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***Abstract*—After a thorough analysis of existing Internet of Things (IoT) related ontologies, in this paper we propose a solution that aims to achieve semantic interoperability among heterogeneous testbeds. Our model is framed within the EU H2020's FIESTA-IoT project, that aims to seamlessly support the federation of testbeds through the usage of semantic-based technologies. Our proposed model (ontology) takes inspiration from the well-known Noy et al. methodology for reusing and interconnecting existing ontologies. To build the ontology, we leverage a number of core concepts from various mainstream ontologies and taxonomies, such as *Semantic Sensor Network* (SSN), *M3-lite* (a lite version of M3 and also an outcome of this study), *WGS84*, *IoT-lite*, *Time*, and *DUL*. In addition, we also introduce a set of tools that aims to help external testbeds adapt their respective datasets to the developed ontology.**

***Keywords*-Semantic Web of Things; Internet of Things; Semantic Web Technologies; Ontology; Interoperability; Federation; Testbed.**

I. Introduction

One of the most highlighting features of the Internet of Things (IoT) domain is the heterogeneity of the information that comes from the underlying diverse platforms/testbeds (a testbed is "*an environment that allows experimentation and testing for research and development products. A testbed provides a rigorous, transparent and replicable environment for experimentation and testing*" [1]). Such diversity and openness brings about a lack of standards that every platform should have followed prior to implementing their own solutions. Many testbeds owning devices or applications interacting with the sensors, store their inherent observations and other related data in their own proprietary format. In other words, making a testbed independent and isolated from others that cannot directly interact with each other. Differences in the data format lead to interoperability issues between the testbeds and much work has to be done in order to ensure the compatibility (interoperability is "*the ability of two or more systems or components to exchange information and use the information that has been exchanged*" [2]). One has to parse different data formats and create the mapping between them. As a result, a testbed must understand other testbed's format and create the mapping while sending and receiving information.

One method to accomplish this interoperability is through the usage of semantic-based technologies to annotate all the information shared by the platforms. In this paper, we propose a full-fledged ontology that spans across the necessities for the observations produced by resources in a testbed. We leverage our previous background from the Linked Open Vocabularies for Internet of Things (LOV4IoT)[1] [3], [4] where 39 relevant ontologies are referenced in the domain of sensor networks and IoT. Nevertheless, some of the relevant existing ontologies promise interoperability but: *(i)* do not address the problem to describe the observation in an interoperable manner to ease further tasks, such as reasoning, *(ii)* many of them are domain-specific and cannot be applied across domains, *(iii)* they have missing concepts and do not suffice the needs of the measurements provided by the sensors, and *(iv)* many ontologies do not follow best practices making it hard to correctly interpret and reuse concepts.

In order to address the above-mentioned limitations, we provide a unified semantic model that follows best practices. Together with the semantic model, we introduce Reference Annotator and Validation Tools (***RAT*** and ***AVT***, respectively), so that testbeds can use them (as reference) to induce interoperability. Best practices have been applied within our ontology, mainly for the development and support phases.

Furthermore, we are motivated not by creating new concepts in a new ontology, but by creating an ontology where all concepts are borrowed from existing ones and by addressing interoperability issues and various aspects of IoT device observations. Our solution focuses on the description of the underlying testbeds' resources (i.e. sensors, tags, etc.) and the observations gathered from them. The current ontology is developed under and applied to EU H2020's FIESTA-IoT project[2], that aims to support federation and interoperability among different orthogonal testbeds by using semantic-based techniques. For this reason, we called our semantic model, ***FIESTA-IoT*** ontology.

This paper is structured as follows: Section II presents a thorough state-of-the-art analysis that provides all the necessary background regarding IoT-related ontologies. Section III introduces the *FIESTA-IoT* ontology that is built from: *(i)* various models studied in Section II, and *(ii)* new elements exclusively adapted for the ontology, currently available from *M3-lite taxonomy*. Moreover, the ontology is supported via

[1]http://sensormeasurement.appspot.com/?p=ontologies
[2]http://fiesta-iot.eu/

RAT and **AVT** along with best practices and guidelines. In Section IV, we identify some potential uses of the ontology. Finally, we conclude (in Section V) and present some open issues that will be addressed in the future.

