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Connected Smart Cities: Interoperability with SEG 3.0 for the Internet of Things

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***Abstract*—The Internet of Things (IoT) is driving the technology and advances of the Internet and every day it is becoming more popular to talk about IoT systems in multiple domains: Smart Cities, Agriculture, and Industrial Internet, etc. Increasingly, IoT systems will need to interact and be interconnected for offering the always-promoted everything-connected paradigm. Current IoT systems rely on semantic web technologies for integrating data and ensure web services interoperability. However there are yet a gap to ensure semantic interoperability among IoT systems. Most of the existing proposed (open) approaches and solutions lack on formal methodologies for interoperability in technology and standard format of the data. We studied and analyzed most available semantic-based IoT approaches to identify the main requirements hindering IoT semantic interoperability. In this paper, we present SEG 3.0 a methodology to federate, unify and provide semantic interoperability. SEG 3.0 emerges from methodologies for ontology engineering and the idea of unification and federated systems. We propose SEG 3.0 and apply it to Internet of Things (IoT) and particularly on use cases for smart cities as proof of concept. Firstly, we define characteristics required for the methodology. Secondly, we describe the processes and the different formal steps. Thirdly, we provide a proof of concept framework and architecture applying this methodology; thus the benefits of using SEG 3.0 methodology in IoT domains are described. Finally, we demonstrate that the SEG 3.0 methodology is applied to three use cases: (1) the M3 framework to assist developers in designing semantic-based IoT applications, (2) the VITAL EU project for smart cities, and (3) the FIESTA-IoT EU project for IoT semantic interoperability. SEG 3.0 is a formal methodology generic enough to be applied to other domains than IoT and smart cities, since the main benefit of the SEG 3.0 is integrating heterogeneous data and adding value to it to build innovative applications.**

Keywords*—*Semantic Web of Things; Internet of Things; Semantic Web Technologies; Ontology; Methodology; Unification; Federation; Smart Cities; Interoperability

I. Introduction

Internet of Things (IoT) is a recent research field aiming to connect objects and devices to the Internet [1]. More recently, a new research field 'Web of Things' (WoT) [2] is being connecting Internet Connected Objects (ICOs) [3] to the web to easily get access to the data. Semantic Web of Things (SWoT) [4] is the most recent research field which is aiming to integrate semantic web technologies to WoT to ensure interoperability and for: (1) enriching and adding value to the data produced by ICOs to deduce high-level abstractions, (2) designing a common description of ICOs and their data, (3) agreeing on a common catalogue of ontologies to annotate sensor data in an interoperable manner and reuse domain knowledge, (4) providing smarter applications, and (5) ensuring security as explained in [5] [6] [7].

Until now, a big amount of projects, components, methods and techniques have been developed by different institutes and companies to be part of the Internet of Things (IoT). All existing solutions are trying to deal with the heterogeneity of devices, data and services. Some of them integrate semantic web technologies to enhance interoperability. The consequence is clear, the absence of standardized activities, life cycles and methodologies as well as a set of techniques and tools hinder an interoperable IoT. From one project to another project, semantic interoperability challenges remain. For instance, the existing projects neither use the same model to structure the data produced by Internet Connected Objects (ICOs) nor the same reasoning approach to deduce new knowledge from data produced by ICOs.

Moreover, most of the time the researchers are focused on one specific research field. The main novelty of this work is to take a different approach since we cover thirteen research fields related to semantic-based IoT: (1) Ubiquitous Computing, (2) Pervasive Computing, (3) Context-Awareness, (4) Ambient Intelligence, (5) Smart Homes, (6) Semantic Sensor Networks, (7) Ambient Assisted Living, (8) Internet of Things, (9) Web of Things, (10) Machine-to-Machine, (11) Semantic Web of Things, (12) Smart Cities, and (13) Cyber-Physical-Social (PCS). A deep analysis and explanations of current limitations and challenges are explained in [8]. All of these research fields addressed different challenges. However, all have the same vision which is providing innovative applications to end-users based on ICOs available in our surrounding environment. The current state of Internet of Things and related research fields are full of pieces of puzzle, numerous semantic-based components are available but not interoperable with each other. The main novelty and contribution of this paper is understanding as much as possible the existing components to build the final puzzle, a real interoperable semantic-based Internet of Things and Smart Cities.

