

## Overview of IoT semantics landscape

*Christian Groves (Christian.Groves@nteczone.com)*

*Lui Yan (scarlett.liuyan@huawei.com)*

*Yang Weiwei ([tommy@huawei.com](mailto:tommy@huawei.com))*

*Huawei Technologies*

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### 1 Introduction

One of the goals of the IoT Semantic Interoperability Workshop is to discuss the harmonization of information and data models for use with IoT deployments. The authors believe that a first step is to understand what information and data models exist. As paper (Appendix II) is an attempt to survey the current IoT ontological / semantic space.

It does not propose the use of a particular semantic vocabulary or representation technique. Given the breadth of the identified data models/vocabularies there was no single one that would cover all potential uses of IoT. The discussion section highlights a number of issues that should be considered when developing / adopting / harmonising IoT semantics/data models. For example if one data model is technically better than another but requires payment to download it. Will this succeed over the less advanced free one?

This paper provides:

1. References to a number of ontological databases and collections to provide a snapshot to people where to search for information (Appendix I).
2. An overview of information / data models (ontologies). They have been chosen on the basis that may be relevant for IoT semantics. The ontologies listed are a broad set given the nature of things. Things have attributes, they may be used in certain disciplines, they can be measured, they can occur in financial transactions, they are present in time and space etc. The intention is to illustrate that ontologies beyond pure device control ones will be needed in IoT systems (Appendix II).
3. A short overview of building automation system to provide a background on existing smart home/building technologies. (Appendix III).
4. A reference to a number of classification / numbering schemes that are used to categorise things to illustrate rather complete systems describing categories of things exist (Appendix IV).
5. References to organisations related to ontological research are provided (Appendix V).

The paper does not seek to study the various ontological representation languages nor their serialization formats.

Note: The appendices borrows heavily from online sources to describe the various projects and organisations. The links to the sources have been provided. The authors would like to thank all the authors of the material.

### 2 Discussion

#### 2.1 Systems

It appears the recent focus on IoT standardisation efforts around smart appliances has largely been around the devices/sensors themselves. However these devices will be part of an overall system. The data that the devices produce/consume will be part of a larger system. The Healthcare sector has recognised this fact. Device data is but one part of an overall health system detailing patient records, biological descriptions etc. The data models and ontologies in this sector are more highly developed (e.g. SNOMED) than home consumer space.

Another example is in the industrial sector where some effort has gone into standardising descriptions of business processes for business exchange. Use cases have been presented where home appliances autonomously partake in business exchanges (e.g. purchase of consumables). This means that such business ontologies may be relevant to IoT in the home.

In industry there are vocabularies to describe data generated/consumed by machines as well as data describing parts of machine. One example of this is ISO P13399 on machine tooling vocabulary. Tooling can be considered a part of CNC machining centre. This CNC machining centre can be connected to the internet (thus an IoT device). However the tooling itself would not be connected to the internet. Despite this the tooling plays a critical role in determining how the machining centre operates (e.g. determine feed rate, spindle speeds).

In internet connected systems one may also consider the provenance of information (e.g. by using the PROV-O ontology). Again this is not device specific and may not be relevant when used in a personal or local area but may be essential when considering wider spread systems (such as envisaged in smart cities) to ensure reliability of data.

It needs to be recognised that IoT devices will not all fall under the consumer smart appliance category. The availability of IoT device platforms such as the Intel Galileo and Edison toolkits mean that it is very simple for anybody to develop an internet connected thing. The use of sensors from readily available online marketplaces (such as <http://www.seeedstudio.com/>) enables these platforms to provide a myriad of applications that can be used in home, industrial, farm, scientific and other areas. These devices (and developers) too should be able to participate in the semantic IoT without having to join or closely follow the work of standards organisations.

Another trend to be considered is the rise of prosumer / desktop manufacturing. It's not uncommon for CNC equipment to share the same local network that provides home automation, media, etc. More internet connected medical devices are being used in the home. This leads to a blurring of vertical domains. Also devices need to be provisioned and maintained in addition to reporting their data. Data models considering these aspects need to be considered.

So any efforts on harmonisation of semantics need to consider that devices may be used in a wide range of environments. Therefore harmonisation of additional non-device specific ontologies may be required to maximise the potential use of the devices.

## 2.2 Search

As can be seen in Appendix II there is a wide range of work with regards to information and data models that could be applicable to IoT scenarios. There has been a lot of research in upper and lower ontologies, languages and data formats. However it appears still a rather specialised field of study with many ontologies defined by Universities, Scientific and Research organisations.

This presents a rather large barrier to new comers wanting to use the semantic IoT. How does one determine what ontologies to use? How do they work together? As developer I might find 4 ontologies related to time but which one to use? This may not be such an issue for vendors for their own walled gardens of "things" but is a long term problem for consumers. There is work on developing techniques for things to discover things but equally important is how do developers find the ontology to describe their things in the first place?

In trying to develop Appendix II we searched for a database that contained a wide range of ontologies. Rather than finding a widely used website repository we found a collection of sites with a mix of ontologies in various states of maintenance. Sites devoted to a particular domain e.g. biology were typically more comprehensive than general sites. However it wasn't particular clear that a user with a particular device/application in mind would be able to determine through a basic web search what to use.

Compounding the issue was that many data models were either embedded in standard documents whose contents weren't searchable via a web search or were only available for purchase. Again this provides a barrier to implementers who may not want to purchase standards only to find out they're not applicable.

Open publically available standards and searchable repositories are a must for IoT developers. The IETF have recognised the benefit of the open standards process. IANA also have experience in maintaining repositories of information.

We believe that standards organisations need to move beyond using specifications to document data models to using on-line tools that better allow humans to search for semantics and to allow a wide range of people to participate. They should also consider synonyms when defining the data model descriptions so that searches of similar terms will identify a relevant data object. E.g. SNOMED provides synonyms as part of its ontology.

## 2.3 Simplicity

As has widely been discussed the use of REST principles has allowed for the massive growth in the web since its inception. This is partly to their simplicity. Simplicity is also one of the reasons for the success of JSON over other representations and serialisations. Typically web developers have favoured simple approaches over more complex ones. Simplicity should also be the goal of any ontological developments. Makers of things are probably not worried about what upper level ontologies are but more worried about easily identifying vocabulary that is relevant for them. This is applicable to both "makers" in the individual scene and company sense. For example: The ETSI SMARTER (SAREF ontology) initiative didn't use an upper level ontology because a whole industry segment (Smart appliance manufacturers) didn't understand them.

Multiple ontologies with similar vocabularies are also problematic due to semantic ambiguity. The name of similar term may be used leading to developers to assume they're the same thing. This is particularly a problem where

vocabulary has purely been described in a formal definition such as an OWL. Quite often the reasoning and full text description of the item is lacking. Whilst this may not be important for a “thing” consuming the information, the person developing the “thing” will have to have a clear understanding. Thus it’s important that ontologies capture this information in a form that implementers can understand.

Having a clear description of a particular semantic will help with harmonisation of different data models as it will be clearer to developers what the intention behind the semantic is.

## 2.4 Community

The Web (and the IETF) has prospered on the tenant of open standards and processes. The Web of Things also needs to follow this approach. It is certain that any ontology that is created will need continual extension to account for new IoT use cases. A key part of the definition of any ontology will be documenting and implementing the process for maintaining the ontology. Through research for Appendix II it seems that many ontologies appear to have been developed in response to a particular industry project and no longer appear to be funded and thus do not appear to be maintained. Any Web of Things ontology/ies will need to be maintained long term. The goal should be a clearly defined process that any community member can use to update the ontology. Industry associations that require membership are obviously a barrier to smaller “makers” wanting to introduce something new. The OMA have in some way addressed this by having a user interface (<http://technical.openmobilealliance.org/Technical/technical-information/omna/lightweight-m2m-lwm2m-object-registry>) to request new device objects however it talks about “vendors” and the process to determining what gets approved isn’t clear. We believe that the IETF and IANA may have a role to play due to experience in handling administration of naming by clearly defined processes and allowing the community to participate in these processes.

Having said that, we believe that there are some ontologies that will be rather static and would only be changed by a relevant authority. For example: a measurement ontology should be in conjunction with the BIPM ([www.bipm.org](http://www.bipm.org)). An individual shouldn’t be able to add a new a measure. To avoid the proliferation of multiple ontologies related to the same area a core set of ontologies could be recommended to developers, or example: measurements, currency etc. where the values are allocated by an international organisation. This would ensure developers were using the same building blocks. A best current practise (BCP) RFC may be an appropriate means to this.

It is important that the work in the IETF is consistent with regards to use of ontologies. For example: CoRE Link Format (RFC6690) makes reference to the NASA temperature ontology. Does this send a message to developers that the NASA ontology should be used instead of another time ontology? This is potentially confusing to developers.

One further aspect to consider is the motivation for developers and users to use this semantic metadata on their things. One of the learnings of schema.org was that annotating web pages with semantics really only took off when search engines penalised pages (through rankings) that didn’t have semantic annotations. Whilst using a rich set of semantics to describe a thing is advantageous to the person commissioning the thing it may be simplest to use a minimal set. Many IoT devices report data to manufacturers and according to the terms and conditions this data remains the property of the manufacturer. As data privacy becomes more of an issue consideration will need to be given to permissions around data. A BCP RFC may also address the above issues in order to provide thing developers as means to readily identify what they need to develop their “web connected things”.

## 2.5 Harmonisation

Whilst Appendix II paints a picture of somewhat wide spread data model chaos we believe that harmonisation is already underway. The European work is instructive on building experience and consensus. Appendix II.10 highlights a number of projects that shows a staged approach to developing IoT ontologies and testing IoT interwork. The oneM2M group has a wide membership of most of the regional standards development organisations. They are seeking to work with various groups to harmonise semantics. European industry also appears to be coalescing behind the Industrie 4.0 initiative using the widely supported MTConnect and OPC UA work. Many of the world’s leading machine tool manufacturers are behind this initiative. For medical devices the Continue Health alliance may be the way forward. The Eclipse Vorto project (Appendix III.8.3) takes another approach to provide a technology agnostic description that can be mapped to devices. However at this stage the number of descriptions seems limited. It is clear that the industry sees a need to harmonise IoT semantics and that this is already underway.

## 3 Conclusion

This paper has sought to shed further light on the IoT semantic landscape. Hopefully by identifying a set of ontologies / data models further work can be done on identifying relevant data that can be harmonised for IoT. Furthermore it has raised a number of areas that the authors believe should be considered in future IoT semantic standardisation.

The authors welcome any feedback and on the Appendices in particular to correct any errors or omissions.

## Appendix I Ontology / Data model databases

This Appendix provides links to collections of ontologies. As can be seen from the sites there doesn't appear to be an easy way for developers to find and determine which ontologies would be relevant for a "thing".

### I.1 DAML

<http://www.daml.org/>

Lists 282 ontologies.

### I.2 Dublin Core

The organisation responsible for the Dublin Core upper ontology keeps reference to projects using this ontology at: <http://www.dublincore.org/projects/>

### I.3 Linked Model

<http://www.linkedmodel.org/>

This provides OWL Ontologies and SKOS Vocabularies for Linked Models of Industry and Government Standards.

### I.4 Linked Open Vocabularies for the Internet of Thing (LOV4IoT)

<http://www.sensormeasurement.appspot.com/?p=ontologies>

This provides additional ontologies that may be used for IoT that don't meet semantic web best practises and thus aren't listed on the linked open vocabulary site below.

### I.5 Linked Open Vocabulary

<http://lov.okfn.org/dataset/lov/vocabs>

Website dedicated to linking different vocabularies. It contains links to 538 vocabularies in different languages and categories. Categories include:

- [Methods \(39\)](#) : Contains links to measurement ontology.
- [Metadata \(37\)](#)
- [Catalogs \(33\)](#) : Ontologies describing assets.
- [Geography \(30\)](#) : Severals ontologies related to geometric information and naming.
- [API \(26\)](#)
- [Quality \(26\)](#) : Ontologies related to data quality and provenance.
- [RDF \(25\)](#)
- [Society \(25\)](#) : Ontologies related to cities. Relevant for "things" in Smart cities.
- [Support \(25\)](#)
- [People \(20\)](#) : Ontologies related to people and organisations. Such vocabularlies may be relevant to describe people's relationships to things.
- [Vocabularies \(19\)](#) : Onotologies related to language.

