A Unified Semantic Engine for Internet of Things and Smart Cities: From Sensor Data to End-Users Applications

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***Abstract*—Smart cities are becoming more and more popular. Currently, there is no unified and interoperable system which could be reused and redeployed in future smart cities. Having an interoperable: (1) system, (2) architecture, (3) workflow to process IoT data, (4) interoperable applications and services, and (5) secure access to data is becoming essential to reduce development cost in smart cities and ensure interoperability among vertical IoT applications (i.e., domain-specific). Firstly, we survey existing work integrating semantic web technologies to Internet of Things, also called 'Semantic Web of Things' and applying it to smart cities. Secondly, we share in this paper, our vision of Semantic Web of Things applied to smart cities and highlight main research challenges. Finally, the main contribution of this work is the semantic engine applied to IoT and smart cities. Moreover, the proposed semantic engine is applied to three use cases: Machine-to-Machine Measurement (M3) framework, FIESTA-IOT EU project and VITAL EU project.**

***Keywords*—Semantic Web of Things; Internet of Things; Smart Cities; Semantic Web Technologies**

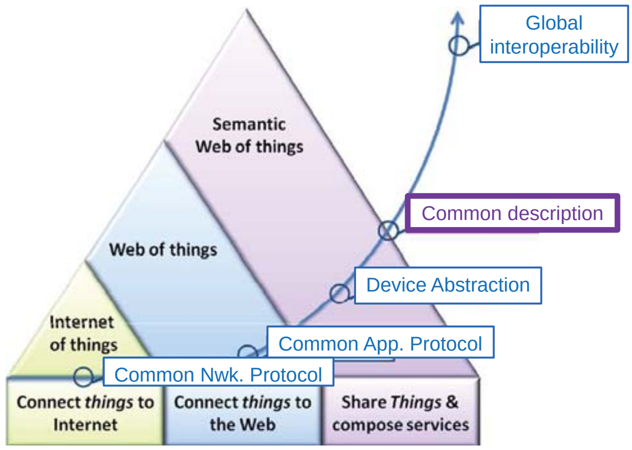

Fig. 1: The evolution of Internet of Things, Web of Things and Semantic Web of Things [4]

I. Introduction

Smart cities are becoming more and more popular. Unfortunately, each city deploys its own system, which is not interoperable with another city. For the existing cities which have not deployed any systems yet, a challenge would be to provide an interoperable system which can be reused and redeployed in all cities and compatible with the existing ones. Hence, it would be easier to reuse sensors, produced data, combine data and provide complex reasoning and innovative applications and services. This is the purpose of Internet of Things (IoT) [1]. Initially, IoT's goal was to connect physical devices to Internet. Then, Web of Things (WoT) [2] emerged to easily connect sensors to the web, get the data and exchange data on the web that has been produced by devices. The new challenge is to define an unified approach to represent the data produced by such devices called Internet Connected Objects (ICOs) [3]. This is essential to later combine data produced by different cities, or re-use the same system in different cities. To address such challenges, semantic web technologies could be used as explained by Jara et al. [4] depicted in Figure 1. Semantic web technologies bring a lot of advantages such as: (1) providing machine-understandable data, (2) describe data with common vocabularies, (3) reuse models to share and reuse the background knowledge, (4) easing the reasoning, and (5) easing the linking of data to enrich it [5].

We address in this paper main challenges to build such interoperable systems: (1) a unified language and model is required to describe interoperable data produced by IoT testbeds, (2) a unified reasoning mechanism is required to reuse and share the way to interpret IoT data, (3) hide the complexity of semantic web technologies to end-users, (4) provide unified web services to get access to enriched IoT data, (5) secure access to IoT data, (6) real-time processing, and (7) scalability to process big data produced by ICOs. The M3[1] [6] project, FIESTA-IOT[2] and VITAL[3] [7] European projects are partially addressing such challenges.

In this paper, we design an entire workflow/semantic engine to semantically annotate and reason over data by providing services hiding semantic web technologies to IoT developers and end-users.