We also analyze commonalities to build a generic approach to add value to heterogeneous data to build end-users semantic-based applications in fourteen domains: (1) healthcare, (2) smart homes, (3) transportation, (4) agriculture, (5) tourism, (6) weather, (7) smart city (8) smart energy, (9) food, (10) affective sciences, (11) activity recognition, (12) music, (13) environment, and (14) security. In this paper, we address the following challenges:

- How to add value to the data produced by ICOs?

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- How to ease the access of data to end-users?
- How to assist the research fields mentioned above and encourage interoperability among projects and components (e.g., integrating semantic web technologies, reasoning)?
- How to encourage the reuse of the existing literature?
- How to interconnect the existing components already designed?

On the one hand, methodology frameworks are widely accepted in different fields such as Software Engineering and Knowledge Engineering. Taking inspiration from such methodologies such as the one from the NeON project [9] [10], the main challenge will be proving a methodology to deal with heterogeneous data, an entire chain from heterogeneous data, to unify it, link it, reason on top of it to provide innovative applications and services. On the other hand, we also take inspiration from quantum physics which aims to unify approaches and theories, called 'theory of everything'[1]. In the same way, we are unifying the existing semantic-based technologies and approaches for IoT and smart cities.

The main contribution of this paper is an innovative and well-structured methodology called SEG 3.0 which defines: (1) each step precisely and the purpose, (2) the input and output of each step, (3) when the execution of each step is more convenient, and (4) the set of methods, techniques and tools to be used for executing each step, (5) the architecture associated to the methodology, and (6) the uses cases employing the proposed methodology. SEG 3.0 comes from segmentation and the new intelligent web of data called 3.0 based on semantic web technologies to interlink and enrich data instead of documents[2]. This methodology is applied to the context of IoT and smart cities but could be reused in different research fields aiming to integrate semantic web technologies to enrich heterogeneous data. We have to facilitate the use of this methodology by software developers and IoT practitioners. This methodology could be applied to all IoT-related research fields such as pervasive computing, ubiquitous computing, etc.

The rest of the paper is structured as follows: section II presents the related work and clearly explains the limitations. Section III describes the characteristics required for building the methodology. Section IV discusses the different steps of the proposed methodology called SEG 3.0. Section V describes the architecture applying the SEG 3.0 methodology in the context of IoT and smart cities. Section VI details three use cases: the M3 framework, FIESTA-IOT and VITAL projects taking benefit from the SEG 3.0 methodology. Finally, we conclude the paper in section VII.

II. Related work

In this section, we review existing ontology methodologies and the IERC AC4 which is focused on semantic interoperability for IoT and we highlight limitations of current approaches.

A. *Ontology Methodology*

In this section, we describe work regarding ontology methodologies since ontology is a cornerstone component to ensure semantic interoperability: Noy et al., Neon, On-to-Knowledge and Methontology. Noy et al. explain in the second step of their **ontology development 101 methodology** that ontology designers should consider reusing existing domain knowledge (e.g., ontologies) [11]. The **Neon** project[3] recommends reusing available knowledge and proposes a set of methodologies [9] [10]. The Neon project focuses on nine scenarios [10]: (1) from specification to implementation, (2) reusing and re-engineering non-ontological resources, (3) reusing ontological resources, (4) reusing and re-engineering ontological resources, (5) reusing and merging ontological resources: ontology matching tools enable ontology aligning or merging, (6) reusing merging, and re-engineering ontological resources, (7) reusing ontology design pattern (ODPs), (8) restructuring ontological resources, and (9) localizing ontological resources to translate of all the ontology terms into another natural language. **On-to-Knowledge** is another methodology for designing ontologies comprised of four steps: (1) kick-off, (2) refinement, (3) evaluation, and (4) ontology maintenance [12]. **Methontology** is a methodology used to build ontologies from scratch [13] and highly encourages the reuse of existing ontologies. The methodology comprises several steps: (1) planification, (2) specification, (3) knowledge acquisition, (4) conceptualization, (5) formalization, (6) integration, (7) implementation, (8) evaluation, (9) documentation, and (10) maintenance.

