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ONTOLOGICAL BASE MODELS MACHINE-TO-MACHINE M2M APPLIED TO THE INTERNET OF THINGS IOT

MODELOS BASE ONTOLÓGICOS M2M MÁQUINA A MÁQUINA APLICADOS AL INTERNET DE LAS COSAS IOT

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ABSTRACT

Machine-to-Machine M2M technology being a specific discourse universe of the Internet of Things IoT for the connectivity of intelligent devices, the support of said environment requires a basic conceptual scheme; for which the present article, proposes an evaluation about the different ontological models that consider the M2M and the IoT in simultaneous, recognizing the syntactic and semantic capacity of the interoperability of such devices, from the study of the basic schemes in mention, and identifying

its most outstanding properties according to the Quality of Service QoS metric, obtaining the oneM2M ontology as the most appropriate.

RESUMEN

La tecnología Machine-to-Machine M2M al ser un universo discursivo específico del Internet de las Cosas IoT para la conectividad de dispositivos inteligentes, el soporte de dicho entorno requiere de un esquema conceptual básico; por lo que el presente artículo, propone una evaluación sobre los diferentes modelos ontológicos que consideran el M2M y el IoT en simultáneo, reconociendo la capacidad sintáctica y semántica de la interoperabilidad de dichos dispositivos, a partir del estudio de los esquemas básicos en mención, e identificando sus propiedades más destacadas según la métrica Calidad de Servicio QoS, obteniendo la ontología oneM2M como la más adecuada.

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KEYWORDS

Internet of Things IoT, Machine to Machine M2M, ontology, Quality of Service QoS, model.

Palabras clave: Internet de las cosas, IoT, máquina a máquina M2M, ontología, calidad de servicio QoS, modelo.

I. INTRODUCTION

Being constantly communicated and informed has become a necessary and peremptory aspect in our current society, a situation that we intend to satisfy in various ways; one such way is through electronic equipment that has Machine-to-Machine M2M technology (ETSI, 2013), facilitating the identification, monitoring and respective management when connected to the Internet of Things IoT.

This article proposes an evaluation about the different elementary ontological models of the IoT Internet of Things, which have been developed supported by the Machine to Machine M2M technology. As a result, conceptual systems with a universe of discourse concerning smart device networks were selected, whose fundamental architecture considers the functional aspects of Quality of Service QoS such as modularity, compatibility with emerging technologies, the hierarchy of components, the formatting of data and the stratification of services, so that said QoS has been proposed as a metric to discuss the various ontologies.

The result was the identification of the functional ontological base model oneM2M as the most appropriate and convenient, since it facilitates the development of syntactic and semantic interoperability of smart appliances (ETSI,

2017), by implementing it as its respective framework.

II. BACKGROUND

The architecture of the Internet of Things IoT facilitates the structuring, interaction and functioning of the components of said network of devices, which is why it is necessary to know the various ways in which entities that can be formally organized can be organized. they configure the IoT (Vermesan, 2013), as their characteristics and their possible relationships with each other within a specific domain. The latter is what is known as “ontology” (Grønbaek, 2008).

Approximately from the middle of the year 2008 to date, several architectures for the IoT have been developed, starting from a conceptual framework (ontology), from the initiatives of communications projects belonging to Western Europe, the Far East and North America. which are related:

- European Telecommunications Standards Institute ETSI.
- International Telecommunication Union ITU
- Internet Engineering Task Force IETF
- Open Geospatial Consortium OGC
- One Machine To Machine oneM2M
- Internet Of Things Architecture IoT-A

The different ontological models that are integrated in the functional architecture of the Internet of Things IoT, are detailed below.

III. RELATED JOBS

The research articles in table 1 are related to this work and serve as the theoretical framework of it:

No.	Autor	Artículo de investigación	Ontología
1	Compton, M. et. al. W3C (SSN-XG)	The SSN Ontology of the W3C Semantic Sensor Network Incubator Group Standardizing generic	Semantic Sensor Network SSN
2	Gyrard, A. et. al.	cross-domain applications in Internet of Things	Machine to Machine Measurement M3
3	oneM2M.	TS-0012 Base Ontology. Technical specification. V.0.8.0	one Machine to Machine oneM2M
4	Bermudez-Edo, M. et. al.	IoT-Lite: A Lightweight Semantic Model for the Internet of Things	Internet of Things Lite IoT-Lite

Table 1. Works related to research

Each ontological model is supported in a scientific document that describes it in detail in terms of its entities, relationships and restrictions within a specific discourse universe, which is Machine-to-Machine M2M technology applied to the Internet of Things IoT. In this, the conceptual model of the Semantic Sensors Network SSN is sponsored by the W3C work group incubator. Likewise, the ontology of machine-to-machine measurement M3 for transversal domains is developed by a group of scientists led by Gyrard A. Alike, the monadic machine-to-machine model is built by the oneM2M alliance, which consists of the association of various organizations recognized worldwide in the field

of Information and Communication Technologies ICT. Finally, the light conceptual scheme for the semantics of the IoT-Lite internet of things has been developed by a group of researchers led by Bermúdez-Edo M.

