State-of-the-art of Internet of Things ontologies

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ABSTRACT
The internet of things will integrate an extremely large amount of heterogeneous entities, which need to be consistently and formally represented and managed. These issues have recently received considerable interest from both academia and industry that are working on technologies to develop the future Internet. In this paper we will discuss needs for semantic description and ontologies to solve the challenges that we face in IOT. We will also do some state-of-the-art analysis for some existing IOT ontologies and will discuss approaches for ontology evaluation.

Keywords: ontology, Internet of things, semantic description.

1. Introduction:

Challenges the Internet of Things (IOT) is facing are directly inherited from today's Internet. However, they are amplified by the anticipated large scale deployments of devices and services, information flow and involved users in the IOT. It is a joint and complex discipline that requires synergetic efforts from several communities such as telecommunication industry, device manufacturers, semantic Web, informatics and engineering, among many others. IOT consists of interconnected "Things" and their virtual representations addressable by using standard communication protocols. However, the large scale of IOT and heterogeneity of the "Things" makes interoperability among them a challenging problem. We will in this paper discuss in detail what are the challenges that today IOT faces, and what steps should be taken in order to solve them. We will begin our discussion in section 2: with the introduction to ontology? And what do we mean by it? Ontology is a term defined as *specification of conceptualization*. Design criteria for ontology include concepts coherence, clarity and extendibility. It is important to also evaluate ontology: evaluation can be done by asking competency question such as nature of domain, and resources of data etc. In section 3: we will describe about Internet of things and discuss in details the challenges such as large scale IOT network handling, deep heterogeneity and unknown topology. And will also dig deep into what the core functionalities for IOT (such as automate discovery and provide interoperability). As we know, that the volume, velocity and volatility of the IOT data impose significant challenges to existing information systems. And to design useful application for IOT we need to transform this raw data into meaningful intelligence. Also different IOT domains need to interoperate with each other in order to provide state-of-the-art IOT applications. Once we have already understood the IOT challenges and key functionalities of IOT we move to section 4: which discusses about the state-of-the-art IOT ontologies. The first part of this section has build the conceptual foundation for the need of semantic description and Ontology use. As we know Semantic technologies based on machine interpretable representation have shown promise for describing objects, sharing and integrating information, and inferring new knowledge together with other intelligent processing techniques. But semantics alone will not be able to solve fully the problem of interoperability among different domains inducing the need for the ontology design. But applying semantic technologies to IOT, however, has several research challenges, pointing out that IOT and using semantics in IOT is still in its early days. The second half of the section 3: discuss about the some of the state-of-the-art ontologies which includes swamo, mmi device ontology, ontosensor, CSIRO, SSN etc. Note that also a standard approach for service layer for M2M i.e. onem2m functional model is discussed. In section 5: some of the other related work found during the study is presented. In the last section 6, we discuss briefly the observation found during the study and what conclusions were made: like answer to questions such as, is there a common main ontology that can be implemented or used regardless of the domain? In our study what we observed that having a main global ontology that can be used to any device or service etc is still not yet existent. If the ontology exists, there are two scenarios: i) it would be very simple abstract ontology that will not suffice the use for real users or ii) it will be very complex i.e. unrealizable. In the last a brief discussion is provided for the future work.

2. ONTOLOGY

Ontology as a term comes from field of philosophy, which means: study of being or existence. Historically [1] in information science the term 'ontology' has been used as a technical term denoting an artifact that is designed to enable the modeling of knowledge about some domains real or imaginary. The term was adopted by artificial intelligence researchers (during 1980). AI Community used the term 'Ontology' to refer to both a theory of a modeled world and component of knowledge system. In the early 1990's, an effort to create interoperability standards identified a technology stack that called out the ontology layer as a standard component of knowledge systems [3]. A paper [2] associated with that effort is credited with a deliberate definition of ontology. The research paper [2] defines 'ontology' *as a formal, explicit specification of a shared conceptualization, which is, used to represent knowledge within a domain as a set of concepts related to each other.* Formal ontologies are designed. In order to guide and evaluate our design we need design criteria for ontologies. A preliminary set of design criteria [2] for ontologies:

- *Clarity*: Ontology should effectively communicate the intended meaning of defined terms (definitions should be objective and complete).
- *Coherence:* Ontology should be coherent: that is, it should sanction inferences that are consistent with the definitions. Ontology is incoherent if a sentence inferred from axioms contradicts a definition or example given informally.
- *Extendibility:* Ontology should offer a conceptual foundation, for a range of anticipated tasks, and representation should be crafted so that one should be able to define new terms for special uses based on the existing vocabulary, in a way that does not require the revision of the existing definitions.
- *Minimal encoding bias*: Knowledge-sharing agents can be implemented in different representation, so encoding bias should be minimized, that is, the conceptualization should be specified at knowledge level without depending on particular symbol-level encoding.
- *Minimal Ontology commitment*: Ontology commitment is based on consistent use of vocabulary. So ontology should make few claims about the model.