The rest of the paper is structured as follows: section II presents the state of the art and clearly explains the limitations. Section III describes the way to combine semantic web technologies to Internet of Things to build interoperable systems to deploy in future smart cities. Section IV discusses challenges

[1] http://sensormeasurement.appspot.com/
[2] http://www.fiesta-iot.eu/
[3] http://vital-iot.eu/

and research directions. Section V explains the semantic engine for IoT and smart cities. Section VI details three use cases: M3, FIESTA-IOT and VITAL projects. Finally, we conclude the paper in section VII.

II. State of The Art

In this section, we begin with existing surveys related to Internet of Things, more precisely the ones encouraging the use of semantic web technologies. Secondly, we introduce existing Smart Cities platforms. Thirdly, we address semantic reasoning applied or not to sensor data. Finally, we highlight main shortcomings of the existing works.

A. Existing Surveys Related to Internet of Things

In this section, we describe existing surveys related to IoT.

Aztori et al. survey Internet of Things and describe: (1) technologies for IoT such as communications, middleware and protocols, (2) main application domains, and (3) open issues such as standardizations, addressing & networking, and security & privacy [1]. They do not explain the challenges to overcome to integrate semantic web technologies to IoT.

Zeng et al. survey the Web of Things topic and highlight open issues such as: (1) heterogeneity of devices and communications protocols, (2) security and privacy, (3) sensor discovery, (4) context-awareness to adapt the environment according to the user profile, (5) Semantic Web Services adapted to the Web of Things [2]. They conclude their survey by indicating that the smart things should speak the same language to communicate with each other.

Aggarwal et al. discuss the challenge to interpret sensor data. They say: "too much data, too little interoperability and too little knowledge" [8]. A main challenge would be to interpret IoT data by reusing domain knowledge.

Perera et al. survey context-awareness with a focus on Internet of Things [9]. They highlight the necessity to interpret, analyze and understand sensor data to perform machine-to-machine communications in IoT. They classify six techniques such as supervised learning, unsupervised learning, rules, fuzzy logic, ontological reasoning and probabilistic reasoning. Further, they clearly explain pros and cons and sum up them in a table. According to their table, rule and ontology-based techniques contain few cons. The main shortcoming of these two-techniques is that the rules must be manually created, which can be error-prone and that there is no validation or quality checking. Stemming from the 'Linked Open Data' approach, there is a need to have a dataset of rules which can be shared, reused and validated by domain experts. With such approach, rules are only defined once in an interoperable manner. Pros regarding rule-based systems is that rules are simple to define, easy to extend and require less computational resources.

Barnaghi et al. highlight the need of semantics to: (1) provide unambiguous IoT data descriptions to be interpreted by machines, (2) combine data from different physical worlds, (3) semantic reasoning, and (4) sensor discovery [5].

None of these works underline the need of an entire process from sensor data to the final applications which could be applied to both Internet of things and smart cities.

B. Smart Cities Platforms

In this section, we describe existing smart cities platforms.

The **READY4SmartCities**[4] project aims at reducing energy consumption and CO2 emission in smart cities exploiting ontologies and linked data [10]. This project provides guidelines to help data providers to generate energy-related data as Linked Data. It introduces the concept of cross-domain data such as climatic, occupation, pollution, traffic, activity, etc. It builds a dataset with 50 domain ontologies specific to smart cities and smart home. This project does not cover main IoT domains such as healthcare, smart farm, etc. They do not mention the need to integrate a reasoning engine to analyze IoT data.

The **STAR-CITY** project is deployed in four cities: Dublin, Bologna, Miami and Rio [11]. They use semantic web technologies to diagnose and predict road traffic congestions [12]. For their processing they use 6 heterogeneous sources: (1) road weather conditions, (2) weather information, (3) Dublin bus stream, (4) social media feeds, (5) road works and maintenance, and (6) city events. They use Semantic Web Rule Language (SWRL) rules to define rules such as heavy traffic flow. This project is mainly focused on the traffic analysis.

