AIOTI

ALLIANCE FOR INTERNET OF THINGS INNOVATION

Semantic Interoperability

Release 2.0

AIOTI WG03 – IoT Standardisation

2015

Executive Summary

Technical Interoperability has been the focus of most standards organizations, alliances and consortia for many years and consequently strategies, standards and implementations supporting this level of interoperability are generally available.

Strategies for Informational Interoperability, which includes the whole subject of semantic interoperability, are less mature in term of deployments. Roadblocks towards large scale deployments are less about technical maturity and more about understanding the business opportunities (and threats), education of the engineers and consensus building around ontologies (domain knowledge represented as concepts and relationships) to be used within and across the proposed IoT Large Scale Pilots (LSPs).

Semantic technology is essential for integration within each LSP and across LSPs, bypassing the current practices of predetermining all structures before deployment (static data models). Its near-term value is related to cost savings, flexibility, efficiencies and capability enhancements. The metadata approach appears to be very attractive in terms of incremental deployment of semantic technology; it may also be beneficial for privacy.

The following recommendations are made:

- AIOTI should create a venue to achieve a common vision (value proposition, high level approach to semantics) around semantic interoperability for AIOTI LSPs. IERC (WG1) has the expertise to support building this vision through providing use cases that show market-place benefits to the stakeholders.
- AIOTI WG3 must further develop the link between the High Level Architecture (HLA) and semantic technology by reusing existing standards work. This development should be tutorial in style and benefit the task of educating the market.
- AIOTI vertical working groups should seek the development of ontologies (if those do not exist in ongoing standards) for the different LSPs. This work must be based on consensus and engage all relevant stakeholders, in particular domain experts. The results should be liaised to established standards organizations and open source foundations which have the tools and processes to maintain and evolve those ontologies.

1. Scope and focus of the WG

This document provides an overview of the problem statement, value proposition and key techniques pertaining to semantic interoperability within and across the AIOTI Large Scale Pilots. The document also describes ongoing standardization work in support of semantic interoperability for the IoT

2. Challenges and IoT Value Proposition

The IoT Interoperability Challenge

The IoT is about enabling connections between objects or "things"; it's about connecting anything, anytime, anyplace, using any service over any network.

IoT refers to the growing pervasiveness of sensors and devices which can communicate over wired and wireless networks, and the value creation opportunities that this presents in terms of new applications and services. The interconnection of smart devices, sensors, and actuators exposing data services, control functions and analytics presents opportunities for novel applications and new ways of thinking about the links between the physical and virtual worlds.

For example, a car navigation system could interact with the local city information system to locate the best parking option, given the current destination. Even better, if the city offers parking reservation services then the navigation system could make the reservation in advance, with payment to be made by a smart phone transaction once the car was parked.

This is a hypothetical case but illustrates the kind of convenience and efficiency benefits that are expected from IoT technologies in various domains: smart cities, smart homes, smart health, energy efficient and green buildings, transportation, aviation, and industrial control.

Delivering these benefits requires interactions between smart devices, network elements, cloud services and the end-user (in this example, the final smart phone payment authorization). Whereas many of today's architectures achieve interoperability through statically defined services, service options, data models, and security models, the IoT context is much more dynamic and, consequently, interoperability in the IoT world needs greater semantic depth. Such depth will allow these various elements and entities in the IoT ecosystem to interact with each other in a unified and ubiquitous manner.

However, the ability to successfully execute ad-hoc, secure, interactions between otherwise unrelated devices raises significant technical challenges. How do the respective parties know how to talk to each other? How do they identify each other and establish a level of trust? How are issues related to security and confidentiality resolved?

Significant work has been done on these kinds of challenges, particularly in the late 1990s in relation to semantic-web [1].

According to Gridwise [2] interoperability incorporates the following characteristics:

- Exchange of meaningful, actionable information between two or more systems across organizational boundaries
- A shared understanding of the exchanged information
- An agreed expectation for the response to the information exchange
- A requisite quality of service: reliability, fidelity, and security.