IV. ONTOLOGICAL MODELS

A. Semantic Sensor Network SSN Ontology

The Semantic Sensor Network SSN of the group of incubators of the W3C, presents an ontology that describes sensors, observations, and related concepts. The concepts of domain, time,

locations, etc., that are intended to be included in other ontologies through OWL imports (Compton, et al., 2012) are not described (W3C, 2011).

This ontology is developed by the Group of Incubators of Semantic Sensor Networks of the W3C (SSN-XG), who discusses the concepts and the structure of the same. It is based on concepts of systems, processes and observations. Supports the description of the physical structure and processing of the sensors. Sensors are not limited to physical detection devices: rather a sensor is anything that can estimate or calculate the value of a phenomenon, so a device or computational process or combination could play the role of a sensor. The representation of a sensor in the ontology links what it measures (the phenomena of the domain), the physical sensor (the device) and its functions and processing (the models) (ibid.).

The ontology is available as a single OWL file, containing the SSN ontology and a semiautomatically generated documentation derived from it, which is also provided as a stand-alone document. Additional annotations have been added to divide the ontology into thematic “modules” that are presented later. In order to make the ontology and its documentation more useful, separate documentation pages for each module are provided with ontology fragments extracted from the examples developed by the XG participants. Five worked examples are included to illustrate different parts of the SSN ontology: university deployment, intelligent product, wind sensor, agricultural meteorology and linked sensor data. The OWL files for the examples and for the imported ontologies are also available (ib.).

The ontology of the Semantic Sensor Network revolves around the central pattern of stimulus-sensor-observation. Several conceptual modules are built on the pattern to cover key sensor concepts. These modules can be seen

in Figure 1 and the relationships between them appear in Figure 2 (ibid.), Which contains an overview of the main classes and properties within the ontology modules.



Figure 1. Modules of the SSN ontology (Compton, et al., 2012) (W3C, 2011)

The ontology can be used to focus on any one (or a combination) of a series of perspectives (ibid.):

- A sensor perspective focused on what, how and when it perceives.
- A data or observation perspective, with a focus on related observations and metadata.
- A system perspective, with a focus on sensor systems.
- A property and property perspective, with a focus on what can be detected from them.

The modules, as described here, allow these views to be further refined or grouped into sensors and sensors. The description of the sensors can be detailed or abstract. The ontology does not include a hierarchy of sensor types; These definitions are left to the domain experts, and for example could be a simple hierarchy or a more complex set of definitions based on the functioning of the sensors (ibid.).

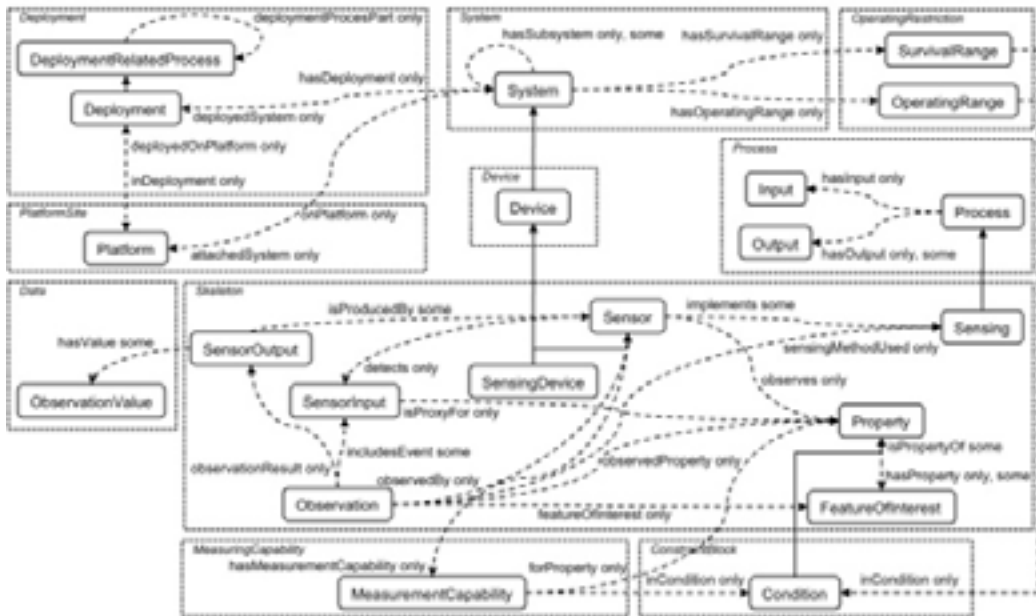


Figure 2. Classes and Properties of the SSN ontology (Compton, et al., 2012) (W3C, 2011)

The modules contain the classes and properties that can be used to represent particular aspects of a sensor or its observations: for example, sensors, observations, features of interest, the detection process (ie, how a sensor operates

and observes), how they are the sensors, the measurement capabilities of the sensors, as well as their environmental and survival properties of the sensors in particular environments (ibid.).