- [Time \(17\)](#) : Several ontologies related to time.
- [General & Upper \(16\)](#) : Links to Dbpedia (wikipedia) ontology.
- [Events \(14\)](#) : Links to event ontologies.
- [FRBR \(13\)](#)
- [Geometry \(13\)](#) : Overlaps with the geography category.
- [Multimedia \(13\)](#) : Includes links to “Frappe” visual analytics. , media resources,
- [Biology \(12\)](#) : Includes medical ontologies
- [Industry \(12\)](#) : The vocabularies listed here include road traffic management, smart grids, smart energy aware systems, fridge and freezer vocabularies and consumer electronics.
- [SPAR \(12\)](#) : Publishing
- [Services \(12\)](#)
- [Environment \(11\)](#) : Includes ontologies related to smart home activities, home weather, domestic (home automation) environments, etc.
- [PLM \(11\)](#) : Product lifecycle management
- [W3C Rec \(11\)](#)
- [Academy \(10\)](#)
- [Government \(10\)](#)
- [Security \(8\)](#) : Reference Web of Trust (WOT)
- [Tag \(8\)](#) : Defines relationships between tag objects and URIs.
- [Press \(7\)](#)
- [eBusiness \(7\)](#)
- [Contracts \(6\)](#) : Includes tender, contract and payment ontologies. May be relevant when “Things” become agents in the digital economy.
- [Food \(6\)](#) : Includes smart products food appliances
- [Music \(6\)](#)
- [Travel \(6\)](#) : Describes transit information.
- [SSDesk \(5\)](#)
- [Health \(4\)](#)
- [Image \(4\)](#)
- [CSV \(2\)](#) “Data descriptions in CSV”
- [Games \(2\)](#) “Video Game”
- [PROTON \(2\)](#) “Proton Upper level ontology”
- [Rec \(2\)](#) “Recommendations and Review”

## **I.6 Measurement Ontologies**

The Ontolog forum provides a reference to numerous Quantities and Units of Measure (UoM) ontologies: <http://ontolog.cim3.net/cgi-bin/wiki.pl?UoM>

It can be seen that creators/user of IoT devices could potentially use many different types of ontologies.

The work on UoM has been taken up also by the OASIS Quantities and Units of Measure Ontology Standard (QUOMOS) TC.

[https://www.oasis-open.org/committees/tc\\_home.php?wg\\_abbrev=quomos](https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=quomos)

Note: The international bureau of measurement provides a document with the vocabulary of measurement: [www.bipm.org/utis/common/documents/jcgm/JCGM\\_200\\_2008.pdf](http://www.bipm.org/utis/common/documents/jcgm/JCGM_200_2008.pdf)

<http://www.telegraphis.net/ontology/measurement/measurement#>

No human readable documentation.

## **I.7 Obo Foundry**

<http://obofoundry.org/>

The OBO Foundry is a collective of ontology developers that are committed to collaboration and adherence to shared principles. The mission of the OBO Foundry is to develop a family of interoperable ontologies that are both logically well-formed and scientifically accurate. To achieve this, OBO Foundry participants voluntarily adhere to and contribute to the development of an evolving set of principles including open use, collaborative development, non-overlapping and strictly-scoped content, and common syntax and relations, based on ontology models that work well, such as the Gene Ontology (GO).

Primarily related to biology.

## **I.8 Ontohub**

<https://ontohub.org/>

Ontohub is a project to collect repositories, ontologies, logics and mappings. The site currently contains 5536 ontologies.

## **I.9 Ontolingua**

Ontolingua ontology library (<http://www.ksl.stanford.edu/software/ontolingua/>)

Does not appear to be operating anymore?

## **I.10 Open Ontology Repository**

<http://www.oor.net/>

This site contains a repository for ontologies. Only 8 sites listed.

## **I.11 OWL Ontology Libraries**

A list of OWL libraries can be found at:

[http://protegewiki.stanford.edu/wiki/Protege\\_Ontology\\_Library](http://protegewiki.stanford.edu/wiki/Protege_Ontology_Library)

Note: OWL used by the OMG.

Web search <http://www.google.com/search?q=filetype:owl+owl> returns 13600 hits.

## **I.12 Schema.org**

See section [Schema.org](#).

## **I.13 W3C**

The W3C site <http://dir.w3.org/directory/pages/listing.xhtml?view> provides a directory containing a listing of organizations creating and/or publishing data on the Web.

There appears to be no centralised place to find RDF schemas. E.g. according to <https://www.w3.org/wiki/VocabularyMarket> many of the links are outdated.

## **Appendix II Groups dedicated to data model / ontology research and definition**

The Appendix lists organisations that are conducting ontology / data model research and definition. Not all organisations are actively developing ontologies for IoT / Web of Things applications. Many of the ontologies are effectively “historical” or are used in domain specific areas. Their consideration may be helpful in understanding ontology evolution and may provide stimulus for enhancing current “IoT” / “Web of Thing” specific ontologies.

Some organisations have been listed that whilst not defining formal ontology syntax they define data models that could be considered for the development of ontologies.

### **II.1 Allseen Alliance (Alljoyn)**

<https://allseenalliance.org/framework/documentation/learn/core/system-description>

The AllJoyn model re-implements the wire protocol set forth by the D-Bus specification and extends the D-Bus wire protocol to support distributed devices.

D-Bus uses an object model to express the semantics of communications between clients and services. (<https://en.wikipedia.org/wiki/D-Bus>). The D-Bus specification can be found at:

<https://dbus.freedesktop.org/doc/dbus-specification.html>

### **II.2 Apple Homekit**

<https://developer.apple.com/homekit/>

Homekit views a home as a collection of home automation accessories. The data model / classes can be found at:

[https://developer.apple.com/library/ios/documentation/HomeKit/Reference/HomeKit\\_Framework/index.html#protocols](https://developer.apple.com/library/ios/documentation/HomeKit/Reference/HomeKit_Framework/index.html#protocols)

### **II.3 CENELEC**

<http://www.cenelec.eu/aboutcenelec/whatwedo/technologysectors/Informationandcommunicationtechnology.html>

BES (Home and Building Electronic Systems) work is performed by technical committee CLC/TC 205 and its SC 205A. The work initially concentrated on an information bus for the home but the work had been extended to the so called "SmartHouse" i.e. all integrated information exchange within the residential environment and its interface to intelligent networks.

### **II.4 DARPA Agent Markup Language**

The DAML language was developed as an extension to XML and the [Resource Description Framework \(RDF\)](#). The latest release of the language ([DAML+OIL](#)) provides a rich set of constructs with which to create ontologies and to markup information so that it is machine readable and understandable.

<http://www.daml.org/about.html>

Many of the concepts were incorporated were incorporated into the W3C OWL work.

More info: [https://en.wikipedia.org/wiki/DARPA\\_Agent\\_Markup\\_Language](https://en.wikipedia.org/wiki/DARPA_Agent_Markup_Language)

A list of 282 ontologies can be found at: <http://www.daml.org/ontologies/counts>



There are multiple ontologies related to similar areas e.g. Currency, time and location.

This project appears no longer operational.

## **II.5 DBPEDIA**

[https://www.wikidata.org/wiki/Wikidata:WikiProject\\_Ontology](https://www.wikidata.org/wiki/Wikidata:WikiProject_Ontology)

Uses the FOAF, GEO, SKOS ontologies.

This could be useful to provide a wider range of information associated with an IoT device. E.g. linking a location to further information about the location.

## **II.6 DOAP (Description of a Project)**

<https://en.wikipedia.org/wiki/DOAP>

DOAP is an RDF Schema and XML vocabulary to describe software projects, in particular free and open source software.

## **II.7 ECHONET Consortium**

<http://www.echonet.gr.jp/english/>

ECHONET is a communication protocol designed to create the “smart houses” of the future. Today, with Wi-Fi and other wireless networks readily available in ordinary homes, there is a growing demand for air-conditioning, lighting and other equipment inside the home to be controlled using smartphones or controllers, or for electricity usage to be monitored in order to avoid wasting energy.

The specification detailing device objects can be found at:

[http://echonet.jp/wp/wp-content/uploads/pdf/General/Standard/Release/Release\\_F\\_en/SpecAppendixF\\_e.pdf](http://echonet.jp/wp/wp-content/uploads/pdf/General/Standard/Release/Release_F_en/SpecAppendixF_e.pdf)

## **II.8 Eclipse**

### **II.8.1 IoT**

<http://iot.eclipse.org/>

Eclipse IoT provides open source implementations of the standards, services and frameworks that enable an Open Internet of Things.

Uses the OGC SensorThings API based on OGC/ISO Observation and Measurement.

### **II.8.2 SmartHome**

<https://eclipse.org/smarthome/>

The SmartHome API can be found at:

<https://eclipse.org/smarthome/documentation/javadoc/index.html>

### **II.8.3 Vorto**

<https://www.eclipse.org/vorto/>

Vorto is an open source tool that allows the creation and management of technology via agnostic, abstract device descriptions, so called information models. Information models describe the attributes and the capabilities of real world devices.

The idea is to have high level information models that can be mapped to OSGi, oneM2M, HGi etc.

Model repositories can be found at: <http://vorto.eclipse.org/repo/#/>

## **II.9 ETSI**

### **II.9.1 SmartM2M**

#### **II.9.1.1 ETSI TR 101 584: "Machine-to-Machine communications (M2M); Study on Semantic support for M2M Data".**

[http://www.etsi.org/deliver/etsi\\_ts/103200\\_103299/103264/01.01.01\\_60/ts\\_103264v010101p.pdf](http://www.etsi.org/deliver/etsi_ts/103200_103299/103264/01.01.01_60/ts_103264v010101p.pdf)

This ontology uses the outputs of the Smart Project. See separate sub-clause on the SMART project.

Observation regarding SAREF (from clause 4.4/[above document] ): *SAREF currently does not contain explicit references to upper ontologies such as DUL or SUMO. The use of upper ontologies is a best practice in ontology engineering , but the smart appliances industry - main user of SAREF - is very pragmatic and is not acquainted with high-level upper ontologies. Introducing DUL would have unnecessarily complicated the understanding and, consequently, the adoption of SAREF by the smart appliances industry. Anyway, SAREF has been built on a solid ontological foundation and can be related to DUL, but this will not be done at this early stage of SAREF in order not to confuse the smart appliances industry's users. Furthermore, SAREF currently has mappings to the W3C® SSN ontology, which is in turn related to DUL. Therefore, SAREF currently includes an indirect reference to DUL through the W3C® SSN ontology.*

#### **II.9.1.2 TS 103 264 “SmartM2M Smart Appliances Common Ontology and SmartM2M/oneM2M mapping”**

[https://www.etsi.org/deliver/etsi\\_ts/103200\\_103299/103264/01.01.01\\_60/ts\\_103264v010101p.pdf](https://www.etsi.org/deliver/etsi_ts/103200_103299/103264/01.01.01_60/ts_103264v010101p.pdf)

The specification is an adaptation of the EU Smart Appliances project. Additionally, it develops the mapping to oneM2M. Therefore the present document has two major objectives:

- 1.To provide a standardized framework for the Reference Ontology derived from the EC Study Group on Smart Appliances.
- 2.To map the Reference Ontology onto the elementary oneM2M

#### **II.9.1.3 TS 103 267 “SmartM2M Smart Appliances Application of ETSI M2M Communication Framework”**

[https://www.etsi.org/deliver/etsi\\_ts/103200\\_103299/103267/01.01.01\\_60/ts\\_103267v010101p.pdf](https://www.etsi.org/deliver/etsi_ts/103200_103299/103267/01.01.01_60/ts_103267v010101p.pdf)

The oneM2M specifications define a framework for the communication and sharing of information. The major paradigm can be referred to as "store & share". De facto any object and information is mapped to resources that can be shared, discovered and accessed via a resource oriented architecture and its related protocols, IP protocols and URI formats are at the basis of

the communication and identification, making the solution Internet of Things friendly, so the oneM2M system is a component of IoT.