Further, interoperability "enables a larger interconnected system capability that transcends the local perspective of each participating subsystem".

Technical Interoperability has been the focus of standards organizations, alliances and consortia for many years and consequently strategies, standards and implementations supporting this level of interoperability are generally available.

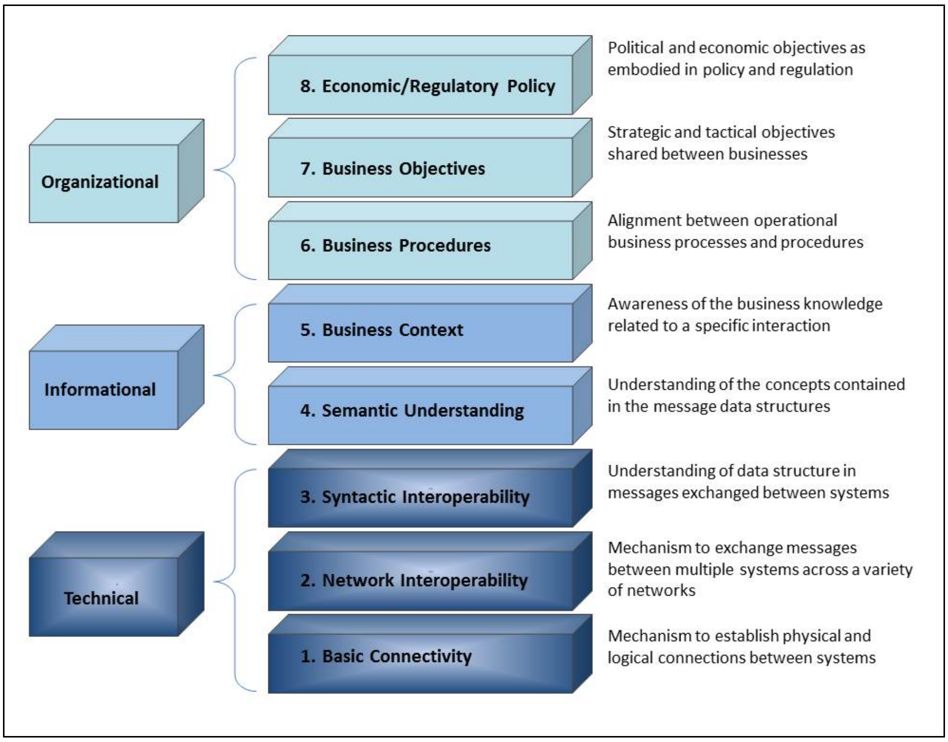

Figure 1 Gridwise Interoperability Context Setting Framework

Strategies for *Informational Interoperability*, however, which includes the whole area of semantic interoperability, are less mature. Improving this situation means addressing a number of key challenges, including:

- Techniques to formalize the meaning of annotated data and information models
- Semantic merging, matching and alignment strategies
- Formal models/representations for semantic enrichment of data
- Patterns for bridging structured data and its semantic representation
- Mediators to enable integration of disparate data resources
- Information management mechanisms for knowledge-based approaches
- Semantic discovery of applications and services
- Promising technologies, tools and practices are emerging, particularly from work on the semantic web, but further research, development and validation is required.

The Value of Semantics for the Internet of Things

Semantic approaches provide essential support for the dynamic, cross-domain requirements of the IoT including interoperability, discovery, consistency, scalability, reusability, composability, enhanced human-machine interaction, automatic operations, analysis and processing activities concerning IoT data, resources and services:

- *Interoperability*: Semantic approaches enable dynamic and easier integration and cross-domain interoperability on multiple scales and levels, bypassing the current practices of pre-deployment determination and configuration.
- *Discovery*: Semantic approaches enable dynamic discovery of IoT services, data and resources. This supports application composition and service reuse.
- *Consistency*: Through semantic approaches, services, data, and resources can consistently refer to the same meaning within and across IoT domains.
- *Scalability*: Semantic approaches (such as semantic annotation) provide support for component independence and decentralized management and act as scalability enablers.
- *Efficiency*: Semantic technologies enable the efficient description of data, resources and services, so that machines and humans can have a common understanding of resources, data and services in the IoT. This benefits automatic operations, analysis and processing activities and enhances human-machine interaction

The aggregation of these capabilities provides powerful support for cross-domain innovation, a core value proposition of the IoT.

