Approach for Semantic Interoperability Testing in Internet of Things

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***Abstract*—The Internet of Things (IoT) systems must support deployment of new services capable of supporting multiple, scalable and cross-domain applications. But the current IoT applications and services are highly fragmented in terms of platform development, data and security. Semantic interoperability is widely acknowledged to be the key to address the challenges and achieve the full potential of the IoT systems. Although semantic interoperability has received increased attention in the recent days, the current IoT systems lack means for testing that. This paper describes our approach for semantic interoperability testing in the IoT. We have identified three main requirements for semantic tests - (i) lexical check, (ii) syntactic check and (iii) semantic checks. To examine semantic interoperability between IoT systems, we define two types of tests - (i) semantic conformance test and (ii) interoperability test. The operational steps are presented along with detailed test scenarios.**

***Keywords*-Internet of Things; Semantic Interoperability; Testing; Web of Things.**

I. Introduction

The Internet of Things (IoT) is ushering many benefits to individual consumers and enterprises by deploying new services capable of supporting scalable and horizontal applications. While there are many IoT products and services available now-a-days, there is a clear fragmentation in the market. It is dominated by many IoT platforms with proprietary use of data exchange protocols, common service functions and security mechanisms. As a result, cross-platform exchange of IoT data and collaborative scenarios are very difficult to achieve. It is widely acknowledged that semantic interoperability can harmonize the IoT platforms and address the fragmentation problem. According to [1], semantic interoperability is the ability of two or more IoT systems to automatically interpret the meaning of high-level information communicated to them and arrive at equivalent meanings.

Semantic web technologies (SWT) allow representing IoT resources and interpreting the IoT data in a uniform way [2]. For this purpose, a collection of ontologies for the IoT can be found in [3]. SWT enables machine understandable metadata, annotations that ease IoT device discovery, device management, reasoning on raw IoT data and combine data from many domains to build a true cross-domain IoT application involving different sources of the IoT data. Therefore, use of SWT is of paramount importance to achieve semantic interoperability among the IoT systems. Many research and industrial initiatives are giving increased attention to this feature to achieve the full potential of the IoT systems. For example, the EU H2020 FIESTA-IoT project provides a reference architecture for federating IoT testbeds and other infrastructure while supporting semantic interoperability [4].

But an extensive survey performed in this paper to examine the current state of the IoT reveal that there is no mechanism to test semantic interoperability between two IoT systems. Therefore, the paper is dedicated to present approaches for semantic interoperability testing among IoT systems. Our contributions focus on - (i) identifying the requirements for semantic tests and (ii) proposing two types of test to check semantic interoperability. The test scenarios of both the types along with their operational steps are also described in detail.

The remainder of the paper is structured as follows. Section II reports the state-of-the-art in semantic interoperability. Section III surveys three Standard Development Organizations and their ongoing works on semantic web technologies relevant for our study. Section IV describes the requirements, types and test scenarios of semantic interoperability. Finally, the paper concludes in Section V.

II. State-of-the-art

This section studies the relevant current literature that have addressed IoT interoperability through semantic web technologies. We have classified them into several broad areas - (i) architecture, framework & data, (ii) ontologies and semantic modeling, (iii) application layer and (iv) platform interoperability. The rest of the section describes our findings related to these areas.

A. Architecture and Framework Aspects

A semantic level interoperability architecture is presented in [5]. The capabilities of heterogeneous IoT devices and data generated by them are represented using semantic web technologies. Therefore, all interactions with such devices with rest of the IoT ecosystem are based on semantic information sharing with SPARQL 1.1 [6]. The proposed IoT architecture is composed of many local smart spaces which are managed by a semantic information broker (SIB). It provides a method for monitoring and updating the virtual instances of the physical devices. The authors have also compared their architecture with IoT-A Architecture Reference Model (ARM) to further outline the interoperability aspects.

