Smart Cities Design using Event-driven Paradigm and Semantic Web

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The concept of "smart city" has attracted considerable attention lately. Still, common definitions are hard to find, and there is a lack of formal models to guide their design. This paper introduces the architecture of Event-driven Smart City, the kind of city where digital artifacts enable the interoperability between Internet of Services, Internet of Things and Internet of People in order to empower inhabitants to quickly react to a larger variety of events, even remotely and using fewer resources than before. Configurability of actions to be carried out automatically when events happen is considered here as core requirement for a smart city. We also explore the usability of the latest advances in Event-driven SOA and Semantic Web technologies to implement smart cities as systems based on the proposed architecture.

Keywords: Smart Cities, Event-driven Architecture, Business Rules, Semantic Web

1 Introduction

The rapid urban population growth worldwide is challenging many cities to define smarter ways to manage the increasing number of issues generated as a consequence of the growth. The new label for such cities is "smart city". One way to conceptualize a smart city is an icon of a sustainable and livable city [7]. However, there are still divergent opinions with respect to the understanding of the concept among practitioners and academia. A study made by Vienna's Centre of Regional Science has identified six dimensions of a smart city[1]:smart economy; smart mobility; smart environment; smart people; smart living; and, finally, smart governance. As a consequence, one can find a variety of definitions for smart cities, many of them not necessarily considering ICT (Information and Communications Technology) or the ubiquitous computing paradigm as implicit pre-requisites for the system design. Regardless of how many dimensions a smart city may expose, a literature review reveals two main streams of research ideas: 1) smart cities should do everything related to governance and economy using new thinking paradigms and 2) smart cities are all about networks of sensors, smart devices, real time data and ICT integration in every aspect of human life.

A representative of the first approach, Hall [11] believes a smart city should monitor and integrate conditions of all of its critical infrastructures, from roads and bridges to major buildings, to better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens. In the already mentioned study, Giffinger et al [1] describe smart cities as well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens. The Natural Resources Defense Council [9] defines smarter in the urban context as more efficient, sustainable, equitable, and livable. Toppeta [10] emphasizes the improvement in sustainability and livability.

In contrast, the second approach to smart cities focus on ICT applied to redesign every aspect of urban life. In Harrison et all's study [8], a smart city denotes an instrumented, interconnected, and intelligent city. Instrumentation enables the capture and integration of live real-world data through the use of sensors, kiosks, meters, personal devices, appliances, cameras, smart phones, implanted medical devices, the web, and other similar data-acquisition systems, including social networks as networks of human sensors. Interconnection means the integration of those data into an enterprise computing platform and the communication of such information among the various city services. Intelligence refers to the inclusion of complex analytics, modeling, optimization, and visualization in the operational business processes to make better operational decisions. Washburn et al. [12] view a smart city as a collection of smart computing technologies applied to critical infrastructure components and services. Smart computing refers to a new generation of integrated hardware, software, and network technologies that provide IT systems and real time awareness of the real world and advanced analytics and actions that optimize business processes. In [27] we find out that South Korea is promoting the development of a stand-

ard architecture for a service management plat-
form that integrates ubiquitous computing and
green technologies. The paper introduces a soft-
ware platform for managing urban services that
include Convenience, Health, Safety, and Com-
fort. In [13], the authors highlight the need to col-
lect data form a lot of urban sensors, such as
smart water, electric meters, GPS devices, build-
ing sensors, weather sensors, and so on, in order
to build a true smart city.

In this paper we rally to the second research di-
rection (as described above) and we will intro-
duce a reference model for smart cities as well as
the method to involve ICT in the implementation
of such model. The motivation comes from our
belief that it is about time to define the logical ar-
tifacts needed to *design* smart cities as systems.
Our approach builds on the basis of three axioms:

- a smart city has well designed ITC infrastruc-
  ture;
- a smart city transforms real time data into
  meaningful information;
- a smart city allows inhabitants to predefine
  automated actions in response to events.