The **CityPulse** project defines 101 scenarios such as public parking space availability prediction, real time travel planner, air pollution countermeasures, what is my route and efficient public transport [13]. These scenarios underline the need of tools to design interoperable and reusable IoT applications. The CityPulse project is focused on large-scale analysis and real-time processing.

The **SmartSantander** project clearly explains that current deployments are closed and vertically-integrated solutions tailored to specific application domains [14]. The project deployed 20,000 sensors measuring temperature, humidity, particle, CO, NO2 or monitoring parks and gardens irrigation, outdoor parking area management and traffic intensity monitoring [15]. These sensors have been deployed in six cities: Santander, Melbourne, Lubeck, Guildford, Belgrade and Arhus [16].

All of these projects are independent and ignore the other projects, there is a real need to provide semantic interoperability on top of these projects.

C. Semantic Reasoning for Smart Cities

In this section, we describe existing semantic reasoning approaches which could be reused in IoT.

Intelligo is a semantic-based approach to integrate abductive logic framework and Parsimonious Covering Theory (PCT) to interpret and reason on sensor data ('Semantic perception') [17] [18] [19]. Moreover, they outline that perception does not enable a straightforward formalization using logic-based reasoning. However, we do not completely agree with this fact as for simple sensors such as temperature or precipitation, logic-based reasoning is faster, flexible and easier for sharing. Regarding complex sensors such as accelerometer or ECG, this is true as logic-based reasoning is insufficient, and the use of data mining approaches is unavoidable.

[4] http://www.ready4smartcities.eu/

Knowledge Acquisition Toolkit (KAT) is designed to infer high-level abstractions from sensor data in gateways to reduce the traffic in network communications [20] [21] [22]. KAT is composed of three components: (1) an extension of Symbolic Aggregate Approximation (SAX) algorithm, called SensorSAX, (2) abductive reasoning based on the Parsimonious Covering Theory (PCT), and (3) temporal and spatial reasoning. They use machine learning techniques (k-means clustering and Markov model methods) and then Semantic Web Rule Language (SWRL) rule-based systems to add labels to the abstractions. They propose to use domain-specific background knowledge, more precisely the Linked Data, but they do not clearly explain the incompatibility issues to reuse and combine the domain knowledge relevant for Internet of Things. Ganz et al. evaluate their work on real sensor data (temperature, light, sound, presence and power consumption). Ganz et al. are focused on real-time processing of the data and high scalability rather than assisting developers to design interoperable IoT applications [23]. They explained that inferring high-level abstractions can be done through machine-learning techniques such as classification and clustering or even logical inference with the help of reasoning mechanisms and rule-based systems can be also used.

Sensor-based Linked Open Rules (S-LOR) is an approach to share and reuse the rules to reason over IoT data [24]. This is a logical reasoning based on semantic Web Rule Language (SWRL). It would be interesting to extend this approach with machine learning approaches proposed in KAT and Intelligo.

Large Knowledge Collider (LarKC) is a scalable distributed platform for web scale reasoning [25]. One of the use cases of LARKC is related to smart cities, more precisely parking lot assistance and predict traffic congestion problems. They addressed the challenge to take only few milliseconds per query even by querying billions of triples that are continuously being updated.

All of these projects are independent and ignore the other projects, there is a real need to provide a semantic reasoning platform to address at the same time: (1) real-time, (2) scalability, (3) sharing and reusing-based approach, and (4) flexible to deal with rule-based or machine learning based reasoning according to the needs and computational capabilities.