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B. Machine to Machine Measurement M3 ontology

The framework Machine-to-Machine Measurement M3 helps developers semantically

annotate M2M data and build new applications by reasoning in M2M data from heterogeneous IoT domains. The M3 frame is shown in Figure 3 and consists of several layers as follows (Gyrard, et. Al., 2014):

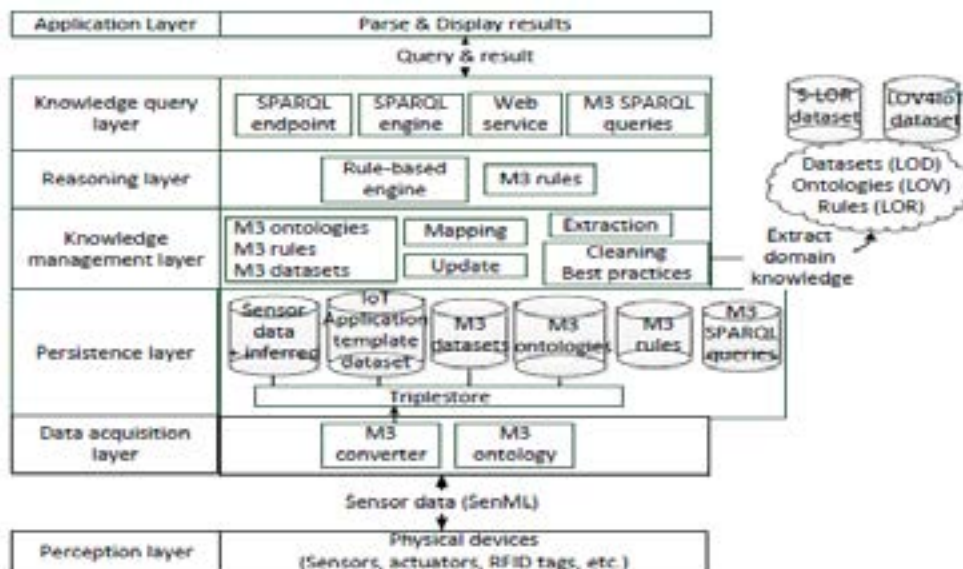


Figure 3. M3 framework (Gyrard, et al., 2014)

- The perception layer is composed of physical devices such as sensors, actuators and RFID tags (ibid.).
- The data acquisition layer retrieves the data from the sensors (SenML) of the M2M devices and converts them in a unified way (RDF/XML) according to the M3 ontology, an extension of the SSN observation value concept of the W3C to provide a basis for reasoning (ib.).
- The persistence layer stores M3 domain ontologies, data sets and semantic sensor data in a triple store. A triple store is a database for storing data from semantic sensors, queries and SPARQL rules (ibid.).
- The knowledge management layer is responsible for finding, indexing, designing, reusing and combining domain-specific knowledge (for example, smart home, intelligent transport systems, etc.) as ontologies and data sets to update ontologies, sets of data and rules of the M3 domain. The Linked Open Vocabularies to IoT (LOV4IoT) concern knowledge based on domain ontologies, data sets and rules based on semantic web technologies that could be reused for applications between domains (ibid.).
- The reasoning layer infers new knowledge using reasoning engines and M3 rules extracted from the Linked Open Rules to the Sensors (S-LOR). The M3 rules are a set of rules that comply with the M3 ontology to infer new knowledge about sensor data. For example, with a brightness equal to 50000 lux, the M3 rules indicate that it is very sunny outdoors (ib.).
- The knowledge query layer runs SPARQL queries (a language similar to SQL) in inferred sensor data (ibid.).
- The application layer uses a program (that runs on smart devices) that analyzes and displays the results to the end users. For example, the M3 framework suggests security devices to turn on your smart car, according to the weather forecast (ibid.).

