European Commission

Study on Semantic Assets for Smart Appliances Interoperability

D-S3: THIRD INTERIM REPORT

A study prepared for the European Commission
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by:

TNO innovation for life

Digital Agenda for Europe

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Summary

About two thirds of the energy consumed by buildings originates from the residential sectors and thus household appliances. Household appliances or home appliances are electrical/mechanical machines which accomplish some household functions. Nowadays, appliances are not stand-alone systems anymore. They are often highly intelligent ("smart") and networked devices, that form complete energy consuming, producing, and managing systems. Reducing the use of energy and production of greenhouse gasses is therefore not only a matter of increasing the efficiency of the individual devices, but managing and optimizing the energy utilization on a system level. The systems will therefore inevitably consist of devices and sensors from different vendors, and open interfaces enabling further extensions. The interfaces need to be properly standardized and offer external access on a semantic level both to any manageable and controllable function of the system as a whole, and to any device that is part of the system.

However, the problem is not the lack of available standards. Actually, there already exist many standards, too many really, all dealing with a smaller or larger part of the problem, sometimes overlapping and competing. Various workshops and projects already explored this field and concluded that defining a useful and applicable reference data model should in principle be possible. One single, reference ontology could be created to cover the needs of all appliances relevant for energy efficiency, and it can be expanded to cover future intelligence requirements. The European Commission therefore issued a tender for a Study on "Available Semantics Assets for the Interoperability of Smart Appliances. Mapping into a Common Ontology as a M2M Application Layer Semantics", defining 3 tasks:

- **Task 1:** Take stock of existing semantic assets and use case assets
- **Task 2:** Perform a translation exercise of each model (or use case) to a common ontology language and a mapping or matching exercise between all the models
- **Task 3:** Propose a reference ontology and document the ontology into the ETSI M2M architecture

TNO was invited to perform this study. In task 1 we have analysed 43 semantic assets and we have defined their initial semantic coverage. Moreover, we have created a visual representation of the key terms used by each asset, and provided a visual representation of the most recurring key terms among all assets. In this way, we were able to short-list 20 semantic assets that provide a good basis for further development of a reference ontology for the smart appliances domain. In task 2 we have translated the assets in the short list to corresponding OWL ontologies, and we have created initial mappings among these ontologies.

This document, *D-S3 Third Interim Study Report*, presents the results of task 3. We created a first version of the Smart Appliances REFerence (SAREF) ontology explicitly specifying recurring core concepts in the smart appliances domain as given by the short-listed assets, the main relationships between these concepts, and axioms to constrain the usage of these concepts and relationships. SAREF is based on the fundamental principles of r*euse and alignment* of concepts and relationships that are defined in existing assets, *modularity* to allow separation and recombination of different parts of the ontology depending on specific needs, e*xtensibility* to allow further growth of the ontology, and *maintainability* to facilitate the process of identifying and correcting defects,

accommodate new requirements, and cope with changes in (parts of) the SAREF ontology. We subsequently mapped SAREF on the ETSI M2M Architecture, and found that there is a good correlation between the ETSI M2M Architecture and SAREF's function-related device categories. The mapping with energy-related and building-related device categories is still minimal.

The Smart Appliances REFerence (SAREF) ontology is available online at http://ontology.tno.nl/saref. The Turtle version of the SAREF ontology can be downloaded at http://ontology.tno.nl/saref.ttl , and can be opened with any ontology editor, such as TopBraid Composer , Protégé and NeOn . In order to guarantee transparency during the process and take into account the feedback of the stakeholders, it is possible to post comments at https://sites.google.com/site/smartappliancesproject/ontologies/reference-ontology (this functionality is available when logged on to the website with a Google-account) . Next to that it is possible to comment on this *D-S3 Interim Study Report,* not just at the project website but also at a dedicated ETSI website: http://sap.etsi.org. A third stakeholders' workshop will take place on the 10th February 2015 in Brussels in order to officially present this *D-S3 Interim Study Report* and collect feedback from the stakeholders about the reference ontology. Finally a forth stakeholders' workshop will take place on the 1st April 2015 in Brussels to officially present the final *D-S4 Study Report* resulting from the collected feedback from the stakeholders on all three interim deliverables and the reference ontology.

Contents

Abbreviations

3G	Third Generation
AMM	Automated Meter Management
API	Application Programming Interface
BACnet	Building Automation and Control Networks
BACS	Building Automation and Control Systems
BEMO-COFRA	Brazil-Europe - Monitoring and Control Frameworks
BEMS	Building Energy Management Systems
BIM	Building Information Model
CECED	European Committee for Domestic Equipment Manufacturers
CEM	Customer Energy Managers
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CLC	CENELEC
CoAP	Constrained Application Protocol
COSEM	Companion Specification for Energy Metering
CSEP	Consortium for SEP2 Interoperability
DCP	Device Control Protocol
DECT	Digital Enhanced Cordless Telecommunications
DEHEMS	Digital Environment Home Energy Management System
DHCP	Dynamic Host Configuration Protocol
DLMS	Device Language Message Specification
DomoML-env	An ontology for Human Home Interaction
DPWS	Devices Profiles for Web Services
E2BA	Energy Efficient Buildings Association
Ebbits	Enabling business-based Internet of Things and Services
EC	European Commission
ECHONET	Energy Conservation and HOmecare NETwork
eDiana	Embedded Systems for Energy Efficient Buildings
EE	Energy Efficiency
EEP	EnOcean Equipment Profiles
ELC	European Lamp Companies Federation
EMU	Energy Management Unit
ENV	Environmental and Contextual data
EP	Energy Profile
EPI	Energy Performance Indicators
ERP	EnOcean Radio Protocol
ESCO	Enery Service Company
ESO	European Standardization Organisation
ETSI	European Telecommunications Standards Institute
EU	European Union
eu.bac	European building automation controls association
EupP	Energy using and producing Product
FAN	FlexiblePower Alliance Network
FIEMSER	Friendly Intelligent Energy Management Systems in Residential

	Buildings
FIPA	Foundation for Intelligent Physical Agents
FP7	European 7th Framework Program
FPAI	Flexible Power Application Infrastructure
FttH	Fiber to the Home
GENA	General Event Notification Architecture
GHz	Gigaherz
HAN	Home Area Network
HAN FUN	Home Area Network FUNctionality
HFC	High Frequency Communication
HGI	Home Gateway Initiative
HTTP	Hypertext Transfer Protocol
HVAC	Heating, ventilation, and air conditioning
Hydra	Heterogeneous physical devices in a distributed architecture
ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IES	Illuminating Engineering Society
IETF	Internet Engineering Task Force
IFC	International Foundation Classes
IoP	Internet of People
IOPTS	Internet of People, Things and Services
IoS	Internet of Services
IoT	Internet of Things
IP	Internet Protocol
IPR	Intellectual Property Rights
kbps	kilobit per second
KNX	KNX Association
LDN	Logical Device Name
LEP	Local Energy Providers
LWM2M	Lightweight M2M
M2M	machine-to-machine
ME3GAS	Middleware for Energy Efficient Embedded Services & Smart Gas Meters
MDA	Model Driven Architecture
MIRABEL	Micro-Request-Based Aggregation, Forecasting and Scheduling of Energy Demand, Supply and Distribution
MUC	Multi Utility Communication
OASIS	Organization for the Advancement of Structured Information Standards
oBIX	Open Building Information Exchange
OBIS	Object Identification System
OMA	Open Mobile Alliance
OMS	Open Metering System
OSGi	OSGi Alliance / OSGi technology

OWL	Web Ontology Language
OpenIoT	Open Source cloud solution for the Internet of Things
PC	Personal Computer
PHEV	plug in hybrid electric vehicle
PLC	Power Line Carrier
R&D	Research & Development
RDF	Resource Description Framework
REST	REpresentational State Transfer
RF	Radio Frequency
RFC	Request for Comments
SAREF	Smart Appliances REFerence ontology
SCL	Service Capability Layer
SD	Study Document
SDK	Software Development Kit
SDO	Standard Development Organization
SEEMPubS	Smart Energy Efficient Middleware for Public Space
SEIPF	Semantic Energy Information Publishing Framework
SensorML	Sensor Model Language
SEP2	Smart Energy Profile 2.0
SG-CG	Smart Grid Coordination Group
SIG	Special Interest Group
SKOS	Simple Knowledge Organization System
SmartCoDe	Smart Control of Demand for Consumption and Supply to enable balanced, energy-positive buildings and neighbourhoods
SML	Smart Message Language
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SSDP	Simple Service Discovery Protocol
SSN	Semantic Sensor Network Ontology
SUMO	Suggested Upper Merged Ontology
SWE	Sensor Web Enablement
TC	Technical Committee
TM	Technical Memorandum
TNO	Netherlands Organisation for Applied Scientific Research TNO
TR	Technical Report
TRV	Thermostat Radiator Valves
TV	Television
ULE	Ultra-Low Energy
UML	Universal Markup Language
UPnP	Universal Plug and Play
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
USR	User Preferences
VoCamp	Vocabulary Camp

W3C	World Wide Web Consortium
WG	Working Group
Wi-Fi	Wireless Fidelity
WSN	Wireless Sensor Network
xDSL	x Digital Subscriber Line
XML	eXtensible Markup Language
XSD	XML Schema Definition Language

1. Introduction

1.1. Context

Achieving higher energy efficiency is an important goal for the European society. The residential and tertiary sector, the major part of which are buildings, accounts for more than 40% of the final energy consumption in the European Community and is expanding, a trend which is bound to increase its energy consumption and hence its carbon dioxide emissions [1]. It is not so much the buildings as such that consume energy and produce greenhouse gasses, but the so-called Energy using and producing Products (EupP), also called “appliances”, inherently present in the buildings’ ecosystems, and the people using them.