D. Shortcomings of the existing work

We analyze the following limitations:

1) The existing IoT-related surveys are not applied to smart cities and are limited regarding the description of the use of semantic web technologies.
2) Each platform redesigns its own ontology. We analyze incompatibilities issues to reuse the existing IoT/domain ontologies. Indeed, frequently, semantic web best practices are not followed. Further, there is a lack of ontology matching/alignment tools applied to IoT. There is a real need to unify existing IoT-related ontologies to ensure semantic interoperability among existing platforms.
3) Each platform designs its own language to describe IoT data. There is a need to define a common dictionary to describe sensors, measurements, units and applicative domains in the same manner in all projects (e.g., to deal with synonyms, abbreviations).
4) IoT applications are not interoperable with each other. The same IoT applications/use cases are constantly redefined, redesigned and implemented. There is a need of tools for providing default templates to design interoperable IoT applications.
5) The reasoning mechanism is not reused in other platforms. There is a need to unify reasoning approaches to ensure interoperability among smarter data.
6) Access control to IoT datasets is neglected. There is a need to address security issues.
7) There is no system yet providing approaches for horizontal applications (e.g., combining heterogeneous applicative domains). There is a need to combine applicative domains to ensure interoperability among applications and provide smarter applications.

Features/Projects	Ready4 SmartCities	STAR-CITY	CityPulse	SmartSantander
Real-time	No	Yes	Yes	Yes
Scalability	Yes	Yes	Yes	Yes
Applicative domains	All	Transport	All	All
Horizontal objective	No	No	No	No
Semantic web technologies used	Yes	Yes	Yes	Yes

TABLE I: Comparison of existing projects involved in smart cities

Table I shows the comparison between existing smart cities projects. The projects are compared according to the following features: real-time, scalability, applicative domains, horizontal objective, use of semantic web technologies. This table highlights the need to provide new approaches for designing horizontal applications. Semantic web technologies are used in all projects, but the next challenge would be to ease the integration of such technologies to the IoT developers and users and facilitate interoperability. They almost all address real-time and scalability issues. In this paper, we are not addressing these two main important challenges.

III. COMBINING SEMANTIC WEB AND INTERNET OF THINGS FOR FUTURE INTEROPERABLE SMART CITIES

Figure 2 shows our vision of Internet of Things through the EU OpenIoT, VITAL and FIESTA projects. Internet of Things is not just the interoperability among hardware devices and network communications (i.e., Internet or wireless technologies). IoT gets the data though network communication and send it to the Web of Things (WoT), to later process it. Machine-to-Machine (M2M) enables communications between machines without human intervention. Semantic Sensor Networks (SSN) provides the mechanism necessary for sensor discovery and mashups, but does not really interpret the data. Semantic Web of Things (SWoT) is focused on interoperability of data and ontologies. The use of Artificial Intelligence (AI) is essential to process the IoT data to infer high level knowledge. Frequently, machine learning algorithms are used to process the data. From our point of view, to interpret the value of a temperature, we do not need such mechanisms which are time-consuming