In this paper we will explore the potential of us-
ing Event-driven Architecture (EDA) and the lat-
est knowledge management technologies to de-
sign and implement smart cities as systems. We

first create a formal model for smart cities, the
Event-driven Smart City (EdSC), and then we
discuss the technological support for its imple-
mentation. As a consequence, our work is further
structured into the following sub-parts: 1) the
EdSC concept and architecture; 2) EDA applied
to smart cities design; 3) the potential of Seman-
tic Web technologies to EdSC implementations;
4) related work; 5) conclusions and future work.

2 The Event-driven Smart City – Concept and Architecture

We define the "smartness" of a city as the ability
to provide the infrastructure needed for the nodes
(people, software services, devices and sensors)
to produce, discover, understand and process
events in real-time. Events are more than data.
They represent meaningful information based on
which people or software agents may take action.
Services may be seen also as agents acting in the
name of people. Thus, signals (data) may come
from any of the four entities which coexist within
the smart city space. So, in our vision, inhabitants
of a smart city integrate themselves into an eco-
system where ubiquitous computing is the norm
and software agents may be configured to act in
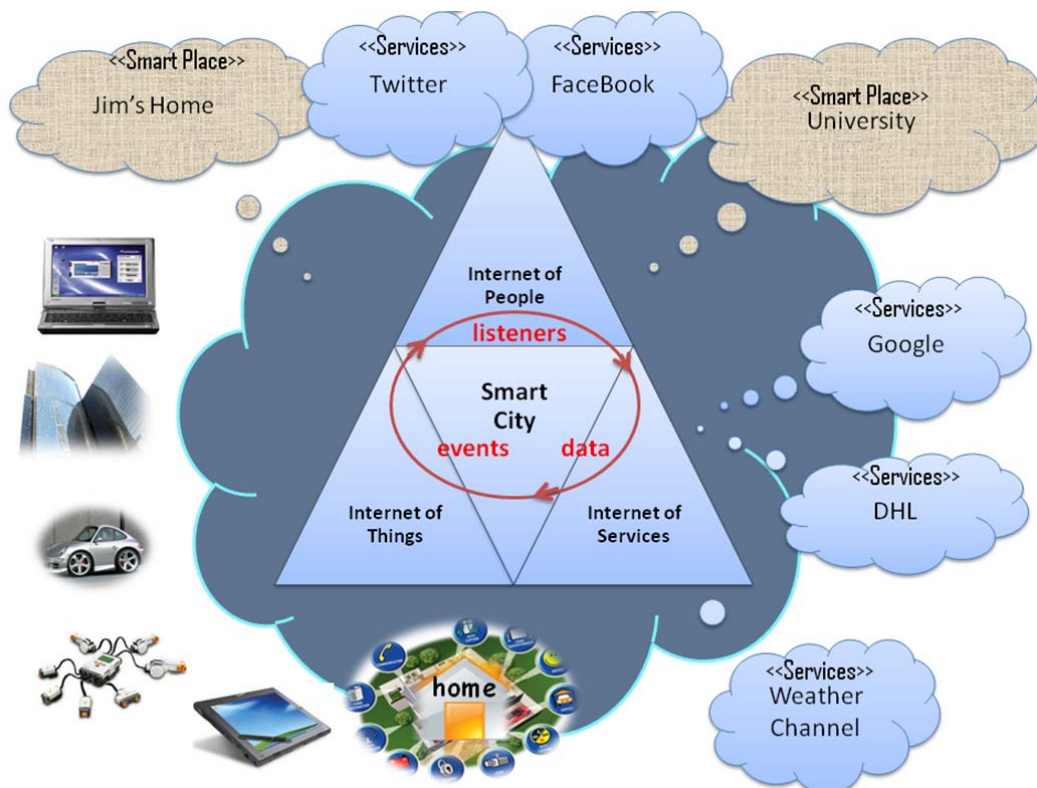the name of people by analyzing real-time data
converted into events.