An appliance is an instrument or device designed for a particular use or function. About two thirds of the energy consumed by buildings originates from the residential sectors and thus household appliances. Household appliances or home appliances are electrical/mechanical machines which accomplish some household functions, such as cooking or cleaning. The broad definition allows for nearly any device intended for domestic use to be a home appliance, including stoves, refrigerators, toasters, air conditioners as well as TVs, PCs, and light bulbs. Home appliances can be classified into major appliances (or White goods), small appliances (or Brown goods), and consumer electronics (or Shiny goods).

Nowadays, appliances are not stand-alone systems anymore. They are often highly intelligent (“smart”) and networked devices, that form complete energy consuming, producing, and managing systems. Therefore, reducing the use of energy and production of greenhouse gasses is not only a matter of increasing the efficiency of the individual devices, but managing and optimizing the energy utilization at a system level. One of the requirements for making such systems adopted by the mass market, is the flexible and dynamic extension with new smart devices and applications, based on the user’s needs and available budget. The systems will therefore inevitably consist of devices and sensors from different vendors, and open interfaces enabling further extensions. An open interface is a public standard for connecting hardware to hardware and software to software. Said otherwise, networked devices can be managed for energy saving measures if there is a system that can be flexibly enhanced. They also need to be able to communicate with service platforms from different service providers.

In such a system, the interfaces need to be properly standardized and offer external access on a semantic level both to any manageable and controllable function of the system as a whole, and to any device that is part of the system. However, the problem is not the lack of available standards. Actually, there already exist (too) many standards, all dealing with a smaller or larger part of the problem, sometimes overlapping and competing [2]. What is needed is a reference ontology, a shared data model.

Various workshops and FP7 projects already have explored this field and concluded that defining a useful and applicable reference data model should be possible in principle. Several of those exploratory discussions were held at the Energy Efficiency research community at the 2nd (2011) and 3rd (2012) Workshop on eeBuildings Data Models (Energy Efficiency Vocabularies and Ontologies).

These workshops presented results of FP7 and Artemis funded projects[1] related to energy efficiency with different approaches and solutions to bridge over the connectivity standards "jungle" for the smart appliances, but more importantly, explored expanded semantic ontologies to cover broader areas of interactions (more intelligent machine-to-machine "conversations") as the ones covered by the traditional control networks. The conclusion from these workshops were the following: Indeed, one single, reference ontology can be created to cover the needs of all appliances relevant for energy efficiency; indeed, this ontology can be designed in a way that it can be expanded to cover future intelligence requirements; and indeed, this ontology is a rather simple ontology as compared to the state of the art ontology engineering level of complexity. The workshops also concluded that these models show high mapping correlations, and that all what is needed is a formal agreement, a recognised standard and combined efforts of standardization organizations.

However, before launching a formal exercise, the industry was consulted to discover their support and their perception of this need. On 24 September 2012 the European Commission (EC) hosted a workshop on a roadmap for the standardization of smart appliances, inviting all relevant stakeholders:

<u>Stakeholders associations</u>

- Energy Efficient Buildings Association (E2BA)
- CECED, European Committee for Domestic Equipment Manufacturers
- eu.bac, European building automation controls association
- ELC, European Lamp Companies Federation (now succeeded by LightingEurope)
- Smart Grid Task Force
- Agora du Réseau Domiciliaire

<u>Standardisation Bodies and Organisations</u>

- ETSI M2M (now called ETSI Smart M2M)
- CENELEC TC59x WG7, Smart Grid/Smart Home Activities
- HGI Home Gateway Initiative
- buildingSmart International
- OASIS Open Building Information Exchange (oBIX)
- OSGi Alliance

The main recommendation of this meeting consisted of two objectives:

1. Propose a high-level semantic modelling of information to be exchanged (API-like) – the first step is a common vocabulary for appliances product information, commands, signals (like price or sensor information) and feedback.
    a. Take stock of the existing semantic assets, across different stakeholders and standardisation efforts, and perform a translation exercise. Agree on a nuclear vocabulary.
    b. Discuss a complete range of use cases, covering all devices (white goods, HVAC, plumbing, security and electrical systems, lightings, sensors and actuators (windows,

[1] E.g. SmarCoDe (www.fp7-smartcode.eu), eDiana (www.artemis-ediana.eu), ENERsip (www.enersip-project.eu), and FIEMSER (www.fiemser.eu)

doors, stores), micro renewable home solutions (solar panels, solar heaters, wind, etc.), multimedia and home computer equipment and all Building Energy Management Systems (BEMS), Building Automation and Control Systems (BACS), Customer Energy Managers (CEM), and Energy Boxes as defined by the Consumer Electronics industry, finding the messages and signals they may need to share. Extend the nuclear vocabulary.

2. With regard to connectivity, agree on an abstract architecture with a clear horizon and considering the world's machine-to-machine (M2M) standards, approaches and architectures to bridging the manifold communication layers already available.
    a. Propose available architectures that go in that direction
    b. Create open repositories of reusable pieces

With regard to objective 1, the European Commission has the intention to launch a standardisation exercise at ETSI to propose this high-level model, an ontology for smart appliances, as an ETSI standard. With regard to objective 2, the results should be integrated in the abstraction layer of the ETSI M2M architecture for the Home and Building environment.

1.2. Goal and objectives of this study

To provide this ETSI working group with the relevant background, the European Commission issued a tender for a Study on "Available Semantics Assets for the Interoperability of Smart Appliances. Mapping into a Common Ontology as a M2M Application Layer Semantics" [3] , defining 3 tasks:

- **Task 1:** Take stock of existing semantic assets and use case assets
- **Task 2:** Perform a translation exercise of each model (or use case) to a common ontology language and a mapping or matching exercise between all the models
- **Task 3:** Propose a reference ontology and document the ontology into the ETSI M2M architecture

The study will thus contribute with recommendations for a reference ontology, based on semantic assets defined and examined within this study.

TNO was invited to perform this study. The study aims to provide the material needed to define these tools and data models, for the collection of devices that helps the EU to reach its 2020 goals regarding the reduction of greenhouse gas emission and buildings' energy consumption, being the said appliances. The work packages and tasks defined in the study will fulfil the following objectives:

- An overview of existing explicit or implicit semantic assets and use case assets.
- Detailed analysis of the existing semantic assets or requirements in an exhaustive way.
- Proposal for a reference ontology to be contributed to ETSI for consideration as a future standard.
- Documentation of the proposed ontology into the ETSI M2M architecture.

The first document, *D-S1 Interim Study Report*, presented the results of task 1 "take stock of existing semantic assets and use case assets". D-S1 was first reviewed by the project's Expert Group, and later on discussed in the 1st stakeholders' workshop that took place in Brussels on May 27/28, 2014. *D-S2 Second Interim study report,* resulted from task 2 "perform a translation exercise of each model (or use case) to a common ontology language and a mapping or matching exercise between all the models" and covers a translation of the most relevant assets identified in task 1 into OWL ontologies and an initial mapping between these ontologies. D-S2 was discussed at the 2nd stakeholders' workshop at the ETSI premises in Sophia Antipolis on October 15, 2014. Important changes in D-S1 and D-S2 after the stakeholders' workshops will be addressed in the *D-S4 Final Study report*. D-S4 will include all the results described in the previous reports, as well as an executive summary.

This deliverable, *D-S3 Third Interim study report*, covers the definition of the Smart Appliances REFerence (SAREF) ontology and a description of this ontology within the ETSI M2M architecture. It should be emphasized that this report, D-S3, like D-S1 and D-S2, is an *Interim* study report. The *D-S4 Final Study report*, to be published in 2015, is the final result of the study and only D-S4 will be officially passed to ETSI Smart M2M for further development into, as is currently foreseen, a Technical Specification. In D-S4 the results of D-S3 will be updated with the newest insights.

1.3. Structure of the document

Chapter 2 describes the scope of the study and in particular of this document. It provides a brief introduction on ontologies and the ontology language of choice (OWL-DL). For a more extensive description we refer to D-S2 [8]. Chapter 3 elaborates on the approach that we have followed in task 3 to construct the SAREF reference ontology. Chapter 4 is the core of this document in which we provide an overview of SAREF. Chapter 5 provides a high-level mapping into the ETSI M2M architecture. Chapter 6 presents our conclusions and outlines the activities that will be carried out to finalize the study.

2. Scope

2.1 Sectors, use cases and appliances

Our study mainly addresses 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 out of scope.

The following appliances are covered:

- Home and buildings sensors (temperature, humidity, energy-plugs, energy clams, energy meters, water-flow, water quality, presence, occupancy, air monitors, environmental sensors, CO_2 sensors, weather stations, etc.) and actuators (windows, doors, stores). Sensors belonging to appliances are treated individually.
- White goods, as classified by CECED[2]
  - 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[3]
- Lighting, with use cases as defined by LightingEurope[4] (f.k.a. ELC)
- Micro renewable home solutions (solar panels, solar heaters, wind, etc.)