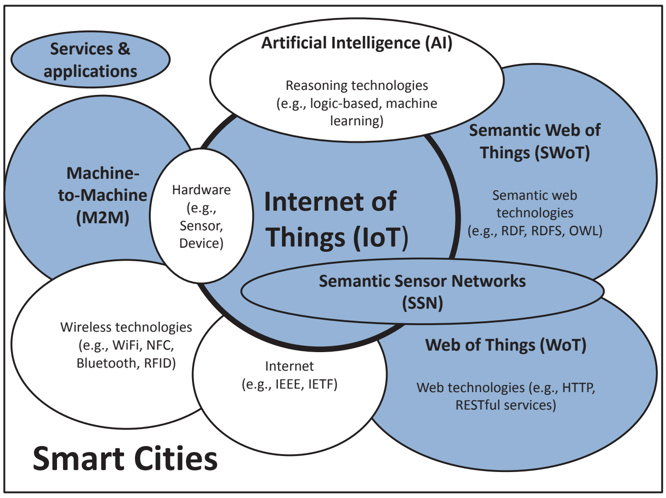

Fig. 2: Technologies required to build smart cities

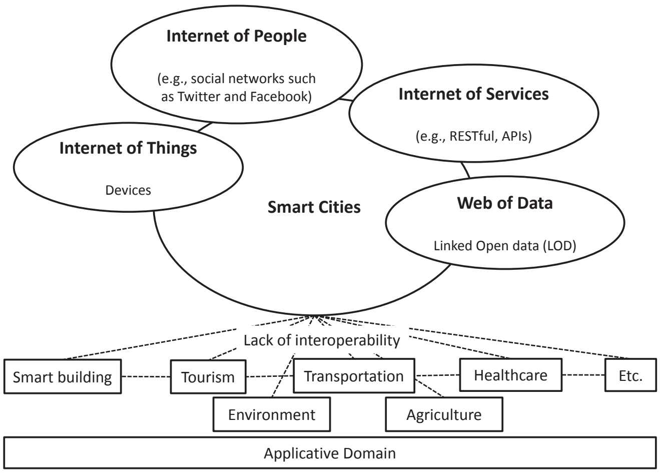

Fig. 3: The smart city vision covers multiple applicative domains

especially the learning phase. We would like to differentiate two kinds of Internet Connected Objects (ICOs): the simple Objects such as thermometer, and complicated ICOs such as accelerometer. For the simple ICOs, we preconize that logic-based reasoning is sufficient to infer high level knowledge.

Figure 3 shows our own smart city vision and its applicative domains. Smart cities exploit ICOs which are connected to Internet of even the Web. The IOCs data are send to the web to provide the Web of Data which is essential to provide services. Finally, connecting IoT data with data generated by social networks enables to personalize Internet services. Nowadays, they are more and more domain-specific applications (e.g, healthcare), but they still lack of interoperability. To provide sophisticated services, there is a real need to combine and reuse existing domain-specific applications. A way to address this challenge it to exploit semantic web technologies in the context of IoT and smart cities.

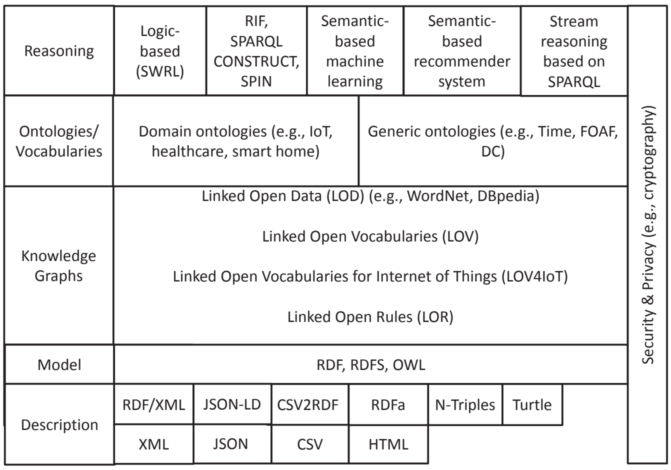

Fig. 4: Semantic web cake applied to Internet of Things

Inspired by the popular Semantic web cake layer designed by W3C[5] and Semantic Web for Internet of Things [5], we design our own cake for Semantic Web of Things and smart cities. Figure 4 shows the first and second layers called description and model which enable describing IoT data with semantic web languages such as RDF, RDFS and OWL. The third layer is the knowledge graph to exploit the background expertise already available on the web with the Linked Open Data (LOD), the Linked Open Vocabularies (LOV), the extended version for IoT (LOV4IoT), and the Linked Open Rules (LOR). The fourth layer is for reusing domain vocabularies. The fifth layer is specific to reasoning: (1) semantic web languages for reasoning such as SWRL, RIF, SPIN, SPARQL CONTRUCT, (2) semantic-based machine learning, (3) semantic-based recommender system, and (4) stream reasoning approaches. This figure also shows the need to address security issues in all layers from describing data and models until the reasoning layer.