Of course above design criteria will require making tradeoffs among the criteria mentioned requirements. A computational ontology is composed of [4] four main components: Classes, relations, attributes and individuals. Concepts, also called Classes, are the core component of most ontologies. A class represents a group of different individuals (individuals are instances of classes or their properties), that share common characteristics. Classes are the main concept to describe. Relations in ontology describe the way in which individuals relate to each other. Now classes can have one or more children known as subclasses, used to define more specific concept. Classes and subclasses have attributes that represents their properties and characteristics. Up till now we have answered what is ontology? It's design criteria? and components of Ontology. In recent years we have seen rapid progress in the development of ontologies as semantic model. Ontology support semantic interoperability and integration. But there is a natural need for having an ontology evaluation criterion to ensure perspective user about its coverage, concepts, effectiveness, semantic interoperability, content and methodology. Two broader classification in evaluating [5] ontologies is whether to perform a component-based or task-based evaluation. Component based evaluation is often seen as glass box evaluation, where it's seen how much effectively have ontology has been able to represent the concepts. Task-based evaluation usually applied to ontologies that are tightly integrated with an application performing specific tasks. Task-based evaluation is often called black box evaluation. Some key considerations, in evaluating an ontology that need to be considered when evaluating an ontology:

- *Expressivity vs. cost of computation*: High expressivity of ontology concepts is desired (keeping in mind the computation cost). Ontology concepts are represented by knowledge representation (KR) language. Some of commonly used KR languages are i) CL (common logic) representation language, ii) interoperable knowledge representation for intelligence support (IKRIS) language, and iii) Semantic web ontology (owl) language. High expressivity and emphasis on minimizing the cost of computation is manifested by OWL-Lite, OWL-DL (description logic) and other description logics. . Ontology, both covering the same domain, expressed in different KR language will be evaluated differently.KR languages define the syntax and the semantics for the ontology models. Properties of KR language also needed to be considered in evaluating the ontology. Properties of KR language includes i) soundness: expression derived from knowledge base (KB) of the ontology implied by that KB, ii) completeness: any expression that can be logically implied by the KB can be derived, iii) decidability: being both sound and complete, iv) consistency: language is consistent, that is, there are no missing concepts or redundancy of information (more classes, relation or instances than needed) or other semantic inconsistencies.
- *Competency Questions*: Questions that ontologist frames prior to the development of the ontology (like

nature of domain and data sources ontology will encompass).

- *Semantic distance and semantic similarity*: Ontology can be represented in a graph-based form [4]. Now in this scenario two quite effective measures, that is, i) semantic distance and ii) semantic similarity are most commonly used to for ontology evaluation. Semantic distance: it measures how closely two nodes are topologically related in a graph; and semantic similarity: captures to what extent two nodes might represent the same entity in reality. These two measures values are calculated mainly by path-length [5] in a network taking into account link-weights. A high quality ontology computation should compute semantic distance as being minimal and semantic similarity as being maximal.

The ultimate evaluation of an ontology is in terms of its adoption and successful use. Future evaluation measures for ontology will high rely on factors such as:

- Measure of human consensus on classification tasks, and semantic agreement
- A formal, standard, and verifiable information system
- Well-defined engineering practices and standard tested theories that allow predictions
- Development of more successfully used ontologies

With these requirements fulfilled, new ontology can be evaluated by comparing it to the 'reference' ontology (suitable reference ontology should be one created under similar condition with similar goals). This process of evaluating ontology by comparison is called ontology alignment. This method is still also used in many scenarios where reference ontology is available (mostly comparing two version of the same ontology). But still fall short of providing full evaluation metrics, as gold standard reference ontologies are still not available. So far we had look into explanation of everything related to ontology and had answered some of the key questions related to ontology definition, design criteria, components and evaluation criteria (consistency and coverage). Now we shift our focus towards Internet of things and build a conceptual foundation for the vision and challenges realizing the internet of things.

3. INTERNET OF THINGS

After the World Wide Web (the 1990's) and the mobile Internet (the 2000's), we are now heading to the third and potentially most "disruptive" phase of the Internet revolution, that is, "Internet of Things". The earliest record mention of the term internet of things (IOT) goes back to a presentation by MIT's Kevin Ashton in 1999. In it, he famously stated that adding *RFIDS to every-day objects would create an Internet of Things*. The Internet of Things links the objects of the real world with the virtual world, thus enabling anytime, anyplace connectivity for anything and not only for anyone. It refers to a world where physical objects and beings, as well as virtual data and environments, all interact with each other in the same space and time. To start with getting oneself comfortable with notion of a 'thing', let first concentrate [7] what do we mean by it? In the context of "internet of things" a "things" could be defined as a real/physical or digital/virtual entity that exists and move in space and time and is capable of being identified. Things are commonly identified either by assigned identification number, names and/or location address. In context to the concept of things as explained before, "internet of things" is an integrated part of future internet and could be defined as a dynamic global network infrastructure with self configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network. In internet of Things, the term thing can be perceived in a different way depending on the domain in which it is used. There has been a broader classification of Application domains in IOT [7] into three domains, i) Industry: activities involving financial or commercial transactions among companies (such as banking, service sector, manufacturing), ii) Environment: activities regarding monitoring environment, natural resources (such as agriculture, recycling), iii) Society: initiatives in development of people, society (such as e-inclusion, society structures). These domains are hard to isolate, new applications and services that apply at inter- or intra-domain level will affect all domains. Now with the technological advancements, communication and processing capabilities are becoming more and more accessible and cheap. And with this notion of things encompassing everything including not only RFIDs, but also sensors, mobile devices, actuators and so on. In this new vision, all of these are considered to be things and by assigning each thing participating in internet of things a global unique identity (UID) or several unique identities and giving them the capability to communicate will create enormous large amount of networks of things. And there most visible effect is that the deployments and operation of these internets of things networks are hard, costly and complex. More increases in these devices (things) are predicted in future, as of recent predictions[1] from technology giants (such as Cisco) by 2020 there will be more than 50 billion devices (things) attached to the existing network and communicating among each other or several other devices: that is, these devices are creating enormous amount of data and it need to be understood in order to really benefit from IOT. In today scenario highly-specialized field experts are needed to interpret the sensor data and come up with actuation commands. This approach is clearly too costly and time-consuming and will not scale as IOT pushes into an era of more than 50 billion connected devices and is going to affect the lives of general population. There comes a natural need by now to explore what are really the core challenges that we face today or in the future, following are challenges underlying IOT summarized by research paper [6] and CERP-IOT cluster [7] report:

- *Scale:* Imagine a scenario, where one needs to sense million of sensors and perform a certain act in response. In this scenario it is normally not feasible to sense all the sensors due to constraints such time, memory, processing power, and energy consumption (What should be alternate to it?).
- *Deep heterogeneity:* In IOT domain many sensors and actuators exhibits different operating systems characteristics, different software platforms, different vendors and different hardware implementation, and there are many heterogeneous systems interacting. So IOT typically have deep heterogeneity embedded by default to its architecture.
- *Unknown Topology*: Much like the existing internet, one of the IOT's main characteristics is the fact that its topology is both unknown and dynamic. Consequences that results because of this and results in not proper functioning of application, i) applications will end up demanding on services which are not actually available from any single pre-existing component of the network at that given time, ii) service might themselves rely on devices that had once joined the network and left it abruptly.
- *Unknown Data-Point Availability*: Another consequence of the unknown topology is that sometimes there will be no suitable device at the desired geographical location or, other times, the device has not collected/stored the data-point that is desired.
- *Conflict resolution*: dealing with actuators a situation can arise where a conflict arise, for example, when multiple application attempts to act on the device in different ways.
- *Incomplete or inaccurate metadata*: Many of the challenges mentioned can likely be solved by extensive use of metadata. But metadata entered by a human operator at installation time, in a massive network will result in incomplete or inaccurate information due to human error. In addition, some of this information can include characteristics that change over time (e.g., calibration parameters). Therefore, even discounting human error, the state of the metadata in the network is bound to degrade until it no longer represents reality. In these scenarios, how can be missing metadata be recovered? And how can be existing information be monitored and updated when necessary?

So in totality future IOT poses many challenges and there is a need for considerable steps to be taken for the solution of these challenges. Heterogeneity of "things" makes interoperability among them a challenging problem, which prevents generic solutions from being adopted on a global scale. Many researchers are focused, on resolving these issues. Many research papers propose [9, 10, 8, 7] new middleware, that is, an open source service-oriented architecture for the middle-ware is proposed (details for different middle-ware implementation is included in latter section). As told before the primary goal of interconnecting devices (e.g., sensors) and collecting/processing data from them is to create situation awareness and enable applications, machines, and human users to better understand their surrounding environments. The understanding of a situation, or context, potentially enables services and applications to make intelligent decisions and to respond to the dynamics of their environments. Data collected by different sensors and devices is usually multimodal (temperature, light, sound, video, etc.) and diverse in nature (quality of data can vary with different devices through time and it is mostly location and time dependent). Some of the core functionalities that IOT need to have in order to flourish and fully benefit from its full potential are:

- It needs to automate "thing" (sensor or entity) addressing and tracking
- It also needs to exhibit interoperability (different states holders can ambiguously access, interpret, exchange or integrate data)
- The IOT needs search mechanism and discovery mechanism for locating "resources" (thing or entity) or "services" that provide data related to an entity.

Now with these core requirements for IOT in mind and the challenges of IOT mentioned above, we need to design useful applications to get a meaning out of this large, raw, diverse, volatile and ubiquitous data. And for this we need to transform it into meaningful actionable data. This data transformation process [11] can be better illustrated using the well known "knowledge hierarchy" (shown in figure 2.3).

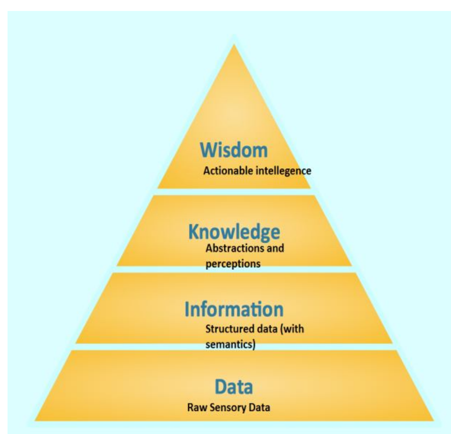

Figure 3.2 "Knowledge Hierarchy" in the context of IOT

Explanation of the "knowledge hierarchy": The lower layer refers to large amount of data produced by the IOT resources and devices. The layer above helps create structured and machine-readable information from the raw data of various forms to enhance interoperability. However, what is required by humans and high-level applications and services often is not the information, but high-level abstractions and perceptions that provide human and machine-understandable meanings and insights of the underlying data. The high-level abstractions and perceptions then can be transformed to actionable intelligence (wisdom) with domain and background knowledge to exploit the full potential of IOT and create end-to-end solutions. Now in above section as you can see, we discuss key challenges and core requirements for Internet of things. We also mentioned some terms such as middleware or semantics, very briefly, which we will explain in detail in latter section. In the next section we will discuss about the research proposals and solution to solve the IOT challenges and will also see, how the semantic-oriented perspective towards IOT is use to solve the problem core interoperability challenge. We would also see that just by providing semantic description alone does not solve the issue of semantic interoperability (as across different domains, semantic description will be interpreted differently). We would also discuss briefly about use of common ontology and with semantic descriptions will make the data semantically interoperable for users and stakeholders that share and use the common ontology. In the last we will in detail review some state-of-the-art ontologies for IOT domain.