Multimedia and home computer equipment devices will be 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 study further covers the following interoperability use cases:

- Interoperability with construction design tools (product information, product performance and product behaviour)
- Interoperability with Facility Management and Energy Management Systems
- Interoperability with Building Control systems
- ESCO (Energy Services) systems
- Interoperability with the Smart Grid

As primary stakeholders the manufacturers of the following home energy producing and consuming products are consulted:

- Manufacturers of white goods
- Manufactures of HVAC, plumbing, security and electrical systems
- Manufacturers of lightings
- Manufacturers of sensors and actuators (windows, doors, stores)
- Manufacturers of micro renewable home solutions (solar panels, solar heaters, wind, etc.)
- Manufacturers of multimedia and home computer equipment

Furthermore stakeholders from directly linked industries are consulted:

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[2] European Committee of Domestic Equipment Manufacturers, www.ceced.org
[3] European building automation controls association, www.eubac.org
[4] www.lightingeurope.org, the successor of the former ELC (European Lamp Companies federation)

- Construction industry
- Facility Management and Building Control industry
- ESCO (Energy Services Providers)
- Utilities and operators of the power grid

2.2 About ontologies

An ontology is here defined as a formal specification of a conceptualization, used to explicit capture the semantics of a certain reality [5,6,7]. As such, we regard an ontology as:

- a set of concepts used to describe the reality under consideration e.g., the concepts of 'household appliance' and 'function';
- precise definitions of these concepts in natural language e.g., 'an appliance is an instrument or device designed for a particular household function, such as cooking or cleaning';
- relations among these concepts e.g., a household appliance of type 'washing machine' realizes the function 'cleaning'; and
- axioms to constrain the intended meaning of these concepts, e.g., special conditions under which an appliance should function, such as a specific timeslot during the night when the energy costs are reduced

Users of the ontology can define instances of ontology concepts that are relevant to them, e.g., the specific household appliance of type 'washing machine' from manufacturer 'A and with serial number '123xyz'.

In this study, ontologies are used to improve the communication among stakeholders, providing a shared understanding that reduces ambiguities and confusion in the terminology adopted in the smart appliances domain. Ontologies are also used here to provide an interpretation to data and, therefore, facilitate interoperability between systems and devices provided by different vendors, providing a reference model that allows translation and mapping among different assets (models/standards/software) from different parties [4].

Ontologies require a language that is suitable to represent the ontology concepts. In practice, people often refer to ontologies as what are in fact specifications of conceptualizations loosely expressed in an informal language, such as natural language. These are not ontologies according to the definition adopted here. In contrast, we consider ontologies as formal specifications expressed using formal semantics and axioms [8]. Informal specifications may lead to ambiguities, and systems that are based on such specifications are more error-prone than systems based on formal ontologies, which, in contrast, allow automated reasoning and consistency checking. Therefore, ontologies expressed using formal semantics are engineering artifacts that can be processed and checked by machines.

It is important to choose a suitable language depending on the purpose of an ontology. The language chosen in the smart appliances study to express the ontologies corresponding to the semantic assets is OWL-DL [8], since it provides formal semantics to explicitly represent the meaning intended for these assets, and allows a high degree of semantic reasoning, being supported by a large number of software reasoning tools. In an OWL-DL ontology, the concepts used to describe the reality under consideration are called *classes*, the natural language definitions of these classes can be annotated as *comments*, the instances are called *individuals*, the relations are called *properties*, and the axioms are called *restrictions*.

3. Approach

3.1 Principles

The Smart Appliances REFerence (SAREF) ontology is conceived as a shared model of consensus that facilitates the matching of existing assets in the smart appliances domain, reducing the effort of translating from one asset to another, since the SAREF ontology requires one set of mappings to each asset, instead of a dedicated set of mappings for each pair of assets, as shown in Figure 1 (figure updated from deliverable DS-2 [8]).

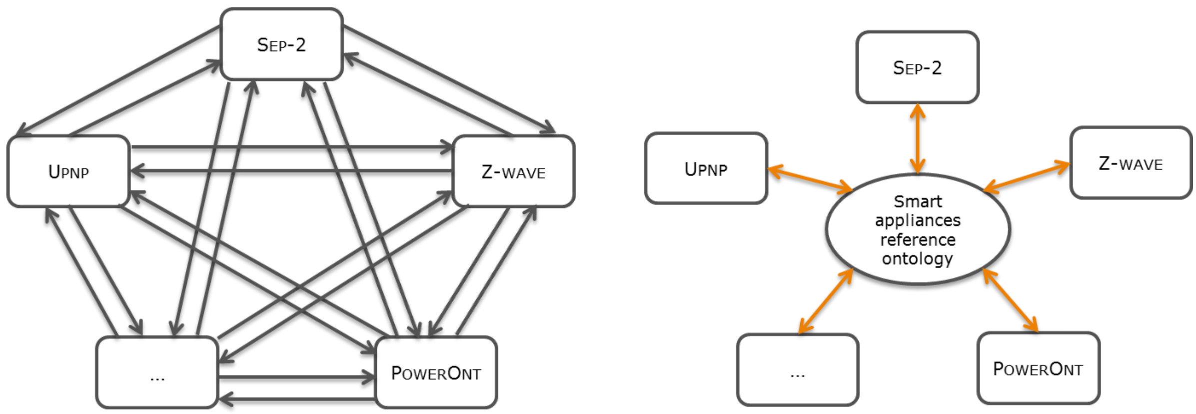

Figure 1- The role of the SAREF ontology in the mapping among different assets

From the analysis realized in the previous deliverables, we could conclude that different assets share some recurring, core concepts, but they often use different terminologies and adopt different data models to represent these concepts. Using the SAREF ontology, different assets can keep using their own terminology and data models, but still can relate to each other through their common semantics. In other words, the SAREF ontology enables semantic interoperability in the smart appliances domain.

The SAREF ontology explicitly specifies recurring core concepts in the smart appliances domain, the main relationships between these concepts, and axioms to constrain the usage of these concepts and relationships. We have created the SAREF ontology based on the following fundamental principles:

- *Reuse and alignment* of concepts and relationships that are defined in existing assets. Since a large amount of work was already being done in the smart appliances domain, we have not invented anything new, but harmonized and aligned what was already there. The SAREF ontology is based on the core concepts that in the previous deliverables were identified as especially relevant to describe the existing assets. Despite the heterogeneity of these existing assets, when considering their semantic coverage, we could identify three main trends with focus on:
  1) devices, sensors and their specification in terms of functions, states and services,
  2) energy consumption/production information and profiles to optimize energy efficiency, and
  3) building related semantic models.

  In the SAREF ontology and the rest of this deliverable, we call these trends, *function-related*, *energy-related* and *building-related*, respectively. The SAREF ontology includes not only the necessary concepts and relationships to characterize these trends individually, but also to link these trends to each other. For example, the concept of *building space* links function-related assets to building-related assets, since a device designed to accomplish a certain function is located in a specific room of the home or office in a building. Another example is the concept of *profile* that links function-related assets to energy-related assets, since a device designed to accomplish a certain function can be associated with a certain energy/power profile that can be used for energy optimization purposes.

- *Modularity* to allow separation and recombination of different parts of the ontology depending on specific needs. The SAREF ontology provides building blocks that can be combined to accommodate different needs and points of view. The starting point is the concept of *device*, which is actually common to all assets considered in this study, although some assets may refer to it with different names, such as *resource* or *product,* but we provide mappings for that. For example, a "switch" is a device. A device is always designed to accomplish one or more *functions*, therefore, the SAREF ontology offers a lists of basic functions that can be eventually combined in order to have more complex functions in a single device. For example, the switch mentioned above offers an actuating function of type "switching on/off". Each function has some associated *commands*, which can also be picked up as building blocks from a list. For example, the "switching on/off" function is associated with the commands "switch on", "switch off" and "toggle". Depending on the function(s) it accomplishes, a device can be found in some corresponding *states* that are also listed as building blocks, so that it is easy and intuitive to combine devices, functions and states. The switch considered in our example can be found in one of the two states "on" or "off". The SAREF ontology also provides a list of *properties* that can be used to further specialize the functioning of a device. For example, a "light switch" specializes the more general "switch" described above for the purpose of controlling the "light" property. An extensive explanation of the SAREF ontology, its classes and relationships is presented in the next section and is available online at http://ontology.tno.nl/saref/.
- *Extensibility* to allow further growth of the ontology. Different stakeholders can specialize the SAREF concepts according to their needs and points of view, add more specific relationships and axioms to refine the general (common) semantics expressed in the reference ontology, and create new concepts, as long as they explicitly link these extensions to at least one existing concept and/or relationship in the SAREF ontology. The minimum requirement is that any extension/specialization must comply with the SAREF ontology.
- *Maintainability* to facilitate the process of identifying and correcting defects, accommodate new requirements, and cope with changes in (parts of) the SAREF ontology. According to the extensibility criterion mentioned above, a new module/ontology can be created to further extend/specialize concepts of the SAREF ontology, but according to the maintainability criterion the creator of this module is responsible for its maintenance and versioning, independently from the SAREF ontology. Therefore, the maintenance of new modules is distributed to the creators of these modules. In contrast, in order to avoid inconsistency and confusion, the maintenance of SAREF is centralized to a single party (i.e., TNO until the end of the project in March 2015 and probably ETSI later) who also takes care of aligning SAREF with new modules when necessary.