The aforementioned uniform descriptions are a fundamental need to develop applications and services between domains. A common nomenclature is described below without claiming to be exhaustive in the lists. Such recommendations are relevant to standardization bodies such as oneM2M, ETSI M2M, W3C Web of Things and W3C SSN. An example of this can be seen in Figure 4 (ibid.):

M3 or SenML domain	M3 or SenML sensor/ measurement name	Description, other names (synonyms)	M3 or SenML Unit
Weather	HumiditySensor/ Humidity	Hygrometer, humidity sensor, moisture sensor, soil moisture probes	Percent
Weather	WindDirectionSensor/ WindDirection	Wind direction	DegreeAngle
Weather	SunPositionDirectionSensor/ SunPosition	sun position direction to detect east, west, south, north	DegreeAngle
Weather	AtmosphericPressureSensor/ AtmosphericPressure	Atmospheric pressure sensor, Barometer, barometric pressure sensor	Pascal
Weather	CloudCoverSensor/ CloudCover	Cloud cover sensor	Okta
Weather	SunPositionElevationSensor/ SunElevation	sun position elevation to detect (twilight, day, night, etc.)	DegreeAngle
Weather	SolarRadiationSensor/ SolarRadiation	Solar radiation sensor, par (photo synthetically active radiation) sensor, sun light, solar sensors, sun's radiation intensity	WattPerMeterSquare
Weather	VisibilitySensor/ Visibility	Visibility sensor to detect fog	Miles, Meter
Weather	Thermometer, AirThermometer/ Temperature	Thermometer, temperature sensor, thermistor	DegreeCelsius
Weather	LightSensor/ Luminosity	Light, luminosity, illuminance, lighting	Lux
Weather	PrecipitationSensor/ Precipitation	Precipitation sensor, rainfall sensor, rain fall, pluviometer, rain, rainfall gauge	MilimeterPerHour
Weather	WindSpeedSensor/ WindSpeed	Wind speed sensor, wind velocity sensor, anemometer	MeterPerSecond

Figure 4. Uniform description for sensors in a climate domain (Gyrard, et al., 2014)

C. oneM2M ontology

One Machine To Machine oneM2M is a partnership initiative between leading organizations in the world in the field of ICT, which aims to develop technical specifications that address the need for a common layer of M2M services, which can be embedded easily within a variety of hardware and software, entrusting the connection to a large number of devices with M2M application servers globally through the Internet (oneM2M, 2018).

The architecture model proposed by oneM2M represents the model in end-to-end support layers (E2E Services) M2M. This model (Figure 5) is composed of three layers: the Application layer, Common Services and the underlying layer of Network Services (ibid.).

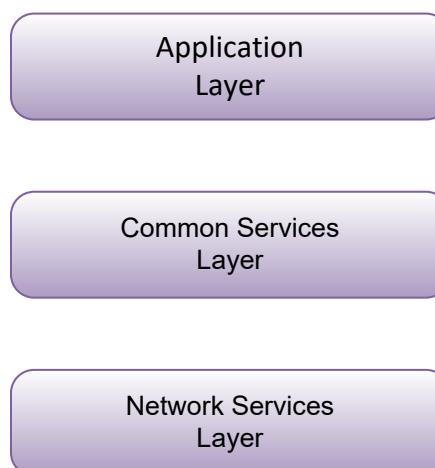


Figure 5. OneM2M layer model (oneM2M, 2018)

The functional architecture of oneM2M, in Figure 5, comprises the following functions:

1) Application Entity (AE): is a function in the application layer that implements an M2M application services logic. Each application service logic can be a resident of a number of M2M nodes or also of a single M2M node. Each execution instance of an application service logic is called an “application entity” (AE) and is identified with a unique AE-ID (ibid.). The events handled by this application entity include instances of tracking, remote monitoring, measurement and control.

2) Common Services Entity (CSE): This entity represents an instance of a set of “common” service functions of the M2M environments. Such service functions are exposed to other entities through the Mca and Mcc reference points. The

Mcn reference point is used to access underlying network service entities. Each common service entity is identified with a unique CSE-ID (ib.).

Examples of service functions offered by the CSE include: data management, device management and M2M subscription management services and location services. Such “sub-functions” offered by a CSE can be logically and informatively conceptualized as Common Service Functions CSF. The normative resources that implement the service functions in a CSE can be mandatory or optional (ibid.).

3) Network Services Entity (NSE): This function provides services of the underlying network to the central storage entities. Examples of these services include device management, location services and triggering device (ibid.). No organization in particular assumes the functions of this entity, since it works with the protocol stack of the TCP/IP model.

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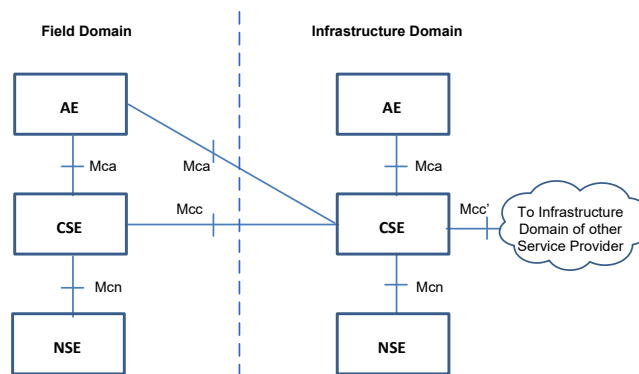


Figure 6. OneM2M functional architecture (oneM2M, 2018)