4. IOT ONTOLOGIES

Issues related to interoperability, automation, and data analytics naturally lead to a [12] semantic-oriented perspective towards IOT. Applying semantic technologies to IOT promotes interoperability among IOT resources [13, 7] and facilitates effective data access and integration, resource discovery, semantic reasoning, and knowledge extraction. As stated in research paper [11] "Defining an ontology and using semantic descriptions for data will make it interoperable for users and stakeholders that share and use the same ontology." Now as we have seen before that in previous sections we discussed about ontology and IOT, now it time we need to explain what is ontology of the internet of things is all about-- ; An ontology for the Internet of Things provides all the necessary semantics for the specification of IOT devices as well as the specifications of the IOT solution (input, output, control logic) that is deployed using these devices. These semantics include terminology related to sensors and observations, reusing the one already provided by the other ontologies, such as, SSN ontology (we will discuss about SSN shortly) and extend them to capture also the semantics of devices beyond sensors — i.e. actuators, identity devices (tags), embedded devices, and of course the semantics of the devices and things that are observed by sensors, that change their status by actuators, that are attached to identity tags. Now a natural next question would be in readers mind will be: risk of moving into the IOT world without an ontology to ground it? The lack of explicit and formal representation of the IOT knowledge could cause ambiguity in terminology, hinder interoperability and mostly semantic interoperability of entities in the IOT world. Furthermore, lack of shared and agreed semantics for this domain, that is, IOT (and for any domain) may easily result to semantic heterogeneity — i.e. to the need to align and merge a vast number of different modeling efforts to semantically describe IOT entities, efforts conducted by many different ontology engineers and IOT vendors (domain experts). Although there are tools nowadays to overcome such a problem, it is not a fully automated and precise process and it would be much easier to do so if there is at least a partial agreement between the related stakeholders — i.e. a commonly agreed IOT ontology. Now we have discussed until now, that semantics description in IOT promotes interoperability, and also has seen that semantics alone cannot be enough to guarantee interoperability and not solve all the issues regarding discovery, management of data, and supporting autonomous interactions. We need an ontology [11] and semantic description in order to make data interoperable (for users in same domain). Now we feel the need to also mention that most of the current ontologies and semantic description frameworks in the IOT domain are defined in the context of different projects and applications or they are currently at an early stage. To achieve global scale semantic interoperability, common semantic annotation frameworks, ontology definitions, and adaptation are key issues. Recent efforts, such as the W3C SSN ontology (SSN ontology will be explained shortly), are effective steps towards achieving this goal. For the current and existing applications, it is also important that their ontologies and knowledge base can be accessed and reused by large groups of potential consumers. Developing and sharing ontologies and contributing towards standard description and standard annotation frameworks that can also support legacy applications are effective steps in achieving semantic interoperability on a large scale. Other solutions, such as ontology mapping and matching (i.e. manual, semi-automated, or automated) can help link the already existing resources using different semantic annotation models. The ontology designers can also reference existing common ontologies and provide links to other upper-level ontologies to support interoperability between different semantic descriptions in the IOT domain. In above we have discussed the use of semantic annotations. In IOT domain semantic annotations provides machine-readable and machine interpretable metadata to describe the IOT resources and data. However, there are some concepts that needs to be understood is that machine interpretable data: read carefully when I mentioned machine-interpretable data, but not machine understandable data. Annotations can make provide machine interpretable data but it is still not machine understandable. Another key aspect is that the semantic annotations can be added to the data at different stages. Figure 4.1 shows that how semantics can be used at different levels in IOT.

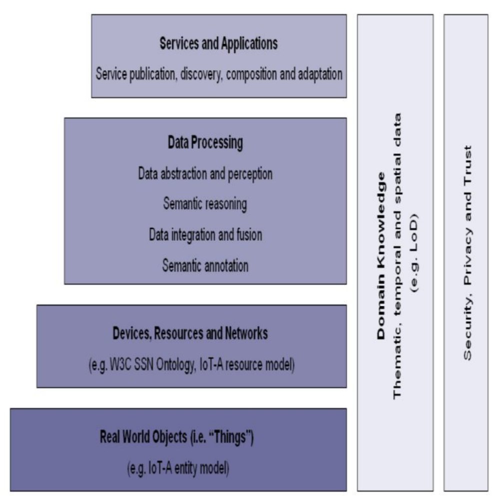

Figure 4.1: Semantics at different levels in IoT

The semantic Web technologies include well-defined standards and description frameworks (e.g. RDF, OWL, SPARQL) and a variety of open-source and commercial tools for creating, managing, querying, and accessing semantic data. However, this still does not eliminate the key role of information analytics and intelligent methods, which can process and interpret the data and create meaningful abstractions.It is important to note here that semantic technologies and Ontology Description are not new concepts. They have existed for long, and have matured over the years. Ontologies and semantic description frameworks provide an effective way to share and agree on a common vocabulary and knowledge model for describing the data, which can be machine-interpretable and represented in interoperable and reusable forms.