3.2 Ontology creation process

Towards the creation of the SAREF ontology we have taken the following steps:

1) We have assessed various additional assets suggested during the stakeholders' workshops in Brussels and Sophia Antipolis (see [8]), and we concluded that in addition to the assets short-listed in D-S1, CENELEC, ZigBeeHA and Adapt4EE should also considered in the creation of the reference ontology. ZigBeeHA[5] and Adapt4EE were expressed in OWL, which allowed us to include them straightforwardly in our catalogue of OWL ontologies, while CENELEC only provided a pdf specification with associated XSDs. It is a major undertaking to translate the CENELEC specification to an OWL ontology, and we advise this to be done in future work. Nevertheless we were able to take the most relevant content of the CENELEC specification into account when constructing SAREF. A more detailed description of these additional assets and their semantic coverage will be included in the final deliverable D-S4.
2) We have (qualitatively) validated the usability of our modular approach of using building blocks to create the SAREF ontology with some stakeholders (representatives of CENELEC, ETSI M2M, and HGI) in a dedicated session organized after the 2nd stakeholders workshop in Sophia Antipolis. The result was that a reference ontology built with such modularity in mind seems to be intuitive and well understood by different stakeholders. Moreover, from our analysis of the existing assets we noticed that several of these assets use a similar modular approach for combining devices, functions and commands, e.g., DogOnt (PowerOnt), OSGi DAL, CENELEC, DECT ULE, KNX, SeemPubs, UpnP and Zwave. Therefore, the building blocks of the SAREF ontology should be intuitive for these stakeholders.
3) We have performed an experiment in collaboration with Jerome Euzenat, member of the Smart Appliances expert group, based on the work he has carried out in the context of the READY4SmartCities project[6] (http://www.ready4smartcities.eu/). In this experiment, automatic mappings were performed using dedicated software for ontology matching[7] to support the manual mappings we have provided in the D-S2 deliverable. This experiment has taken as input the 20 ontologies in D-S2 (https://sites.google.com/site/smartappliancesproject/ontologies) and has produced some interesting preliminary matching results[8], which are hosted on the INRIA server (http://al4sc.inrialpes.fr/). Some of these results showed that the DogOnt, OSGi DAL, Fiemser and Seempubs ontologies present the highest number of exact matching among each other (see http://al4sc.inrialpes.fr/onid/1420470114201/6506). Therefore, these assets could be used as a solid common basis for creating our reference ontology. The results obtained with the automatic ontology matching were then checked against the *D-S2-SMART 2013-0077-Smart*

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[5] We use the ZigBeeHA ontology based on DogOnt provided by the Politecnico di Torino at http://elite.polito.it/index.php/research/research-topics/35-dogont?showall=&start=2

[6] READY4SmartCities was considered here since it presents similarities to the Smart Appliances project, although it focuses on another domain (i.e., smart cities). READY4SmartCities intends to increase awareness and interoperability for the adoption of ICT and semantic technologies in energy system to obtain a reduction of energy consumption and CO2 emission at smart cities communities level through innovative relying on RTD and innovation outcomes and ICT-based solutions. Similarly to our project, READY4SmartCities investigated and identified vocabularies and ontologies related to the domain of interest, and provided mappings among them. These mappings were created using automatic tools for ontology matching, instead of manually relating concepts from different assets, as we have done in the smart appliances project.

[7] Exact match algorithm, LogMapLite, YAM++

[8] http://al4sc.inrialpes.fr/onid/1420470368391/9235 => Smart appliances max-aggregated alignment network with exact match, LogMap, YAM++
http://al4sc.inrialpes.fr/onid/1420470148730/6339 => Smart appliances alignment network with YAM++
http://al4sc.inrialpes.fr/onid/1420470114201/6506 => Smart appliances alignment network with exact match

Appliances-Appendix A-Mappings.xlsx file, consisting of the mappings we have derived manually in task 2. The conclusion was that this experiment validates the results we presented in the D-S2 deliverable, supporting our mappings in *D-S2-SMART 2013-0077-Smart Appliances-Appendix A-Mappings.xlsx* and the choice of core concepts proposed as basis to build the reference ontology. Unfortunately, there are no further resources in the Smart Appliances project to elaborate on these automatic mappings, but they can and should be further explored in a follow-up of the Smart Appliances project to provide tools for stakeholders for automatic mapping using the SAREF ontology.

4) We created the SAREF ontology starting from the core concepts presented in DS2, namely: *Device, Device category, Function, Function category, Service, Command, Parameter, Mode/Status, Energy profile, Energy, Power, Time/Duration, Building, Sensor, Actuator, Meter, Load, Storage, Generator, Unit of Measure.* We have created explicit definitions in natural language for these concepts and, in parallel, we have organized them in hierarchical (vertical) relationships and defined horizontal relationships among them . We have also changed some names and refined some of these concepts in subclasses. For example:
   - the *Mode/Status* concept has been renamed as "State";
   - the *Time/Duration* concept has been renamed as "Time" and then refined in the two concepts of "Instant" and "Interval";
   - The *Sensor*, *Actuator*, and *Meter* concepts have been moved as subclasses of "Device category" (under the "Function-related" category), and also used as basis to create subclasses of the class "Function";
   - The *Load*, *Storage*, and *Generator* concepts have been moved as subclasses of "Device category" (under the "Energy-related" category);
   - The concept of "Property" has been introduced to represent anything that can be sensed, measured or controlled in households, common public buildings or offices, such as "Energy", "Power", "Temperature", "Humidity", and so forth.
     - We have moved the *Energy* and *Power* concepts as subclasses of "Property"
   - the concept of "Commodity" has been introduced to represent homogenous goods traded in bulk on an exchange and available at our homes such as "Electricity", "Gas" and "Water".
   - The *Parameter* concept has been replaced by the two relations "has input Parameter" and "has output Parameter" that characterize the "Service" concept, which must specify the input and output parameters necessary for its operation.

   The documentation of the SAREF ontology is available at http://ontology.tno.nl/saref/ and shows the complete list of concepts and their definitions.

5) In the process of creating the SAREF ontology, we have iteratively checked our intermediate results against the assets in the (extended) short list, mainly using the mappings in the *D-S2-SMART 2013-0077-Smart Appliances-Appendix A-Mappings.xlsx* file, in order to guarantee the link of the reference ontology with the existing assets. DogOnt, OSGi DAL and CENELEC were especially useful for creating the function-related part of the SAREF ontology, SSN for creating the part related to the sensing function and the observation of properties, Fiemser for defining the building-related part, while Fanfpai, Mirabel, PowerOnt and CENELEC provided support especially for creating the energy-related part of the SAREF ontology. Notice that this does not mean that we have neglected the other assets not mentioned above: we have extensively used them all and we acknowledge the value and contribution to the reference ontology in one way or another of all assets in our (extended) short list.

4. Smart Appliances REFerence (SAREF) ontology

The SAREF ontology focuses on the concept of device, which we define in the context of the Smart Appliances study as *"a tangible object designed to accomplish a particular function in households, common public buildings or offices"*. Examples of devices are a light switch, a temperature sensor, an energy meter, a washing machine. The `saref:Device` class and its properties are shown in Figure 2.

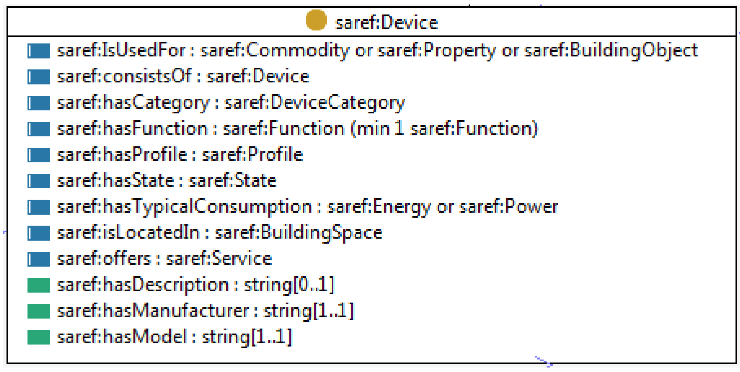

Figure 2 - Device class and its properties

A `saref:Device` must have some properties that uniquely characterize it, namely its model and manufacturer (`saref:hasModel` and `saref:hasManufacturer` properties, respectively). Optionally, a description of the device can also be provided (`saref:hasDescription` property). These properties are depicted in Figure 2 using green rectangles that represent *OWL Datatype properties*, which are properties that relate a class (the `Device` class here) to data values, namely a *string* data value in this example. In contrast, *OWL Object properties* are represented using blue rectangles and relate a class to another class. For example, the `saref:isLocatedIn` object property in Figure 2 relates the `saref:Device` class to the `saref:BuildingSpace` class, whereas a building space defines the physical spaces of the building where a device is located, such as a kitchen or a living room. Figure 3 shows the `saref:BuildingSpace` class and its properties.

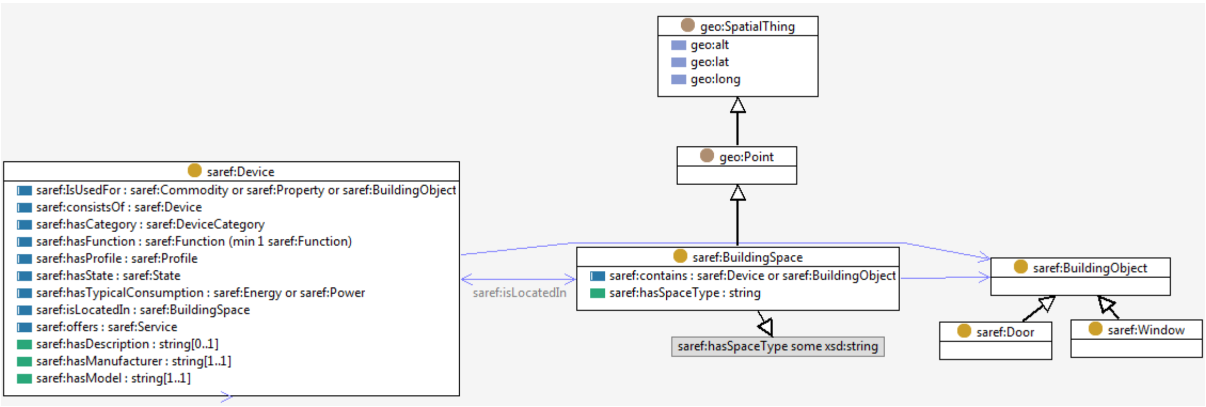

Figure 3 – Building Space and Building Object classes

A building space contains devices or building objects (the `saref:BuildingObject` class), where building objects are objects in the building that can be controlled by devices, such as doors or windows that can be automatically opened or closed by an actuator. A building space has also a `saref:hasSpaceType` property that can be used to specify the type of space, for example, the living room or the bedroom. Moreover, a building space is a `geo:Point` characterized by a certain altitude, latitude and longitude, which are provided by the W3C WGS84 geo positioning vocabulary[9] that we have imported in the SAREF ontology. Notice that the WGS84 geo vocabulary is referred to using the `geo:` prefix, which distinguish it from the classes and properties of the SAREF ontology, which are referred to using the `saref:` prefix.