II. Related work

Many IoT related surveys are available that study related IoT ontologies [5], [6]; however, these works are rather outdated and do not show recent advancements. There are many ontologies that have been made available since that specifically deal with IoT, sensors and other related domains. In this section we describe some of these available IoT related ontologies, and emphasize on those that have a direct impact on our proposed solution.

Out of all available ontologies in the domains of Sensor and IoT, only SSN[3] [7] follows the best practices according to LOV4IoT; besides, it is also recommended by Linked Open Vocabulary[4] (LOV). SSN, originally defined as a part of World Wide Web Consortium, still lacks concepts to describe the sensed physical phenomena, the underlying unit of measurement, the location, and the time thereby leading to interoperability issues between non-standard domain specific ontologies and SSN. Another ontology, IoT-A [8], provides some core concepts such as "Service", and is mainly service oriented. It reuses only the *ssn:condition* concept. Nonetheless, it is complex, lacks usage of standard ontologies, and has redundancy issues. IoT-lite[5], an adaptation of IoT-A, is more powerful and simpler (i.e. lighter) than IoT-A. It reuses concepts from SSN and extends them by addressing some of its known shortcomings. IoT-lite, along with SSN, define most of the concepts used in our ontology. Besides, various updates have been applied to IoT-lite within the context of the FIESTA-IoT project. Other ontologies, such as those defined in VITAL[6] and [9], [10], extend SSN. [9] introduces concepts like utility metrics for physical and virtual sensors, and services. VITAL extends [9] while [10] provides concepts for defining mathematical models for phenomenons. Such concepts though are not available in our current version of the ontology, but can be added in future.

IoT-O [11] is yet another example of an ontology that reuses concepts from SSN and is designed to support heterogeneity in IoT. It reuses concepts like *ssn:Device* and *ssn:ObservationValue*. Additionally, it also uses concepts from other LOV recommended ontologies, such as Semantic Actuator Network (SAN)[7], DOLCE Ultra Lite (DUL)[8], Time[9], and Quantities, Units, Dimensions and Data Types (QUDT)[10]. In addition, IoT-O is well documented and uses the Pellet reasoner for inference. The ontology rules are shared following the idea of Sensor based Linked Open Rules (S-LOR). IoT-O follows best practices, is integrated with the oneM2M standardization [12] and provides the benefit of modularization. We are currently looking towards integrating IoT-O into our ontology.

OneM2M provides a base ontology[11] [12] with the aim to help non-oneM2M compliant data models derive oneM2M concepts to describe their data model. As oneM2M is soon to become a standard, we include equivalent classes from oneM2M to standardize our ontology as well.

Nevertheless, apart from the concepts within an ontology, it is also important to describe a taxonomy. M3 ontology [13] is one such effort where various IoT related concepts from various ontologies are integrated into a unified taxonomy that describes concepts like *Domain of Interest*, *QuantityKind* and *Units of Measurement*. As M3 is heavy, a refactored version of M3 is also proposed by us in Section III-C and used within our holistic solution.

The main contribution of this work is the construction of an *ontology* that deals with IoT domain and guarantees a complete semantic interoperability. To achieve this, we have taken a set of core concepts from various well-known ontologies and integrated them to support the semantic description of IoT services/resources, observations and Virtual Entities that might come from the various underlying testbeds.

III. FIESTA-IoT Ontology: A Unified Ontology

As stated before, many of the existing ontologies are not well connected and are very domain specific. From the previous analysis, SSN stands out by far as a well-adopted ontology that follows best practices, and hence serves as the foundations for the FIESTA-IoT ontology. While other IoT related approaches are bulky and demand much processing time, for us, the main aim is to build a solution that is able to address and maximize interoperability as much as possible, without leading to heavy computational costs.

In order to build the FIESTA-IoT ontology, we leverage various concepts from SSN, IoT-lite, M3-lite taxonomy, Time, DUL, and WGS84. We believe that, by using concepts from these ontologies, we cover most of the concepts needed towards achieving the goal of the interoperability and the federation. Further, in order to link to standards such as OneM2M we use ***owl:equivalentClass*** in the FIESTA-IoT ontology to easy OneM2M compliant testbed use FIESTA-IoT ontology and be part of federation provided by platforms like FIESTA-IoT.