There is often confusion between the notion of semantic interoperability and the Open Data approach built around the idea that "*data should be freely available to everyone to use and republish as they wish, without restrictions from copyright, patents or other mechanisms of control*" [3]. That confusion is often a source of concerns for several stakeholders.

However, while Open Data builds on top of semantic techniques, semantic interoperability does not imply that all data is generally available at no cost. Access Control Policy metadata can and shall be used to control who can access which data and within which context (e.g. time of the data, geographical location, etc.). Further, semantic techniques can use business rules to establish trust between the data providers and data consumers to control the data access under different contexts.

Analytics and reasoning can be achieved using unstructured data or data structured according to static data models. However, the integration of new data sets incurs additional costs related to reprogramming the related applications to add the needed logic to process the data. This burden is overcome when the data is enriched with semantic information that enables applications to understand the meaning of the data and to ensure subsequent usage for analytics, reasoning and more.

Relationship to AIOTI High Level Architecture (HLA)

The functional model of AIOTI HLA depicts three layers; Application Layer, IoT Layer and Network Layer. See Figure 2.

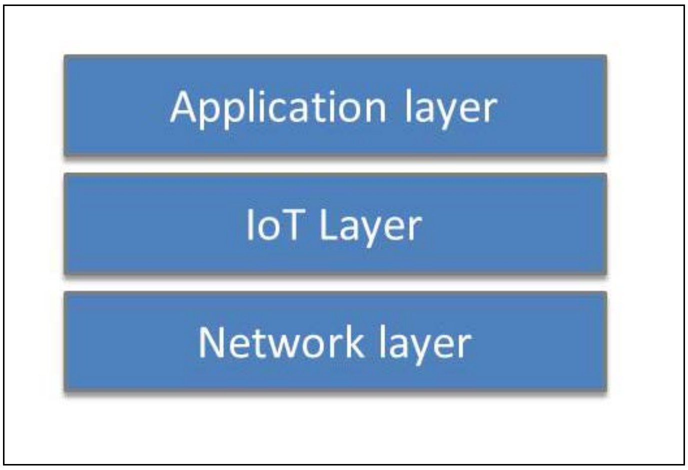

Figure 2 AIOTI High Level Architecture

At the Application Layer, Semantic Interoperability provides Application Entities with benefits such as semantic discovery of things, representations and related services (i.e. services that can be invoked). It also enables Application Entities to semantically describe the meaning of the data that is exchanged or eventually stored in the IoT Layer.

The IoT Layer provides the means to store semantic descriptions of data, e.g. using the metadata approach. It also allows the handling of queries for discovery and may offer other value added services such as analytics and reasoning.

At the Network Layer, Semantic Interoperability may play a role in discovering and invoking network services such as location. It can also help support network configuration based on application needs.

Gaps and Challenges

Although there is significant depth and breadth to the number of available publications, technologies and tools supporting semantic approaches, it's clear that there are gaps and challenges to be addressed, including:

- Lack of elaborated use cases providing the drivers that businesses require to engage in broader application of semantic approaches
- Learning requirement within the developer community regarding semantic technologies and tools, e.g., interactions between domain experts and developers
- Weakness of links between reference architectures and semantic technologies
- Need for domain specific ontologies

Firstly, addressing the business issues will be critical to building a sustainable IoT ecosystem. For companies to invest in semantic approaches, the commercial benefits of supporting cross-domain capabilities have to be rationalized and elaborated.