Such methodologies are mainly for designing and reusing ontologies. Taking inspiration from such work, we design a new methodology to encourage the reuse of semantic-based IoT components, tools and approaches.

B. *IERC AC4 Cluster: Semantic Interoperability for IoT*

The European Research Cluster on the Internet of Things (IERC) AC4 released in March 2015 a set of best practices and recommendations for semantic interoperability [3] [14]. They mention the need to overcome the following challenges: (1) a unified model to semantically annotate IoT data, (2) reasoning mechanisms, (3) linked data approach, (4) horizontal integration with existing applications, (5) design lightweight versions for constrained environments, and (6) alignment between different vocabularies.

In this paper, we propose to go beyond their recommendations by designing a methodology to encourage semantic interoperability among IoT applications. IERC AC4 defines four interoperability issues: (1) technical interoperability, (2) syntactical interoperability, (3) semantic interoperability, and (4) organizational interoperability. *Technical interoperability* that concerns heterogeneous software and hardware (e.g., communication protocol heterogeneity). *Syntactical interoperability* that concerns data formats (e.g., JSON or XML). Syntactical interoperability is also an issue for combining and reusing ontologies or semantic datasets developed with different software dealing with different syntaxes (e.g., RDF/XML, N3). *Semantic interoperability* that concerns (1) ontology heterogeneity (e.g., ontology designed by different persons differ

[1]https://en.wikipedia.org/wiki/Theory_of_everything
[2]http://www.tweakandtrick.com/2012/05/web-30.html
[3]http://www.neon-project.org/

in the structure), (2) terms used to describe data (e.g., t, temp and temperature are several terms to describe temperature), and (3) the meaning of data exchanged according to the context (e.g., body temperature differs from room temperature). This is important to later interpret IoT data and build smarter and interoperable semantic-based IoT applications. IERC AC4 underlines the need to be agreed on common vocabularies to describe data. *Organizational interoperability* that concerns heterogeneity of the different infrastructures.

In this paper, we are mostly focused on semantic interoperability challenges and provide a methodology to ensure semantic interoperability among IoT projects.

C. Limitations of current approaches

The NeON methodology is focused on ontology networks and reusing ontologies. We take inspiration from the NeON methodology to design a methodology regarding semantic interoperability applied to IoT and smart cities. Besides the IERC AC4, we did not find any approaches designing methodologies and best practices regarding semantic interoperability applied to IoT. The IERC AC4 proposes a set of best practices, but do not provide or recommend any methodologies to ensure semantic interoperability. To the best of our knowledge we did not find any work analyzing all IoT-related research fields and deeply analyzing interoperability issues.

III. CHARACTERISTICS

We have taken as a staring point the NeON methodology and adapt the research methodology, development process, life cycle models in software engineering and we have adapted them to the specific characteristics of Internet of Things and related research fields such as Smart Environments (e.g., smart cities or smart homes), Pervasive Computing, Ubiquitous Computing, Context Awareness, Machine-to-Machine, etc.

We define the following twelve characteristics to design the methodology inspired from the NeON methodology [10] [9]: (1) generality, (2) completeness, (3) effectiveness, (4) efficiency, (5) consistency, (6) finiteness, (7) transparency, (8) easiness, (9) scalability, (10) horizontality, (11) verticality, and (12) security. **Generality** means that the methodology should be to be generic enough to be applicable to all research fields mentioned above or even broader research fields such as healthcare. **Completeness** means it supports all uses cases. **Effectiveness** means it solves adequately the uses cases. **Efficiency** would be able to achieve its objective or goal. It means that the proposed methodology should allow the construction of semantic-based IoT applications. In order to achieve this goal, we should provide concrete tools and recommendations as well to ease the adoption of the proposed methodology. **Consistency** means that the result of the methodology should be the same when we apply it several times to the same problem. **Finiteness** means that the number of steps within the methodology should be finite. **Transparency** hides the complexity of technologies employed in a black box. **Easiness** facilitates the understanding and the learning phase in order to encourage its success and its generalized use. **Scalability** deals with 'Big Data' analysis. **Horizontality** deals with different application domains. **Verticality** deals with different layers of the system. **Security** addresses security, privacy and trust issues.