Similar concepts are also applied to an IoT framework for agriculture [7]. This paper presents an Agri-IoT information model which together with the framework is applied to two scenarios - (i) fertility management of dairy cows and (ii) soil fertility for crop cultivation. Evaluations performed show that the use of can scale up to a medium sized firm that deploys around 300 sensors. The authors noticed some limitations around dynamicity and autonomy of the system.

Global IoT services must achieve semantic interoperability among IoT architecture components for seamless consumer experience. The authors of [8] have argued in favor of using oneM2M for this purpose. The paper introduced the concept of semantic mediation gateway (SMG). It transforms IoT data from a representation used in an IoT system (e.g. oneM2M) into IoT data representation used in another IoT system (e.g. FIWARE). This transformation of IoT data is aided by semantic annotations and knowledge base. The paper also presents a semantic validation phase which allows testing and verification leading to semantic interoperability check between IoT systems.

An IoT architecture containing an semantic interoperability mapping layer is introduced in [1]. It is essential for defining how the same high-level information is used by different actors (e.g. device manufacturer, platform provider, end-user etc.) of the IoT ecosystems. The layer makes use of a semantic registry and ontologies.

The IoT data can be efficiently used when the IoT ecosystems achieve seamless interoperability. In that case, the processed high level information will be interpreted in same manner across the ecosystems. The authors of [9] focus on semantic data provisioning and reasoning methods.

B. Ontologies and Semantic Modeling Aspects

Several research projects including the EU Inter-IoT project[1] have investigated semantic technologies and consider ontologies as the basis of providing interoperability [10].

The authors of [11] has pointed out semantic modeling as a key to achieve interoperability among heterogeneous IoT entities (devices, middleware etc.). They have considered ontologies as the central pieces to create a unified semantic knowledge base for IoT. Most of the ontologies used in IoT include only resources, services and location. But the authors extended them to incorporate context information and policies for execution. Through the work, the authors effectively point out that interoperability can be achieved among heterogeneous IoT resources, location and context information.

Recently, several IoT consortia and standard development organizations (including oneM2M) have achieved interoperability at the communication and networking level. The paper [12] proposes an expressive ontology IoT-O for semantic interoperability. The IoT-O defines models for service, observation, sensor, actuator and actuation. The authors incorporated the ontology to OM2M[2] which provides an open source implementation of oneM2M IoT standard architecture. Discovery of newly plugged devices and their automatic management (through self-configuration) are performed as an experiment to demonstrate the semantic interoperability. An instance of IoT-O for smart building is also provided.

Automatic deployment of the IoT services can be done through a semantic model called Semantic Service Description (SSD) ontology [13]. It mainly provides a common description of heterogeneous IoT devices. The top level concept of SSD includes a service object which has a property, capability and server profile. This ontology claims to achieve IoT platform interoperability through semantic service deployment. It is done in three steps - metadata extraction, service description generation and service deployment.

Including SWT in the IoT systems increase processing time and code complexity. To address these concerns of software developers, IoT-Lite is proposed in [14]. It is a lightweight instantiation of W3C SSN ontology. IoT-Lite provides a compact mechanism to represent key IoT concepts for quick resource discovery and promotes interoperability. An experiment on sensor query RTT time using IoT-Lite and IoT-A model shows that - (i) the former outperforms the latter significantly and (ii) IoT-Lite is highly scalable and works well with high volume of sensors.

Life cycle of IoT devices and software stacks are often not fully explored. The authors of [15] applied semantic modeling and ontologies that collect and reuse product-service life cycle data from IoT frameworks. They have demonstrated the utility of the ontology though an use case on IoT enabled electric vehicle services.

An adaptive ontology based model for interoperability for resource discovery in IoT is described in [16] while a unified IoT ontology for interoperability and federation of test bed is presented in [17].