Fig. 1. The Event-driven Smart City concept – a high level view

Following our definition on "smartness" of a city, we define the Event-driven Smart City as a system representing an internet-aware digital living environment where people, software services, sensors and smart devices interact by means of events and listeners. The EdSC is a system which provides a software platform and the tools for all the registered entities (people, services, sensors and devices) to be able to produce and react to events. Figure 1 shows the high level view of the EdSC concept. The EdSC environment takes the signals (data) received from any of the four entities and transforms them into meaningful events. Listeners are defined by people to execute actions (software services calls or remote execution of functions provided by smart devices) when certain events and conditions are met.

The EdSC may be seen as one consequence of the advancements in internet-related technologies. The Internet has evolved into a multi-dimensional universe comprising at least four prominent worlds: Internet of People (IoP – made of Social Web, Wikis), Web of Data (with its representative Linking Open Data community project – LOD[14]), Internet of Services (IoS – it refers to RESTful [15] services organized in Clouds) and the Internet of Things (IoT - the wireless world of smart devices and sensors which includes home and business environments). Inter-connecting these worlds seems like the intrinsic goal of any smart city. After all, regardless the multi-disciplinary approach over the smart city concept [1], the main goal of such a city is to inter-connect the world of smart devices (internet aware) with people and services in order to provide a smarter living environment.

The EdSC model is built based on the following principles:
1. every system is part of an ecosystems;
2. ecosystems generate inter-dependency, thus every action may have consequences within the ecosystem;
3. every event has a cause (principle of causality);
4. the entities living within the ecosystem share the same knowledge about the environment.

The EdSC should allow: 1) knowledge sharing about the things that happen within a particular EdSC space; 2) predefinition of actions to be taken when something happens. As a consequence, we consider the following four main requirements for a smart city:

1. Signal-to-event convertor – the system has to be able to convert signals into meaningful events. By meaningful events we understand structured information which can be used both by humans and the machines.
2. Knowledge sharing – each particular event has to be described using the body of knowledge available for that city.
3. Action definition, storage and event-condition-action (ECA) relationships – people need tools to predefine actions to be taken for certain kinds of events. Later on, the system has to be able to identify and execute all these actions when event instances will occur.
4. Action-to-signals convertor – when actions refer to executing functions of smart devices, the system needs the ability to transform the execution into the right remote signals.

To better understand the EdSC vision we take the following example: when it comes to bad weather conditions, people usually take measures such as closing the window covers and/or starting up the heating machine. In normal cities, the inhabitants will see the weather change happening or they will listen the forecast to the radio. If the person is not at home, he will not be able to do much more that maybe ask a neighbor to take the required actions. However, in a smart city, more precisely within an EdSC environment, the following scenario should be possible:

A) Pre-condition (inhabitant's responsibility):
   1) search the knowledge base to find out events descriptions about the weather;
   2) define the action to be taken when bad weather events are raised for one's home area - supposing this home has Internet-aware windows covers and heating machine, this would mean to automatically close the covers and start the heating.
B) EdSC behavior – when bad weather events occur for certain areas:
   3) search all the pre-defined actions for that event type;
   4) if the event instance falls within the scope of particular constraints specified by the inhabitant, execute the action.