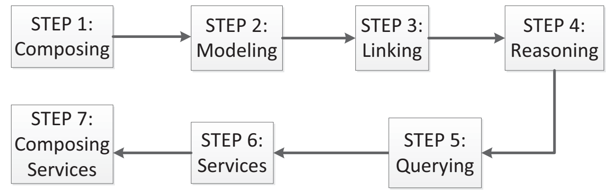

Fig. 1: The SEG 3.0 conceptual framework

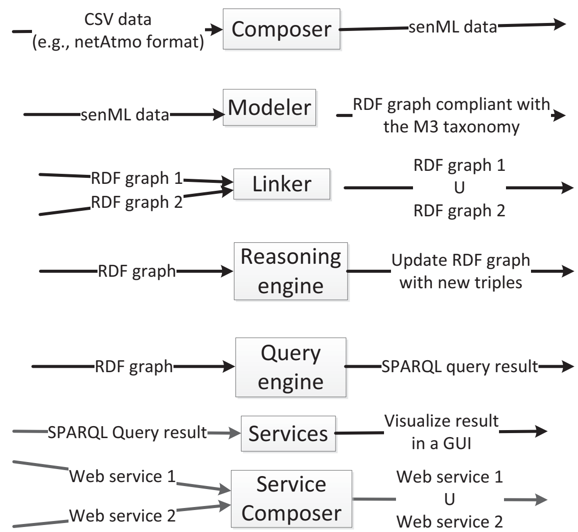

Fig. 2: The SEG 3.0 functional framework

To sum up, the methodology should answer to the six following questions: what, who, why, when, where and how.

IV. SEG 3.0 METHODOLOGY: PROCESSES AND STEPS

In this section, we describe the different processes and steps required to combine data from heterogeneous sources to build innovative and interoperable applications as depicted in Figure 1, Figure 2 and Figure 3. The figures introduce the SEG 3.0 methodology which comprises the following steps: (1) composing, (2) modeling, (3) linking, (4) reasoning, (5) querying, (6) services, and (7) composition of services.

1) **Composing** enables unifying heterogeneous data coming from different projects and using different data formats (e.g., CSV, Excel) or different terms (e.g, temp or temperature). It requires a common dictionary to unify terms employed to describe data. The composer will return the SenML format to describe sensor data [15].
2) **Modeling** enables semantically annotating data with semantic web technologies (e.g., RDF, RDFS and OWL). This step employs models/vocabularies/ontologies to unify data, a required step for the following processes. The M3 ontology is used to unify semantic sensor data [16].

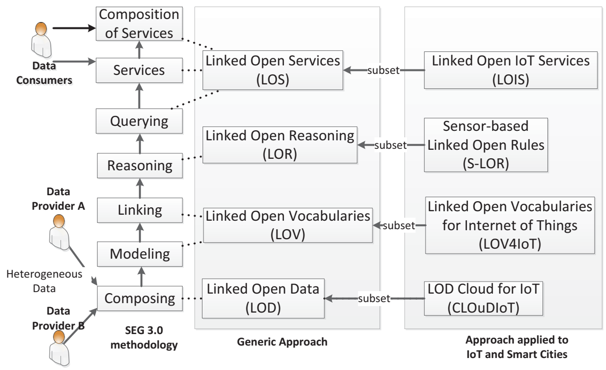

Fig. 3: The SEG 3.0 methodology ensuring Semantic Interoperability from data providers to data consumers

3) **Linking** enables enriching the data with other RDF datasets to get additional information. It exploits the idea of Linked Data and Linked Vocabularies.
4) **Reasoning** enables updating the database/triple store with additional triples for instance by using reasoning engine (e.g., Jena rule-based inference engine) to infer high level abstraction from sensor data. It exploits the idea of Linked Rules.
5) **Querying** enables querying RDF datasets through the SPARQL language based on ontologies used in the previous steps. It is an essential steps to get data and build end-users services/applications.
6) **Services** enables providing access to smarter data to end-users. The data is available through interoperable APIS or web services (e.g., RESTful web services). Such web services returns the result provided by the SPARQL query engine.
7) **Composition of services** enables building complex application by composing several services together. It can be achieved through the use of web services or semantic web services.