C. Application Layer Aspects

Similar to the Machine-to-Machine Measurement (M3) framework[3], [18] applied SWT to smart city applications for sharing, integrating and reusing data. Semantic data annotation is the key topic addressed in this paper. The solution is deployment to three cities for trial and experimentation.

Additionally, best practices to achieve semantic interoperability at ontologies and data interpretation are mentioned in [19].

D. Platform Interoperability Aspects

The IoT Platforms have become a central element in every domains like smart home, connected car, fitness, industry 4.0 etc. But the fragmentation arising due to lack of interoperability among the platforms hinder a quick adoption of the IoT. The EU project BIG IoT[4] aims to bridge the interoperability gap among current and emerging IoT platforms [20]. Naturally

[1] http://www.inter-iot-project.eu/

[2] http://www.eclipse.org/om2m/

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

[4] http://big-iot.eu/

the project exploits SWT to provide interoperability at IoT applications, services and among platforms. The first step towards that involves syntactic interoperability. It can be achieved through common vocabularies, agree data formats, interface definitions and encodings. The second step builds upon the first step and considers agreed-upon information model for the exposed interfaces and exchanged data. Together the two steps achieve semantic interoperability. The authors have closely examined the interaction of functional elements in the IoT platforms. Five interoperability patterns have emerged from the analysis - (i) cross platform access, (ii) cross application domain access, (iii) platform independence, (iv) platform scale independence and (v) higher level service facades. A BIG IoT architecture is presented that supports all of the five patterns and this is a significant contribution of the project.

Apart from the above, we found a new concept of dynamic control interoperability and a middleware for that is presented in [21].

III. Semantic Interoperability in Standard Development Organizations

Semantic interoperability is an emerging area that Standards development organizations such as W3C Web of Things Working Group, ETSI, oneM2M, and the AIOTI Working Group 3[5] are investing a lot of resources to address it. This section discusses the semantic interoperability initiatives in major standard development organizations.

A. oneM2M

oneM2M is a global IoT standardization initiative, and one of the main standardization bodies in the IoT, Machine-to-Machine (M2M) Communications context. SWT is considered as a promising solution to address one of the biggest challenges: the interoperability between numerous and heterogeneous entities.

The oneM2M ontology[22], named *base ontology*, aims to provide a high level ontology for the IoT market in order to provide a minimal set of common knowledge that enables the cross-domain syntactic and semantic interoperability. As it is quite high-level and abstract, oneM2M expects external ontologies that describe a specific domain of interest in a more detailed way to be mapped to the oneM2M base ontology. With these mappings of different domain-specific ontologies to oneM2M base ontology, the communication between devices and things from different domains is enabled.

Semantic related specifications have been already progressed and several oneM2M implementations support these semantic features. oneM2M had organized its first semantic interoperability session[6] where four implementations were interconnected to test the semantic features. They implementors had shared their experiences on applying semantics in interoperability and security aspects.

[5]https://aioti.eu/working-groups/

[6]http://www.etsi.org/news-events/events/1211-onem2m-interop-5

B. ETSI SmartM2M and ISG CIM

The Smart Appliances REFerence (SAREF) [23] ontology is designed for household and home appliances in residential buildings, especially for the purpose of energy management. SAREF aims to align existing ontologies in the domain of smart appliances. Many standards have been proposed to enable the interoperation of appliances from diverse vendors. However, the number of standards is so high that overlapping is inevitable. To address this problem, the European Commission launched a study for the purpose of proposing a reference ontology gathering the efforts of existing appliances standards relevant for energy efficiency. The final result of this study is the SAREF reference ontology that is intended to be transferred to European Telecommunications Standards Institute (ETSI) Smart Machine to Machine (SmartM2M) that could contribute it to oneM2M initiative. The latest version of SAREF[7] includes several extensions in order to cover different application domains (Energy, Environment and Buildings).

