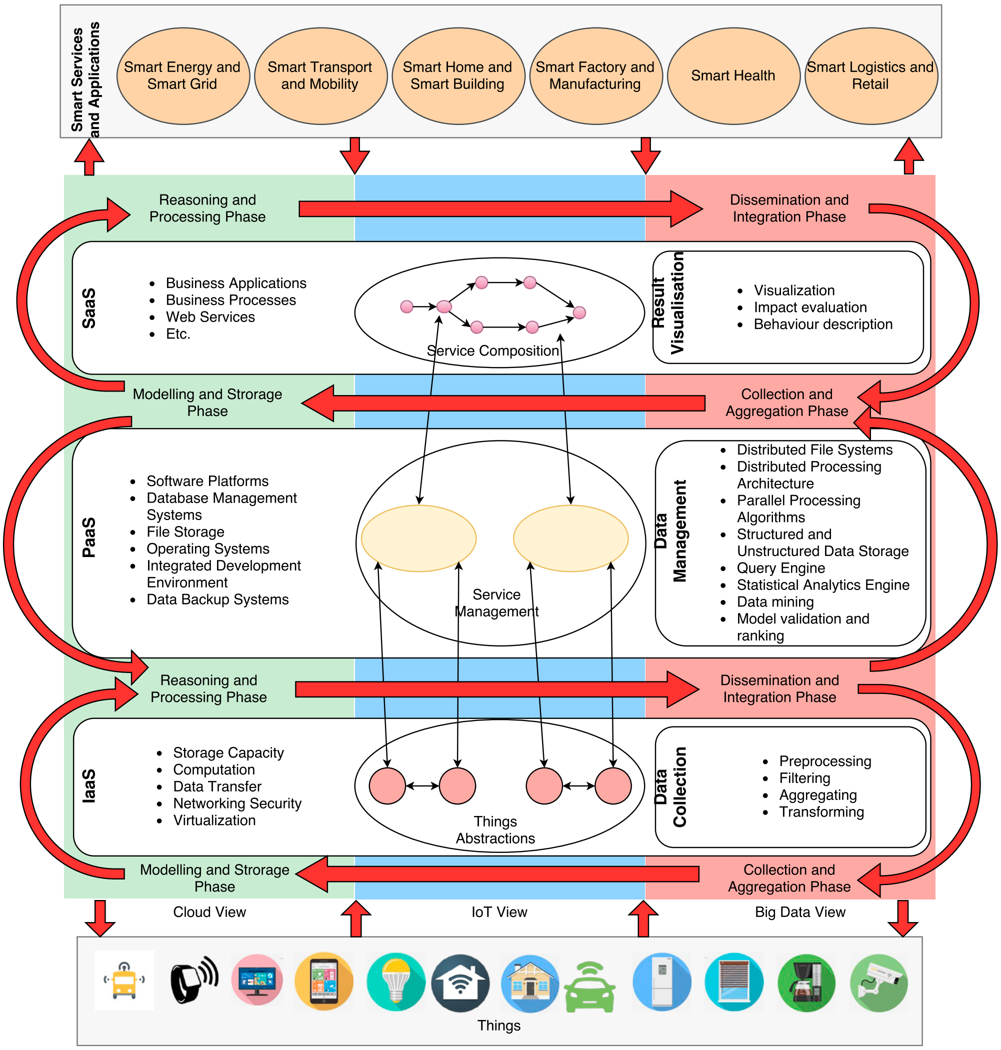

Fig. 2. Overall view of the C2IoT Framework

In the context of our work toward the 'smartification' of the cities through he integration of ICT enablers, we strongly believe that context-awareness can bring intelligence to the data in IoT, to the services in the Cloud and to decision making in Big Data. Therefore, we argue that the integration of context management in the development of smart applications and services is vital. To that end, we present in figure 2 a context-aware holistic view of our framework for the development of smart city applications and services, focusing on the relationships between the mentioned enablers. In this view, we map the context management life cycle to the important aspects and offering of the other enablers, namely Cloud Computing; IoT and Big Data Computing. Because of the specifics of our work, aiming to ease and improve the development of smart services, we have taken a services computing perspective of the IoT [12] to develop our framework of the smart city.