The SEG 3.0 methodology also encourages the vision to enhance semantic interoperability from data to end-users applications which is inspired from the 'sharing and reusing' based approach as depicted in Figure 3 which comprises: (1) Linked Open Data (LOD), (2) Linked Open Vocabularies (LOV) (3) Linked Open Rules/Reasoning (LOR), and (3) Linked Open Services (LOS). In this paper, the contribution is envisioning, enriching and extending these approaches and apply it to IoT and smart cities. **Linked Open Data (LOD)** is an approach to share and reuse the data [17] [18]. Previous work regarding 'Linked Sensor Data' [19] [20] do not provide any tools for visualizing or navigating through IoT datasets. For this reason, we are currently designing Linked Open Data Cloud for Internet of Things (CLOuDIoT) to share and reuse data produced by sensors. **Linked Open Vocabularies (LOV)** is an approach to share and reuse the models/vocabularies/ontologies [21]. LOV did not reference any ontologies when they do no follow the best practices. Due to this requirement, almost all ontologies for IoT and relevant domain ontologies were not referenced on this tool. For this reason, we have designed the Linked Open Vocabularies for Internet of Things (LOV4IoT) [8], a dataset of almost 300 ontology-based IoT projects referencing and classifying: (1) IoT applicative domains, (2) sensors used, (3) ontology status (e.g., shared online, best practices followed), (4) reasoning used to infer high level abstraction, and (5) research articles related to the project. This dataset contains a background knowledge required to add value to the data produced by Internet Connected Objects (ICOs). **Linked Open Reasoning (LOR)** is our proposed approach to share and reuse the way to interpret the data to deduce new information (e.g., machine learning algorithm used, reusing rules already designed by domain experts). We have designed Sensor-based Linked Open Rules (S-LOR), a dataset of interoperable rules (e.g., if then else) used to interpret data produced by sensor data [22]. Such rules are executed with an inference engine (e.g., Jena) which updates the triple store with additional triples. For example, the rule can be if the body temperature is greater than 38 degree Celsius than fever. In this example, the triple store will be updated with this high level abstraction 'fever'. Our proposed approach is inspired from the idea of 'Linked Rules' [23] which provides a language to interchange semantic rules but not the idea of reusing existing rules. **Linked Open Services (LOS)** to share and reuse the services/applications. This approach is inspired by [24] [25] [26], we have in mind to extend their work. To build complex applications, we could provide composition of services. A service can be implemented according to RESTful principles or with the help of semantic web technologies to enhance interoperability (e.g., OWL-S). We have in mind to design Linked Open Services for Internet of Things (LOS4IoT), a set of interoperable services specific to IoT.

The main novelty of our vision, is not only sharing and reusing data, but sharing and reusing the entire chain from Linked Open Data (LOD) to Linked Open Services (LOS) to add value to the data: the models, the reasoning and the services associated to the data.

V. Framework and Architecture

In this section, we describe our proposed architecture applying the above SEG 3.0 methodology which comprises 12 layers as depicted in Figure 4: (1) *Hardware layer* is specific to IoT and smart cities to get data produced by ICOs, (2) *Communication layer* sends data to the Internet and Web to easily get access to data from ICOs, (3) *Middleware layer* harmonizes existing platforms, (4) *Data layer* unifies data coming from heterogeneous sources and projects, (5) *Ontology layer* models data in a unified way, (6) *Linking layer* enriches data with other datasets, (7) *Reasoning layer* deduces high level knowledge from data, (8) *Security layer* covers all layers, (9) *Query layer* to select a subset of data or specific ontologies, rules etc. (10) *Validation layer* validates the previous steps to check that interoperability is ensured, (11) *Service layer* provides interoperable services to facilitate the composition of existing ones, (12) *Visualization layer* provides interoperable and reusable friendly user interfaces to display selected and enriched data.

Its main goal is dealing with heterogeneity of: (1) resources/devices, (2) communication networks, (3) data, (4) reasoning, and (5) services.