The Context Information Management (CIM) Industry Specification Group (ISG)[8] aims to bridge the gap between abstract standards and concrete implementations by issuing technical specifications. They enable developing interoperable software implementations of a cross-cutting Context Information Management (CIM) Layer. The ISG drafts technical specifications on extending the OMA NGSI API using JSON-LD in order to take into consideration the missing features for a software that needs to implement the current IoT standards.

C. W3C Web of Things

The W3C Working Group on Web of Things (WoT) also identifies the fragmentation problem in the IoT market. The WoT initiative[9] aims improve interoperability and usability of the underlying IoT platforms. Within the WoT, the Thing Description (TD) fosters semantic interoperability through a common and uniform format through which details necessary to access the Things and their capabilities are described [24].

IV. Testing of Semantic interoperability

As described in section II and III, many efforts have been put on semantic interoperability research, however, no generic methodology for testing such interoperability has been clearly identified and formulated. Starting from the key enabling aspects identified through the above research, we will describe our proposition for such testing methodology and the way to achieve that.

A. Requirements for semantic tests

One of the core aspect to achieve the semantic interoperability is the ontology and the data annotation using ontology. The evaluation of ontologies and annotated data is essential to determine if they are interoperable with other

[7]http://ontology.tno.nl/saref/

[8]http://www.etsi.org/news-events/news/1152-2017-01-news-etsi-launches-new-group-on-context-information-management-for-smart-city-interoperability

[9]https://www.w3.org/WoT/

ontologies, especially the reference ontologies recognized by standardization bodies such as W3C-SSN ontology, ETSI-SAREF ontology and oneM2M base ontology. Once reference ontologies have been defined, one important step to ensure semantic interoperability is to test conformity to such reference ontology(ies) [25]. In this perspective, we propose a three-level validation for conference testing.

1) **Lexical check**. This level of check consists of verifying the correctness of RDF serialization regarding to the declared type. For example, the semantic data is marked in XML representation (ex. Specified in the file suffix) whereas the semantic annotation is indeed serialized in JSON, or the document is detected as XML but contains some error that causes parse error, the lexical check fails.
2) **Syntactic checks**. After the basic lexical checks, the syntactic check consists of verifying the correctness of the syntax of the RDF triples represented by the underlined serialization format, more specifically:
    a) **Untyped of resources and literals**. Here resource refers to instances of a class, and literal refers to a textual or numerical value. The type of resource or literal is the link of an annotation back to the ontology which enables the semantic capabilities. Any untyped element presented in an annotation is problematic towards the semantic interoperability.
    b) **Ill-formed URIs**. URI is essential and critical for identification of a resource. They shall be checked against RFC 3968[10] which defines the generic syntax of URI.
    c) **Problematic prefix and namespaces**. Namespaces play the role of linking the annotation to the reference ontologies and vocabularies. If the URI of the namespace is problematic (e.g. wrong URI, URI contains illegal character), it may cause others to mis-interpret the data semantics and types. Prefix is a unique reference to replace the namespaces in the local file. A one-to-one mapping between the prefix and namespace is essential and shall be checked to ensure a correct reference.
    d) **Unknown classes and properties**. A prerequisite of semantic interoperability is that all the resources use a common and agreed vocabulary. As consequence, if any resource uses in its annotation a class or property that is not defined in the reference ontology(ies), other resources would have no way to understand it, so that the semantic interoperability is impossible.
3) **Semantic checks**. Following a successful syntactic validation, the semantic check consists of verifying the logical consistence of the semantic annotation regarding to the reference ontology(ies):
    a) **Cardinality inconsistency**. If the ontology defines that class A can have one and only one instance of child class B, and in the annotation, there are two instances of B related to one instance of A, there is a problem.
    b) **Problematic relationship or inheritance**. Following the relationship defined in the reference ontology, if an instance of a class A is wrongly annotated to be at same time an instance of class B which is disjoint from class A, there is a conflict and the instance cannot be resolved by the semantic engine.