Review of IOT ontologies:

Ontologies in IOT have been developed for a number of uses, including the description of sensor and sensor networks, IOT resources and services, smart "Things", etc. In this section we review some of the most important ontologies in the IOT domain and give a brief overview of the recent activities on the ontology developments in this field. We will also review proposed IOT middleware architecture [16] which use backbone of knowledge base composed of three ontologies (device, physics, estimation ontology). Later in end part we will briefly discuss about Machine-to-machine standards and particularly will discuss about oneM2M architectural consideration. Now we first begin by the reviewing Sensor and Observation ontologies. These ontologies were evaluated by set of questionnaire [14], which are very close to the evaluation criteria mentioned in section 2 for ontology evaluation.

CSIRO Sensor Ontology: This ontology was created for describing and reasoning about sensors, observations and scientific models. Provide a semantic description of sensors for use in workflows. This ontology is still in the process of actively been developed. It is the ontology that became the starting point for the development of the Semantic Sensor Network ontology. It fairly describe key concepts behind the ontology such as for grounding (location, mobility, range of sensing), Operation Model and Process (and then Feature etc. from a domain perspective). With respect to sensor this ontology is reasonably broad, but there is more to include from say from SensorML, O&M and OntoSensor. Ontology not a hierarchy of concepts, has some restrictions etc. The ontology was not adopted widely, only few examples. As we have mentioned before that this ontology was used to develop SSN ontology. So feature like plug-and-play and composition were widely appreciated features for this ontology.

OntoSensor: This ontology was created to build a knowledge base of sensor. This knowledge base can be queried via a Protege plugin. The ontology is still incomplete, but it is mainly organized around sensor, sensor capabilities description. It is not very well featured ontology. It provides a small taxonomy of sensors, but, it contains several complicated properties. Downside of the ontology is that the organization of concepts and properties is so messy to use in other application or to extend.

SWAMO: Ontology was created to enable dynamic, composeable interoperability of sensor web products and services. It describe autonomous agents for system-wide resource sharing, distributed decision making, and autonomic operations. Ontology is actively maintained, and in progress (not complete).The ontology provide maximum interoperability. It focuses on the sensor domain, and particularly on processes to control them. Ontology is Sophisticated, and is interoperable with SWE descriptions. One downside to it, is classes look a little mixed and the highest level class (Component) does not appear to reference itself.

MMI device Ontology: This ontology was designed for oceanographic specific devices, including both sensors (which measure things) and samplers (which pick up things). The first priority is to be able to broadly characterize the devices (i.e., sort them into groups). One significant use of such characterizations is to help users (or web applications) discover sensors or data of interest. The ontology is organized around a system concept. System is a Process. System has capabilities, like measurement capabilities (accuracy etc). Even though it was meant to be for oceanographic sensor it could be used in other contexts.

SensorML Processes: Ontology was created to represent SensorML model and serve as a starting ontology for the MMI device ontology. It is based on the SensorML schema.

SEEK OBOE: SEEK Extensible Observation Ontology (OBOE) was developed for the SEEK project, and has since been used by Spire. The comment documentation for the ontology concept is good. The Ontology SEEK OBOE comprise of a core observations ontology, a units extension, and a further extension for domain use (coastal ecosystems).The observation ontology separates observations from the entity being observed: the observation has a measurement while the entity has characteristics, and the measurement is then of that characteristic. SEEK OBOE is much of observation ontology, not device ontology.

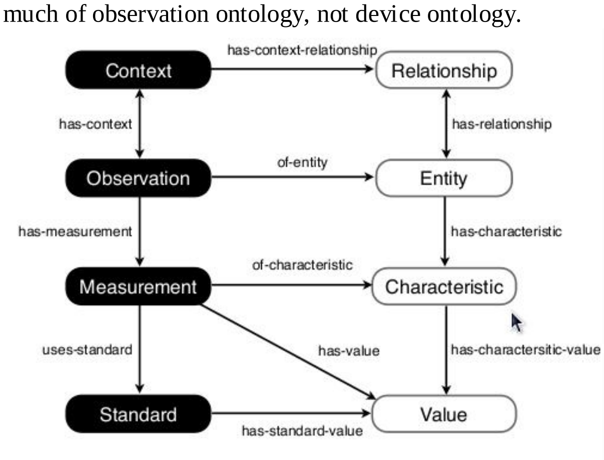

Figure 4.2 - Overview of the OBOE ontology

Stimulus-Centric: This ontology aims at bridging between the *sensor-centric* Sensor Model Language (SensorML) and the *user-centric* Observations & Measurements (O&M)[14] specification by focusing on stimuli as objects of sensing. It does not require a strong link between sensors and *features of interests* such as O&M. It also include humans as sensors which are the key to volunteered geographic information. It is actively maintained. As it is a top-level kind of ontology, it is not complete in the sense of listing sensor (types) or observations but focuses on establishing a common ground for both. The key concepts are stimuli, observations and sensors. It is based [14] on sensorML, O&M and Dolce.