A. Core Concepts

We have adopted the IoT-A Architecture Reference Model (ARM) [14] core concepts [15] as the foundations to build our ontology. These core concepts are:

- A **Physical Entity** "*Any physical object that is relevant from a user or application perspective*".
- A **Resource** is a "*Computational element that gives access to information about or actuation capabilities on a Physical Entity*".

[3]http://purl.oclc.org/NET/ssnx/ssn#
[4]http://lov.okfn.org/dataset/lov/
[5]https://goo.gl/Gk5U7n. IoT-lite is also referenced within LOV
[6]http://vital-iot.eu
[7]https://www.irit.fr/recherches/MELODI/ontologies/SAN
[8]http://www.loa.istc.cnr.it/ontologies/DUL.owl#
[9]https://www.w3.org/TR/owl-time/
[10]http://qudt.org/schema/qudt#
[11]http://www.onem2m.org/ontology/Base_Ontology/oneM2M_Base_Ontology-V_2_0_0.owl

- A **Virtual Entity** is a "*Computational or data element representing a Physical Entity*".
- An IoT **Service** is a "*Software component enabling interaction with IoT resources through a well-defined interface. It can be orchestrated together with non-IoT services (e.g., enterprise services). Interaction with the service is done via the network*".

In FIESTA-IoT ontology, *Resource*s are mainly related to Sensor, Actuator or Tag hosting devices. The conflict between SSN ontology and IoT-A lies in the *Resource* concept. SSN adopts a more device-centric approach. We argue that the closest property in SSN that resembles the IoT-A *Resource* is the *Process* concept. In IoT-A, this property is used for Service sub-model. IoT-A specifies that a *Resource* is hosted on a *Device*, although no information model has been provided for the *Device*. This is where SSN ontology plays an important role in FIESTA-IoT ontology. The *Device* concept is adopted so that a *Resource* is hosted on a *ssn:Device*. This is made explicit using a property e.g. *isHostedOn*. In this case, we redefine the *Resource* concept, even though this does not provide any added value to the information, especially upon querying it. Also in IoT-A, multiple *Resource*s can be hosted on a single *Device*. However, in SSN, a *Device* can be made up of multiple smaller *Device*s. On this basis, an implicit link (without annotation) between a *Resource* and a *Device* is made, whereby one *Resource isHostedOn* one *Device* and hence is treated as one *Entity*. Another aspect to consider is that the *Device* concept in SSN has a subclass that focuses on *Sensing*, i.e. the *SensingDevice*. However, currently SSN only addresses sensing aspects even though IoT-A contemplates other aspects, such as *actuation* and *identification*. Therefore, we instantiate *ssn:Device* for *Actuator*s and *Tag*s as well. This is where the IoT-lite ontology plays an essential role in extending SSN to include these concepts.

B. Ontology

As discussed before, the current version of the FIESTA-IoT Ontology[12] is a combination of existing IoT ontologies into a single one with minor updates to overcome the most common issues associated to the mainstream ontologies. The FIESTA-IoT ontology reuses concepts from a number of "third-party" ontologies and taxonomies such as WGS84, SSN, IoT-lite, M3-lite taxonomy, Time, and DUL Figure 1). Note that for referencing overlapping concepts in FIESTA-IoT ontology, such as *ActuatingDevice* and *TagDevice*, we chose IoT-lite. For *QuantityKind* and *Units of Measurement*, M3-lite taxonomy that references QU[13] ontology is used while for other concepts WGS84, SSN and DUL ontology is used.

Summing up the different classes, object and data properties (see Figure 1), it is worth to highlight the following elements:

- ***ssn:Deployment*** is the root of the graph for every device in order to identify its owner (i.e. testbed).
- ***ssn:Platform*** is "*an Entity to which other Entities can be attached, particularly Sensors and other Platforms.*" [7]. From this description, we attach the physical location of each device. Furthermore, we use the data property ***iot-lite:isMobile*** to know whether the *ssn:Platform* is mobile or not.
- ***geo:Point*** describes the physical location of the devices and is based on the WGS84 ontology. Here, we use ***geo:lat*** and ***geo:long*** data properties to describe the latitude and longitude, respectively (in WGS84 these data properties are described as annotation properties). *geo:Point* is also used to describe the ***iot-lite:Coverage*** concept and all its underlying subclasses (e.g. Polygon, Circle, Rectangle, etc.). *iot-lite:Coverage* is used in situations where a point geo-location is not enough. Using *iot-lite:Coverage* we define area covered by a particular object, for example, whole region over which a testbed has a direct influence. In addition, this is also used to describe Virtual Entities for which the *geo:point* location is just not enough.
- ***ssn:Device***, core of the resource description, is "*a physical piece of technology - a system in a box. Devices may of course be built of smaller devices and software components (i.e. systems have components)*" [7]. Within the scope of our ontology, these devices are either ***iot-lite:ActuatingDevice***, ***iot-lite:TagDevice*** or ***iot-lite:SensingDevice***. From now we focus on the latter one.
- *ssn:Device* is exposed by an IoT services (***iot-lite:Service***). Note that, since all the types of Devices actually inherit its properties, an IoT service might indistinctly apply for Devices, SensingDevices, etc. Indeed, we actually use the IoT Service endpoint to expose SensingDevices instead of Devices.
- According to the IoT-A principles, Virtual Entities are one of the core parts in an IoT model, together with Devices and Services. By creating a layer on top of Devices, Virtual Entities (***iot-lite:VirtualEntity***) create associations with a potential number of devices through the observed ***iot-lite:Attributes***, that define the virtual entity properties.
- ***iot-lite:SensingDevice*** represents physical sensors deployed throughout the different testbeds. As seen from Figure 1, *ssn:Sensor* is the superclass of *iot-lite:SensingDevice* and plays an essential role, both in describing different devices and services, and handling the data gathered from the observations.
- ***ssn:Sensor*** maps to the physical phenomena that it is actually "sensing" via ***m3-lite:QuantityKind*** and ***m3-lite:Units*** in the M3-lite taxonomy. More information on the taxonomy is described in III-C.
- Apart from the physical aspects of *iot-lite:SensingDevice*, it is also important to include other information (i.e. ***iot-lite:Metadata***) associated with the resources, to increase understanding. *iot-lite:Metadata* can be either the frequency of the measurements, or the accuracy of the sensors, or the precision. Further, we associate *iot-lite:Metadata* to data properties such as ***iot-lite:metadataType*** and ***iot-lite:metadataValue***.
- ***m3-lite:DomainOfInterest*** represents the applicative domain in which the device is operative.
- ***m3-lite:QuantityKind*** represents sensed phenomenon

[12]http://ontology.fiesta-iot.eu/ontologyDocs/fiesta-iot.owl
[13]http://purl.org/NET/ssnx/qu/qu#