With the definition of the EdSC and the above discussed requirements in mind, we define the formal architecture shown in Figure 2.
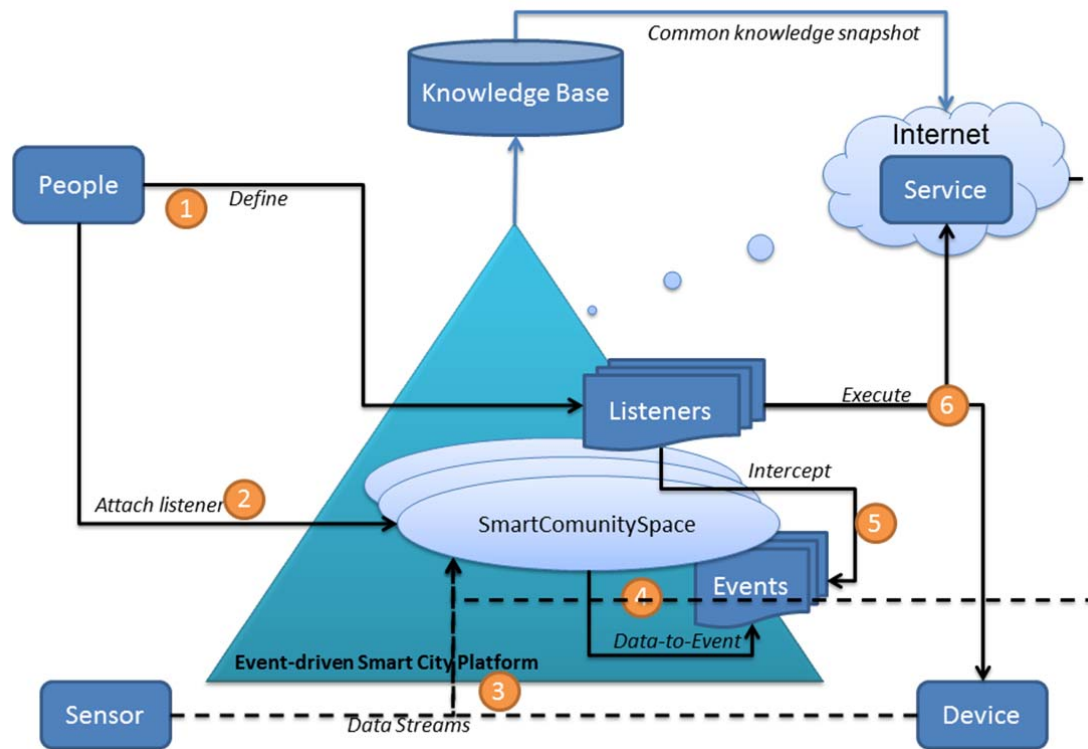
Fig. 2. The Event-driven Smart City architecture

The proposed EdSC architecture should be read as follows (each of the building blocks is described in table 1):
1. the inhabitants use EdSC tools to define listeners for known events, meaning events which have been formally described basedon available common knowledge (a city owned snapshot of the human knowledge available on the Internet);
2. then they associate listeners with a Smart Community Space (SCS);
3. the EdSC Platform receives data from the environment (sensors, smart devices, services, people) and routes these signals to the corresponding SCSs;

4. the SCS transforms data into events (structured information);
5. then the listeners registered for that type of event are notified about the event instance, each listener analyses the event and executes the predefined actions such as calling a service or remotely execute a smart device's functions (according to the new Things as a Service paradigm, or better a "Cloud of Things"[16]).

This collaboration may work only if a set of prerequisite requirements are satisfied: (a) events have to be formally described and available to all participants; (b) sensors, devices and services have to be registered as data providers for one or more SCSs.

Tabel 1. The artifacts of EdSC architecture

Artifact	Description
People, Services, Devices, Sensors	Entities external to the EdSC Platform but part of the EdSC system. May behave as event producers or receivers. People interact with the EdSC by means of services or devices. This way, they can also produce events (e.g as a consequence of a Twitter message they share)
Knowledge Base (KB)	A snapshot of the Internet available knowledge (vocabularies and ontologies) which is built gradually on a per-needed basis. It is a cache used by any specific EdSC system in order to increase the performance of the queries to be executed when the need comes to define listeners, register devices and services or to transform data into events.

Event	Formal description of something that happened. The description is in the form of structured information using knowledge from the KB.
Listener	A set of rules to be applied on the target events and a set of actions to be taken if the rules are satisfied. Actions are formal representations of service calls or remote controls for smart devices. A Listener is defined by a person (usually, the smart city inhabitant) using the EdSC system's tools. Rules have to be described using the same KB as for the events. Only this way, both will share the same meaning of the real events.
Smart Community Space (SCS)	A Social Web system (also a private Cloud) with the following properties: a) it is defined for a group of persons sharing the same interests; b) provides tools for each user to associate listeners; c) provides tools to register sensors, devices and services as event producers. The SCS has the main responsibilities of generating Events based on received signals as well as of calling the right Listeners. Within the EdSC system, Events are raised only by SCS based on data sent by the registered sensors, devices and services.