We base our view on Cloud Computing's service models (Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS)), as they provide all the necessary flexibility and effectiveness to deliver services dealing with the challenges of smart applications (e.g. scalability, heterogeneity, resource consumption, etc.). To better understand the Cloud service models, consider the following analogy :*"Imagine the Interstate transportation system in the U.S. Even with all these roads built, they wouldn't be useful without cars and trucks to transport people and goods. In this analogy, the roads are the infrastructure and the cars and trucks are the platform that sits on top of the infrastructure and transports the people and goods. These goods and people might be considered the software* *and information in the technical realm.*"[4]. In the SaaS model, the provider offers software functionality as a service, that can be accessed either through a web browser or an API. In the PaaS model, the service vendor provides the tools required to manage, develop, test, deploy applications. In the IaaS service model, the cloud provider offers resources (e.g., processing, network and storage) as services according to the consumer's needs. In the following, we discuss the synergies between the enablers at every cloud level (service model) and how context information can benefit the development process.

4.1. Infrastructure level

Through IaaS, the cloud offers the infrastructure and the tools (e.g. processing, storage, networking, etc.) needed for the collection of data from the physical objects. Though cloud is usually referenced as a centralized technology, Fog or Edge Computing [13] and Mobile Cloud Computing [14] present themselves as promising technologies to complement the Cloud in insuring better service offerings and meeting all kinds of application requirements. On the one hand, and while Mobile Clouds deal with mobile devices' resource scarceness, disconnections problems, through distributing the applications' execution on external devices in the mobile's vicinity thus forming a Mobile Cloud, the concept can easily be extended to cover IoT infrastructure through the abstraction of the Things (expose their basic functions as services). On the other hand, Fog Computing proposes a hierarchical pooling of resources between the cloud and the sources of the data, where, some small operations can be done on the collected data (e.g. Preprocessing, filtering, etc.), to reduce the amount of data going through the network to the cloud and enhance data quality.

For example, let us consider an infrastructure to support our motivating scenario (e.g. Road Side Units, Smart Traffic Lights, Smart Traffic Panels, Video Cameras, etc.) all connected through the cloud in an IaaS model. While, context information related to the vehicles(e.g. speed, consumption, etc.) and the users (e.g. route, social media activity, etc.) is transferred to upper levels, a context-aware load balancing algorithm would take advantage of the data coming and/or going to these things, to optimize the resources allocated according to the daily changes in demand during weekends, holidays and peek times.

4.2. Platform level

At the Platform level, the tools to ease and aid the developers and data specialists in the development, processing, testing, validating and storing of the data and services collected during the underlying level (IaaS). From an IoT perspective, Service Management concerns the operations to manage the services exposed through it [12] (e.g. discovery of services, selection of services, monitoring of services, mapping services to things, service configuration, service composition, etc.). From a Big Data perspective, Data Management deals with the way data is stored (Structured or Unstructured), retrieved and processed (e.g. Data mining, Statistical Analysis, etc.) (see figure 2). In our previous work [15], we've proposed a conceptual architecture for a cloud-based context-aware service composition platform. The architecture takes advantage of service composition to reduce the development efforts and time, and also, context-awareness to manage the dynamics of ubiquitous environments. Due to the high abstraction level of our architecture (see figure 3) and our context metamodel (see figure 4) (see [15] for more information), we argue that the architecture can be extended to cover services exposed by things but we did not yet consider to deal with challenges related to Big Data. Big Data techniques bring new ways to leverage context data, as we can also consider the use of context data and business data owned by service providers to enhance and customize their service offerings.

At this level, context information regarding different entities can be used. User's context is used to refine and enrich the queries through capturing user intents behind the queries (e.g. current time, weather, user's location, schedule and preferences, etc.). Several context information at the process stage can influence the planning of business processes (e.g. the user could prefer taking public transport to avoid driving stress, choose specific routes based on other travelers' recommendations or expert ratings, etc.). Here, big data is expected to play an important role, for example, in the analysis of data from past experiences and users to propose new recommendations. Service's context can reduce the number of pertinent services offered to the user/developer through their QoS (Quality of Service) or through user's preferences (e.g. cab driver, environmental impacts, time , cost, etc.).