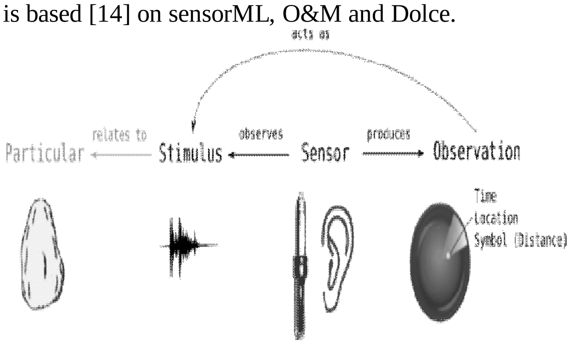

Figure 4,3 - The role of stimuli as a proxy between the sensor and the object of sensing

SENSEI Observation and measurement ontology: The purpose for this ontology is to annotate sensor observation and measurement data; The O&M ontology [14] is then incorporated into the SENSEI resource model. Ontology is hierarchical in concept. The ontology organized around the key concepts of observing and measuring data (provided via a resource) that can be related to an Entity of Interest (EOI).The processes and services that make the O&M data available are provided through a Resource End Point (REP).

O&M-OWL (SemSOS): The O&M-OWL ontology was created so that we may reason over sensor data to infer "high-level" concepts from "low-level" phenomena. These concepts were then incorporated into a Sensor Observation Service (SOS) so that users may query for events without requiring expert knowledge of how events and phenomena are related. The ontology is highly documented. The ontology is organised around four major concepts: (1) Observation -- act of observing a phenomenon (2) Process -- method, algorithm or instrument, or system of these (3) Feature -- an abstraction of real world phenomena, or "real-world" entity (4) Phenomenon -- property of a feature that can be "sensed" or measured. The ontology mostly deal how sensors can be combined. Semantics are found in the relations between the four major concepts described before. Using OWL to infer types of observations, phenomena, sensors, etc., given partial annotation. Since our ontology is based on O&M, it is already aligned with the SensorML language [14], which is a major foundation for the SSN ontology [14]. For example, the concept of process within O&M is taken directly from SensorML.

The SEMANTIC SENSOR NETWORK ONTOLOGY: We will discuss SSN ontology in detail here. Now we have seen in previous sections about the IOT challenges. To solve those challenges and meet IOT today's and future requirements, SSN ontology was proposed [14]. Back 11 years from now, Sensor Web Enablement (SWE) [14] was created by Open Geospatial Consortium (OGC). SWE main agenda, i) sensors reporting position, ii) sensors connected to web and all readable remotely, iii) all with meta-data registered and can be controlled remotely. So what SWE came up was a service-oriented architecture. So basically they define a set of services-interfaces such as:

SOS (sensor observation service):which is a way to query and access sensor descriptions and sensor data

SPS (sensor planning services): This allows you to task sensors to engage in different behaviors.

SAS (sensor alert service): allow to subscribe to different sensing events. So these different services communicate with one-another through standard XML protocols [14]. There was standardization in protocols, and because of that it solved many problems such as sensor discovery. But still what it did not allow us to do was integrate or interpret the data (We lack interoperability). So 4 years ago from now W3C (World Wide Web Consortium) brought together a group of researchers and see if they can apply semantic technologies to help solve some of these problems. An SSN incubator group was made, and the first thing they did was build a SSN Ontology [14]. The SSN ontology is based around concepts of systems, processes, and observations. It supports the description of the physical and processing structure of sensors. Sensors are not constrained to physical sensing devices: rather a sensor is anything that can estimate or calculate the value of a phenomenon, so a device or computational process or combination could play the role of a sensor. The representation of a sensor in the ontology links together what it measures (the domain phenomena), the physical sensor (the device) and its functions and processing (the models). The Ontology structure revolves around the central Stimulus-Sensor-Observation pattern as shown in the figure 4.3. Several conceptual modules (such as device, platform, data etc) build on the pattern to cover key sensor concepts can be seen on the figure.

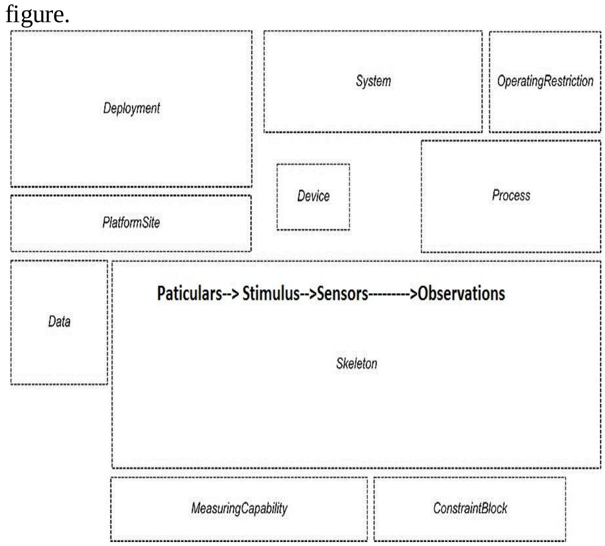

Figure 4.4 SSN ontology structure

Explanation for this ontology structure can be explained briefly: As we know sensors are often implemented within device and these devices can be integrated into systems and systems have particular operating restrictions, they can only work in particular temperature and within particular location, they have critical measurement limitations (example can only measure certain irregularities). These system can be integrated with platforms (like example the airplane internal control system) and then deployed. So we set our modeling an ontology in this fashion, that is very systematic fashion; and the reason we did this, we wanted to make ontology as simple as possible. For example If I have an application and I want to use SSN ontology. I can pull in the modules we need, to add more complexity or more concepts (but only when I need them). But if we do not need some modules we just leave them, and this facilitates simplicity and thus interoperability. The figure4.5 shows us an overview of the main classes and properties inside the ontology modules.