The core of the EdSC architecture is the Smart Community Space which provides both virtual social environment and event router functionalities. The main differences between SCS and a regular event router are:1) it is capable to link different data representations (reasoning about signals) to the same common knowledge (by creating events) and 2) the ability to correlate unrelated events in order to identify new facts (also known as Complex Event Processing – CEP). One example for the first expected behavior could refer to data sent by two or more entities having different representation of the facts. If one sensor sends an earthquake signal and a person posts a Twitter message saying the same about the same area, SCS must generate two events having the same meaning: earthquake in area X.

An example for the second main capability of SCS refers to data streams over certain periods of time: a sudden drop in atmospheric pressure over a few hours often forecasts an approaching storm. For EdSC, this should imply the raise of say Wather Change Event for the area indicated by the GPS location of the sensor.

Yet a third different example highlights a scenario for the correlation of originally unrelated events. Say one sensor provides data related to the movement of a car. A personal device (e.g. mobile phone) signals the GPS location of a person. A car-renting service announced before that some person has rented a car. If all these data refers to the same person and car, and if the location of the person is not the same as the moving car, then probably a car-stolen event has just happened. It is the Listener's decision if to take action or not, but the SCS should raise this Event anyway and should identify all the interested listeners.

SCS is the EdSC architectural component which implements the *partial view over the world* and thus securing the performance of the system by using *localized* reasoning mechanisms. The partiality is the portion of domain that is represented, and in our case it is composed by the events and listeners associated with a particular SCS. The localized reasoning does not consider all that is known about a domain, but rather a subset of the knowledge, as shown in a classical work of Giunchiglia [19], as well as in [20] where we can find the concept of Multi Context Systems. We consider this segmentation as crucial for EdSC in order to keep the complexity at sustainable levels when it comes to real-time data processing and CEP. The SCS may be built on different levels of aggregations of interests: family, building, physical area, common interest (logical) area, school and so on.

3 The Evolution of Event-Driven Architecture and Its Value for Smart Cities Design
In order to build interoperable software services or software systems, the state-of-the-art today offers three well known architectures: Service Oriented Architecture (SOA), ROA (Resource Oriented Architecture)as a particular implementation of REST (Representational State Transfer) using common Internet protocols and Event-driven SOA, as the evolution of EDA (Event-driven Architecture) from loosely coupled components to loosely coupled software services. After a period of SOA effervescence, the EDA has come back into attention as the right paradigm to develop the Internet of Services.

EdSC architecture is built on top of EDA, as the most reliable design styleto support the implementation of dynamic relationships between

events and services. It has been successfully applied in software systems development for many years and now EDA technical solutions are shifted to the Internet scale in order to build the vision of the Internet of Services.

RSS feeds are the well-known first implementation of EDA on the Internet scale. However, one of the major disadvantages of RSS is that there's no standard notification system. The only way to get new items is to constantly poll the system hosting the RSS feed. Pubsubhubbub, recently proposed by Google, is a decentralized and free protocol which comes to rectify that by defining a way for systems to register their interest in a particular feed notifying then the subscribers once a new feed is published. Basically, an event is raised telling subscribers there are new items.

Pubsubhubbub is based on the webhook concept popularized by Jeff Lindsay as an example of a simple event system built on top of the existing Web infrastructure. In the webhooks model, anything that can call a URL can be a generator, and events are raised by performing a HTTP method on a URL. The channel in webhooks is the HTTP protocol. The engine and responder are the web application that the URL points to. Webhooks overlay an event model on the Web. There's no "system" per se, just a design pattern for enabling user-defined callbacks on the Web. There are already a number of leading Web applications that support Web hooks like: PayPal's instant payment notification; Amazon payments has a merchant callback API that functions as a webhook plugin.