The conformance testing is mainly based on a client-system architecture as the user need a remote system that perform the validation. In the same sense, we extend this architecture to include a client-client architecture. In this case, the interoperability test is to check whether two Systems Under Test (SUTs) put together can understand each other and work together. Applying this basic definition to semantic interoperability test, a semantic interoperability needs to check if two systems can collaborate on the data level using the semantic data exchanged. Thus, three levels of validation are necessary:

1) **The communication level check**. The message sent from system 1 should be received completely and correctly by system 2.
2) **The lexical/format level check**. The message issued from system 1 should be in a correct and understandable format for system 2 for further data processing
3) **The data processing level check**. The content in the semantic data sent by system 1 should be able to be consumed by system 2. The data processing result conducted by system 2 should be the same as the one conducted by system 1 itself

The three-level validation is progressive: the precondition of the success of one step is the success of all the previous steps. To conclude that the two SUTs are semantically interoperable, all the three levels of validation need to be successfully passed.

B. Test scenarios

To implement and perform the semantic interoperability testing both on conformance and interoperability aspects as we described in the previous section, we worked within F-Interop project , which provides a cloud-based platform supporting test scenarios with the test system and the SUT being remotely located. Thanks to this cloud-based platform, interoperability tests can be performed without traveling of the system developers, which makes the tests more accessible and convenient in terms of time and cost.

The following paragraphs describe the high-level testing scenarios proposed and implemented within the EU H2020 F-Interop project[11].

1) Semantic conformance test scenarios: Conformance testing consists of the interaction between the SUT (System Under Test) and the tester (usually a software program). The tester checks the semantic data sent by the SUT regarding to the 3 aspects defined in the previous subsection. At the