The `saref:hasCategory` object property in Figure 2 relates the `saref:Device` class to the `saref:DeviceCategory` class, which provides a way to classify devices into certain categories. Notice that when analyzing the semantic assets in D-S1 we have identified three main trends in the context of the Smart Appliances study with focus on 1) devices, sensors and their specification in terms of functions, states and services, 2) energy consumption information and profiles to optimize energy efficiency, and 3) building related data models. Therefore, according to these trends, we suggest in the SAREF ontology a classification of devices in three main categories that we have called `saref:FunctionRelated`, `saref:EnergyRelated` and `saref:BuildingRelated`, respectively. These categories are shown in Figure 4.

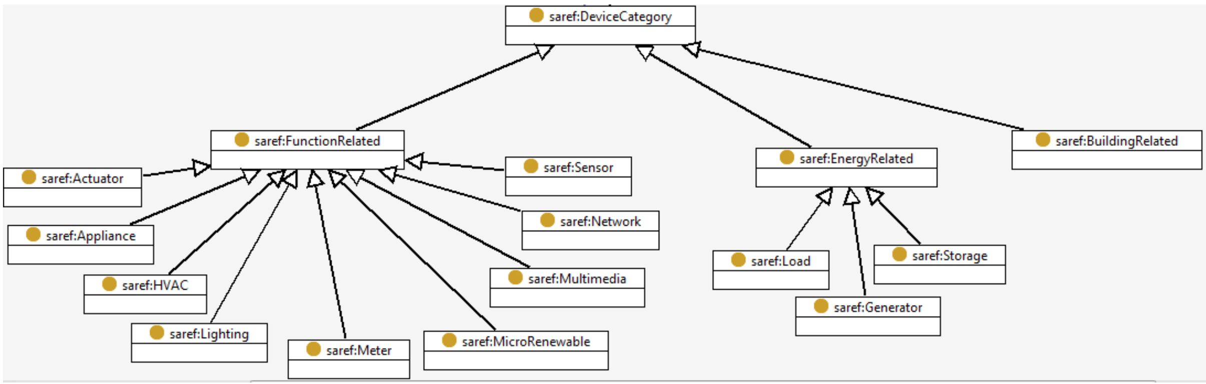

Figure 4 – Device Category class

Depending on which trend a certain semantic asset focuses, this asset can be assigned to one of these categories. For example (see [8] and http://sites.google.com/site/smartappliances/ontologies for links to their respective ontologies), Echonet, EnOcean, OSGi DAL, SEP2, and UPnP could identify their devices with the category `saref:FunctionRelated`, FAN and Mirabel could be assigned to the category `saref:EnergyRelated`, while FIEMSER devices would better fit under the category `saref:BuildingRelated`. Moreover, some assets can belong to several categories, for example, PowerOnt[10] and CENELEC could be assigned to both the `saref:FunctionRelated` and `saref:EnergyRelated` categories. In any case, the assignment of devices provided by specific assets to a certain category is not mandatory and is completely flexible since the asset's owners are free to define a new category as a subclass of `saref:DeviceCategory` that suits better to their point of view.

The SAREF ontology is conceived in a modular way in order to allow the definition of any device from pre-defined building blocks, based on the function(s) that the device is designed for and the purpose for which it is used. Therefore, Figure 2 shows that a `saref:Device` must accomplish at least one function (`saref:hasFunction min 1 saref:Function`), and can be used for

[9] http://www.w3.org/2003/01/geo/wgs84_pos
[10] https://sites.google.com/site/smartappliancesproject/ontologies/dogpower-ontology

(`saref:isUsedFor` property) the purpose of i) offering a commodity, such as `saref:Water` or `saref:Gas`; ii) sensing, measuring and notifying a property, such as `saref:Temperature`, `saref:Energy` and `saref:Smoke`, respectively; or iii) controlling a building object, such as a `saref:Door` or a `saref:Window`. Moreover, a device may consists of other devices (`saref:consistsOf` property). For example:

- a washing machine is a device that has category `saref:Appliance` and accomplishes an actuating function of type `saref:StartPauseFunction`;
- a sensor is a device that has category `saref:Sensor` and accomplishes a `saref:SensingFunction`;
- a temperature sensor is a device that consists of a sensor, has category `saref:Sensor`, accomplishes the `saref:SensingFunction` and is used for the purpose of sensing a property of type `saref:Temperature`;
- a smoke sensor is a device that consists of a sensor, has category `saref:Sensor`, accomplishes the `saref:SensingFunction` and `saref:EventFunction` , and is used for the purpose of sensing a property of type `saref:Smoke` and notifying that a certain threshold has been exceeded;
- a switch is a device that has category `saref:Actuator` and accomplishes an actuating function of type `saref:OnOffFunction` or `saref:OpenCloseFunction`;
- a door switch is a device that consists of a switch, has category `saref:Actuator`, accomplishes the `saref:OpenCloseFunction` and is used for the purpose of controlling a building object of type `saref:Door`;
- a dimmer lamp is a device that has category `saref:Lighting` and `saref:Actuator`, accomplishes an actuating function of type `saref:LevelControlFunction` and is used for the purpose of controlling a property of type `saref:Light`;
- a meter is a device that has category `saref:Meter` and accomplishes a `saref:MeteringFunction`;
- an energy meter is a device that consists of a meter, has category `saref:Meter`, accomplishes the `saref:MeteringFunction` and is used for the purpose of measuring the `saref:Energy` property

A function is represented in the SAREF ontology with the `saref:Function` and is defined as *"the particular use for which a device is designed"*. Examples of functions are the `saref:ActuatingFunction`, `saref:SensingFunction`, `saref:MeteringFunction` and `saref:EventFunction`. The `saref:Function` class and its properties are shown in Figure 5.

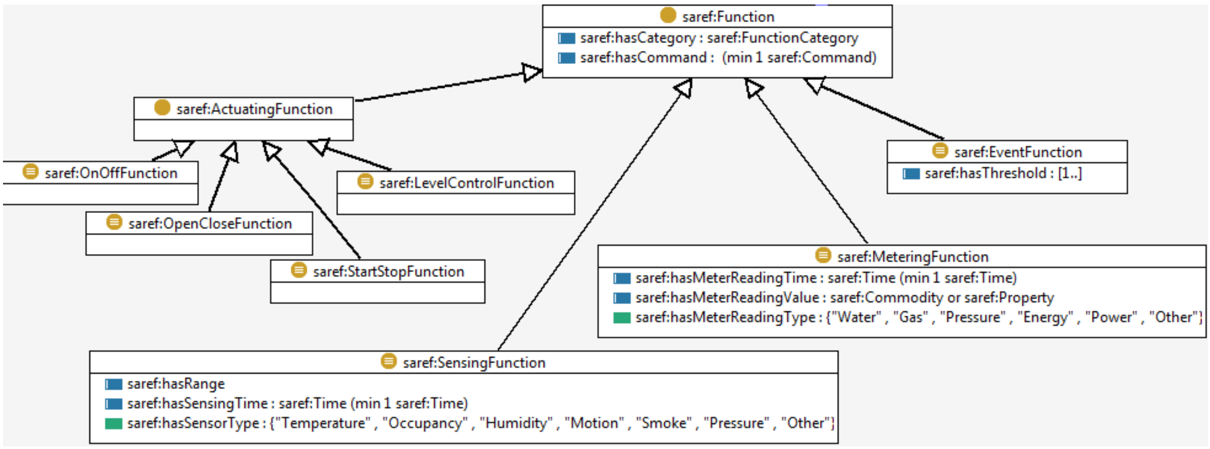

Figure 5 – Function class and its properties

A `saref:Function` can belong to a function category (`saref:hasCategory` property). Analogously to the `saref:DeviceCategory` class, we decided to leave the `saref:FunctionCategory` class open in order to grant the asset's owners the flexibility to use their own categories. For example, OSGi DAL could map its `osgidal:FunctionType` class to the SAREF ontology, defining `osgidal:FunctionType` as a subclass of `saref:FunctionCategory`. Figure 5 further shows that a `saref:Function` must have at least one command associated to it (`saref:hasCommand min 1 saref:Command`). Figure 6 shows the list of commands currently available in the SAREF ontology. This list is used here for illustration purposes and can be extended with new commands.