Secondly, assuming that business cases can be found, then the developer community needs guidance on building capabilities and establishing practices which enable productive and successful application of semantic technologies. This can be effectively achieved by interactions between domain experts (who may not necessarily be IT experts) and the developer community.

Thirdly and closely linked to the previous point, reference architectures should provide clear description of their relationship with and use of semantic approaches.

Finally (here at least), there is a growing need for verticals to begin development and drive standardization of their own ontologies – with due to regard to interoperability across domains.

Note that an in depth discussion of challenges, development and recommendations are available. For example see [4], [5].

Conclusions

Growth in the IoT will drive wider application and deployment of semantic technologies. Semantic technologies are not fundamentally new and there is an existing body of work which will be increasingly exploited as the IoT matures.

However, semantic approaches will expose many firms and individual engineers to new interoperability architectures and will require changes in tools, technologies, and thought processes. These changes will also impact SDOs particularly those involved in the definition of domain specific system and application interfaces.

3. Examples of Related SDO/EU Projects

Introduction

This section overviews a number of projects which have contributed to the work on semantic interoperability. The projects are included here as examples; subsequent releases of this document may provide a more complete review of work in this field.

W3C

Web of Things, an initiative and vision from W3C's, focuses on the role of Web technologies for a platform-of-platforms as a basis for services spanning IoT platforms from microcontrollers to cloud-based server farms. Shared semantics are essential for discovery, interoperability, scaling and layering on top of existing protocols and platforms. For this purpose, metadata is used and can be classified into: things, security and communications, where things are considered virtual representations (objects) for physical or abstract entities.

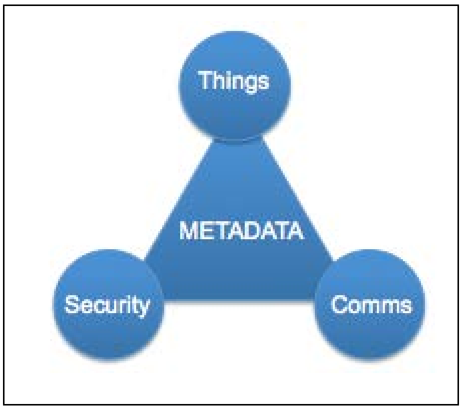

Figure 3 Metadata Classification (1)

Thing descriptions
- Links to thing semantics
- Data models & relationships
- Dependencies and version mgmt.
- Discovery and provisioning
- Bindings to APIs and protocols

Security related metadata
- Security practices
- Mutual authentication
- Access control
- Terms & conditions
- Relationship to "Liability"
- Payments
- Trust and Identity Verification
- Privacy and Provenance Resilience

Communication related metadata
- Protocols and ports
- Data formats & encodings
- Multiplexing and buffering of data
- Efficient use of protocols
- Devices that sleep most of the time

Figure 4 Metadata Classification (2)

Thing descriptions are expressed in terms of W3C's resource description framework (RDF). This includes the semantics for what kind of thing it is, and the data models for its events, properties and actions. The underlying protocols are free to use whatever communication patterns are appropriate to the context according to the constraints set by the given metadata.

Metadata can be further grouped into core metadata which is used across application domains and metadata which is specific to particular application domains. See Figure 5.

Reuse of existing vocabularies/ontologies simplifies service composition as otherwise intermediaries are necessary to handle translations between vocabularies. This will often be imperfect and may impede open markets of services.