IV. Challenges and Research Directions

We highlight main research challenges in Figure 5 as follows:

1) **Unifying IoT data**. Taking inspiration from the Linked Open Data (LOD), we could build the Linked Open Data for Internet of Things (LOD4IoT) which need to provide new functionalities such as scalability to deal with huge volumes of data and real-time processing. There is a need to define best practices to link, unify and validate heterogeneous data coming from various testbeds.
2) **Unifying model/vocabulary/ontology to semantically annotate the data** to easily share it among applications. There are interoperability issues among ontologies to semantically annotate IoT data. the Linked Open Vocabulary for Internet of Things (LOV4IoT) is a a catalogue of ontologies, datasets and rules relevant for IoT. New approaches and tools need to be designed to exploit this domain knowledge

[5] http://www.w3.org/2007/03/layerCake-small.png

Domain / Challenges	Semantic Web approaches	Internet of Things (IoT) approaches	Limitations
Unifying data	Linked Open Data (LOD)	Linked Open Data for Internet of Things (LOD4IoT)	- Not adapted to real-time - To reuse and combine data
Unifying model/ vocabulary/ ontology	Linked Open Vocabularies (LOV)	Linked Open Vocabularies for Internet of Things (LOV4IoT)	- Lack of best practices - To reuse, extract and combine ontologies - No ontology matching tools adapted to IoT ontologies
Unifying reasoning	Linked Open Rules (LOR)	Sensor-Based Linked Open Rules (S-LOR)	- Need more approaches for interoperable reasoning and sharing and reusing-based approaches - S-LOR limited for complex ICOs
Unifying architecture	?	Architecture Reference Model (ARM)	- ?
Unifying service	Semantic web services	Semantic Web of Things (SWoT) generator	- Composition of services

Fig. 5: Comparison of uses cases addressing challenges

already designed by domain experts. There is a real need to provide a unified model aligned with the existing ones.

3) **Unifying reasoning to interpret IoT data**. A major challenge would be to reuse, combine and extract the domain knowledge available on the web to interpret IoT data. Moreover, the same reasoning is constantly redefined in all IoT applications to interpret IoT data. A main challenge is to design a unified reasoning which could be reused in other IoT applications.
4) **Unifying architectures**. A major challenge is to unify IoT architectures to provide interoperability among projects and would enable combining, reusing and unifying semantic-based IoT projects.
5) **Unifying services**. The main challenge would be to hide the complexity of using semantic web technologies to the IoT developers. Another important challenge would be to provide interoperable services to easily combine existing ones, combine heterogeneous domains to build sophisticated applications.
6) **Real-time and scalable data analytics**. In the context of smart cities, some applications need real-time reasoning. Further to exploit the huge amount of data produced by sensors, we have to deal with large scale challenges.

Sharing and reusing data is becoming popular, but our main vision is to share at the same time the data, the model (e.g., ontology) and the reasoning mechanism used to add a real value to the data.

V. A Semantic Engine for IoT and Smart Cities

Figure 6 shows the semantic engine to semantically enrich IoT data, reason over it and build interoperable semantic-based IoT applications. The semantic engine comprises the following components:

1) *Unifying IoT data* is overcome with the **composer** which unifies data generated by heterogeneous testbeds. IoT data can be raw data (e.g., provided by VITAL and SmartSantander) or already semantically annotated (e.g., CityPulse, OpenIoT). We preconize to extend the M3 nomenclature/language, an approach for unifying IoT data from different testbeds, application domains and delete any ambiguities regarding a same kind of measurement (e.g., body temperature and room temperature) [26] [27]. The composer should support all formats of IoT data, in priority, those supported by OpenIoT, Vital, SmartSantander and CityPulse, Linked Sensor Middleware (LSM) and Global Sensor Networks (GSN) platforms. The M3 language will be extended to fit our needs and align it with the sensor used within our testbeds.
2) *Unifying model/vocabulary/ontology to semantically annotate the data* is addressed by the **converter** which semantically annotates data in a unified way, thanks to a unified model which is aligned with existing IoT-related models. We preconize to extend the M3 converter which semantically annotates data according to the M3 ontology, an implementation of the M3 nomenclature/language and also an extension of the W3C SSN ontology. Moreover, the M3 ontology is already aligned with IoT ontologies such as OpenIoT, SSN and Spitfire. We will extend and align the M3 ontology with existing ontologies provided by the platforms such as VITAL and CityPulse.
3) *Unifying reasoning to interpret IoT data* is addressed by the **semantic reasoning engine**, a unified reasoning approach. The Sensor-based Linked Open Rules (S-LOR), is a sharing and reusing based approach and a dataset of interoperable rules to infer high-level abstraction from IoT data. S-LOR is compatibles with the M3 language and ontology. We suggest to extend S-LOR to deal with more complicated sensors and more complex reasoning approach such as machine learning [28] [29]. The M3 approach should be extended to address real-time and scalability challenges.
4) *Unifying architectures*. The FIESTA-IOT project reuses the **Architecture Reference Model (ARM)** designed by the IoT-A project [30] to unify architectures and projects.
5) *Unifying services*. A **Semantic query engine** is used to query a sub-set of high level abstractions inferred by the semantic engine to build sophisticated applications. The **Service** component will facilitate the task of end-users by hiding the semantic query engine or reasoning engine and get access to high-level data though web services and APIs. We could exploit the SWoT generator [6] [29] which produces Semantic Web of Things (SWoT) templates with an interoperable domain knowledge composed of rules, ontologies, datasets and SPARQL queries. SWOT is compatible with S-LOR, M3 ontology and language. The SWoT generator could be enriched and extended with a composition of templates to provide sophisticated smart city services/applications. Such challenges could be addressed with the composition of semantic web services.
6) *Real-time and scalable data analytics*. This challenge is addressed by the CityPulse EU project which is reused in the FIESTA project.

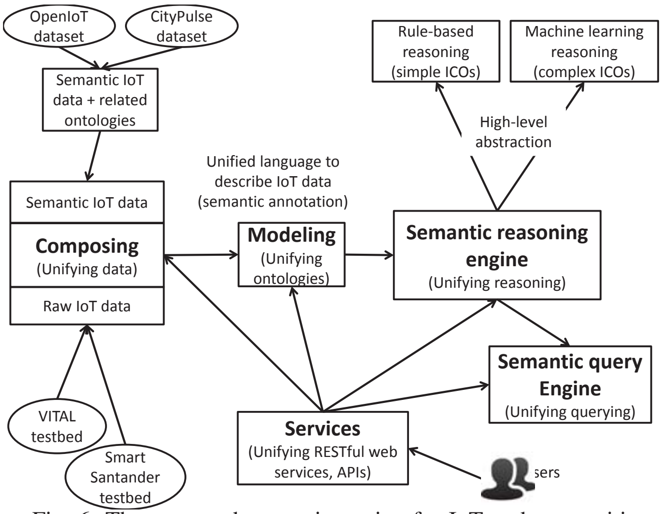

Fig. 6: The proposed semantic engine for IoT and smart cities

Unification feature/Projects	M3	VITAL	FIESTA
IoT data	Yes (M3 language)	Yes	Yes (Ongoing)
Ontology	Yes (M3 interoperable domain knowledge)	No	Yes (Ongoing)
Reasoning	Yes (S-LOR)	No	Yes (Ongoing)
Architecture	No	No	Yes (IoT-A reused)
Services	Yes (SWoT generator)	Yes (OpenIoT reused)	Yes (OpenIoT reused)
Real-time & scalability	No	Yes	Yes (CityPulse reused)

Fig. 7: Challenges for unifying data, vocabularies, reasoning, architectures and services applied to Internet of Things

VI. Use Cases

In this section, we discuss three projects that we are involved in which apply or will apply the proposed semantic engine to Internet of Things and/or Smart cities: Machine-to-Machine Measurement (M3), VITAL and FIESTA-IoT as depicted in Figure 7. For each project, we explain if they address the challenges presented above in section IV.