However, while webhooks are easy to implement since there is no heavy framework, just pure event-listeners mechanisms, interactions in EdSC require not only an event exchange mechanism but special techniques to facilitate data integration, meaning the events issued by each application have to be commonly understood. Therefore, an ontology formalizing the information contained in the events is required [3]. It can be used to annotate the events, thus facilitating unambiguous event exchange. Using events with ontologies and the domain knowledge encoded therein can be hardly exemplified, only very few works being available among which a promising concept, called *semantic event processing* [4] within semantic event-driven systems. In the field of event detection, the author's approach uses modular event ontologies for different domains to enable more sophisticated semantic event processing mechanisms based on ECA rules. The authors propose to use reasoning to detect more complex event patterns in a stream of events described by ontologies, and to identify important events from non-important ones. The idea of modular event ontologies is also present in [5]and [6] where we can find a modular approach where not only different ontologies, but also different languages can be used for individual parts of ECA rules. In this versatile approach, applications on the semantic web can register their rules as well as the corresponding processing units. Annotated events are then processed in a distributed fashion by dynamically calling the registered processing.

4 The Value of Semantic Web Technologies for the Event-Driven Smart City Implementation

Semantic Web (SW) has reached the maturity level nowadays with the proliferation of the semantic technologies based on Resource Description Framework (RDF). RDF provides an infrastructure for uniquely identifying and merging both distributed data and metadata. RDF Schema (RDFS) and Web Ontology Language (OWL) are W3C standards for representing semantic models. RDFS offers a simple vocabulary for describing schemas or metadata. OWL provides a richer vocabulary (on top of RDFS) with a set of pre-built formalisms for expressing logical definitions and constraints. Ontologies and controlled vocabularies have been increasingly applied in many domains within the last years, such as in Medicine, Biology, eGovernment, Web Services, Blogs, Social Web etc. This trend is becoming even more prominent as more vocabularies (RDFS vocabularies or OWL ontologies) are being defined for and used by datasets in the Linked Open Data Cloud (see Linked Open Vocabularies - http://labs.mondeca.com/dataset/lov/index.html). Following the advancement of the SW, we have been motivated to explore the applicability of related technologies to our event-driven smart city system. Ontologies built using RDF and OWL enable integration of distributed data without assuming a single, monolithic, centrally controlled knowledge base. They also enable progressive capturing of new insights, shared understanding and formal structures. Additionally, SPARQL (the new knowledge query language) supports key RDF usage scenarios that are critical to EdSC, such as semantic interoperability, data integration and meaningful searching.

While Semantic Web has the goal to build a global Web of machine-readable data, known as the Web of Data, the Linked Data provides the means to reach that goal [30]. In fact, bootstrap-

ping this Web of Data was the aim of the W3C Linking Open Data –LOD project[31] - since its creation back in 2007, by identifying existing data sets available under open licenses, converting them to RDF according to the Linked Data principles, and publishing them on the Web. Since then, a significant number of individuals and or generations have adopted Linked Data as a way to publish their data, and as a result, the current Web of Data consists of billions of RDF statements from numerous sources covering all sorts of topics [32], such as geographic locations, people, companies, books, scientific publications, films, genes, proteins, statistical data, census results, online communities and reviews, and historical events. More information about available data sets can be found by exploring the LOD Cloud Data Catalogue (http://thedatahub.org/group/lodcloud) which is maintained by the LOD community within the Comprehensive Knowledge Archive Network – CKAN (http://www.ckan.net/)-, a generic catalogue that lists open-license datasets represented using any format.

Beyond publishing facts regarding certain domains, ontology is meant to provide a conceptual description about that domain by defining a set of classes, the properties of the classes, and the relationships between these classes. These relationships are either explicitly defined in the ontology, or can be asserted based on the existing ones from the ontology based on already defined *structural assertions*. Multiple inheritances are allowed in RDFS as well as in OWL. However, structural assertions are not enough to instruct a reasoner to infer new knowledge from other knowledge. We need also *action assertions* and *derivations*. This is why the W3C also proposes the Rule Interchange Format (RIF) as RDF rule language designed to support advanced reasoning capabilities by integrating it with ontology languages.