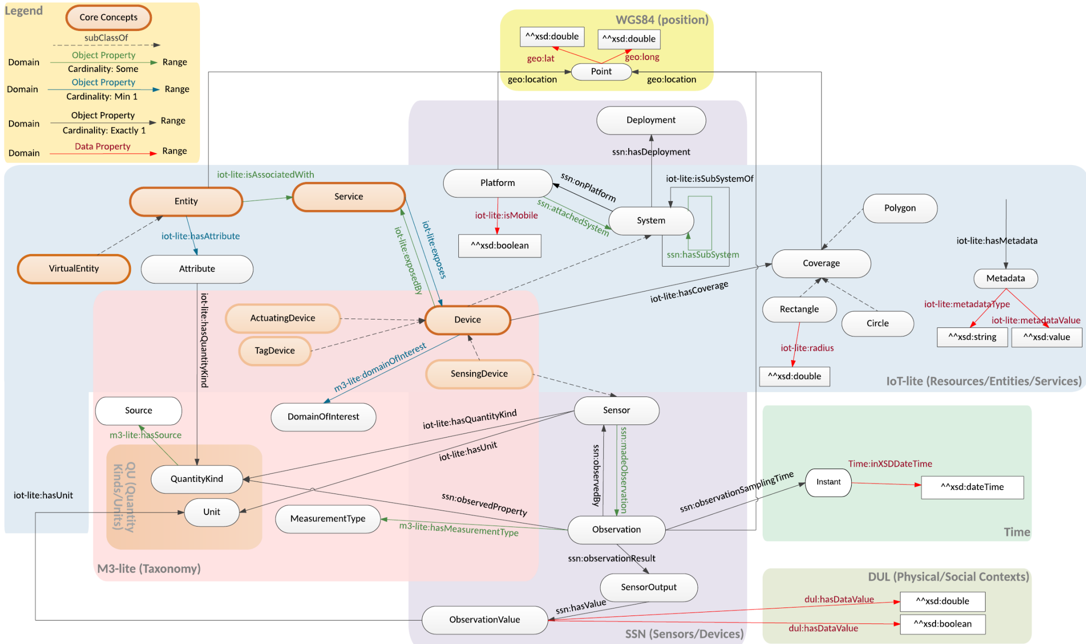

Fig. 1: FIESTA-IoT Ontology.

while ***m3-lite:Unit*** is the unit of measurement. *m3-lite:QuantityKind* is also linked to ***m3-lite:Source*** that hold the source of sensed phenomenon for example ***m3-lite:SoundSource*** can be construction work or siren etc.

- Finally, the observations taken by the SensingDevices are link to: *(a)*, the corresponding *m3-lite:QuantityKind* via ***ssn:observedProperty***, *(b)* ***ssn:observationSamplingTime*** that further links to ***Time:Instant*** to represent when the observation was taken (i.e. timestamp), *(c) geo:Point*, *(d)* ***ssn:ObservationValue*** via ***ssn:SensorOutput*** (*ssn:ObservationValue* links to the actual value of the observation via data property ***dul:hasDataValue***, and *m3-lite:Unit* concept), and *(e)* ***m3-lite:hasMeasurementType*** to know whether the measurement was manual, automatic or generated from an experiment.

The current concepts in the ontology inherently support streaming data, mobility and reasoning/composite data. The concept ***ssn:SensorOutput*** links to multiple *ssn:ObservationValue* via ***ssn:hasValue***, thereby providing a mechanism to address streams. Mobility and composite data is handled via *geo:Point*, and *iot-lite:VirtualEntity* and *m3-lite:QuantityKind*, respectively. As each platform has *geo:Point* and all the ***ssn:Observation*** have *geo:location* object property, mobility of devices with respect to data is also handled. Note, we do not consider handovers and intermittent connectivity in the ontology as our ontology is observation oriented. Next, the composite data or the new kind of data obtained after reasoning or created using *iot-lite:VirtualEntity* is also handled. This requires specific QuantityKind-Unit pair to be available in M3-lite. We envision to have near real-time update to QuantityKinds and Units by allowing users of the ontology to request for updates.

C. M3-lite Taxonomy

The M3-lite[14] taxonomy is an optimized version of the M3[15] ontology, modified to fulfill the FIESTA-IoT ontology main needs and goals. Providing such taxonomy is an essential step since IoT data comes from heterogeneous testbeds using different terms for describing e.g. a same physical phenomenon. The main benefit of the M3-lite taxonomy is to align and interlink numerous off-the-shelf IoT-related ontologies to facilitate interoperability.

Most of the time, the domain ontologies are linked through the ***rdfs:seeAlso*** property within M3-lite, such links can be easily ignored if there is no need to deal with such ontologies. M3-lite also follows the idea of "modular ontology" in order to support different needs. The refactoring of the M3 ontology is done to clean non-relevant classes and properties. Besides, when the ontologies are reliable (e.g., SSN), instead of using the ***owl:equivalentClass*** property, M3-lite reuse the concept from the reliable ontology such as QU[13], SWEET_unit[16] and SSN[3], to name a few.

The main purpose of the M3-lite taxonomy is to extend SSN, by providing a unified taxonomy for *ssn:SensingDevice*, *m3-lite:QuantityKind*, *m3-lite:Unit* and *m3-lite:DomainOfInterest*.