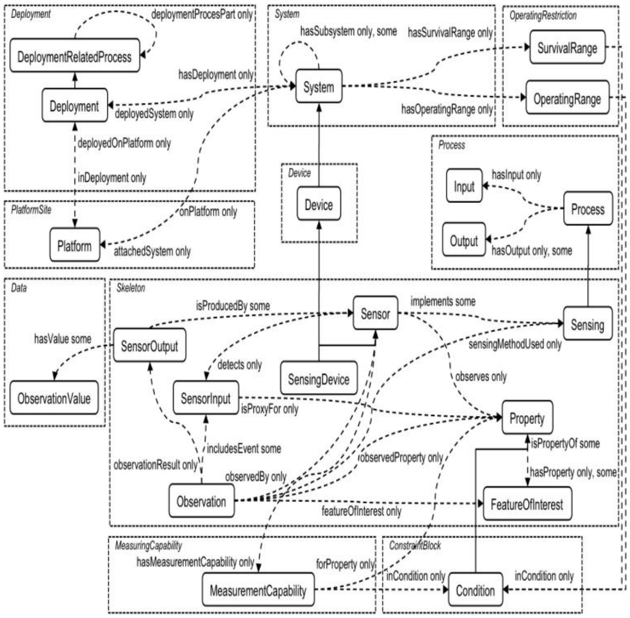

Figure 4.5 overview of main classes (SSN ontology).

One aspect to note here is that the main classes of the Semantic Sensor Network ontology have been aligned with classes in the DOLCE Ultra Lite (DUL) foundational ontology [14] to facilitate reuse and interoperability. So SSN ontology is backward compatible: so if you have an SOS or other services, we can accommodate the data with the concepts from the SSN ontology. (So we can have advantage of high expressivity when we want to integrate with systems that are semantically aware, otherwise we ignore backward compatibility). Since we develop SSN ontology, we see a good adoption of the ontology [15].

Figure 4.6 some of adopters of SSN ontology

Some of adopters that have adopted SSN ontology [15, 14] include projects such as CSIRO, IOT.est, SPITFire etc. when some of the groups using the ontology were contacted and asked why they want to use this semantic technology? And from there we came up with four major use cases that are shown in the figure 4.7

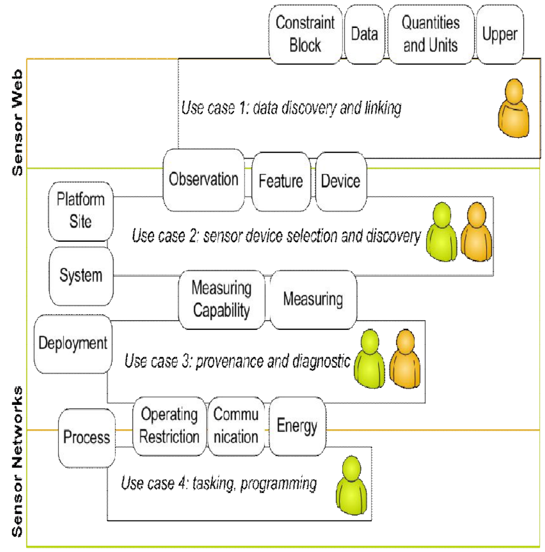

Figure 4.7 Four major use cases

So four needs that people needed to use ontology for: data discovery and linking, sensor device selection and discovery, provenance and diagnostic and tasking, programming. Modules that will be used to address these four major needs were platform, system, deployment, and process. We know that deployment and process is hardware centric and in IOT this will be more interested modules.

IOT middleware architecture: As we have already mentioned the challenges of IOT (such as scale, unknown topology etc) for which we need to have a IOT middleware based on the service-oriented paradigm [16] that abstracts things as services, therefore allowing us to keep services loosely coupled in order to increase reusability. The architecture will makes widespread use of approximations and estimations in order to address the IOT's challenges without requiring the intervention of domain experts. For this, in the backbone of our middleware, lies a knowledge base composed of three ontologies: a Device Ontology, a Physics Domain Ontology, and an Estimation Ontology. The overall architecture of our proposed IoT middleware is shown in Figure 4.8

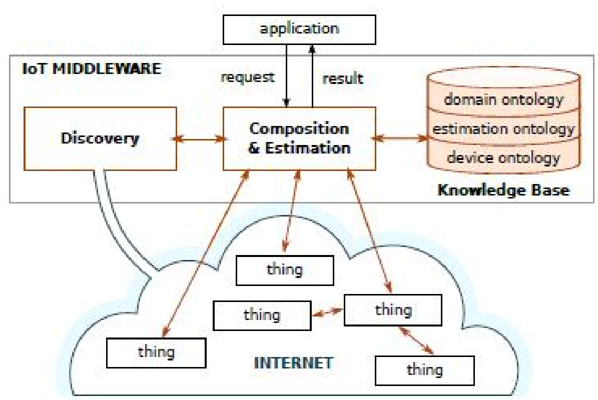

Figure4.8 Middleware architecture

The three ontologies that make the knowledge base are:

Device Ontology: The Device Ontology models actual hardware devices that may exist in the network. For our middleware, it can be regarded as the device description repository that can be accessed for discovery.
Domain Ontology: The (Physics and Mathematics) Domain Ontology models information about real world physical concepts and their relations among each other. For our middleware, it can be regarded as the main repository to access for service composition.
Estimation Ontology: The Estimation Ontology contains information about different estimation models (such as linear interpolation etc.), the equations that drive them, the services that implement them, and so on. For our middleware, it can be mainly regarded as the repository describing the device's quality of service, and provides information needed for service composition.

OneM2M: Now after discussing some of the existing semantic technologies, and IOT Ontologies in previous section, now it's the right time to discuss about functional architecture for oneM2M. The purpose [19] and goal of oneM2M is to develop technical specifications which address the need for a common M2M Service Layer that can be readily embedded within various hardware and software, and relied upon to connect the myriad of devices in the field with M2M application servers worldwide. A critical objective of oneM2M is to attract and actively involve organizations from M2M-related business domains such as: telematics and intelligent transportation, healthcare, utilities, industrial automation, smart homes, etc.
Now here we now want to discuss [20] about the description of functional components as well as a functional model to support semantics for various machine-to-machine applications. Now in this technical report [20] and keeping in mind the future standardization perspective in oneM2M [21], the proposed generic functional model to support semantics for various M2M applications is shown in figure 4.9.

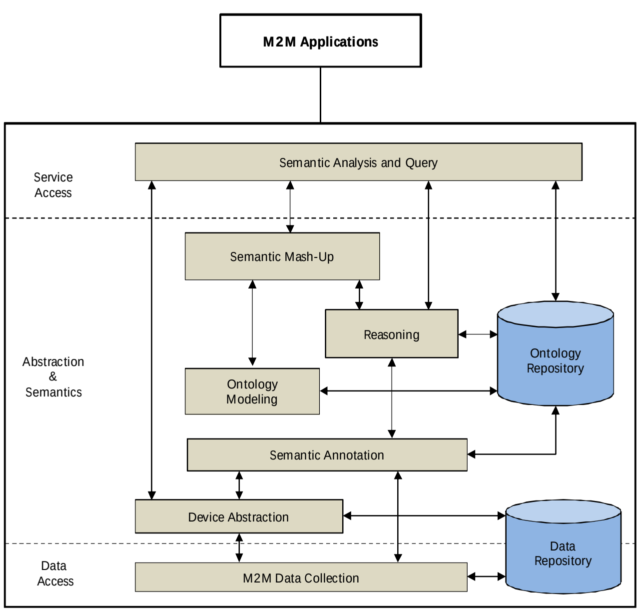

Figure4.9: Generic functional model for supporting semantics.

The functionalities of the model [20] are logically composed of three main parts: i) S**ervice access** which provides an interface with various M2M applications; ii) **Abstraction & semantics** which perform main functionalities for semantics to M2M data and resources; iii) **Data access** which provides connections with a device and/or a gateway for accessing M2M data Now we briefly explain the modules of the model: Any query request from m2m application are analyzed semantically. And to answer these semantic analyzer requests mechanism called reasoning to derive a new implicit knowledge from semantically annotated data and to answer complex user query (note our is m2m application). Ontology repository is storage of resources defined based on Ontology. Ontology modeling is the process for building an ontology which is used to model a domain and support reasoning about concepts. Semantic mash-up provides functionalities to support new services through the creation of new virtual devices. Semantic annotation of M2M resources is a method for adding semantic information to M2M resources. Device abstraction is a process of mapping between a set of Device Application Information Models. Data repository basically stores new data collected by m2m data collection module.

5. RELATED WORK

There had been many studies been done on this specific topic of semantic technologies and IOT ontologies. One study that is particularly important: as it includes the review of SSN ontology and existing standards for semantics from OGC [21]. The aim of this contribution [21] is to review the current progress on semantics standardization and identifying new work items for the standardization in oneM2M.The TR team proposed to analyze existing standards for semantics from OGC and W3C in some details for reference to identify new work items for future standardization in oneM2M.

6. CONCLUSION AND FUTURE DIRECTIONS

In our study what we observed that having a main global ontology that can be used to any device or service etc is still not yet existent. If the ontology exists, there are two scenarios: i) it would be very simple abstract ontology that will not suffice the use for real users or ii) it will be very complex i.e. unrealizable. Most of ontology that exist today are either domain specific, and so the problem of having a simple global ontology (able to model everything from sensors to services and overcoming the issue of interoperability) always remains a challenge. To achieve global scale semantic interoperability, common semantic annotation frameworks, ontology definitions, and adaptation are key issues. Recent efforts, such as the W3C SSN ontology, are effective steps towards achieving this goal. IOT ontology modeling and using semantics in IOT are still in their early days. The IOT community requires coordinated efforts to define more vocabularies and description frameworks to represent resources, data and services in the IOT domain. Also there was a need felt for synergetic efforts from other fields such as service computing, data mining and social science to enhance the processing and utilization of semantic data in the IOT domain.

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