The RIF languages are designed for two main kinds of dialects: logic-based dialects (e.g., the RIF Core Dialect and the Basic Logic Dialect (RIF-BLD) [33-34], and dialects for rules with actions (e.g., the Production Rule Dialect (RIF-PRD). Other dialects are expected to be defined by the various user communities. RIF Core is basically a syntactic variant of Horn rules, which most available rule systems can process. Although developed for rule interchange, the RIF language is a full-fledged rule language and can be used as standard rule language as well. Another rule language for Semantic Web data is

SWRL, which is supported by many tools like *Jena*. There is also the Semantics of Business Vocabulary and Business Rules (SBVR), an adopted standard of the Object Management Group (OMG) intended to be the basis for formal and detailed natural language declarative description of a complex entity, such as a business or a city.

Over the time, rules have been used not only to model business constraints or derivations but also to control devices and processes in real-time applications, perform calculations or inference, enforce integrity constraints on databases, represent and enforce policies and determine the need for human intervention.

Based on these strengths, we believe that the application of the Semantic Web technologies and techniques to smart cities may lead to a range of new opportunities such as information discovery and aggregation, categorization of events, equivalencies and further reasoning needed for complex event processing. Moreover, semantic annotation techniques, meaning adding meta-data (or structured data) to existing (unstructured) data on the web, may provide very powerful for transforming natural language text into machine readable content. More specifically, these technologies are ready to offer support in the following areas:

1. RDF representation of events as well as semantic annotation of data with ontologies available in LOD Cloud will make it easy to identify the meaning of various signals traveling through EdSC platform.
2. OWL is useful to define equivalences between otherwise unrelated terms. Thus, it is the right technology to implement signal-to-event transformers in EdSC, CEP algorithms as well as to identify all Listeners for certain events.
3. SWRL and RIF implementations (or dialects)are suitable to define EdSC Listeners. If we add the SBVR, the human beings may write rules in plain natural language while they will still be understood by machines too. The RIF extension mechanism (by means of community-defined dialects) seems the perfect choice for the Smart Community Space implementations.
4. The availability of LOD vocabularies which can be used for creating these rules as well as for Event representations, and SPARQL as the query language needed to identify the right Listeners registered for certain Events, makes our EdSC architecture look even more feasible.

5 Related Work
Although smart cities are hot subject in literature nowadays, as we have seen in the introduction section, little could be found on the design methods and architectures for smart cities and even less on the event-driven approach for the smart city design. This entitles us to claim that the present paper may be seen as pioneering in the mentioned research area. However, there are also many recently published works which may help for the internal design or the implementation of Event-driven Smart Cities services.

We will start with other architectures which may be applicable to smart cities systems. For example in [17], Mitton et all take the smart cities as the reference scenario for the implementation of a pervasive infrastructure architecture for IoT where new generation services interact with the surrounding environment, thus creating new opportunities for contextualization and geo awareness. The architecture proposal is based on Sensor Web Enablement standard specifications and makes use of the Contiki Operating System for accomplishing the IoT. The authors identify three main components for the Cloud of Sensors architecture: Hypervisor, Autonomic Enforcer, and Volunteer Cloud Manager. The Hypervisor, works at the level of a single node, where to abstract away either embedded sensors available on a personal device (e.g., smartphone) or standalone sensors, smart or otherwise belonging to a network (Wireless Sensors Networks - WSNs). Among its duties are relaying commands and data retrieval, abstraction of devices and capabilities, virtualization of abstracted resources, semantic labeling and thing-enabled services. The Adapter enables the communication directly with sensing/actuation devices and keeps track of resources connectivity. It translates application commands and forwards them to the underlying physical resources, using the native communication protocol of the resource.

It is clear that [17] may prove to be a valuable part of the solution for our Smart Community Space component in the following areas of concern: 1) data gathering from sensors networks; 2) translating Listener actions into signals (the Adapter component described above).

Following a different path, Schaffer et al develop on the concept of user-driven services [29], exploring "smart cities" as environments of open and user-driven innovation for experimenting and validating Future Internet-enabled services. The authors discuss the sharing of common resources regarding research and innovation for the purpose of establishing urban and regional innovation ecosystems and, thus, smarter cities. In this case, EdSC shares a similar vision of user-defined services (Listener) based on formal representation of knowledge, only it takes it to a different scale.