D. Some Stats for the unified Ontology

Currently, the FIESTA-IoT ontology holds: 434 Classes, 28 object properties and 10 data properties in all. Note that we do not consider the data properties of WGS84 since they are provided as annotation properties. Moreover, we have 7 classes that are equivalent, 3 equivalent objects properties, and

[14]http://purl.org/iot/vocab/m3-lite
[15]http://sensormeasurement.appspot.com/m3#
[16]http://sweet.jpl.nasa.gov/ontology/units.owl#

4 inverse object properties. Almost all the object properties and data properties used have domains and ranges specified along with cardinalities. Moreover there are many ***SubClassOf*** relations, and 1 ***SubObjectPropertyOf*** relation. In the ontology, the number of classes is high because most of them come from M3-lite taxonomy. As we add more concepts the numbers mentioned above are likely to change in the future.

E. Best Practices

When it comes to the creation of an ontology and publishing of the data that uses a certain semantic model, best practices should be applied to enhance efficiency, re-usability and interoperability. Below, we list the set of best practices that have been followed to create the ontology and guidelines to be accomplished in order to publish the data.

1) Best Practices followed to create unified ontology: The FIESTA-IoT ontology follows Noy et al.'s methodology [16]. Beside the methodology, we use external concepts from ontologies that already fulfil best practices (maintained, standardized and recommended by LOV) [17]. Further, following steps, are also used:

- Both Web documentation and tutorial are provided in order to encourage re-usability. The web documentation is generated using open source ontology documentation tool called ***LODE***[17]. The FIESTA-IoT documentation is available online[18]. Note that there are many other tools available (such as *OWLDoc* plugin for *Protégé*, *Parrot*[19], *WebVOWL*[20] and *Widoco*[21]) but we refrain ourselves from describing them as it is out of the scope of this paper.
- Maintenance and online availability of the ontology for easy import.
- Ongoing effort towards standardization of the ontology and cataloging in LOV. FIESTA-IoT ontology and M3-lite are already available in LOV4IoT, while M3-lite is also available in LOV and FIESTA-IoT ontology is under submission in LOV.

2) Guidelines for testbeds to publish Data: Annotated data produces benefits by providing context about the readings or observations that are captured from the real world. But at the same time, it adds overhead in terms of communication and storage. Besides, the access to this information should be exposed so as to ease its further reuse. The following steps, also mentioned in [17], should be used as a guide to produce better data:

- Registration of Devices and Virtual Entities must identify their respective semantic instances using dereferenceable URIs. This will allow descriptions to be managed and retrieved by using their URIs as URLs.
- Derefenceable URIs must only be applied to instantiations of *ssn:Device* concept or any of its subclasses (*ssn:SensingDevice*, *iot-lite:ActuatingDevice*, and *iot-lite:TagDevice*).
- Descriptions must be annotated using RDF serialization format, such as *RDF/XML*, *JSON-LD*, *Turtle* or *N3* (among others).
- As the ontology is expected to handle large amounts of data being produced by the testbeds, the annotation applied to raw/proprietary-formatted data should be minimal, and any triples created must provide added-value towards experimentation. This alleviates unnecessary load on the testbed when it comes to the delivery and storage.
- Prior to the publication of the annotated data to the data store, the owners of the data are encouraged to validate samples of their descriptions with an FIESTA-IoT's Annotation Validation Tool in section III-H.

F. Reference Annotation Tool (RAT)

To provide support for FIESTA-IoT ontology and help testbeds translate from their intrinsic formats (e.g. FIWARE-compliant, oneM2M, raw JSON, etc.) to the one that is understood and interpreted by the FIESTA-IoT federation, we provide a sample Reference Annotation Tool (**RAT**) that is compliant with the created ontology and annotates both the resource descriptions and its subsequent observations. An example **RAT** is available online[22] (tailored to translate the resources and observations coming from the SmartSantander platform). One of the first steps to be performed when a testbed wants to be a part of a federation, such as FIESTA-IoT, is the registration of all its Devices and IoT Services. The next step is to then annotate the observations produced by the Sensors. The annotations provided by the **RAT** follow the guidelines described in Section III-E. Access to some of the annotated resources and observations are made available[23].

G. Semantic Storage Management

We store the devices metadata and the data provided by the them in the Jena[24] TDB store and query it using SPARQL[25] language. We leverage from the Jena TDB store provided by FIESTA-IoT Meta Cloud Platform. Some sample queries are available via Github[26].