## **II.9.2 oneM2M Base Ontology**

OneM2M has several deliverables related to the definition of an ontology and mapping to other ontologies. The documents below can be downloaded from:

<http://www.onem2m.org/technical/latest-drafts>

### **II.9.2.1 TS-0012**

It is based on SAREF. Clause 5.1.1.2/[TS-0012] indicates the purpose of the Ontology:

*Ontologies and their OWL representations are used in oneM2M to provide syntactic and semantic interoperability of the oneM2M System with external systems. These external systems are expected to be described by ontologies.*

*The only ontology that is specified by oneM2M is the oneM2M Base Ontology, as described in the present document. However, external organizations and companies are expected to contribute their own ontologies that can be mapped (e.g. by sub-classing, equivalence..) to the oneM2M Base Ontology.*

*Such external ontologies might describe specific types of devices (as e.g. in the SAREF ontology) or, more generally, they might describe real-world “Things” (like buildings, rooms, cars, cities..) that should be represented in a oneM2M implementation. The value for external organizations and companies to provide their ontologies to oneM2M consists in supplementing oneM2M data with information on the meaning/purpose of these data. The OWL representation of that ontology provides a common format across oneM2M.*

*The oneM2M Base Ontology is the minimal ontology (i.e. mandating the least number of conventions) that is required such that other ontologies can be mapped into oneM2M.*

### **II.9.2.2 TS-0023 Home Appliances Information Model and Mapping**

This technical specification includes oneM2M defined information model for home appliances and the mapping with other information models from external organization.

This document is not complete but shows that work mapping the OneM2M schema to others such as the HGT SDT ([Eco Smart Appliances](#)), AllJoyn (pre-study in oneM2M TR-0014), OIC (pre-study in oneM2M TR-0023), SDT, ECHONET etc. is underway.

## **II.10 EU Projects**

### **II.10.1 The Alliance for IoT (AIOTI)**

<https://ec.europa.eu/digital-agenda/en/aioti-structure>

### **II.10.2 City Pulse Project**

CityPulse provides innovative smart city applications by adopting an integrated approach to the Internet of Things and the Internet of People. The project will facilitate the creation and provision of reliable real-time smart city applications by bringing together the two disciplines of knowledge-based computing and reliability testing.

A number of ontologies used by the project can be found at:

<http://www.ict-citypulse.eu/page/content/tools-and-data-sets>

It uses the stream annotation, PROV-O, timeline, W3C SSN Ontology and quality ontologies mentioned in this document.

### **II.10.3 European Research Cluster on IoT**

<http://www.internet-of-things-research.eu/>

Their report on “Internet of Things IoT Semantic Interoperability: Research Challenges, Best Practices, Recommendations and Next Steps” ([http://www.internet-of-things-research.eu/pdf/IERC\\_Position\\_Paper\\_IoT\\_Semantic\\_Interoperability\\_Final.pdf](http://www.internet-of-things-research.eu/pdf/IERC_Position_Paper_IoT_Semantic_Interoperability_Final.pdf)) discusses the need for and challenges of semantic interoperability:

### **II.10.4 Federated Interoperable Semantic IoT Testbeds and Applications (FIESTA)**

<http://fiesta-iot.eu/>

FIESTA is a global federation of IoT testbeds and data sets. They recently demonstrated semantic interoperability between OneM2M and FIWARE.

### **II.10.5 Light House Integrated Project (IoT-A)**

<http://www.iot-a.eu/public>

IoT-A, the **European Lighthouse Integrated Project** has addressed for three years the Internet-of-Things Architecture, and created the proposed architectural reference model together with the definition of an initial set of key building blocks. Together they are envisioned as foundations for fostering the emerging Internet of Things. Using an experimental paradigm, IoT-A combined top-down reasoning about architectural principles and design guidelines with simulation and prototyping in exploring the technical consequences of architectural design choices.

Deliverable D4.3 ([http://www.meet-iot.eu/deliverables-IOTA/D4\\_3.pdf](http://www.meet-iot.eu/deliverables-IOTA/D4_3.pdf)) makes reference to the W3C SSN and W3C time ontologies.

### **II.10.6 Open IoT**

<http://www.openiot.eu/>

OpenIoT is pertinent to a wide range of interrelated scientific and technological areas spanning:

- Middleware for sensors and sensor networks,
- Ontologies, semantic models and annotations for representing internet-connected objects, along with semantic open-linked data techniques (c) Cloud/Utility computing, including utility based security and privacy schemes.

Defined ontologies and semantic models based on the W3C Semantic Sensor Networks ontology (ssn), the SPITFIRE ontology (spt) and the SM vocabulary. The ontology can be found at:

<http://cordis.europa.eu/docs/projects/cnect/5/287305/080/deliverables/001-OpenIoTD312130325DraftAresreg.pdf>

### **II.10.7 PESCaDO**

An ontology for personalized environmental decision support.

[http://cordis.europa.eu/project/rcn/93834\\_en.html](http://cordis.europa.eu/project/rcn/93834_en.html)

[https://ontohub.org/fois-ontology-competition/PESCaDO\\_Ontology](https://ontohub.org/fois-ontology-competition/PESCaDO_Ontology)

For example it can recommend an action to stay indoors if the pollen count is high and you have hay fever.

## II.10.8 Smart Appliances Project

<http://www.eco-smartappliances.eu>

The Preparatory study on smart appliances in the framework of Ecodesign. This study provides the European Commission with an analysis of all technical, economic, environmental, market and societal aspects that are relevant for a broad market introduction of smart appliances.

An excellent overview of the standards situation for smart appliances can be found at:

[http://www.eco-smartappliances.eu/Documents/Prep%20Study%20Smart%20Appliances\\_Task1%20\\_final\\_151221.pdf](http://www.eco-smartappliances.eu/Documents/Prep%20Study%20Smart%20Appliances_Task1%20_final_151221.pdf)

and

[http://www.eco-smartappliances.eu/Documents/Baumeister\\_2015\\_11\\_19%20IEC-CLC-Consortia%20Smart%20Home%20-%20Standardization.pdf](http://www.eco-smartappliances.eu/Documents/Baumeister_2015_11_19%20IEC-CLC-Consortia%20Smart%20Home%20-%20Standardization.pdf)

The goal is to have the SAREF ontology as the base ontology for IoT.

<https://sites.google.com/site/smartappliancesproject/home>

The project addressed the consumer (mass) market of the home, private dwellings, but also common public buildings and offices, and the standard appliances used in that environment. Elevators and other special equipment are not covered.

The project covers the following appliances:

Home and buildings sensors (temperature, humidity, energy-plugs, energy clams, energy meters, water-flow, water quality, presence, occupancy, air monitors, environmental sensors, CO<sub>2</sub> sensors, weather stations, etc.) and actuators (windows, doors, stores). Sensors belonging to appliances are treated individually.

- White goods, as classified by CECED
- Rinsing and Cleaning
- Cooking and Baking
- Refrigerating and Freezing
- Vacuum Cleaning
- Washing and Drying
- HVAC; heating, ventilation, and air conditioning, plumbing, security and electrical systems, as classified by Eu.bac
- Lighting, with use cases as defined by LightingEurope\_(f.k.a. ELC)
- Micro renewable home solutions (solar panels, solar heaters, wind, etc.)

Multimedia and home computer equipment devices were explored only with respect for semantic requirements for the energy relevant operations (switch on, standby), but not for the content management (i.e. channel choice).

The reference ontologies can be found at:

<https://sites.google.com/site/smartappliancesproject/ontologies/fan-ontology>

During the Smart Appliances project a reference ontology for the smart appliances domain, called "Smart Appliances REFERENCE (SAREF) ontology" was created:

- [SAREF](#)

We also created ontologies for each semantic asset in the short list. Each ontology has a subpage that contains its description and a URL that points to the file in which the ontology is specified.

- [DECT ULE](#)
- [ECHONET](#)
- [eDIANA](#)
- [EnOcean](#)
- [FAN](#) (Flexible Power Infrastructure)
- [FIEMSER](#)
- [FIPA](#)
- [Hydra](#)
- [KNX](#)
- [Mirabel](#)
- [OMA Lightweight M2M](#)
- [OMS](#)
- [OSGi DAL](#)
- [PowerOnt \(previously SEIPF\)](#)
- [SEEMPubs](#)
- [SEP2](#)
- [SmartCoDE](#)
- [UPnP](#)
- [W3C SSN](#)
- [Z-Wave](#)

A report can be found at: [http://www.etsi.org/images/files/Events/2015/201502\\_SMARTAPP/D-S4%20-%20SMART%202013-0077%20-%20Smart%20Appliances%20-%20Final%20Study%20Report\\_v1.0.pdf](http://www.etsi.org/images/files/Events/2015/201502_SMARTAPP/D-S4%20-%20SMART%202013-0077%20-%20Smart%20Appliances%20-%20Final%20Study%20Report_v1.0.pdf)

## **II.11 FIWARE**

<https://www.fiware.org/>

The FIWARE Community is an independent open community whose members are committed to materialise the FIWARE mission, that is: “to build an open sustainable ecosystem around public, royalty-free and implementation-driven software platform standards that will ease the development of new Smart Applications in multiple sectors”.

It is based on the work of a EU project.

The support of ontologies and semantics is discussed at:

[https://forge.fiware.org/plugins/mediawiki/wiki/fiware/index.php/Semantic\\_Application\\_Support\\_-\\_Users\\_and\\_Programmers\\_Guide](https://forge.fiware.org/plugins/mediawiki/wiki/fiware/index.php/Semantic_Application_Support_-_Users_and_Programmers_Guide)

## **II.12 Friend of a Friend (FOAF)**

[https://en.wikipedia.org/wiki/FOAF\\_%28ontology%29](https://en.wikipedia.org/wiki/FOAF_%28ontology%29)

Is a machine-readable ontology for describing persons enabling the description of social networks:

<http://www.foaf-project.org/>

This may be applicable when linking IoT devices to their owners.

## **II.13 Haystack**

<http://project-haystack.org/>

Project Haystack is an open source initiative to streamline working with data from the Internet of Things. We standardize semantic data models and web services with the goal of making it easier to unlock value from the vast quantity of data being generated by the smart devices that permeate our homes, buildings, factories, and cities. Applications include automation, control, energy, HVAC, lighting, and other environmental systems.

The data models used can be found at:

<http://project-haystack.org/doc>

These appear to be more focussed on industrial building controls rather than home building control associated with other smart appliance projects.

An ontology developed for Haystack can be found at:

<http://lov.okfn.org/dataset/lov/vocabs/hto>

## **II.14 Home Gateway Initiative (HGi)**

<http://www.homegateway.org/>

Publishes requirements and test plans for home gateways and wireless/wireline home networks. It has a strategic focus is helping applications, home gateway middleware and home network-based devices to connect seamlessly.

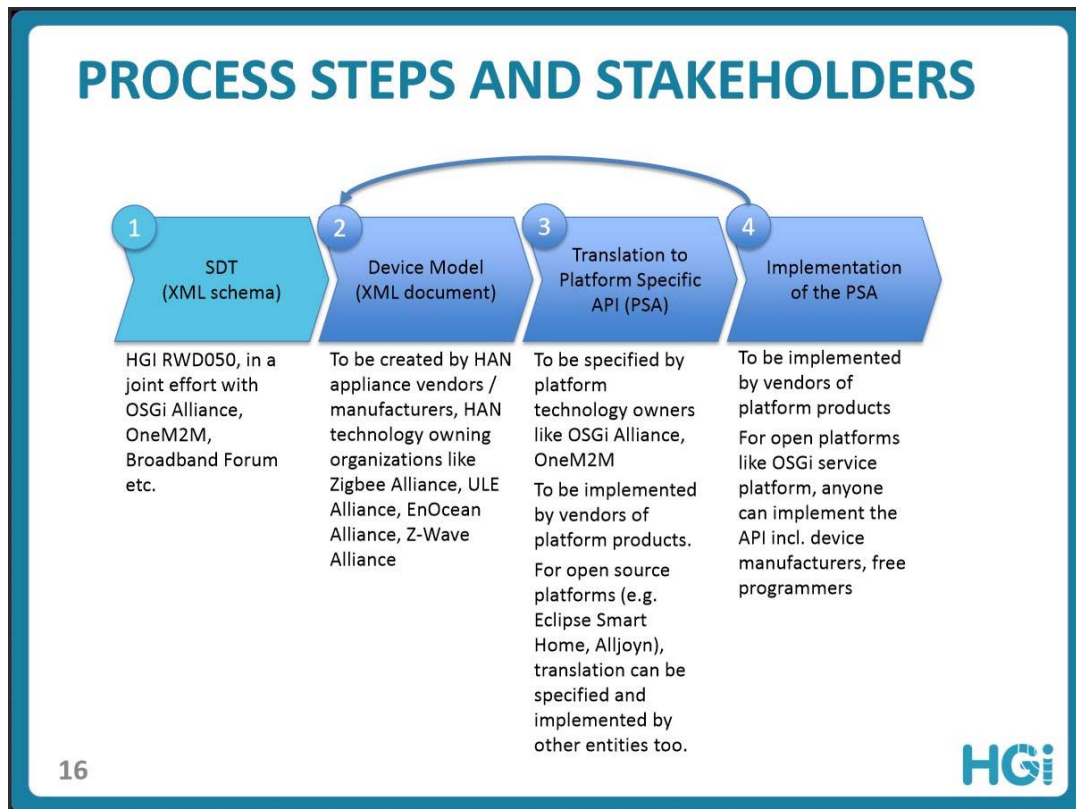
It defines a Smart home abstraction layer and uses a Smart Home Device Template (SDT) (XML based). They provides unified APIs for application developers independent of underlying architecture.