The reference points are known as interfaces between the different M2M entities (Guevara, 2017). The following reference points are supported by the Common Services Entity CSE. The nomenclature “Mc (-)” is based on the mnemonic “M2M communications” (op.cit.):

a) Mca reference point: communication flows between an Application Entity (AE) and a Common Services Entity (CSE) between a field

and a domain infrastructure. These flows allow the AE to use the services admitted by the CSE for communication with another AE (ibidem).

b) Mcc reference point: communication flows between two Common Services Entities (CSEs) crossing from a field to a domain infrastructure. These flows allow a CSE to use the services supported by another CSE (ib.).

c) Mcn reference point: communication flows between a Common Services Entity (CSE) and a Network Services Entity (NSE) within the same field or domain infrastructure. These flows allow a CSE to use the supported services (other than the transport and connectivity services) provided by the NSE (ibid.).

d) Mcc' reference point: communication flows between two Common Services Entities (CSE) in different Infrastructure Nodes (IN), being compatible with the oneM2M architecture and resident in different M2M domains of other Service Providers (SP). These flows allow an incoming CSE of a resident in the domain infrastructure of an M2M service provider to communicate with a CSE of another SP in the domain infrastructure of a different M2M service provider using their supported services and vice versa. The Mcc' extends the accessibility of the services offered above the Mcc reference point, or a subset thereof. The trigger for these communication flows can be initiated in the oneM2M network elsewhere (ibid.).

The oneM2M system to be understood in its entirety, requires a base ontology that has been designed with the intention of providing a

minimum number of concepts, relationships and restrictions that are necessary for the semantic discovery of the entities in said system. To make this type of entities detectable in the oneM2M system, a semantic description is needed as classes (concepts) in a specific provider technology/standard of its ontology, in such a way that these classes (concepts) are related to some classes of the ontology of base as subclasses (oneM2M, 2018a).

In addition, the basic ontology allows non-oneM2M technologies to build derived ontologies, which describe the data model of said technology, with the purpose of working with each other with the oneM2M System (ibid). The base ontology only contains the classes and properties but not instances, because such an ontology and the derived models are used in oneM2M, only to provide a semantic description of the entities they contain (ibid).

The instantiation, that is, the data of the different entities represented in the oneM2M system –for example, devices, things, etc.– is done through the oneM2M resources (id.).

Figure 7 shows the general outline of the oneM2M base ontology in which, its backbone refers to the entities or classes “Thing”, “Device” and “Service” (ibid.).

The oneM2M Base Ontology

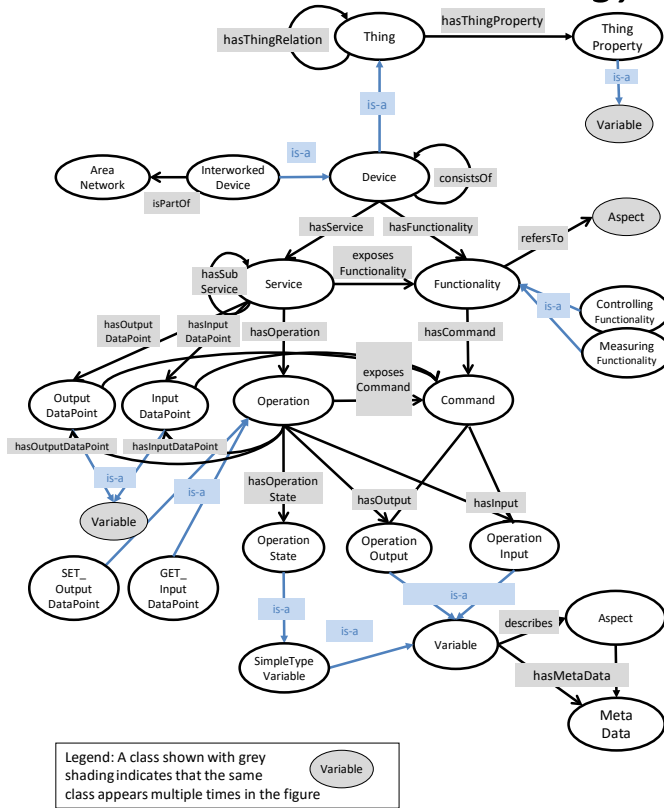


Figure 7. The oneM2M Base Ontology (oneM2M, 2018a)

D. IoT-Lite ontology

IoT lite is a light ontology that represents the resources, entities and services of the Internet of Things. Lightweight allows the representation and use of IoT platforms without consuming an excess of processing time when consulting the ontology. However, it is also a goal ontology that can be extended to represent IoT concepts in a more detailed way in different domains (Bermúdez-Edo, et al., 2017).