H. Annotation Validation Tool (AVT)

An important requirement in order to maintain interoperability of information originating from different devices is to make sure that they comply with the presented unified semantic model. Therefore, a validation check is required for the compliance of the annotations. The validator should check for syntactic and semantic issues such as: *(i)* unknown properties and classes with respect to the unified ontology, *(ii)* problematic prefix namespaces, *(iii)* ill-formed URIs and language tags on literals, *(iv)* data-typed literals with illegal lexical forms, *(v)* unexpected local names in schema namespaces, *(vi)* untyped resources and literals, *(vii)* individuals

[17]http://www.essepuntato.it/lode
[18]http://ontology.fiesta-iot.eu/ontologyDocs/fiesta-iot.html
[19]http://ontorule-project.eu/parrot/parrot
[20]http://vowl.visualdataweb.org/webvowl/
[21]https://github.com/dgarijo/Widoco
[22]https://gitlab.fiesta-iot.eu/demos/SmartSantanderAnnotator
[23]https://api.smartsantander.eu/v2/resources/urn:x-iot:smartsantander:u7jcfa:t10000?format=jsonld
[24]https://jena.apache.org/documentation/tdb/index.html
[25]https://www.w3.org/TR/rdf-sparql-query/
[26]https://gist.github.com/UniSurreyIoT/fcde3a7825ba723463fc

having consistent types, assuming complete typing broken RDF list structures, *(viii)* inheritance relationships for classes and properties, *(ix)* cardinality, and *(x)* unexpected domains and ranges.

Such validation should be performed at the platform side when the data is being registered. We adopt SSN validator[27] to create **AVT**. The same is made available as a service[28]. **AVT** provides a check on both correctness and completeness of the data and uses Jena Eyeball[29].

IV. Current Implementations and uses of the Ontology

As FIESTA-IoT ontology[30] supports resource description and data produced, currently it finds its implementation in the EU funded H2020 FIESTA-IoT project that aims to provide federation and interoperability to the IoT devices and the data produced by them in an agnostic way. However, the ontology is not just specific to FIESTA-IoT platform. In our vision, the ontology can also be applied to all IoT projects willing to semantically annotate data that is produced by devices, want to achieve interoperability and store locally the measurements. We also see the applicability of our ontology to testbeds that comply to either FIRE[31] (such as FED4FIRE[32], FI-WARE[33]), GENI[34], oneM2M or even to other Future Internet initiatives. Currently, SmartSantander, SmartICS, Com4Innov's and KETI's respective testbeds, and SoundCity[35] testbeds (whose owners are actual part of the FIESTA-IoT consortium[36]) are the prime users of both FIESTA-IoT ontology, **RAT** and **AVT**.

V. Conclusion

In this work we present a unified ontology (FIESTA-IoT) that aims to address interoperability issues by interconnecting existing IoT solutions. The motivation to build such unified ontology comes from: *(i)* not overloading the domain with a new ontology but integrating various existing required ontologies (i.e. the needed concepts) into a single and holistic one, in order to fulfill the needs of the testbeds (and experimenters), *(ii)* reusing as much possible existing ontologies in order to help testbeds not re-annotate their datasets prior to join the federation, *(iii)* ensuring a better interoperability with existing semantic-based IoT platforms, projects, and standardizations, and *(iv)* following best practices.

Nevertheless, the current version of the ontology lacks integration with latest version of SSN[37]. We are currently working to address the integration of this new version and would like to address this in the second iteration of the ontology (envisioning that not much would change). Further, there is an ongoing effort towards the evaluatiion of our proposed ontology with the mechanism described in [18]. We also envisage to update M3-lite taxonomy by other domain knowledge and provide a mechanism for suggesting updates to the taxonomy.

[27] http://iot.ee.surrey.ac.uk/SSNValidation/

[28] http://validator.fiesta-iot.eu

[29] https://jena.apache.org/documentation/tools/eyeball-getting-started.html

[30] Validation report from Vapour is available at https://goo.gl/4eHCdp

[31] https://www.ict-fire.eu

[32] http://www.fed4fire.eufire

[33] https://www.fiware.org

[34] https://www.geni.net

[35] http://ambiciti.io/index.html#

[36] More information about the testbeds is available at http://fiesta-iot.eu/fiesta-testbeds/

[37] https://www.w3.org/TR/vocab-ssn/

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