Unification is required with other organisation working on device abstraction:

AllSeen Alliance, CENELEC, Eclipse IoT, ETSI SmartM2M, IEEE P2413 IoTArchitecture, OpenIoT, Open Interconnect Consortium

The process is outlined in the following slide

<https://www.eclipsecon.org/europe2014/sites/default/files/slides/HGI-SmartDeviceTemplates-Project.pdf>



## II.15 HL7 FHIR

<http://www.hl7.org/FHIR/DSTU1/overview.html>

Fast Healthcare Interoperability Resources (FHIR) Specification, is a standard for exchanging healthcare information electronically. The basic building block in FHIR is a [Resource](#). All exchangeable content is defined as a resource. Resources all share the following set of characteristics:

- A common way to [define](#) and [represent](#) them, building them from [data types](#) that define common reusable patterns of elements
- A common set of [metadata](#)
- A [human readable](#) part

## II.16 HyperCat

<http://www.hypercat.io/standard.html>

HyperCat is an open, lightweight JSON-based hypermedia catalogue format for exposing collections of URIs (uniform resource identifiers). It is extremely simple - described by one participant as "the most that 40 companies companies could agree on" - with a strong security model and is designed for exposing information about IoT assets over the web.



## II.17 IEEE

### II.17.1 IEEE 1451 Standards for Smart Transducers

Potentially related to provisioning aspects of sensor is: (from Wikipedia): *IEEE 1451 is a set of [smart transducer interface standards](#) developed by the [Institute of Electrical and Electronics Engineers](#) (IEEE) Instrumentation and Measurement Society's Sensor Technology Technical Committee describing a set of open, common, network-independent communication interfaces for connecting transducers (sensors or actuators) to microprocessors, instrumentation systems, and control/field networks. One of the key elements of these standards is the definition of [Transducer electronic data sheets](#) (TEDS) for each transducer. The TEDS is a memory device attached to the transducer, which stores transducer identification, calibration, correction data, and manufacturer-related information.* [[https://en.wikipedia.org/wiki/IEEE\\_1451](https://en.wikipedia.org/wiki/IEEE_1451)]

### II.17.2 IEEE P2413 “IoT Architecture”

[http://standards.ieee.org/develop/wg/IoT\\_Architecture.html](http://standards.ieee.org/develop/wg/IoT_Architecture.html)

This standard defines an architectural framework for the Internet of Things (IoT), including descriptions of various IoT domains, definitions of IoT domain abstractions, and identification of commonalities between different IoT domains. The architectural framework for IoT provides a reference model that defines relationships among various IoT verticals (e.g., transportation, healthcare, etc.) and common architecture elements.

For further information see: <http://grouper.ieee.org/groups/2413/Intro-to-IEEE-P2413.pdf>

IEEE P2413 has initiated alignment with the EU AIOTI project, IIConsortium. There is collaboration between IEEE P2413 and ETSI oneM2M.

## II.18 IETF

We did not focus on IETF activities given that we expect that IETF participants would have an overview of the work. The IETF have a historical involvement in the definition of MIBs for devices using ASN.1 and now more recently YANG.

SenML (<https://datatracker.ietf.org/doc/draft-jennings-core-senml/>) is a markup language to describe sensors.

## II.19 IoTDB

<https://iotdb.org/pub/iot-purpose.html>

Open Source project for internet of things. This current schema appears to be related to consumer type of things. There are overlaps with existing ontologies.

## II.20 IoT Ontology

The aim of the ontology is to support the automated deployment of applications in heterogeneous IoT environments. It mainly serves as a semantic registry for the registration of associations of sensing/actuating/identity/embedded with features of interest, as well as for the registration of applications that utilize the services provided by these associations.

<http://ai-group.ds.unipi.gr/kotis/ontologies/IoT-ontology>

[http://ai-group.ds.unipi.gr/kotis/sites/default/files/IoT-ontology\\_v2.1.owl](http://ai-group.ds.unipi.gr/kotis/sites/default/files/IoT-ontology_v2.1.owl)

## **II.21 IoT ToolKit**

<http://iot-toolkit.com/>

The IoT Toolkit is an Open Source project to develop a set of tools for building multi-protocol Internet of Things Gateways and Service gateways that enable horizontal co-operation between multiple different protocols and cloud services. The project consists of the Smart Object API, gateway service, and related tools.

Based on the IPSO Smart Object guidelines and OMA lightweight M2M (LWM2M) standards.

## **II.22 IPSO Alliance**

<http://www.ipso-alliance.org>

The goal of the IPSO Alliance is to develop, establish, and create the industry leadership of an “IPSO Platform” that includes the definition and support of Smart Objects with an emphasis on object interoperability on protocol and data layers and of Identity and Privacy technologies. The mission is to create a platform and support system that includes libraries, repositories, design kits, and industry awareness for discovery and interoperability of IoT Smart Objects.

Committed to using IETF protocols particularly CoAP.

So far it has defined a number of basic objects, using the LWM2M object model. They have two outputs related to the definition of Smart Objects that can be found here:

<http://www.ipso-alliance.org/ipso-community/resources/smart-objects-interoperability/>

## **II.23 ISO**

### **II.23.1 ISO 11179 Metadata Standards**

<http://metadata-standards.org/11179/>

Is a standard for representing metadata for an organization in a metadata registry.

Such techniques could be applied to web enabled things.

### **II.23.2 ISO 13399 Cutting tool data representation and exchange**

[http://www.iso.org/iso/catalogue\\_detail?csnumber=54167](http://www.iso.org/iso/catalogue_detail?csnumber=54167)

ISO/TS 13399-2:2014 specifies a reference dictionary for cutting items, together with their descriptive properties and domains of values, containing definitions and identifications of the classes of cutting items and their features, with an associated classification scheme, definitions and identifications of the data element types that represent the properties of cutting items and their features, and definitions and identifications of domains of values for describing those data element types.

Whilst it is not expected that the cutting tools are themselves IoT devices they would form part of an industrial IoT system.

### **II.23.3 ISO 15926 Industrial automation systems and integration—Integration of life-cycle data for process plants including oil and gas production facilities**

[https://en.wikipedia.org/wiki/ISO\\_15926](https://en.wikipedia.org/wiki/ISO_15926)

<http://15926.org/standards/>

In short, ISO 15926 is a standard for data modelling and interoperability using the Semantic Web (RDF+OWL+FOL). ISO 15926 also contains an upper ontology and a reference data ontology.

It is originally made for the Oil and Gas industry, but it is set up generically so that it can be used for any type of information exchange and integration.

For an overview see: <http://15926.info/presentation.pdf>

Unfortunately the standard is not available for free download. This limits the adoption outside industry.

#### **II.23.4 ISO 19450 Automation systems and integration – Object-Process Methodology**

[https://en.wikipedia.org/wiki/Object\\_Process\\_Methodology](https://en.wikipedia.org/wiki/Object_Process_Methodology)

Object Process Methodology (OPM) is a conceptual modeling language and methodology for capturing knowledge and designing systems, specified as [ISO 19450](#). Based on a minimal universal ontology of stateful objects and processes that transform them, OPM formally specifies the function, structure, and behavior of artificial and natural systems in a large variety of domains. Catering to human cognitive principles, an OPM model represents the system under design or study bimodally in both graphics and text for improved representation, understanding, communication, and learning.

The elements in an object-process diagram (OPD) are things – objects and processes – and links that connect the things to express relations among them. An OPM object is a thing that exists, or might exist, physically or informatically.

#### **II.23.5 ISO/IEC/IEEE P21451-1-4 XMPP Interface for Smart Transducers**

From [http://ontolog.cim3.net/file/work/OntologySummit2015/2015-04-13\\_14\\_OntologySummit2015\\_Symposium/Standard-for-IoT\\_WilliamMiller\\_2015-04-14.pdf](http://ontolog.cim3.net/file/work/OntologySummit2015/2015-04-13_14_OntologySummit2015_Symposium/Standard-for-IoT_WilliamMiller_2015-04-14.pdf)

Smart Transducer Interface Standard for Sensors, Actuators, and Devices eXtensible Messaging and Presence Protocol (XMPP) for networked device communications

ISO/IEC/IEEE P21451-1-4 (Sensei/IoT\*) using ISO/IEC WD 29161, IoT Unique Identification JID (EUI-64) which is a Universal Unique IDentifier (UUID), defined in the draft ISO/IEC 29161 Automatic Identification for the Internet of Things developed by ISO/IEC/JTC1/SG31/WG6 Automatic Identification & Data Capture and ISO/IEC/TC122 Packaging and Internet of Things (IoT).

- `jid = [ node "@" ] domain [ "/" resource {device} ]`
- There are hundreds of ways to identify Things and ISO/IEC 29161 offers a unified approach.
- NOTE - EUI-64 is a IEEE SA 64-bit Global Identification.

SENSEI, SemSorGrid4Env (*G. Berg-Cross*)

#### **II.23.6 ISO 19115 Geographic Information - Metadata**

[http://www.iso.org/iso/home/store/catalogue\\_ics/catalogue\\_detail\\_ics.htm?csnumber=53798](http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumber=53798)

ISO 19115 defines the schema required for describing geographic information and services. It provides information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference, and distribution of digital geographic data.

#### **II.23.7 ISO 11073 Health Informatics Devices**

[https://en.wikipedia.org/wiki/ISO/IEEE\\_11073](https://en.wikipedia.org/wiki/ISO/IEEE_11073)

**Personal Health Data (PHD)** standards are a group of standards addressing the interoperability of personal health devices (PHDs) such as weighing scales, blood pressure monitors, blood glucose monitors and the like.

The OPC UA support the use of this data model.

The Continua Health Alliance (<http://www.continuaalliance.org/>) also makes use of this ISO specification.

### **II.23.8 ISO/IEC 30141 Information technology —Internet of Things Reference Architecture (IoT RA)**

[http://www.iso.org/iso/home/store/catalogue\\_tc/catalogue\\_detail.htm?csnumber=65695](http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=65695)

Clause 7 of the working document contains an “IoT Conceptual model presented using Unified Modelling Language (UML). It defines relationships between IoT entities.

## **II.24 International Telecom Union (ITU-T)**

### **II.24.1 Recommendation ITU-T H.810 “Interoperability design guidelines for personal health systems”**

<https://www.itu.int/rec/T-REC-H.810/en>

The Continua Design Guidelines (CDG) defines a framework of underlying standards and criteria required to ensure the interoperability of devices and data used for personal connected health. It also contains design guidelines that further clarify the underlying standards or specifications by reducing options or by adding a missing feature to improve interoperability.

It defines guidelines for the connection of a wide range of devices using WAN, LAN, PAN and NFC technologies.

This Recommendation comes out of the work of the Continua Health Alliance (<http://www.continuaalliance.org/>).

### **II.24.2 Recommendation ITU-T H.860 “Multimedia e-health data exchange services: Data schema and supporting services”**

<https://www.itu.int/rec/T-REC-H.860-201404-I/en>

This Recommendation defines the following for health data exchange:

- A common health data schema to form a common language, for all participants in the health system, to exchange health information.
- Formats and mechanisms for exchanging health information.

It provides an overview of the current health care data standards. It follows on from the Continua Health Alliance work. HL7 and ISO 111073 data standards are supported.

### **II.24.3 Recommendation ITU-T Y.2076 "Semantics based requirements and framework of the Internet of Things"**

<https://www.itu.int/md/T13-SG13-151130-TD-PLN-0241/en>

It recommends that existing ontology such as the W3C SSNO be integrated into an overall IoT ecosystem. It does not attempt to define an ontology.