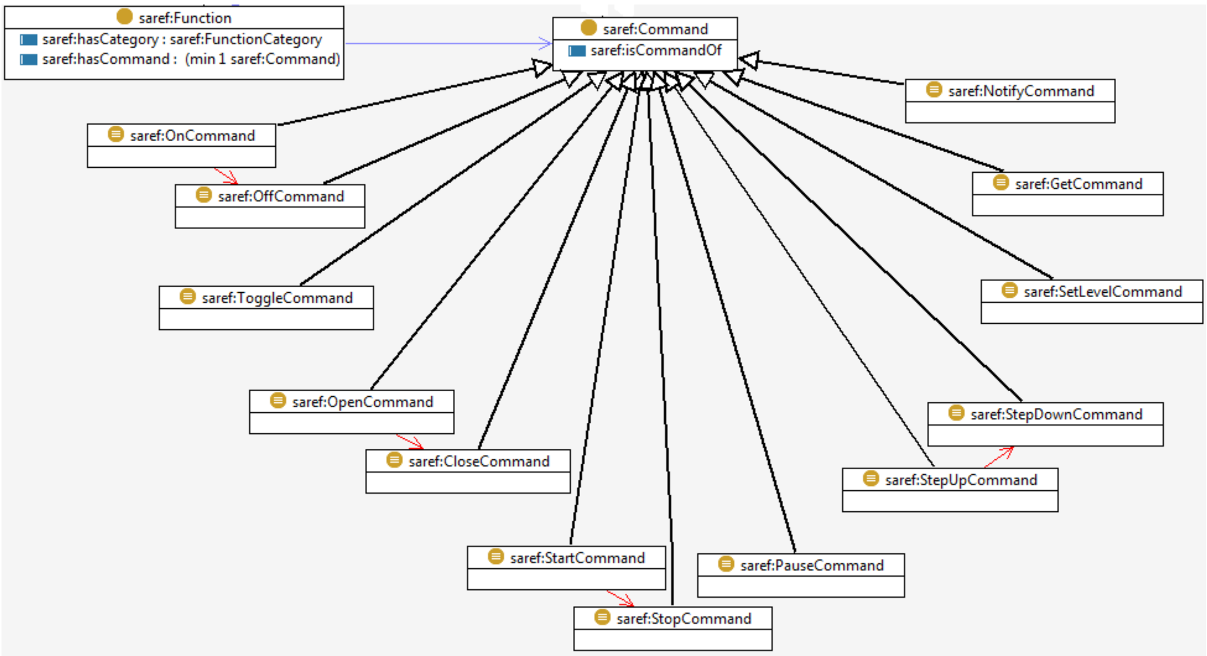

Figure 6 – Command class

For example:

- the `saref:ActuatingFunction` allows to *"transmit data to actuators, such as level settings (e.g., temperature) or binary switching (e.g., open/close, on/off)"*
    - the actuating function of type saref:OnOffFunction in Figure 5 allows to "*switch on and off an actuator*". This function allows the commands saref:OnCommand, saref:OffCommand and saref:ToggleCommand shown in Figure 6, whereas the saref:OnCommand is disjoint from the saref:OffCommand
    - the actuating function of type saref:LevelControlFunction in Figure 5 allows to *"do level adjustments of an actuator in a certain range (e.g., 0%-100%), such as dimming a light or set the speed of an electric motor"*. This function allows the commands `saref:SetLevelCommand` (which can be of type `saref:SetAbsoluteLevel` or `saref:SetRelativeLevel`), `saref:StepUpCommand` and `saref:StepDownCommand` shown in Figure 6, whereas the `saref:StepUpCommand` is disjoint from the `StepDownCommand`
- the `saref:SensingFunction` in Figure 5 allows to "*transmit data from sensors, such as measurement values (e.g., temperature) or sensing data (e.g., occupancy)*". This function allows the command `saref:GetCommand` shown in Figure 6
- the `saref:EventFunction` in Figure 5 allows to "*notify another device that a certain threshold value has been exceeded*". This function allows the command `saref:NotifyCommand` shown in Figure 6.

Depending on the function(s) it accomplishes, a device can be found in a corresponding `saref:State`, as shown in Figure 7. For example, a switch can be found in the `saref:OnOffState`, which is characterized by the values `ON` or `OFF` (`saref:hasValue` property).

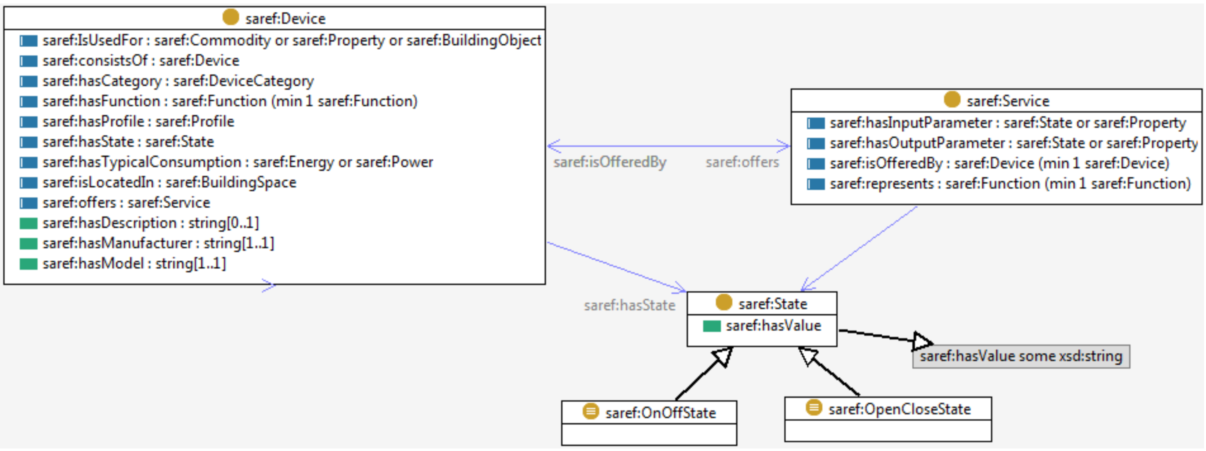

Figure 7 - State and Service classes

Figure 7 further shows that a device offers a service (the `saref:Service` class), which is a representation of a function to a network that makes this function discoverable, registerable and remotely controllable by other devices in the network. A service must represent at least one function (`saref:represents min 1 saref:Function`) and is offered by at least one device that wants (a certain set of) its function(s) to be discoverable, registerable and remotely controllable by other devices in the network (`saref:isOfferedBy min 1 saref:Device`). Multiple devices can offer the same service. A service must specify the device that is offering the service, the function(s) to be represented, and the input and output parameters necessary to operate the service (saref:hasInputParameter and saref:hasOutputParameter properties). For example, a light switch can offer the service of remotely switching the lights in a home through mobile phone devices that are connected to the local network. This "remote switching" service represents the saref:OnOffFunction previously described, it must have a saref:State as input parameter, e.g., with value "ON" , and it must have a saref:State has output parameter, namely with value "OFF" in this example since the input state value was "ON".

Moreover, a device in the SAREF ontology can be characterized by a profile that can be used to optimize the energy efficiency in the home or office under consideration. Figure 8 shows the saref:Profile class and its properties.

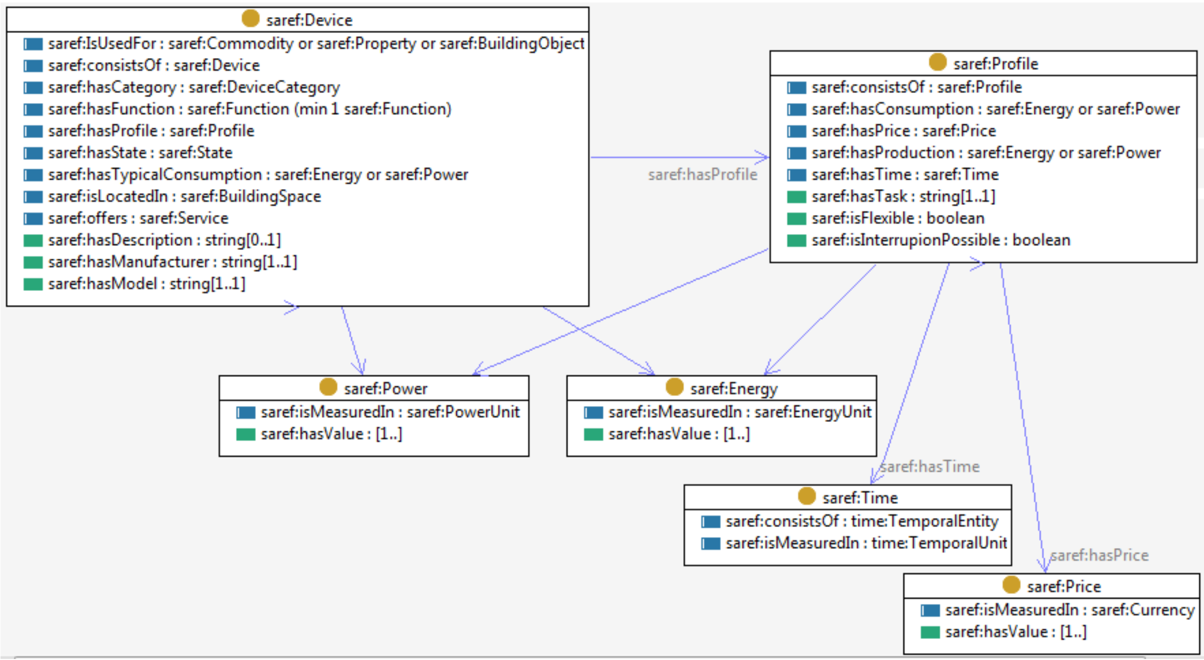

Figure 8 - Profile class

The saref:Profile class allows to describe the energy (or power) production and consumption of a certain device using the saref: hasProduction and saref:hasConsumption properties shown in Figure 8 . This production and consumption can be calculated over a time span (the saref:hasTime property) and, eventually, associated to some costs (the saref:hasPrice property).

The saref:Power and saref:Energy classes are characterized by a certain value (saref:hasValue property) that is measured in a certain unit of measure represented by the saref:UnitOfMeasure class, namely Kilowatt and Kilowatt_Hour, respectively. Analogously, the saref:Price class is characterized by a certain value (saref:hasValue property) and is measured using a certain saref:Currency, which is a subclass of the saref:UnitOfMeasure class.