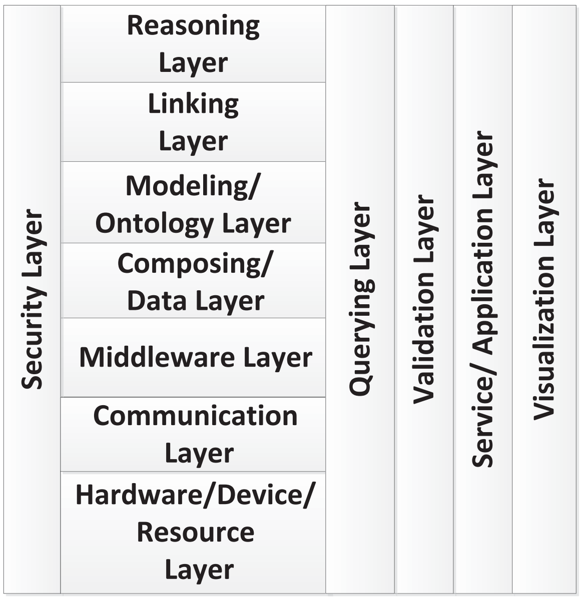

Fig. 4: Overview of the architecture

Feature	M3	VITAL	FIESTA
Generality	Yes	No	Yes
Completeness	No	No	Yes
Effectiveness	Yes	No	Yes
Efficiency	Yes	Yes	Yes
Consistency	No	Yes	Yes
Finiteness	No	No	No
Transparency	Yes	No	No
Easiness	Yes	No	Yes
Scalability	No	Yes	Yes
Horizontality	Yes	No	Yes
Verticality	Yes	No	Yes
Security	Yes	No	Yes

TABLE I: Use cases satisfying characteristics

VI. USE CASES

In this section, we emphasize the SEG 3.0 methodology through the description of three use cases: (1) the M3 framework to ensure interoperability of IoT data and applicative domains, (2) smart cities with the VITAL EU project to ensure interoperability of applications, and (3) the FIESTA-IoT EU project to ensure interoperability among systems, data and applications. Table I reuses the characteristics presented in section III and indicates if they are addressed for each project.

A. M3: Semantic Interoperability of IoT Data

The Machine-to-Machine Measurement (M3)[4] is at the same time a workflow, a semantic engine and a framework [27]. M3 has been mainly focused on interoperability of data to later provide high level abstractions from sensor data by using linking and reasoning approaches using Linked Rules and Linked Data principles. Moreover, M3 provides an approach to bridge the gap of horizontal and vertical features by proving a method for interoperable domain knowledge through pre-defined semantic-based IoT templates. Further, M3 addresses security issues by helping IoT developers secure applications.

In [28], we designed the semantic engine called M3. A same sensor measurement/IoT data (e.g., temperature 38.7 DegC) is produced by a thermometer from two different applicative domains: healthcare and weather forecasting. This example highlights the necessity to: (1) explicitly add description to sensor measurements, (2) interpret IoT data, and (3) combine domains to design cross-domain applications. The M3 workflow comprises the following steps:

- **Composing**. This component returns sensor descriptions such as temperature 38.7 DegC. Such descriptions are implemented according to the SenML language [15].
- **Modeling**. This components semantically annotates SenML data according to the M3 language and ontology, which is required to ensure interoperability in the future steps.
- **Reasoning**. This component uses the idea of 'Linked Rules' applied to IoT [22], a set of interoperable rules compliant with the M3 ontology to infer high-level abstractions. The reasoning engine infers additional knowledge: the concept 'fever' from the body temperature, and the concept 'hot' from the outside temperature. If-then-else rules are implemented using the Jena framework and inference engine,
- **Linking**. The reasoning engine updates the triplestore with additional knowledge which is linked to the M3 interoperable domain ontologies and datasets used in pre-defined semantic-based IoT templates. The interoperable domain knowledge has been extracted from the Linked Open Vocabularies for Internet of Things (LOV4IoT) dataset[5] that we designed.
- **Querying**. A SPARQL query engine is used to query the M3 interoperable cross-domain knowledge compliant with the semantically annotated sensor data to get smarter data and suggestions.
- **Services**. The M3 interoperable domain knowledge is used to combine domains and provide suggestions. For instance, food related to the fever symptom, and food related to season. Since food referred to the same namespace in both domain knowledge, it is easy to combine domains. This step enables building final applications (e.g., naturopathy, tourism, transport) by using the Semantic Web of Things (SWoT) generator [29], a tool to assist IoT developers in designing semantic-based IoT applications.