## II.25 MMI Marine Metadata Interoperability

<http://mmisw.org/orr/>

Lists many different ontologies related to marine science.

Potential overlap with other ontologies e.g. seismometer, water velocity meter -> flow meter.

e.g. [http://mmisw.org/orr/#http://mmisw.org/ont/ooi\\_epe/instruments](http://mmisw.org/orr/#http://mmisw.org/ont/ooi_epe/instruments)

## II.26 Micro Electro Mechanical Systems Industry Group (MEMS)

<http://www.memsindustrygroup.org/>

MEMS & Sensors Industry Group

Important as new sensor technologies would be developed by companies associated with this group. Whilst it does not define ontologies or data models, a brochure

([http://www.st.com/web/en/resource/sales\\_and\\_marketing/promotional\\_material/brochure/brmems.pdf](http://www.st.com/web/en/resource/sales_and_marketing/promotional_material/brochure/brmems.pdf)) from one of their members illustrates the types of sensors available for IoT scenarios by segment. This would provide a good check against existing ontologies.

## II.27 MTConnect

<http://www.mtconnect.org/>

The MTConnect standard enables manufacturing equipment to provide data in structured XML rather than proprietary formats. With uniform data available from production equipment, sensor packages, and other hardware, a world of applications to provide more efficient operations, improved production optimization, and increased productivity is opened up to industry.

It is a widely used Industrial standard and interworks with OPC UA. Whereas MTConnect specifically facilitates the connection of machine tools and other related manufacturing equipment to a data-collection network, standards such as OPC-UA address the interoperability required for plant-wide data communication. MTConnect provides a RESTful interface. It also supports ISO 13399.

The specification can be downloaded from: <http://www.mtconnect.org/standard?terms=on>

The XML device information model can be found in “Part 2 – Components and Data Items”.

## II.28 NASA

### II.28.1 Quantities

<http://qudt.org/>

The goals of QUDT are to provide:

- A standardized consistent vocabulary, focused on terminology used in science and engineering.
  - The vocabulary in this standard consists of standardized terminology, definitions, identifiers, and information models.

- The intent is to use this vocabulary with a variety of encodings, formats, and data definitions, so it is defined independent of those forms.
- Some or all portions of this vocabulary will be of interest to various users and applications, depending on the use case and policy mandates.
- It is expected that a large set of existing corpus will not be changed, and so this standard serves as a critical “Rosetta Stone” to reference existing uses of quantities, units, dimensions, and types to a consistent base.

The ontology is available at: <http://www.linkedmodel.org/catalog/qudt/1.1/index.html>

## **II.28.2 Semantic Web for Earth and Environmental Terminology (SWEET)**

<https://sweet.jpl.nasa.gov/>

SWEET ontologies are written in the OWL ontology language and are publicly available. SWEET 2.3 is highly modular with 6000 concepts in 200 separate ontologies. You can view the entire concept space from an OWL tool such as Protege by reading in sweetAll.owl. Alternatively, these ontologies can be viewed individually. SWEET 2.3 consists of nine top-level concepts/ontologies. Some of the next-level concepts are shown in the Figure. SWEET is a middle-level ontology; most users add a domain-specific ontology using the components defined here to satisfy end user needs.

As the web of things evolve beyond consumer devices many of the ontologies or concepts defined by SWEET may be relevant. SWEET is already referenced by IETF CoAP RFCs.

## **II.29 OASIS**

### **II.29.1 Open Building Information Exchange (oBIX)**

[https://www.oasis-open.org/committees/tc\\_home.php?wg\\_abbrev=obix](https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=obix)

The purpose of oBIX (open Building Information Exchange) is to enable the mechanical and electrical control systems in buildings to communicate with enterprise applications, and to provide a platform for developing new classes of applications that integrate control systems with other enterprise functions. Enterprise functions include processes such as Human Resources, Finance, Customer Relationship Management (CRM), and Manufacturing.

The data model used can be found at:

[http://docs.oasis-open.org/obix/obix/v1.1/csprd01/obix-v1.1-csprd01.html#\\_Toc361929155](http://docs.oasis-open.org/obix/obix/v1.1/csprd01/obix-v1.1-csprd01.html#_Toc361929155)

Can be used with Haystack as a data exchange for building automation protocols.

### **II.29.2 Service Oriented Architecture**

<http://docs.oasis-open.org/semantic-ex/ro-soa/v1.0/pr01/see-rosoa-v1.0-pr01.html>

Service Oriented Architecture (SOA) is a way thinking about IT assets as service components.

Service Oriented Architecture provides an architectural mechanism for building applications from unassociated units of functionality, called services. The perceived value of SOA is that it provides a powerful framework for matching needs and capabilities and for combining capabilities to address those needs, by enhancing the ability of adapting applications more quickly to changes in market conditions and improving the reusability, modularity, composability and interoperability of functionality.

Doesn't appear to be directly applicable to IoT devices. A list of other service description efforts can be found at: <https://www.w3.org/2005/Incubator/usdl/wiki/D1> .

### **II.29.3 Web Services Business Process Execution Language (BPEL)**

[https://en.wikipedia.org/wiki/Business\\_Process\\_Execution\\_Language](https://en.wikipedia.org/wiki/Business_Process_Execution_Language)

BPEL is a standard executable language for specifying actions within business processes with web services.

As the “Web of Things” evolves devices may become driver of business transactions. E.g. autonomously ordering consumables, autonomously invoicing for service etc.

### **II.29.4 Message Queuing Telemetry Transport (MQTT)**

[https://www.oasis-open.org/committees/tc\\_home.php?wg\\_abbrev=mqtt](https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=mqtt)

Provides a lightweight publish/subscribe reliable messaging transport protocol suitable for communication in M2M/IoT contexts.

Not directly relevant to ontologies or data models other than providing a means for data transport.

## **II.30 Open Mobile Alliance (OMA)**

<http://openmobilealliance.org/>

The OMA Device management (DM) work group The Device Management (DM) Working Group (WG) specifies protocols and mechanisms to achieve the management of mobile devices, services access and software on connected devices.

A more detailed description of their work can be found at:

<http://openmobilealliance.org/about-oma/work-program/device-management/>

### **II.30.1 LWM2M**

The OMA DM have defined the Light Weight Machine to Machine (LWM2M) which is used for remote management of M2M devices and related service enablement. It builds on the IETF CoAP work.

LWM2M can be found at:

[http://member.openmobilealliance.org/ftp/Public\\_documents/DM/LightweightM2M/Permanent\\_documents/](http://member.openmobilealliance.org/ftp/Public_documents/DM/LightweightM2M/Permanent_documents/)

OMA provides users an interface (Appendix D/[OMA-TS-LightweightM2M]) to request for new object definitions, which should quickly bring many devices under this standard.

The interface as well as existing objects can be found at:

<http://technical.openmobilealliance.org/Technical/technical-information/omna/lightweight-m2m-lwm2m-object-registry>

Many IPSO objects are defined in this registry. They are also working in with oneM2M on management interfaces.

## **II.31 Object Management Group**

### **II.31.1 Industrial Internet Consortium**

The Industrial Internet Consortium is the open membership, international not-for-profit consortium that is setting the architectural framework and direction for the Industrial Internet. The consortium's mission is to coordinate vast ecosystem initiatives to connect and integrate objects with people, processes and data using common architectures, interoperability and open standards.

Their reference architecture (<http://www.iiconsortium.org/IIRA-1-7-ajs.pdf>) discusses the need for semantic compatibility and makes reference to needing an open standards based metadata solution such as ISO 11179.

### **II.31.2 Data Distribution Service (DDS)**

The DDS specification describes a Data-Centric Publish-Subscribe (DCPS) model for distributed application communication and integration. This specification defines both the Application Interfaces (APIs) and the Communication Semantics (behaviour and quality of service) that enable the efficient delivery of information from information producers to matching consumers.

<http://portals.omg.org/dds/>

Being middleware it doesn't define an ontology / semantics for web-of-things.

The SysML (Systems Modeling Language) and IFML (Interaction Flow Modeling Language) may also be relevant for IoT.

### **II.31.3 Object Data Metamodel**

[https://en.wikipedia.org/wiki/Common\\_Warehouse\\_Metamodel](https://en.wikipedia.org/wiki/Common_Warehouse_Metamodel)

The Common Warehouse Metamodel specifies interfaces that can be used to enable interchange of warehouse and business intelligence metadata between warehouse tools, warehouse platforms and warehouse metadata repositories in distributed heterogeneous environments. CWM is based on three standards:

- [UML](#) - Unified Modeling Language, an [OMG](#) modeling standard
- [MOF](#) - Meta Object Facility, an [OMG](#) metamodeling and metadata repository standard
- [XMI](#) - XML Metadata Interchange, an [OMG](#) metadata interchange standard

May be relevant when things become more linked to business processes.

### **II.31.4 Ontology PSIG**

<http://www.omg.org/ontology/>

The mission of the To enable development of ontology-related technology by bringing together the expertise in the semantics of software with the expertise for knowledge representation, consistency checking, and knowledge-processing, in order to leverage each other's technologies.

This group does not appear to be active anymore.

### **II.31.5 QUOMOS TC**

[https://www.oasis-open.org/committees/tc\\_home.php?wg\\_abbrev=quomos](https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=quomos)

The OASIS Quantities and Units of Measure Ontology Standard (QUOMOS) Technical Committee works to develop an ontology to specify the basic concepts of quantities, systems of quantities, and



systems of measurement units and scales, various base dimensions and units of the SI system, metric prefixes (nano-, micro-, milli-, kilo-, ...), rules for constructing various derived units, and designations of the most common derived units (joules, watts, ...) for use across multiple industries.

The TC does not appear to be active since 2014.

### **II.32 Open Platform Communications Unified Architecture (OPC UA)**

<https://opcfoundation.org/about/opc-technologies/opc-ua/>

Is an industrial M2M communication protocol for interoperability developed by the OPC Foundation.

The information model is specified in “Part 5: Information Model”

<https://opcfoundation.org/developer-tools/specifications-unified-architecture/part-5-information-model>

This is being proposed as a key component of Industrie 4.0.

### **II.33 Online Presence Ontology (OPO)**

OPO aims to model the dynamic aspects of a user’s presence online and to enable exchange of the Online Presence data. It is one of the vocabularies that support the publishing of Social Web data on the Semantic Web, along with FOAF and SIOC. <http://online-presence.net/>

Also related is the Web of Trust Ontology (<http://xmlns.com/wot/0.1/>)

### **II.34 Open Geospatial Consortium (OGC)**

<http://www.opengeospatial.org/standards>

GeoSPARQL - A Geographic Query Language for RDF Data

GeoSPARQL defines a vocabulary for representing geospatial data in RDF, and it defines an extension to the SPARQL query language for processing geospatial data. In addition, GeoSPARQL is designed to accommodate systems based on qualitative spatial reasoning and systems based on quantitative spatial computations.

<http://www.opengeospatial.org/standards/geosparql>

The main [OGC Standards](#) in the SWE framework are:

- [Observations & Measurements](#) (O&M) [<http://www.opengeospatial.org/standards/om>] –The general models and XML encodings for observations and measurements.
- [PUCK Protocol Standard](#) [<http://www.opengeospatial.org/standards/puck>] – Defines a protocol to retrieve a SensorML description, sensor "driver" code, and other information from the device itself, thus enabling automatic sensor installation, configuration and operation.
- [Sensor Model Language](#) (SensorML) [<http://www.opengeospatial.org/standards/sensorml>] – Standard models and XML Schema for describing the processes within sensor and observation processing systems.
- [Sensor Observation Service](#) (SOS) [<http://www.opengeospatial.org/standards/sos>] – Open interface for a web service to obtain observations and sensor and platform descriptions from one or more sensors.

- [Sensor Planning Service](http://www.opengeospatial.org/standards/sps) (SPS) [http://www.opengeospatial.org/standards/sps] – An open interface for a web service by which a client can 1) determine the feasibility of collecting data from one or more sensors or models and 2) submit collection requests.
- [SWE Common Data Model](http://www.opengeospatial.org/standards/swecommon) [http://www.opengeospatial.org/standards/swecommon] – Defines low-level data models for exchanging sensor related data between nodes of the OGC® Sensor Web Enablement (SWE) framework.
- [SWE Service Model](http://www.opengeospatial.org/standards/swes) (<http://www.opengeospatial.org/standards/swes>) – Defines data types for common use across OGC Sensor Web Enablement (SWE) services. Five of these packages define operation request and response types.