A. Machine-to-Machine Measurement (M3)

The Machine-to-Machine Measurement (M3) framework covers already implemented some parts of the entire workflow to semantically annotate sensor data, reason over it and build-semantic based IoT applications [31] M3 addresses the following challenges and provides concrete tools:

1) *Unifying IoT data* is addressed with the M3 language [27], a dictionary to unify sensor names, units, applicative domains and sensor measurement names.
2) *Unifying model/vocabulary/ontology* to semantically annotate the data. A dataset called Linked Open Vocabularies for Internet of Things (LOV4IoT) has been built to reuse the background knowledge and enhance interoperability [31] [32]. It references almost 300 ontology-based IoT projects exploiting sensors. Based on this catalogue, the M3 interoperable domain knowledge has been designed to ensure interoperability.
3) *Unifying reasoning to interpret IoT data* is addressed with Sensor-based Linked Open Rules (S-LOR) [24], a rule-based inference engine to deduce new information from sensor data. Stemming from the Linked Open Data approach, the authors built the Linked Open Rules to share and reuse interoperable rules to infer high level abstractions from sensor data.
4) *Unifying architectures* is not addressed by M3.
5) *Unifying services* is addressed by M3 with the Semantic Web of Things (SwoT) generator which produces templates to help IoT projects and developers in developing semantic-based IoT applications [26] [6]. The produced template provides a set of ontologies, datasets and rules to easily semantically annotate sensor data, reason over it, and build the application without having to design any ontologies.
6) *Real-time and scalable data analytics* is not addressed by M3.

B. VITAL

VITAL[6] is a EU project which is deployed in two cities: Istanbul and London [7]. The main goal of this project is to provide semantic interoperability between IoT applications and projects. They reuse the work achieved in OpenIoT and the W3C SSN ontology. The main objective of the VITAL project is to reduce the costs associated with developing new smart city applications.

1) *Unifying IoT data* is achieved through the VITAL ontologies.
2) *Unifying model/vocabulary/ontology* is achieved through the VITAL ontologies and the SSN ontology [33] but is not aligned to existing IoT ontologies.
3) *Unifying reasoning to interpret IoT data*. To the best of our knowledge, we did not find any papers regarding the reasoning processing.
4) *Unifying architectures*. The project designs its own architecture which is not based on previous ones such as IoT-A.
5) *Unifying services* is done by reusing the results provided by the OpenIoT project [34].
6) *Real-time and scalable data analytics* is addressed in this project.

C. FIESTA-IOT

The Federated Interoperable Semantic IoT/cloud Testbeds and Applications (FIESTA)[7] project reuses the work previously done in European project such as OpenIoT [34], CityPulse, VITAL and SmartSantander and will integrate the proposed semantic engine.

1) *Unifying IoT data* is addressing this challenge to deal with more than 4 different testbeds such as SmartSantander.
2) *Unifying model/vocabulary/ontology* is addressing this challenge through the FIESTA ontology which

[6]http://vital-iot.eu/
[7]http://www.fiesta-iot.eu/

unifies, aligns and reuses existing IoT-related ontologies to ensure interoperability.

3) *Unifying reasoning to interpret IoT data* is addressing challenges to support various reasoning approaches such as rule-based reasoning or machine-learning based reasoning. A system to unify different reasoning approaches will be designed.
4) *Unifying architectures* is done by reusing IoT-A architecture [30].
5) *Unifying services* is done by reusing the results provided by the OpenIoT project [34].
6) *Real-time and scalable data analytics* is addressed by reusing the results provided by the CityPulse project [13].

VII. Conclusion and Future Works

The main novelty of this paper is surveying and sharing our own vision of semantic web technologies applied to Internet of Things and smart cities. This analysis was essential to build a federated and unified semantic engine for Internet of Things and smart cities. We highlighted main research challenges and we discussed three uses cases: the Machine-to-Machine Measurement (M3) project, FIESTA-IoT and VITAL European projects which are addressing such challenges by designing an entire workflow to semantically annotate and reason over data by providing services to facilitate the integration of semantic web technologies to IoT developers.

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