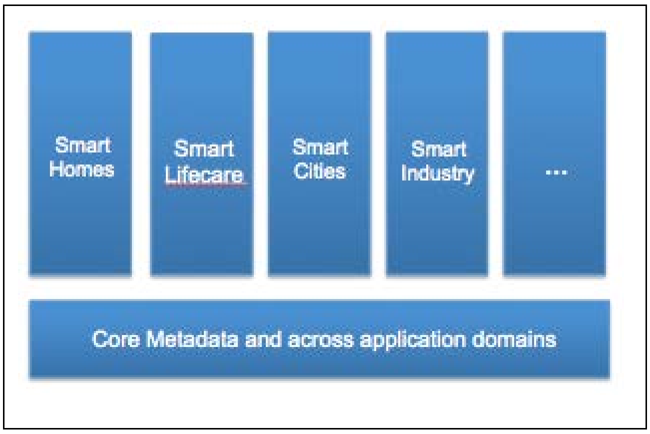

Figure 5 Metadata Reuse

oneM2M

In oneM2M application data are stored under resources. Specific resource types (application, containers, etc.) may have a semanticDescriptor subresource that describes the semantic meaning of the data (also known as "Semantic Annotation") according to a given ontology.

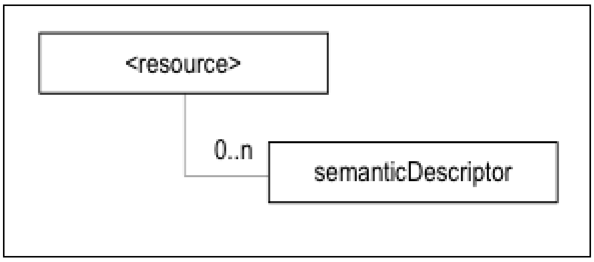

Figure 6 Semantic Descriptor

Such semantic description allows for:

- *Semantic discovery*: enhancing the discovery mechanism, to allow locating and linking resources or services based on their semantic information.
- *Semantic reasoning*: derive new relations and classifications of semantically annotated data.
- *Semantic mash-up*: create virtual devices and offering new services.

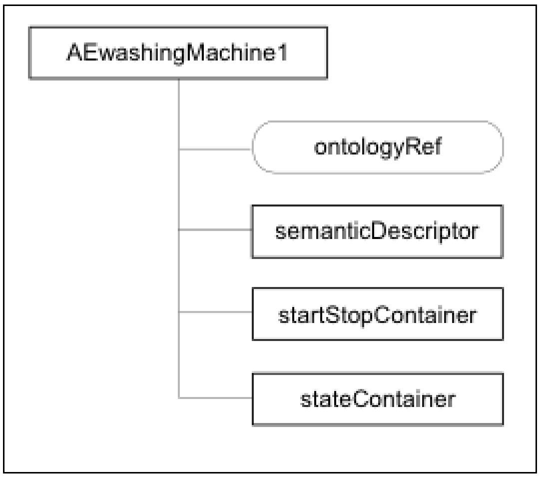

Figure 7 Resource Structure of a Smart Washing Maschine

An example showing the use of the Semantic Descriptor resource is included here to understand how semantic annotations based on the Smart Appliance REFerence Ontology (SAREF) can be used to describe an Application Entitiy (AE) representing a smart appliance.