This ontology describes IoT concepts in three classes: Objects, System or resources and Services. The devices are also divided into, but not limited to, three classes: detection devices, drive devices and tag devices. The services are described with an availability or access control and a coverage. This coverage represents the area covered by the IoT device. Figure 8 represents the concepts of ontology and the main relationships between them (ibid.).

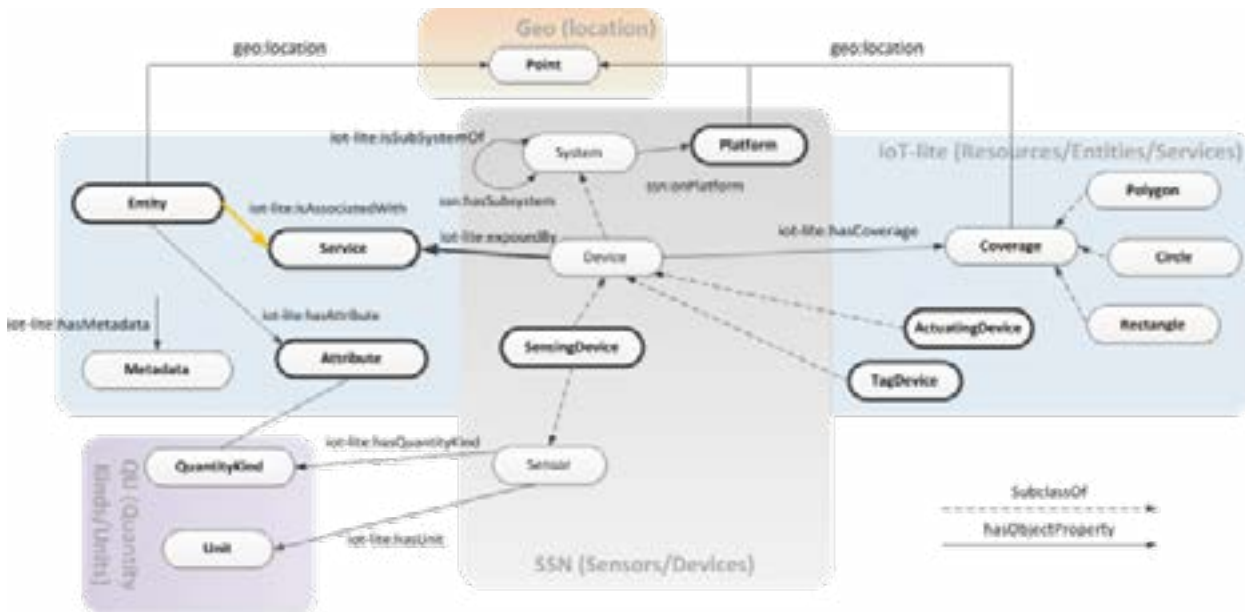


Figure 8. IoT-Lite ontology concepts and relationships (Bermúdez-Edo, et al., 2017)

IOT Lite is an ontology that is created to be used with a common taxonomy that makes it easy to describe the units and number of classes that devices in the IoT can measure. This hierarchy represents individuals in ontology and is based

on well-known taxonomies such as qu and qudt (ibid.).

As an example of a sensor device, the SmartCSR IoT Node is taken. Figure 9 shows a conceptual scheme of the sensor device mentioned (ib.).