In contrast with our presumption that, in EdSC, data may come not only from sensors but also from people (by means of social web services), IoS and smart devices, most of the work today focus to understand how Smart Cities may benefit from Sensor Web technologies. Hernandez-Munoz et al. [28] presented an extension of their framework, called Ubiquitous Sensor Networks, that leverages the Sensor Web Enablement (SWE) standard (defined by the Open Geospatial Consortium) along with the SIP protocol. The authors of [26] outline on the need to collect data form a lot of urban sensors, such as smart water, electric meters, GPS devices, building sensors, weather sensors, and so on. The key idea for getting high-quality services from (cheap) sensor networks is the cross-correlation of sensed data from several sensors and their analysis with sophisticated algorithms. In this respect, we can say the EdSC vision is in-line with modern technological trends and certain implementations may greatly benefit from the above mentioned solutions.

Another subject of strong interest for smart cities, and particularly to EdSC, is provided by research efforts related to data aggregation and correlation in Wireless Sensors Networks (WSNs). The problem to define an abstraction of sensed data representation was also identified in [18]. The authors propose to attach metadata to WSNs, define the notion of context based on metadata elements (they identify four types of contexts)and then a set of rules to ensure dynamic interoperability between WSNs. Using two types of reasoning rules, contextual using rules and bridge rules, it is possible to reason about WSNs contexts. Contexts are presented here as an explicit representation of WSNs' status inferred from metadata elements. The contexts will provide the explicit knowledge about what happens in the WSN and in its surroundings; meanwhile, the bridge rules will be the reasoning mechanism that relates the contexts of different WSNs, and at the global model, a decision-making action will take place in order to decide what should be done to continue interoperating in despite of the dynamic changes. The work presented in [18] is related to our EdSC architecture by means of contexts. Although applied at much higher level, our Smart Community

Space may be seen as a context where reasoning is made based on partial knowledge [19,20].

With respect to knowledge extraction from WSNs data streams, most of the research efforts head to semantic annotation of sensor data. In [21], an approach is proposed to make sensor data and the associated metadata publicly accessible by storing it in the Linked Open Data Cloud. Similarly, in [22] an infrastructure called Sensor Masher provides the ability for non-technical users to access and manipulate sensor data on the Web, while in [23, 24, 25] different ontologies and semantic models are presented for sensor data representation, such as SUMO, Onto sensor, and LENS.

All these works validate our vision of streams of data transformed into meaningful information. Nevertheless, for an Event-driven Smart City, sensor data annotation is not sufficient. We need data aggregation into meaningful events which then may trigger different actions. However, semantic annotation may be the first step and, with the help of LOD Cloud, specific sensor ontologies may be easily linked and integrated into the common body of knowledge.

6 Conclusions and Future Work

In this paper we have described the Event-driven Smart City concept and architecture as well as the technologies that can be used today to implement such a system. The EdSC model is based on Event-driven Architecture, well known in the field of software systems engineering, and has been defined having in mind that, in our opinion, a smart city should provide the required ICT tools for inhabitants to be able to predefine automated actions in response to events. According to this vision, a smart city should offer the ICT platform to interconnect four worlds: Internet of People, Internet of Services, Internet of Things and the Web of Data. Regarding the originality of our approach we have argued that there are plenty of related works addressing various parts of the problem but none to take the global view approach of smart cities design.

Regarding the implementation issues, we have shown that Event-driven Architecture has evolved to Event-driven SOA and it provides cutting-edge technologies to implement the event-driven smart city system. On the other hand, we have seen that in order to achieve the level of data integration needed to support interoperability, Semantic Web technologies play the leader's role. Finally, the state-of-the-art in encoding the behavior as response of the system to a specific set of events is represented by rule-based systems (or logic based systems) typically using close-to-natural language syntax for statements following the Event-Condition-Action (ECA) model.

As future work in this area, our efforts will focus on trying to find answers to more technical subjects, such as: 1) detailed design of each EdSC component; 2) the use of semantic query engines in order to handle floods of events; 3) reasoning on an infinite stream of events; 4) leveraging the elasticity features of cloud environments into smart cities;

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