It consists of an ontologyRef attribute, which contains the Uniform Resource Identifier (URI) of the ontology concept of the smart washing machine, e.g. “http://www.tno.com/saref#WashingMachine". The startStopContainer and the stateContainer represent the functional interface aspects of the washing machine, i.e. it can be started and stopped and the current state can be requested.

```
<rdf:RDF
  <rdf:Description rdf:about="http://www.tno.com/saref#WASH_LG_123">
    <rdf:type rdf:resource="http://www.tno.com/saref#WashingMachine"/>
    <saref:hasManufacturer>LG</saref:hasManufacturer>
    <saref:hasDescription>Very cool Washing Machine</saref:hasDescription>
     <saref:hasLocation rdf:resource="http://www.tno.com/saref#Bathroom"/>
    <msm:hasService rdf:resource="http://www.tno.com/saref#WashingService_123"/>
    <msm:hasService rdf:resource="http://www.tno.com/saref#StateService_123"/>
  </rdf:Description>
 <rdf:Description rdf:about="http://www.tno.com/saref#WashingService_123">
    <rdf:type rdf:resource="http://www.tno.com/saref#WashingService"/>
    <msm:hasOperation rdf:resource="http://www.tno.com/saref#WashingOperation_123"/>
  </rdf:Description>
 <rdf:Description rdf:about="http://www.tno.com/saref#WashingOperation_123">
 <rdf:type rdf:resource="http://www.tno.com/saref#WashingOperation"/>
    <hr:hasMethod>Create</hr:hasMethod>
    <hr:hasURITemplate>/CSE1/WASH_LG_123/startStopContainer </hr:hasURITemplate>
    <msm:hasInput rdf:resource="http://www.tno.com/saref#Action"/>
  </rdf:Description>
  <rdf:Description rdf:about="http://www.tno.com/saref#StateService123">
<rdf:type rdf:resource="http://www.tno.com/saref#StateService"/>
    <msm:hasOperation rdf:resource="http://www.tno.com/saref#StateOperation123"/>
  </rdf:Description>
  <rdf:Description rdf:about="http://www.tno.com/saref#StateOperation123">
 <rdf:type rdf:resource="http://www.tno.com/saref#StateOperation"/>
    <hr:hasMethod>Retrieve</hr:hasMethod>
    <hr:hasURITemplate>/CSE1/WASH_LG_123/state/stateContainer/latest</hr:hasURITemplate>
    <msm:hasOutput rdf:resource="http://www.tno.com/saref#State"/>
  </rdf:Description>
</rdf:RDF>
```

Table 1 Semantic Resource Description of a Smart Washing Maschine AE Based on SAREF

Table 1 shows the semantic annotation stored in the descriptor attribute of the semanticDescriptor resource. The information provides the link between the operations of the washing machines and the containers of the smart washing machine AE and describes the REST methods that can be executed. The washing operation can be started by executing a Create request on the startStopContainer whose URI is provided, the same for the state operation, where a Retrieve request on the latest contentInstance of the stateContainer will provide the current state of the washing machine.

openIoT

OpenIoT is an open source platform for interoperability between sensor data silos and focuses on enabling interoperable semantically-annotated IoT cloud applications. OpenIoT comprises utility-driven security and tools for zero-programming development of applications.

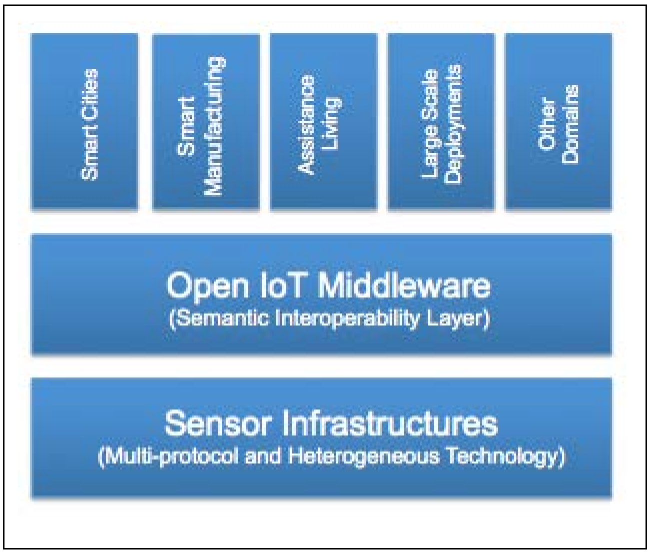

Figure 8 OpenIoT Middleware

OpenIoT uses a well-defined semantic-based model representation, which is the result of exhaustive related existing vocabularies in the area of IoT. The vocabularies are formally represented using Ontologies and it uses OWL (Ontology Web Language) in alignment with the web-orientation of the OpenIoT services.