From the W3C Semantic Sensor Network XG final report

(<https://www.w3.org/2005/Incubator/ssn/XGR-ssn-20110628/>) - The OGC's Sensor Web Enablement activities have produced a services-based architecture and standards, including four languages for describing sensors, their capabilities and measurements, and other relevant aspects of environments involving multiple heterogeneous sensors. These standards assist, amongst other things, in cataloguing sensors and understanding the processes by which measurements are reached, as well as limited interoperability and data exchange based on XML and standardised tags. However, they do not provide semantic interoperability and do not provide a basis for reasoning that can ease development of advanced applications.

- Observations and Measurements (XML schema) for the OGC and ISO Observations and Measurements (O&M) conceptual mode (<http://www.opengeospatial.org/standards/om>)

OGC have the “Sensor Things SWG” (<http://www.opengeospatial.org/projects/groups/sweiotswg>) .

<http://www.opengeospatial.org/domain/swe>

<http://www.ogcnetwork.net/SWE>

There is also Spatial Data on the Web Working Group that is working in conjunction with the W3C:

<http://www.opengeospatial.org/projects/groups/sdwwg>

OGC Sensor ThingsAPI

<http://ogc-iot.github.io/ogc-iot-api/index.html>

<http://ogc-iot.github.io/ogc-iot-api/datamodel.html>

## II.35 OpenHAB

<http://www.openhab.org/>

OpenHAB is a software for integrating different home automation systems and technologies into one single solution that allows over-arching automation rules and that offers uniform user interfaces.

It is based on the OSGi framework / Eclipse and supports device through the use of bundles:

<http://www.openhab.org/features/supported-technologies.html>

## II.36 Open Interconnect (OIC)

<http://openinterconnect.org/>

The OIC has the goal of defining the connectivity requirement and ensuring interoperability of the billions of devices that will make up the emerging internet of things.

The OIC specification can be found at: <http://openinterconnect.org/developer-resources/specs/>

The Smart Home Device and Resource Type files define the data model. The resource type specification defines approximately 50 different types of resources. The Smart Home device specification lists approximately 25 device types.

Allows vendor based additions.

## II.37 User Plug and Play (UPnP)

The OIC has recently acquired the assets of the UPnP forum.

The device control protocols for various devices can be found at:

<http://upnp.org/sdcpss-and-certification/standards/sdcpss/>

In particular the “IoT Management and Control Specification” (<http://upnp.org/specs/iotmc/iotmc1/>) provides a data model for IoT.

There is also an open source project ([IoTivity http://www.iotivity.org](http://www.iotivity.org)) that is open to all, will provide a certified implementation of OIC, and will integrate UPnP into the OIC system.

## II.38 OSGi

<https://www.osgi.org/about-us/working-groups/internet-of-things/>

The IoT Expert Group’s area of concern includes the development and deployment of device abstraction later and endpoint ontologies.

OSGi is gaining popularity as enabling technology for building embedded system in residential and M2M markets. In these contexts it is often necessary to communicate with IP and non-IP devices by using various protocols such as ZigBee, Z-Wave, KNX, UPnP etc. In order to provide a convenient programming model suitable for the realization of end-to-end services it is very useful to define and apply an abstraction layer which unifies the work with devices supporting different protocols.

OSGi RFC196 defines a new device abstraction API in OSGi. It can be found at:

<https://github.com/osgi/design/raw/master/rfcs/rfc0196/rfc-0196-DeviceAbstractionLayer.pdf>

## II.39 Schema.org

<https://schema.org/>

Schema.org is a collaborative, community activity with a mission to create, maintain, and promote schemas for structured data on the Internet, on web pages, in email messages, and beyond.

Schema.org vocabulary can be used with many different encodings, including RDFa, Microdata and JSON-LD. These vocabularies cover entities, relationships between entities and actions, and can easily be extended through a well-documented extension model. Over 10 million sites use Schema.org to markup their web pages and email messages. Many applications from Google, Microsoft, Pinterest, Yandex and others already use these vocabularies to power rich, extensible experiences.

Schema.org is sponsored by Google, Microsoft, Yahoo and Yandex. The vocabularies are developed by an open [community](#) process, using the [public-schemaorg@w3.org](mailto:public-schemaorg@w3.org) mailing list (<https://lists.w3.org/Archives/Public/public-schemaorg/>) and through [GitHub](#).

Ontology is growing ~800 properties, ~600 classes.

<http://www.slideshare.net/rvguha/sem-tech2014c> is an interesting presentation looking at the results of the introduction of Schema.org. Two poignant slides regarding the next for simplicity are below.

## Schema.org principles: Simplicity

- Simple things should be simple
  - For webmasters, not necessarily for consumers of markup
  - Webmasters shouldn't have to deal with N namespaces
- Complex things should be possible
  - Advanced webmasters should be able to mix and match vocabularies
- Syntax
  - Microdata, usability studies
  - RDFa, json-ld, ...

schema.org

## Schema.org principles: Simplicity

- Can't expect webmasters to understand Knowledge Representation, Semantic Web Query Languages, etc.
- It has to fit in with existing workflows
  - A posteriori 'markup tools' don't work
- Avoid KR system driven artifacts
  - Multiple domain / range for attributes
  - No classes like 'Agent'
  - Categories and attributes should be concrete

schema.org

## II.40 Semantic Science Organisation

<http://semanticscience.org/>

Featured Projects: \* SIO - Semanticscience Integrated Ontology \* [SADI - Semantic Automated Discovery and Integration](#) \* [Bio2RDF - Federated Biological Linked Data](#) \* RKB - RNA Knowledge Base and the RNA ontology consortium [RNA Ontology](#) \* [TONES OWL ontology browser](#) \* [SCES - Semantic Chemical Entity Specification](#) \* [Chemical Information Ontology](#) \* [Translational Medicine Ontology](#) \* [Linked Data Hub Proposal](#)

## II.41 Semantically-Interlinked Online Communities Project (SIOC)

[https://en.wikipedia.org/wiki/Semantically-Interlinked\\_Online\\_Communities](https://en.wikipedia.org/wiki/Semantically-Interlinked_Online_Communities)

SIOC provides methods for interconnecting discussion methods such as blogs, forums and mailing lists to each other. <http://rdfs.org/sioc/spec/>

## **II.42 SNOMED CT**

[https://en.wikipedia.org/wiki/SNOMED\\_CT](https://en.wikipedia.org/wiki/SNOMED_CT)

A systematically organized computer processable collection of medical terms providing codes, terms, synonyms and definitions used in clinical documentation and reporting

## **II.43 Standards China**

China established a national SC (TC46/SC15) for smart household appliances and involved leading manufacturers in development.

Two standards on Smart Household Appliances have been published so far:

GB/T 28219-2011 General rules of intelligentisation technology for intelligent household appliances

QB/T 2836 - 2006 General requirements for networked home appliances

The “Made in China 2025” initiative have also agreed to collaborate with the Industrie 4.0 initiative as a key partner.

## **II.44 Temporal Abstractions Ontology**

<http://ksi.cpsc.ucalgary.ca/KAW/KAW98/shahar/>

[http://link.springer.com/chapter/10.1007%2F978-3-642-22218-4\\_32#page-1](http://link.springer.com/chapter/10.1007%2F978-3-642-22218-4_32#page-1)

Research papers on the process. No actual ontology found.

## **II.45 SWRL Temporal Ontologies**

<http://swrl.stanford.edu/ontologies/built-ins/3.3/temporal.owl>

Provides temporal modelling and reasoning based on SWRL (<https://www.w3.org/Submission/SWRL/>).

## **II.46 Universities**

### **II.46.1 University of Applied Sciences Osnabrück**

[https://mobcom.ecs.hs-osnabrueck.de/cp\\_quality/](https://mobcom.ecs.hs-osnabrueck.de/cp_quality/)

The Quality Ontology is used to represent the quality of information for data streams in smart cities. The annotated data streams are represented with the [Stream Annotation Ontology](#). To provide information about the provenance of the streams parts of the [PROV-O](#) ontology are used.

This is used by the EU city pulse project.

### **II.46.2 The Open University**

#### **II.46.2.1 Smart Products**

<http://projects.kmi.open.ac.uk/smartproducts/ontology.html>

The SmartProducts Network of Ontologies (SPO) provides a clear specification of the conceptual model underlying the work on the SmartProducts project, and maximises interoperability not just among all SmartProducts applications, but also between these and other applications in related

domains. SPO comprises three different sets of modules, which reflect different levels of abstraction and reuse, from the most generic to the application-specific ones. Because each layer is itself divided into several sub-modules, we obtain a highly modular design, which makes it possible to reduce the parts to be used by a device, depending on its functionalities - e.g., no need to use the process model on devices that only serve as data providers.

SPO builds on established external ontologies, including the [DOLCE Ultra Lite Ontology](#), the [W3C time ontology](#), and the recently proposed [W3C Semantic Sensor Network ontology](#).

## **II.46.3 University of Surrey**

### **II.46.3.1 Stream Annotation Ontology**

<http://iot.ee.surrey.ac.uk/citypulse/ontologies/sao/sao>

Represents the features of a data stream defining the specifications of an information model on top of Semantic Sensor Networks (SSN), PROV-O and TimeLine Ontologies, and involves connections with the Complex Event Processing Ontology and Quality Ontology.

### **II.46.3.2 IoT Lite Ontology**

<https://www.w3.org/Submission/iot-lite/>

IoT-Lite ontology is a lightweight ontology to represent Internet of Things (IoT) resources, entities and services. IoT-Lite is an instantiation of the [SSN ontology](#). The lightweight allow the representation and use of IoT platforms without consuming excessive processing time when querying the ontology. However it is also a meta ontology that can be extended in order to represent IoT concepts in a more detailed way in different domains. It also can be combined with ontologies representing IoT data streams such as [SAO ontology](#).

## **II.46.4 University of London**

### **II.46.4.1 The Timeline Ontology**

the Timeline ontology developed in the [Centre for Digital Music](#) in [Queen Mary, University of London](#). This ontology is centered around the notion of *timeline*, seen here as a way to identify a temporal *backbone*. A timeline may support a signal, a video, a score, a work, etc. A particular instance of a timeline is the physical one, on which *the 29th of October, 2007* is defined.

<http://motools.sourceforge.net/timeline/timeline.html>

Uses the event Ontology.

### **II.46.4.2 The EventOntology**

This ontology is centered around the notion of event, seen here as the way by which cognitive agents classify arbitrary time/space regions

<http://motools.sourceforge.net/event/event.html>

This ontology is related to timeline ontology.

## **II.46.5 Bundeswehr University Munich**

<http://www.ebusiness-unibw.org/>

E-Business + Web Science Research Group.

## **II.47 Consumer Electronics Ontology**

CEO: Consumer Electronics Ontology - An Ontology for Consumer Electronics Products and Services

<http://www.rdf4ecommerce.org/>

<http://www.ebusiness-unibw.org/ontologies/consumerelectronics/v1>

Directly relevant description of things.

## **II.48 UPnP IOT Datamodels**

[http://upnp.org/resources/documents/UPnP%20DataModels\\_March2015.pdf](http://upnp.org/resources/documents/UPnP%20DataModels_March2015.pdf)

UPnP Device Architecture 1.1, 15 October 2008,

<http://upnp.org/specs/arch/UPnP-arch-DeviceArchitecture-v1.1.pdf>

## **II.49 W3C**

### **II.49.1 PROV-O: The PROV Ontology**

<https://www.w3.org/TR/prov-o/>

The PROV data model for provenance interchange on the Web. The *provenance* of digital objects represents their origins. Provenance can be used for many purposes, such as understanding how data was collected so it can be meaningfully used, determining ownership and rights over an object, making judgements about information to determine whether to trust it, verifying that the process and steps used to obtain a result complies with given requirements, and reproducing how something was generated. PROV defines a core data model for provenance for building representations of the entities, people and processes involved in producing a piece of data or thing in the world.

<https://www.w3.org/TR/2013/NOTE-prov-primer-20130430/>

### **II.49.2 Schema.org Community Group**

W3C hosts discussions regarding Schema.org. See sub-section regarding Schema.org for more details.