The `saref:Time` class allows to specify the "time" concept in terms of instants or intervals according to the existing W3C Time ontology[11] that we import in our SAREF ontology to avoid defining this concept from scratch. The concepts of the W3C Time ontology that are useful for the purpose of the SAREF ontology are shown in Figure 9. We refer to W3C Time ontology with the `time:` prefix in order to distinguish from the classes and properties of the SAREF ontology, which are referred to using the `saref:` prefix.

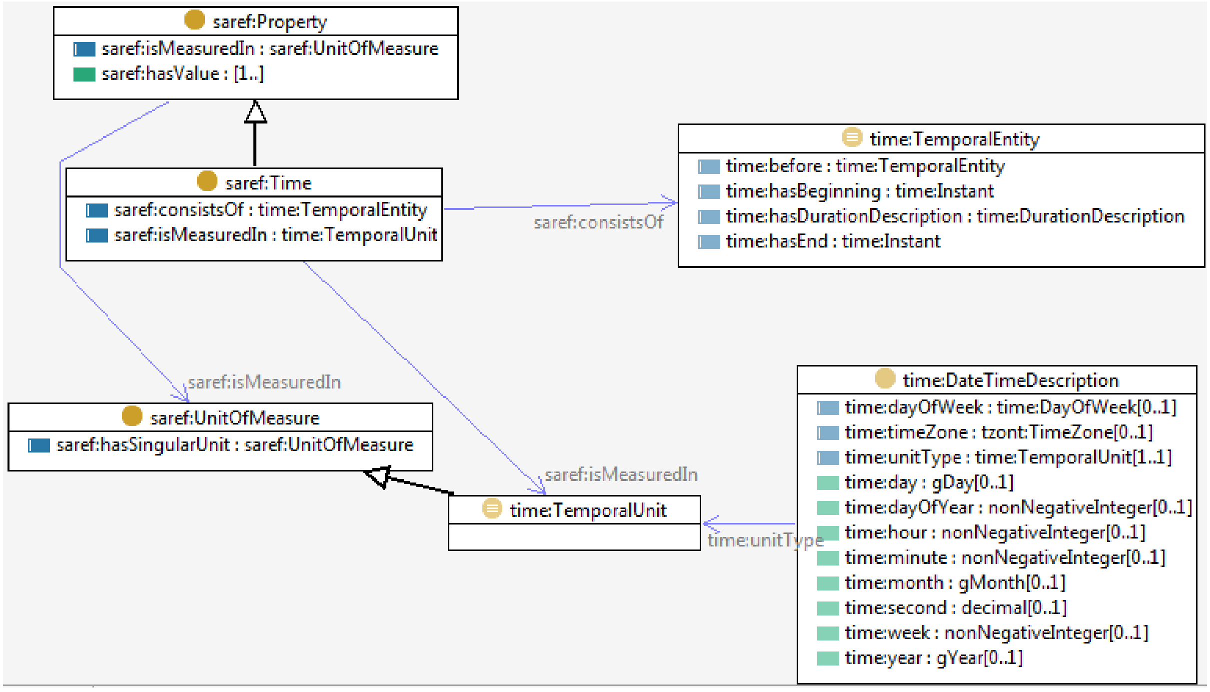

Figure 9 – Time class

[11] http://www.w3.org/TR/owl-time/

5. Application of SAREF in relation to the ETSI M2M Architecture

5.1 ETSI Smart M2M Functional Architecture

Machine to Machine (M2M) is a term being used to describe the technologies that enable computers, embedded processors, smart sensors, actuators and mobile devices to communicate with one another, take measurements and make decisions - often without human intervention [9]. ETSI has created a dedicated Technical Committee, ETSI Smart M2M (previously known as ETSI M2M) with the mission to develop standards for M2M communications. The group will provide an end-to-end view of M2M standardization.

ETSI M2M recently released its Functional Architecture [10], which describes the overall end-to-end M2M functional architecture, including the identification of the functional entities and the related reference points. The high-level architecture is shown in Figure 10. It includes a Device and Gateway Domain and a Network domain. The Device and Gateway Domain contains M2M Devices, M2M Gateways, and M2M Area Networks. M2M Devices run M2M Application(s) using M2M Service Capabilities. M2M Devices connect to the Network Domain either directly via the Access Network (xDSL, HFC, satellite, FttH, 3G, etc.) or indirectly via an M2M Area Networks and one or more M2M Gateways. Examples of M2M Area Networks include technologies such as Zigbee, Bluetooth, Wireless M-BUS and KNX.

The M2M Gateway is a gateway that runs M2M Application(s) using M2M Service Capabilities. The Gateway acts as a proxy between M2M Devices and the Network Domain. The M2M Gateway may provide services to other devices (e.g. legacy) connected to it that are hidden from the Network Domain. As an example an M2M Gateway may run an application that collects and treats various information (e.g. from sensors and contextual parameters).

The Network Domain is composed of Access Networks, Core Networks, and platforms running M2M Service Capabilities, M2M Applications, Network Management Functions, and M2M Management Functions. Network Management Functions consist of all the functions required to manage the Access and Core networks: these include Provisioning, Supervision, Fault Management, etc. M2M Management Functions consist of all the functions required to manage M2M Service Capabilities in the Network Domain.

The M2M Service Capabilities layer is arguably the most important part of the ETSI M2M Functional Architecture. The Service Capability Layer enables the transport of M2M data between devices or gateways and network applications. It provides an abstraction layer hiding the heterogeneity of M2M access networks and provides means for secure data transport. The M2M Service Capabilities:

- Provide M2M functions that are to be shared by different Applications
- Expose functions through a set of open interfaces
- Use Core Network functionalities
- Simplify and optimize application development and deployment through hiding of network specificities

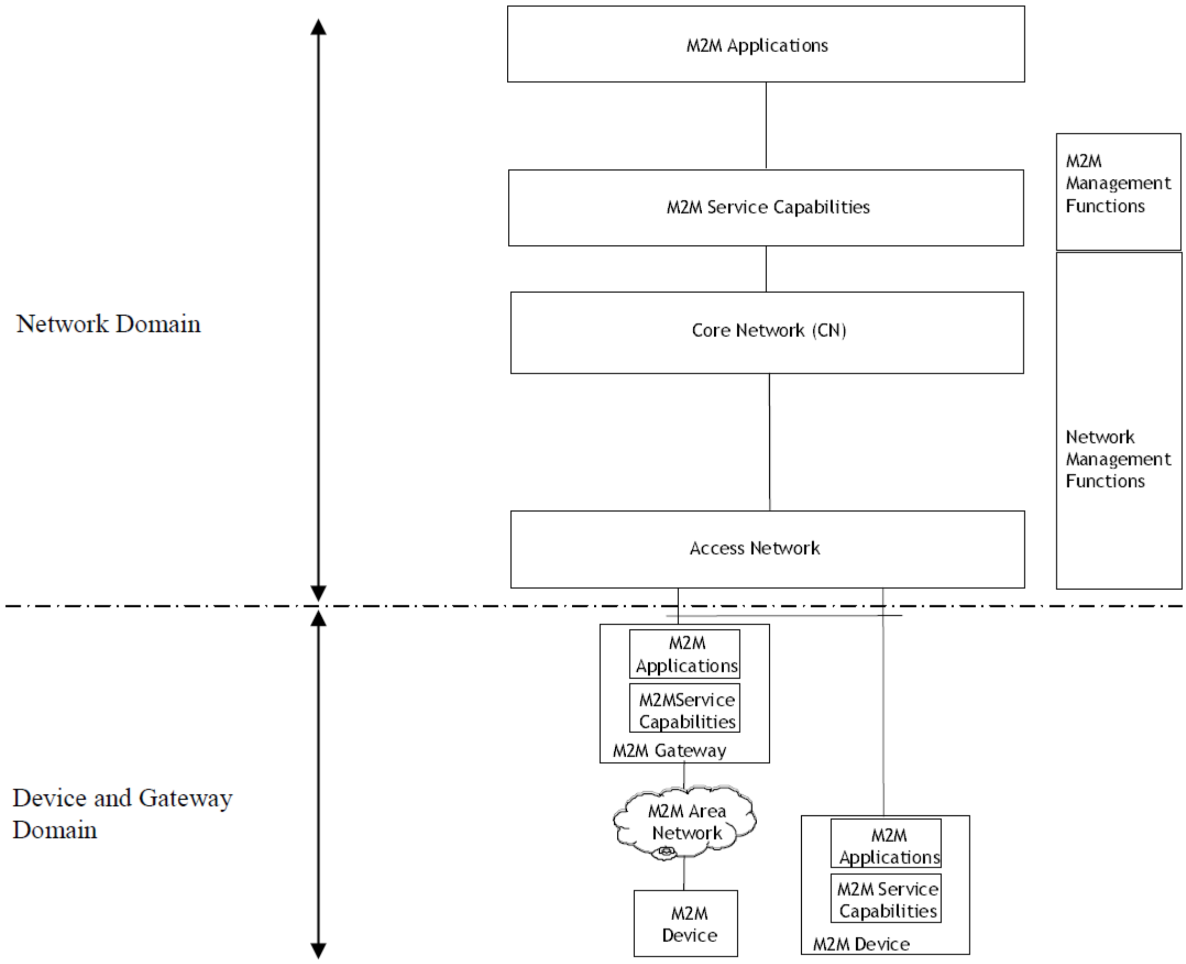

Figure 10 - ETSI M2M High Level Architecture [10]

The M2M Applications run the service logic and use M2M Service Capabilities accessible via an open interface. In [10] this interface is called “dIa” for device applications and “mIa” for network applications. In Figure 11 they are denoted in the ETSI M2M High Level Architecture. It is dIA and mIa that SAREF applies to.