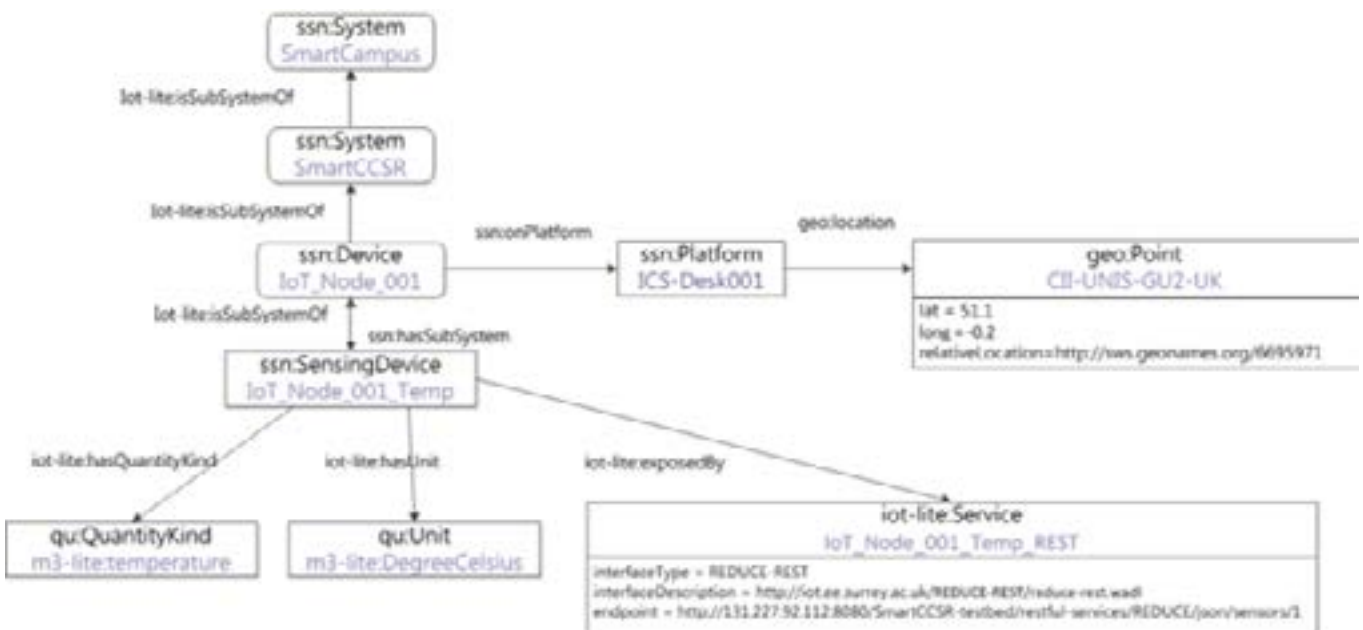


Figure 9. Smart CSR device example of the IoT-Lite ontology (Bermúdez-Edo, et al., 2017)

V. DISCUSSION OF ONTOLOGIES

Within the various base ontologies reviewed, it is noteworthy that the Quality of Service QoS understood as the performance of a computer system at the level of data processing, –i.e., the syntactic and semantic interoperability of smart devices when connected in a network–, serves as an adequate and convenient metric for evaluating them based on the most outstanding aspects that define them in general and particular, such as layered organization , the structure by modules, the formatting of the data, the ontological pattern, the query of graphs, the syntactic and inference rules.

In Table 2 that concerns the QoS metric of the base ontologies, it can be seen that 100% of the models are characterized by having a semantic compatibility and facilitating queries of RDF type graphs. 50% of them have a multiple layer organization (M3 and oneM2M), coinciding in the proportion of the organization by modules (SSN and oneM2M) and facilitating the obtaining of inference rules (M3 and oneM2M).

Regarding the formatting of the data, 75% of the models do so in the OWL web ontologies language with the exception of the M3 scheme, which does it only in RDF/XML, drawing the attention that oneM2M carries out in both syntax types; this being in accordance with the syntactic interoperability property, in which 50% of said models are in a medium consolidation stage (SSN and IoT-Lite), in an early stage for M3 and in an advanced stage for oneM2M.

The pattern or template implemented by each base ontology is unique, 75% being focused on the aspects of the service and the device except for the M3 model; as in the case of the entity or object characteristic, excluding the SSN scheme. It is remarkable for everything that the oneM2M ontological model establishes a difference between “thing” and “device”, considering the latter as an intelligent agent able to treat and/or transfer data without human competition, while the former consists of an entity or element with properties and relationships in a universe of specific discourse, but does not have any type of information within the scope in which it occurs.

No.	Author	Base ontology	QoS Metric							
			Stratification	Modularization	Format data	Pattern	SPARQL	Semantic compatibility	Inference rules	Syntactic interoperability
1	W3C	SSN – Semantic Sensor Network	Monolayer	Yes	OWL	Stimulus–Sensor–Observation	Yes	Yes	No	Middle stage
2	Gyrard, A. et. al.	M3 – Machine to Machine Measurement	Multilayer	No	RDF/ XML	Registration–Reasoning–Application	Yes	Yes	Yes	Early stage
3	ETSI, et. al.	oneM2M – One Machine to Machine	Multilayer	Yes	OWL RDF/ XML	Thing–Device–Service	Yes	Yes	Yes	Advanced stage
4	Bermudez-Edo, M. et. al.	IoT-Lite – Internet of Things Lite	Monolayer	No	OWL	Objects–Resources–Services	Yes	Yes	No	Middle stage

Table 2. Balance of the characteristics of the basic ontological models according to the Quality of Service QoS metric

VI. CONCLUSIONS

The ontological models described (M3, oneM2M, SNN and Lite) are characterized by considering the stratification at the level of the functional architecture (application, services and network), in a 100%, including sublayers within each of the aforementioned by 50% -specifically the M3 and oneM2M ontologies- without compromising the modular structure and / or syntactic and semantic interoperability. It is inferred therefore that the most appropriate or timely ontology is the oneM2M, given that it is in permanent production, updating, definition and maintenance of specifications and technical reports focused on the service layer of M2M technology.

Likewise, the fact that European, North American and Australian organizations leaders in development of standards in Information and Communication Technologies (ICT, CSSA, TTA, ARIB, TTC, ETSI, ATIS) have been associated since 2014 in the OneM2M project, this becomes a letter of guarantee to ensure the deployment of Machine to Machine systems in the near future. In addition, oneM2M is working on aspects of privacy, security, discovery, interoperability, subscription, notification, accessibility and remote management of devices and applications from general use cases.