### **II.49.3 Semantic Web Org**

<http://semanticweb.org/wiki/Ontology.html>

W3C group listing ontologies. E.g. lists VCARD, Basic GEO ontology.

### **II.49.4 Semantic Sensor Network Ontology**

<https://www.w3.org/2005/Incubator/ssn/ssnx/ssn>

### **II.49.5 Semantic Sensor Network**

[https://www.w3.org/2005/Incubator/ssn/wiki/Main\\_Page](https://www.w3.org/2005/Incubator/ssn/wiki/Main_Page)

This ontology describes sensors and observations, and related concepts. It does not describe domain concepts, time, locations, etc. these are intended to be included from other ontologies via OWL imports.

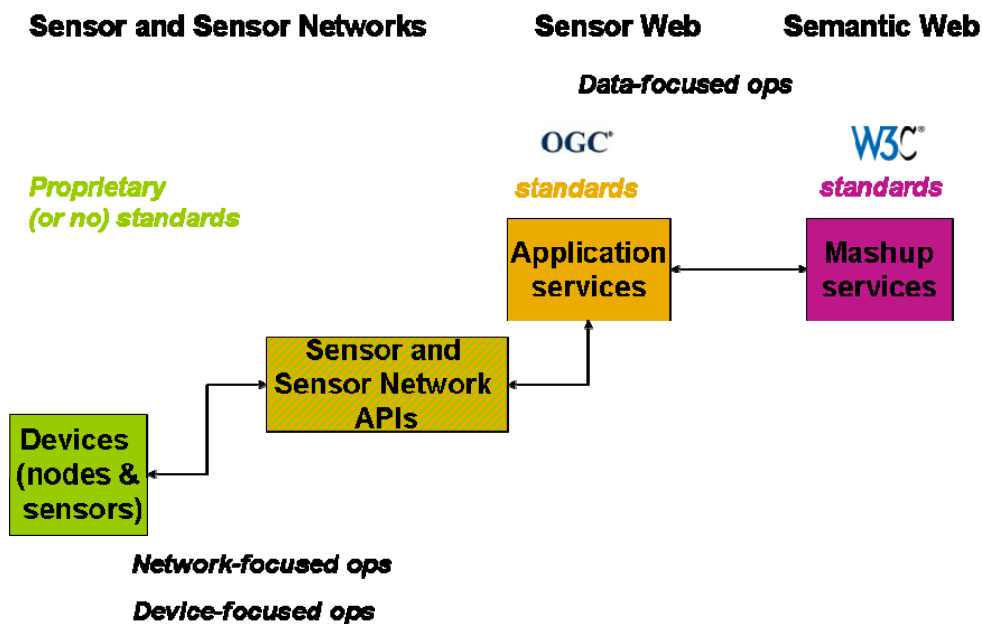
<https://www.w3.org/2005/Incubator/ssn/ssnx/ssn>

For more detail of the activities see:

<https://www.w3.org/2005/Incubator/ssn/XGR-ssn-20110628/>

Strong alignment with OGC SensorML.

From June 2011 report:



Clause 4.1.1/[ <https://www.w3.org/2005/Incubator/ssn/XGR-ssn-20110628/>] report shows a list of ontologies that were reviewed as part of the process of forming SSN ontology. These are also covered at:

[https://www.w3.org/2005/Incubator/ssn/wiki/Review\\_of\\_Sensor\\_and\\_Observations\\_Ontologies](https://www.w3.org/2005/Incubator/ssn/wiki/Review_of_Sensor_and_Observations_Ontologies)

It takes into consideration the SENSEI Observation and Measurement Ontology and the O&M-OWL (SemSOS) Ontologies.

## II.49.6 SKOS Simple Knowledge Organization System

<https://www.w3.org/2004/02/skos/intro>

<https://www.w3.org/2001/sw/wiki/SKOS/Datasets>

Seems to be more about thesauri, taxonomies etc for use with libraries.

## II.49.7 Share-PSI 2.0

<https://www.w3.org/2013/share-psi/>

Thematic Network (EU Open Data initiatives)

Share-PSI is a pan European network offering advice on implementation of the European Directive on the Public Sector Information. Rather than defining a particularly ontology it details best practices around metadata and open data.

## II.49.8 Spatial Data on the Web Working Group

[https://www.w3.org/2015/spatial/wiki/Main\\_Page](https://www.w3.org/2015/spatial/wiki/Main_Page)

The Spatial Data on the Web WG is part of the [Data Activity](#) and is explicitly chartered to work in collaboration with the Open Geospatial Consortium (OGC), in particular, the [Spatial Data on the Web Task Force](#) of the [Geosemantics Domain Working Group](#).



## II.49.9 Time Ontology

<https://www.w3.org/TR/owl-time/>

This document presents an ontology of temporal concepts, OWL-Time (formerly DAML-Time), for describing the temporal content of Web pages and the temporal properties of Web services. The ontology provides a vocabulary for expressing facts about topological relations among instants and intervals, together with information about durations, and about datetime information.

A simple use case example: "Suppose someone has a telecon scheduled for 6:00pm EST on November 5, 2006. You would like to make an appointment with him for 2:00pm PST on the same day, and expect the meeting to last 45 minutes. Will there be an overlap?" In this use case we can specify the facts about the telecon and the meeting using our ontology in OWL that will allow a temporal reasoner to determine whether there is a conflict.

<http://www.isi.edu/~pan/OWL-Time.html>

## II.49.10 Uncertainty Reasoning for the World Wide Web Incubator Group

<https://www.w3.org/2005/Incubator/urw3/>

Uncertainty Reasoning for the World Wide Web (URW3) Incubator Group, part of the [Incubator Activity](#), is to better define the challenge of reasoning with and representing uncertain information available through the World Wide Web and related WWW technologies.

As discussed in the final report of the group much information on the web is likely to be uncertain, incorrect or partially correct. There may be multiple overlapping ontologies that need to exist and co-operate. Things consuming this semantic data must be able to apply reasoning techniques in order to operate correctly. Likewise things that generate data must be precise in what they produce.

## II.49.11 WGS84 Geo Positioning

<https://www.w3.org/2003/01/geo/>

This vocabulary begins an exploration of the possibilities of representing mapping/location data in RDF, and does not attempt to address many of the issues covered in the professional GIS world, notably by the [Open Geospatial Consortium](#) (OGC). Instead, we provide just a few basic terms that can be used in RDF (eg. [RSS 1.0](#) or [FOAF](#) documents) when there is a need to describe latitudes and longitudes. The motivation for using RDF as a carrier for lat/long info is RDF's capability for cross-domain data mixing. We can describe not only maps, but the entities that are positioned on the map.

Currently only a very minimalistic RDF vocabulary for describing **Points** with **latitude**, **longitude**, and **altitude** properties from the WGS84 reference datum specification is specified.

Report on geospatial technologies: <https://www.w3.org/2005/Incubator/geo/XGR-geo-ont-20071023/> provides links to several other geographic related ontologies and modelling languages:

- Geonames Ontology (<http://www.geonames.org/ontology/documentation.html>)
- UK ordnance survey (with broken link).
- GeorSS uses the W3C Basic Geo Vocabulary mentioned above.

## II.49.12 WoT WG

<https://www.w3.org/WoT/IG/>

The mission of the Web of Things Interest Group, part of the Ubiquitous Web Applications Activity, is to accelerate the development of open markets of applications and services based upon

the role of Web technologies for a combination of the Internet of Things (IoT) with the Web of data.

## **II.50 XMPP.org**

<http://www.xmpp-iot.org/>

A number of extensions have been defined to be used in IoT scenarios. These are listed below:

### **II.50.1 XMPP IoT XMPP extensions:**

- XEP-0322-SN EXI Compression
- XEP-0000-SN Battery Powered Sensors
- XEP-0326-SN-Concentrators
- XEP-0325-SN-Control
- XEP-0000-SN-Discovery
- XEP-0000-SN-Events
- XEP-0000-SN-Interoperability
- XEP-0324-SN-Provisioning
- XEP-0000-SN-PubSub
- XEP-0323-SN-SensorData
- XEP-0332-SN-HTTP over XMPP

They can be downloaded from: <http://xmpp.org/extensions/>

### **II.50.2 XEP-0115: Entity Capabilities**

<http://xmpp.org/extensions/xep-0115.html>

This document defines an XMPP protocol extension for broadcasting and dynamically discovering client, device, or generic entity capabilities. In order to minimize network impact, the transport mechanism is standard XMPP presence broadcast (thus forestalling the need for polling related to service discovery data), the capabilities information can be cached either within a session or across sessions, and the format has been kept as small as possible

## **II.51 ZIGBEE Alliance (IEEE 802.15)**

<http://www.zigbee.org/>

The Zigbee alliance are working on Zigbee 3.0 the foundation for the internet of things.

<http://www.zigbee.org/zigbee-for-developers/zigbee3-0/>

ZigBee 3.0 defines more than 130 devices and the widest range of devices types including home automation, lighting, energy management, smart appliance, security, sensors, and health care monitoring products. It supports both easy-to-use DIY installations as well as professionally installed systems. All current device types, commands, and functionality defined in current ZigBee PRO-based standards are available in the ZigBee 3.0.

ZigBee 3.0 defines devices and application clusters.

The Zigbee cluster library can be downloaded from: <http://www.zigbee.org/download/standards-zigbee-cluster-library/>

## **II.52 Z-WAVE**

<http://z-wavealliance.org/>

Z-Wave is a proprietary wireless communications protocol employing mesh networking technology. Command classes are used to perform operations on devices. Unfortunately no official documentation is publically available.

## **Appendix III Building Automation Systems**

Automation in building systems is not new. There are already existing standards in this space, for example: KNX, BACnet, ZigBee, EnOcean, Wireless M-Bus. Replacing this infrastructure may not be possible. In order to utilise this infrastructure for a web of things environment some sort of middle ware would be needed to map the protocols/architectures to new vocabularies.

The IoTSYS project is one such project. More information can be found at:

<http://challenge.ipso-alliance.org/ipso-challenge-2013/iotsys-internet-of-things-integration-middleware>

The OneM2M Base ontology also allow “proxied Devices” allowing devices such as KNX devices etc. to be represented in the ontology.

### **III.1 ISO/IEC 14543-3 KNX**

<http://www.knx.org>

International standard for home and building control.

The IoTSYS project implementing middleware to integrate KNX with IoT can be found at:  
<https://code.google.com/archive/p/iotsys/>

### **III.2 ISO 16484-5 Building automation and control systems**

<https://en.wikipedia.org/wiki/BACnet>

BACnet is a communications protocol for building automation and control networks. The BACnet protocol provides mechanisms for computerized building automation devices to exchange information, regardless of the particular building service they perform.

## Appendix IV Product Codes

There are already existing frameworks for describing products and services that have been used in global business and trade for some time. These could be used to derive ontologies for the Web of Things.

For example the paper “Products and Services Ontologies: A Methodology for Deriving OWL Ontologies from Industrial Categorization Standards” (<http://www.heppnetz.de/files/IJSWIS-eclassOWL-APA-Style-2005-final-11-17-Web.pdf>) discusses such an approach.

Below are some product classification schemes.

### IV.1 Trade numbers

Universal Product Code (UPC) [https://en.wikipedia.org/wiki/Universal\\_Product\\_Code](https://en.wikipedia.org/wiki/Universal_Product_Code)

European Article Number (EAN)

[https://en.wikipedia.org/wiki/International\\_Article\\_Number\\_%28EAN%29](https://en.wikipedia.org/wiki/International_Article_Number_%28EAN%29)

Global Trade Item Number (GTIN) [https://en.wikipedia.org/wiki/Global\\_Trade\\_Item\\_Number](https://en.wikipedia.org/wiki/Global_Trade_Item_Number)  
(incorp

GTIN, is an identification number that may be encoded in UPC-A, UPC-E, EAN-8 & EAN-13 barcodes as well as other barcodes in the GS1 System.

As these numbers typical identify a product they may not be suitable where things are developed that don't end up as consumer items or during the development cycle.

### IV.2 WIPO Classifications

#### IV.2.1 Industrial Design Numbers

<http://www.wipo.int/classifications/locarno/en/>

The Locarno classification contains a comprehensive set of classification of goods. Things that have registered designs can be mapped to the classes.