All of these steps are done by loading the SWoT template provided by the SWoT generator to easily build semantic-based IoT applications and enrich IoT data. The provided results will be later parsed and exploited in the final application such as the naturopathy application which suggests home remedies when fever is detected. The final application could be a user-friendly interface or even send notification, alerts or send order to actuators.

[4]http://sensormeasurement.appspot.com/

[5]http://sensormeasurement.appspot.com/?p=ontologies

B. VITAL: Interoperability of Smart City Applications

The SEG 3.0 methodology can be applied to other use cases such as smart cities willing to integrate semantic web technologies. For instance, the VITAL EU project[6] uses semantic web technologies to provide interoperability among applications and services. Indeed, smart cities want to overcome the same challenges: providing applications based on data produced by Internet Connected Objects (ICO). The SEG 3.0 approach assists in dealing with heterogeneous devices, data and enrich it with semantic web technologies to provide smarter data and build innovative applications. Thanks to the proposed methodology presented above, we are able to provide interoperable components to deal with the entire chain from hardware devices to final end-users applications.

C. FIESTA: Semantic Interoperability for IoT

Federated Interoperable Semantic IoT/cloud Testbeds and Applications (FIESTA-IoT)[7] is a EU project which reuses the work previously done in European project such as OpenIoT, CityPulse, VITAL and SmartSantander.

The FIESTA project works on integrating IoT platforms, testbeds, data and associated silo applications. FIESTA aims for opening up new opportunities in the development and deployment of experiments that exploit data and capabilities from multiple testbeds. The FIESTA infrastructure looks at enabling experimenters to use a single Experiment-as-a-Service (EaaS) API (i.e. the FIESTA-IoT EaaS API) for executing experiments over multiple IoT federated testbeds in a testbed agnostic way i.e. like accessing a single large scale virtualized testbed. The main goal of the FIESTA project is to open new horizons in the development and deployment of IoT applications and experiments at an EU (and global) scale, based on the interconnection and interoperability of diverse IoT platforms and testbeds. FIESTA project's experimental infrastructure is targeting to be the entry point for European experimenters in the IoT domain with the unique capability for accessing to and sharing IoT datasets in a testbed-agnostic way. Execution of experiments across multiple IoT testbeds, based on a single API for submitting the experiment and a single set of credentials for the researcher and the portability of IoT experiments across different testbeds and the provision of interoperable standards-based IoT/cloud interfaces over diverse IoT experimental facilities.

FIESTA will integrate the proposed SEG 3.0 methodology through the semantic engine [30] which comprises the following components:

- **Composing** enables unifying IoT data to deal with more than four different testbeds such as SmartSantander.
- **Modeling** enables unifying models/vocabularies and ontologies is addressing this through the FIESTA ontology which unifies, aligns and reuses existing IoT-related ontologies to ensure interoperability.
- **Semantic reasoning engine** enables unifying reasoning approaches to interpret IoT data such as rule-based reasoning or machine-learning based reasoning. A system to unify different reasoning approaches will be designed.
- **Semantic query engine** enables unifying SPARQL queries to get access to data or inferred data.
- **Services** enables unifying applications and services to provide complex ones by composing services.

[6]http://vital-iot.eu/

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

VII. Conclusion and Future Works

The main contribution of this paper is providing an entire methodology, called SEG 3.0 to deal with heterogeneous data and add value to it. The methodology comprises steps and components to combine and unify heterogeneous data using semantic web technologies. Moreover, it enriches data through linking and reasoning processes and provides access to inferred data through interoperable services. We also presented the architecture to apply this methodology in the context of IoT and smart cities by reusing implemented (open) tools. The main novelty and contribution of this paper was analyzing interoperability issues to be able to provide the glue to connect existing semantic-based projects (e.g., IoT, smart cities, pervasive computing, etc.). As a future work we plan to provide tools to encourage the use of the methodology.

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