[10] https://tools.ietf.org/html/rfc3968

[11] http://www.f-interop.eu/

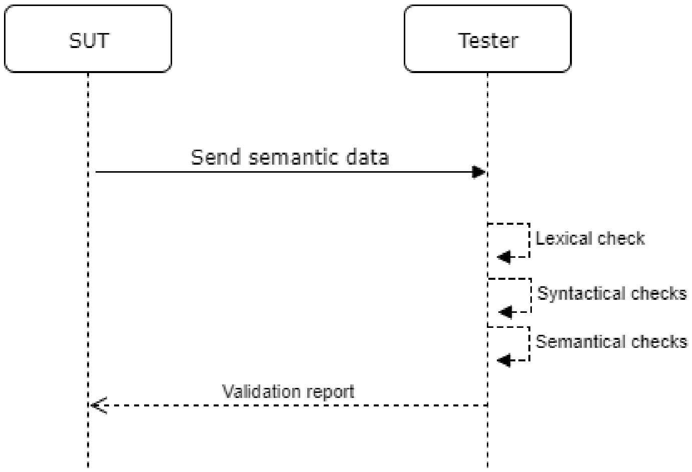

Fig. 1. Semantic conformance testing work flow

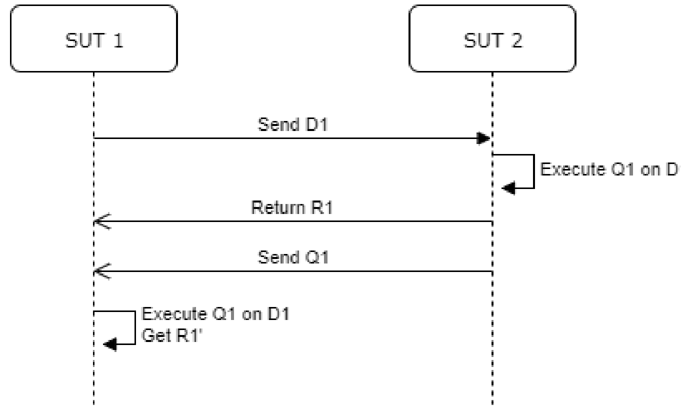

Fig. 2. Interoperability tests between two Systems under Test

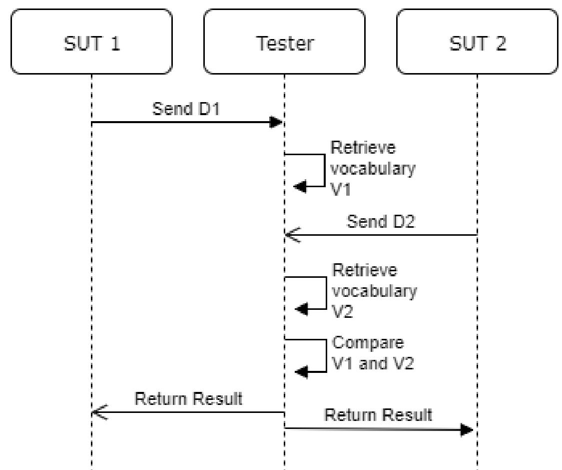

Fig. 3. Interoperability at the data level

end of the conformance testing process, the issuer should receive a report from the tester reporting whether the semantic data is compliant with the reference ontology. If there are some problems, details of the problems should be included in the report. The figure 1 illustrates the semantic conformance testing work flow.

2) Semantic interoperability test scenarios: Two semantic interoperability test scenarios are considered. The first one consists the two SUTs, the second one needs an intermediate tester to accomplish the test.

The semantic interoperability tests described here are platform/technology agnostic, which means it does not aim to test any platform-specific semantic-related features, for example, to test whether the semanticDescriptor resource is well created which contains the semantic data for oneM2M system, or to test the semantic data against the W3C WoT Thing Description ontology. The objective here is to propose some tests generic to all semantic data systems following the RDF specifications [26], so that these tests can be easily integrated to the platform implementing a specific standard, together with all the tests specific to that standard.

1) **Interoperability tests between two systems**. Semantic interoperability is firstly understood as *the meaning of the data is interpreted independently from the process system*. Thus, in this scenario, each part initiates one piece of the semantic data processing element: the semantic data and the semantic query. We will check if the final results of the semantic processing from the two parts are equivalent. If they are equal, it means that the two systems understand the piece of semantic data in the same way, thus interoperable. Figure 2 illustrates the test configuration and steps. To be able to execute the test, SUT1 and SUT2 should all have the semantic query processing capability. At the end of the tests, if the same query (Q1) executed on the same data (D1) by SUT1 gives the same result as the result from SUT2, it can be concluded that the two SUTs understand the data in the same way, thus interoperable.
2) **Interoperability at data level**. As explained before that ontology is the basis of providing interoperability, we aim to check semantic data against the ontology they use. One ontology consists of a set of vocabulary and the relationship defined between the vocabulary. In this test, we check if the data submitted from the two SUTs share the same vocabulary defined in the same ontology. If yes, it implies that they are interoperable at the semantic data level. Figure 3 illustrates the test configurations and steps. The pre-condition of this test is that the transmitted semantic data (D1 and D2) issued from SUT 1 and SUT 2 have been validated its conformance. The tester retrieves the vocabulary V1 and V2 from both D1 and D2 and checks if they are the same. If the vocabularies are the same, D1 and D2 are thus interoperable.

V. Conclusion

In this paper, we presented the current activities in semantic interoperability research. We can observe that the semantic interoperability testing aspect is not the focus of research work at the current stage however it is essential to establish a semantically interoperable IoT ecosystem. Within the scope of

EU H2020 project F-Interop, we made a first step to address this problem and implement a testing tool to be integrated with the project platform. We discussed the technical aspects that need to be addressed in a semantic interoperability testing and the test scenarios proposed within the project. The implementation of the testing scenarios and the integration with the F-Interop platform are ongoing, and are planed to be accomplished before June 2018. The tool will be presented and tested during standardization interoperability events to help developers to prove their semantic interoperability and to help us to fine tune the tool.

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