[4] http://www.qrimp.com/blog/blog.The-Difference-between-IaaS-and-PaaS.html

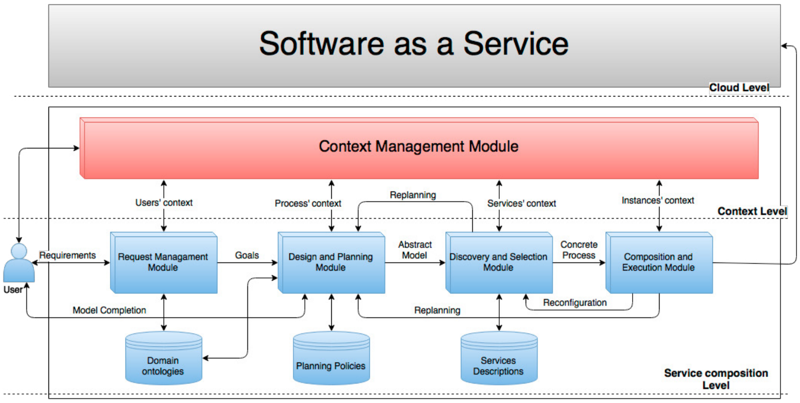

Fig. 3. Cloud-based context-aware service composition platform

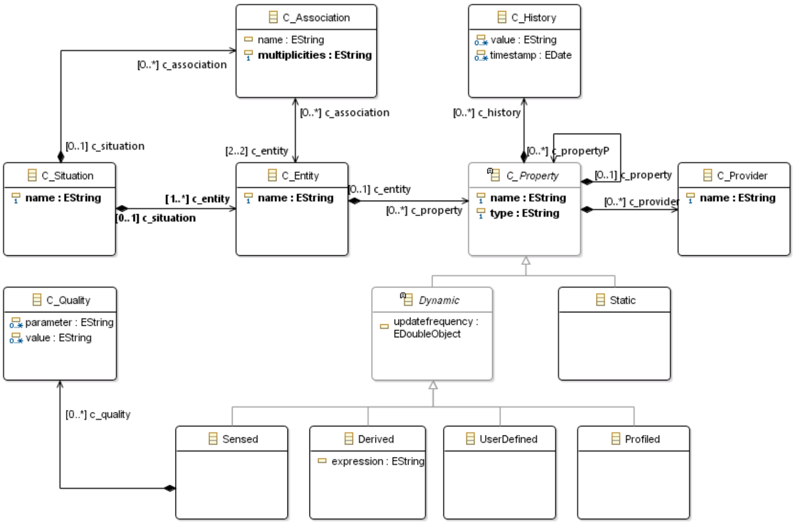

Fig. 4. MOF compliant context metamodel

4.3. *Software level*

At this level, the cloud presents a way to deliver the software product to the user (e.g. Business Application, Business Processes, APIs, etc.). This is generally done through the use of the tools and techniques provided by the platform at the underlying level (Platform level). From an IoT perspective, the software can be a service composition process (orchestration or choreography) representing a sequence of service calls that will be managed at the underlying layers and mapped to physical things (e.g. a process illustrating each leg of a route, annotated with time of departures for each leg and enriched with directions and payment details if the route is multi-modal). From a big data point of view, the product can be the visualization of the processed data in charts to assist in decision making or to identify new patterns in the data or predict the impact of new data (e.g. the impact of offering free WiFi on user satisfaction, the need to propose new bus routes or buses on demand rather than predefined routes, etc.).

5. Conclusion and Future Works

Through this paper, our aim was providing a framework that would serve us as a stepping stone for the development of smart city application. We presented our vision for a smart city, empowered by four enablers namely, Internet of Things; Cloud Computing; Context-Awareness and Big Data, while highlighting the necessity for their integration. To address the lack of a clearly defined view for the integration in literature, we proposed a framework called C2IoT for Cloud-based Context-aware Internet of Things services in smart cities, leveraging and encompassing the necessary techniques and components to ease the deployment, development and offering of new smart services for the future smart city. We've argued that context-awareness can bring intelligence to the data in IoT, to the services in the Cloud and to decision making in Big Data, while Cloud computing provides all the necessary flexibility and effectiveness to deliver services dealing with the challenges of smart applications (e.g. scalability, heterogeneity, resource consumption, etc.).

As this work is part of the SMARTROAD project, aiming at the fluidification of traffic through the provision of smart services, to the betterment of user experience in travel; and to consolidate this work's contribution, we have proposed a motivating scenario for our work, pertaining to the mobility and transport domains. In our future works, we first intend on implementing our scenario on a small scale use case, using the proposed framework to evaluate its performances (e.g. efficiency and effectiveness, etc.) and its feasibility, to take stock and analyze its strong points and try to address its weak points; before moving to larger scale use cases to also test its scalability.

The work presented in this paper also allowed us to reflect back on the shortcomings of our previous work [15], and gave us new ideas and prospects regarding the integration of big data techniques to deal with the ever increasing number of services and amount of data in the Cloud. In this regard, we believe our framework architecture could benefit greatly from big data based recommender systems. Such systems could further enrich our framework, recommending pertinent services with regards the users' context and new patterns discovered through big data analysis; these services would be later selected in the composition process. To that end, we have taken keen interest in the interplay between data science and process science [16].

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