OpenIoT follows the common and desired approach to reuse existing ontologies as much as possible, simplifying the development since one can focus at the domain or application-specific knowledge only, and, the integration between applications in the future since defined parts of ontologies will be shared. The vocabulary that OpenIoT uses and the extension of current ones alike the new terminology that is not covered by the existing ones is using the following namespace abbreviations:

```
@prefix ssn:< http://purl.oclc.org/NET/ssnx/ssn#>
@prefix spt:http://spitfire–project.eu/ontology/ns/
@prefix dul :<http://www.ontologydesignpatterns.org/ont/dul/DUL.owl#>
@prefix rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
@prefix rdfs:<http://www.w3.org/2000/01/rdf-schema#>
@prefix owl:<http://www.w3.org/2002/07/owl#>
@prefix xsd:<http://www.w3.org/2001/XMLSchema#>
@prefix ex: <http://www.example.org/ns#>
@prefix: openiot:http://www.openiot.eu/ontology/ns
```

Table 2 Semantic Dependencies and Ontology Reuse

OpenIoT involves the concept of virtual sensors, the basic concept that support representations of new data sources created from live data. Virtual sensors can filter, aggregate or transform the data. In OpenIoT, and from an end-user perspective, both virtual and physical sensors are very closely related concepts since they both, simply speaking, measure data. OpenIoT defines the concept of a virtual sensor as a subclass of the sensor concept as defined in the SSN ontology.

Openiot:VirtualSensor rdfs:subClassOf ssn:Sensor; rdfs:isDefinedBy <http://openiot.eu/ontology/ns>

Table 3 Virtual Sensor Definition

In the scope of the OpenIoT, utility metrics will be used in a variety of utility-based algorithms will be designed and deployed, notably regarding resource management, utility-driven privacy and utility-driven security mechanisms. In addition to resource management, optimization, privacy and security, utility metrics will serve as a basis for accounting and management of SLAs (Service Level Agreements) between the OpenIoT cloud services providers and end users. These utility metrics will be recorded as part of the implementation of the Utility Manager component of the OpenIoT platform, while they will be also used to drive the utility based mechanisms of the project in WP5.

IETF/IRTF

The Internet Engineering Task Force (IETF) works on the specification of Internet based protocols that are able to support at least technical and syntactic interoperability. IETF specifies modeling languages, which can be any artificial languages used to express information or knowledge or systems in a structure that is defined by a consistent set of rules, see [6].

The IETF NETMOD [7] working group is enhancing the semantic interoperability properties of the YANG data modeling language by specifying a YANG extension statement that allows for defining syntax of metadata annotations in YANG modules [8]. This extension also specifies XML and JSON encoding of annotations and other rules for annotating instances of YANG data nodes.

IoT semantic interoperability is currently being supported by the Internet Research Task Force (IRTF) Thing to Thing Research Group (T2TRG) [9]. This (proposed) research group will investigate open research issues in turning a true "Internet of Things" into reality, an Internet where low-resource nodes ("Things", "Constrained Nodes") can communicate among themselves and with the wider Internet, in order to stimulate innovation. In particular, a subset of the T2TRG main areas of interest is listed below:

- Operating Things that have multiple masters/ stakeholders (including understanding role definitions of devices, owners, operators etc.)
- Deployment considerations; scaling considerations; cost of ownership
- Cooperation with W3C, e.g. on data formats and semantics

4. References

[1] Tim Berners-Lee, James Hendler and Ora Lassila, "The Semantic Web", Scientific American, May 2001, p. 29-37.

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[3] Open data - Wikipedia, the free encyclopedia. 2015. Open data - Wikipedia, the free encyclopedia. [ONLINE] Available at: https://en.wikipedia.org/wiki/Open_data. [Accessed 13 October 2015].

[4] EUROPEAN RESEARCH CLUSTER ON THE INTERNET OF THINGS , "IoT Semantic Interoperability: Research Challenges, Best Practices, Recommendations and Next Steps", European Commission. March, 2015

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[9] Proposed Thing-to-Thing Research Group. 2015. Proposed Thing-to-Thing Research Group. [ONLINE] Available at: https://datatracker.ietf.org/doc/charter-irtf-t2trg/. [Accessed 14 October 2015].

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