The oneM2M ontology, by bringing together the relevant properties of ETSI's M2M machine-to-machine technology with the characteristics of other reference models for smart devices such as e.g. SAREF manages to establish a high degree of specificity in the entities and their conceptualization (Device, Service, Operation, Order, Entry, Exit, Method, Destination, Value, Functionality, Thing), overcoming the differences between definitions and opening the way to the standardization of architecture.

From a robust ontology (oneM2M) and a functional structure of the M2M technology supported in

the aforementioned layers, the initiative of an architecture for the Internet of Things coincides with the three-level computer system model (presentation, business and persistence), in which the service layer (equivalent to the business layer) and managing the mentioned above ontology, allows to integrate the various devices for its management as follows:

- Subscription and notification devices through MQTT.
- Devices restricted by CoAP
- Autonomous devices through REST

In this way, any device or machine is able to connect permanently to the Internet either directly (GSM) or indirectly (Gateway) and send requests and receive responses at the appropriate time (subscribe-publish), which facilitates its implementation in a lot of contexts.

BIBLIOGRAPHIC REFERENCES

- Grønbæk, Inge. (2008). Architecture for the Internet of Things (IoT): API and interconnect. The Second International Conference on Sensor Technologies and Applications. Telenor R&I.
- Vermesan, Ovidio. Friess, Peter. (2013). Internet of Things: Converging Technologies for Smart Environments and Integrated Ecosystems. River Publishers. Denmark. URL: http://www.internet-of-things-research.eu/pdf/Converging_Technologies_for_Smart_Environments_and_Integrated_Ecosystems_IERC_Book_Open_Access_2013.pdf

- ETSI. (2013). ETSI TR 101 584 V2.1.1 (2013-12). Technical Report. Machine to Machine Communications (M2M); Study on Semantic support for M2M Data. European Telecommunications Standards Institute. URL: https://www.etsi.org/deliver/etsi_tr/101500_101599/101584/02.01.01_60/tr_101584v020101p.pdf
- ETSI. (2017). ETSI TS 103 264 V2.1.1 (2017-03). Technical Specification. SmartM2M; Smart Appliances; Reference Ontology and oneM2M Mapping. European Telecommunications Standards Institute. URL: https://www.etsi.org/deliver/etsi_ts/103200_103299/103264/02.01.01_60/ts_103264v020101p.pdf
- W3C. (2011). Semantic Sensor Network Incubator Group by W3C SSN-XG. URL: <https://www.w3.org/2005/Incubator/ssn/XGR-ssn-20110628/>.
- Compton, M. Barnaghi, P. Bermúdez, L. et. al. (2012). The SSN Ontology of the W3C Semantic Sensor Network Incubator Group. *Journal of Web Semantics*, vol 17, December 2012, pp 25-32.. DOI: <https://doi.org/10.1016/j.websem.2012.05.003>
- Gyrard, A. Kanti Datta, S. Bonnet, C, Boudaoud, K. (2014). Standardizing Generic Cross-Domain Applications in Internet of Things. *Globecom 2014 Workshops – IEEE*. DOI: <https://doi.org/10.1109/GLOCOMW.2014.7063496>
- oneM2M. (2018). TS-0001-V3.12.0. Functional Architecture. Technical Specification. V3.12.0. oneM2M Partners Type 1 (ARIB, ATIS, CCSA, ETSI, TIA, TSDSI, TTA, TTC). URL: http://www.onem2m.org/component/rsfiles/download-file/files?path=Release_3_Draft_TS%255CTS-0001-Functional_Architecture-V3_12_0.docx&Itemid=238.
- oneM2M. (2018a). TS-0012-V3.7.1 Base Ontology. Technical Specification. V.3.7.1. oneM2M Partners Type 1 (ARIB, ATIS, CCSA, ETSI, TIA, TSDSI, TTA, TTC). URL: http://www.onem2m.org/component/rsfiles/download-file/files?path=Release_3_Draft_TS%255CTS-0012-Base_Ontology-V3_7_1.docx&Itemid=238
- Guevara, A. Salcedo, O. Pava, R. (2017). M2M: Technological Basis for Internet of Things. *Contemporary Engineering Sciences*, Vol. 10, 2017, no. 34, 1669 - 1676. DOI: <https://doi.org/10.12988/ces.2017.711183>
- Bermúdez-Edo, M. Elsaleh, T. Barnaghi, P. Taylor, K. (2017). IoT-Lite: a lightweight semantic model for the internet of things and its use with dynamic semantics. *Pers Ubiquit Comput*. Springer-Verlag. June 2017, Volume 21, Issue 3, pp 475–487. DOI <https://doi.org/10.1007/s00779-017-1010-8>