#### IV.2.2 International Patent Classification (IPC)

<http://www.wipo.int/classifications/ipc/en/>

The IPC contains is a hierarchical scheme for the classification of patents and models. A key element of a patent is that the invention must be able to be made. One assumes into a thing. Given the breadth of inventions this patent classification could be used to describe a wide range of things.

## Appendix V Groups dedicated to Ontology research

### V.1 Laboratory for Applied Ontology

The Laboratory for applied ontology has produced the DOLCE ontology.

### V.2 DOLCE

<http://www.loa.istc.cnr.it/old/DOLCE.html>

An upper ontology descriptive ontology for Linguistic and Cognitive Engineering

DUL (DOLCE Ultralite) used by W3C is a simplification of this ontology.

### V.3 Ontolog Forum

<http://ontologforum.org/index.php/WikiHomePage>

Is an online forum dedicated to ontology research. They hold a conference each year dedicated ontology research. Their Google discussion group can be found at:

<https://groups.google.com/forum/#!forum/ontolog-forum>

The forum has a number of sub-activities specialising in particular areas:

Eg. Building Services (<http://ontolog.cim3.net/cgi-bin/wiki.pl?BuildingServicePerformance>)

In 2015 they held a conference on the IoT and ontologies:

[http://ontolog-02.cim3.net/wiki/OntologySummit2015\\_Symposium/](http://ontolog-02.cim3.net/wiki/OntologySummit2015_Symposium/)

From the abstract:

*Ontologies will play a significant role in the realization of smart networked systems and societies (SNSS). For example, a considerable amount of data passes through the network and should be converted into higher abstractions that can be used in appropriate reasoning. This requires the development of standard terminologies which capture objects and events. Creating and testing such terminologies will aid in effective recognition and reaction in a network-centric situation awareness environment. This would involve identifying a methodology for development of terminologies for multimodal data (or ontologies), developing appropriate ontologies, developing testing methods for these ontologies, demonstrating interoperability for selected domains (e.g., healthcare, situational awareness), and using these ontologies in decision making.*

There were four tracks being discussed at the conference. The presentations raised a number of issue directly related to any potential “Web of Things” semantic/ontology work. The summary presentations for these tracks are discussed below as well as some relevant issues for the definition of WoT ontologies/semantics.

#### V.3.1 Track A: Ontology Integration In IoT

[http://ontolog.cim3.net/file/work/OntologySummit2015/2015-04-13\\_14\\_OntologySummit2015\\_Symposium/Track-A\\_Symposium-Synthesis\\_RamSriram-LeoObrst\\_2015-04-13.pdf](http://ontolog.cim3.net/file/work/OntologySummit2015/2015-04-13_14_OntologySummit2015_Symposium/Track-A_Symposium-Synthesis_RamSriram-LeoObrst_2015-04-13.pdf)

Issue: How to use existing ontologies? For example different ontologies may need to be combined to produce the desired system, e.g. as per slide 11 “quantities, wearables, body parts, symptoms, diseases.”

Issue: IoT ontologies need to deal with dynamic time varying data vs. the often static Semantic Web.

Slide 15 provides some insights for creating IoT ontologies. These are listed below:

1. *Design for large scale and provide tools and APIs.*
2. *Think of who will use the semantics and how when you design your models.*
3. *Provide means to update and change the semantic annotations.*
4. *Create tools for validation and interoperability testing.*
5. *Create taxonomies and vocabularies.*
6. *Try to re-use existing ones as much as you can.*
7. *Link your data and descriptions to other existing resources.*
8. *Define rules and/or best practices for providing the values for each attribute.*
9. *Remember the widely used semantic descriptions on the Web are simple ones like FOAF.*
10. *Semantics are only one part of the solution and often not the end product so the focus of the design should be on creating effective methods, tools and APIs to handle and process the semantics. Query methods, machine learning, reasoning and data analysis techniques and methods should be able to effectively use these semantics.*

### **V.3.2 Track B: Beyond Semantic Sensor Network Ontologies**

[http://ontolog.cim3.net/file/work/OntologySummit2015/2015-04-13\\_14\\_OntologySummit2015\\_Symposium/Track-B\\_Symposium-Synthesis\\_GaryBergCross\\_2015-04-13.pdf](http://ontolog.cim3.net/file/work/OntologySummit2015/2015-04-13_14_OntologySummit2015_Symposium/Track-B_Symposium-Synthesis_GaryBergCross_2015-04-13.pdf)

Slide 7: Enhancing SSN

- SSNO: Most of the existing IoT or sensor related ontologies represent IoT devices only partially, e.g. only sensing devices in SSNO ([.](#)). Current work extends this to include other entities including tight links to actuator devices, aggregators, control entities etc.

Slide 8: Semantics in sensor networks

There are two fundamental approaches:

- Semantics in the cloud where all sensor observations are sent to the cloud for semantic annotation and processing.
- Semantics at the edge where semantic representation and reasoning are locally processed.

Both of these methods would need to be considered.

Slide 9: There are different ontologies required for sensor data discovery and integration versus in-network data stream processing.

Slide 10: Big Picture View. A semantic registry for IoT entities is needed!

### V.3.3 Track C: Decision Making in Different Domains

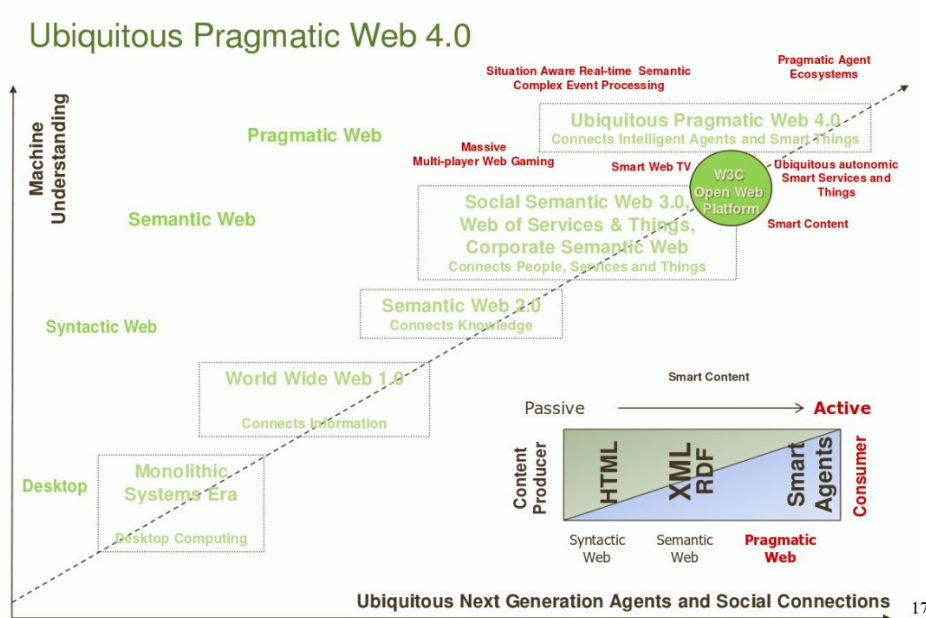
[http://ontolog.cim3.net/file/work/OntologySummit2015/2015-04-13\\_14\\_OntologySummit2015\\_Symposium/Track-C\\_Symposium-Synthesis\\_KenBaclawski-MikeBennett\\_2015-04-13.pdf](http://ontolog.cim3.net/file/work/OntologySummit2015/2015-04-13_14_OntologySummit2015_Symposium/Track-C_Symposium-Synthesis_KenBaclawski-MikeBennett_2015-04-13.pdf)

Slide 4: (Michael Gruninger) - Process Ontologies for Smart Objects in Manufacturing. There are existing ontologies used for process engineering in manufacturing for example: PSL.

Slide 5: The Role of Ontologies in Building Automation, Matthew Giannini (SkyFoundry)([http://ontolog.cim3.net/file/work/OntologySummit2015/2015-03-19\\_OntologySummit2015\\_Decision-Making-in-Different-Domains-2/Track-C\\_The-Role-of-Ontologies-in-Building-Automation--MatthewGiannini\\_20150319.pdf](http://ontolog.cim3.net/file/work/OntologySummit2015/2015-03-19_OntologySummit2015_Decision-Making-in-Different-Domains-2/Track-C_The-Role-of-Ontologies-in-Building-Automation--MatthewGiannini_20150319.pdf)) references the work of Haystack.org.

Slide 10: Pragmatic Web ([www.pragmaticweb.info](http://www.pragmaticweb.info)) versus Schema.org

#### Vision of the future of the Web (from Paschke)



The pragmatic web consists of the tools, practices and theories describing why and how people use information. In contrast to the Syntactic Web and Semantic Web the Pragmatic Web is not only about form or meaning of information, but about interaction which brings about e.g. understanding or commitments.

### V.3.4 Track D: Related Standards and Synergies for Emerging IoT Ontologies

[http://ontolog.cim3.net/file/work/OntologySummit2015/2015-04-13\\_14\\_OntologySummit2015\\_Symposium/Track-D\\_Symposium-Synthesis\\_MarkUnderwood\\_2015-04-13.pptx](http://ontolog.cim3.net/file/work/OntologySummit2015/2015-04-13_14_OntologySummit2015_Symposium/Track-D_Symposium-Synthesis_MarkUnderwood_2015-04-13.pptx)

Slide 14: Craft vs Engineering Ontologies

#### Craftsperson Approach

- Design new framework for device generation
- Set bits to turn features on or off
- “Fast” prototyping



- Distaste for overhead
- **Developer impersonates a domain expert**

### Engineering Approach

- Create models for each device
- Leverage existing models (even if from different domains)
- Build cross-generational self-describing frameworks
- Slower initial prototyping, but faster with each new model
- Accept overhead, generated- / interpretative solutions
- Developer facilitates domain expert scripting / templating
- Accept “fragility”

### Slide 36: Standards Influence Maze

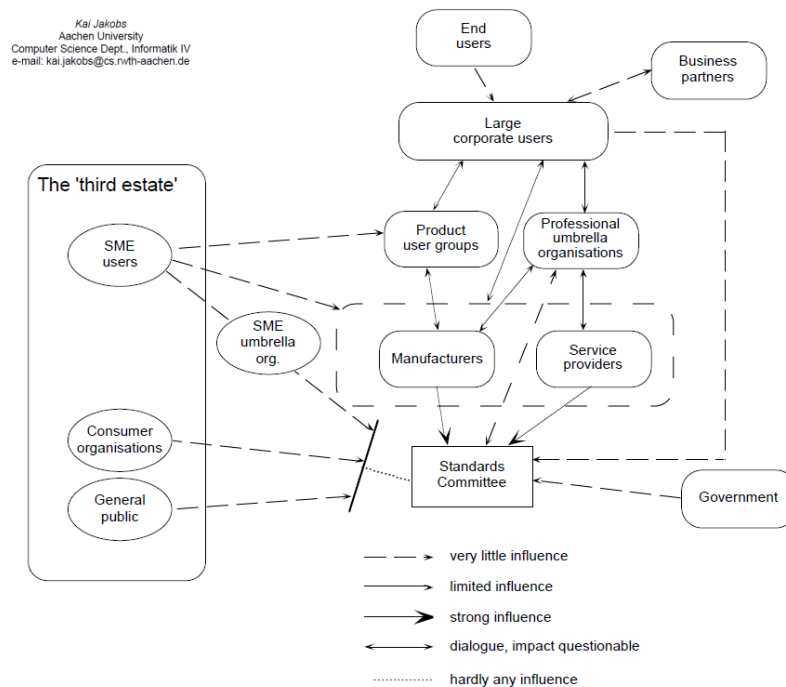


Figure 5: A more realistic view of the relations between stakeholders in standardisation

Slide 44: Highlights that ambiguities and weak definitions and provenance are issues when assigning semantics to things.

## V.4 International Society for Ontology and its Applications

<http://iaoa.org/>

There are several special interest groups dedicated to:

- Semantic Web Applied Ontology (SWAO)
- Ontologies and Conceptual Modelling
- Geospatial Ontologies and Standards
- Design Semantics: Ontologies, Inference, and Standards for Spatial Design

## **V.5 Linked Group on Stakeholders on Smart Appliances**

This group functions as a networking group for people and parties interested in the results of the Study on the available semantic assets for the interoperability of Smart Appliances and the Mapping of the identified semantic assets into a common ontology as a M2M application layer semantics that TNO is performing for the European Commission

<https://www.linkedin.com/groups/7450648/profile>

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