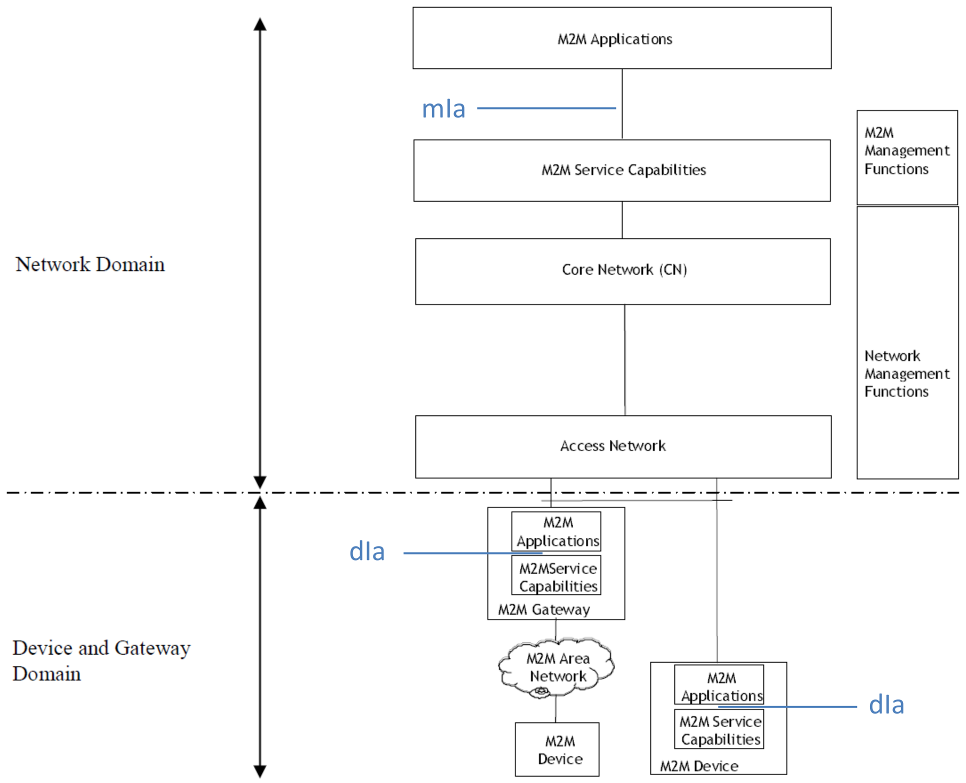

Figure 11 - dIa and mIa interfaces in the ETSI M2M High Level Architecture

5.2 Current semantic support for M2M data

At the moment, the Service Capability Layer is handling only data containers without any knowledge of the data contained. As described in [11], this approach has a number of limitations, including:

- The common-place vertically integrated, but isolated M2M applications are now replaced by M2M applications which are re-using a common data transport, but which are still vertically integrated and isolated from each other;
- There is no support in the SCL to enable an open market of data, e.g. in which data owner publish (sell) their data and independent data users provide applications that make use of the data.

After studying various use cases and different approaches to semantics, reference [11] subsequently suggests the following potential requirements regarding semantics in a next release of the M2M Functional Architecture:

1. M2M system support for a common (e.g. per vertical domain) semantic data model (e.g. represented by Ontology) available to M2M application.
2. M2M system provision of discovery capabilities enabling the discovery of M2M resources based on their semantic information, e.g. semantic categories and relationship among them (e.g. all heaters and windows in a room; the room in which a window is located…).
3. M2M system provision of representation and discovery functionality of real-world entities (rooms, windows) that are not necessarily physical devices.

4. M2M system ability support the mapping of control commands issued towards an abstract device to the concrete commands of a specific device.
5. M2M system support of a semantic data model that is at least common to the vertical industry in which a Thing is used to describe Things registered in the M2M System.
6. M2M entities ability to expose their semantic description to the M2M System.
7. M2M System ability to re-use semantic information provided by external entities to create a virtual representation. System ability to describe the semantic relationship between Things.

The term M2M System indicates in a general way M2M entities like: device, gateway and network infrastructure, equipped with M2M Service Capabilities. A Thing is defined as an element of the environment that is individually identifiable in the M2M system.

SAREF can thus subsequently be applied by the industry to produce ETSI M2M compliant devices, or interoperability boxes to make existing, non-ETSI-M2M devices interwork with an ETSI M2M system. Ideally, the achieved interoperability would comply with the highest levels as defined by e.g. CENELEC [12], but it all depends on the richness of the protocol interfaces, and how well the already implemented data models translate into the unified ones.

In reference [11] and [13] ETSI Smart M2M elaborated some preliminary examples on how this interoperability could be achieved given a preliminary ontology.

5.3 Mapping SAREF into the ETSI M2M resource structure

SAREF is somewhat different and also more extensive than the preliminary semantic model as presented in [11]. Here, we will not discuss the differences in detail but use the methodology as provided in [11] and [13] to provide a mapping between SAREF and the ETSI M2M architecture.

A saref:Device obviously maps to an ETSI M2M Device. ETSI separately defines an M2M Gateway. In SAREF this should be (we have not defined it explicitly yet) a saref:FunctionRelated saref:DeviceCategory.

In ETSI a M2M Device is described in terms of its so-called resources it provides. They can be mapped on SAREF as shown in Table 1.

Table 1: mapping of ETSI M2M Device Resources to SAREF

etsiSclMo	This is the management object of the service capability layer. SAREF has not yet considered remote management of devices.
etsiDevicInfo	Includes the saref:hasModel, saref:hasManufacturer properties and saref:FunctionRelated saref:DeviceCategory. There is no space for a free-format saref:hasDescription field.
etsiDeviceCapability	Maps to saref:Function except for the saref:EventFunction.
etsiBattery	No direct match. However, one saref:DeviceCategory is saref:EnergyRelated saref:Storage which in principle describes a battery function.
etsiMemory	No match

etsiTrapEvent	Maps to saref:EventFunction
etsiPerformanceLog	No match
etsiFirmware	No match
etsiSoftware	No match
etsiReboot	No direct match. However, there may be a relation with the saref:OnOffFunction.
etsiAreaNwkInfo	Possibly maps to saref:Network, but we have not elaborated this DeviceCategory any further yet.
etsiAreaNwkDeviceInfo	Possibly maps to saref:Network, but we have not elaborated this DeviceCategory any further yet.

There is no match between ETSI M2M and the SAREF saref:EnergyRelated and saref:BuildingRelated Device Categories, nor is there a relation yet with the saref:BuildingSpace location, the saref:Profile, or the saref:Time class.

There is possibly a relation between the concepts of M2M Applications and Services in SAREF, but this needs further study.

6. Conclusions

This deliverable presents the work that has been carried out in task 3. The aim of task 3 was to propose a reference ontology and document the ontology into the ETSI M2M architecture. We have succeeded in doing so, and created a first version of the Smart Appliances REFerence (SAREF) ontology. SAREF explicitly specifies recurring core concepts in the smart appliances domain as given by the short-listed assets, the main relationships between these concepts, and axioms to constrain the usage of these concepts and relationships. SAREF is based on the fundamental principles of r*euse and alignment* of concepts and relationships that are defined in existing assets, *modularity* to allow separation and recombination of different parts of the ontology depending on specific needs, ex*tensibility* to allow further growth of the ontology, and *maintainability* to facilitate the process of identifying and correcting defects, accommodate new requirements, and cope with changes in (parts of) the SAREF ontology.

We subsequently mapped SAREF on the ETSI M2M Architecture, and found that there is a good correlation between the ETSI M2M Architecture and SAREF’s function-related device categories. The mapping with energy-related and building-related device categories is still minimal. For further implementation of SAREF into ETSI M2M, the following actions need to be taken:

- SAREF needs to be extended with ETSI M2M specific functionality, such as M2M Gateway, and Remote Management functionality.
- ETSI resource description should be extended with (more) energy-related functionality and building-related functionality.
- The ETSI architecture should introduce a clear separation between functions (device capabilities) and services (the interface a device offers to a network).

The reference ontology is published online at http://ontology.tno.nl/saref/ . Its turtle version can be downloaded at http://ontology.tno.nl/saref.ttl and can be opened with any ontology editor, such as TopBraid Composer[12], Protégé[13] and NeOn[14]. In order to guarantee transparency during the process and take into account the feedback of the stakeholders, it is possible to post comments at http://sites.google.com/site/smartappliancesproject/reference-ontology (this functionality is available when logged on to the website with a Google-account). It is also possible to comment at a dedicated ETSI website[15]. A third stakeholders’ workshop will take place on the 10th February 2015 in Brussels in order to officially present this *D-S3 Interim Study Report* and collect feedback from the stakeholders about the reference ontology. Any eventual change after the workshop and until the end of the project in March 2015 will be covered in the online version of the reference ontology, and major changes will be addressed in the *D-S4 Final Study report*, which will be officially passed to ETSI Smart M2M. A final fourth stakeholders’ workshop will take place on the 1st April 2015 in Brussels to officially present the final *D-S4 Study Report* resulting from the collected feedback from the

[12] http://www.topquadrant.com/downloads/
[13] http://protege.stanford.edu/
[14] http://www.neon-project.org/
[15] http://sap.etsi.org

stakeholders. After the end of the project, it is up to the industry to maintain and extend the reference ontology as needed. We recommend that this process is supported by ETSI.

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